VEHICLE LOCATOR FEASIBILITY STUDY

FINAL REPORT

013975

ct 72-14-09

CITY OF ORLANDO
POLICE DEPARTMENT
ORLANDO
FLORIDA

April 26, 1974

ERRATA SHEET
VEHICLE LOCATOR FEASIBILITY STUDY
FINAL REPORT PROJECT (72-14-09)

Identification and correction of major errors which might change or confuse meaning of the Text.

Page Number	Paragraph (line)	Is	Should be
6	2(20)	"intersections. __"	"intersections. A"
49	3(3)	"apparent degragation in"	"apparent degradation in"
88	3(4)	"5 bit coded"	"4 bit coded"
107	Fig. 30 Vehicle Electronics	"Ant. We. Contr."	"Ant. Sw. Contr."
124 125	All	Topic out of order - Describes Sierra Trilateration System, not Boeing Flair System.	
131	4(5)	"savings ($210,000)"	"savings ($230,000)"
132	2(7)	"would environment"	"world environment"
142	1(3)	"mofel"	"model"
149	Fig. 46	Unit response time scale on graph should indicate average travel time to incident opposite non AVL response with 34 cars. The scale is then linear percentage of this value down to AVL response time with 34 cars. Time values were not given due to difficulty in assigning an average travel time.	
150	1(4)	"replaced $914,000 was"	"replaced $501,000 was"
150	2(5)	"Figure __ "	"Figure 47"
151	Fig. 47	"Figure __ Cash flow"	"Figure 47 Cash Flow"

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PROJECT (72-14-09)

FINAL REPORT

MARCH 1974

SUBMITTED TO

GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

TALLAHASSEE, FLORIDA

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This Report represents effort contributed, by members of the Orlando Police Department and Florida Technological University. Although it is not possible to list all who participated, the contribution of those most directly involved are listed for recognition.

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Members of the Florida Governor's Council on Criminal Justice who provided financial support and guidance throughout the project.

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SECTION I

INTRODUCTION AND SUMMARY

- o Background of Study
- o Executive Summary

The purpose of this project was to identify feasible Automatic Vehicle Locator Systems and evaluate them against the operating requirements of the Orlando Police Department in order to determine several of the more promising for possible incorporation into the Command/Control System. This project was selected after a previous project (70-04-05), Computer Simulation of Command/Control Operation, specifically identified the inherent advantages of incorporating an AVL System into OPD operations. It was noted that there were a number of vehicle locator designs which might be applicable and that each had inherent capabilities which were dependent on the operating environment. Consequently a system analysis was necessary to identify the most cost effective system for OPD, and even more basic, if it were justifiable economically.

A survey was conducted initially to determine the State-Of-The-Art in AVL Systems by mailing a questionaire to 150 potential suppliers. The mailing list was compiled from a literature review and included firms and agencies engaged in developing systems and equipment of performing related services. Approximately 30% responded but only 8 returned completed forms giving information on their systems.

Based on the interest and capabilities indicated by the questionaire 3 firms representing Proximity, Dead Reckoning, and Trilateration implemented systems were selected for further consideration. Each was contacted individually and the specific requirements of OPD were discussed with their engineers. On this basis they furnished information on their respective systems relative to performance and how they might be integrated into the OPD Command/Control System. Two have received contracts from other police agencies for installation of their system. A proximity system, LOCATES, has been installed by Applied Technology for the Montclair, California Police Department and FLAIR, the Boeing Company system, which uses an augmented dead reckoning technique is scheduled for completion in August, 1974, for the Saint Louis Police Department.

The Proximity technique was selected to implement a prototype system for OPD to demonstrate the operational capabilities of an AVL System. This decision reflected the practical considerations of its relative maturity, simplicity and availability of off-the-shelf components. The system was designed and assembled in the Special Projects Laboratory at Florida Technological University. Two patrol cars were equipped and location transmitters placed in traffic controller boxes at 10 intersections in a selected district. A large backlighted City map was used as a display at headquarters with Light Emitting Diodes at the intersections to indicate the car locations. The prototype was used to obtain field operational data from which problem areas associated with integration of an AVL System into the existing Command/Control System could be identified.

A computer simulation model of the OPD Command/Control System was used to assess the value of introducing an AVL capability. The model was exercised for AVL System accuracies of $\pm$ 0, $\pm$ 500, and $\pm$ 1000 feet to determine the effect of accuracy on the Command/Control System performance in terms of response times and number of incorrect dispatches. The study showed that incorporation of an AVL System would improve the efficiency of the field force such that it could be reduced by two patrol cars and still maintain the same response time. An economic analysis using the annual cost of operating and supporting two cars in the field showed that these potential savings would justify an expenditure of approximately $1,000,000.

BACKGROUND OF STUDY

The feasibility of incorporating an Automatic Patrol Vehicle Locator into the Orlando Police Department operations was selected for this study based on data resulting from a September 1972 study report (Project 70-04-05) which used a computer simulation model of the Command/Control System to analyze the effectiveness of a number of proposed operational alternatives.

The Orlando area has experienced a rapid increase in population, business, and industrial growth over the last decade which when viewed statistically shows it to be one of the major growth areas in the nation. Unfortunately criminal activity has registered an even larger increase in this period of time. For example, during the last 10 years, the population and area of the City of Orlando increased 29% and 55% respectively; however, total annual offense incidents recorded by the Police Department increased [illegible]%. A most disturbing aspect of this sharp increase is that it has assumed an exponential form. If the rate is sustained, a conservative estimate of offenses shows a 44% increase over the next 5 years.

Clearly, this projected criminal activity will introduce a major demand on the City's justice agencies, creating new personnel, facilities, and equipment needs as well as increased management responsibility to organize and plan effectively. A major portion of this responsibility must necessarily be assumed by the Police Department since it is the front line of defense against criminal activity.

This study was broadly based on observations and recommendations assembled by the members of the Science and Technology Task Force of the President's Commission of Law Enforcement and Administration of Justice.[1] Their effort described how technology and analytical techniques could be used to increase the efficiency and effectiveness of police operations in the apprehension process.

Within the apprehension process the Command/Control function was singled out as one of the more promising areas to consider for improvement, and a number of critical Command/Control problems that limit police operational effectiveness were identified.

A previous project (70-04-05), Computer Simulation of the Command/Control Operation, specifically related these problem areas to the Orlando Police Department. A basic model of the Command/Control System was developed using GPSS/360 simulation language and statistically validated at the 90% confidence level. The model was then used as a vehicle for experimental investigation and evaluation of selected operational changes in the operational System which were considered significant - Combining the Dispatch Officer and Radio Operator Positions and Installation of an Automatic Patrol Vehicle Locator System. These changes were tested by prediction of system effectiveness against projected incident demands up to 1980.

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[1] Institute for Defense Analysis, Task Force Report: Science and Technology (Washington, D.C.: President's Commission of Law Enforcement and Administration of Justice, 1967), p. 21.

The primary measure of system effectiveness was considered to be response time. Response time in turn is comprised of two major components - time required in the Communication Center from receipt of call to dispatch of the patrol vehicle and field response time or that required by the vehicle to reach the scene.

The urgency to improve response time derives from its correlation with the probability of apprehension of a suspect. It was determined from statistics based on Los Angeles Police Department data that with a response time of <1 minute 62% of the emergency calls ended in an arrest. As the response time was increased the apprehension probability rapidly decreased and at 14 minutes the cummulative cases exhibited only 44% arrest probability.

In addition it was found that the Communications Center accounts for 30-50% of total response time delay. Further examination showed it to be one of the best areas to invest dollars to decrease response time. Accordingly, a number of administrative and procedural changes were recommended based on the model.

Expenditures to decrease travel time are also cost effective but typically require higher investments. This approach can be typified by installation of an Automatic Patrol Vehicle Locator or introduction of additional patrol vehicles. Table 1 presents the data generated by the model for a comparison of average travel time delay with and without an AVL System at varying incident loadings representative of 1971, 1976 and 1980. It is safe to conclude that at least .26 minutes of travel time could be saved by incorporation of an AVL System compared to the existing Orlando Police Department District assignments operation. As the City expands it can also be expected that this predicted improvement in travel time will improve markedly. An AVL System also affords the advantage of additional safety for field officers since the Communications Center has information at all times on the patrol unit location. It can also be equipped with an "Officer Needs Assistance" signal device which the officer can use to unobtrusively summon help in an emergency. Accordingly it was recommended that the feasibility of incorporating an AVL into the Orlando Police Department Operations be studied.

It was noted that there are a number of vehicle locator system designs which may be applicable. Each has inherent performance capabilities which depend on the operating environment and sensor subsystem used in the design. Consequently a system analysis is a primary requisite to identify the most cost effective system for the Orlando Police Department.

TABLE 1

COMPARISON OF PREDICTED TRAVEL TIMES WITH AND WITHOUT AUTOMATIC VEHICLE LOCATOR SYSTEM

	Base Travel Time Minutes	AVL Travel Time Minutes	Travel Time Saved Minutes
Minimum (5%)	3.52	3.24	.28
Mean	4.12	3.85	.27
Maximum (95%)	4.72	4.46	.26

EXECUTIVE SUMMARY

A computer simulation model of the OPD Command/Control System showed that Orlando has reached the maturity where it could benefit significantly from an AVL System, and a prototype proximity system was designed and installed in a selected district to obtain field operational data.

The objective of this project was to determine the state-of-the-art of AVL Systems for Police operations and relate this information to the specific requirements of the Orlando Police Department, so that the feasiblity of incorporation an AVL System in their Command/Control operations could be determined. Several technically feasible system were identified; moreover, the study showed that an AVL System would be a good economic investment for the City.

The primary source of information on AVL Systems was a simplified questionaire which was mailed to a list of approximately 150 firms and government agencies. The list was compiled from a literature search conducted to identify firms engaged in developing AVL Systems and equipment or performing related services. Potential suppliers were queried concerning their experience, availability of equipment and performance parameters of their systems. Approximately 30% of the firms responded to the questionaire and of these more then half indicated some specific interest in the project.

The response identified four major system types - Proximity, Trilateration/Triangulation, Dead Reckoning and Loran could be identified with several suppliers. Further analysis showed that although no one technique was clearly dominant, the Proximity system had been identified by 38% of the response followed by Dead Reckoning with 28%. Based on the interest and capabilities indicated in the questionaire, three firms associated with the systems judged most feasible were selected for further consideration.

LOCATES was developed by Applied Technology of Costa Mesa, California using the Proximity technique. An operational System was installed for the Montclair, California, Police Department and has been in daily operation for well over a year. In addition to providing automatic location of police vehicles, it includes a keyboard for 3 - 10 code digital two-way communications between headquarters and the vehicle. An added feature is the capability of the officer to unobtrusively transmit an officer-needs-help signal while away from his vehicle.

Sierra Research Corporation of Buffalo, New York, developed and demonstrated a phase Trilateration AVL System under contract from the Department of Transportation. The demonstration was conducted in Philadelphia and results documented in Final Report TR - 0932, February 1973. The Sierra System has the capability of transmitting 8 -10 code message and an officer-needs-help signal. The system utilizes the phase difference of vehicle transmitted UHF signals to determine distances of the vehicle from a number of sensor stations. In the case of OPD it was believed that the existing satellite receiver sites could be used thus reducing installation cost. The display utilizes a cathode ray tube on which the vehicle location is shown on a grid map; an incident location can be entered by the dispatcher using an electronic process board and map overlay. The computer will then search out the nearest available vehicles.

Over the past two years, the Boeing Company in cooperation with the Wichita, Kansas, Police Department has developed a prototype Dead Reckoning AVL System known as FLAIR. FLAIR utilizes the vehicle odometer and a solid state magnetic compass to obtain travel and heading information which is transmitted to headquarters and displayed in a video grid map. Each dispatcher can individually zoom-in on an individual portion of the city to read street names. A cursor can be used to locate an incident, and the system then automatically displays the 8 nearest available vehicles. The system also has capability of digital transmission of up to 99 different 10 code messages and an officer-needs-help call. Boeing is presently under contract to the Saint Louis Police Department to furnish a system for 25 cars with guaranteed accuracy of $\pm$ 50 feet.

The proximity technique was selected to implement a prototype system to demonstrate the operational capability and effectiveness of an AVL System. This decision reflected the practical consideration of its relative maturity, simplicity and an availability of off-the-shelf components with which to implement it. The system was designed and assembled in the Electronics Project Laboratory at Florida Technological University. Standard commercial transmitter/encoders with capability of 100 mw output were mounted in traffic controller boxes at selected intersections. commercial available citizen band mobile radio receiver was used to detect the emitter location signals and was packaged with an encoder to add a patrol vehicle code. A control circuit was added to key an existing PREP radio transmitter and activate the vehicle encoder when a location signal was detected. The mixed location/vehicle tone coded signals are received by the PREP System satellite receivers which relay the audio signals to headquarters where they are subsequently decoded and co-occurring intersection and vehicle identification data is stored in a display memory. The display electronics scans the data in memory and activates Light Emitting Diodes (LED) to indicate the car identification number at the appropriate intersection. The system is designed to handle 2 patrol cars and 18 locations. The purpose of this system was to obtain field operational data which would identify problem areas associated with integrating an AVL System into the OPD Command/Control operation.

A computer simulation model of the OPD Command/Control System was used to assess the value of introducing an AVL capability. Initially the model was validated and then modified to incorporate a Command/Control policy to dispatch the available patrol vehicle closest to the incident. The simulation was conducted for AVL system accuracies of $\pm$ 0, $\pm$ 500, and $\pm$ 1000 feet to determine the impact of accuracy on Command/Control System performance in terms of response time and number of incorrect unit dispatches. The study showed that by incorporating an AVL System with an accuracy of about 800 feet the efficiency of the Uniformed field force could be improved such that two less patrol cars would be required to maintain the same response time. An economic analysis was then performed to evaluate the AVL System on the basis that the annual cost of maintaining a one-man patrol car in the field would be about $115,000. Since no "hard" estimates for an AVL System were available, the analysis was conducted to determine the capital investment which could be justified by the potential savings of the two patrol cars. Assuming a 5% rate of return and a 10 year life, the potential $230,000 annual savings will justify an investment of $1,000,000. This is well above the $400,000 rough estimate for an AVL System to handle 30-35 cars, and accordingly it was recommended that OPD develop performance specifications and obtain bid from reputable suppliers for evaluation and installation of a suitable AVL system.

SECTION II

PURPOSE OF PROJECT

- o Importance of Command/Control in Police Operations
- o Contribution of AVL System to Command/Control
- o Objectives and Potential Benefits of Project

All police departments utilize some system by which they direct and control their field forces in a dynamic response environment. This system of Command and Control must have the inherent capability of rapid and complete information assembly, decision making and execution which assures rapid response to the threat situation and minimizes the danger to both citizen and police officer.

Continuous force status monitoring is one of the most effective methods of improving the Command/Control function since it provides a dynamic display which combines offense locations with deployment/availability of patrol units. Typically continuous force status monitoring information improves command decisions which in turn improves operational efficiency of the system by:

- o reducing response time
- o dynamically deploying patrol units
- o maintaining better administrative control of patrol units

An AVL System provides the key to a quicker response because it enables the Command/Control Center to dispatch the nearest available patrol units. Also to be considered is the increased safety afforded the field officer; at all times the Command/Control Center has knowledge of his location and can respond if assistance is needed.

In addition the AVL System provides the command officers with locations of their forces during major civil disturbances or disasters. Typically the police must rely on their force mobility to extend their limited field capabilities in responding to such emergencies. The ability to concentrate on trouble spots and control them is worth many additional units in the field. Knowing the locations of patrol units also improves administrative control and avoids over or under responses that may inadvertently leave sections of the city without protection.

The primary objective of this project focused on identifying feasible Automatic Vehicle Locator Systems and evaluating them against the operating requirements of the Orlando Police Department in order to recommend the most promising configuration for incorporation into their Command/Control System. A number of vehicle locator systems for police operations have been conceived and some have undergone prototype evaluation. Generally, however, these have been in the larger cities such as New York, Chicago, and Philadelphia. It is evident from a review of the literature that the locator technique must be carefully selected and the system designed to satisfy not only the police operational requirements but also the physical and environmental conditions in which it must operate.

In addition to identifying the requirements for an AVL System for OPD, a Prototype System was developed and operated to identify human factor interface problems inherent in introducing AVL into the Command/Control System. Secondary objectives of the research can generally be identified with application of the report data to other police agencies where the environment is similar and in related operational areas. The system could also be used on buses, taxies, armored cars and high-value truck loads where a signal from the driver would automatically alert authorities and give the vehicle position.

IMPORTANCE OF COMMAND AND CONTROL IN POLICE OPERATIONS

A Command and Control System capable of rapidly responding to all complaint calls is necessary for the effective coordination and deployment of police operational forces.

Command and Control is typically a military terminology for the activities associated with planning, direction and control of operations. A Command/Control System in turn can be defined as "an organization of personnel and facilities to perform the functions of planning, situation intelligence force status monitoring, decision making and execution."[1] All operations management whether industrial, military or law enforcement require some type of Command/Control System to perform these functions.

In most police departments, the Communications Center is the focal point of all public calls and other inputs to the system. The Center houses the personnel and equipment necessary to receive and integrate all information pertaining to routine or emergency situations and control and coordinate the men and equipment needed to respond to the situation. Personnel typically include Dispatch Officers to receive the incident calls, assess the force status situation and assign the necessary response and Radio Operators to communicate with the field forces. The communications system consists of an integrated network of radio circuits and land lines linking the Center with the public, department personnel and other law enforcement agencies. Key components in a manual system are phone lines, VHF/UHF radio and control console, teletype links to other agencies, a force status display board, and a computer information display terminal. A computer augmented system would include the capability of integrating all pertinent information on a complaint call and assigning the nearest available patrol unit subject to approval of the dispatcher.

Figure 1 on the opposite page is a simplified functional block diagram of the Basic Command/Control Process. The diagram defines the relationship of the functions necessary to discharge a command responsibility and the importance of feedback from the field to control and respond effectively. The commander must know the dynamic environment in which the forces are operating as well as the plans, procedures and capabilities of his command. The threat is the forcing function on the system. Unfortunately it cannot be evaluated until after the complaint call is completed, and the information must then be integrated into the overall tactical situation for analysis and decision on the type of response. Once the decision has been made it is executed by field forces. As the units respond it is vital that the commander monitor the field operations and use this information to update his estimate of the current situation and modify his response accordingly.

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1 Institute for Defense Analysis, Task Force Report: Science and Technology (Washington, D.C.: President's Commission on Law Enforcement and Administration of Justice, 1967), p. 21.

Any Command/Control operation must have the inherent capability of rapid and complete information assembly, decision making and of execution. In the police apprehension process, for example, studies[2] of the Los Angeles Command/Control System showed that the Communications Center delay accounted for 30 to 50% of the total response time on emergency calls. Here response time is defined as the period from receipt of the call until the patrol vehicle arrived at the complaint site. It is apparent that speeding up the Command/Control process offers an effective method of improving the effectiveness of a police apprehension system. Again referring to the Los Angeles study, a correlation of percent of arrests in relation to response time showed a sharp increase in arrest probability with a decrease in response time. The curve could be described as an exponential function exhibiting a sharp increase in arrest probability for response times of less than 4 minutes. In addition many calls which are initially termed routine often escalate into emergency situations due to the delay in response. An effective Command/Control System is a vital part of both citizen and police safety.

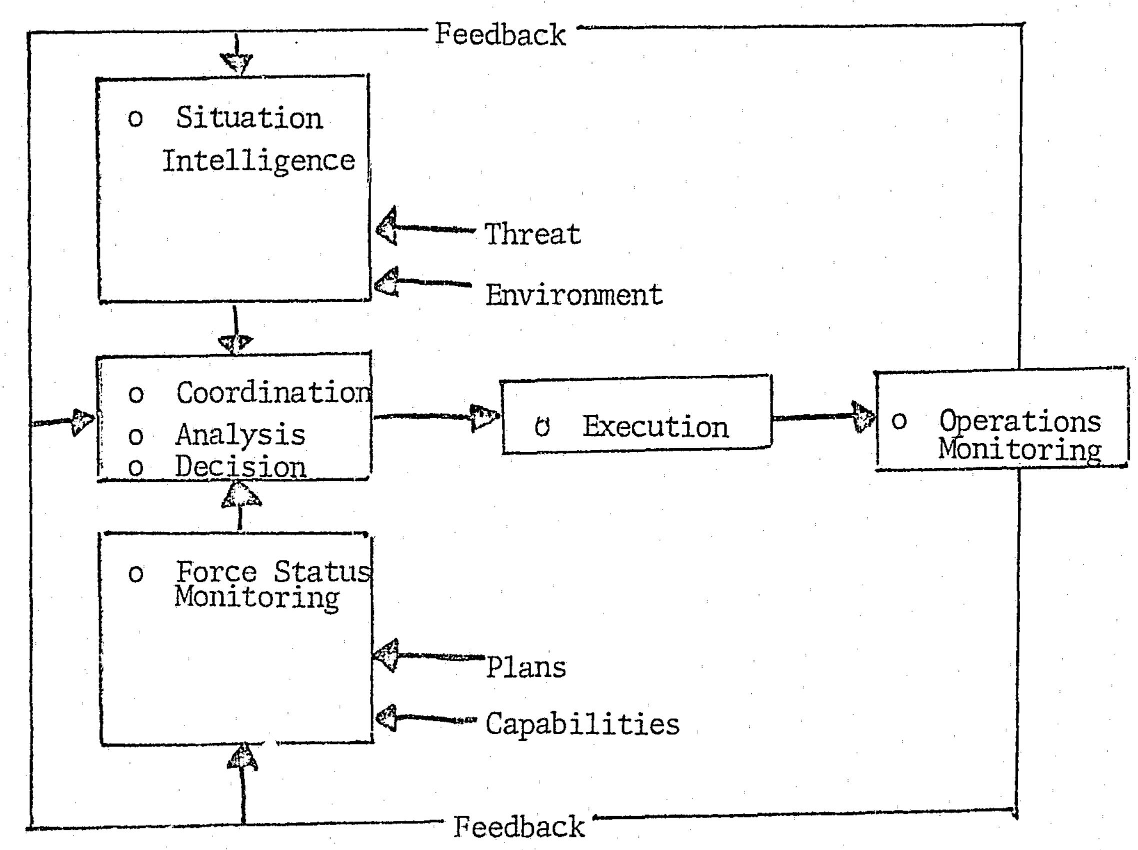

Figure 1 : Functional Block Diagram Of Basic Command/Control Process Shows Its Dependency On A Closed Loop Feedback System.

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2 Ibid

CONTRIBUTION OF AVL SYSTEMS TO COMMAND/CONTROL

An Automated Vehicle Locator System can provide the continuous force status intelligence needed to realize the full potential of force mobility which is so essential to police operations.

Continuous force status monitoring is one of the most effective methods of improving the Command/Control function since it provides the command officers with a dynamic display of information combining offense locations and deployment/availability of patrol units. It is also a key element in a fully automated Command/Control system which would incorporate a digital computer to further integrate and expedite the response. Typically continuous force status monitoring information improves command decisions which in turn improve the operational efficiency of the system by

---reducing response time
---dynamically deploying patrol units,
---maintaining better administrative control of patrol units.

The effectivity of a police force can be measured by the rapidity with which it can direct field units to a scene of action. It has been established[1] that the number of arrests and subsequent clearing of crimes has materially increased when the response time is decreased. Also studies[2] have indicated that calls that have been classified as routine have often escalated into emergencies by the time the police arrive. A quicker response to routine calls would in many instances prevent a crime from occurring. An AVL System provides the key to a quicker response because it enables the Command/Control Center to dispatch the nearest available patrol unit. Also to be considered is the increased safety afforded the field officer. At all times the Command/Control Center has knowledge of his location and can respond if assistance is needed.

In addition to rapid response to a single incident, it is imperative that command officers know the location of all their forces during major civil disturbances or disasters. Typically the police must rely on their force mobility to extend their limited field capabilities in responding to an emergency. The ability to concentrate primarily on trouble spots and control them is worth many additional units in the field. In a hot pursuit situation, for example, the Command/Control Center can program the police units to more quickly intercept the target. The apprehension most probably could be accomplished with fewer units thus decreasing the probability of incidents or accidents which might involve police officers, motorists, and pedestrians.

[1]Knickel, Ray E., "Car Locator Uses and Patrol Car Emitter-Call Box Sensor Technique," Law Enforcement Science and Technology, Thompson Book Co., 1967.

[2]Issacs, Herb, Task Force Report: Science and Technology, U. S. Government Printing Office, Washington, D. C., 1967.

Knowing the locations of patrol units also improves the administrative control of the Command/Control Center. It avoids over or under responses and the resulting possibility that sections of the city may be inadvertently left without protection especially during emergencies. Additionally it permits more efficient allocation of field forces since patrol units can be easily redeployed to match the shift loading by area of the city.

Some surveys have attempted to translate the typical benefits claimed for AVL systems as summarized in Table 2 into cost savings. Generally these have stated improvements in Command/Control Systems performance on the order of 5 to 10%.

In a survey[3] performed for the Los Angeles Police Department, Hughes Aircraft showed that a field force of 75 units could theoretically be reduced to 70 units through use of an AVL system. This is a reduction of about 7% in field force requirements while maintaining the same median response time. The Mitre Corporation on a similar survey hypothesized that in a police department normally deploying 80 units; addition of an AVL system would be equivalent to adding 5 additional field units. This approximates a 6% increase in field capabilities attributed to the AVL system.

TABLE 2

SUMMARY OF MAJOR BENEFITS OF AN AUTOMATIC VEHICLE LOCATOR SYSTEM

IMPROVED RESPONSE TIME

- Real time location and identification
- Silent emergency alarm for officer

IMPROVED EMERGENCY OPERATIONAL CAPABILITY

- Priority dynamic control
- More effective force mobility
- Vehicle surveillance

INCREASED MANAGEMENT INFORMATION

- Vehicle status information
- More efficient resource assignment
- Reduced operational costs

3 Bussard, D.L., Los Angeles Police Department Operations Simulation, T.P. 69-16-29, Fullerton, California: Hughes Aircraft Company, Ground Systems Group, August, 1969.

OBJECTIVES AND POTENTIAL BENEFITS OF PROJECT

The primary objectives of this study focused on identifying feasible Automatic Vehicle Locator Systems and evaluating them against the operating requirements of the Orlando Police Department in order to recommend the most promising for incorporation into the Command/Control System.

Without the aid of a vehicle locator system, dispatching procedures in the Orlando Police Department require that a car operating in an assigned district be assigned to respond to an emergency call if it happens within his district. This procedure is based on the management premise of assigning authority commensurate with responsibility. Since the Communications Center does not have current intelligence of the patrol vehicle locations it must of necessity broaden the assignment responsibility of the field unit to a known area for accountability. Although this is a proper approach under the circumstances, it sacrifices response time and administrative control. There is a high probability in many instances that a car in an adjacent district will be closer to the scene. To overcome this situation, the dispatcher might call all cars in the vicinity of the complaint and be assured of getting the closest unit; however, this will result in an unnecessary number of cars converging on the site. These extra cars would clearly be more effective remaining on their own beats or being strategically deployed along likely escape routes, especially in the event of a chase.

The key element in implementing a continuous force status monitoring system in a suitable patrol vehicle locator. A number of vehicle locator systems for police operations have been conceived and some have undergone prototype evaluation. Generally, however, these are in the larger cities such as New York where a LORAN type system is being considered. Other types of tracking systems which have been investigated include a modified RADAR Transponder, emitter/sensor Proximity Systems, Car-Borne Position Computers, and Trilateration/Triangulation System. It is evident from a review of the literature that the locator technique incorporated in the system must be carefully selected. For example, a LORAN system appeared to be most feasible for New York because of multi-path problems created by the high buildings which introduce serious operational problems for a high frequency ranging or direction finding type system. It is important then to ensure that a system is designed to satisfy not only the police operational requirements but also the physical and environmental requirements in which it must operate.

The maturity of the Orlando Police Department is such that an Automatic Patrol Vehicle Locator System could make a significant contribution to its continued successful operation. This was noted in a previous report[1] which used operational data to model and analyze the Command/Control System and recommended special emphasis be addressed toward reducing travel time through incorporation of an Automatic Vehicle Locator System. Before implementing such a system, however, a systems engineering evaluation of the various automatic vehicle locators is necessary to determine which will provide a system most cost effective within the performance and

[1]Doering, R.D., Computer Simulation of Command/Control Operations, Project 70-04-05, Report to Governor's Council on Criminal Justice, Sept. 1972.

environmental requirements of the Orlando Police Department. It is important to recognize that each police department, although having similar operational function, may vary widely in its actual physical characteristics due to the environment in which they perform. Only by application of systems engineering methodology can these varied inputs and constraints be successfully integrated and analyzed.

This study was conducted as the first step incorporating a real time force status monitoring system into the Orlando Police Department Command/Control System. The primary objective was to investigate the known vehicle locator techniques relative to their feasibility and capability to satisfy the Orlando Police Department requirements. The logic of this emphasis on vehicle techniques is evident when one considers that it is the key to a successful force status monitoring system. The other subsystems, computer and display, are much less dependent on the future environmental constraints and operational requirements. The principal objectives of the project are summarized in chronological sequence in Table 3.

Secondary objectives of the research can be generally identified with application of the report data to other police agencies where the environment is similar and in related operational areas. For example, the system could also be used on buses, taxis, armored cars and high-value trck loads where a signal by the driver would automatically alert authorities and indicate the vehicle position.

TABLE 3

LISTING OF PRIMARY OBJECTIVES OF PROJECT IN CHRONOLOGICAL SEQUENCE

- Construct a Scenario of OPD operations. This will provide the system operational description for OPD which integrated the functional situations with environmental requirements.
- Identify dynamic tracking systems for patrol vehicles. This will provide descriptive data on vehicle locator methodologies currently available in hardware form and adaptable to police operations. It will include technical information on operational and maintenance aspects of the systems.
- Evaluate feasibility of Tracking systems for OPD application. This will require constructing an evaluation profile for each system against Scenario requirements using a computer simulation model of the Command/Control System.
- Perform system design analysis to identify the most promising tracking system. This will include an overall design review in sufficient detail to permit estimation of prototype performance parameters.
- Design and develop a feasible prototype system for installation and evaluation in a selected district

SECTION III

PROJECT RESULTS AND RECOMMENDATIONS

- o Observation and Recommendations for Orlando Police Department
- o Research Program Planned by Orlando Police Department

Generally considerable experimental work has been accomplished in developing AVL systems for police Command/Control operations. To date however, the study showed only one, (LOCATES, in Montclair California), has been installed and is being used under operating conditions in the United States. A number of prototype systems have been installed for demonstration purposes and then dismantled. It appears that up to this point the police have been reluctant to contract for what is essentially a development system and the suppliers have been reluctant to guarantee system performance on a fixed price basis. Two operational systems, however are now under contract to a police agencies, LOCATES (Applied Technology Inc), and FLAIR (Boeing Co.) in Saint Louis, Missouri. It is understood that the FLAIR contract is firm fixed price with guaranteed $\pm$ 50 feet accuracy.

The FCC has also recognized the growth impact of AVL Systems and is currently engaged in hearings to determine a frequency spectrum which will be reserved for AVL usage.

It was also observed that the majority of the AVL Systems which were reviewed included provision for digital transmission of communications messages. This appears to be a logical approach since the systems are closely allied and simultaneous implementation should effect a cost reduction.

The study showed that the Orlando Police Department has reached the maturity where it could benefit significantly from installation of an AVL System. A computer simulation model of the Command/Control System was used to compare existing Uniformed Field operations with similar operations augmented by an AVL System. Comparison of the model output showed that for equivalent response times, an AVL augmented system would require 2 less patrol vehicles in the field. A subsequent economic analysis showed that for a 10 year system life and a 5% return on investment the potential savings would justify a capital investment of $1,000,000.From informal discussions with potential suppliers, it appears that a system could be installed for 30-35 vehicles in Orlando for a cost of about $400,000.

The experimental proximity system installed during the project should be maintained and operated to gather information on human factors problems attendent with introducing an AVL System into the Command/Control operations. Although operational and useful, the prototype performance was compromised by the inexpensive components which were used to implement it. Also the design was constrainted to use the existing communications equipment which limits its flexibility and growth capability.

It should be recognized that the AVL System is a key element in an Automated Command/Control System and a big step toward the concept of a near instantaneous arrival of the officer at an incident site. As such, this project is an integral part of an overall Research Program planned by the Orlando Police Department.

OBSERVATIONS AND RECOMMENDATIONS FOR ORLANDO POLICE DEPARTMENT

The Orlando Police Department should install an Automatic Vehicle Locator System; it appears to be a good economic investment and in addition will provide increased safety and security for both officers and citizens.

In general the study showed that the Orlando Police Department has reached the maturity where it could benefit significantly from the installation of an Automatic Vehicle Locator System. A computer simulation model of the Command/Control System was used to compare existing Uniformed field operations with similar operations augmented by an AVL System. Input data for the simulation model was based on extensive sampling of actual system operations on a 24 hour basis for two six week periods in Spring 1972. After validation, the model was modified to incorporate the logic of an AVL sugmented system in which the nearest available vehicle to the incident is dispatched.

Prior to accumulating output data the model was exercised to obtain equilibrium and each run then processed incidents equivalent to 3-4 days of normal operation. Evaluation parameters included travel distance and time, and the number of incorrect vehicle dispatches. The model was exercised for assumed accuracies of ± 0, ± 500 and ± 1000 feet to provide data with which to evaluate the different types of AVL Systems.

Comparison of model output for the existing and the AVL augmented Command/Control System showed that, for an equivalent response times, an AVL augmented system with about ± 800 feet accuracy would require 2 less patrol vehicles in the field. This reduction in field force requirement agrees closely with other similar studies which conclude that a saving of about 7 - 8% can be effected.

The annual cost of maintaining a one-man uniformed patrol car in the field was estimated to be $115,000. This figure includes operation and maintenance of the vehicle, officer wages with an assumed 100% overhead and administration support factor. Further economic analysis using a 6% return on investment and 10 year life shows that replacement of 2 cars would justify a capital investment of $1,000,000.

The variation in performance characteristics together with environmental interface made it impractical to compare the different AVL Systems on a cost basis at this time. In addition the suppliers were generally reluctant to supply cost information without considerable additional engineering effort. It appears, however, based on discussion with the two suppliers who are under contract, that a system with accuracy of less than 900 feet and capability of monitoring 30-35 vehicles with the city limits of Orlando could be installed for approximately $400,000.

On this basis it is recommeded that OPD install an Automatic Vehicle Locator System. It appears to be a good economic investment for the City and offers increased safety and security to both officer and citizen. In addition the fuel saved by two cars would be a significant contribution in this era of energy shortage. As a first step toward implementation of this recommendation this study should be extended to develop a performance specification for the system so that bids can be obtain for reputable suppliers.

The experimental proximity system installed during the project should be maintained and operated to gather information on human factors problems attendent with use of an AVL System. Due to the low budget constraints under which the system was developed, the design incorporated the less expensive, tone-coded method of data transmission. As pointed out in the body of the report, this system suffers from interference problems, and a more reliable system could be achieved with digital transmission. In addition the transmission could be via cable TV network which exists in Orlando. Both suggested modifications would relieve the problem of overloading the UHF communication channel with AVL signals. The prototype however, can be used to familarize and prepare the dispatcher for an AVL augmented operation. In addition it undoubtedly will define interface problems between the dispatch personnel and the system such as lighting, signals, and display presentation.

The survey to determine the State-Of-The-Art in AVL Systems showed that considerable experimental work has been accomplished. To date, however, the data showed only one system has been installed and is being used under operating conditions by a police jurisdiction in the United States. This is the LOCATES proximity system installed for the Police Department of Montclair, California. A number of prototype systems have been installed for demonstration purposes and then dismantled.

The survey response data identified four major system types - Proximity, Trilateration/Triangulation, Dead Reckoning and Loran which could be identified with several suppliers. Further analysis showed that, although no one technique was clearly dominant, the Proximity System had been identified by 38% of the responses followed by Dead Reckoning with 28%. A comparison of system types by performance parameters showed Proximity with the most maturity and "hard" data. The Dead Reckoning system however, exhibited the best overall performance due to the accuracy (± 50 feet) and operational flexibility (location signals are generated by the vehicle from any position). Both systems had been demonstrated and both are under contract to a police agency for installation, LOCATES in Montclair, California and Boeing FLAIR in Saint Louis, Missouri.

It was also observed that the majority of AVL Systems addressed Command/Control communications by including provision for digital transmissions of 10 code type messages. This is a good approach since the two systems are closely allied. Implementing them together will simplify the overall installation and should effect a considerable cost reduction. Accordingly, it is recommended that digital communications capability be a part of the AVL System. It is noted that the FCC has recognized the need for AVL systems and is now actively holding hearings to determine the frequencies which will be allocated for locator system usage.

Typically the AVL system can contribute operational features which benefit both officer and citizen. The AVL system can be equipped to unobtrusively transmit a coded officer-needs-help signal. Since his position is indicated at all times at headquarters, help can be directed quickly to him. The safety of the citizen needing help is also increased because the officer nearest him can be dispatched, thus reducing the response time. In unusual cases the dispatcher may help the officer to the scene by noting his progress on the display and directing him over the shortest route.

The AVL system is a key element in an Automated Command/Control System and a big step toward the concept of near instantaneous arrival of the officer at an incident site.

RESEARCH PROGRAM PLANNED BY ORLANDO POLICE DEPARTMENT

The Automatic Vehicle Locator Feasiblity Study is part of an overall plan to effect a "fusion" of personnel, technology and management techniques toward implementation of an Automated Command/Control System at Orlando Police Department.

Police Administrators throughout the nation today are becoming increasingly aware of the advantages which a "fusion" of men and new technology may offer their operation. They visualize the added leverage which the technological tools such as secure communications, automatic patrol vehicle locators, information storage and retrieval and computer aided dispatching can contribute to the response capabilities of their departments toward the concept of near instantaneous arrival of officers at the crime site.

It must be recognized, however, that a technological fusion process cannot be instantaneous. It must be planned and organized such that each component will blend into the total system. Interfaces must be recognized, defined and reflected in the conceptual planning. A well planned system should have the inherent capability to incrementally add the necessary technical system support to meet the operational growth needs. This approach is being used by Orlando Police Department to build toward a fully Automated Command/Control System which uses a digital computer to perform the overall integration function.

Three parallel areas of effort are necessary for an effective technological fusion process. These generally can be defined as personnel training, development of new management techniques and specification of technology requirements. Too often the focus is on technology. This approach can only result in a less effective system since the personnel have not been trained to fully utilize it and management may not have the knowledge or tools to direct and control the resulting system.

Figure 2 is a logic diagram which relates the planned studies needed to implement an Automated Command/Control System within the Orlando Police Department. The initial step was the Computer Simulation of Command/Control Operation project (70-04-05) which was completed in September 1972. The simulation model was used to determine the feasibility and effectiveness of alternate operational methods which introduce new technological concepts and field force assignments against emergency and projected tactical situations.

As spin offs from the Simulation study, a conceptual Command/Control Training Model was tested and a Statistical Data Base is being compiled. The studies which are underway or completed have been indicated by shading the area on the diagram. The Automatic Vehicle Locator Feasibility Study is described in this report. The function of this system is to continually update the location and status of all patrol units in the field and display this intelligence on a large back lighted map for use of the Command/Control Personnel. This force status display board would also be equipped to show the incidents to provide a visual correlation and facilitate dispatch of the nearest available unit. A study was required because there are a number of alternate approaches, and the design must reflect the specific conditions of the Command/Control System under consideration.

Correlation/Regression Analysis is planned to provide background for a Resource Allocation System (RAS). Its primary objective is to provide management with a method to plan and control their response to a predicted requirement. Its forecasting capability would include predictions of the number, kind, time and general locations for the occurrances of incidents and the numbers of patrol units necessary for varying levels of service to satisfy their demands.

The Computer Assisted Training (CAT) study would be directed toward application of advanced instructional technology to meet the increasing training demands imposed by the increasing level of equipment sophistication. For example, the original Dispatch Officer Training Game would be computer augmented for increased flexibility and effectiveness. This could also be used to introduce the requirement of typing capability to communicate with the computer to enter and extract information thus duplicating the real Automated Command/Control System. It would precede the implementation so that personnel could be trained and available.

The complete Automated Command/Control System would require that the Dispatch Officer answer the call and enter the information in the computer. The computer would then search its memory for any pertinent information on the incident site and also locate the nearest unassigned patrol unit. This recommendation would be displayed for decision by the Dispatch Officer who may override the computer if he chose . If the recommendation is acceptable he could automatically transfer it for radio transmission to the field.

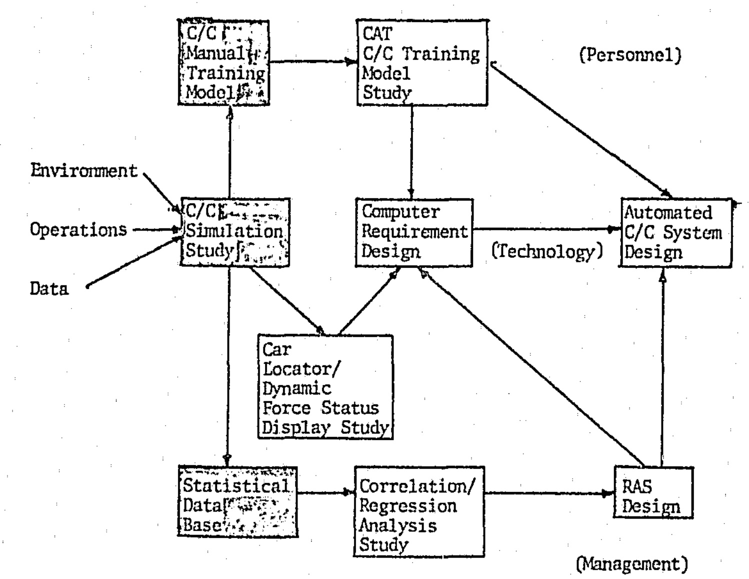


Figure 2: Logic Diagram Relating System Studies And Determination Of Design Requirements For Orlando Police Department Automated Command/Control System Identifies Three Major Areas Of Effort, Personnel, Technology and Management, Which Are Required.

SECTION IV

ORLANDO POLICE DEPARTMENT OPERATIONAL SCENARIO

- o Organizational Structure Of The Department
- o Incident Profile
- o Response Capabilities
- o Physical Environment
- o Regional Influences

The Orlando Police Department uses a functional organizational structure. The major line functions are assigned to four Bureaus - Field Operations, Staff Support, Administrative Services and Detention, each of which reports directly to the Chief of Police. The Chief is supported by staff sections in Inspectional Services, Research and Development and Legal. The Department presently has a complement of 393 sworn personnel.

The Incident Profile of the Department is reported by Part I, II, and III classifications, reflecting the Uniform Crime Reporting Program, and a category of Other Aided Cases. This latter category includes all incidents which require a response and case number but are not identifiable under the other categories. Orlando is presently experiencing an exponential increase in the crime rate. A computer curve fit of the data shows a projected increase of 44% within the next five years. It is noted also that the Part I crimes closely follow this projection.

The response of the Orlando Police Department is keyed to a district system. The City is currently divided into 18 districts which have been designed such that the normal load based on the number of incidents and service time requirements is relatively equal. One uniformed patrol car is normally assigned to each district and is responsible for all complaints within that district. There are also five sector cars manned by assistant squad leaders and five sector station wagons manned by squad leaders. These units are as backup for the district cars in theirrespective sectors. In addition service cars such as K-9 and traffic control are used to handle special incidents; two accident investigation cars are assigned to each watch. Motorcycle and unmarked cars are dispatched on incident calls only in emergencies.

Demographically and economically Orlando has entered an explosive growth period. It is the Economic Center of the eight county Central Florida region which is one of the fastest growing in the nation today. It is projected that the population of Orlando will increase over 40% within the next five years; present population is 107,000.

The topography is flat with many lakes which effectively increase the travel distance from point to point. Through annexation of large unincorporated areas south and west, it is expected that the area of the City will increase approximately 30% in the next five years.

The climate is mild and semitropical. Police operations however are affected by heavy percipitation and wind from tropical distrubances, thunderstorms, and infrequent tornadoes.

ORGANIZATIONAL STRUCTURE OF THE DEPARTMENT

The Orlando Police Department is organized on a functional basis with similar activities combined within four operating Bureaus which report to the Chief who has staff sections in Research and Development, Inspection Services, and Legal Advisement.

Organizing as a management function can be defined as the process of segmenting the overall task into controllable subtasks which are designed to optimize the specialization of labor. It thus involves a grouping of activities to attain the objectives of the Department and delegation of authority to complete the assignments. The resulting organization structure must effectively define the resulting activity-authority relationships and provide for coordination among them both vertically and horizontally to ensure effective coordination and team work.

An organization chart is a graphic presentation of the formal organization structure, and is used to define the organizational functions, functional relationships, lines of authority and responsibility. Individual blocks can be used to show a functional responsibility or title of the individual assigned to it.

The Orlando Police Department uses a functional type organization structure as shown by the chart in Figure 3. The chart identifies the major line functions as Bureaus and their subfunctions as divisions and sections. The rank of the supervisor of each section is shown together with the number of personnel currently assigned to the section; these figures include both sworn and civilian personnel. The Department presently has a sworn complement of 393 personnel.

The Chief reports to the Director of Public Safety who in turn is responsible to the Mayor and City Council of Orlando. The Department is also responsible to a Civil Service Board for its personnel practices.

The Field Operations Bureau includes two major functional areas. The Uniformed Division is charged with achieving a primary objective of the Department-crime prevention. It is organized around a patrol section which functions to preserve the peace, protect life and property and prevent crime. It also provides a substantial effort in preliminary investigation. Other activities of the Bureau are organized to meet specific situations in dynamic environment where high mobility and special skills and training are required.

The Criminal Investigation Division is responsible for investigating serious crimes, recovering stolen property and preparing cases for court. Its activities are typically after-the-fact and consist primarily of identifying and arresting perpetrators of major crimes, and collecting and organizing cases to convict these perpetrators in court. It is organized in five sections which are keyed to the crime type.

The Detention Bureau is charged with operating the detention facilities. It is organized around maintaining the security and well being of all prisoners committed to the facilities.

The Staff Support Bureau is responsible for those activities which generally support the other functions. It maintains records, processes data and furnishes statistical analysis on operations. The Communications section directly supports the field operations of the Uniformed Division and the Criminal Investigation Division.

The Administrative Services Bureau also primarily performs a support function. It is charged with controlling fiscal committments, preparing the budget, and providing the social interface with the citizen community. Within the organization it is responsible for all training and maintaining personnel records.

The Special Investigation Services Section is responsible for conducting staff inspections of the condition of personnel, equipment, operations, and procedures and investigation of complaints which allege misconduct by any member of the force. The intelligence gathering function is also located in this section and investigates incidents involving civil disobedience, organized crime, subversive groups and labor disputes.

The Research and Development Section provides assistance to the Chief, disseminates information on Department policy and performs such other activities as the Chief may direct.

TABLE OF ORGANIZATION

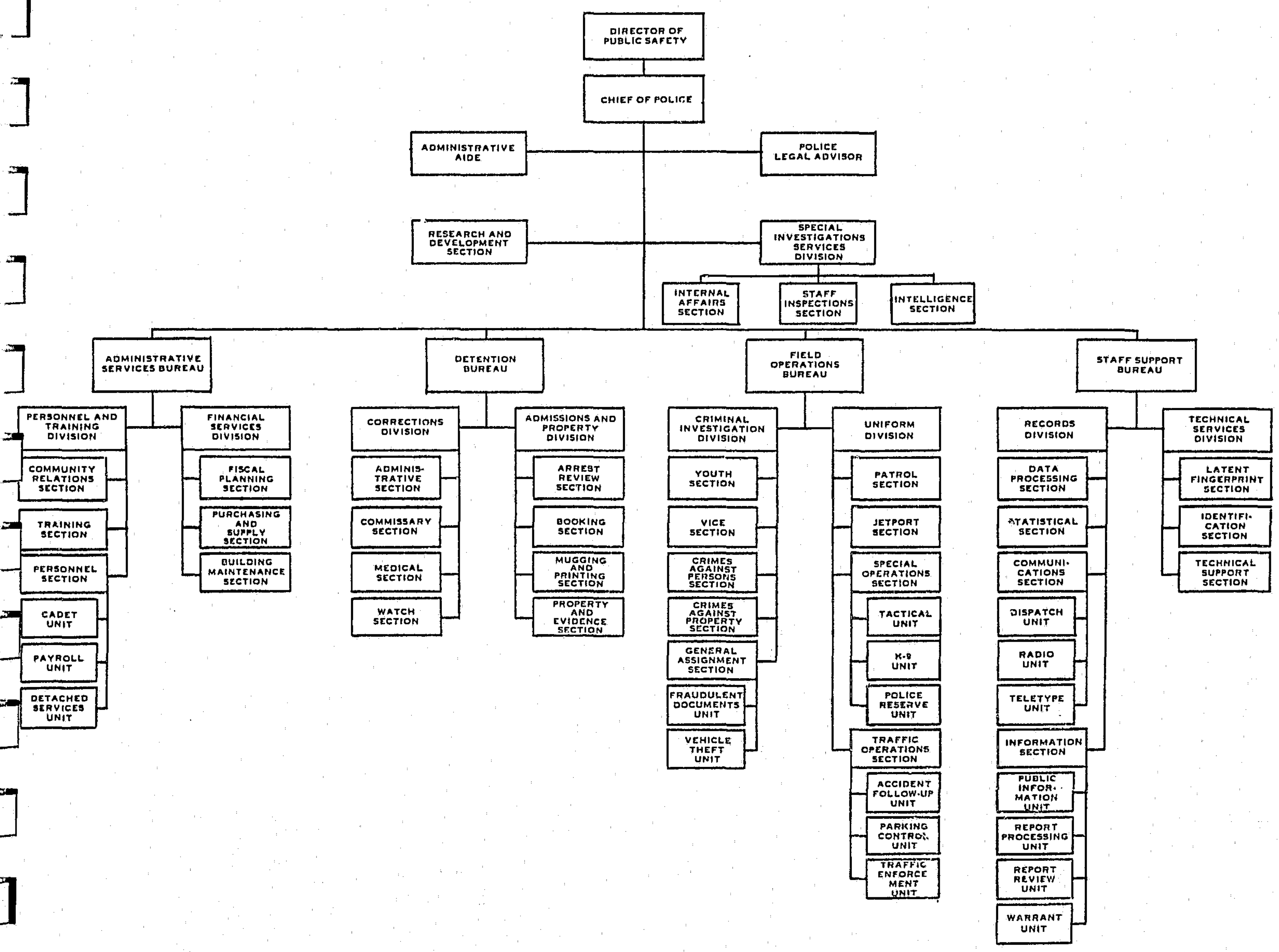


Figure 3 : Organization Chart Of Orlando Police Department Shows It Is Organized By Functional Assignment.

INCIDENT PROFILE

The Incident Profile experienced by the Department has been expressed in terms of descriptive statistics so that trends and special situations which are necessary for effective administrative and operational decisions can be more readily detected.

The Incident Profile can be defined as a description of the threats to the lives and welfare of the citizens to which the police department responds. The incidents range over a broad spectrum of types from offenses which jeopardize life to those which involve simply serving a warrant. Each must be clearly defined in order to effectively analyze the operation of a department and standardize if it is desired to communicate with other agencies. To meet this need the Federal Bureau of Investigation organized the Uniform Crime Reporting Program. Under this program the Uniform Crime Reporting Handbook[1] is used to identify and classify offenses.

Offense Incidents are categorized for analysis into three major classes. These are listed together with numbers known to the Orlando Police Department for the last three years in Table 4. The category of other aided cases includes accidents, unfounded cases and those calls which required no response by the police.

TABLE 4

OFFENSE BY CLASS AND NUMBER KNOWN TO

ORLANDO POLICE DEPARTMENT

OFFENSE CLASS	TOTAL RECORDED 1970	1971	1972
Part I	7932	8997	8304
Part II	6644	6127	6363
Part III	4090	4602	5287
Other Aided Cases	33813	39125	48200

Although the Police function is typically associated with the more hazardous Part I offenses, a police officer assigned to patrol is generally confronted with few serious crimes in the course of his watch. The numbers in Table show that he spends considerably more time keeping order and servicing accidents than he does in responding to incidents that require arrest action.

Orlando is presently experiencing a period of explosive growth which can only result in making the Police Department task more difficult. This is emphasized by reference to Figure 4 which is a plot of Part I and Total offenses and for Orlando over the last 12 years; both have assumed an exponential form.

1 U.S. Department of Justice, Uniform Crime Reporting Handbook (Washington D.C.: Federal Bureau of Investigation, July, 1966)

A computer curve fit program was used to analyze this data. The resulting equation predicted a 44% increase in the next 5 years, as shown in the plot of the projected data.

On a working level basis the Incident Profile can also assume added dimensions. For example, the incident by district typically varies with the physical characteristics of the district. A study[2] in Orlando based on a random sample showed the offense rate correlated most positively with population density, total population, poverty income and area of the district.

The incidents can also vary significantly by watch both by number and type. Typically, Watch 2 experiences the highest frequency of incidents followed by Watches 1 and 3. Days of the week also exhibit different Incident Profiles. Sunday is lowest, about 0.70 of the average and Saturday the highest at 1.7.

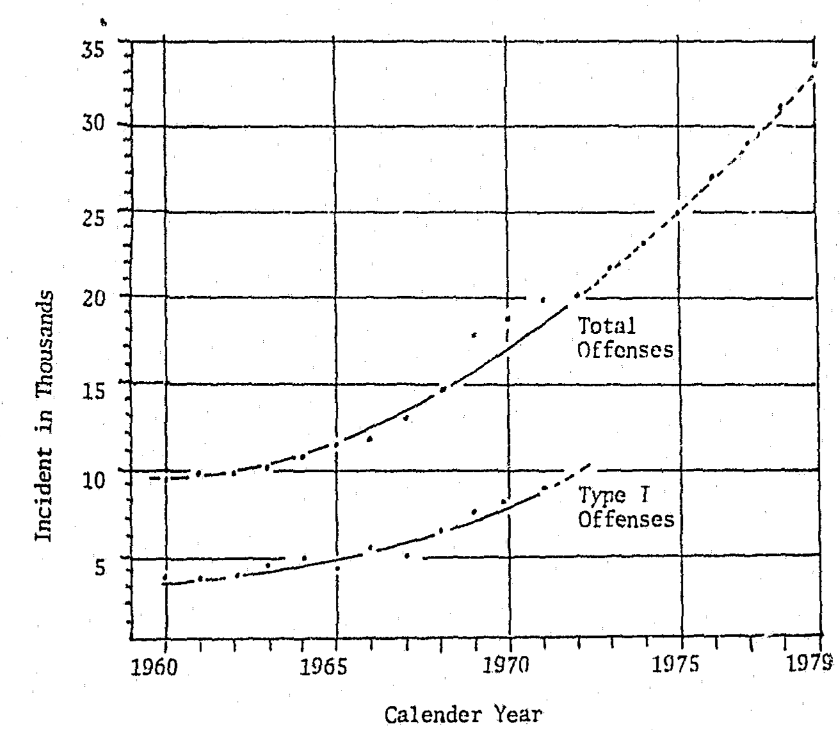


Figure 4 Graphic Display of Actual And Computer Predicted Offenses By Year, Shows Characteristic Exponential Increase Pattern

2 R.D. Doering, A Statistical Study of Orlando Police Department Operation, Report to the Administrative Services Bureau, Orlando Florida, April, 1971 (Orlando, Florida: Orlando Police Department 1971)

RESPONSE CAPABILITIES

The Orlando Police Department utilizes a response system which requires all complaint calls originating within a District be answered by the uniformed patrol unit assigned to the District; backup is provided by four Sector supervisory vehicles.

The response of the Orlando Police Department is keyed to a district system. The City is currently divided into 18 Districts which have been designed such that the work load, based on number of incidents and service time requirements, is relatively equal. One uniformed patrol car is normally assigned to each district and is responsible for all complaint calls within that district. There are also four zone cars manned by Assistant Squad Leaders (ASL) who act as backup when required. All district cars are supervised by four Squad Leaders (Sergeants) who patrol each of the zones.

The map of the City on the opposite page shows the districts and their relationship to the two major freeways. These freeways, I-4, which runs north-south and US 50, which runs east-west, effectively divide the City into four sectors since they restrict free passage across them.

There are also special service patrol cars such as K-9 and traffic control which are used to handle special incidents. Two accident investigation cars, AI 42, AI 43, are identified on the district map to handle traffic incidents east and west on I-4, respectively. Investigative and motorcycle units move in all districts but are dispatched to complaints only under emergency conditions. The primary assignment of the motorcycle units is traffic control and accordingly these units typically focus on traffic problem areas.

Under normal conditions the standard operating procedure is to dispatch the district patrol car to service a complaint which occurs within the district. If the primary car is unavailable the squad leader may move in to answer the call followed by special assignment cars, investigative and motor units generally in that order. Since the Communications Center does not have information on the specific whereabouts of a field unit, except within his assigned district, this appears to be the best method of operation; it assures primary and backup coverage for each complaint.

The Orlando Police Department averages 29 Uniformed Bureau patrol units per watch. The three shifts change at 6:30 a.m., 2:30 p.m., 10:30 p.m., and are scheduled to provide a 30 minute overlap to assure continuous field coverage. Because of illness, vacations, or car repair, all patrol units may not be available for duty during a watch. This requires reassignment of the units to cover all districts. There are a number of additional uniformed vehicles available for special duty; these are identified in the corner of the district map of the City.

A previous study[1] based on a random sample of one week operational data showed the average time was 4.4 minutes for all offense complaints

1 R.D. Doering, A Statistical Study of Orlando Police Department Operation, Report to the Administrative Services Bureau, Orlando Florida, April, 1971 (Orlando, Florida: Orlando Police Department 1971)

over all shifts and days of the week. The highest was 7.5 minutes for District 36 and lowest 2.5 minutes for District 24. Referring to the district map, it can be reasoned that much of the longer response time in District 36 might be attributed to the travel times associated with odd shape and distance from end to end of the coverage area. District 37 was also high, 6.0 minutes, and again the effect of the large dimensions of the area is apparent.

The Department is also a member of a mutual aid net consisting of all Orange County Law Enforcement Agencies. Under this agreement the participants provide men and equipment to handle major civil disturbances. In addition Orlando has a Police Reserve Organization whose members are available as backup to the regular force; however their activity is typically limited to special events such as ball games or the County Fair.

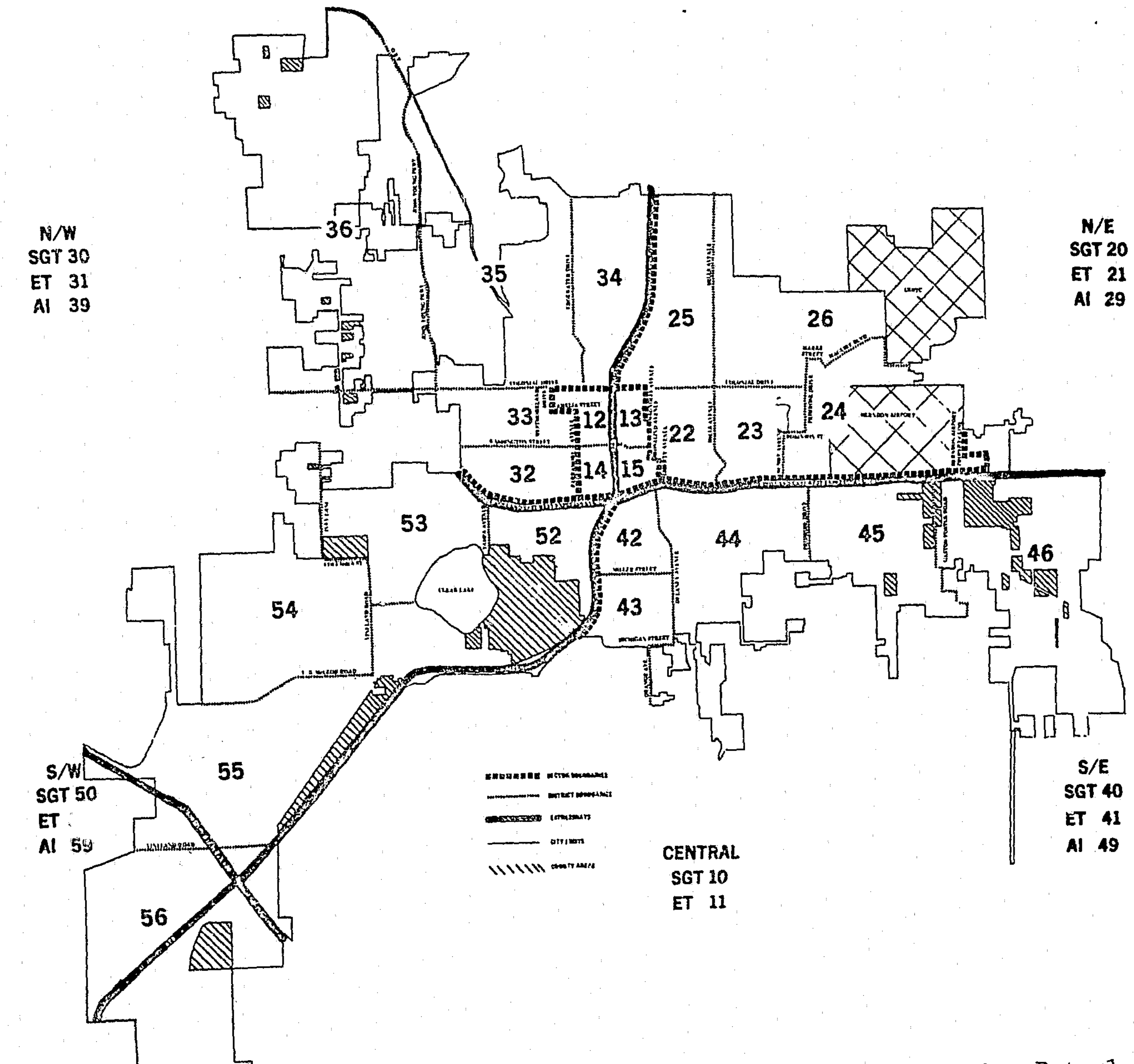


Figure 5 Reduced Scale Map of the City of Orlando Identifying Police Patrol Districts shows the Relative Difference in District Areas and Distance which Contribute to Difference in Response Times.

PHYSICAL ENVIRONMENT

The physical environment in which the Police Department operates is of concern in the study of the Command/Control System because it directly influences the incidents and the field force response capability.

The environment in which any system functions influences its ability to accomplish the assigned mission through the interface relationships which are inherent in the operational Scenario. An effective system design will examine and define these interfaces and how they are affected by changes in the environment so that the system can readily adapt to a dynamic situation.

The effect of the physical environment on the Command/Control System occurs in two basic areas. Both the Incident Profile and response of Field Forces are directly dependent on the characteristics of the environment. As discussed earlier the incidents occuring in a given district can be readily correlated with the physical characteristics of the district. Likewise, the travel portion of the system response time reflects the topography features of the district and weather conditions. Accordingly, for purposes of this study the physical environment can best be described in terms of demographic-economic, topographical and climatological characteristics associated with the City. A summary profile of these characteristics is contained in Table 5.

Demographically and economically Orlando is entering an explosive growth period. It is projected that the population will increase over 40% within the next 5 years; this compares with a 30% increase in the 10 year period from 1960 through 1970. This projection reflects the expected annexation of additional large unincorporated areas south and east of the present city limits. The major population growth of the City can be generally described as a transition of land use from agriculture to commercial, apartment and residential subdivisions. In turn the population impetus is the result of the strong economic growth of the area reflecting regional influences such as Walt Disney World, Kennedy Space Center, the Naval Training Center and Florida Technological University. Population and economics of the City are also geared to the large influx of tourists which occurs mostly in the winter months. The tourist population is now estimated to exceed 8,000,000 annually and to contribute over $106,000,000 to the greater Orlando area. In addition there are a number of smaller residential communities surrounding Orlando, such as Winter Park and Maitland whose citizens either work in Orlando or move through it each day on their way to work.

The topography is flat with no canyons or hills to create natural barriers; however there are over 60 lakes presently within the City limits. Although most are relatively small they effectively increase the travel distance from point to point. Two other large barriers are the Municipal Airport and Naval Training Center both of which are within the City limits and effectively block free surface movement in a large area in the eastern part of the City. Two major freeways, N-S and E-W, effectively also divide the City into four quadrants impeding movement across the right-of-way. Through projected annexation, it is expected that the area of the City will increase approximately 30% in the next 5 years with corresponding changes in dimensions as summarized in Table 5.

The climate can be classified as mild, semitropical. There are no severe winter storms or snow; however the temperature infrequently does reach minimal freezing conditions. In summer there are frequent heavy rains which impede surface movement for short periods of time. Also in late summer hurricanes form in the Caribbean but their movement into Central Florida is infrequent. When experienced, hurricanes typically disrupt normal traffic and communications due to wind damage, flooding and trees which fall in the street or on power and telephone lines.

TABLE 5

CHARACTERISTICS OF PHYSICAL

ENVIRONMENT IN ORLANDO AREA

		1972	1976
DEMOGRAPHIC			
Population		109,000	140,000-160,000
TOPOGRAPHY			
City Limits			
Area, Sq. Mi.		35	50
N-S Dimension, Mi.		8	11
E-W Dimension, Mi.		6	12
Streets, Miles		414	550
Lakes		62	75

WEATHER	Low	High	Average
Temperature, °F			
Spring	31	102	72
Summer	60	100	82
Fall	24	102	73
Winter	24	81	63
Precipitation, Inches			
Mar.-May	3.4	15.0	10.2
June-August	8.6	31.4	22.4
Sept.-Nov.	33.8	74.2	51.2
Dec.-Feb.	3.0	11.0	6.2
Max. Rate In./Hr.	2	4	
Patchy Ground Fog in Winter & Spring			

SEVERE WEATHER	
Hurricanes	Annual Average-One
Tornadoes	Infrequent-Random Location
Thunderstorms	Annual Average-62

REGIONAL INFLUENCES

Orlando is the Economic Center for the eight county East Central Florida Region which has become one of the fastest growing in the nation today and consequently is experiencing severe demands in its public safety organizations and social service facilities.

Knowledge of the structure and relationship of the economic, social, and demographic variables in the environment is essential to effectively plan the governmental services. It has also become increasingly evident that government at every level is playing an increasing role in influencing and guiding the growth pattern. At Federal and State level monetary, social and environmental controls have been instituted to guide and stimulate growth. At the local level government must plan and invest in recreation and cultural facilities, airport and services such as police. Additionally it is noted that at the local level the regional factors may interact strongly or combine to accelerate and shape the growth of a particular area.

The Orlando area is experiencing such a growth pattern and is in its second boom of the modern era, the first being the space boom in the late 50's. From 1965 to 1970 Florida grew at the rate of 14% while the nation grew at 5% and the Orlando Metropolitan Area grew 38% in population. It is projected that from 1970 to 1975 the Orlando Metropolitan Area will increase in population by 31% while Florida grows 11% and the nation grows 10%. The metropolitan area has moved from 82nd to the 69th among metro areas in the nation during the past decade.[1] As shown in Figure 6 Orlando is located in the central part of the State midway between the two coasts. It is bounded by Kennedy Space Center in the east and Walt Disney World in the west.

Kennedy Space Center triggered a fast-growing aerospace electronics industry which has had great impact on the industrial development of Orlando. It is also a large tourist attraction. It is generally agreed, however, that the single most important factor in the region in the present growth pattern is Walt Disney World. This resort-amusement complex is presently directly employing over 11,000 people and attracting visitors at the rate of 10,000,000 annually which exceeds the total population of the State. Also to be considered is the influence of a new state university. Florida Technological University, which opened in 1968 now has 7,500 students and is continuing to grow. It is located a few miles east of Orlando. In 1968 the Navy also opened its third Recruit Training Center on the northeast fringe of the City limits. This is continuing to develop on a 1,100 acre site toward a planned capacity of 8,000 recruits and 7,500 permanent Navy personnel.

These factors combine to form a future growth profile for Orlando Area:

- It is a major trade center and is becoming a leading center for precision manufacturing supported by the new technological base presented by the University.

- It enjoys a major supporting role to the aerospace activities centered at Kennedy Space Center.

1 Orlando Area Chamber of Commerce, Statistical Data Orlando Metropolitan Area (Orlando, Florida: Economic Research Department, 1971)

- It has become a major tourist destination due to the drawing power of Walt Disney World.

- Corporate Orlando will receive less of the total population influx into the County, although it will continue to grow at a phenomenal rate through annexation, multifamily housing and high-rise structures.

It is noted, however, that all these gains are not without problems. With population growth comes increases in crime and social needs. A tendency on the part of the disadvantaged in other areas to migrate to boom areas is standard, and the Orlando Area is experiencing something of a strain on its social service facilities such as the Salvation Army housing for transients. Impartial observers probably would say that crime increases, including the use of drugs, have been about what you would expect in a growing metropolitan area of the size of Orlando.

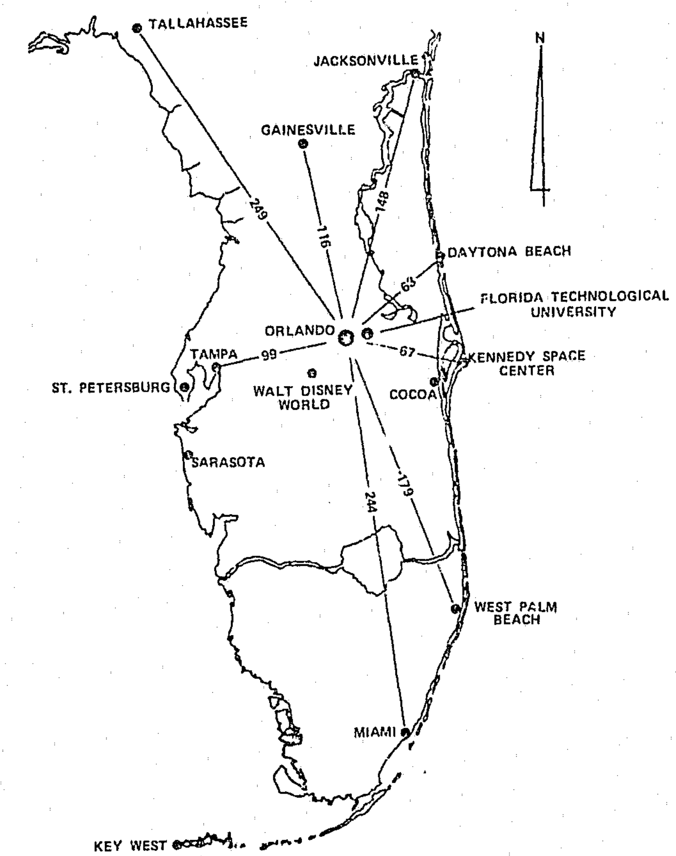


Figure 6 Map of Florida Mainland Shows Geographical Location of Orlando In Relation to Other Major Population Centers.

SECTION V

ORLANDO POLICE DEPARTMENT

COMMAND/CONTROL SYSTEM

- o Command/Control System Organization
- o Functional Analysis of Command/Control System
  - o Dispatch Officer
  - o Radio and Teletype Operators
  - o Uniformed Field Patrol Force
- o Command/Control Center Communciation Equipment
  - o Control Console
  - o PREP Radio System

A Police Command/Control System includes specialized personnel and equipment whose activities must be planned, organized, directed and controlled to most effectively protect lives and property of the citizenry.

A key element in the System is the Communications Section. It provides a point contact between the inside world and the field forces, integrates the sources of information and has functional authority to direct and coordinate the field activities. Input to the system can be initiated by the public via telephone, other law enforcement or public service agencies via telephone, radio or teletype and field units via radio or telephone. Typically an input requires a data screening and analysis at the Complaint Desk station, information dissemination at the Radio and Teletype stations and information renewal at Teletype station.

Staffing the Communication Section for continuous operation requires personnel skilled in these three work areas. An average watch manning includes a Supervisor, two dispatch officers, one teletype operator and two radio operators. Personnel are trained in the functions of each work station so that they can relieve each other as required.

The field patrol units are organized under a Watch Commander with four Sector Commanders supervising the Patrol Units in their sector. Each patrol unit has an assigned area or district in which they cruise and respond to calls. A patrol unit receives and responds to a dispatch order from the Communications Center. All assignments are monitored by the Sector Commander and other patrol units, and the Sector Commander may modify the dispatch order based on his knowledge of the field situation.

Operation of the system requires special communication equipment. All voice communications via radio and teletype are recorded on a continuous time synchronized tape. Department radio communications are via four channel UHF equipment which is designed as a PREP (Personal Radio Equipped Police) system.

This permits two-way officer to officer or officer to headquarters communications. Several VHF channels are also available for vice and investigation communications as required and one for intercity police transmissions. The teletype system is tied to both FCIC and NCIC. The Complaint Desk and Radio Operator stations are connected by intercoms and have multi-extension phones for incoming calls and direct lines to F.H.P., O.C.S.D., Electric Securities, Fire Departments and ambulance services. A Force Status Board located in the Radio Room is visible at the other stations and maintains the status of all patrol and detective units on watch.

COMMAND/CONTROL SYSTEM ORGANIZATION

The organizational structure of the Communications Section reflects the functional authority which it has been delegated in the Command/Control System to discharge the task of communication interface between Field Forces and calls for service.

The Communications Section organizationally reports to the Captain in charge of the Records Division. It is charged with providing an effective communications interface between the person calling for service and the field forces, between various units of the Department and other law enforcement and emergency agencies. The Center is responsible for manning telephone, teletype, telegraph, computer terminal and radio communication facilities necessary to provide effective Command/Control communications capability within the Department. The unit thus has both an operational and technical orientation.

The organization structure consists of three operational groups--- Radio, Teletype, and Dispatch as shown on the Organization Chart in Figure 7. Personnel staffing consists of both civilians and sworn personnel. Typically the Radio and Teletype operators are civilians and the Dispatch or Complaint Desk position utilizes both sworn and civilian personnel. The current number of assigned staff in each position is shown in the small box in the corner of each block of the organization chart.

The Communications Section Supervisor is responsible to the Captain for the effective operation of the Section. The duties of this position include typical management functions such as planning, organizing, staffing, directing and controlling. It is noted that the planning and organizing functions are unique in that the internal policies and operating procedures of the section must directly reflect and complement the operational field forces procedures.

It is important to note that the Communications Section has been assigned functional authority in dispatching the field forces. This is necessary to preserve the unity-of-command principle which is essential for effective response. The line responsibility for response by the field forces however remains within the Uniformed Division, and the watch or sector commander may modify a dispatch order based on his assessment of the field situation. When this procedure is used, the field commander must realize that he is interrupting the normal event chain and is now assuming responsibility for dispatch. He must ensure that he is aware of all service needs and can respond to them appropriately. He also has the responsibility to inform the Communications Section via the Radio Operator of the new dispatch assignments and that he is now returning functional authority to the Section.

Under the supervisor in direct line command are the Dispatch or Complaint Desk personnel. When the Supervisor is not in the Communications Center, the responsibility of command rests with one of the Dispatch officers. In the general functions of the Communications Center, the Dispatch officer coordinates the Radio, and Teletype operations to ensure a smooth orderly flow of information and assignments to the field units. Unusual telephone inputs or incidents are reported to the Supervisor or acting supervisor for disposition.

The Radio and Teletype operators also report to the Supervisor. Each has direct responsibility within the total Command/Control function and must advise the Supervisor of unusual communications and/or incidents. Both Radio and Teletype interact with field forces and with the Complaint Desk. All Broadcasts received from N.C.I.C. and F.C.I.C. must be approved by the Dispatch Officer before Teletype can relay the information to Radio. This ensures that there is no unintentional repetition in information broadcast to the field units.

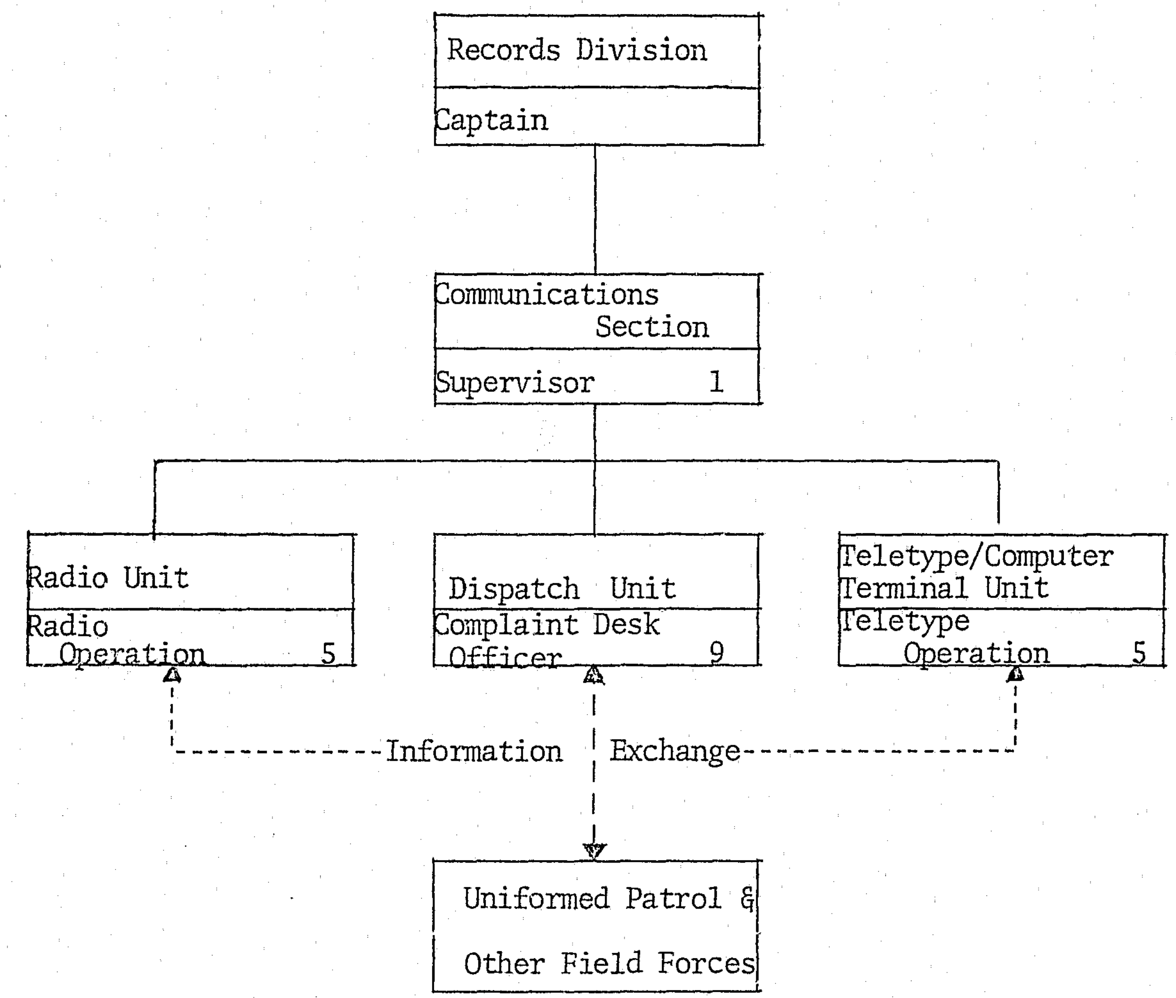


Figure 7 : ORGANIZATION CHART OF THE COMMUNICATIONS SECTION

FUNCTIONAL ANALYSIS OF COMMAND/CONTROL SYSTEM

Four operational modes must be defined in order to ensure that all the functional steps within the Communications Center can be accurately described and keyed to interactions with the Uniformed Field Force, other Public Safety Agencies and the General Public.

To discharge its mission the Communications Center must interface with the General Public, all police functions within the City of Orlando and other law enforcement and Public Safety Agencies. In addition there are a number of operational modes to be considered which add to the complexity of the system since each interface may require a different response from the Center. For example, the actions may include giving watch personnel assignments, calling an ambulance, answering questions on laws, relaying information and dispatching police units. Each response may involve one or more components of the Command/Control System which must work in unison to perform the function. Although procedures exist, they clearly cannot cover all situations and required actions. It is possible, however, to categorize the response by type of operational modes required. Accordingly, four operational modes were defined to analyze the Command/Control System. The result was a functional analysis which described the actions of units in the System, given a specific operational mode. The operational modes are listed in Table 6 together with their definitions.

The first operational mode is termed Routine. This mode includes normal daily activities which do not result in a permanent case or file number. The Dispatch Officer's action includes answering an information request on a call that requires a 602-09 form. The routine functions of the Teletype Operator would be a query to NCIC or FCIC and find a negative response to the questions. The radio operator routine operational mode requires monitoring the assigned channels and transmitting 602-09 assignments. Interactions between the Communications Center and the Uniformed Field Units exists in the Routine mode.

The Incident Mode does not differ significantly from the Routine. The 602-03 form is completed by the Dispatch Officer, however, which creates a permanent file on the incident. Typically in the Incident Mode a crime has been committed or a suspect arrested. The functional responsibility for clearing the case is with the Field Unit and the responsibility for dissemination information in aid of the unit is with the Communications Center.

Whenever an in-progress crime is reported, or a 'unit-needs-assistance' call is received or any personal injury is reported all units of the Communications Section and Field Forces assume the Emergency Operational Mode. This mode may be initiated at the Communications Center when a Field Unit witnesses an armed robbery, a routine identification check results in hot pursuit or when an on scene unit requires assistance. The Emergency Mode requires close interaction between the Communications Center and the Field Force.

The final mode requires no interaction between the sections of the Command/Control System. The Internal Mode is comprised of operations or tasks which are unique to the subsystem involved.

For each mode a detailed functional flow diagram relating the major subsystem activities was prepared; this has been included in Appendix A for reference. The true complexity of the operation can only be visualized, however, when it is realized that at least 34 uniformed patrol units may be in the field and each may be in any mode. The Command/Control System mode depends upon the type call being processed, the type of call being answered on the telephone, the type of teletype information requested and the type of radio traffic existing at any given time.

TABLE 6

DEFINITIONS OF SELECTED OPERATIONAL MODES
FOR THE COMMAND/CONTROL SYSTEM

Routine mode - normal nonemergency and/or general daily operation of Command/Control System which does not result in a case or file number.

Incident mode - those daily operations which would result in a case number being required, but which did not include any personal injury or require more than one regular patrol unit to answer call.

Emergency mode - those operations which arise from incidents requiring response by more than one regular patrol unit, personal injury and/or in progress crimes.

Internal mode - those periodic operations or functions which are unique to the several subsystem operations involved in the Command/Control System.

DISPATCH OFFICER

Whether answering general information questions or gathering pertinent facts, the Dispatch Officer must be thorough, tactful and efficient because he is the primary interface between the Police Department and the General Public and his ability to obtain the required information and act accordingly contributes directly to the success of the Department in its primary mission.

Telephone calls from the general public account for approximately half of all the calls answered by the complaint desk. The remaining calls originate from other activities within the police department and other law enforcement agencies such as the Florida Highway Patrol and Orange County Sheriff's Department.

The general public calls the police department when it needs emergency aid, wishes to report a crime or suspicious activity, or simply desires information. In Orlando the Police Department 'emergency' number is on the front inside cover of all telephone directories and on every 'marked' patrol unit. Dialing this number will automatically place the caller in contact with a Dispatch Officer at the Command/Control Center. Although the caller may never see this officer, his very life could depend on the officer's decisions and actions. To this citizen the Dispatch Officer is the Police Department; how he conducts himself over the phone will be equated with the actions of all uniformed police.

Until it is determined otherwise, a call to the Dispatch Officer must be considered an emergency. The call must be answered, information obtained, all requisite forms completed and a patrol unit dispatched if required, within the shortest possible time. How the information is obtained is based on training and experience, but the same general information is required on each incoming call before any decisions can be made.

The Dispatch Officer must determine.

- o Name and location and telephone number of the caller;
- o Location of the incident;
- o Nature of the call, that is, to report a crime or disturbance, to report an accident, or to request information;
- o Names of any involved persons;
- o Whether the call required immediate or emergency assistance, such as an ambulance.

With this information the Dispatch Officer determines if the site is within the Orlando Police Department jurisdiction, whether a patrol unit should be sent, an ambulance or other assistance should be dispatched, and if a case number for a permanent police record is required. These decisions have to be made for all incoming calls, although the order in which they are made typically reflects the experience and training of the individual Dispatch Officer.

If a call is determined to require service where the Orlando Police Department has no jurisdiction, the Dispatch Officer may either record all the information and then relay it to the appropriate agency, or

he may interrupt and give the caller the telephone number of the appropriate agency if it is a non-emergency type call.

If a call does require a police response, the Dispatch Officer completes either a 602-09 or a 602-03 form. These forms summarize the information pertinent to the call and enable the Dispatch Officer to indicate the patrol district and patrol unit to be assigned if available. The 602-03 form is completed whenever a patrol unit is required. The 602-03, however, has a sequenced record number in the top right corner and is completed when a police report file will be created on the incident. When either form is used, the time of day and date is electronically stamped on the card before it is deposited in a conveyer belt, which transports it to the Radio Operator.

Table 7 shown below, lists the responsibilities of the Dispatch Officer and shows that he has duties other than answering the telephone. All 'messages' or 'local-look-outs' must be approved by the Dispatch Officer. This is done to minimize the broadcasting repetitive information to the field units. He is also responsible for informing owners of businesses where burglaries have been attempted, and notifing other law enforcement agencies of the incident which could affect communities outside of the city. He is the advisor as to which units to dispatch and the source of information to the field unit relative to pertinent information on the incident, such as the general mood of the caller. The Dispatch Officer interfaces with all other functions within the Command/Control System, other areas of the Orlando Police Department, other public safety agencies and the general public. He is the focal point of force status and complaint information which is the nerve center of the Command/Control System.

TABLE 7

LIST OF FUNCTIONS PERFORMED
BY DISPATCH OFFICER IN
DISCHARGING HIS RESPONSIBILITIES

- o Monitor and answer all phone extensions within a specific number of rings.
- o Ascertain nature of call
- o Ascertain jurisdiction
- o Determine the nature of assistance required
- o Complete 602-09 or 602-03
- o Locate district in which report pertained
- o Record time received and time given to radio operator
- o Complete 602-03 from field request
- o Contact responsible persons of burglar alarms or reported B & E's at their place of business
- o Notify law enforcement agencies of serious crimes
- o Complete 'local-look-out' form from T/T or phone information
- o Sign T/T 'message' forms for broadcast
- o Contact local news media of information for broadcast to public to assist police.

RADIO AND TELETYPE OPERATORS

The Radio and Teletype Operators are an essential part of the Command/Control System since they provide the respective information interfaces between the Dispatch Officer and Field Force and the Dispatch Officer and other police and public safety agencies.

A continuous flow of information must be exchanged quickly and reliably between the Communication Center and Field Forces in order for the Command/Control System to operate effectively. The Radio Operator relays dispatch assignments and information to the patrol units and receives request for clarification and/or additional information via four channel UHF radio. Additionally this position can communicate via radio and direct telephone lines with other regional law enforcement agencies and fire and ambulance services.

Inputs to the Radio-Operator may originate from four sources:

- o A form completed by the Dispatch Officer;
- o Monitoring the City wide alert channel;
- o A 'message' from the teletype operator via the Dispatch Officer;
- o Field force requests via radio.

The actions by the Radio Operator have been keyed to the respective input sources and summarized in Table 8 on the opposite page. These operational steps are designed to assign a patrol unit, investigative vice unit, K-9 or 'motor' unit to the area of need as quickly as possible. To facilitate determination of the nearest available patrol unit a Force Status information system is used which indicates all units assigned on the particular watch together with their primary assigned district and their immediate status.

When a card is received via the conveyor belt, the Radio Operator checks the Force Status Board and calls the designated unit if available. The time at which the unit is called, and the time when the Radio Operator has completed transmitting the information to the unit are recorded on the form by time stamp. This card is then filed in the numbered slot in an electronic status file corresponding to the number of the unit dispatched. This action causes a light keyed to the unit on the Force Status Board to change from green, which signifies the unit is available, to red, which signifies the unit is on a call and not available.

When the unit arrives at the incident site it calls the Radio Operator and reports 10-6 or 'at the scene'. The Radio Operator then removes the Dispatch form from the status file slot, stamps the time reported 10-6, and replaces the form in the status file. At the discretion of the Radio Operator, a status check of that unit may be instituted by calling the unit and determining if it requires assistance. A status check is recorded on the reverse side of the form. This status check is routine when an 'in progress' crime call is being answered or when an unusually long time has passed before the unit has cleared the scene. When the

patrol unit has completed the assignment, it reports code 10-8 to the Radio Operator; this time is also stamped. The Radio Operator is also notified when a patrol unit requests a change of status. This may be instituted to indicate unavailability due to mechanical difficulty or investigation of observed suspicious activity, for example. When this request is made, a form with the patrol unit number and location is stamped and put in the status file; this causes the corresponding light for that patrol unit to show red on the Force Status Board.

Input to the Teletype (T/T) Operator may occur from a departmental field unit. The National Crime Information Center (NCIC) or the Florida Crime Information Center (FCIC). When a field unit requests information, it calls on a UHF channel, other than the dispatch channel, directly to the T/T Operator. If T/T Operator has the requested information on file, the response is immediate. Otherwise a query is referred to NCIC and/or FCIC and the results transmitted via radio to the patrol unit by the T/T Operator.

NCIC and FCIC also communicate to all law enforcement agencies information on stolen items, persons wanted and other pertinent information. The T/T Operator receives this information, updates the appropriate files and relays the pertinent information to the Complaint Desk and other Bureaus as appropriate.

TABLE 8

FUNCTIONAL RESPONSIBILITIES OF THE RADIO AND TELETYPE OPERATORS

RADIO FUNCTIONS	o	Obtain 602-03
	o	Assign nearest field patrol unit or units to investigate reported incident
	o	Record dispatch time, unit arrival time, and unit clear time
	o	Perform unit status check
	o	Monitor channels for units requested change of status or requesting aid of information
	o	Relay information to the field unit as requested
	o	Monitor status board to keep it active and current
	o	Complete 602-03 per unit request from field for csse number
	o	Monitor 'intercity' radio frequency and complete 'local-look-out' form
	o	Broadcast information from 'local-look-out'
	o	Send 'local-look-out' form to complaint desk
	o	Broadcast information from 'messages' to all channels for all units
	o	Relay by phone if field unit requests special units (non O.P.D.)
TELETYPE FUNCTIONS	o	Relay information to field units via channel 1
	o	Record 'messages' from T/T or phone
	o	Send 'messages' to complaint desk
	o	Broadcast via T/T to other law enforcement agencies information requested
	o	Broadcast to NCIC and FCIC information requests and answers to information requests

UNIFORMED FIELD PATROL FORCE

The field operating units of the Uniformed Division are organized on three levels of line authority each of which may receive functional direction from the Communications Section in order to discharge the mission of the Department.

The police function can only be served by a concerted team effort between the unit on patrol and the Communications Section. This effort is two fold. First, communications necessary for the assignment of patrol units to the areas of need must be concise and accurate. Secondly, all unnecessary or personal air traffic must be minimized so that the necessary communications can be broadcast. This team effort also includes informing the Communications Center of any changes in unit status or change in normal patrol assignment during the watch.

At the first level of authority it is the Watch Commander's primary responsibility to ensure a team effort exists between his Uniformed field units and the Communications Center. His more detailed responsibilities are supervisory in nature and are listed in Table 9. The Watch Commander has responsibility for all patrol units during his watch, monitors all the channels of communication, and may redirect the assignment of units by the Communication Center. In any reassignment of units the Communications Center must be informed to establish a primary responsibility for each call.

The second level is the Sector Commander. As a first line supervisor, he is assigned a quadrant of the City which contains several Districts and is responsible for the supervision and training of the patrol units in his sector. In the field the Sector Commander monitors all unit assignments in his sector and may modify these as his experience and knowledge of field conditions indicate. He also functions as a patrol unit which is available for assignment by the Communications Center. This is not common but does occur when a serious incident is reported and no other units are available.

The Sector Commander will assist any patrol unit in his sector as the type of call indicates. This backup may be simply patroling the district until the unit on assignment is again available, or it may mean direct supervision to train a patrol unit in techniques of investigation, rules of evidence, or other pertinent police procedures.

His responsibilities also include administrative duties such as inspection, scheduling extra duty and vacations and counseling the men under his supervision on personal or professional problems. He reviews the crime statistics and training progress for his assigned area on a periodic basis and must also investigate reported misconduct and submit written reports.

The third level of responsibility is the Patrol Unit. After the watch briefing meeting, the unit proceeds to the assigned district and relieves the on-duty unit. While on patrol the unit will receive and acknowledge assignment from the Communications Center and the Sector and Watch Commanders. After each assignment the unit resumes patrol activities. If while on patrol, when the unit stops to investigate suspicious activity, it must inform the Communications Center of its location and the type of activity. During the investigation the unit may require information as to stolen goods or warrants. This information is available through the T/T Operators of the Communications Center. The patrol unit and the Communications Center form a team in which each is dependent of the other to discharge his responsibilities to the Department. Regardless of the level of authority and responsibility of the patrol unit, a concise flow of information to and from Communications Center is essential for the effectiveness of the patrol unit.

TABLE 9

THE FUNCTIONAL RESPONSIBILITIES OF THE WATCH COMMANDER, SECTOR COMMANDER AND PATROL UNIT IN THE UNIFORMED DIVISION

WATCH COMMANDER	o Monitor E/W vicinity assignments via radio (channel 2 or 3) o Investigate vicinity calls o Monitor personal air traffic o Enforcement of civil service and O.P.D. rules o Review and recommand disciplinary action o Review manpower distribution with the sector commander o Review crime statistics by type and location with sector commander o Listen to personal problems of men that the sector commander could not handle
SECTOR COMMANDER	o Monitor all district calls o Modify car assignments made by radio operators as required o Backup all serious calls o Notify watch commander of any unusual problems and/or calls in his sector o Investigate misconduct and report to watch commander via written report o Review crime statistics and manpower distribution with watch commander o Prepare vacation schedule o Listen to personal problems of men o Conduct 15 minute watch inspection
PATROL UNIT	o Patrol assigned area o Receive assignment via radio o Acknowledge assignment via radio o Acknowledge arrival on site o Request information from T/T or Communications Center o Relay information to other units o Request change of status o Respond to sector commander or watch commander field commands o Request additional units and/or special units (non O.P.D.)

COMMAND/CONTROL CENTER COMMUNICATIONS EQUIPMENT

The specialized tasks of a Command/Control System require sophisticated communications equipment for the effective operation of the Complaint Desk, Radio and Teletype work stations.

Each work station in the Communications Center is equipped with special equipment designed to provide the communications needed to accomplish that function. The Dispatch Officer, Teletype and Radio Operator functions form an interdependency network of sequential operations which require a reliable multiple mode communications network and which in turn varies with the response made of the Command/Control System. Figure 8 is a layout of the Communication Center and shows the location of all communications equipment relative to the work stations.

The communications equipment at the Complaint Desk station manned by the Dispatch Officer consists of a multiextension phone for each desk and an electronic security alarm system. Each phone has the maximum capability of 29 direct extensions or lines. At the present time not all lines are assigned, only eight direct lines are active. These include two connected to the Fire Department, one to Florida Highway Patrol, one to Orange County Sheriff's Department, one to Electronic Securities Company, two to ambulance companies in the area, and one to a towing service. Six emergency number direct lines are also in service. When the caller dials 843-5000 the call will automatically be routed to a line which is free. Each phone is also equipped for intercom communication with the two Radio Operator stations, the Information Desk and with each of the other Complaint Desks. A Wells-Fargo type signal system is mounted on the South wall of the Complaint Desk room. This is a direct to station alarm system with 24 locations presently connected. It is actuated by a company alarm circuit which automatically lights the monitor panel, and sounds an alarm.

A multichannel, multideck tape recorder is also installed in the Complaint Desk room. This provides a continuous record of all telephone inputs and outputs at the Communications Center and the Information Desk as well as all radio transmissions.

The teletype equipment consists of one I.B.M. 2740 teletype machine which is connected directly to the NCIC and FCIC networks. A R.C.A. 70-752 Video display is connected to the Orange County Criminal Control System and is used to store and retrieve information from a computer on a County wide basis. Two single extension telephones and a single channel UHF radio complete the physical communications equipment at the Teletype station. Support equipment includes a time stamp, Line-O-Dex file system for local warrants, and a typewriter.

The radio room houses the major portion of the communications equipment. This consists of a duplex channel UHF 'PREP' Radio System. Transmission towers are located on the City Hall and Criminal Justice Building. Satellite receivers are located at strategic points around the City to provide high quality communications between officer to officer and officer to headquarters basis. Radio control is through two consoles each manned by a Radio Operator. The console also has two telephones, one for emergency incoming calls and the other for direct line communications simuilar to the Complaint Desk telephones. The emergency phone is used

only when activated by the Complaint Desk personnel. The Radio-Operators also have a radio paging system for City officials and high ranking police officers. Support equipment consist of a Force Status Board which displays the status of all on duty police personnel. It is monitored and updated manually by the Radio Operator.

EQUIPMENT LIST

1. Telephone
2. Electronic Security Alarm
3. Tape Recording Equipment
4. Teletype
5. Video Display
6. Single Channel Radio
7. Time Stamp
8. Typewriter
9. 'PREP' Radio
10. Emergency Telephone
11. Force Status Board

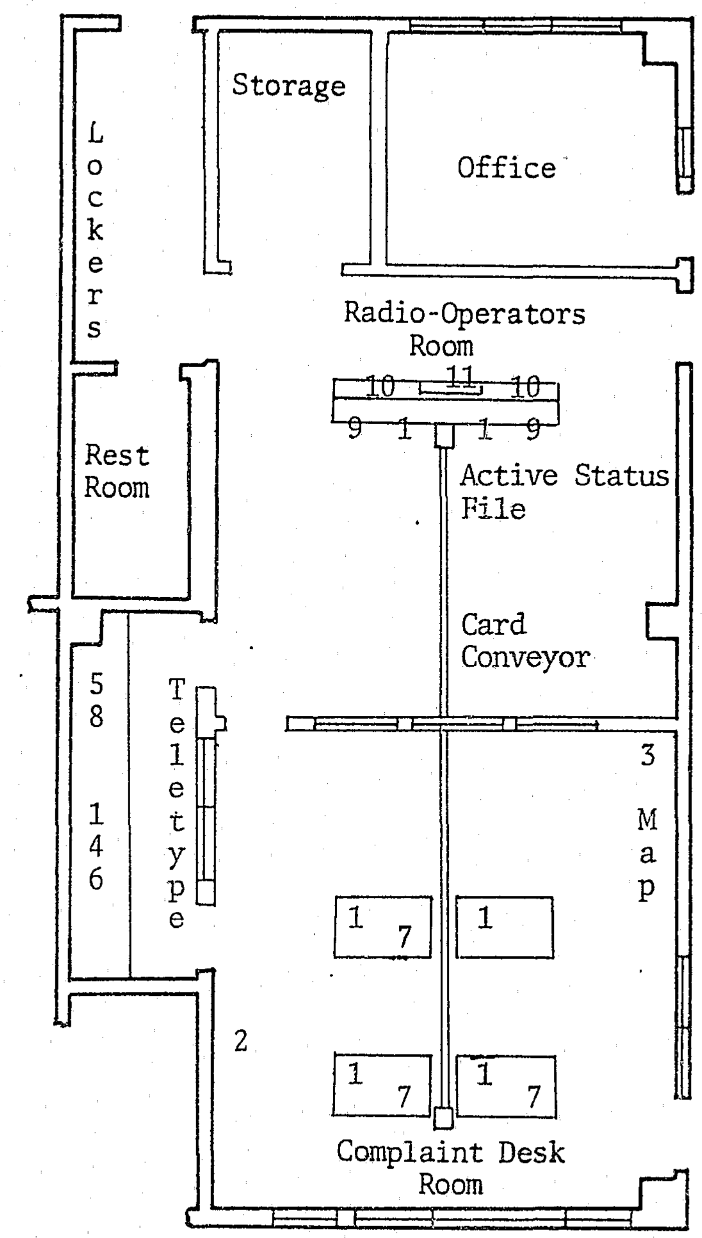


Figure 8 Major Equipment Locations For Each Specialized Task of Command/Control System At The Communications Center

CONTROL CONSOLE

The Radio Operator work station requires the most sophisticated communications equipment in the Communications Center complex because it must interface with the field forces and outside agencies as well as the other work-stations in the Center.

The Radio Operator work station is the coordination point for all incoming and outgoing communications between the Communications Center and the field forces. It is manned by two operators who share the workload on an East/West division of the City. Two control consoles are provided and each is a duplicate of the other to provide the capability of operational redundancy.

Auxiliary equipment includes Force Status Board and Active Complaint Status File. The interface equipment consists of a Complaint Card Conveyer to move assignment cards between the Complaint Desk and Radio Operator work station and the radio and telephone communications network. Figure 9 is a pictorial diagram of the work station identifying the equipment and showing how it is located to facilitate the operational functions.

The radio communication controls are directly in front of the operator since this is the most frequently used portion of the equipment. The console is equipped to monitor the four Orlando Police Department channels as well as Orange County Sheriff's Department and Florida Highway Patrol transmissions and other selected local police agencies. The operator can selectively transmit and receive on the four UHF channels or on all frequencies at once in an emergency. Radio communication is also provided to the local police agency network. A headset microphone is normally used for transmission but a console mounted microphone can also be used.

The telephone are located at the left of each operator. One is a multiposition set duplicating those at the Complaint Desk station. Another handset is provided for push to talk communication to the Sheriff, Florida Highway Patrol, local ambulance service and Fire Department. The operator can either talk and receive with the handset or switch to a speaker position for receiving. The console also contains 12 push to alert switches which are used to reach selected command officer personnel.

The Force Status Board is centrally positioned above the consoles between the Radio Operator position. The Board contains a back illuminated map of the City with each patrol district outlined and identified. To identify each patrol unit the Board has two small lights one red and one green located within each district. To each side of the map there are blocks of numbers corresponding to vice, detective, K-9, motorcycle and other special police units which can be illuminated to indicate the unit is on duty and its status. The Board thus provides the status of every unit on duty by either a red or green light. All units on the Force Status Board are equipped with a PREP radio.

Connected with the Force Status Board is the Active Complaint Status File. This File is designed for the temporary storage of computer size assignment cards. The Status File is wired to the Force Status Board so that when a card is placed in a numbered slot in the File the corresponding number on the Force Status Board changes from green, which indicates available, to red, which indicates unavailable for assignment. At the beginning of each shift the Radio-Operator verifies which special units are on duty and turns the corresponding light on the Status Board to green. Then as assignments are made and assignments completed the Status File and Force Status Board indicate the status of all on duty units at any given time.

Seated at the control console each Radio-Operator can communicate with any on duty field unit using the PREP system, know the status of any unit, communicate by direct lines to other local law enforcement agencies, fire and ambulance, as well as communicate with the Dispatch Officer via intercom. The Control Console with its components is the heart of the Command and Control System Communications.

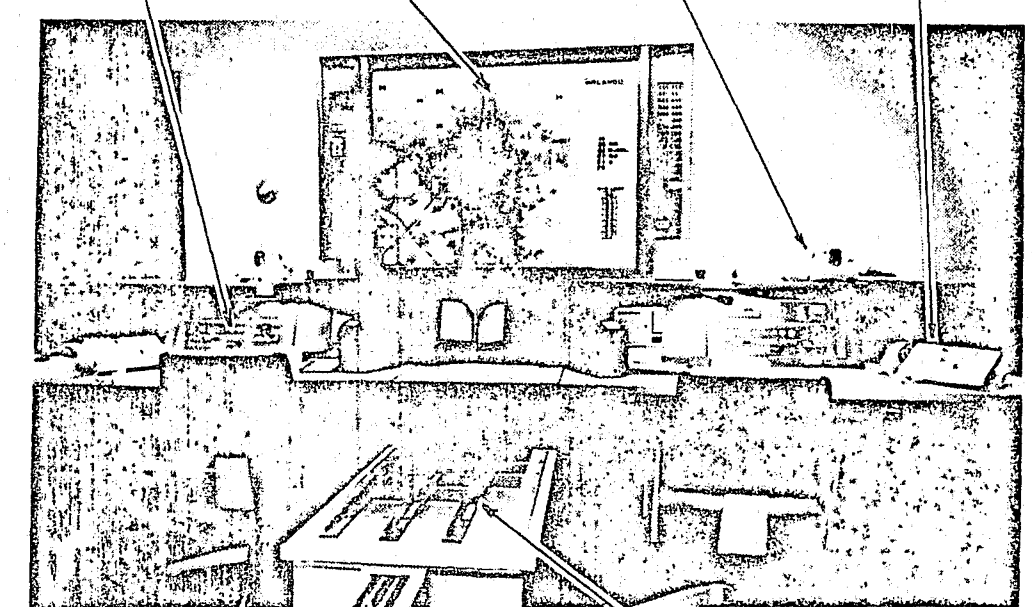


Figure 9 Photograph of the Radio Operator Work Station Showing Major Equipment Positions.

PREP RADIO SYSTEM

The primary element in the communications network is a PREP (Personal Radio Equipped Police) System which provides reliable voice communication among individual field units and between the Communication Center and all field units.

The Orlando Police Department PREP communications system incorporates some of the latest technological and system design techniques. The system is a four-channel duplex UHF radio network designed to cover an area of approximately 25-mile radius. It utilizes four base transmitters, one for each channel with radiated power output of 250 watts. The antennas are located atop the City Hall and Criminal Justice Buildings to decrease the vulnerability of the System to hostile acts by individuals or the natural environment.

The satellite receivers subsystem consists of 36 receivers, one for each channel located at nine sites. These sites are strategically located on elevated structures within the City and immediate surroundings so that the receivers will pick up all signals within their area. These are demodulated and the audio signal is relayed through land lines to the Communication Center. Since more than one satellite station will receive a field signal a signal comparator at the Center is used to select the optimum receiver and releasethe others. This selection is accomplished on signal strength which is coded at each receiver station.

The performance of the system has been excellent. Good voice communications can be established anywhere in the coverage area using one watt portables. In addition there is no apparent degregation in system capability when a receiver site is disabled. Figure 10 relates the system coverage to the City configuration and satellite receiver sites both existing and planned. It is noted that coverage can easily be extended by addition of more receiver sites.

Each police officer is issued a one watt portable transceiver when he goes on watch. The unit clips to his belt and has an extension speaker-microphone which fastens at the shoulder. Normal operation is push to talk duplex, although some units can operate simplex channel for local (stake-out) activities. Mobile units are not used since each officer can be reached at all times through his personal unit.

There are basically four configurations of the portable transceivers: all have the same power. The model used by the uniformed field officers has two channel (1 & 2 or 1 & 3) capability. Those used by detectives and special forces operate on channel 1 with either channel 2,3,or 4 for standby. These units can also be equipped to operate on additional frequency in simplex mode. Command officers are issued units which have all channel capability. The staff model has four channels with paging; these are used by Director of Public Services, Chief of Police, City Council members, and police officers with rank of Major.

A multiple position battery charger and radio storage rack at headquarters is used to refurbish and check each unit. Radios are assigned on a watch basis such that each is equipped with a fresh battery when it is issued.

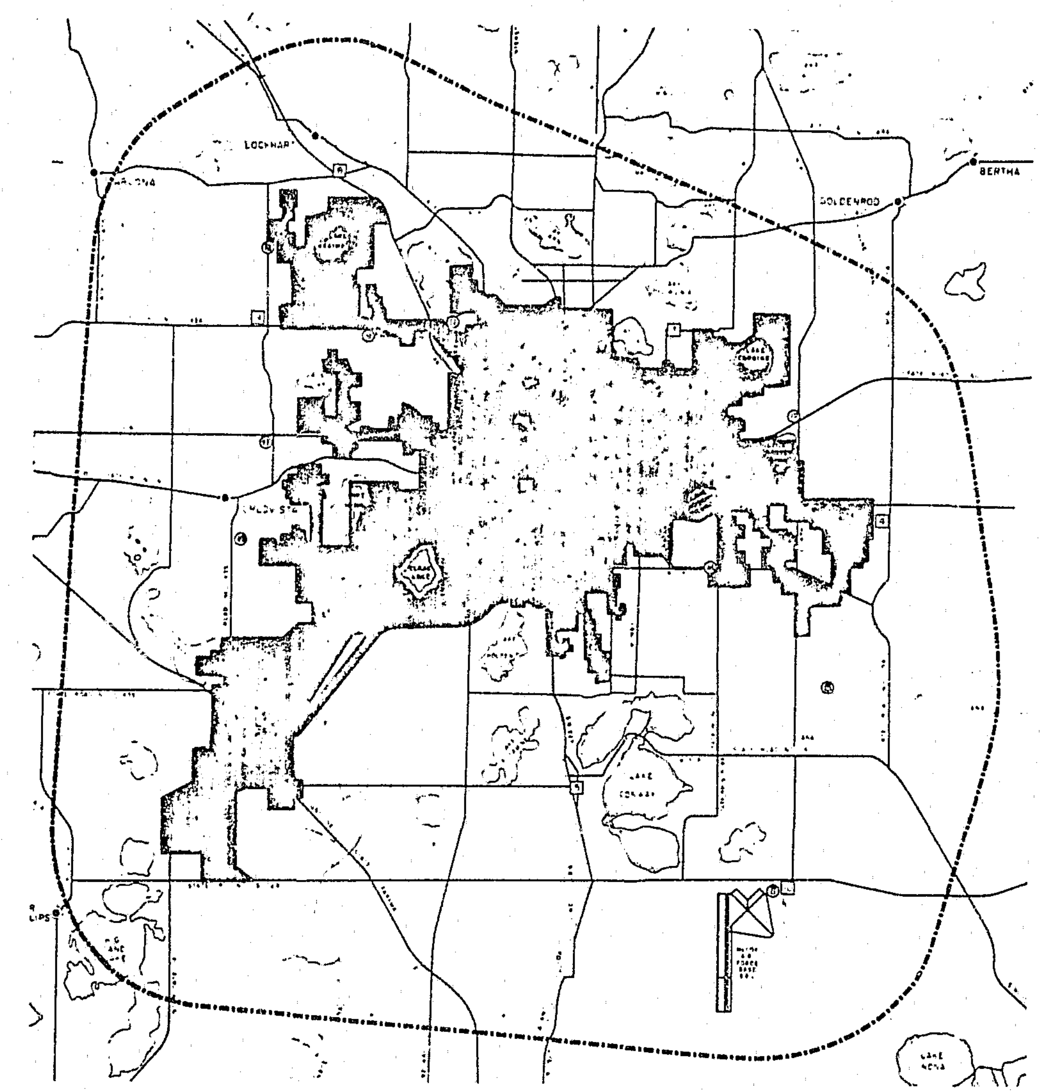


Figure 10 Map Of City Related To System Coverage Shows Range Of Communication Extends Well Beyond Normal Requirements.

SECTION VI

AUTOMATIC VEHICLE LOCATOR SYSTEM TECHNIQUES

- o Proximity
- o Triangulation/Trilateration
- o Dead Reckoning
- o Navigation
- o Officer Up-Date

AVL Systems differ primarily in the technology they employ for locating the monitored vehicles. All have several functions in common: acquistion of locational data, communication of raw data to processing units, processing of raw data and display of information. Although the basic output information is locational, it can be supplemented by other data transmitted and processed by the AVL equipment.

The literature indicates that the principal location technologies can be classified into five major categories.

The Proximity System is based on the concept that the patrol vehicle has electronic "eyes" which recognize what have been termed "signposts" to determine the vehicle location. In this system the wayside signposts are devices which continuously transmit unique location identification codes to the passing vehicles for subsequent transmission to the Command/Control Center. Typically this location code is relayed to the Center as the signpost signal is received so that the vehicle location is updated as it passes. In a modification of this system sometimes termed an "inverted" Proximity System, receivers are placed at the signposts to accept identification information from the vehicles passing the location.

Triangulation/Trilateration AVL Systems are based on trigonometic functions which transform electronically measured distances and angles into a vehicle position. Generally distances from the vehicle to three or more unique receiver sites are determined. This data is then integrated with known fixed distances between receiver sites to plot a family of triangles with the vehicle at the apex and receiver at the other two apexes. Distances are typically measured by Pulse or Phase ranging on signals which are transmitted to the receiver sites upon a cycle initiation command from the Command/Control Center.

A Dead Reckoning AVL System is similar in principle to the inertial navigation systems used in submarines and space vehicles. It consists of a distance sensor, such as the odometer, a bearing indicator, such as a compass, to determine the direction of travel, a simple analog computer for integrating the distance and travel data and a transceiver for responding to interrogation and communicating status to the Command/Control Center. The actual position can be computed on-board or by a computer at the Center.

The Loran System utilizes a receiver in the vehicle to measure the time of arrival of a group of pulses from a chain of master and slave stations. In all cases lines of constant time or phase difference constitute hyperbolic paths with the stations or focii. The vehicle position can be determined by on-board equipment or the time and phase measurement transmitted to the Center where the pattern would be calculated by computer. The system uses existing LORAN, OMEGA or DECCA navigation transmitter grid networks.

The Officer Update System is not automatic in the strict sense since it requires the driver or someone else in the vehicle to perform certain manual operations in order to enter location data into the system. The effectiveness of the apporach is directly dependent on the reliability and judgment of the vehicle operator.

PROXIMITY SYSTEMS

The Proximity System provides the location of patrol vehicles by determining the relationship between the vehicle and fixed sensors or emitters which have been placed at known locations in the field.

The Proximity System is based on the concept that the patrol vehicle has electronic "eyes" which recognize what have been termed "signposts" to determine the vehicle location. In this type system wayside signpost devices continuously transmit unique location identification codes to passing vehicles for subsequent transmission to the Command/Control Center. Typically this location code is relayed to the Center as the signpost signal is received so that the vehicle location is updated as it passes. This location information is retained in memory at the Center until a new location signal is received. In a variation the location information may be retained by the vehicle until it is interrogated by the Center in a roll call sequence. Additional information, such as odometer reading and the time when passing the signpost, may also be transmitted to permit the Center to calculate or "dead-reckon" the location of the vehicle between signpost update signals.

In a modification of the system sometimes termed an "inverted" Proximity System, receivers are placed at the signposts to accept information transmitted from the vehicles passing the location. The vehicle transmitter emits a coded information signal identifying the passing vehicle. This information together with the signpost location is then transmitted to the Center via telephone lines or radio link.

This information may also be temporarily stored at the signpost locations until requested by the Center. In this system the data transmission has several modes--telephone, CATV, Community Antenna Television network, cable, or RF link whereas the signpost emitter system is limited to RF transmission.

Conceptually the two Proximity systems are shown in Figure 11 . When a vehicle, whose location needs to be determined, transmits or receives information data within range of the signpost (approximately 100 feet), this data is retransmitted to the Center. At the Center the signal is processed as to signpost location code and vehicle identity code and then, through interface circuitry, a display system is used to show the vehicle at its specific location in the city. A continuous updating occurs with the simultaneous location of a number of vehicles. Information coding is generally accomplished either through digital or audio tone methods.

The primary technological effort on Proximity systems has focused on developing an inexpensive signpost. This includes not only the data interpath requirements, but also consideration of vandal-proof, weather-proof enclosures, power availability and unit cost. Some systems use

optical labels, including those attached to the pavement. The problem here is one of line of sight reception under adverse environmental conditions. Tuned loop and buried magnetic elements have been used and potentially offer economic and maintenance advantages. Several of this type have reached the prototype phase of development.

The requirement in police apparatus of random routing of vehicles implies that the critical coverage area must be equipped with signposts whose density is determined by the accuracy requirements. This clearly can result in a very expensive system especially in a large area. For example, 10,000 locations at $100 each would cost a million dollars. It does have the obvious advantage, however, of incremental implementation i.e. only those locations needed can be installed and others added and relocated as desired.

The Proximity System has virtually unlimited access and is independent of RF propagation characteristics. It also requires no calibration operations or location computations. The electronics of emitter and sensors are simple and the equipment is relatively rugged. These characteristics have combined to make it one of the more promising locator tehcniques.

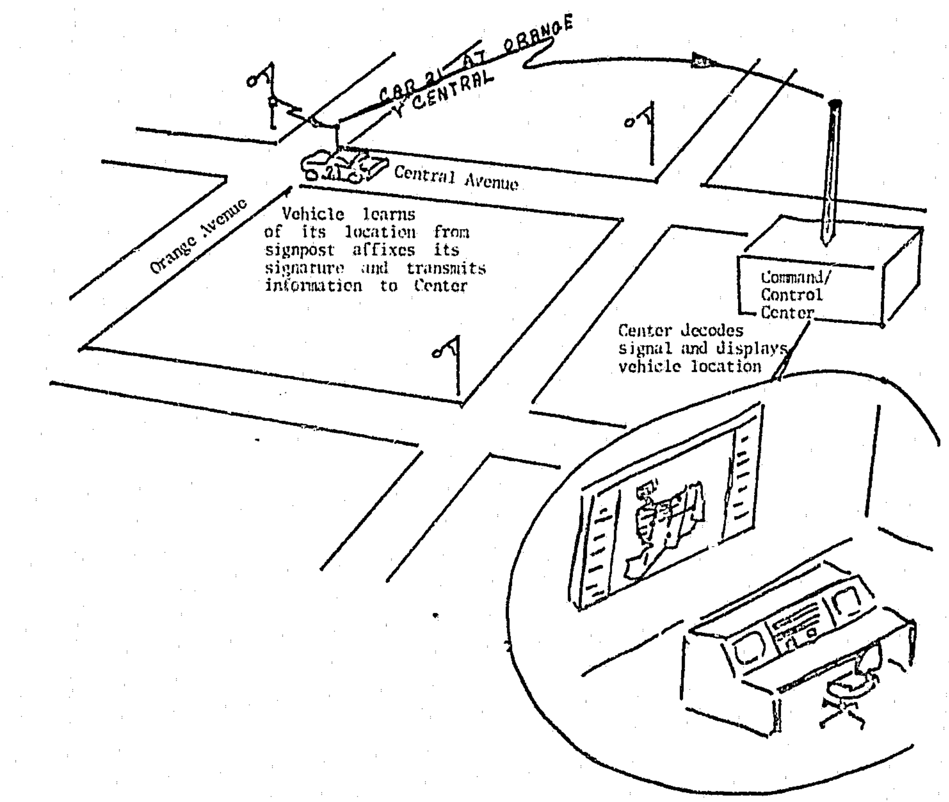


Figure 11: PROXIMITY SYSTEM CONFIGURATION

TRIANGULATION / TRILATERATION SYSTEMS

Triangulation and Trilateration AVL systems incorporate pulse or phase ranging techniques to measure distances between the vehicle and known receivers sites which is then reduced to vehicle location data by application of trigonometric functions.

Triangulation and Trilateration AVL systems are based on trigonometry which transforms electronically measured distances and angles into a vehicle position. Generally, distances from the vehicle to three or more unique receiver sites are determined. This data is then integrated with fixed, known distances between the receivers to plot a family of triangles with the vehicle at the apex and receivers at the other two apexes. Typically more than one triangle is determined as a check and to provide a unique solution for the location of the vehicle.

With this type of system, many variations are possible. Generally, the vehicle carries the emitter which is usually a mobile transceiver of approximately 20 watts and the sensors are spaced strategically within the city at approximate densities of 10 per 100 square miles. These receivers then receive the identity data from the vehicles, retransmit it by either hardwire or microwave links to the Command/Control Center where a computer is used to compare these signals either on the basis of a time difference of arrival (Phase Ranging) or pulse delay (Pulse Ranging) to obtain distance measurements. For computation, signals from 3 or more stations are required in Trilateration and 2 or more in Triangulation. A conceptual Phase Trilateration system is described in Figure 12 on the opposite page. The vehicle receives signal f_1 and transponds a tone coded signal f_2. The phase difference is measured at each receiver site at the Command/Control Center where it is translated into distances and the vehicle location.

The Pulse Ranging mode of system implementation typically utilizes pulse-coded signals which are transmitted from the vehicles to the receiver sites upon a cycle initiation from the Command Control Center. A pulse with a very sharp leading edge is transmitted, received at the vehicle and retransmitted. This approach requires a wide communications bandwidth on the order of 10 MHZ to accurately determine the arrival time of the pulse edge and discriminate it from any multipath generated pulse edges. Although it does not make efficient use of the RF spectrum, it provides in the order of 3 to 4 times the accuracy of a Phase Trilateration system. In addition, two radio equipments are generally needed in each vehicle, a wide-band transmitter for the pulse system, and a transceiver for normal VHF or UHF land mobile voice communications. Coded digital messages from the vehicle to the Center can be transmitted, however, by coding the pulse train. Hazetine Corporation of Long Island, New York has developed a system of this type which has an estimated accuracy of ±300 feet with 95% confidence interval in an urban environment similar to New York City.

The Phase Ranging system utilizes a phase comparison of signals which are multiplexed on the basic communication channels and compares them with reference phased signals at the Center. This then requires no additional bandwidth beyond the normal communications requirements. A number of transmitter sites may be necessary to adequately cover an area depending on the problems associated with RF propagation in the particular environment.

There is a wide range of various emitters and sensors used to implement the basic systems along with many variations of system configurations. An illustrative system might use a modified standard mobile FM transceiver as the vehicle emitter, transmitting, at time division intervals, an audio tone modulated carrier. The sensors would be FM receivers, which could demodulate the signal, retransmit the audio tone over dedicated telephone lines or some comparable line to the Command/Control Center. Each vehicle emitter would be assigned a certain time "slot" in which to transmit; this would prevent simultaneous transmissions being received from several emitters at any one sensor. At the Center, signal processing equipment determines the time delay of arrival from various sensors of a particular vehicle signal. This data, along with known location of sensors, is used by preprogrammed computers to compute the vehicle location.

Available information sources indicate that a Pulse system is inherently about 3 times more accurate than a comparable Phase Trilateration system. At the 95% confidence level the estimated radial location error of the Phase Trilateration system in an urban environment ranges from 900-1200 feet. Although phase is less accurate than pulse ranging, it is not as susceptible to multipath problems, has lower bandwidth requirements and generally offers compatibility with existing voice communication systems. Cubic Corporation Sierra Research, General Electric and Raytheon Co. are actively developing systems of this type.

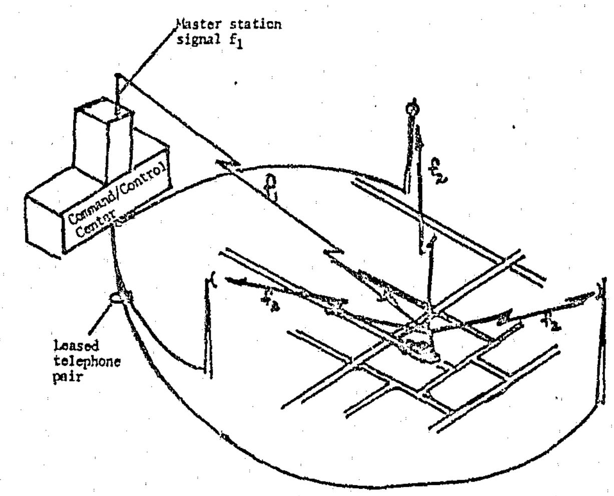


FIGURE 12 PHASE TRILATERATION AVL SYSTEM CONCEPT USING SATELLITE RECEIVERS

DEAD RECKONING SYSTEMS

The Dead Reckoning AVL system utilizes direction and distance sensors on board the vehicle to determine its location; thus it is self-contained, and requires no external transmission inputs.

A Dead Reckoning Automatic Vehicle Locator System is similar in principle to inertial navigation systems used in submarines and space vehicles. It consists of a distance sensor, a bearing indicator for determining the direction of travel, a simple analog computer for integrating the distance and travel data and a transceiver for responding to interrogation and communicating status to the Command/Control Center. The actual position of the vehicle can be computed on board or by a computer at the Center. Figure 13 on the opposite page is a functional diagram of an AVL system using the Dead Reckoning (DR) location-fixing technique.

The major advantages of this system are speed and flexibility. It is fast because data transmission involves only the x, y coordinates of the vehicle position which may be transmitted in digital format. Also, since it is self-contained, multipath transmission problems are of little concern and it is theoretically possible to locate vehicles anywhere in the urban environment. This has been demonstrated by one firm which tracked vehicles to various levels of an underground parking area.

The primary thrust in development of this system has concentrated on reducing the cost of the travel and bearing sensors. Clearly sensors used in inertial navigation systems would make the cost of a vehicle equipped with a system of this degree of sophistication prohibitive. Accordingly, the systems under development generally use some adaption of the vehicle odometer and a modified magnetic compass for direction sensing. All odometer sensors are relatively inexpensive and are driven directly from the vehicle wheels or from the power train. The front wheels are preferred since the power train and rear wheels may not accurately measure the vehicle travel. This would occur, for example, on an icy road. The magnetic compass is inexpensive but has inherent inaccuracies. These can be minimized by calibration of the installation in each vehicle. Also flux measuring loops can be used to eliminate moving parts at approximately the same cost.

A Dead Reckoning system is vulnerable to a cumulative error problem. This can be relieved, however, by providing some form of periodic location information feedback system. Using this approach accuracies of 50-500 feet with update times of 1-2 seconds have been achieved.

This feedback can be provided by wayside recalibration units which transmit a location signal as the vehicle passes or by means of a map matching process conducted by a computer at the Command/Control Center.

In this control mode the computer compares the vehicle transmitted location with its memory which contains a digital representation of the street network in the area. Each time a new report is received, corrections for known sensor bases on the reporting vehicle are applied and then a decision is made to locate the vehicle on a "most probable" street. Techniques resembling statistical correlation are used to describe the "most probable" location with the street network segments closest to the corrected location report forming the least squares regression line.

Conceptually, Dead Reckoning appears to be the most attractive AVL system assuming the costs are competitive with the other approaches. It offers a very economical use of the radio spectrum and has more monitoring capacity in terms of vehicles per time interval. A limitation is its inability in its present form to locate non-rolling objects such as an officer on foot.

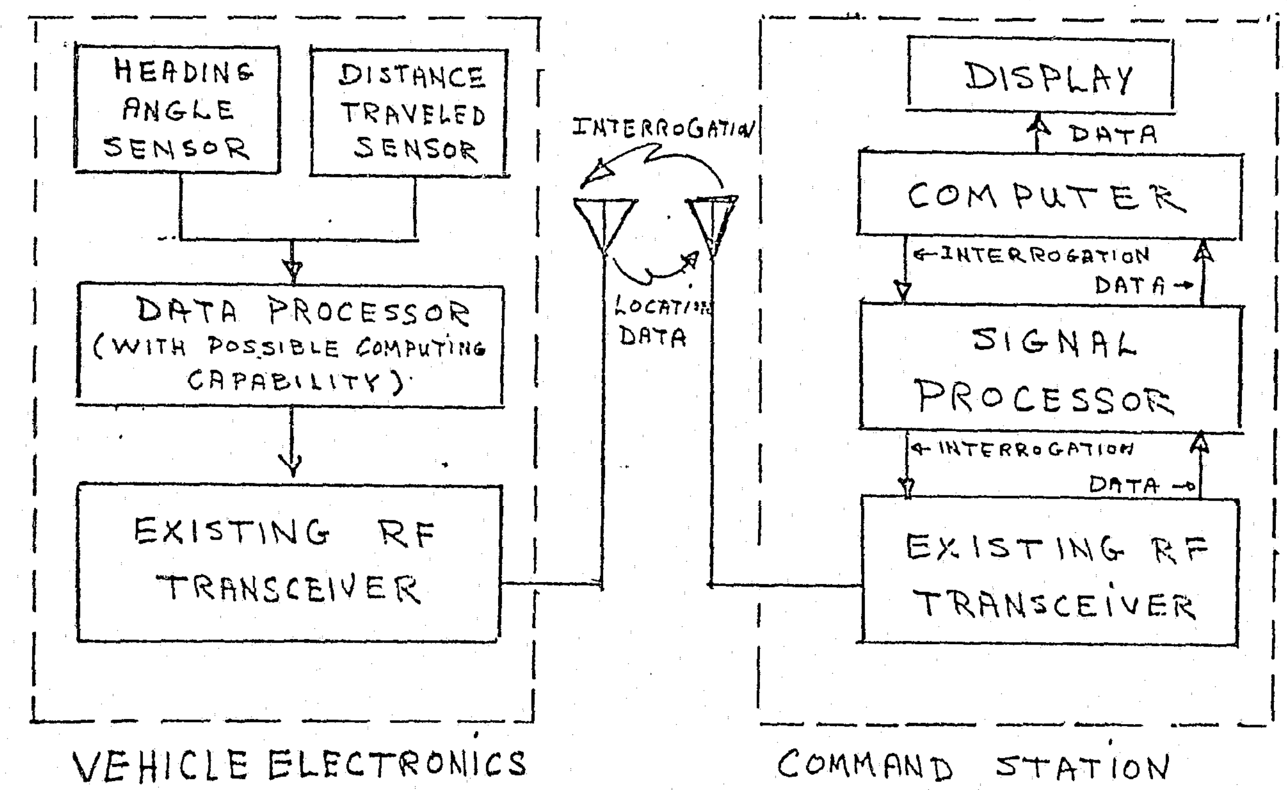


FIGURE 13 FUNCTIONAL BLOCK DIAGRAM OF DEAD RECKONING AVL SYSTEM SHOWING MAJOR COMPONENTS

LORAN (NAVIGATION) AVL SYSTEMS

The LORAN Type AVL systems use the existing LORAN, OMEGA, or DECCA navigation transmitter grid networks by installing receiver-transponders in the vehicles. This system can cover large areas, both urban and suburban, but is limited to those which are served by the navigation networks.

LORAN is a long-range navigation system which has been in operation since WWII when it was instituted to locate aircraft and ships. It has now been augmented by OMEGA and DECCA networks which are in the same operational category. The navigation system approach is inherently very flexible relative to application and can be adapted to ground vehicles. System performance for vehicles, however, has not yet been well established under the varied operational conditions which might be encountered in an urban environment.

The LORAN type system utilizes a receiver in the vehicle to measure the time of arrival of a group of pulses from a chain of master and slave stations. OMEGA functions in a similar manner but utilizes a burst of carrier and operates on a lower frequency. The DECCA system measures lines of phase from a chain of master and slave stations. In all cases lines of constant time or phase difference constitute hyperbolic paths with the stations as foci. The time/phase difference between master and slave stations measured at the vehicle determines the hyperbola references to a master/slave pair on which the vehicle is positioned. Since a number of master/slave pairs are used the vehicle position can be determined by intersection of the identified hyperbolae. The different stations pairs are typically identified by their assigned operating frequencies. This concept is shown in Figure 14 which illustrates a time difference location fix for LORAN. The two hyperbolic lines of position TDA and TDB are established as differences in time-of-arrival of the master and slave station pulses. The intersection of TDA and TDB designates the receiver position.

The vehicle position can be determined by on-board equipment or the time and phase measurements can be transmitted to the Command/Control Center where the pattern would be calculated. In the latter case the vehicle units are simpler and less expensive since all signal processing is done at the Center. There is a trade-off, however, relative to the bandwidth used in transmission. When the location signal processing is done on board the vehicle, less bandwidth is required to retransmit the data.

The basic LORAN type grid networks presently used for navigation are LORAN A (1.9 MHZ), LORAN C (100 KHZ), DECCA (75-85 KHZ) and OMEGA. The East coast has a LORAN C network grid which has been considered for an AVL system. The LORAN systems are termed long base line because of the hundreds of miles separating the master and slave transmitters.

One of the limitations of this system is that a LORAN network does not cover the whole United States, only the Eastern part, hence LORAN AVL systems could only be implemented in this geographical area. Generally a system of this type would use a time division multiplex set up which would have a limited, but large capacity, user access.

Experimental systems have shown that LORAN C operation in rural areas up to 900 miles from the transmitters provided accuracies in the 500-1000 feet range. In suburban areas, this accuracy could be maintained when transmitter distance was 700 miles or less. In industrial areas, it was reduced to 550 miles, with dense urban areas being 450 miles. Errors are due to multipath propagation, man made and atmospheric noise, interfering radio transmissions adjacent frequencies, and some signal delay changes with time of day and the season of the year.

A modification of both LORAN and OMEGA is the use of a local reference stations of known location to calibrate out the larger geographic variations in path length. This modification has been termed "differential operation" and the military has obtained accuracies in the order of ± 50 feet with a fair level of confidence. Tests by Astrophysics Corporation in California using the DECCA grid show errors of less than 500 feet with 95% confidence level in an urban environment.

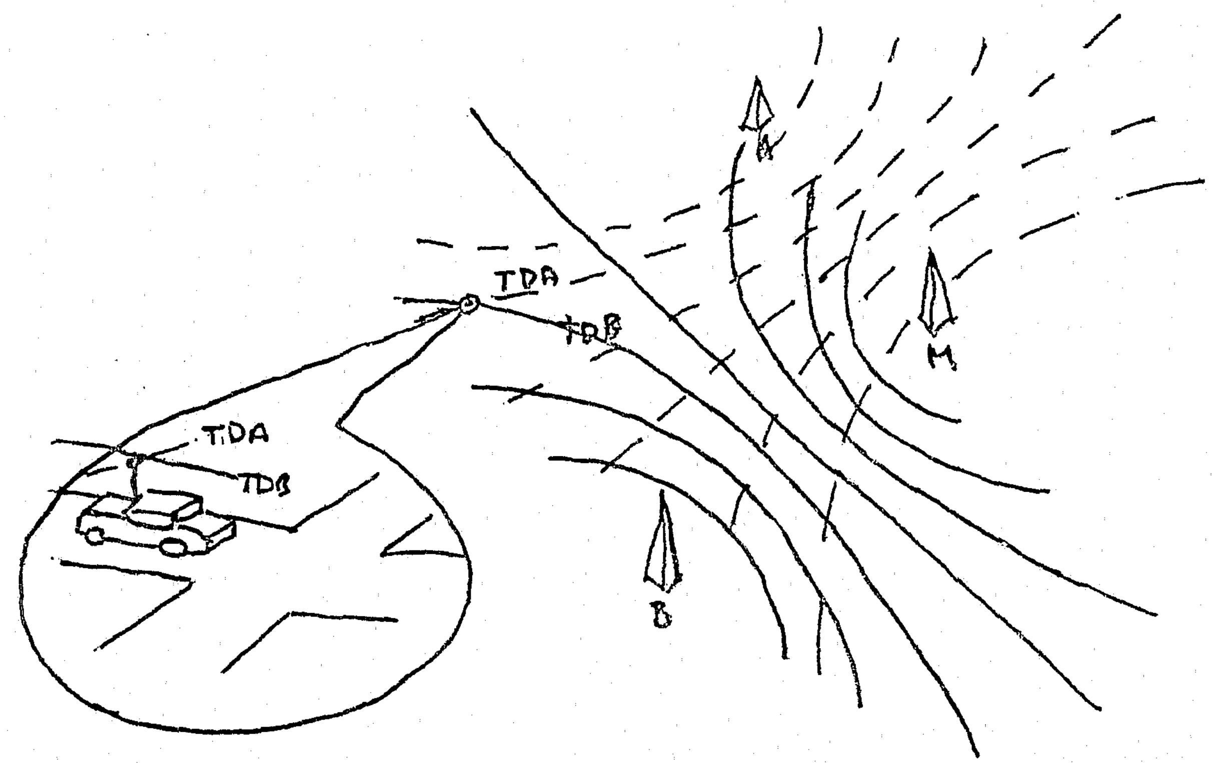


FIGURE 14 ILLUSTRATION OF TIME DIFFERENCE LOCATION FIX FOR LORAN

OFFICER UPDATE

The Officer Update System represents a simple viable approach to vehicle location; however its effectiveness depends directly on the reliability and judgment of the vehicle operator.

The Officer Update System has been included even though in a strict sense it could not be classified as an automatic vehicle locator system. The technique is not automatic in that it involves the vehicle driver or someone else in the vehicle to perform certain manual operations in order to enter location data into the system. Without the automatic location feature this approach is dependent on the vagaries of the human part of the system. The vehicle occupant also represents a data source which is not an independent measure of the vehicle location since he is aware of where the vehicle should be at a given time.

In event of an emergency or "officer-needs-help" situation the chances are remote that the vehicle occupants could make use of this system to signal their location since it requires an overt move and being in the vehicle. This reasoning would not apply to non-public vehicle fleets such as taxis where automatic vehicle location with continuous position update is not a necessity.

Despite these inherent problems, the Officer Update is a simple workable system which has been developed and tested for police applications. The Digicom System laboratory of GTE Sylvania has a digital data transmission system which can be used to implement the Officer's manual update of this vehicle location. This system has been installed on an experimental less-than full scale basis for the Oakland Police Department and is currently under evaluation.

In the Oakland system, each vehicle is equipped with a photographic map mounted in front of a pressure sensitive grid matrix. The officer simply presses the map periodically to indicate the location of his vehicle. This location data is transmitted in digital format to the Command Control Center where it is translated by an interface unit into computer input. The location information is displayed in x, y coordinates on a map display at the Center. The display is comprised of slide projector with map images which is integrated with the location signal than a dichroic mirror technique. The final display is imaged on a television receiver for viewing by the dispatcher.

The System provides the dispatcher with location information on all field units without polling them by voice. Its demonstrated accuracy is 300-4000 feet depending upon resolution of the map used in the field and its coverage capacity obviously depends on the map size. For example, as a vehicle moved from an assigned district, additional grid sensition maps would have to be provided in the vehicle.

SECTION VII

REVIEW OF FEASIBLE AUTOMATIC VEHICLE LOCATOR METHODOLOGY

- o Data Collection Survey
- o Industry Response
- o Analysis of Response Data
- o Overall Comparison by System Performance
- o Qualitative Comparison by System Type
    - o Comparison of Proximity Systems
    - o Comparison of Trilateration/Triangulation and Loran Systems
    - o Comparison of Dead Reckoning Systems

The primary source of information on feasible AVL Systems was obtained through use of a simplified questionaire which was mailed to a list of approximately 150 firms and government agencies. The list was compiled from a literature search conducted to identify firms engaged in developing systems and equipment or performing related services applicable to the use of vehicle location systems. The format of the survey questionaire was carefully considered to ensure that it was simple enough to encourage a response and yet would include the data necessary for a firm data base. Potential supplies were queried concerning their experience, availability of equipment and performance parameters of their respective systems. A cover letter and information sheet on the Orlando Police Department operations accompanied each questionaire to aid those responding.

Approximately 30% of the firms responded to the survey questionaire, and of these more then half indicated some specific interest in the project. Eight returned completed forms giving detailed information concerning their system.

The response data showed four major system types - Proximity, Trilateration/Triangulation, Dead Reckoning and Loran which could be identified with several suppliers. Further analysis showed that no one technique was clearly dominant although the Proximity System (38% of the total response distribution by type of system) is slightly favored. This apparently results from the fact that it can claim the highest development activity perhaps because of lower developmental and equipment costs. The runner-up in percentage response was the Dead Reckoning system with approximately 28% followed by Trilateration/Triangulation (19%) and Loran (15%).

A comparison of system types by performance parameters shows that the Proximity System generally offered the best overall performance maturity; however to attain this performance requires installation of a large number of fixed sensor sites which may result in prohibitive installation and maintenance costs for large areas of coverage.

A listing of the various operating characteristics of the more generally recognized AVL Systems was used to obtain a relative qualitiative comparison between systems configurations. The resulting comparison matrix favored the Dead Reckoning and Proximity Systems in that order.

DATA COLLECTION SURVEY

A questionaire was used to survey potential suppliers of Automatic Vehicle Locator Systems concerning their experience, availability of equipment, and performance parameters of their respective systems.

Primary information on feasible AVL Systems was obtained through use of a simplified questionaire which was mailed to a list of approximately 150 firms and government agencies. The list was compiled from a literature search to identify firms engaged in developing systems and equipment,or performing related services applicable to the use of vehicle location systems. It is noted that since this is a relatively new field, there were very few references which directly related vendors and AVL Systems. Accordingly reports on funded AVL studies were the primary sources used in compiling the list. An important derivative of this approach was the knowledge acquired on the systems from reviewing these reports.

The format of the survey questionaire was carefully considered to ensure that it was simple enough to encourage a response and yet would include the data necessary to provide a meaningful information base. It was recognized that the recipient would have to contribute time from his other business activites to respond. Accordingly before determining the final format, it was discussed with several interested firms and their suggestions were included.

The questionaire was constructed to obtain technical information in four basic areas. These are identified in Figure 15 on the opposite page which is a reduction of the information pages of the questionaire. The third page asked if the firm were interested in setting up a demonstration at the Orlando Police Department, if they could be contacted for additional detailed information and whether their information could be included in the report. This page also provided space for identification of the firm and person responding. A complete survey form and cover letters are included in Appendix B for reference.

The first and second questions were intended to identify the firm by the area of interest in AVL Systems and the depth of its experience. The system description area was designed to permit a classification of the system by sensor type and physical configuration. It also included logistics support areas to measure the system maturity. The system performance queries were included to obtain data which could be used to analyze the effectiveness of the different systems in meeting Orlando Police Department requirements.

A cover letter and information sheet on Orlando Police Department operations accompanied each questionaire to aid the respondees The letter identified the project as being sponsored by the Florida Governor's Council on Criminal Justice and the role of Florida Technological University in conducting the study for Orlando Police Department. It was explained that the objective of the survey was to assemble engineering information on the state-of-the-art for AVL systems and to identify interested system suppliers. The Information Sheet included pertinent physical data describing the City of Orlando, operating data on Orlando Police Department, and how the system procurement might be realized.

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier ( )
Component Supplier ( )
Other ____________

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research ____________

Design ____________

Prototype ____________

Operating Systems ____________

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity ( )
- Dead Reckoning ( )
- Trilateration ( )
- Triangulation ( )
- Loran-Decca-Omega ( )
- Other ____________

Vehicle Electronics ____________

Base Station Electronics ____________

Data Link ____________

1

Base Station Display ____________

Dispatchers CRT Console Display ____________

System Computer ____________

System Documentation ____________

Personnel Training ____________

System Equipment Maintenance (annual) ____________

Additional System Capabilities ____________

Other Notes on System ____________

4. SYSTEM PERFORMANCE DATA DESIGN ( ) FIELD TEST ( )

Accuracy ____________
Capacity ____________
Update Time ____________
Frequency ____________
Band Width ____________
Power Levels ____________
Sites ____________
Coverage Area ____________
Advantages ____________

Limitations ____________

Figure 15:

INDUSTRY RESPONSE

Approximately 30% of the firms responded to the survey letter. Of these more than half indicated some specific interest in the project, and eight returned completed forms giving detailed information concerning their systems.

To ensure that an interested firm could respond the schedule was extended and 10 weeks were allowed from time of initial mail-out. It was noted that many of the inquiries were forwarded to other people in the firm for response. Additionally some firms who were no longer interested referred our survey to others whom they knew personally or suggested that we contact them. On this basis it is submitted that the industry was generally very cooperative and helpful. Of the 150 survey letters sent out, 32 were returned unopened due to obsolete addresses; 45 were returned with some type of response and the remaining 73 were not returned.

It is felt that this represents a relatively good response considering the difficulty in compiling a productive list without prior knowledge that the firms were interested in the AVL systems field. It is noted that reducing the total by those returned for insufficient or obsolete addresses results in a 38% response. Table 10 on the opposite page presents the overall results of the survey letter by response categories.

The summary shows that of those responding only 9 could complete the survey form. The remainder responded with a letter generally indicating interest which was limited to a subsystem or component area; several were software or systems engineering firms only. Some were involved in test and studies of AVL systems for other type vehicles such as buses or trucks. Apparently AVL systems are being examined seriously for controlling and operating public conveyances in a more responsive and optimum manner and as an effective deterrant to truck hijacking. Almost all who responded also provided capabilities, brouchres or specification sheets describing their hardware.

Those who were able to complete the survey form also provided supplementary information. These included copies of government sponsored proposals and studies on AVL system. A few of which are listed below.

- AVM System - Contract No. DOT-UT-10024 (Feb 1973 - final report - Sierra Research Corp)
- Loran C - AVM System - Report No. DOT-UT-72 (July 1972 - final report - Teledyne Systems Co.)
- Vehicle Location and Status Reporting System, (LOCATES), Project No. 182, - final report - phase I, City of Montclair Police Department, March, 1972.

Based on the interest indicated on the form selected firms were contacted by telephone to determine if a demonstration were feasible. Three were then selected based on their demonstrated experience in the three most feasible AVL system types:

Sierra Research, Buffalo New York,	Trilateration
Boeing Co., Wichta Kansas,	Dead Reckoning
Applied Technology, Costa Mesa, Cal.,	Proximity

All agreed to discuss a conceptual system design for OPD. None however, offered to set up and demonstrate their system. This is understandable in part because of the difference in system complexity and the effort and equipment required to implement a demonstration.

TABLE 10

TABULATION OF RESPONSES TO SURVEY BY CATEGORY

Response Category	Number	%
Lost (No Response or Return)	73	48.5%
Returned Unopened	32	21.5%
No Interest Letters	21	14.0%
Interest Letters	15	10.0%
Form Completed	9	6.0%
TOTAL	150	100.0%

ANALYSIS OF RESPONSE DATA

Analysis of the response data showed that the Proximity System was favored by the highest number of firms and had more demonstrated maturity in Police Agency Applications than the other proposed major system types - Trilateration/Triangulation, Dead Reckoning and Loran.

All firms responding indicated active design work was being done on an AVL system and all except one company stated that active continued research was being conducted. From the returned survey forms, six companies showed they had a prototype system in operation, while three stated they had a completed operational system on hand. Of these, one was a dead reckoning system, the others were three proximity systems and one company indicated they had both types.

Analysis of the survey data showed that of the four main types of Automatic Vehicle Locator Systems, the proximity system can claim the greatest development activity. Eight companies indicated their engineering efforts have been in this area. This can probably be attributed to lower development costs, lower equipment costs and greater simplicity of design. Six companies reported work being done in the Dead Reckoning area of AVL Systems. Triangulation/Trilateration types of systems and the navigation (Loran) systems were reported as areas of activity by three companies in each area. Of these firms responding, some stated that they were exploring more than one type of system and had actually had parallel efforts going in two to three different systems including some hybrid variations of system.

Figure 16 presents the response distribution by type of system. As the pie chart shows, no one technique clearly dominates; however, the Proximity System is slightly favored probably for the reasons mentioned earlier. This distribution seems to verify the assumption that the approach may more directly be a function of experience and initial application, than a listing of the companies which responded by systems type as has been indicated in the Figure. This clearly shows the maturity dominance of the Proximity type system. Those indicated by the asterik (*) have indicated an interest to provide a system concept or demonstrate their particular system. All, however, indicated a demonstration would involve a contracted cost.

It is interesting to note, however, that some of the more prominent electronic firms who currently market communication system and radio equipment to police agencies (RCA, Motorola, General Electric) were unwilling to respond or commit themselves concerning Automatic Vehicle Locator Systems. This reluctance on the part of leaders in police agency communication may result from the fact that no one has a complete police AVL system in operation although each has experimented with prototype systems. Cost information for a system is even more difficult to obtain. This may result from the realization that the problem is not amenable to a package or off-the-shelf hardware approach. Each police

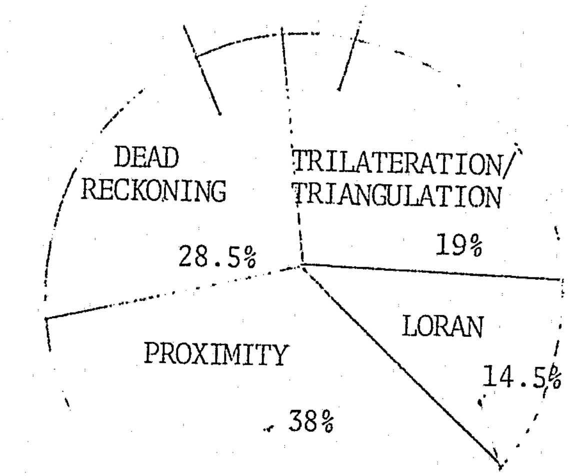
agency, although typically having the same functional requirements, will have different operational and environmental requirements. These must be recognized in the system design which will require trade-off studies among several basic system concepts. Field tests had been completed or partially completed by all except in one case where the company was still engaged in the design stages of the system.

Dead Reckoning Systems

Lockheed Corp. Electronics Division
AGA Corp.
Boeing Corporation*
Bendix Corporation*
Marconi, Ltd.
Martin Marietta Corp.

Triangulation/Trilateration Systems

Sierra Research Corporation*
Sanders Associates, Inc.
Marconi, Ltd.
Cubic Industrial Corporation



Proximity Systems

Applied Research Corporation*
Products of Information Systems*
Capitol Science Corporation
Sanders Associates, Inc.*
Marconi, Ltd.
RCS Associates, Inc.*
Mitre Corporation
Bendix Corporation*

Loran (Navigation) System

Lockheed Corp./Electronics Division
Teledyne Systems Co.
Hazeltine Co.

Figure 16 : Survey Response Distribution By Firm Shows That Most Favor The Proximity Type System.

OVERALL COMPARISON BY SYSTEM PERFORMANCE

A comparison of system types by performance parameters shows that the Proximity System generally offers the best overall performance; however, to attain this performance requires installation of a large number of fixed sensor sites which may result in prohibitive installation and maintenance costs for large areas.

Major performance parameters for each of the four basic vehicle locator systems have been listed in Table 11 on the opposite page to form a basic type comparison matrix. Hybrid type systems were grouped under a basic type category. These data represent the summary of information obtained from the survey questionnaire. For each system type performance ranges are indicated to reflect the responses from different designs and applications of the same system.

As Table shows, Proximity systems have normally the greatest accuracy; however, there is an accuracy/cost trade off due to the larger number of fixed sites required. Update time, bandwidth, capacity and frequency bands are comparable for all four systems. The Proximity system also has the advantage of lower power level requirements for mobile location emitters (transceivers); in fact some systems use passive emitters which provide a signal as the vehicle passes near or over them. The update time is also variable depending on the number of sites and is within the typical requirements of a police system.

Dead Reckoning systems show an accuracy comparable to the Proximity systems without the necessity of having a large number of intermediate fixed sensors for system operation. At the present time, however, development for commercial application does not appear as popular as the Proximity type. Perhaps this is because the vehicle electronics would typically be relatively costly for this listed accuracy. However it is noted that the accuracy can be improved substantially by augmenting the basic system with feedback correction. This might be in the form of signpost emitters which would reinintialize the car computer of by use of a small computer at headquarters which would check the location transmitted from the car with its memory of street locations.

Trilateration/Triangulation systems are plagued by multipath problems, hence the resultant accuracy suffers as the listed range of 600'-1250' shows. LORAN systems fared better although there was very little information available and therefore the true parameter ranges may be somewhat different if a larger sample of data had been received. It is noted again that these data were obtained from the survey questionaire and a review of the literature might result in some changes in the comparison. Also cost is obviously a major factor and a cost effectiveness comparison is needed.

TABLE 11

SYSTEM PERFORMANCE PARAMETER COMPARISON BY TYPE OR SYSTEM

	PROXIMITY	TRILATERATION/ TRIANGULATION	DEAD RECKONING	LORAN
ccuracy	10-100 feet	600-1250 feet	50-100 feet	150-500 feet
pdate time	(1) .1 to 2-3 seconds	.03 to 4 seconds	1 second	Less than 1 second
Bandwidth	(2) ½ to 25 KHZ	25-125 KHZ	10 KHZ	10 KHZ
pacity	Unlimited	1000+	Unlimited	Unlimited
Frequency	20 KHZ to 450 MHZ	30 to 450 MHZ	30-450 MHZ	(5) 100 KHZ
wer levels (ehicle Radio)	1 mw to 3 watts	10-20 watts	25-40 watts	10-20 watts
Number of fixed sites	(3) 20/sq. mile	1-9/25 sq. miles	(4) -------------	(small) depends on system
verage	Within grid network of signposts	25-100 sq. miles +	Range of mobile radio	Extensive, depends on system

(1) Update time here actually depends on signpost passing frequency.

) Though the general bandwidth range was within these limits, one company response indicated a bandwidth of 3 MHZ.

(3) The density (and power levels of the emitters) determines the accuracy and update times hence this figure could vary considerably.

) No fixed sites are needed in this configuration unless calibration type sites are introduced in a particular system of this type.

(5) The only information available concerned a LORAN C system which operates at this frequency.

QUALITATIVE COMPARISON BY SYSTEM TYPE

A listing of the various operating characteristics of the more generally recognized Automatic Vehicle Locator Systems was used to obtain a relative qualitative comparison between system configurations; the resulting comparison matrix appears to favor Dead Reckoning and Proximity Systems.

All performance characteristics cannot readily be translated into quantitative terms. Accordingly, a qualitative comparison was made of the competing systems by evaluating some of their advantages and disadvantages. The results are summarized in Table 12 in matrix form.

Several advantages of the Proximity and Dead Reckoning systems are shared, including being independent of RF propagation problems which is a large source of error in the Trilateration/Triangulation systems. The Proximity system has the advantage of not requiring any location computation since location is determined by being in the vicinity of known position sensors. The Dead Reckoning system, however, offers the advantage of having all the location computation equipment aboard the vehicle and requires no intermediate fixed stations for transmission of location data and is therefore, least vulnerable to tampering. Also it is the only system which does not require radio emission for the location function.

All systems can claim efficient use of RF spectrum and all but Trilateration/Triangulation systems have unlimited user access. A true LORAN system has the greatest coverage (within LORAN station areas) while that of the Proximity type would be most limited.

Major disadvantages of the Proximity system are the large number of signpost stations which require telephone lines for final data transmission if wire transmission is used. For the Dead Reckoning system, the most serious disadvantage appears to be the expensive vehicle equipment needed, which is also an inherent limitation of the LORAN system. Multipath propagation error could be classified as the major technological problem encountered in the Trilateration/ Triangulation types.

In summary the matrix allows some comparison visibility, but any conclusion must be a function of the individual system performance and environmental requirements. In general, however, the comparison appears to favor the Dead Reckoning and Proximity systems.

TABLE 12

QUALITATIVE COMPARISON OF SYSTEM TYPES

AVL SYSTEM	ADVANTAGES	DISADVANTAGES
DEAD RECKONING	1) Independent of RF propagation and noise characteristics. 2) Efficient use of spectrum. 3) Independent, unlimited user access. 4) One transceiver meets AVL, voice, and digital needs.	1) Error cumulative due to poor heading reference but can be corrected by proximity update stations or computer street network comparison. 2) Potential maintenance problem of complex electro-mechanical system.
LORAN	1) A few transmitters cover a wide area, urban and suburban. 2) Unlimited user access. 3) Efficient use of spectrum.	1) Receivers are expensive currently. 2) Two radio equipments needed to meet AVL, voice, and digital needs. 3) May require "grid mapping".
PROXIMITY	1) Independent of RF propagation characteristic. 2) High system reliability--does not depend on survival of any given emitter. 3) Unlimited user access. 4) No calibration requirement. 5) Efficient use of spectrum. 6) No location computation required.	1) Large numbers of emitter sites needed. 2) Emitter maintenance required. 3) Two radio equipments needed to meet AVL, voice, and digital needs.
INVERTED PROXIMITY	1) Independent of RF propagation characteristics. 2) High reliability. 3) No calibration requirement. 4) Efficient use of spectrum. 5) No location computation required.	1) Large number of sensor sites needed. 2) Large number of communications links to central. 3) Interference when more than one vehicle is in zone of a receiver. 4) Two radio equipments needed to meet AVL, voice, and digital needs.
TRIANGULATION	1) One transceiver meets AVL, voice, and digital needs. 2) Computer solves simple, straight-line, location equations. 3) Efficient use of spectrum.	1) Multipath can change angle of reception drastically. and yield large errors. Siting the receivers away from reflectors may alleviate. 2) May require periodic "RF mapping" of city and computer look-up table to correct severe, but repeatable, multipath distortions.
PULSE TRILATERATION	1) High accuracy, superior to phase system.	1) Requires several MHZ of spectrum to get high accuracy and overcome multipath problem. 2) Two radio equipments needed to meet AVL, voice, and digital needs. 3) High power pulses are potential source of RFI; vehicle must have HV supply. 4) May require periodic "RF mapping" of city and computer look-up table to correct severe, but repeatable, multipath distortions in areas the direct signal is blocked.
PHASE TRILATERATION	1) Simple,vehicle equipment--same transceiver meets AVL, voice, and digital needs. 2) Efficient use of spectrum.	1) Accuracy dependent on multipath propagation environment--may require a large number of sites and diversity techniques to correct. 2) May require periodic "RF mapping" of city and computer look-up table to correct severe, but repeatable, multipath distortions.

COMPARISON OF THE PROXIMITY SYSTEMS FROM RESPONSE DATA

The Proximity Systems, although very similiar in their subsystem functions, exhibited a wide range of values for the system performance parameters.

In general, all proximity systems had the same basic configuration which includes the electronics in the vehicle to present an identification and communicate with signpost subsystem placed at strategic locations along the vehicle routes. There were many variations of this basic system presented. In most cases the vehicle electronics was a receiver of location information being transmitted continuously from a location site which was picked up by each passing sensor equipped vehicle. The range of transmission was 100-500 feet, with emitter power levels ranging from 1 milliwatt with one system to approximately 250 milliwatts for another.

With this approach, all data link is necessarily radio frequency, since the information must be retransmitted to the Command station via the vehicle transmitter. Frequencies used ranged from ultrasonics (20 KHZ) to UHF (450 MHZ). In such a configuration, many transmitters would have to be on the 'air' (although at low power levels) continuously, since to have a specified high accuracy, a closely spaced grid network of sign post emitters would be necessary. Costs of such a system would seem to be higher than signpost receiver type, since transmitters in general have higher power consumption requirements, and, therefore, require more cost', components.

When the vehicle becomes the emitter and the signpost the sensor, a configuration submitted by a few of the responsive companies, the RF transmission are limited to that of a few vehicles to the passive receiver signpost grid network. These in turn, retransmit the information to the Command station via telephone lines, or by a CATV cable network if it is available. Under these conditions, address requirements would also be reduced, since it would require coding of only a small number of vehicles compared to coding of a large number of fixed emitters in a grid network.

Coding for location determination generally was by audio tone or a digital binary coder to supply discrete addresses. Location determination of course, was by proximity to the sign post emitters or sensors.

A few unique methods were disclosed. One such was from Applied Research Associates, whose system incorporated ultrasonic transmission which utilized a very small part of the frequency spectrum (1 KHZ Band Width @ 20 KHZ). RCS Associates proposed a system which uses a RADAR Transponder as a sign post with 'passive labels' on the vehicles in question. A principle of synthetic aperature (as used in aerial mapping with extremely good resolution) is used to give discrete address to the system vehicles. It is noted that this system would require line-of-site view of the vehicle and might be adversely affected by traffic flow patterns.

Generally, display system and computer requirements were not specifically defined. Most dealt with commercially available small computers and CRT display units. The computer input interface was relatively simple in all cases where data is received over a radio link from the vehicles due to the standard format of input data. Inputs from fixed proximity sensors need to be more complicated, depending on the number of party lines which must be sampled during an interrogation interval. The display must also interface with the computer. This provides intelligence to permit the display to hold the readout situation until additional signal information is received from the field. Training time to teach operational use was on the average relatively short (about 2 hrs.). Annual maintenance time and costs were implied as being low since the unit devices are in general simple. Cost per unit (when stated) was anywhere from $100-$1,000. However, for an accurate system, where a large number of signposts would be required, the initial system cost would be fairly high. Nearly all replies stated that a silent 'trouble' alarm could be implemented in the system. General system performance of all the proximity types received in the questionnaire responses are tabulated in Table 13 . Ranges have been used to indicate the variation in systems.

TABLE 13

PERFORMANCE PARAMETERS FOR PROXIMITY SYSTEMS

Parameter	Performance
Accuracy (dependent on sign post grid spacing)	± 100 feet
Up Date	80 Milliseconds to a few seconds
Band Width	500 HZ to 3 MHZ
Sites	Depends on accuracy required and available wire transmissions
Capacity	Unlimited
Frequency	20 KHZ to 450 MHZ
Power Levels	1 to 250 milliwatts
Coverage	Within grid network spacing

COMPARISON OF TRILATERATION/TRIANGULATION AND LORAN SYSTEMS FROM RESPONSE DATA

Although the total number of companies responding in these areas were less compared to the other systems, the detailed information supplied was comparable.

Two companies returned completed forms identifying their systems as the Trilateration type, and one was returned describing a Triangulation system. Several other responses were based on work in the area of LORAN Systems. These have been grouped for discussion because they generally are based on the same mathematical analysis to reduce the data to vehicle location information.

In the Trilateration system, the location determination is based on a solution of intersecting hyperbolas which is derived from time delays of arrival of a location signal from the vehicle to the sensor. The system developed by Sierra Research of Buffalo New York also uses time division multiplexing to give specific identity to each vehicle. In addition, due to inherent delays in the system, Sierra also incorporates a calibration transmitter to correct for this. The calibration transmitter sends sync timing signals to the mobile transceiver and its transmissions are also used at the sensor receivers to measure certain constraint system delays such that they can be calibrated out in the final calculations. Connections for multipath errors are also incorporated in this system through the use of statistical data or multipath delays in specific areas.

Table 14 presents the range of performance parameters value for the different ranging systems reported in the completed questionnaires. LORAN system performance was not included since information response was not significant in this area. In both Trilateration configurations the location emitters were modified standard police mobile radios mounted in the vehicle. The sensors were fixed location receivers installed at 4 to 9 sites within a 10 mile square area. The data link from vehicle to sensors was VHF radio in all systems. From the sensor to the communications center, however, telephone lines were used in two instances and Cubic Corporation utilized a microwave link (X band).

Triangulation techniques were submitted by Sanders Associates, Inc. and the Marconi Ltd. Company of London, England. This system is very similar to the Trilateration scene except that the sensors are multichannel receivers and utilize spaced antennas to measure relative phase of the received tone to assess vehicle direction. Specific details of these systems were not presented, and data on system performance was very limited.

Only one company, Lockheed Electronics Co., responded that they had worked in the area of the LORAN type of AVM systems. No information was given on their system since the work was performed under a classified government contract. The Teledyne Systems Company responded that they had concluded a study of a LORAN C system for the Urban Mass Transportation

System, the results of which was compiled in a final report dated July 1972. A RADAR type IFF system, utilizing interrogator-transponders was demonstrated in New York in 1970 by the Hazeltine Corporation. This system operated independent of LORAN stations.

The LORAN system uses the same mathematical principles for location determination as in the Trilateration methods, that is, intersection of hyperbolas from time difference of arrivals of signals. However, instead of the location signal originating from the vehicle, it originates from an existing LORAN transmitter. The time difference of arrival of the signal is measured at the vehicle receiver and this information is used to compute the vehicle location.

TABLE 14

PERFORMANCE PARAMETERS
FOR TRILATERATION SYSTEMS

Parameter	Trilateration
Accuracy	600 - 1250 feet
Update Time	3-15 seconds
Bandwidth	
Sites	4 - 10
Capacity (vehicles)	1000+
Frequency - Loran C - 90-110 KHZ	VHF - UHF
Power Levels	10 - 20 watts
Coverage	10 sq. miles

COMPARISON OF DEAD RECKONING SYSTEM TYPES FROM RESPONSE DATA

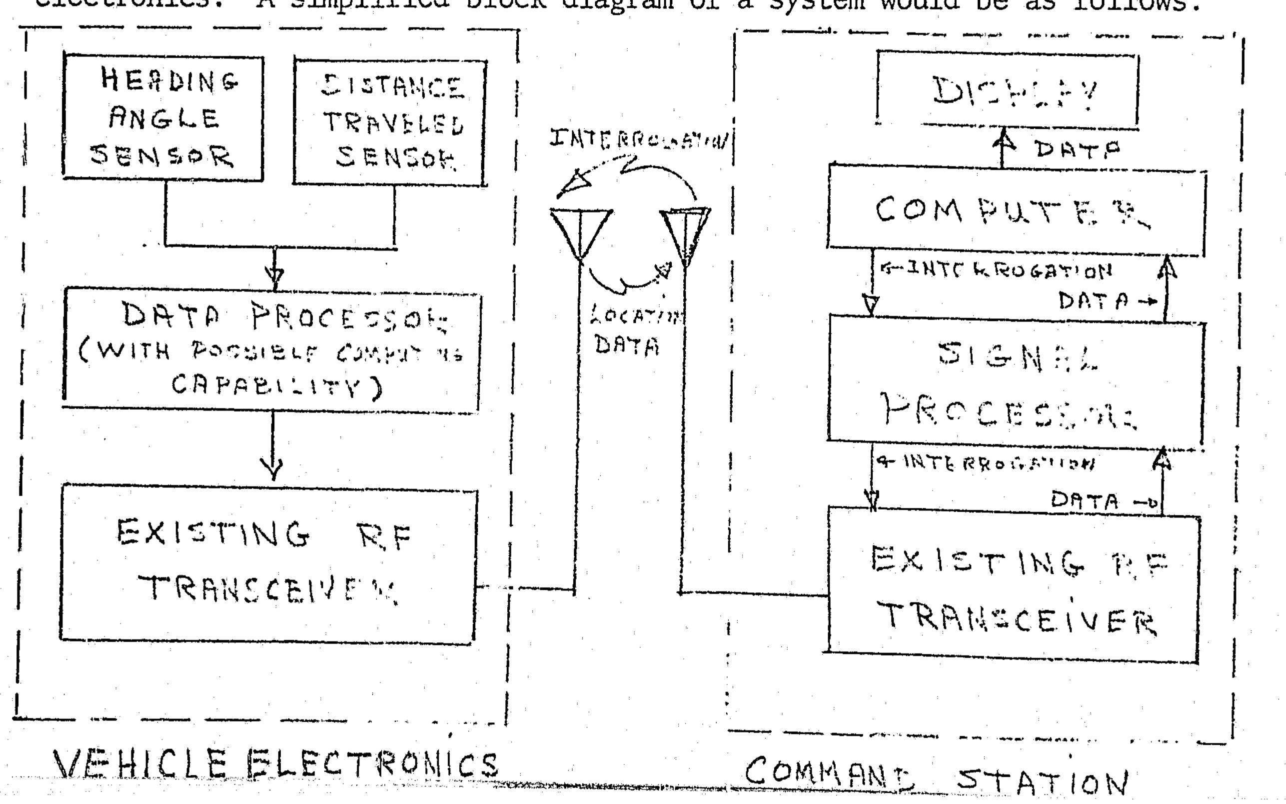
There was a rather limited response in the area of Dead Reckoning Systems of AVM. Though approximately a half a dozen companies indicated they were actively working in this area, few supplied any extensive information about their particular systems.

A Dead Reckoning system does not rely on other supporting units to determine vehicle location. Rather, it uses the vehicle heading and travel distance to compute its own location with the aid of odometers and gyro compasses or magnetometers. A considerable amount of work done in this area was for military purposes, where it was fairly impossible to employ such techniques as Proximity or Triangulation/Trilateration because of the fixed location sensors or emitters required which are not feasible in battle situations.

The number of specific units required for a given area would be much smaller compared to a proximity system, however, the individual units would be much more complex. The on-board vehicle subsystem would be:

- Odometers sensors for distance traveled
- Heading sensors for direction of travel
- Electronics for computing or storing this sensor data.

Normally, this computed or stored data is then relayed to the Command Station via the standard police radio system. Some interface equipment in necessary between the police transceiver and the data processing or computing electronics in order to facilitate this transmission. Thus, the equipment required in the vehicle would generally be larger, more complex and more costly than some of the other types of systems. However, this is offset by the fact that fixed station intermediate sites are not required, since transmission is directly to the command station. Command statión computation is also minimized since some of the data processing and computation has been already accomplished in the vehicle electronics. A simplified block diagram of a system would be as follows:



Unfortunately, few of the responses in this area gave much detail other than the basic configuration of their systems. One dealt only with fixed route vehicles and hence was not applicable. Only one responding company stated they had a prototype system being field tested in a commercial (civilian) environment. A few others indicated that they had systems being tested; however, these were under government classified contracts.

An additional feature of the single company which had a prototype system to offer was a playback capability which would 'recap' vehicle routes over a time period on magnetic tape. Analysis of these playbacks could then be used to determine more efficient or other more effective methods of patrolling or responding to an emergency.

TABLE 15

Performance Parameters for Dead Reckoning Systems

Accuracy	50-500 feet
Up Date Time	fraction of second
Band Width	10-25 KHZ
No. of sites	none
Capacity	unlimited
Frequency	VHF to UHF
Power	25-40 watts (mobile)
Coverage	Range of mobile transceiver

SECTION VIII

PROTOTYPE SYSTEM DEMONSTRATION

- o AVL System Prototype
  - o Location Emitter Subsystem
  - o Patrol Vehicle Electronics
  - o Command/Control Center Electronics
    - o Performance Requirement of Visual Display
    - o Visual Display System Design
    - o Vehicle Identification Number Generator Design

The Proximity System was selected to demonstrate the operational capability and effectiveness of an AVL System. This decision reflected several practical considerations. Of the three most feasible, AVL Systems (Trilateration, Dead Reckoning and Proximity), the Proximity system had demonstrated the greatest maturity. Perhaps more important was its relative simplicity and availability of off-the-shelf components with hich to implement it. The other two systems involved proprietary and/or expensive electronic gear which effectively prohibited their demonstration on the available budget ($3000).

The System selected is the conventional configuration, i.e., wayside emitters which continually broadcast their location information to mobile radios in the patrol vehicles which in turn relay the information to the Command/Control Center. Coded transmitters were located at 10 selected intersections in two Districts in the Northwestern section of the City. Two patrol cars were equipped with radio relay electronics to demonstrate the capability of the system to distinguish between and display data from more than one car passing the same emitter. The system was designed and assembled in the Electronics Project Laboratory at Florida Technological University.

A standard commercial transmitter/encoder with capability of 100 mw output in a single frequency was used as the location emitter. These were mounted in the traffic signal controller boxes at the intersections and the antennas adjusted to control the power output. The encoders use a "micro-fork" circuit to generate the desired tone signature.

A commercially available citizen band mobile radio monitor was selected to detect the emitter location signal. This was packaged with an encoder similar to the one used as location emitter to add a tone code which would identify the patrol vehicle. A control circuit was added to key a PREP radio transmitter and activate the encoder when a location signal was detected.

The mixed location/vehicle tone codes are received by the PREP System satellite receivers which relay the audio signal to a Comparator at the Center. A time delay circuit in the vehicle electronics was used to limit the code transmission to less than one second since the transmissions were over an active police channel.

The audio tone signals from the Comparator are sent to a set of decoders which are similar to the encoder being "micro-fork" oscillator devices. Each encoder has a counterpart decoder which responds to a specific frequency. A memory bank holds the information untill data from the vehicle at a new intersection is received. When both intersection and vehicle identification are available, the new data is stored. This information is withdrawn by a multiplexer circuit with a frequency of about 2000Hz and used to drive Light Emitting Diodes (LED) which display the car identification number at the intersection. The Prototype visual display was a large 5' x 7' backlighted map of Orlando showing all streets and other pertinent physical characteristics.

The System as designed required some modification before reliable operation was achieved. The most disruptive was a signal/noise problem which caused the system to attempt to move the vehicle without an intersection location. This was caused by noise keying the mobile radio and was solved by adjusting the signal input to the decoders.

AVL SYSTEM PROTOTYPE

The Proximity System was selected to demonstrate the operational capability and effectiveness of an Automatic Vehicle Locator System because of its relative simplicity and availability of commercial off-the-shelf components which could be used to implement it.

The primary objective of the Automatic Vehicle Locator System prototype was to demonstrate the operational capability and effectiveness of such a system in a real world environment. A minimum period of several months was planned to afford adequate time to observe the performance of the equipment and the usefulness of the location information to the personnel at the Command/Control Center. Also of primary importance was the identification of human factors problems which were expected to surface in the Display and Vehicle Electronics Subsystems. When identified it was recognized that these interfaces would have general applicability to the design of any type AVL System.

The proximity system was selected for the prototype demonstration model. This decision reflected several practical considerations. Of the three AVL system (Trilateration, Dead Reckoning and Proximity) which were considered most feasible for the Orlando Police Department, the proximity system has the greatest maturity at this time. Perhaps more important, however, is its relative simplicity and availability of commercial off-the-shelf components with which to implement it. These characteristics enabled the prototype system to be designed and installed within a budget limitation of $3,000. The other two systems involved proprietary and/or expensive electronic gear which effectively prohibited their demonstration on the available budget.

The System is a conventional configuration, i.e., wayside emitters continually broadcast their location information to mobile radios in the patrol vehicles which in turn relay the information to headquarters. This contrasts with the inverse system where the patrol vehicle transmits to a wayside receiver, for example, a call box, which relays the signal via telephone pair to headquarters. In the O.P.D. System coded transmitters were located at 10 selected intersections in the northwestern section of the City. Two patrol cars were equipped with radio relay electronics to transmit the information to the Command/Control Center where it was displayed on a large (5' x 7') map of Orlando. Two cars were used to demonstrate the capability of the system to distinguish between and display data from more than one car passing the same emitter. Figure 17 is a block diagram of the system.

The system is composed of three major functional subsystems as identified in the diagram - (1) the intersection emitter, (2) the mobile radio relay electronics and (3) the display unit at the Center.

The intersection emitter is a small commercially available transmitter/encoder unit which operates in the Citizen band of frequencies. This is mounted in the traffic signal controller box and is powered from the 110 volt bus. Output is approximately 100 Mw on a single channel frequency which is coded to identify the intersection location.

The location signal is then picked up by the electronics package in the patrol vehicle as it nears the marked intersection. This equipment consists of a commercially available Citizen band receiver which detects and amplifies the location signal. The disabling of the squelch circuit in the receiver also causes another circuit, the encoder trigger, to generate an audio tone signal identifying the vehicle. The identification signals are mixed, amplified and fed into the output speaker of the receiver which provides an accoustic coupling into the microphone of the transmitter. As shown in the diagram the encoder trigger circuit also activates a solenoid which manually keys the transmitter. Accoustic coupling was used in the demonstration in order to obviate the necessity to modify the existing transceiver units.

The mixed location and vehicle coded signal is received over the existing PREP communications system and relayed to the comparator at the Command/Control Center. The signals are the picked off and processed through a set of tone decoders. The Visual Display consists of a large back lighted map of the City with all street and prominant physical features. This decoder tone signals are used by the Visual Display System (VDS) to activate a LED unit at the proper intersection to show the vehicle identification numbers. The LED units, once activated, remain in that state until a new signal from the particular vehicle identified is received from the field.

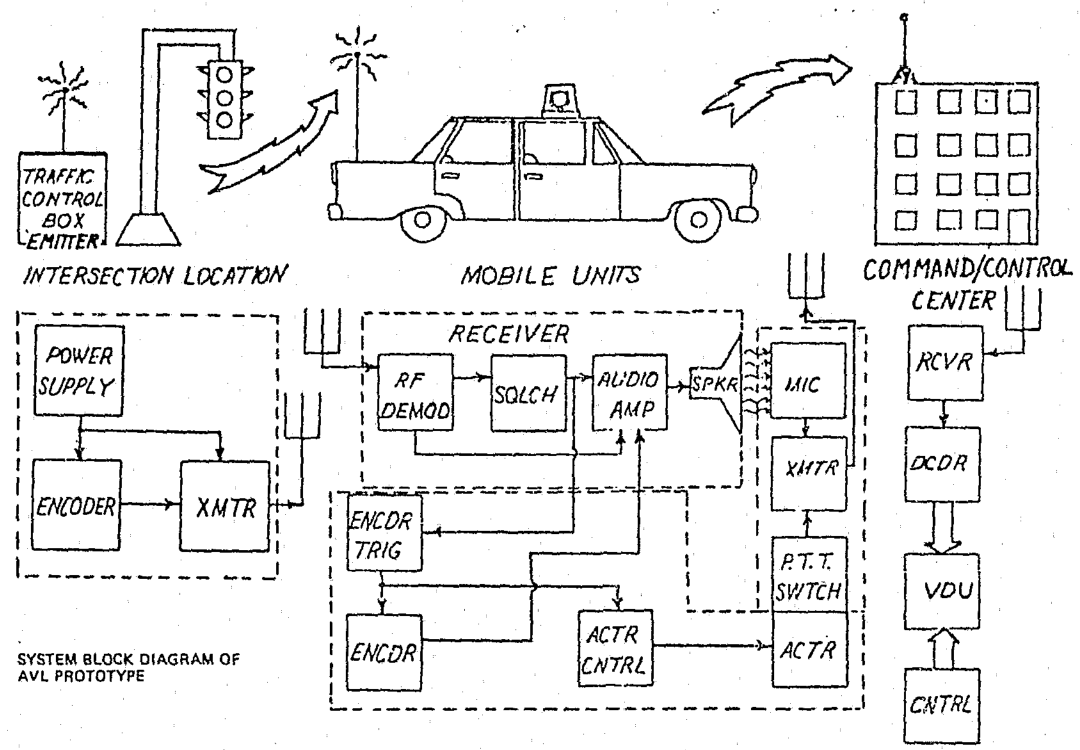


Figure 17 Block Diagram of the System

LOCATION EMITTER SUBSYSTEM

A commercial transmitter-encoder unit with capability of 100 mw output in a single frequency was mounted in traffic signal controller boxes at selected intersections to function as the location emitter.

The transmitter/encoder unit selected for use as the location emitter is a standard commercial product manufactured by Neilson Enterprises of Orlando, Florida. This unit operates on a single channel frequency and requires only the application of 12 volt DC power to go on the air. Neilson Enterprises has designed it to perform a general beacon function as an on-off remote signal with identifiable coding.

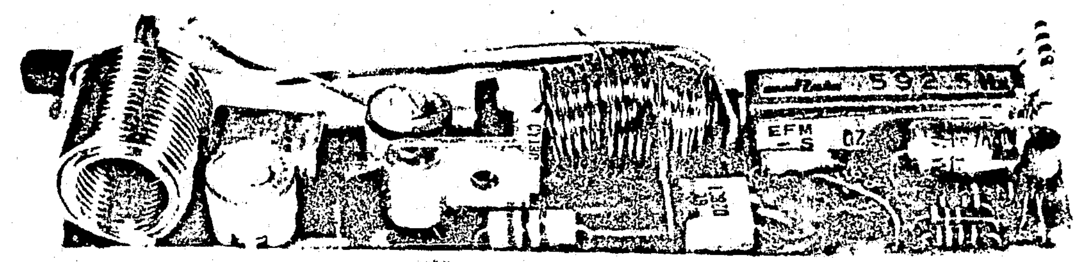
A power supply was assembled in the FTU electronics shop to interface with the transmitter/encoder and 110Volt AC power the total system was remounted on a single board such that it could be installed in the existing traffic signal controller boxes at selected intersections. The power supply was then connected to the 110 Volt AC signal controller power bus.

Figure 18 on the opposite page presents pictures of the equipment. The top photograph is the transmitter/encoder with a scale in the foreground to indicate its relative size. The other photograph shows the emitter package installed in a typical traffic controller box. It is noted that the antenna has been placed to minimize visual exposure to passersby which in turn might trigger curosity and result in damage to the emitter. Since the units are mounted in the controller box, the antenna can be easily reached from the ground.

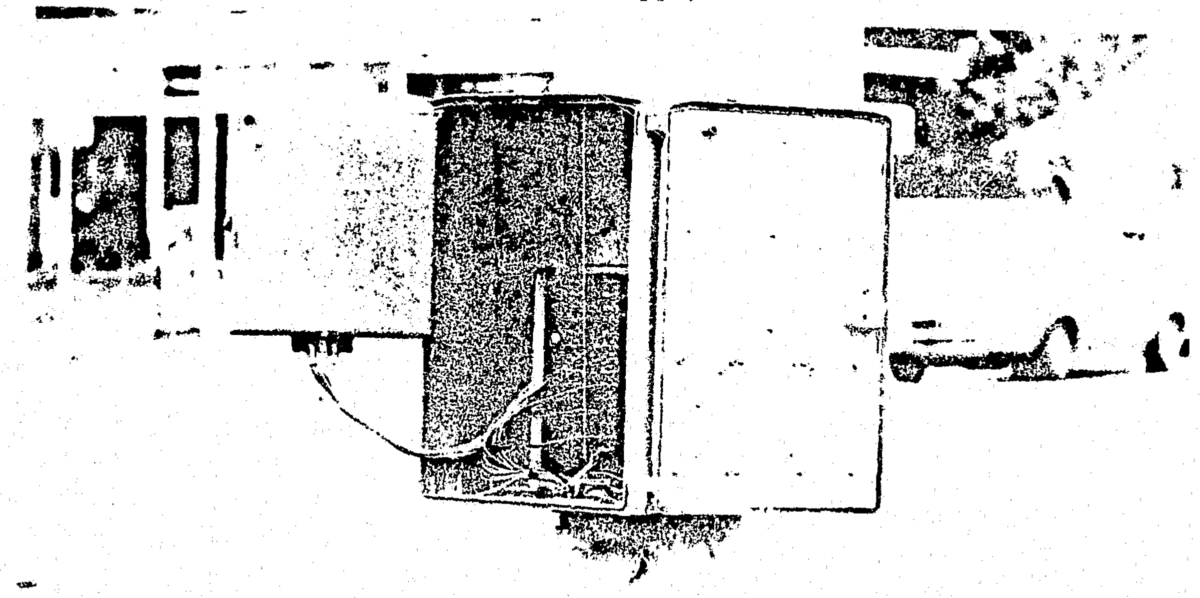
A problem attendant with using the power from the traffic controller in Central Florida is the voltage surge which may occur due to nearby lightening strikes. This also affects the traffic signal circuitry and each controller has been provided with a device to bypass voltage surges to ground. It is difficult to set the air-gap, however, and frequently the signal circuitry is damaged.

In this configuration the effective range of the transmitter was found to be approximately 200 feet. Output power rating is 100 mw working into a 50 OHM load. At this distance the signal received by the mobile unit in the patrol vehicle has sufficient strength to cause the receiver to key the transmitter. At just less than 30 mph the vehicle would receive the location signal for about 5 seconds. This is adequate time since only 1 second has been allocated for introducing the vehicle signature and retransmitting the location signal to the Command/Control Center. The vehicle electronics contains a 1 second limit on location transmissions to mininize interferences with regular voice traffic. If this limit were not imposed a vehicle sitting at an intersection could effectively destroy voice communication.

The encoder uses a "micro-fork" to generate the desired tone signature. This component consists of a small steel tuning fork which is driven by a piezo-electric crystal. A second crystal detects the tuning fork movement and converts the mechanical motion into voltage output at the tuned frequency of the fork. These circuits are stable over a 0-50° C temperature range and have a Q of about 500. Since they are mechanical they do have some inherent limitations. One of the most general is their susceptability to generation of mircophonic signals. This can be minimized however by providing a controlled vibration environment. No problems of this type are anticipated with the signal controller installation. The transmitter operates on the 26.995MHz r-f carrier frequency in the Citizen Band Control Frequencies.



Transmitter-Encoder Unit With Power Supply



Location Emitter Installation In Traffic Signal Controller Box
Figure 18

PATROL VEHICLE ELECTRONICS

The vehicle electronics package consists of a commercial citizens band receiver, tone encoder, and PREP transceiver. A standard issue PREP radio was used to reduce cost of the test installation and simplify the interface with the existing voice communications system.

The vehicle electronics package must perform several interrelated functions to relay the location information to the Command/Control Center. Basically the equipment consists of a receiver, an encoder powered from the vehicle electrical system and a PREP transceiver used as standard issue to the watch personnel. A PREP radio was used to minimize the cost of the test installation. In actual practice it would be replaced by a transmitter assembled as part of the electronics package.

Initially the receiver must detect the location signal from the emitter as the vehicle enters the intersection. When the signal is received two functions are triggered, the transmitter is keyed and the encoder is triggered to generate a signature tone for the vehicle. Both tone signals (location and vehicle) are mixed and transmitted to the Command/Control Center. A circuit is also included to limit the transmission time to one second. This is necessary to prevent the location signals from wiping out the voice communications, especially in event of a vehicle waiting for a light or parked near a marked intersection.

A commercially available PACE CB-9 citizen band mobile radio monitor was selected to detect the emitter location signal. This is a small 4 3/4" wide x 1 1/4" high x 6 1/4" deep unit which weighs about 2 pounds. The squelch mininmum sensitivity is .35 μV with audio output of 0.5 watts. It is noted that the squelch setting can be used to control the effective range of the locator emitter. The receiver is packaged with an encoder similar to the one (Neilson Enterprises) used in the location emitter to identify the patrol vehicle. A control circuit is included to simultaneously key the PREP transmitter and activate the encoder. The transmitter is keyed by a mechanical solenoid which manually depresses the talk button and holds for one second. The solenoid in turn is activated by a RC time constant circuit which drives a transistor to saturation.

This permits the tone signals (location and vehicle identification) to be transmitted simultaneously. The signal is detected by the satellite receivers which relay the audio signal to the comparator at the Center. The comparator selects the preferred receivers based in RF signal strength and releases the others. The RF signal strength is coded at each receiver by audio tone for selection at the comparator. The photograph of the electronics package is shown in Figure 19 with a scale to indicate the relative size. Figure 20 is a photograph of the package installed in one of the patrol cars. The mounting under the dashboard was chosen to mininize interference with normal actions in the vehicle and exposure to possible vandalism during periods when the car may be unattended. The mounting is designed to easily accept a standard PREP radio so that it can be replaced at the beginning of each watch. This permits these units to be checked out by the same procedure which is being used to issue the personnel PREP radios.

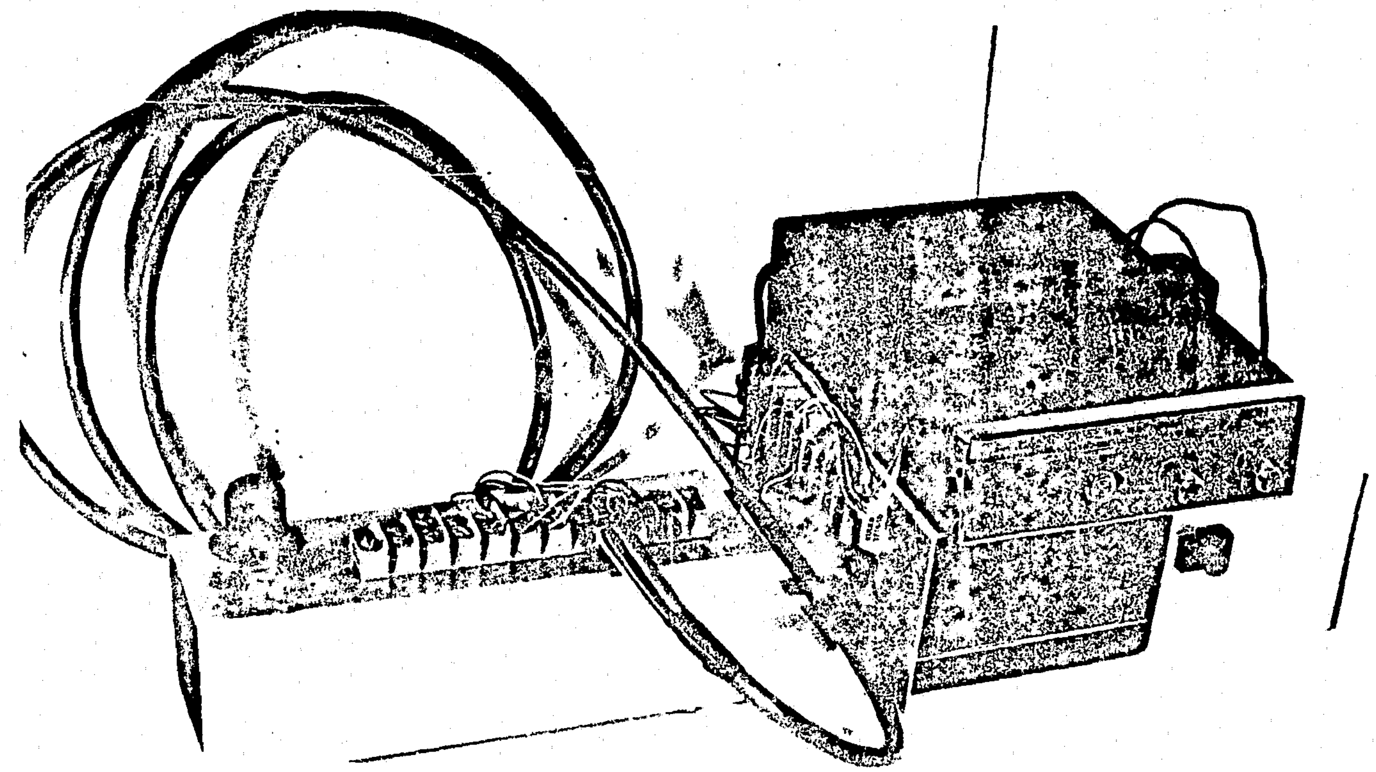


Figure 19 Photograph of Patrol Vehicle Electronics Package

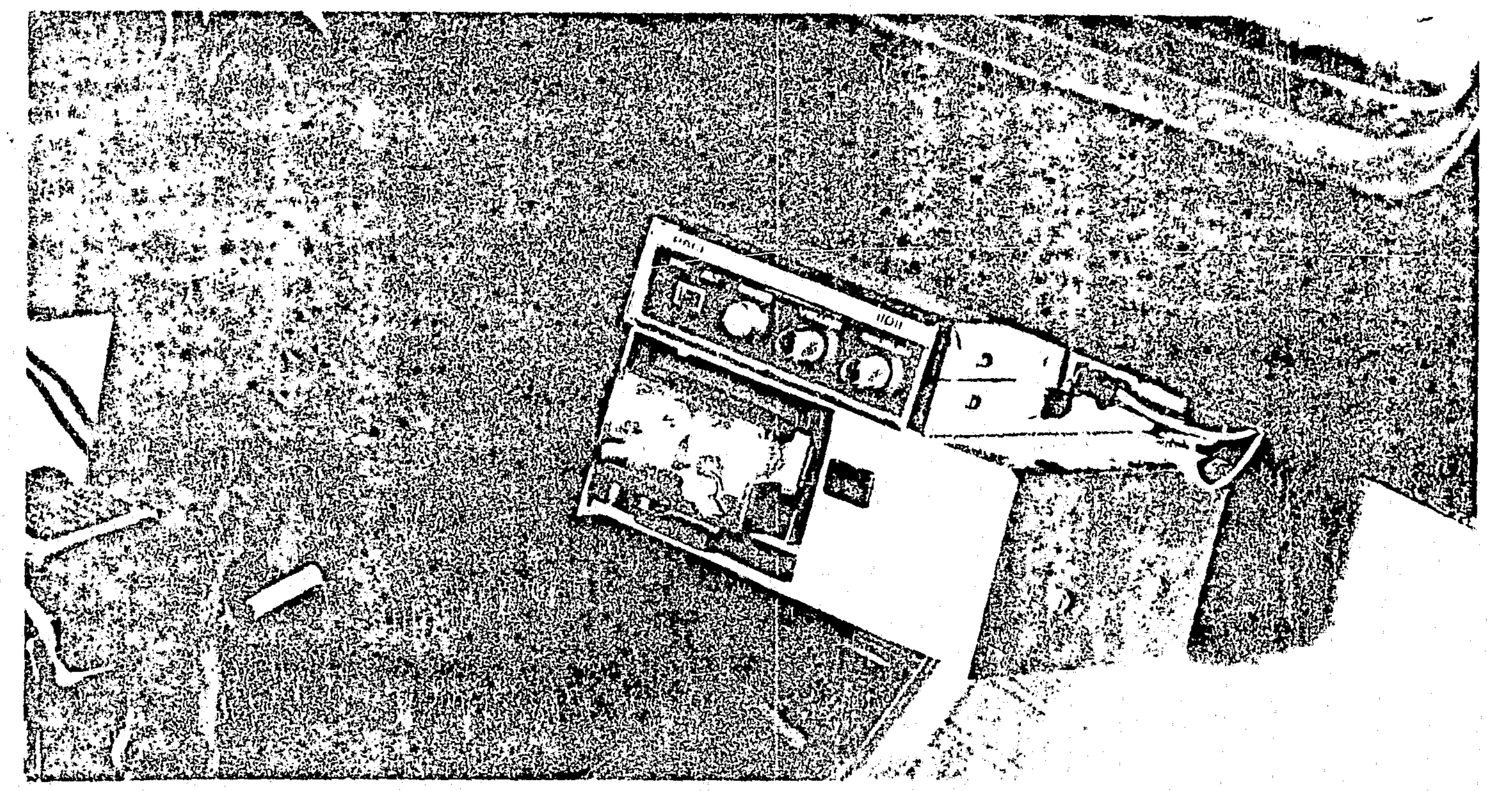


Figure 20 Photograph of Vehicle Electronics Package Installed In Patrol Car

COMMAND/CONTROL CENTER ELECTRONICS

The Visual Display System (VDS) at the Command/Control Center is comprised of five major subsystems which convert the analog location and vehicle identification signals into a binary format for storage and processing. The information is then reconstituted as analog signals which operate the visual display.

The electronics equipment in the Visual Display System at the Command/Control Center must recover the intelligence from the mixed location and vehicle identification codes and present this an information on a visual display. The two tones, once recovered from the incoming communication lines, are sent a 600 ohm feedline to a set of tone decoders. These decoders are, as were the encoders described earlier, "microfork" oscillator devices. Each encoder has a counterpart decoder which responds to a specific frequency. The output impedence of the decoder drops from a value of infinity to approximately zero when it recognizes its assigned frequency. This converts the information into a form compatible with operation of the VDS.

Figure 21 on the opposite page is a functional block diagram of the VDS showing it consists of 5 major subsystems. Initially the location information is processed through the Encoder which perform 3 functions. It converts the analog input into a 5 bit coded parallel binary signal, codes the intersection signal and routes these into the Memory.

The Memory holds the information until data from the vehicle at that intersection is received. When both intersection code and vehicle identification are present, the intersection code is stored in memory. A separate register is required for each vehicle under observation.

The multiplexer withdraws information from the Memory. This stage is controlled by a clock with a frequency of about 2000 Hz, such that the information in memory is scanned 2000 times per second for each vehicle.

The information, still in 4 bit binary format, then enters the Location Decoders which convert it to a single analog signal on one of 10 separate output lines, keyed to the 10 marked intersections. This signal pulse triggers the proper LED (Light Emitting Diode) at the intersections illuminating them on the Map Display. The LED read out at each intersection has the capability of displaying any 3 digit vehicle identification number which may enter that intersection.

The LED units are located such that the operator can identify the intersections by a quick visual inspection. An external circuit has also been provided to permit controlled flashing in lieu of steady illumination to indicate the vehicle is an assignment status. Although this is presently a separate manual input, it can be easily tied into the existing assignment card holder matrix. This circuit opens when the card is inserted indicating an assignment which would be translated into a flashing type illumination.

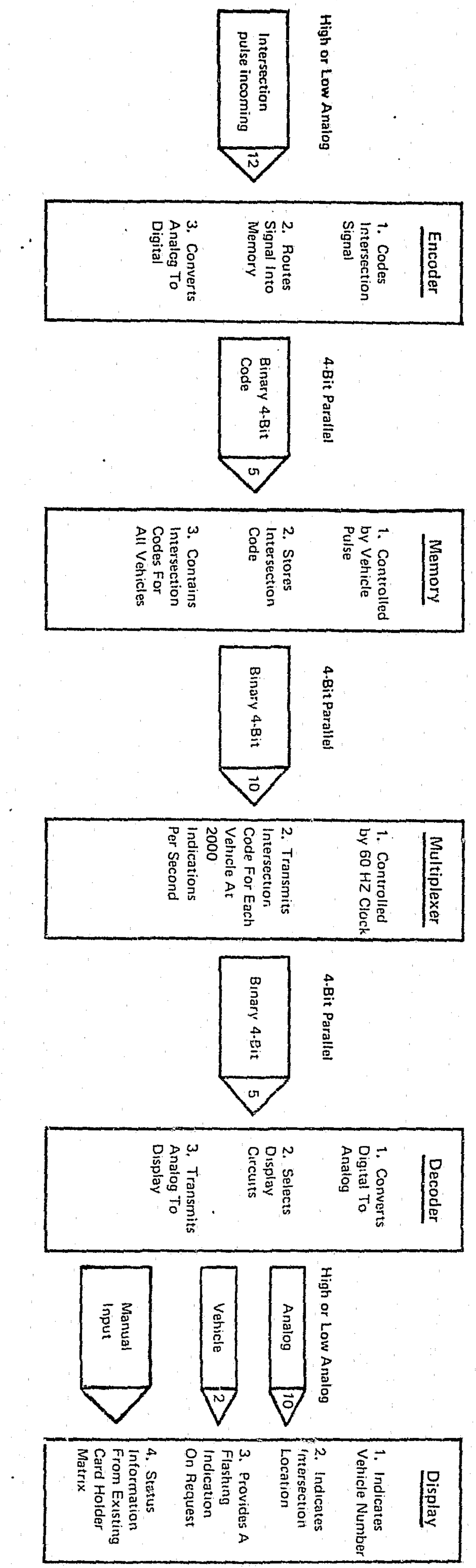


Figure 21 FUNCTIONAL BLOCK DIAGRAM OF VISUAL DISPLAY SYSTEM SHOWING 5 MAJOR SUBSYSTEMS AND SIGNAL INTERFACED.

PERFORMANCE REQUIREMENTS OF VISUAL DISPLAY

Some of the more important performance requirements for the Display System are concerned with the human factors of the visual presentation since the information must be transferred quickly and accurately to the Command/Control Center personnel.

The Visual Display is a key part of the total Automatic Vehicle Locator System since it transforms the electronic intelligence from the field into a visible presentation which can be comprehended and acted upon by the Command/Control Center personnel.

To successfully design the presentation, the environment in which the Display System will function was first defined. In addition to the physical facilities of the Command/Control Center, the environment was also recognized as including the dispatch process.

When a call is received at the complaint desk, the Complaint Officer completes a card with necessary information which is then transported by a conveyor system to the Radio Operators. There are presently two Operators; one handles the East side of the City and the other, the West. The Operators are seated side by side at the radio communications console separated by a card holder at the termination of the belt conveyor. Immediately above the radio console is a 4' x 6' map of the City which displays the status of all patrol vehicles. This is presently up-dated manually to note the status of all patrol vehicles by insertion or withdrawal of cards from the holder.

In order to facilitate the ease of assigning units when complaints are received, the display system must be a presentation which is readily available to both Radio Operators. It must be updated frequently and automatically. The readout must also be legible from the operator position with minimum possibility for error.

The prototype visual display (5' x 7') will be larger than the existing map. Districts 35 and 36 were chosen for instrumentation for the purpose of this study after consultation with Uniformed Bureau personnel since they encompass a large area with diverse activities. Ten intersections, considered to be of primary importance, were chosen initially to test the system. Two cars were equipped so that the distinguishing capability of the system could be tested. Both cars will pass the same intersection at different times. Although limited to two districts at this time the design of the display is such that it can be readily expandable to incorporate all districts if desired in the future.

Figure 22 on the opposite page illustrates the method of readout which is required to identify the patrol vehicle with the intersection. The display utilizes a mylar map of the City with all major physical characteristics and intersections shown and modified to accommodate lights to identify the vehicle. The map was sandhiched between glass and backlighted for easy reading.

A design consideration was the illumination level of the Display. The lighting should be bright enough to be easily read by the Operator, but dim enough to minimize glare. Since it is possible that many different Operators will be utilizing the display the light intensity is adjustable.

Each major intersection was denoted on the map by a three digit readout which tells which vehicle is in the intersection. These characters must be large enough for the Operator to read easily. The Radio Operator is approximately two to three feet from the Display. In addition to showing the location of a vehicle the Display must also inform the operator of the vehicle status--assigned or available. This will be done with a flashing display at the intersection if the vehicle is assigned and a steady signal otherwise.

The Display is also able to process new information every second. This is the minimum time interval required for transmission of new data to the System. The Display holds information about a specific intersection until the intersection is occupied by another vehicle or the initially displayed vehicle moves to another instrumented intersection.

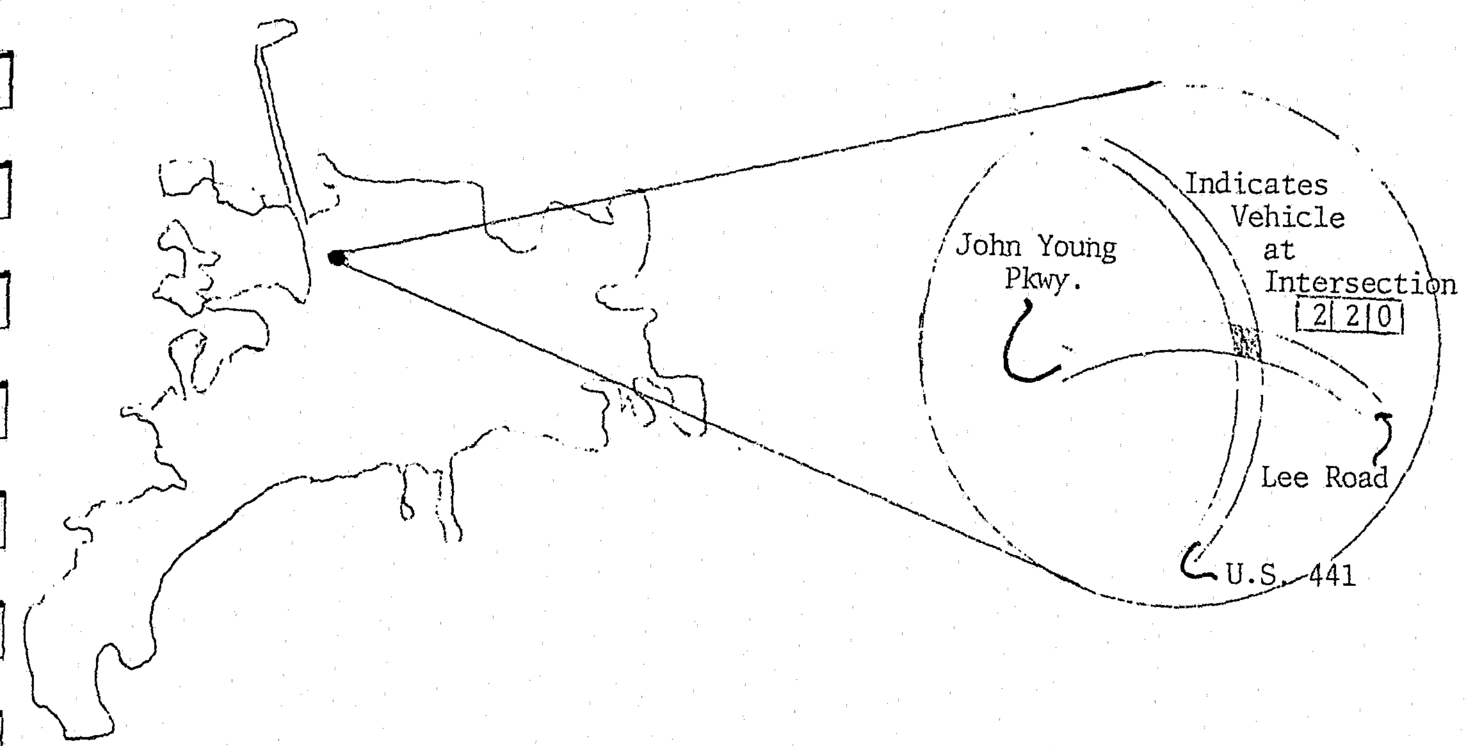


Figure 22 Typical Display Of Major Intersection Shows How Information Would Be Presented To Identify Patrol Vehicle And Its Location.

VISUAL DISPLAY SYSTEM DESIGN

A multiplexing digital circuit design using LED elements to identify the patrol vehicles was used because it offers the best choice for positive display, is relatively low cost, and can be easily expanded to accommodate growth in the future.

Input to the Visual Display System (VDS) consits of twelve data lines, ten of which carry location data and two of which carry vehicle identification data. These lines are connected directly to the output of the decoder unit so that, when a dual tone is received by the decoder, two of the input lines to the VDS (one for the car and one for the intersection) are brought to a zero level. This constitutes a loading of digital information into the VDS. The process by which this information is converted into an actual visual display is shown by the block diagram in Figure 23 .

The first stage of the display unit circuitry, the BCD encoder, transforms the data on the location lines into binary form, which is more easily handled by the digital circuitry that makes up the VDS. This is done by means of a diode encoding matrix, the output of which is a four-bit positive logic binary code. This information is then transferred simultaneously to vehicle location memories A and B, the A and B designating which vehicle is at the received location. The information on the vehicle identification lines determines which memory unit, A or B, will receive the information. For example, if the level of line A has dropped to zero, the information will be stored in memory A and if the level of line B has dropped to zero, the information will be stored in memory B.

The outputs of the location memories are fed to the inputs of a multiplexing stage. This stage is a clock driven integrated circuit which, depending on whether the level of the clock signal input to it is low or high, will output the information from memory A or memory B respectively. The clock that drives this stage has a continuous square wave output. That is, its output waveform is a sequence of consecutive high and low levels, each of the same time duration, providing a constant frequency of oscillation for the waveform of several thousand cycles per second. This means that the multiplexer will alternately output the information stored in memory A and memory B several thousand times in one second. This information, still in four-bit binary form, then enters the location decoder which converts it back to a single signal on one of ten separate output lines representing the ten different intersections. These lines are connected directly to the cathodes of the ten three digit seven-segment light emitting diode readouts that visually display the identification numbers of the patrol vehicles on the map.

The readouts are placed at the monitored intersections on the map so that when a location memory unit indicates that a vehicle is at a given location in the City its identification number will actually be displayed on the map at that location. Each time a vehicle enters a different

monitored intersection the information stored in its memeory section of the VDS circuitry will be updated and the information corresponding to its previous location will be erased. It is also of interest to note that information stored in a location memory will be displayed until it is erased. This means that during the time a vehicle travels between two intersections the map will continue to display its identification number at the last intersection it passed through until it arrives at another monitored intersection. By this means a fairly continuous display of the vehicle location as it travels within the City is achieved.

One of the main advantages to this design is its flexibility, in that intersections or vehicles can be added without redesigning. The only changes would involve increasing the number of registers and the size of the multiplexer. This would allow the system to be expanded at a rate consistant to the availability of funds, without large variations in cost due to redesign.

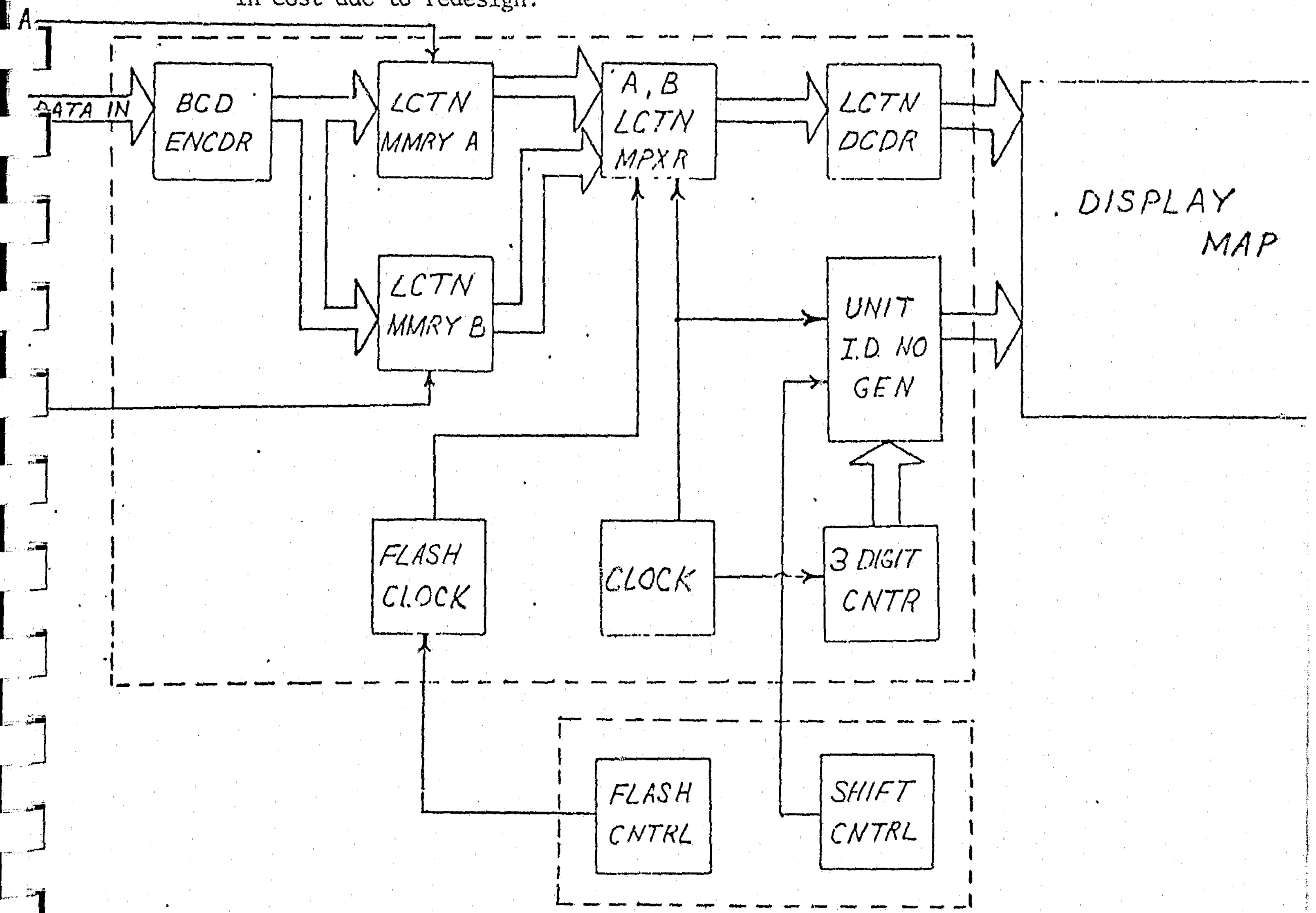


Figure 23 Visual Display System Block Diagram

VEHICLE IDENTIFICATION NUMBER GENERATOR DESIGN

The vehicle identification number generator operates in a binary mode to activate LED units and uses the clock signal as a method of synchronizing the generator of vehicle numbers at the respective locations.

The Orlando Police Department uses three digit numbers to identify their patrol vehicles. The first digit identifies the working shift; the day being divided into three shifts, the first digit will be either a one, a two, or a three. The final two digits indicate the district to which the vehicle is assigned. In this particular case districts 35 and 36 are being monitored and two vehicles are involved. Therefore, the vehicle identification numbers will be either 135 and 136, 235 and 236, or 335 and 336. These numbers are produced within the map circuitry by the unit identification number generator.

This section of the VDS consists of three seven-segment LED readout drivers, one for each digit of the car identification number. These devices convert four-bit binary codes at their inputs to seven-bit codes at their outputs. When these seven-bit codes are applied to seven-segment LED readouts, arabic numerals corresponding to the input binary codes are formed. Therefore, if each digit of a patrol vehicle identification number is converted to a four-bit binary code and these codes are applied to the unit identification number generator's inputs, the result will be a numeric display of the vehicle number at a selected location on the map. It should be noted here that although the outputs of the unit identification generator are fed simultaneously to all the readouts on the map the digits will only appear at intersections that also have a signal applied by the location decoder. And the location decoder only generates one intersection location at a time.

From Figure 24 it can be seen that the clock signal is also fed to the unit identification generator. This provides the method of synchronizing the generation of the vehicle numbers with their locations. That is, when the location decoder applies a signal to one of the intersection locations the identification generator must be caused to generate the correct set of digits identifying the vehicle at that location. The clock output waveform merely synchronizes the location multiplexer and unit identification generator so that when the multiplexer outputs the information from locations memory A the identification generator outputs the seven-segment code identifying vehicle A, and likewise for memory B and vehicle B.

Due to the fact that the three digit LED readouts contain only one set of input data lines to be shared by all three digits, it is not possible to display all three digits of any vehicle number simultaneously. To avoid this a three digit control device has been added to the circuitry. This device, also synchronized with the clock, has three separate output lines, of which only one at a time may provide an output pulse.

That is, the first, second and third output lines will consecutively carry pulses but no pulses will occur simultaneously on more than one line. The time duration of these pulses is twice that of a clock pulse and they are used to consecutively enable the three seven-segment LED drivers. The result of this is that the first digit of vehicle A will be displayed, followed by the first digit of vehicle B, followed by the second digit of vehicle A, and so on. It should be noted here that since the whole process occurs several thousand times in one second anyone viewing the map will get the impression that the six digits constituting the two numbers are being displayed simultaneously.

The only controls external to the display unit circuitry are those controlling the flasher circuitry and shift numerals. The flasher controls are two toggle switches that provide a means of coupling a pulse train of approximately one pulse per second to the location multiplexer. This signal is used to flash the number of either vehicle A or vehicle B or both A and B to indicate whether one or both units are on call. The shift control is a three position lever switch which causes the first digit of the identification generator to be either a one, a two, or a three, indicating during which shift the car is operating.

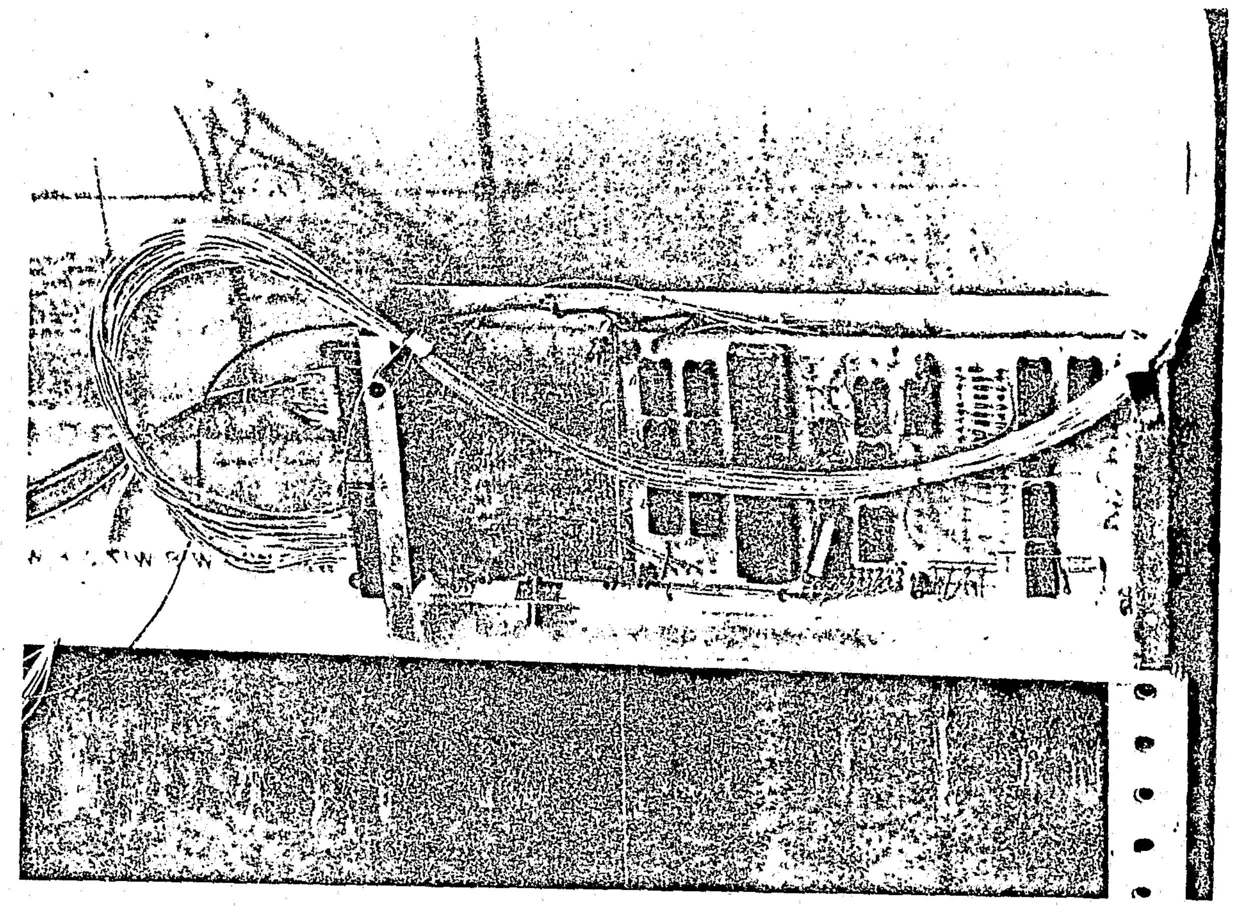


Figure 24 Photograph of Memory, Multiplexer and Identification Number Generator Circuitry Of The Visual Display System

SECTION IX

SYSTEM DESIGNS SUBMITTED FOR

ORLANDO POLICE DEPARTMENT

- o Applied Technology Locates System
  - o System Operational Description - Field Equipment
  - o System Operational Description - Command/Control Center Equipment
  - o System Performance Characteristics
- o Sierra Research Corporation System
  - o Sierra AVL System Operational Features
  - o Vehicle Equipment
  - o Sensor and Calibration Stations
  - o Computer System
  - o System Performance Characteristics
- o Boeing Company Flair System
  - o System Operational Description - Vehicle Equipment
  - o System Operational Description - Command/Control Center Equipment
  - o Command/Control Center Equipment
  - o System Performance Characteristics
  - o System Support Requirements

Based on interest and capabilities indicated on the survey questionaire, three firms associated with the systems judged most feasible for OPD were selected for in-depth discussions. This was effected by the Principal Investigator visiting their plants, viewing the equipment in operation, and specifically reviewing the OPD requirements with their engineers. All them furnished information on conceptual designs for OPD.

LOCATES was developed by Applied Technology of Costa Mesa, California, using the Proximity Technique. An operational system has been installed for the Montclair, California, Police Department under a grant funded by the California Governor's Council on Criminal Justice. This system has been operational for over a year and provides automatic location of police vehicles on a map grid and display at the communications center. It also includes keyboard for 10 code digital communication between the patrol vehicle and the dispatcher, and the capability for the officer while away from his vehicle to unobtrusively transmit an emergency alert message. The display is a large backlighted street map of the city on which the vehicle locations are shown by lights at the intersections. The display also maintains status information on all vehicles and command officers on a side panel.

Sierra Research Corporation of Buffalo, New York, developed and demonstrated an Automatic Vehicle Locator System under contract DOT-WT-10024 from the Department of Transportation. The demonstration was conducted in Philadelphia, Pennsylvania, and results documented in Final Report TR-0932, February, 1973. In addition to the basic location function, the Sierra System also has the capability to transmit 8 standard 10 code messages in digital format. This includes an unobtrusive transmission of an "officer-needs-help" signal.

The system utilizes the phase difference of vehicle-transmitted UHF signals to determine distances of the vehicle from a number of sensor stations. In the case of OPD the existing satellite receiver sites could be used. The display utilizes a cathode ray tube on which the vehicle location is shown on a grid map. An incident location can be entered by the dispatcher using an electronic press-board equipped with map overlay such that the computer will search out and display the nearest available vehicles.

Over the past two years, the Boeing Company in cooperation with the Wichita, Kansas, Police Department has developed a prototype police vehicle locator system known as FLAIR. FLAIR is based on the dead reckoning technique and updates the location of each vehicle every 2 seconds. This information is displayed on a video map and the dynamics of the display are such that the dispatcher can estimate the vehicle travel rate and observe when they stop. Each dispatcher can individually select a portion of the city for detailed observation and "zoom-in" to read street names. To locate vehicles closest to an incident the dispatcher uses a cursor which automatically causes the eight nearest vehicles to be displayed on the map. The system also has the capability of digital transmission of up to 99 different "10 code" messages and an emergency "officer-needs-help" call.

The system utilizes the vehicle odometer and a solid state magnetic compass to obtain distance and heading information. The design rationale combines inexpensive on-board components augmented by a computer at the Command/Control Center to provide corrective feedback to enhance the field data and increase the inherent "drift" of a dead reckoning system.

APPLIED TECHNOLOGY LOCATES SYSTEM

LOCATES is an Automatic Vehicle Locator system which was developed by Applied Technology using the Proximity-Sensor technique. An operational system has been installed by the Montclair California Police Department for evaluation under a grant funded by the California Governor's Council on Criminal Justice.

The Applied Technology Division of Product of Information Systems, Costa Mesa, California, has developed an operational Proximity System, LOCATES, for the City of Montclair, California. This was accomplished as part of a study project funded by the California Council on Criminal Justice under Grant Number 192 and final report on the Phase I effort was issued in March, 1972. The demonstration LOCATES system provides automatic location of police vehicles on a map grid display at the Command/Control Center using an active signpost sensor, and also includes capability of digital communications between officer in the patrol vehicle and the dispatcher. In addition an integral part of the system is the capability for the officer while away from his vehicle to unobtrusively transmit an emergency alert message to the dispatcher. The scenario shown in Figure 25 illustrates the LOCATES approcah to police requirements for an Automatic Vehicle Location and status Reporting System.

As shown in Figure 25 , police units are automatically located by the use of Wayside Emitters Which are strategically placed throughout a prescribed geographic area.. These Wayside Emitters transmit, via a specified radio frequency, digitally coded location identification data to police vehicles as they pass within proximity of the Wayside Emitters. Each police unit, in turn, transmits this location data and its identification to the police Command Center (Headquarters). At the Command/Control Center, the location of each vehicle in the System is automatically displayed to the dispatcher, Display techniques for Vehicle Location include large wall-type map displays, as well as console displays for use by individual police personnel.

Status messages are digitally transmitted via a radio frequency communications link to and from the patrol vehicles by means of convenient small size keyboards. These keyboards are located in the patrol vehicles and the Command/Control Center for use by the police personnel. Incorporated with these keyboards are display panels to enumerate messages received by the patrol vehicles and by the Dispatcher at the Center.

In addition to vehicle location and status reporting capabilities the LOCATES System provides for emergency signalling by a Police Officer while away from his patrol vehicle. A miniature belt unit enables the officer to transmit a signal to the police vehicle, which re-transmits the message to the Command/Control Center. At the Center annunciators (light and buzzers) alert the Dispatcher that a particular Officer needs assistance.

Applied Technology is now working with the Montclair Police Department on Phase II of the study which has been funded by the Governor's Council. This effort involves installation of a fully operational LOCATES System for the Montclair and Chino areas. To date, the System has been installed and is being evaluated for its operational and maintenance effectiveness. The final report is scheduled for submittal, September 1973

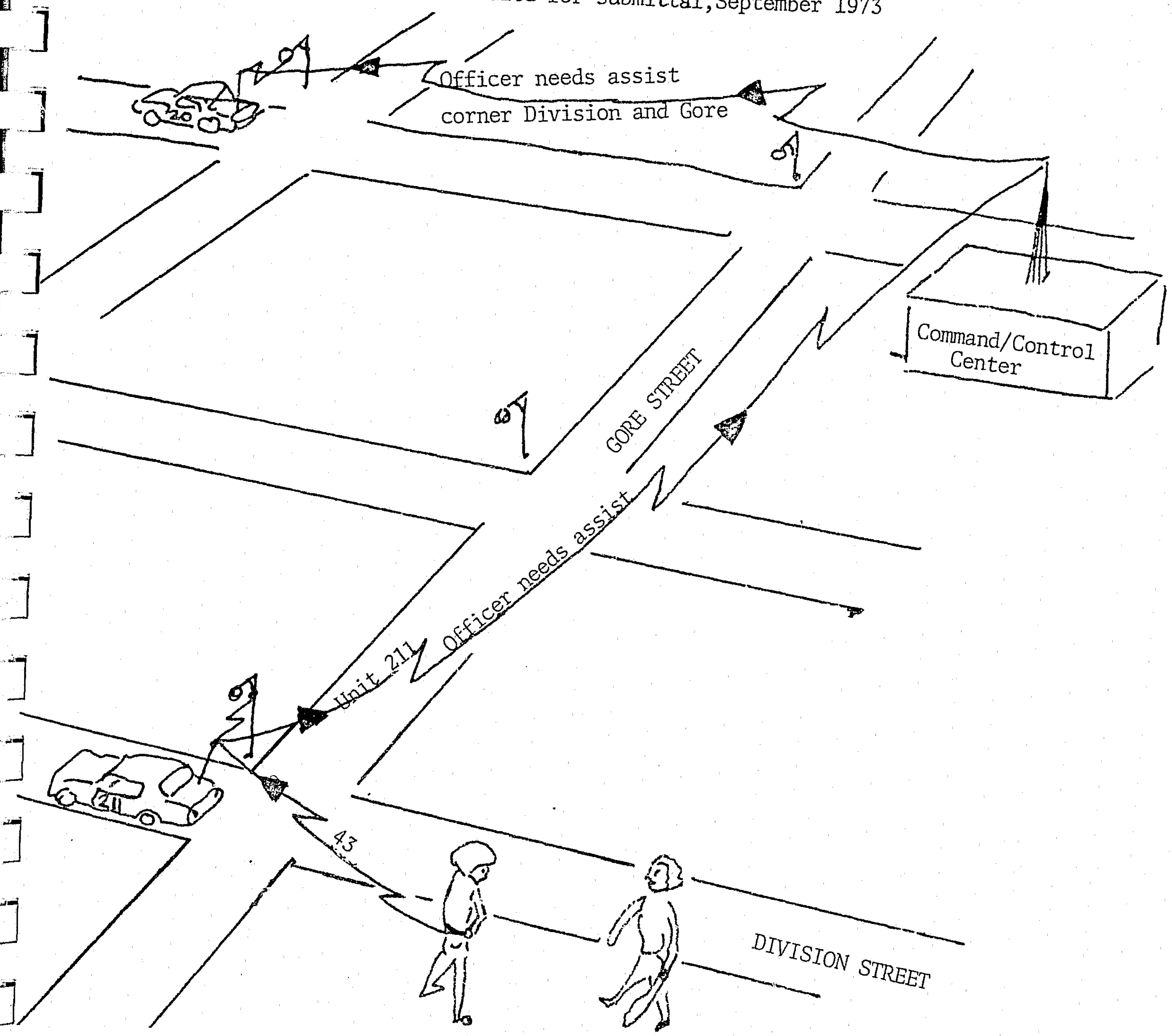


Figure 25 LOCATES Proximity System Operational Scenario

SYSTEM OPERATIONAL DESCRIPTION-FIELD EQUIPMENT

The LOCATES Field Equipment is designed to utilize the existing mobile radio communication system in the patrol vehicle, and includes not only the location function but also 10 code digital message receipt and transmission and an emergency "officer-needs-help" signed capability.

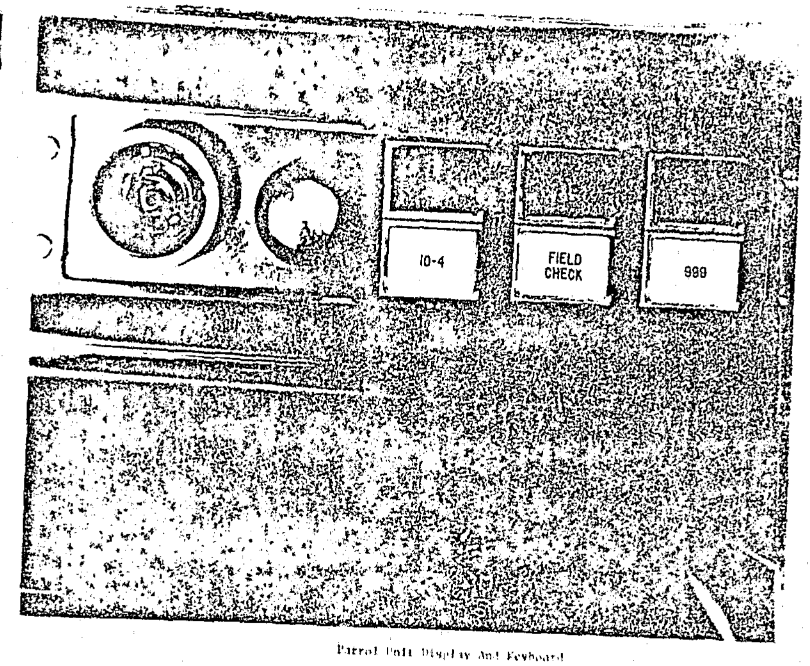
Operationally the field equipment can be classified into three major functional areas-vehicle location, 10 code digital communication, and emergency signal communication. The location function consists of the wayside emitters and the vehicle electronics which receive and transmit the location data via radio link to the Command/Control Center. Each wayside emitter contains a repetitive code generator, modulator, and low powered VHF transmitter. The emitter code is set to identify a discrete signpost in the city. Figure 26 on the opposite page is a picture of a typical wayside emitter used in system at Montclair California. The electronics consist of solid state components housed in a weather proof, tamper resistant enclosure, 8" x 6" x 3". These units were battery powered for ease of installation and relocation during the development phase of the program but can be readily converted to AC power for a permanent installation. The units in Montclair are located on traffic signal structures at a height which makes it difficult for the average person to reach from the ground. It is significant to note that during the initial 18 months of system operation, not a single act of vandalism against the emitters was noted.

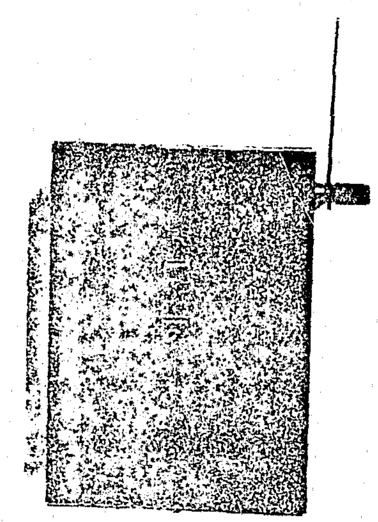
Each patrol vehicle in the system is equipped with an electronics unit which contains a receiver, decoder, position, vehicle identification and status register and FSK tone modulator. The electronics package is approximately 7" x 8" x 11", and is configured for rapid and easy replacement down to the circuit board level. This gear is coupled into the normal communication radio system in the vehicle. As described earlier each emitter signal is coded to identify its physical location. This signal is received, again tone coded to identify the vehicle, and transmitted via the radio link to the Command/Control Center.

The vehicle electronics also include a display and keyboard mounted between the front seats for transmission and receipt of 10 code digital messages. The display used in the demonstration at Montclair contained three message codes as shown in the photograph in Figure 27 . It measures approximately 3" x 9".

Also included in the field equipment is a Personnel Remote Transmitter which can be used to let headquarters know he needs help. Since headquarters also knows his vehicle location it permits the dispatcher to send the nearest field units to his aid. This unit is about the size of a cigarette package and is carried in a case mounted on the police officer's belt. The transmit button is located on the underside of the case to guard against accidental activation but still permits the officer

to signal without making an overt move in event that he is surrounded and cannot reach his vehicle. A photograph of the unit mounted on a typical belt is shown in Figure 28 . The transmitter is a low power, short range unit designed to operate the patrol vehicle transceiver. Test during the evaluation program in Montclair showed that the signal range was almost two city blocks under ideal conditions. When the officer was behind a parked truck or inside a building, however, the range was about 50 feet.





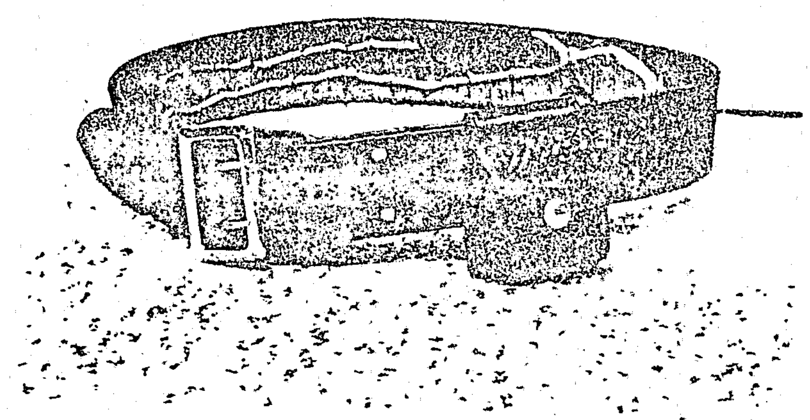


Figure 27 : Patrol Unit Display and Keyboard

Figure 26 : LOCATES Wayside Emitter

Figure 28 : Belt Unit Transmitter

SYSTEM OPERATIONAL DESCRIPTION-COMMAND/CONTROL CENTER EQUIPMENT

The Command/Control Center equipment is designed to work through the base station communication set to receive the location data which it then automatically displays by lights on a large map overlay of the city; it also includes capability of digital communications and display of field force status.

In the LOCATES System the tone coded signals transmitted by the patrol vehicle mobile radio and received via the conventional base station communications unit. The location information is then extracted and processed by an electronics package which is designed to interface with the base station equipment. This unit consists of an FSK (Frequency Shift Key) demodulator, display logic and display electronics. In a PREP communications system, such as Orlando has installed, the audio signals would be obtained from the output of the comparator unit which receives and determines which satellite receiver should be used based on strength of signal.

As described earlier each signpost transmitter unit is assigned a distinct tone location code. This signal is received by the patrol vehicle mobile communications unit where a new tone code is added by the locator electronic equipment in the vehicle to identify the particular vehicle. The resulting two tone identification code is modulated by the FSK unit and then transmitted to the Command/Control Center.

The locator electronics at the Center subject the signals to FSK gating circuits. These identify the signals and activate a light corresponding to the signpost location on the map and the identification number of the patrol vehicle. These lights remain activated until the patrol vehicle passes another signpost transmitter station. This causes the holding circuit to drop-out and release the lights while at the same time the new location/identification lights are activated.

Figure 29 on the opposite page is a photograph of the Command/Control Center display used in the Montclair LOCATES Phase I demonstration system. The Display consists of a backlighted map which is opaque except for the streets and geographic landmarks. The signpost lights are located at the assigned intersections together with the vehicle identification number. In addition the lights are wired to blink slowly if the vehicle is on assignment and rapidly if on a hot pursuit.

The left side of the display contains display lights indicating the status of all vehicles in the department. The status of each unit on field check is automatically updated and displayed as messages are digitally transmitted to the Command/Control Center from the patrol vehicles. The display unit is also equipped with a digital message keyboard with which the Dispatcher can communicate with the field units.

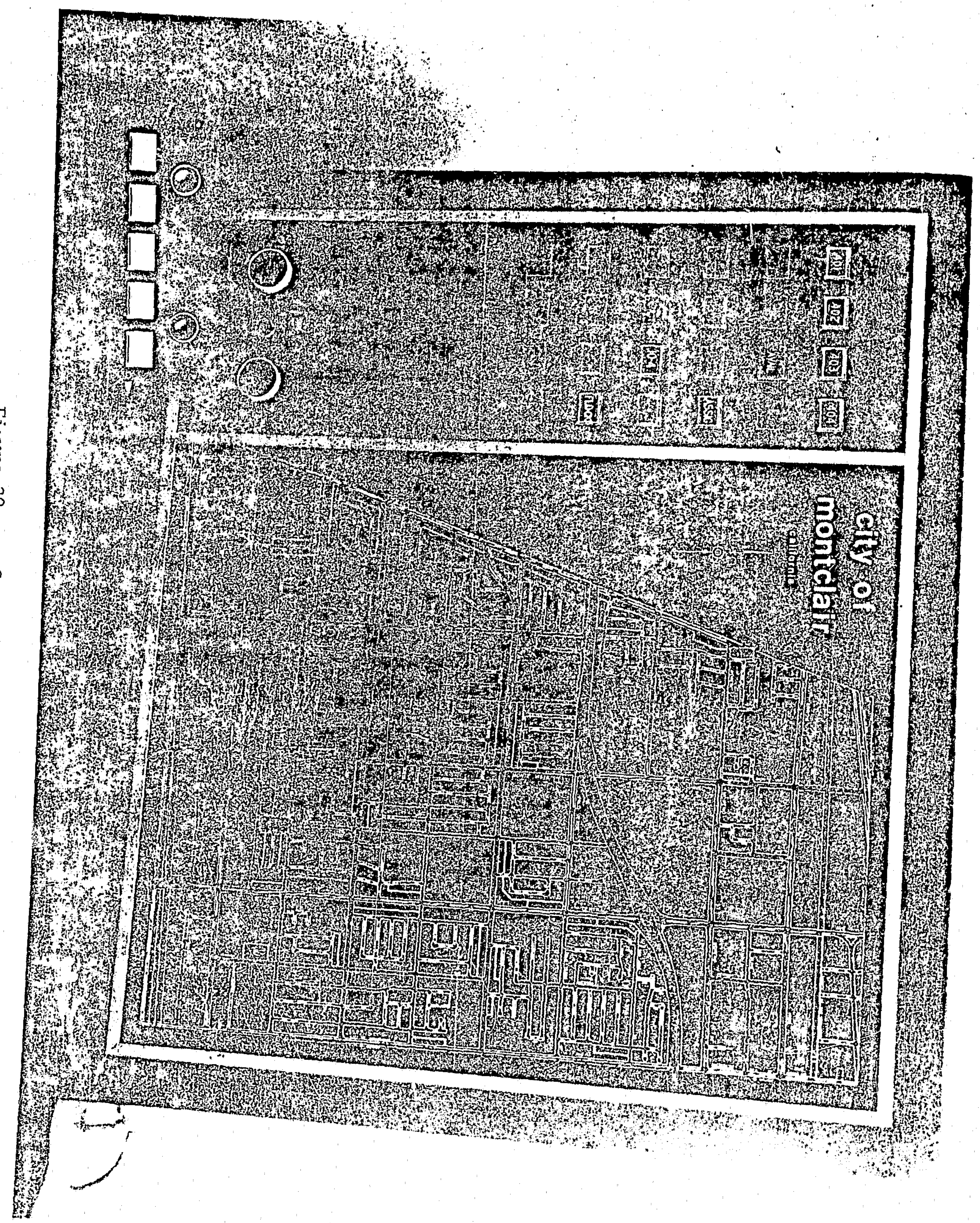


Figure 29: Command Center Display

SYSTEM PERFORMANCE CHARACTERISTICS

Performance characteristics of the LOCATES System are heavily dependent on the density and number of signpost emitters which are used to cover the patrol area; a density of 10 per square mile is recommended based on operating data obtained from the Montclair Police Department system.

The performance of a proximity system is largely a function of the number of signpost emitters and how their data is encoded and transmitted to the Command/Control Center. Accuracy for example is not dependent on the precision of the emitter/sensor circuitry. This contrasts directly with the other systems where accuracy is depended on precision components and design of inherent correction feedback loops. In the LOCATES System inexpensive low-power emitters are used to communicate with the existing mobile radio in the patrol vehicle. The mobile radio then completes the relay link to the Center. The performance cost tradeoff in this type system is between the number of sensors and their installation/maintenance cost.

The LOCATES System typically is designed for a density of about 10 locators per square mile. These are strategically located along the most frequently travelled streets and at "choke" points which the vehicles must pass. In a purely random patrol assignment 10 emitters per square mile may not be adequate to maintain required contact with the patrol vehicle. Additionally some districts are more active than others and greater accuracy and contact would be desirable. Each system must be examined and designed to satisfy the requirements. This concern is reflected in the Performance Summary Table 16 on the opposite page.

Another significant operational characteristic which impacts the performance is the method of transmitting the location data to the Command/Control Center. Utilization of the normal voice channel imposes an additional load which is a direct function of the number of emitter locations. Recoding of the location information in digital format reduces the air time. Hard wire transmission can also be used. This might be feasible in districts which have a high density of call boxes, such as the inner core of Orlando. Also to be considered is the utilization of the Cable TV network which exists in Orlando. The franchise agreement with the City typically provides that the City can use it without charge.

The LOCATES System has been designed for effective maintenance by replacement at the component level. The mininizes the support requirement of Police agencies and permits non-technical personnel to perform routine maintenance. Applied Technology provides modular replacement components and repairs those which have malfunctioned in their shop. Complete operation and maintenance manuals are supplied with the system.

TABLE 16
SYSTEM PERFORMANCE SUMMARY

Vehicle Tracking Technique	Real Time-Proximity
Data Link Requirement	Any licensable mobile base radio channel which will support 20db signal to noise ratio
Data Format	----------------
Area of Coverage	Limited only by communications data link range
System Accuracy	Depends on density of emitter locations
Tracking Mode	Fully automatic up date, triggered by vehicle detecting emitter signal
Number of Vehicles	Unlimited
Computer	Not required
Dispatcher Display	Backlighted area map with streets and salient physical features of the area. Vehicle location shown by L.E.D. numbers at intersections. Includes status of field forces and digital communications in 10 codes.

SIERRA RESEARCH CORPORATION SYSTEM

The Sierra Research AVL System uses the Phase Trilateration location technique and thus offers the advantage of being able to utilize the existing satellite receivers of the Orlando Police Department PREP communications system.

Sierra Research Corporation of Buffalo, New York, has developed and demonstrated a practical Automatic Car Locator System under a contract DOT-WT-10024 from the Urban Mass Transportation Administration of the United States Department of Transportation. The demonstration was conducted in Philadelphia, Pennsylvania, under the supervision of DOT and results were documented in Final Report TR-0932 issued February 1973. The results of this demonstration were that on over 5,000 locations in the dense high rise area, Sierra was able to "track" a vehicle within an RMS accuracy of 650 feet. The location information is presented at the Command/Control Center on a display unit designed to complement the existing dispatch system and enables the dispatcher to determine the closest available vehicle to an incident. In addition to the basic car location function, the Sierra system also has the ability to transmit 8 standard messages in digital format from the vehicle to the Center. This includes unobtrusive transmission of an "officer-needs-help" signal.

The Sierra System Concept is shown in block diagram form in Figure 30 . This configuration is designed for locating 20 to 30 vehicles; however, for simplicity, only one vehicle is shown. The system utilizes the phase (time) difference of arrival of a vehicle-transmitted UHF signals (location time) as received at a number of sensor stations. The location tone, after demodulation at the various satellite sensor stations, is transmitted via dedicated telephone lines to the Command/Control Center. The relative times of arrival of the location tone from the various satellites are compared in a unique manner at the Center with the aid of a computer to determine vehicle location.

The display utilizes a cathode ray tube on which the vehicle location is shown on a grid map. To correlate the vehicle location with the incident the dispatcher uses an electronic "press-board" which has an over lay of an area map. By pinpointing the incident location on the press-board with an electric pen, an expanded scale display is created with the incident at the center. The computer then searches out the nearest available vehicles and displays their positions and vehicle numbers for reference. Available or assigned status of the vehicles is indicated by colored light on the display.

In Figure 30 the blocks representing existing equipment have been shaded to show how the Sierra System has been designed to incorporate and interface with equipment comprising a typical police system. Basically, the AVL system utilizes existing communications equipment without compromising normal voice transmissions. In operation, voice

communications would be handled in the normal manner on duplex frequencies with the minor exception of a sync signal to the vehicle for 1/10 of a second every 3.3 seconds on the dispatcher frequency. All data/location tones from the vehicles plus other housekeeping signals would be transmitted on a single independent frequency.

It is noted that this approach offers a high degree of compatibility with a PREP (Personal Radio Equipped Police) communications system. The PREP system typically uses low power field transceivers and satellite receivers located at strategic elevated sites throughout the city. At the present time the Orlando Police Department PREP system has 9 such satellite receiver stations which have proven signal coverage. By using existing channel frequencies these receiver stations could function as the sensors required by a Trilateration system.

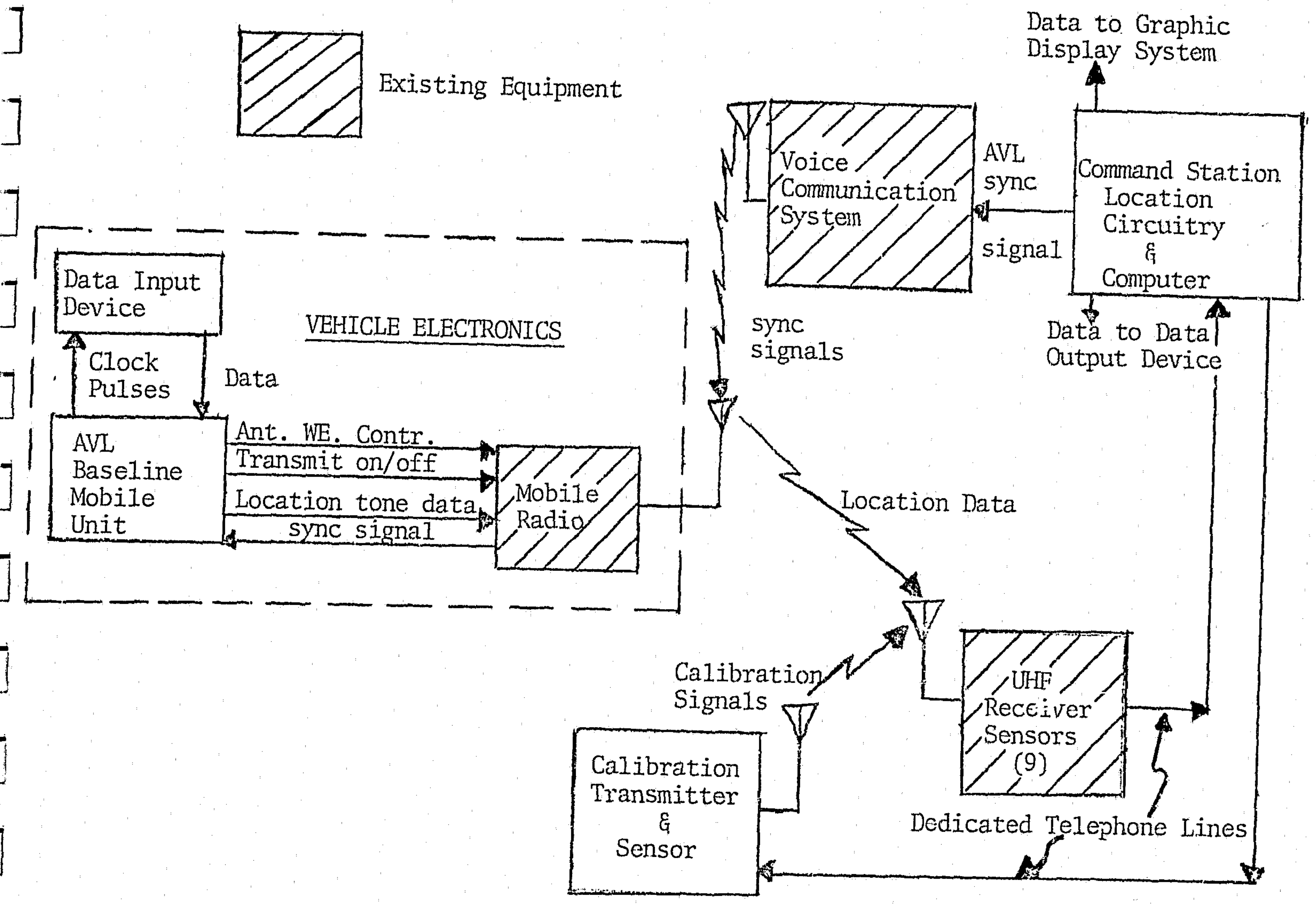


Figure 30 AVL System Block Diagram Shows Compatibility with Existing PREP System

SIERRA AVL SYSTEM OPERATIONAL FEATURES

The basic system philosophy is contained in the baseline system conception where the location data is transmitted by time division multiplexing at a rate of 4000 time "slots" per minute.

To conserve the use of the R-F frequency spectrum, Sierra Research has chosen to use a time division multiplex scheme for their Automatic Vehicle Monitor System. The basic repetition period (an epoch) is one minute long. The epoch is divided into ten equal "cycles". Each cycle, then, is subdivided into 400 equal time "slots". A time slot is 15 milli-seconds long. All AVL vehicle transmissions occur in assigned slots, thereby giving each vehicle an "address" or positive identification. There are 3 ms of dead space and 12 ms used for information transmission. Of the 10 cycles, number 0 and 5 are used as data cycles, and numbers 1,2,3,4,6,7,8,9 as location cycles.

With this configuration, Sierra, for variable route vehicles (as police cars), assigns specific time slots for each vehicle, which provides 8 location slots and 2 data slots per vehicle, which gives an up date time on location once every 7.5 seconds. In a single multiplex channel, 340 vehicles could be accommodated (the other time slots being used for emergency alert condition and status data transmission).

In operation, the location transmission can be accomplished even though the vehicle transmitter is being used in voice communications as the 15 ms duration the transmitter is keyed to the AVL frequency will not noticably disrupt this voice mode of operation. With this system, continuous location information is being transmitted without the need for interrogation transmission required from the base station. However, repetition rate sync information is needed (at least once every 6 minutes) from the master sync clock at the base station to keep the vehicular sync clocks in the right synchronous relationship for correct vehicle identification. To keep this synchronous relationship, a 2-pulse sync signal is transmitted from the base station transmitter which puts the vehicular AVL base line unit "in step" with the master clock of the base station.

With this basic synchronous information transmission set up, continuous location data is sent from every vehicle being monitored to the various sensor stations. The sensor receiver demodulates these signals (translates down to audio frequencies or digital information) and sends them, via designated telephone lines, to the base station where location circuitry "measures" the phase differences for each individual vehicle from signals received at different sensor location. This information, along with sensor station location, is fed to a series of 5 small computers, which through multilateration computation, establishes the location of the vehicle. A block diagram of the complete system is shown in Figure 31 .

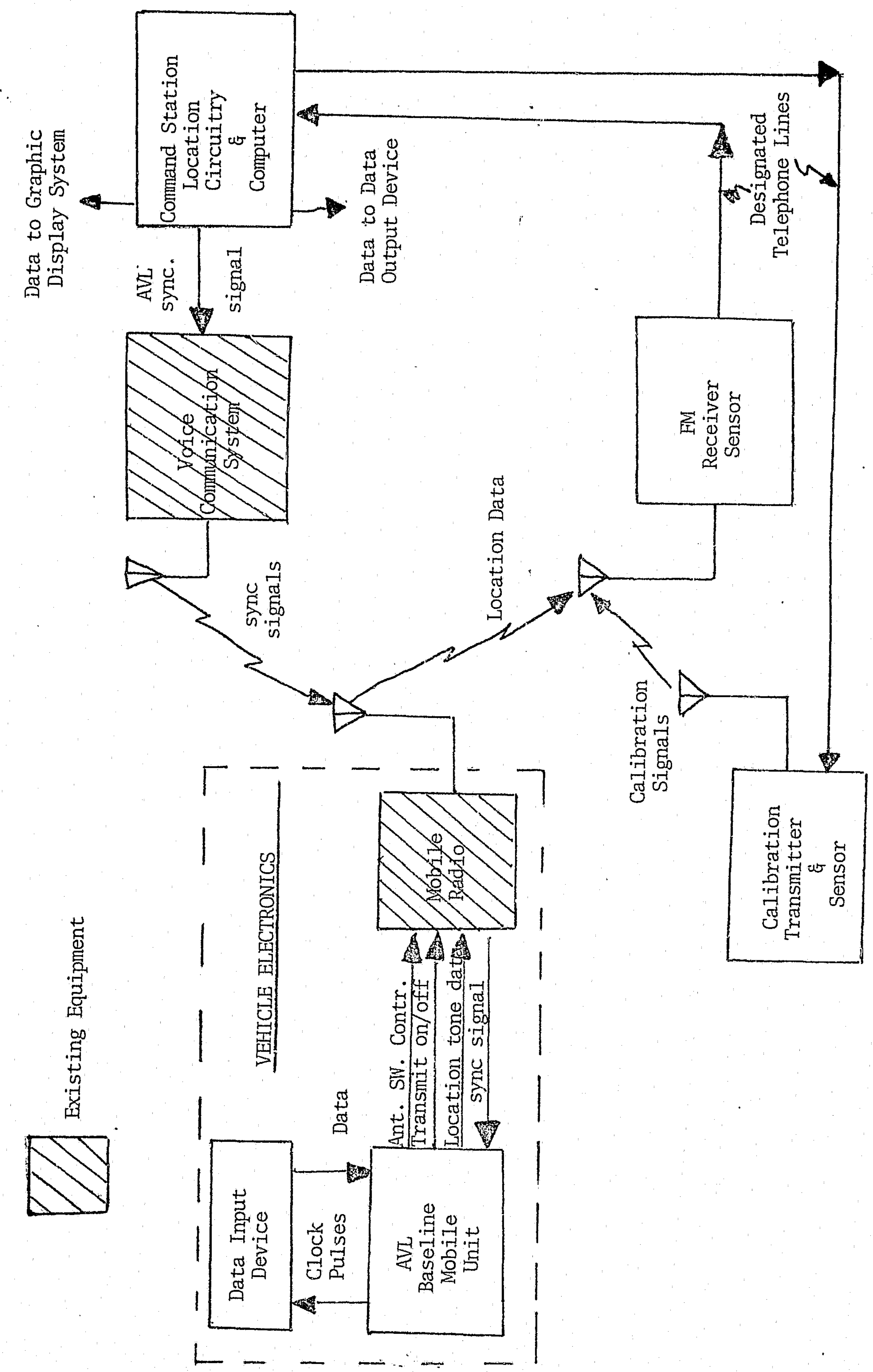


Figure 31 : AVL System Block Diagram.

VEHICLE EQUIPMENT

The vehicle equipment is designed to provide continuous location data via the existing mobile transceiver as long as the receiver is on and the transmitter can be enabled.

In the Sierra System, the vehicle transceiver normally operates in the voice communication mode, but for each occurrence of its assigned time slot, the transmitter is automatically switched from the voice frequency to the Locator System frequency. The transmission of the data/location tone for each vehicle is only 100 milliseconds in duration which causes no degradation of the voice communications.

Each vehicle is assigned a time slot in which to transmit a data/location tone. The time slots are 100 milliseconds in duration and 33 are required for a complete cycle. Of the 33 time slots, one is assigned to calibration, another for synchronization, and one is used as a spare. This leaves 30 time slots for 30 vehicles. Data/location tones from each vehicle are transmitted approximately once every 3-1/3 seconds, or 18 times per minute.

When each vehicle enters the system, the vehicle is in an unsynchronized state. The transceiver in the vehicle monitors the vehicle voice receiver output and detects the "sync" signal through a special filter circuit. Once synchronization is achieved, the vehicle transmits the data/location tone in its assigned slot once every 3-1/3 seconds by modulating the carrier frequency.

The data location tone of 100 milliseconds is divided as follows:

Data Time	Transient Time	Location Tone
20 ms	20 ms	60 ms

During the 20-millisecond data portion of the transmission, information relative to the odometer is given to ascertain the amount of movement since the last transmission (3-1/3 seconds earlier). Also during the data time, one of eight preselected messages is indicated to determine the status of the vehicle. The transient time of 20 milliseconds is used as a buffer between the data and location tone. The location tone is transmitted for 60 milliseconds. This "burst" consists of a carrier modulated by a sine wave location tone to assure that the spectrum is fully compliant with FCC regulations.

A brief discription of the principle signal can be related to the block diagram presented in Figure 32.

Detection of Sync Pulses & Reset of Timing Chain Sequencing: There is a two tone sync signal (267 HZ & 1500 HZ) which when received, sets the vehicle electronics in the proper time division sequence. The first tone

alerts the equipment of a sync signal, the second directs the acquisition control circuitry to reset its timing clock in the proper sequence. Each vehicle has a preprogrammed transmission time slot allowing the location tone to be 'gated' out at its specific identity time.

Location Tone Generator: The tone generator consists of a 384 KHZ crystal controlled oscillator which is accurate to within two parts in 10^6, allowing its time base to drift no more than 120 μ sec per minute. Because of this, the unit requires a sync signal only once every 6 minutes. The 384 KHZ frequency is divided by 128 to obtain the final 3 KHZ location tone which is transmitted.

Operational Signal Level Conditions: Since sync signal detection is possible when the Carrier-to-Noise Ratio (CNR) is greater than 10 dB, the following calculations were made to show that adequate signal levels do exist.

Base Station Power (250 W)	+ 54 dB
Transmitter Antenna gain	+ 10 dB
Transmitter Losses	- 2 dB
Free Space Attenuation (10 miles considered)	- 110 dB
*Excess path loss (due to tall buildings)	- 30 dB
Receiver Antenna Gain	+ 2 dB
Receiver Losses	- 2 dB
Total Carrier Signal Power Received	- 78 dB
Input Noise Power:	
Receiver Noise Power (KTB)	- 132 dB
Receiver Noise Figure	+ 15 dB
Total Noise Generated by Receiver	- 117 dB
Urban Environment Noise (-147 dB/HZ) for 16 KHZ BW	- 105 dB

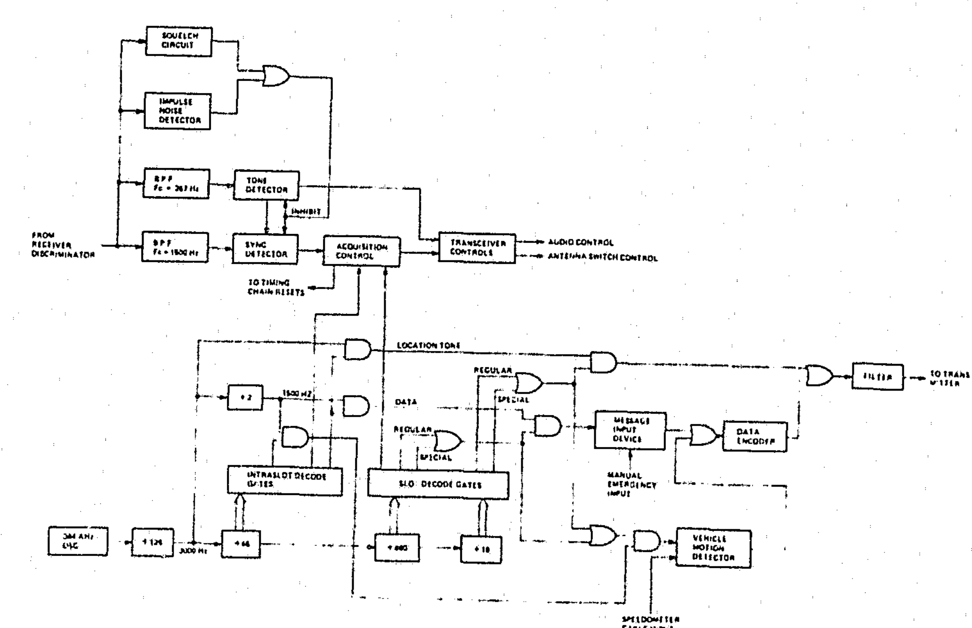


Figure 32: AVM Vehicular Unit Block Diagram

SENSOR AND CALIBRATION STATIONS

The AVL Sensor Stations are equipped with typical PREP system receivers which pick up location signals from the vehicles and convert these into audio signals which are then relayed to the Command/Control Center via dedicated telephone lines.

Sierra has indicated that 9 sensor stations in and around a 25 square mile area would be required to provide adequate coverage in an urban environment. This is based on information from the DOT Philadelphia tests. Of the 9 sites, 7 would perform a sensor function only and the 2 remaining would be Combination Sensor-Calibration stations. The equipment would be the same as used in the Philadelphia demonstration tests.

The sensor stations should be relatively high to provide a maximum unobstructed view of the area. All electronic equipment would be housed in a tamper-proof, weather-proof steel enclosure which has an adjustable thermostatically controlled heater/fan to prevent the temperature from exceeding preset values. Power would be supplied from a regulated power supply.

A block diagram of the Combined Sensor-Calibration Station is presented in Figure 33 . As noted earlier, there is one calibration time slot (1/10 of a second) for every complete cycle (3.3 seconds). With two calibration stations, one toward each end of the area, it is planned to alternate the calibration transmissions from one station during the first cycle (3.3 seconds) and from the other station on the next cycle. This arrangement permits calibration of the sensors at each of the combined stations. The ideal selection of the combined Sensor-Calibration Station would be of sufficient height so all the other sensors will be in line-of-sight to be relatively free from multipath.

In general, the receivers would use onmi-directional antennas, however, those at the outside edge of the system would have antennas with 180° beam widths. The receivers would be similar to those used in the normal PREP system (450-470 MHZ), but include a delayed AGC system to hold the output signal constant when input signals are 80 dBM or greater. A PIN diode attenuator would be used to implement the AGC because of its characteristic fast acting ability and because it does not introduce any phase distortion. To reduce variations of receiver phase delay for signals from different transmitters, an Automatic Frequency Control would be employed.

Based on the average minimum and maximum vehicle to sensor distance of 1.5 to 3.75 miles, the following average signal levels were calculated to exist.

Vehicle to Sensor Station Radio Link

	1.5 miles	3.75 miles
Sensor Station Received Carrier Power		
transmitter output power 20 watts	+ 43.0 dBM	+ 43.0 dBM
Vehicle signal transmit gain	+ 0.2 dBM	+ 0.2 dBM
Mean Propagation path loss	-123.5 dBM	-131.4 dBM
Sensor Station receive gain	+ 5.5 dBM	+ 5.5 dBM
Sensor Station Received Carrier Power	- 74.8 dBM	- 82.7 dBM
CNR-Sensor receiver (with receiver noise = -99.5 dBM)	+ 24.7 dBM	+ 16.8 dBM
SNR-After detection (considering FM improvement factor, + 6.0 dBM; Parabolic Noise factor, + 4.8 dBM; Filter improvement (16 KHZ to 3 KHZ) + 7.3 dBM.)	+ 42.8 dBM	+ 34.9 dBM

The probability of errors due to signal fading or to impulse noise was shown to be very small, on the order of 4×10^{-4} and 5×10^{-4} for a combined probability of error of 9×10^{-4} for the maximum distance considered.

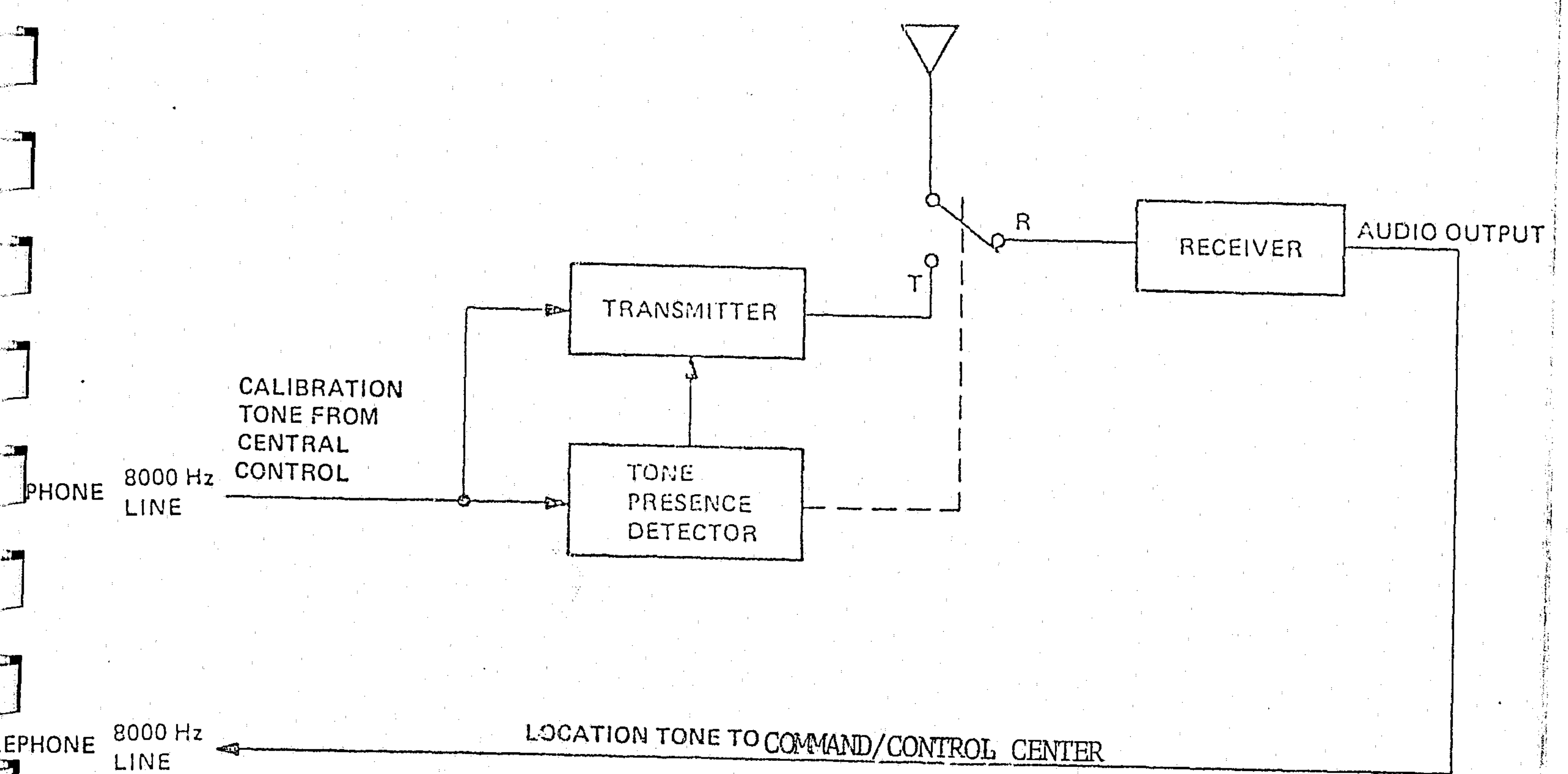


Figure 33 Combined Sensor-Calibration Station

COMPUTER SYSTEM

A series of five small computers are used to precess the incoming signals for location information, verify this information, interface with the display and act as a buffer for messages going to and from the Center and the vehicle.

The Command/Control equipment accepts the incoming data, reduces and corrects this data with the aid of signal processing equipment, and then, through the use of 5 different computers calculates and drives the display units to show the locations of the vehicles. This system of small computers is designed to perform and check a series of multilateration computations.

Incoming data is received on telephone lines. These are fed to the first unit which is a signal processing type used to process the numerous zero crossing data. The 50 MHZ master sync clock is utilized in this unit. The raw cycle arrival times are sent to the next unit which corrects the data with regard to calibrate and phase delay corrections. The data is then sent for final processing in the final data reduction unit which finds the sample mean standard deviation of the corrected data values and rejects those cycles whose value is greater than 3 times the sample mean standard deviation or that is greater than a preset constant which equals about 2000 nanoseconds. This process is described as 'editing the data'.

The five computers can be described functionally.

1. Pre-Location Computer selects the master sensor to be used as the time reference in the linear, location algorithm; it determines the RF weighting coefficients which are used in the algorithm, and determines the time difference of arrival (TDA) data for those sensors which have passed the RF (coherency) criteria and also have a minimum number of cycles remaining after the editing process. This computer is a NOVA 800 type with an 8K memory.

2. Location Computer is a NOVA 800 computer with 12K memory and performs the initial least squares location estimate. This initial estimate is a linearized least squares location.

3. Final Estimate Computer determines the final vehicle location estimate using the non linear algorithm, previous location history, and, if necessary, large error tabular correction methods. It also drives the various displays in the system. This computer has direct access to disk memory, and therefore can be used to prepare forms and summarize system activity for statistical uses. This is a NOVA 800 with 8K memory.

4. Coordinator Computer supervises the interaction of the hardware interfaces and the computers in the system. It drives the various displays and line printer. In the case of system failure, it restarts the system. It also acts as the interface between the several computers and the disk memory unit and it coordinates messages, transfers to and from the base station and the vehicles. The unit is a NOVA 1200 with 12 to 16K memory and a communications adapter.

5. Communications Computer acts as the buffer for messages going to and coming from the base station and the vehicle. It performs the interface between command verbal messages and the digital code used in the communications mode. It alerts systems operators to emergency situations and keeps a running account of the status of the vehicles. It also acts as a channelized demodulator and performs the voting technique used to reduce the probability of errors in the communications mode.

The Center computer to data output and to the display system devices were not well defined. The AVL circuitry of the base station provides the sync signals from its master clock to the voice station transmitter at the rate of twice per minute. This keeps all the vehicle AVL units in time synchronism for exact vehicle identification. A block diagram of the major components of the baseline computer and their interrelationships are summarized in Figure 34 .

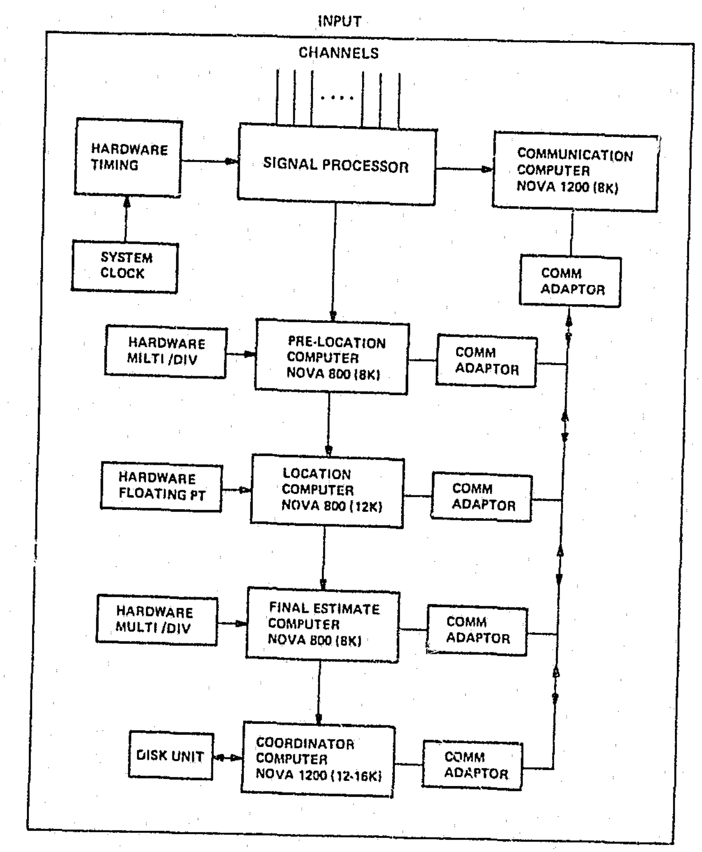


FIGURE 34 Major Components Of Baseline Computer

SYSTEM PERFORMANCE CHARACTERISTICS

Performance characteristics for the Sierra Trilateration System are extrapolations from prototype development data generated during the D.O.T. sponsored AVL tests in Philadelphia, Pennsylvania, and it should be recognized that these tests were conducted in an environment which was considered very demanding for a trilateration system due to the RF propagations problems.

The Sierra Trilateration System was originally designed to the performance requirements stated in RFP-DOT-UT00012. The system was subsequently demonstrated, along with several others in Philadelphia, Pennsylvania under supervison of D.O.T. The performance summary, Table 17 on the opposite page reflects the results of these tests and subsequent efforts by Sierra to modify and improve their system.

One of the most difficult problems inherent in a Phase Trilateration System is associated with RF multipath propagation and signal blockage effects. Due to the nature of the time difference of arrival locations technique, perturbations of the transmitted signal up to the transmitting antenna of the vehicles are cancelled because they are common to all vehicle-sensor links. However, the individual perturbations in the different links are not cancelled and errors can be introduced in the location estimation by error in the measurement of time phase of arrival of the time at each sensor station.

In an urban area multipath propagation can be caused by reflections from buildings, vehicles, airplanes, etc., and diffraction. Direct paths are unusual in an urban environment. Usually there is one dominant path and numerous secondary paths. In some cases the cumulative effect of the secondary paths can essentially cancel out the dominant signal and result in a signal "drop-out" i.e. the received signal level falls below the received system threshold. Signal blockage occurs when the dominant path between transmitter and receiver is obstructed by a large object such as a building or hill. The effect is that the signal level is diminished and in several cases may make communication impossible. Thus signal blockage has the same effect as multipath except that it lasts only as long as the receiver stays in a particular location. These problems make it difficult to assign general performance parameters; each system application should be analyzed. It is noted, however, that the system should be near its peak effectiveness in Orlando because of the flat terrain and minimum grouping of large buildings.

In order to conserve radio spectrum the Sierra System is designed to operate in two standard land mobile radio channels (25 KHz in the 450-512 MHz region) and on a time multiplexer basis, rather than a polled basis, to reduce the number of channels requested. The system uses standard commercial FM land mobile voice transceivers and utilizes a general purpose digital mini-computers for all control and operational functions.

The baseline system is designed to locate up to 680 vehicles on each land mobile radio channel used. This channel is time multiplexed into 4000 time slots met the entire 4000 slot format being repeated once per minute. Thirty-four hundred slots are assigned to specific vehicles. The remainings slots are used for calibration, synchronization and as special assignments to provide a higher sampling rate for vehicles in an emergency or critical situation; a silent alarm function is also provided by these special slots.

TABLE 17
SYSTEM PERFORMANCE SUMMARY

Vehicle Tracking Technique	Real Time-Phase Trilateration Navigation
Data Link Requirements	Any Licensable Mobile/Base Radio Channel Which Will Support 20db Signal to Noise Ratio Narrow Bank (25 KHz)
Data Format	15 Bits- 15 milli-second including 3 millisecond guard bank and .7 millisecond XMTR turn-on time
Area of Coverage	Limited only by Communication Data Link Range
System Accuracy	± 1100 Feet 95% of time
Tracking Mode	Fully Automatic Computer up date every 3 1/3 seconds
Number of Vehicles	680 per channel (Dependent on update time)
Computer	For 1000 car systems 4 Nova type computers 3 with 8K and 1 with 16 K memory, ASR 33 teletype
Dispatcher Display	One console control/display per Dispatcher. Display is TV format with computer generated symbols indicating vehicle status and location. Zoom capability to expand area of interest on screen

BOEING COMPANY FLAIR SYSTEM

FLAIR (Fleet Location and Information Reporting) is an augmented dead reckoning system which uses a computer at the Command/Control Center to periodically correct any cumulative error problems.

Over the past two years, the Boeing Company in cooperation with the Wichita, Kansas, Police Department has developed a prototype police vehicle locator system known as FLAIR (Fleet Location and Information Reporting). FLAIR is based on the dead reckoning location technique and updates the location of each vehicle every 2 seconds. This information is displayed on a video map at each dispatchers control console. It also has the capability of digital transmission of up to 99 different "10 code" messages and an emergency "officer needs help" call.

The system concept is shown in Figure 35 and consists of four basic units. The Vehicle Locator Unit works on the fundamental navigation principle that if the original location of a vehicle is known, its location at any later time can be determined if heading and distance changes are added to the original location. The heading and incremental distance moved for each 2-second period are transmitted from the Vehicle Locator Unit to the Command/Control Center Unit which interfaces with the Computer Unit to update the vehicle location. The Display Unit receives the vehicle location information from the computer and presents it at the proper position, in the form of bright dots on a video map displayed on a TV monitor located in each control console.

The dynamics of the display are such that the dispatcher can estimate the cars travel rate and observe when they stop. Each dispatcher can individually select a portion of the city for detailed observation and "zoom in" to read street names on the video map display. Also, each dispatcher may choose to selectively display a single precategorized group of officers or any combination of the categorized officer groups.

In order to locate the cars closest to an incident, the dispatcher slews the map until the point of interest is under the cursor. The four cars in order of proximity to the cursor are continually displayed on the display and control console, and the location and number of the eight cars closest to the incident are displayed on the video map provided map display of car numbers has been requested by the dispatcher. Again, cars from any combination of categorized groups can be selected for display.

Since the dispatcher can view the continuous movement of the field forces, communication security can be provided by directing a car to an incident by travel route rather than by incident address. The dispatcher can also use this information to direct cars around barriers, such as street construction, and to assist a car in finding an address.

In a similar manner a car in trouble can be located and the nearest available cars dispatched to assist him. Car location is initiated

through Display Unit controls which cause the map location of the car to be positioned under a cursor displayed at the center of the TV monitor. In addition to the car number, the numbers of the three closest cars in order of proximity, are instantaneously displayed. If the dispatcher desires that more than three cars be sent to assist a car (officer) in trouble, the location and number of the eight cars closest to the incident can be displayed on the video map. Map display of car numbers is initiated by the dispatcher depressing a control switch. Cars from any combination of categorized groups can also be selected for display. The dot on the video display which is placed at the location of the car blinks slowly for cars "in service and on call", is steady for cars "in service and not on call", and blinks rapidly for cars relaying an emergency status.

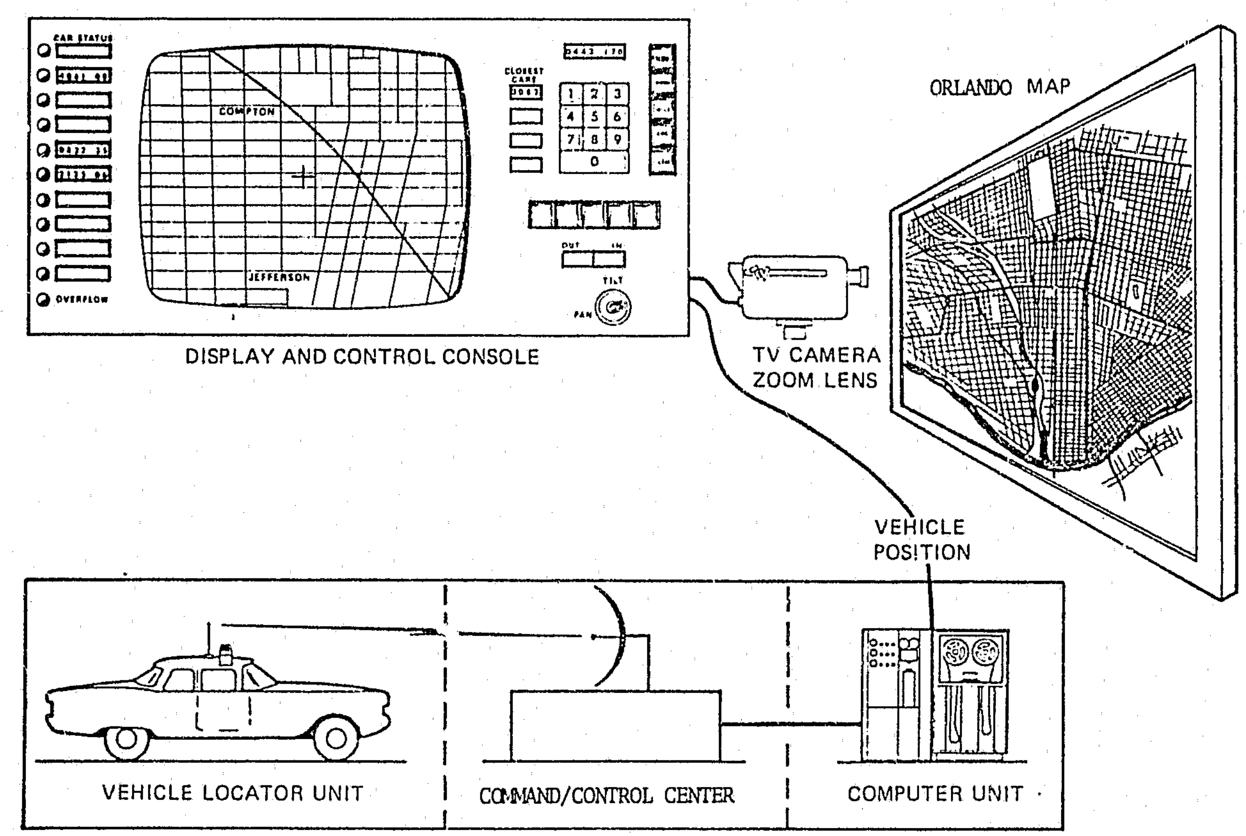


FIGURE 35 FLAIR SYSTEM CONCEPT SHOWS MAJOR FUNCTIONAL COMPONENTS AND THEIR INTERRELATIONSHIP

SYSTEM OPERATIONAL DESCRIPTION--VEHICLE EQUIPMENT

Operationally, the vehicle equipment associated with the location function automatically provides heading, distance and identification data in response to a query from the Center; digital transmission of 10 codes to the Center is also available for operator response.

Operationally the FLAIR system includes those functions performed in the vehicle, at the Command/Control Center and the communication interface between the vehicle and Center. The vehicle equipment consists of a heading sensor, odometer pickoff, data processor, 10 code keyboard and radio transceiver. Location of these components in a typical police car is shown in Figure 36 .

The heading sensor consists of a solid state magnetic compass whose output is resolved to digital data electronically by the data processor. It is approximately 3" x 3" x 1" and can be easily mounted inside the car and out of sight if desired. The solid state construction results in a sensor that has no moving parts, requires little or no maintenance and can be packaged to withstand any expected amount of shock and vibration. The disadvantage is that nearby metallic masses may disturb the local magnetic field by amounts exceeding the earth's field in the horizontal plane. Severe field distortions from fixed objects, however, appear to be limited to areas within 30 feet of the object and are thus amenable to the moving average computational procedures performed by the computer unit at the Command/Control Center.

The odometer pickoff can be either magnetically or optically coupled to one of the front wheels. These methods were developed to make the sensor more flexible and easily adapted to the vehicles. Tire inflation and tread wear will affect odometer readings and although a calibrated run can furnish partial compensation of data, it must be recognized that wheels may slip during turning, braking and acceleration or when transversing rough pavement so that total error correction is not possible. Generally these are random variables, however, and then overall effect should therefore be negligible. The odometer data is transferred to digital format by the vehicle processor unit.

Digital transmission of 10 codes from the cars to the Command/Control Center provides communication security and significantly reduces voice communication congestion, thus keeping the voice channel clear for other uses. Ten-code transmissions are initiated by use of a keyboard in the police car which also features an emergency key. Upon transmission, the 10 code status and applicable car number are reflected on a set of numeric displays located on the display and control console. When an officer depresses the emergency key an audible alarm also in the display and control console is caused to sound and the car number and emergency 10 code status is displayed in a like manner. The dot on the video display is caused to blink rapidly for easy location of the car which has relayed the emergency status.

On this basis the vehicle transceiver experiences a low duty cycle with transmit time of approximately 1%. Typically the normal mobile voice communications unit is used.

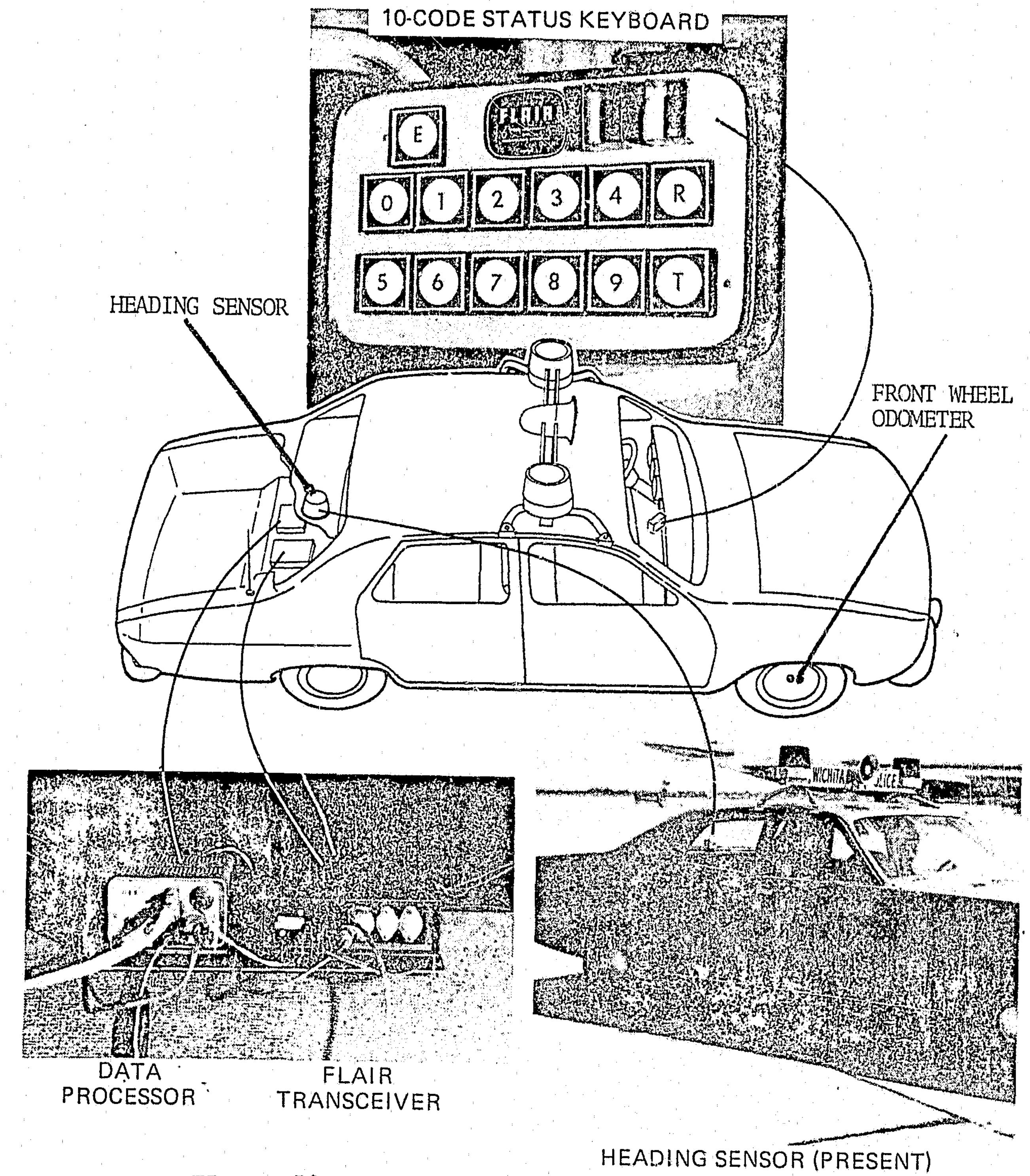


FIGURE 36 VEHICLE LOCATOR UNIT AND 10 CODE DIGITAL RESPONSE KEYBOARD INSTALLATIONS

SYSTEM OPERATIONAL DESCRIPTION--COMMAND/CONTROL CENTER EQUIPMENT

The Command/Control Center equipment controls the transmission of location data from the vehicle, examines its validity and displays the resulting location information on a TV map screen; it also has selected capability to view selected areas and determine cars nearest an incident or an officer-needs-help call.

At the Command/Control Center the digital data is received by the base station and translated by minidigital computer into display information for presentation by the Situation Display Unit. The Base Station Unit generates the main timing signal upon which all vehicles initiate a timing mode and then switches to a receive mode to "listen" for each vehicle to report its identification number, heading, distance traveled since last reporting and any 10 code or the emergency function entered on the 10 code keyboard in the vehicle. The data is received, processed to improve signal quality and sent to the computer unit for further processing.

The Situation Display Unit consists of a display and control console, a switching central, and a TV map vault. The switching central provides the interface to which the computer and each Situation Display Unit element is connected by cable.

A TV camera directed at a city map generates a video image upon which dots representing cars and a selective cursor are dynamically superimposed. The TV camera is provided with a zoom lens and is mounted on a pan/tilt mechanism in the TV map vault such that any area of the city map may be magnified or the total city may be viewed. The display and control console provides the dispatcher with independent control of displayed information generated in the TV map vault. A cursor is also provided on the TV monitor video display. Its position always correlates to the approximate center of the map area selected by the TV camera pan and tilt control or the locate function switch.

The dispatcher at his discretion may also select any one or more of five officer categories which would be titled by the user police department to be displayed on the TV monitor and the closest cars numeric display panel. Resetting the switches causes all units to be displayed on the panel. Resetting the closest cars of all categories on the numeric display monitor and the closest cars of all categories on the numeric display panel.

As an option, a separate set of controls can be provided in a Situation Display Unit display and control console provides a playback capability. This capability permits a replay of previously recorded sequences allowing the evaluation of vehicle utilization during normal patrolling or periods of high police activity. The primary Computer Unit consists of one minidigital computer, one magnetic disc, one teletypewriter, one magnetic tape and the necessary interface cards for interfacing the Base Station Unit and the Situation Display Unit. This computer reads, decodes and updates each vehicle position and 10 codes information transmitted to the base station from the Vehicle Locator Units. A secondary Computer Unit

interfaces with and controls the Situation Display Unit having playback capability. The Computer Unit is also used as a backup computer to the primary Computer Unit. The backup mode will automatically override any other programs being implemented in the secondary Computer Unit.

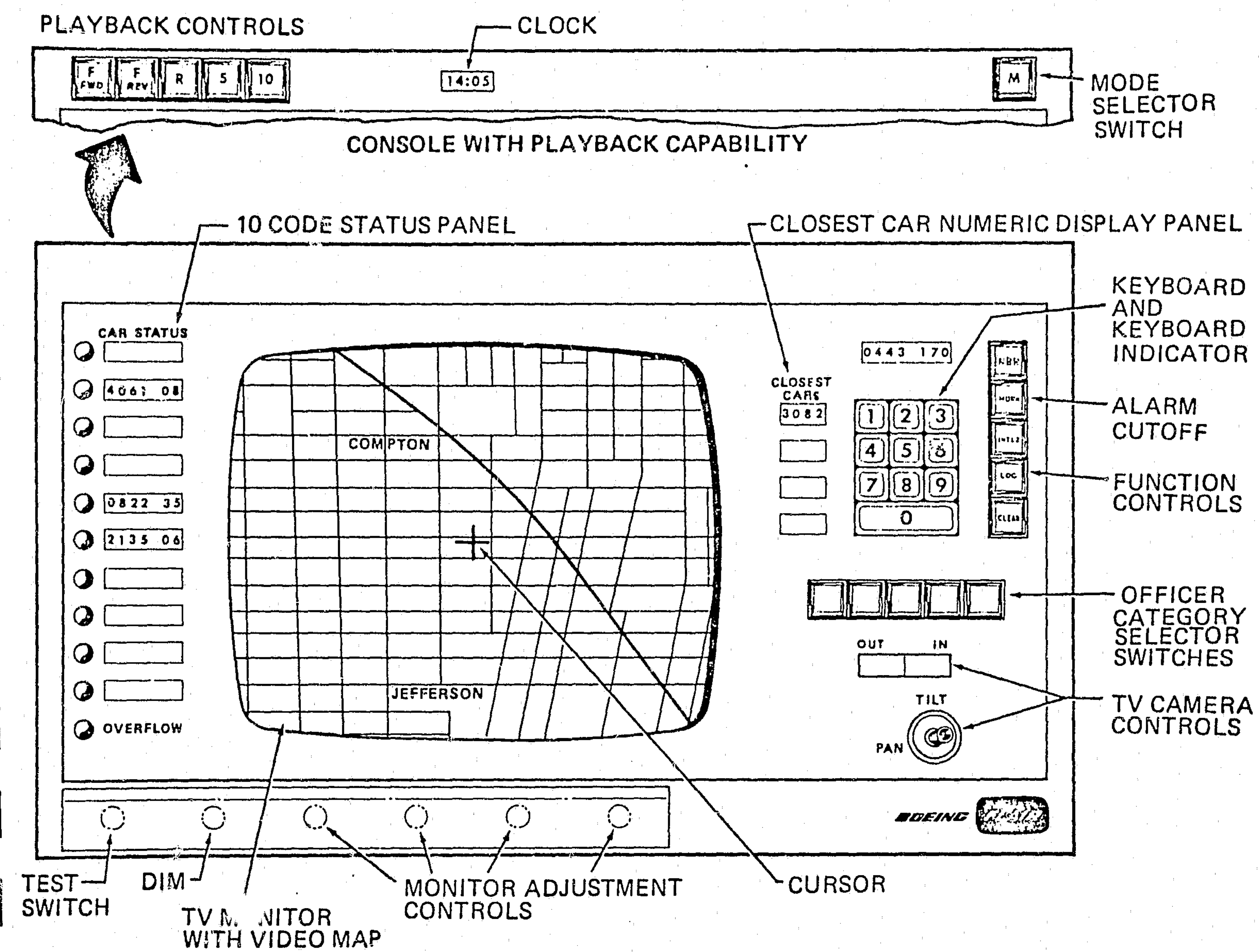


FIGURE 37 SITUATION DISPLAY AND CONTROLS

COMMAND/CONTROL CENTER EQUIPMENT

The equipment at the Command/Control Center resolves the vehicle signals into location data and officer messages which are displayed on a cathode ray tube; incodents are correlated with vehicle location on an expanded scale by the dispatcher using a pressure sensitive grid map.

The Command/Control Center equipment measures the phase differences for each individual vehicle from signals received at the different sensor stations. The equipment at the Center includes a PDP 11/45 writer, 9 Bell Systems Type 603B Data Phone Receiving Terminals, a 9-channel Sierra-built zero crossing measurement circuit, a 50-MHZ time reference, and the cathode-ray tube display.

The equipment of primary importance to system operation is the cathode-ray tube display since this is the unit that the dispatcher utilizes in selecting the closest vehicle(s) for assignment to an incident.

Each dispatcher would be provided a map of their assigned areas, east/west for OPD, under plexiglas on the desk-top portion of the console. These maps not only show the streets in the area, but also the patrol districts. Dispatching at the present time is done by assigning the vehicle from the district where the incident occurred, or if the unit is not available (due to another assignment), the vehicle from an adjacent sector or an umbrella patrol vehicle which overlaps several patrol sectors, is assigned.

Since the dispatchers know the streets in their districts, it is proposed that the dispatchers pinpoint the incident location on a "Rand tablet" (or an "electronic press-board"), which has an overlay of the area map. Pinpointing the incident location on the Rand tablet with an electric pen would cause the cathode ray display tube to draw a map on an expanded scale with the incident location near the center. The computer would then search out the three nearest available vehicle and display their positions and identify the vehicle numbers on the display. A proposed display for the dispatcher is shown in Figure 38 . There are, of course, numerous ways to display the information concerning the nearest available vehicles. It may be desirable to have all vehicles displayed, whether or not they are available and have the dispatcher ascertain which one to select. The available vehicles could be shown in green, the ones that are on an administrative assignment or an assistance to an incident could be shown as yellow, and those on assignment shown as red. The exact display details could be determined by the Command/Control Center personnel.

Eight preselected push-button messages can be transmitted from the vehicle to the Center.

- Available for assignment
- On assignment
- At scene of incident
- Lunch break
- Off duty
- Mechanical trouble
- Administrative assignment
- Officer-in-trouble-emergency

These can also be indicated at the display console for each field equipped vehicle.

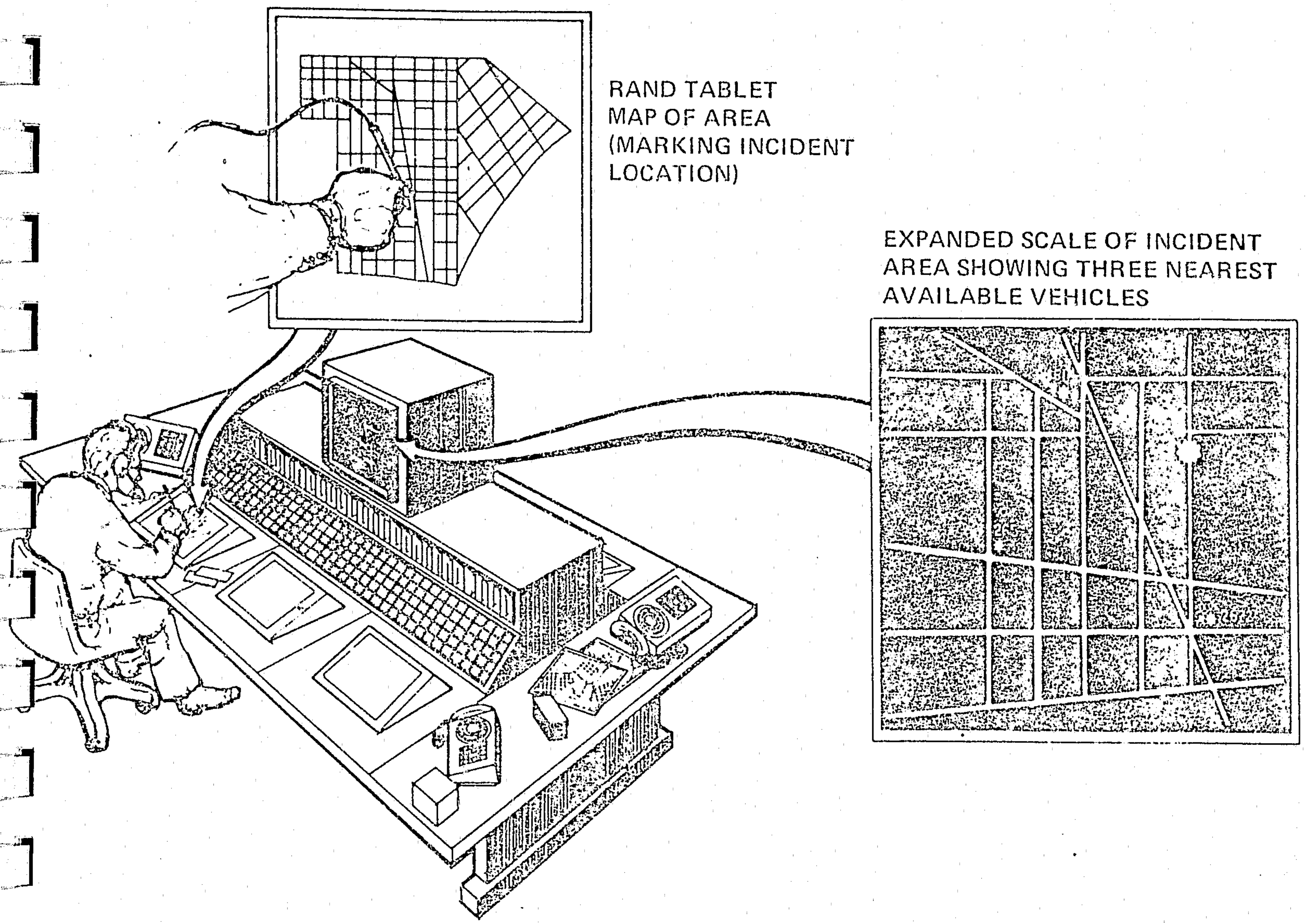


Figure 38 Proposed Dispatcher Display System Shown Method of Entering Location or Incident so it can be Correlated with the Nearest Available Patrol Vehicles

SYSTEM PERFORMANCE CHARACTERISTICS

Performance characteristics for the FLAIR system at this time are extrapolations of prototype development data generated while working with the Wichita Police Department; however a 50 car pilot operational system is currently under contract with St. Louis Police Department.

The dead reckoning location technique has many features which make it attractive; however its performance characteristics are largely dependent on the components and/or the system configuration selected. As discussed earlier dead reckoning navigation is subject to a cumulative error buildup which must be minimized. This can be accomplished by use of precision on-board sensors in the vehicle or by augmenting less precise sensors with some type of corrective feedback loop in the system configuration. Inherently, then, there is a performance/cost tradeoff between precision sensors and a feedback system.

The FLAIR system features inexpensive on-board components augmented by a computer at the Command/Control Center which periodically provides corrective feedback data to enhance the field data. After receiving the location data from the vehicle, the Center computer evaluates and corrects the data and applies geographic (street, etc.) constraints to the vehicle location. This approach has an obvious advantage for large fleets where inexpensive components can be used in the vehicle and only one control computer is needed.

When cars are driven off of roadways, alleys, or parking lots (normal drivable surfaces) the FLAIR system automatically reverts to a secondary mode of operation termed "open loop". Under such conditions (such as a high speed chase across a large open field) the dispatcher will still know and have displayed the general location of the car. Any time the system reverts to an "open loop" condition for any reason, including Vehicle Locator Unit malfunction, the dispatcher will receive an automatic indication on the Situation Display Unit which will show that the dispatcher should verify by voice the position and status of that car. Once the car returns to a normal drivable surface, reinitialization of the car can easily be performed by the dispatcher.

The design goal of the FLAIR system to provide the dispatcher with the capability to locate each police car within ± 50 feet 95% of the time. Test data conducted with FLAIR prototype equipment to date provides a high degree of confidence that this accuracy is achievable under all normal police operation conditions. Table 18 on the opposite page summarizes the performance for the system in its present state of development. It is noted that the system is designed to be operated with conventional communications support equipment.

It is noted that this information reflects extrapolation of prototype development data obtained while working with Wichita Police; no actual historical data is available to establish system performance capability of the FLAIR system in an operating environment, the Boeing Company is presently actively working with the St. Louis Police Department to set

up a development program Phase I of which includes 50 police equipped cars operating in a selected portion of the City. It is understood that this is a fixed price contract with guaranteed accuracy of ± 50 feet.

TABLE 18

SYSTEM PERFORMANCE SUMMARY

Vehicle Tracking Techniques	Real time self-contained dead-reckoning navigation
Data Link Requirements	Any licenseable mobile/base radio channel which will support 20 db signal-to-noise ratio narrow band (10 KHZ) digital data (1600 band).
Data Format	16-bit, 10 millisecond word length (1 time slot), non-return-to-zero (NRZ), synchronizing signal from base radio station o occupies any time slot each two seconds
Area of Coverage	Limited only by communications data link range
System Accuracy	± 50 feet 95% of the time
Tracking Mode	Fully automatic computer up-date with no vehicle operator assistance required
Number of Vehicles	1500 vehicles per computer unit
Computer	20K fixed memory, 16-bit word core, 2.34 million word disc, ASR-35 teletype
Dispatcher Display	One console control/display per dispatcher. Display is TV format with computer generated and controlled symbols indicating vehicle location. Symbols superimposed (double intensity) on computer generated map (with street names). Magnification of city map is selectable by dispatcher (x1, x2, x4, x8, x16). Vehicle/officer identification is displayed with location symbol.
OPTIONS	
Remote Monitor(s)	The remote monitor option permits the information displayed to the dispatcher to be viewed at other locations.
Playback	Vehicle location and status data can be recorded and played back at a later time to evaluate vehicle utilization. The addition of a magnetic tape unit and minor console modification are required to add the playback feature.

SYSTEM SUPPORT REQUIREMENTS

The FLAIR system has reached a level of maturity such that support requirements for personnel training test equipment, recommended spares and physical facilities interfaces can be defined.

It is advantageous to describe the support requirements in terms of Integrated Logistics Support (ILS) which includes all composite elements necessary to assure the operational availability of the system over its programmed life cycle. Development of an effective ILS plan requires repeated review and refinement of emerging support requirements as the design matures and consequently involves a close working relationship between design and support areas. The primary objective of the ILS plan is reduction of the support effort to minimize cost consistent with system readiness requirements.

Early in the development of a system consideration must be given to the type and number of personnel who will be required to operate and maintain the system. Clearly allied to this support requirement is the training of these personnel which should start as early in the system development as possible. Plans for training of system operators and maintenance personnel must address how the training is to be accomplished and the prerequiste qualifications. The Boeing Company would provide training for key Police Department personnel at the Department in system operations, computer and maintenance during the initial phase of a FLAIR implementation program. Boeing then proposes that the customer would assume responsibility for training the remainder of personnel required in these areas. Personnel training in Operations would consist of two--2 hour sessions. Training in use of the computer and associated peripheral equipment would require an additional 4 hour session. Maintenance training would consist of 40 hours of instruction over a two week period to familiarize personnel with the functional aspect of the system. In all cases it is assumed that the personnel would have the necessary educational and experience prerequistes.

Closely allied with training is the requirement for operational and maintenance manuals. Boeing proposes to supply 2 sets of maintenance manuals which include the theory of operation, illustrative parts list, test procedures, repair instructions, calibration and alignment instructions. In addition 2 sets of operating instruction manuals for the Situation Display and Computer units are provided.

Facilities planning as related to ILS is based upon operations and maintenance analysis of equipment design drawings, specifications and similar documents which define the types of facilities, locations, space needs, operating environment, personnel interface, shipping/ installations procedures and training/test functions. Table 19 on the opposite page summarizes the physical characteristics, power and test equipment of the requirement FLAIR equipment. It is noted that a diagnostic program is also provided by Boeing such that the secondary computer can be used to automatically check various functions of the Situation Display Unit. Diagnostic procedures for the Computer Unit is also supplied.

Boeing has also analyzed FLAIR to identify a list of spare parts and assemblies which they recommend be inventoried to support the system.

TABLE 19

FLAIR EQUIPMENT FACILITIES REQUIREMENTS

PHYSICAL CHARACTERISTICS	Dimension (Inches) L	W	H	Weight (Pounds)
Vehicle Equipment				
Vehicle Data Processor	9	6	4	4
Control Panel	2	3	8	2
Radio Transceiver	16	14	6	25
Heading Sensor	3	3	1	2
Base Station Equipment				
Base Radio with Data Demon Units	20	22	36	220
Radio Antenna	12	12	20 (ft.)	40
Console Display & Control	18	20	18	100
Video Processor (Includes rack and power supplies)	18	20	8	240
Computer Unit (Includes disc, teletype, power supplies)	36	26	78	600
	24	24	36	150

POWER REQUIREMENTS

Vehicle Equipment .... 2 amps 12 v. DC continous
10 amps 12 v. DC 0.5% duty cycle (for radio transmitter)

Base Station Equipment .... 115 v. AC commercial power
60 Hz - 500 watts

Computer (Includes disc, teletype, power supplies) .... 115 v. AC commercial power
60 Hz - 30 amps

TEST EQUIPMENT RECOMMENDED

- Digital Voltmeter Hewlett-Packard 3440W/Hewlett-Packard 3444A Plug In or Equivalent
- 1000:1 High Voltage Probe Hewlett-Packard 11021A or Equivalent
- Voltmeter Calibrator Hewlett-Packard 738BRW/Hewlett-Packard 1801A &
- Hewlett-Packard 1802B Plug In or Equivalent
- Square Wave Generator Hewlett-Packard 211B or Equivalent
- Function Generator Hewlett-Packard 651B or Equivalent
- 10/1 Scope Probe Hewlett-Packard 10004B or Equivalent
- 1/1 Scope Probe Hewlett-Packard 1008B or Equivalent
- Logic Comparator Hewlett-Packard 10529A or Equivalent
- Reference Board Hewlett-Packard 10541A or Equivalent
- Logic Clip Hewlett-Packard 10528A or Equivalent
- Test Clip AP Inc. P/N 923700 or Equivalent

SECTION X

SYSTEM SIMULATION EVALUATION MODEL

- o System Simulation Techniques
- o Computer Program Logic
- o Input Data and Assumptions
    - o Assumed Dispatching Disciplines
- o Output Information
- o Validation of Simulation Model
    - o Statistics of Validation
- o System Response to Automatic Vehicle Locator (AVL) Accuracy
- o Comparison of Present and Automatic Vehicle Locator (AVL) Systems
- o Economic Evaluation of AVL System for OPD

A computer simulation model of the Orlando Police Department Command/Control System was used to assess the value of incorporating an AVL capability. The model was structured to match the basic design of the actual system and operates as a dynamic, Monte-Carlo simulation by generating calls from known or postulated statistical distributions, processing these calls through each step a call would encounter in the real system, and by gathering data on individual system components as well as overall operations. As is the case with any computer model, the program does not exactly match the real world system, but rather serves as a close approximation to actual system operations. The long run statistical averages of model outputs and real system historical data, however, are sufficiently close to permit management to make use of model outputs in analytic and decision-making applications.

Initially the model was validated by comparing its output against the existing Command/Control operational data. The model was then modified to incorporate a Command/Control policy to dispatch the available patrol vehicle closest to the incident. The simulation was conducted for AVL Systems accuracies of $\pm$ 0, $\pm$ 500, and $\pm$ 1000 feet to determine the impact of accuracy on the Command/Control System performance in terms of response time and number of incorrect unit dispatches.

The study showed that by incorporating an AVL System with an accuracy of about 700 feet the efficiency of the Uniformed Field forces could be improved such that two less patrol cars would be required to maintain the same response time. An economic analysis was then performed to evaluate the AVL system on the basis of annual savings attributed to maintaining two less one-man patrol cars in the field. The estimated savings included operation and maintenance of the vehicle ($5,000), officer wages (5 men @ $10,500) and an assumed 100% overhead and administration support factor.

Since no "hard" estimates for an AVL System were available, the analysis was conducted to determine the capital investment which would be justified by the potential annual savings of two patrol cars. On the basis of a 10 year facilities life and 5% rate of return investment, the estimated savings ($210,000) will justify an investment of $1,000,000. This is well above the $400,000 rough estimate for an AVL System to handle 30-35 cars.

SYSTEM SIMULATION TECHNIQUES

The Computer Model used to describe the operation of the Orlando Police Department Command/Control System provides an inexpensive, easily-used tool for describing system activity under a wide range of operating environments and design configurations.

Experimentation and data collection activities concerning the operation of complex man/machine systems such as the OPD Command/Control Center are difficult to perform when the system must be in continuous around-the-clock operation. Such studies must be designed to avoid interference with the normal operation of the system, and at the same time, provide a detailed picture of the system internal operation to be of any value to the analyst.

One approach for systems studies which has been receiving considerable attention recently relates to the computer-based simulation of these systems. "Simulation", according to one popular interpretation, is the art of predicting reality from an abstract model of reality formulated by an analyst. This process may be illustrated by examining Figure 39 . The diagram in that figure represents a system operating in the real would environment. The system may be thought of in an engineering sense as a "Black Box", which transforms, or converts, a set of inputs into a set of outputs. The system operation is often constrained by outside restrictions, such as legal aspects, economic conditions, and possibly even humanitarian and moral considerations. The managers and workers in an organization may be thought of as generating additional control inputs within the system structure to further influence the transformation process.

The Orlando Police Department Command/Control Center operation may be readily related to the "Black Box" system operation. Citizen requests for assistance and information comprise the majority of the inputs to the system. The system, defined as the Command/Control Center and its on-duty personnel together with the Uniformed Field Forces, transform these calls into field unit assignments for further investigation and action when deemed appropriate, resulting in outputs representing completed tasks. Constraints acting on the system are primarily those relating to legal procedural rules and physical equipment limitations, e.g., radio system capabilities and patrol unit availabilities.

A computer simulation model, then, represents a working system by imitating the "Black-Box" representation of the system. The basic system description is supplied to the computer in the form of a set of instructions. Also required are the known limitation on the system performance capabilities, e.g., the number of available telephone lines for receiving input calls. The computer program is then given representative inputs and asked to predict the related outputs that the real world equivalent system would generate for the same conditions. The actual computer outputs are tested for validity and the model is changed or expanded until these outputs reach the desired degree of correspondence with their real world counterparts.

The advantages of experimentation with a model of a real system rather than with the system itself are several: (1) the real system is not disturbed by data collection activities, (2) proposed changes in the system are easily tested by changing a few computer cards in the model, (3) the modelling approach is both faster and less expensive than actual field work for the reasons cited above.

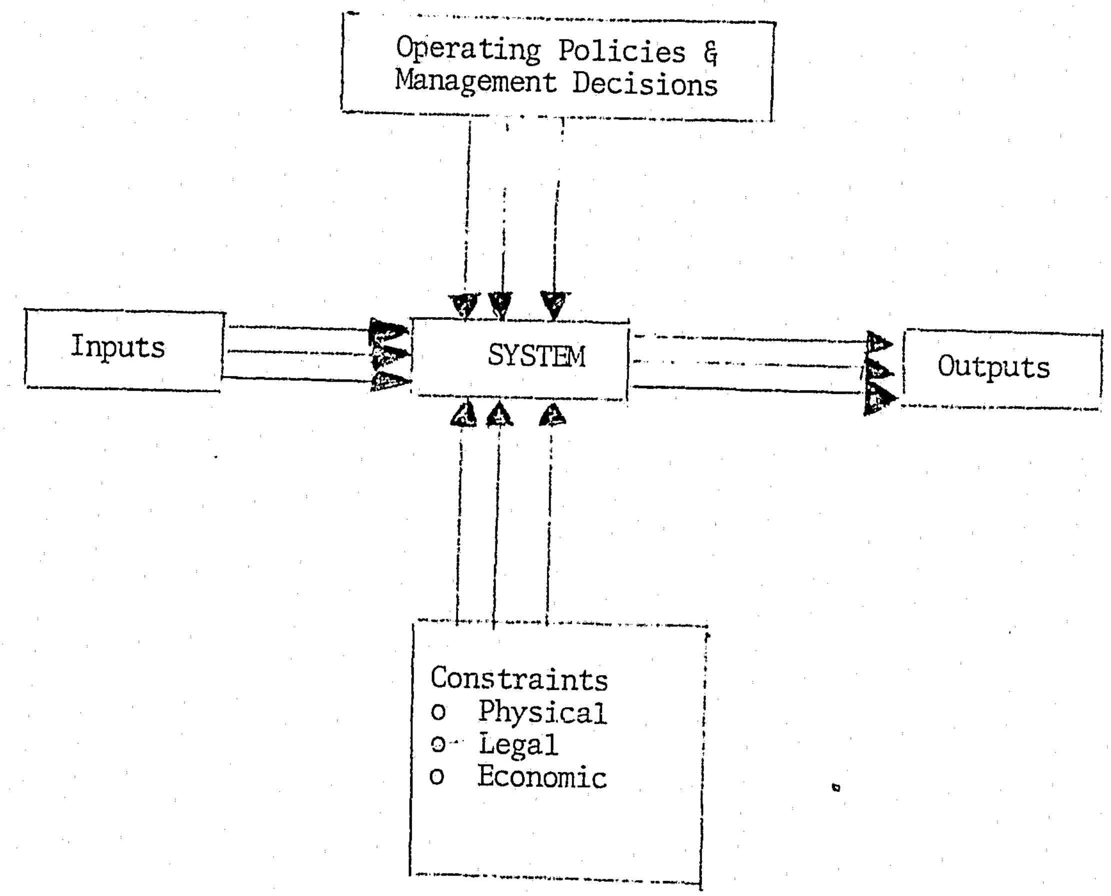


Figure 39 "Black-Box" Diagram Shows System Operating Environment Typically Consists Of Constraints, Controls and Inputs.

COMPUTER PROGRAM LOGIC

The IBM General Purpose Simulation System/360 (GPSS/360) Program was used to develop and exercise a comprehensive computer model of the Orlando Police Department Command/Control System.

The criteria used for the selection of an appropriate computer language to be used for a given simulation model involve several interlocking considerations. Perhaps the foremost of these is the inherent suitability of the language for implementation of the particular set of operating data and structural information available for the system under study. In the case of the Orlando Police Department Command/Control System project, a detailed flow chart of the operating procedures had been developed previously to support the computer work. In addition, statistical data in the form of means, standard deviations, and graphical distributions had been developed for the various times associated with the operation of the Command/Control System. These two factors suggested the use of a block-oriented simulation language to minimize the programming effort required to achieve a working model. Such language was available in the IBM GPSS/360 and this system was used for all subsequent computer runs on this project. GPSS/360 is one of the so-called user-oriented languages. With this program, many of the internal operations are transparent to the user of the language, and the analyst can construct a simulation model simply by selecting one language element, or command, for each block in the flow chart of the real-world system.

The flow diagram on the facing page represents an overview of the basic simulation logic which is presented in more detail in subsequent sections. The block sequence along the left of the diagram represents activites in the servicing of a typical call through the actual Command/Control System. Calls arrive at the system according to some pattern depending on such factors as the time of day, the present level of criminal activity in the community, the weather, etc. Complaint Desk clerks answer the phones, gather the information as to the location and severity of the incident being reported, and if necessary, generate an Orlando Police Department form 602-03 or 602-09 for subsequent Radio Operator use. Information-only requests and other calls not requiring field unit attention are not documented on a form. A conveyor transports the completed forms to the Radio Operator who in turn contacts the appropriate field unit to service the call by consulting the duty roster and field unit assignment map board. The field unit assigned to a particular call must then travel to the location of the request and perform any necessary investigative and action services. When this processing is completed, the calls are removed from the system by the Radio Operator.

The corresponding system operation in the computer model is accomplished by the use of program devices called "transactions". The logic flow of the computer model is shown on the right of Figure 40 , parallel to the actual System operations. These may be thought of as individual calls

passing through the system. The computer uses statistical call arrival information from the real system to produce service requests at random intervals from the "generate" command. The resulting transactions pass through the remainder of the model just as the service calls would pass through the actual system, e.g., when a transaction passes through the Complaint Desk officer, it encounters a time delay determined by statistical sampling of the time delays encountered by real-world service calls at the Complaint Desk. This correspondence of model/system activity is maintained throughout the simulation process, and thus allows actual statistical data collected from the actual system to be used to predict the behavior of the simulation model. GPSS/360 generates statistics describing the performance of structural components of the model based on actual data. A typical statistic would be the percentage of time during an eight-hour shift that a unit was "busy".

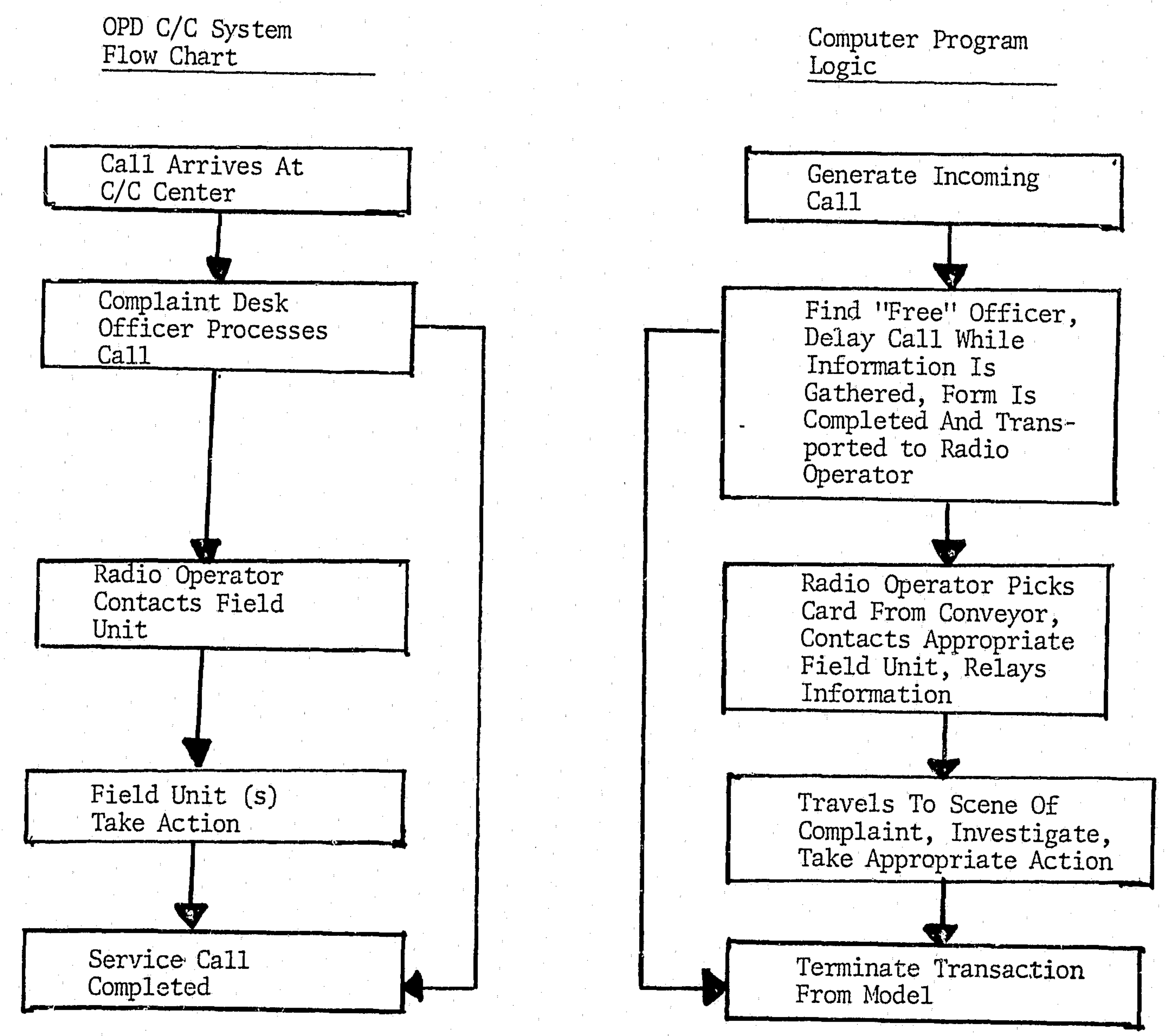


Figure 40 Shows Equivalence Of GPSS/360 Program Logic Blocks To Flow Chart Of Actual System

INPUT DATA AND ASSUMPTIONS

The computer model data input for system action times for the Orlando Police Department Command/Control System was based on extensive statistical sampling of the actual system operation on a 24 hour basis for two six-week periods in early 1972.

The construction of the computer simulation model used in this project required essentially two types of data about the Command/Control System. The first of these categories was fixed structural data on the configuration of the system, e.g., the number of Radio Operator and Complaint Desk stations to be considered for each simulation run; or, somewhat more detailed data, such as which radio channels were assigned to which field units. This data was typically obtained from physical plans of the Command/Control Center and from discussions with Command/Control Center personnel and supervisors. The second major category of data was that relating to operational characteristics of the system. This classification included such factors as the determination of times for the human operator actions required to service an incoming call requesting police action. It is instructive at this point to consider how a representative data item was obtained from the actual system operation and transformed into a form suitable for the computer model.

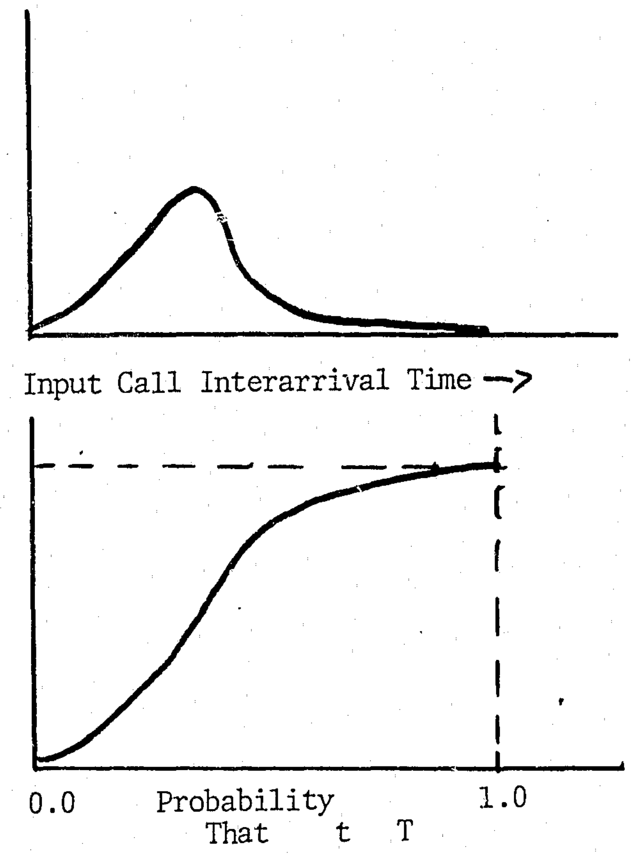
Consider the problem of generating service request calls to the System which simulates the actual calls seen at the Command/Control Center. The timing of the intervals between the arrival of successive calls over a long period of time allows the specification of a statistical interarrival time distribution for these times. This distribution can be entered into the computer simulation program in the form of a table of numbers, called a "FUNCTION" in GPSS/360. This procedure, outlined in the table on the facing page, requires an intermediate step consisting of the preparation of a cumulative statistical distribution on the time variable involved. The cumulative distribution gives the probability that the particular time element in question is less than or equal to some stated value. This distribution is then converted to a sequence of (x,y) data points and punched onto computer cards in the format shown in level III of the figure, representing a GPSS/360 "FUNCTION" statement. The name "SHIFT 1" is a symbolic name assigned to the data curve in the function and whenever this name is referenced in the computer model, this curve will be selected for processing. When in operation, the simulation program selects a random number from one of the built-in generators, and addresses the SHIFT 1 function to obtain the next call's interarrival time. This value is added to the master simulation clock time to determine the time at which the next outside call will enter the Command/Control System.

All of the Command/Control Center operational time elements were entered into the model in the manner described above, resulting in a total of some 17 time functions in the final model. The standard caution directive that "a computer model is only as good as its input data" was noted throughout the data collection and preparation process; every attempt was made to include only valid data values.

STEP — FORM OF DATA

I — Frequency

II — Cumulative Interarrival Time, T.



III — Function To Describe 1st SHIFT (2300-0700)
Call Interarrival Times
SHIFT I FUNCTION RN1, C 17

0.0	0.0	.11	50.	.22	100.	.33	150.	.41	200.	.47	250.
.51	300.	.60	350.	.65	400.	.71	450.	.78	500.	.86	550.
.89	600.	.91	650.	.94	700.	.99	750.	1.0	1600.		

Figure 41 Steps In The Transformation Of Basic Statistical Data About The Command/Control Center Into Form Useable By The Computer Model

ASSUMED DISPATCHING DISCIPLINES

To operate the computer simulation model, a decision logic must be defined for the assignment of patrol units to an incoming call, to introduce a decision structure into the simulated operations.

The Orlando Police Department operates four major classifications of patrol units: individual cars operated by patrolmen, individual cars operated by Sergeants, individual cars operated by Lieutenants, and motorcycle units, which are principally assigned to traffic duty. Cars operated by Sergeants and Lieutenants are generally assumed to be supervisory but these units do respond to incident calls under certain conditions. The rules applied in the computer model are discussed below under the major operating categories of the computer model. In the "present system" the decision rules correspond approximately to the current methods in use at OPD. Under the Automatic Vehicle Locator System (AVL System) the postulated assignment discipline is described. Although this is a future system, the rules applied are deemed to be reasonable and close to expected operating procedures.

Existing Assignment by District: When an incident occurs, an attempt is made to dispatch a car in the district in which the incident has occurred. If no unit is available in that district, then the district north (south) of the incident district is searched for a free unit. If no unit is available in those districts, then the district east (west) of the incident district is searched for a unit to be dispatched. If no available unit is located through this 360^{o} search, the Sergeant and motorcycle units are searched for dispatch. If no unit is located among these resources, the call is essentially unanswered and is inserted into a queue for accomplishment when an unassigned unit is available. On high priority calls in a queue situation, the higher priority (emergency) incident bumps lower priority incidents into the queue. Examples of district search are shown in Figure 42 . For incident 1 (in District 2) District 2 is searched first followed by a search of Districts 4,1, and 3 respectively. Similarly, for incident 2 (in District 4) the order of search is Districts 4, 2, 3, and 1 respectively. Similarly for incidents 3 and 4 the order of search is 1, 3, 2, 4 and 3, 1, 4, 2.

Automatic Vehicle Locator (AVL) System: Dispatch decisions in a system using AVL are made by computing actual distance from an incident scene to available field units. The closest available field unit is assigned (exclusive of Lieutenants and motorcycles). If a unit manned by a patrolman is not available, the closest Lieutenant or motorcycle is dispatched. As with the present system, if no available units are found the call is placed in a queue to await the first available unit. In calculating distances in the computer model, the operating area is overlaid with a system of grid lines providing coordinates of any point. These coordinates, then, are used to determine the rectangular distance (as with city streets) between any two points of interest. Distances

computed in this manner become highly important in experimentation with the simulation model. Since locations and distances are known exactly, the influence of accuracies of various AVL systems can be evaluated in terms of incorrect dispatches and additional unnecessary distance travelled.

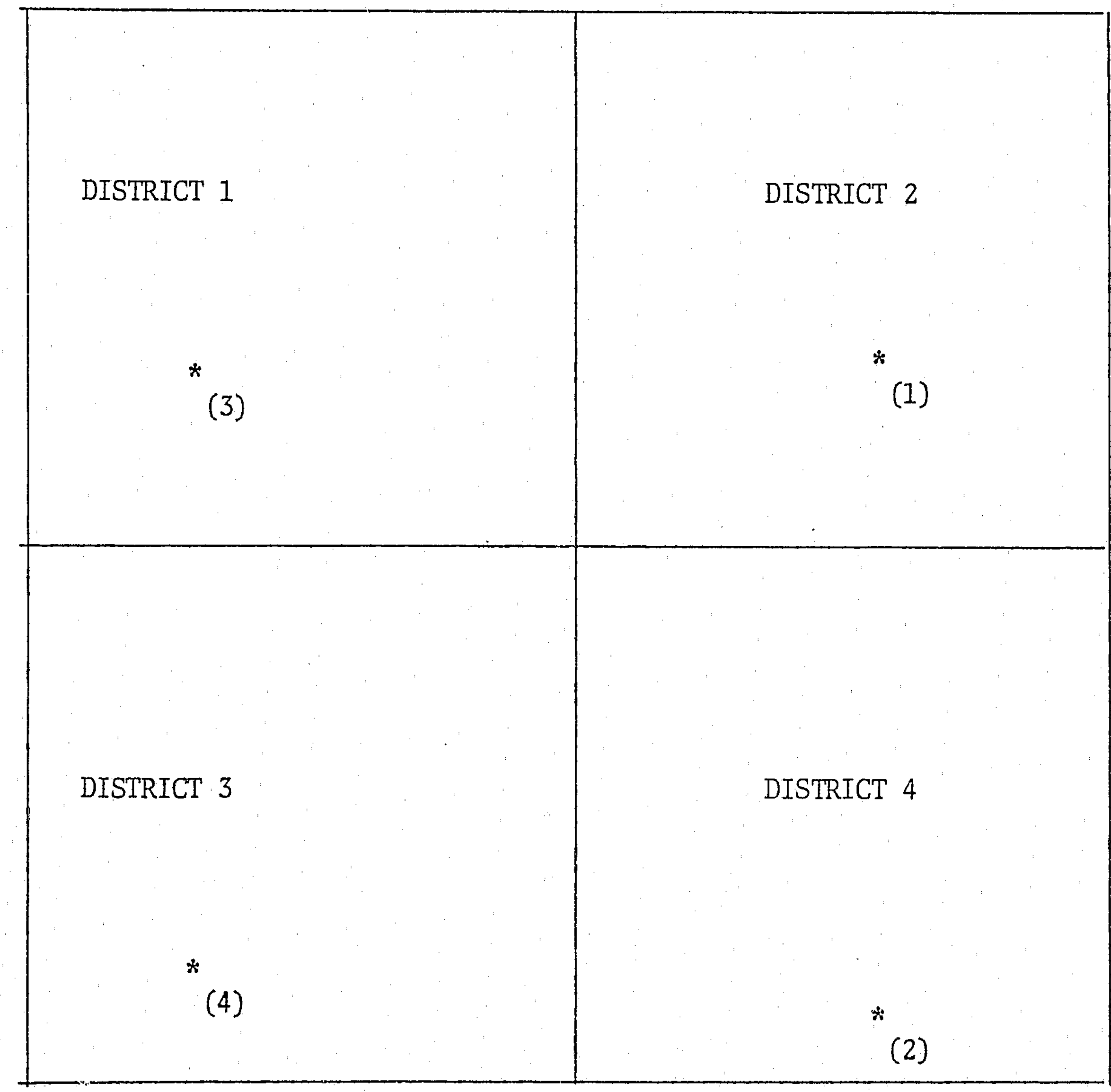


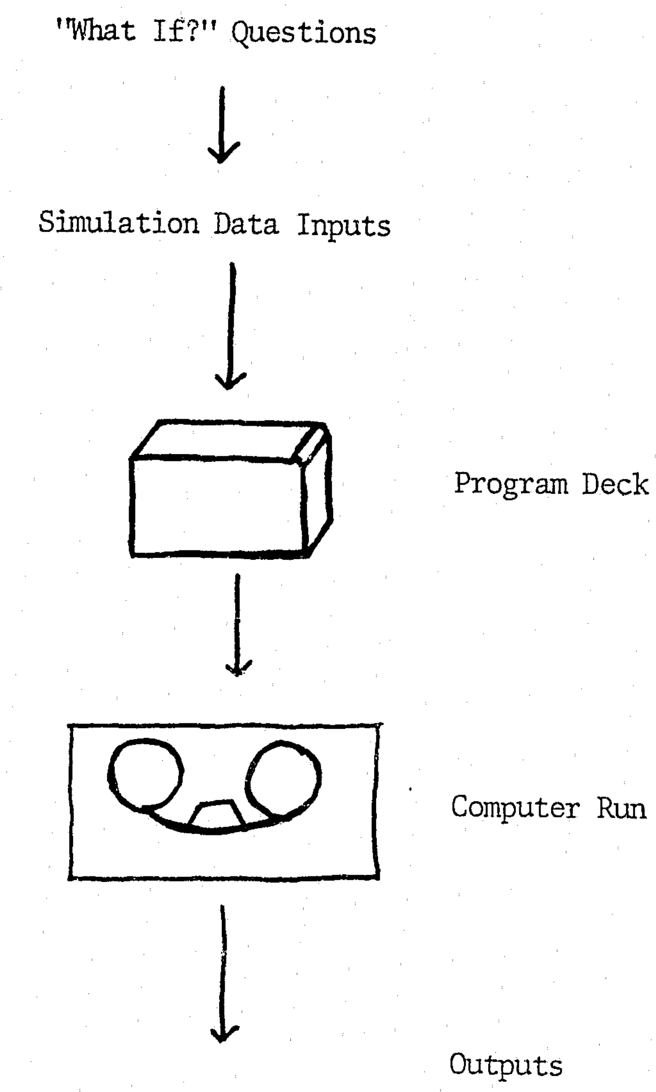
Figure 42 Example of Dispatching Routine For Existing (Non-AVL) System.

OUTPUT INFORMATION

The GPSS/360 simulation model of the Orlando Police Department Command/Control System developed on Project 70-04-05 was modified to incorporate the AVL System and provide a range of simulation data output useful in evaluating different types of AVL Systems under present and anticipated system operations.

The output information from the computer simulation model may be used for two major steps of the systems study process: model validation, and evaluating proposed system design changes under varied operational and environmental conditions. In the first phase, model outputs such as those depicted on the facing page were compared with known system performance data for standard and non-standard operating conditions. The model was then refined through data resolution changes or structural modifications to bring its outputs within an acceptable correspondence to those of the real world system. In GPSS/360 modelling, this process of model "tuning" typically occupies a significant portion of the total model preparation time. As with any Monte-Carlo simulation procedure, GPSS/360 is sensitive to the various values selected as initial conditions on the random number generators providing the dynamic stochastic behavior of the model. For this reason, several runs with different initial random number values were made for each proposed system design or data change to assure that the range of model variation due to this condition was adequately represented.

The various model outputs are used in both design and analysis applications once the model has been validated. For example, In the case where the feasibility of an Automatic Vehicle Locator (AVL) is under study, the statistical properties of field unit 10-6 times (time for a unit to reach an incident scene after dispatch) are obtained from several computer runs. These data provide a measure of system response to permit a comparison of AVL and the existing distinct dispatching system. In this study, two principle areas of comparison are under consideration: the economy of an AVL system versus present system, and effects of varying accuracies of the AVL system. Toward the first objective, the simulation model is modified to increase the number of operating units to a point of equivalence of system response between AVL and non-AVL operations. The number of additional cars required to achieve this equivalence is seen as a measure of the economic contribution of an AVL system. Similarly, the effects of varying AVL accuracies can be studied by examining model outputs while stepping through several AVL accuracy levels. The overall simulation process is portrayed in Figure 43 showing the flow of effort beginning with a "what if" question leading to the broad range of possible model outputs. These outputs are futher discussed in later sections of this report.



Facility Utilization	Number and Type of Calls Generated	Behavior of Queue at Radio Operators	System Response Timings
o Radio Operators	o Districts Where Originated	o Maximum Number Waiting	o 10-6 Distribution
o Field Units		o Average Number Waiting	o 10-8 Distribution
		o Average Waiting Time In Queue	

Figure 43 Range of Outputs Generated By GPSS/360 Simulation Model Of Orlando Police Department Command/Control System Modified For Evaluation Of AVL Systems.

VALIDATION OF SIMULATION MODEL

Comparison of the computer model outputs with corresponding parameters from the real world Orlando Police Department Command/Control System was the primary validation mode used for the simulation model of the present dispatching method.

The concept of the validation of a computer simulation model is often stated in absolute terms, although a more realistic approach may involve working towards relative states of mofel agreement with reality. One reference[1] has defined the validity of a simulation model as "... the extent to which it satisfies its design objectives." The goal of the Orlando Police Department Command/Control System model was not to obtain exact duplication of real system performance, which would be impossible to achieve, but rather to achieve a reasonable approximation of real system performance and produce a model that would yield useful information about the system's operations. This goal was achieved.

There are three basic approaches to assuring model validity;[2] all were employed in the construction of the Command/Control System Model to some extent. The first approach requires building realism into the model structure, and typically involved making detailed analyses of actual system operating procedures and translating these into model language statements on a " one-to-one " basis. Representative coding from the model structure for the complaint desk personnel activity and the field unit operations is included elsewhere in this report. The model statements, in general, have a direct relationship to known actions in the real world on an elemental basis, which is the rationale for declaring that exact agreement between the model outputs and the actual system operations is extremely unlikely. For example, incident investigation time is modelled by a GPSS/360 language statement of the form "ADVANCE FN$INV03". This has the effect of causing the simulator to pick a random number internally and use its value to obtain an investigation time value for the unit from the data function named "INV03". This time function was derived from the statistical sampling of actual OPD investigation times. While the simulation model will not exactly match actual OPD statistical behavior, on the average investigation time in the model will correspond to the theoretical real-world investigation time. This result is, in fact, the statistical description basis for Monte Carlo system simulation, e.g., the statistical description of a system operating characteristics may be obtained from the aggregation of a member of samples from the system expected operating regimes.

The second validation approach involves assessing the reaction of knowledgeable personnel to the model outputs for familiar operating conditions. This action may be helpful in isolating and identifying doubtful results in the model outputs.[3] This comparison was done for the project simulation model and yielded the extremely important

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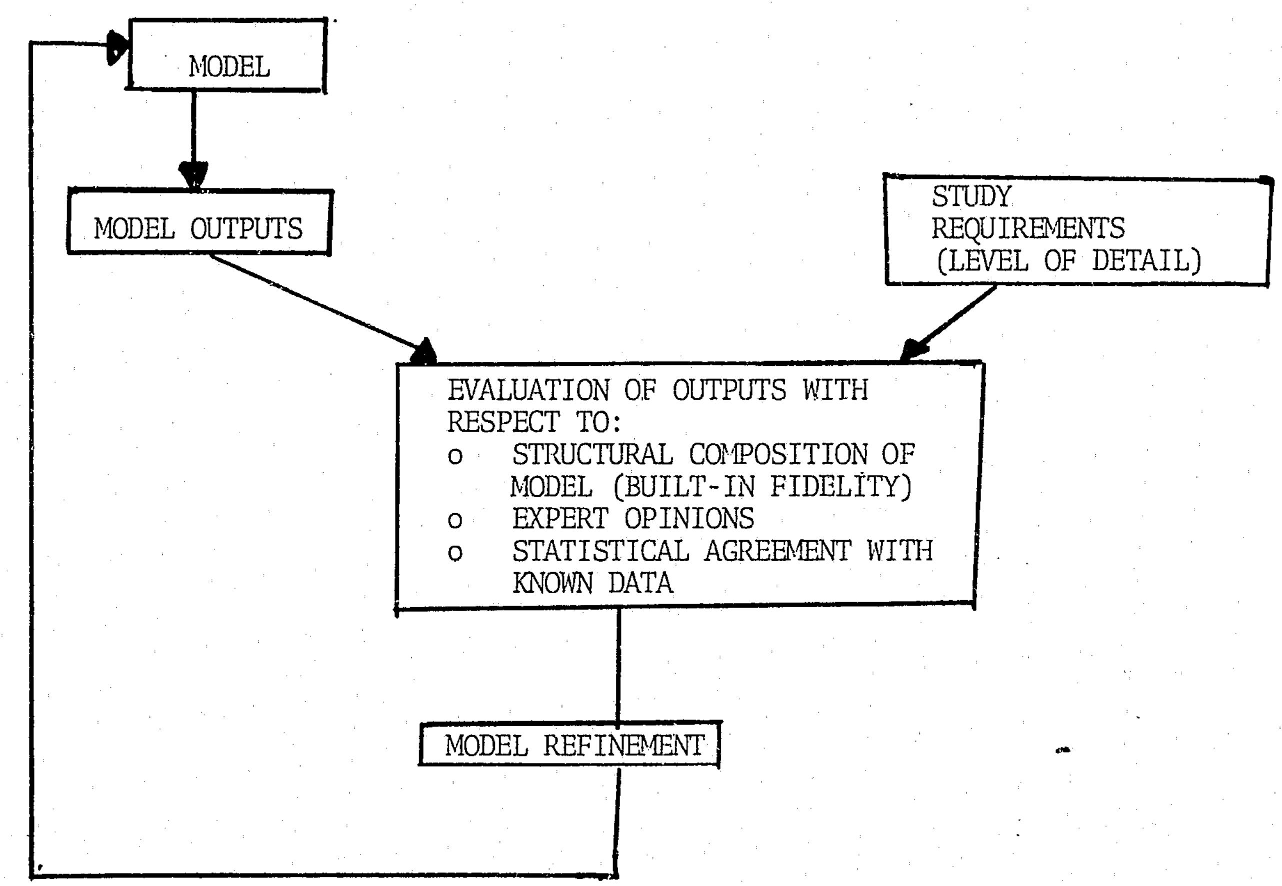
1 Maisel and Gnugnoli, Simulation of Discrete Stochastic Systems, (Chicago, Illinois: Science Research Associates, 1972) p.33
2 Op. Cit., pp. 33-35
3 Op. Cit., p. 35

information that predicted Radio Operator "busy time" statistics were uniformly too low to represent a reasonable cut at reality. This discrepancy was investigated, and found to be due to the ommission of certain types of background radio message traffic, e.g., detective unit calls and accident investigation car reports. The accurate simulation of the full Radio Operator's task spectrum in the completed model was thus found to require additional statistical sampling of these necessary events.

The third approach to validation relates to formal comparison of simulation model outputs to reference data which may be available for the system being studied. This reference data is typically historical data on system operations under known conditions in the past. Again, the exact correspondence of Model/System output is not required or sought, but rather the objective is to achieve a degree of correspondence satisfying the needs of the study.

TABLE 20
MULTI-STEP PROCESS OF A
MODEL VALIDATION



STATISTICS OF VALIDATION

"An empiricist is one who believes only what his senses tell him; in this case he has made an outrageous leap into the unknown."[1]

The question of the relationship between the problems of validation and inference arising from simulations of human systems is challenging. Validation, as mentioned earlier, relates to the degree of "realism" associated with a model, whereas inference, or the methodology of drawing conclusions from data, often requires consideration of the "formalism" associated with a simulation process.[2] The statistical procedures for initial model validation require the analyst to carefully consider these somewhat mutually conflicting concepts. Consider the accompanying chart, taken from Pfaff and Pfaff[3], and representing the range of simulations of human behavior. The Orlando Police Department Command/Control System model would fall somewhere near the "complex all computer experiment" region of the chart, the primary classification criteria is the relative degree of variable interactions that exist within the model structure. The primary effect of this classification is that variable responses in the model are not independent in nature, and therefore cannot be treated with classical experimental design techniques. Analysis of such models typically then depends on single runs or replications to obtain descriptive model behavioral patterns.

One additional theoretical concept should be addressed with respect to statistical validation of model behavior. This concept is that if a model describes some hypothetical or proposed system, no validation can in fact, be accomplished. This is a natural consequence of the fact that "... if no numerical data exists for an actual system, it is not possible to establish the quantitative congruence of a model with reality."[4] The importance of this fact in the present study is that the output data relating to the future Command/Control systems considered as alternate designs to the present system will have this characteristic.

To illustrate the statistical testing typical of that which can be done to validate the model, the analysis of model behavior for field unit travel time data will be presented. Manual sampling over several weeks with the actual system produced a mean of 4.605 minutes for this data element. The computer model yielded a mean value of 4.14 minutes and a standard deviation of 2.918 minutes for this same variable over a series of 3 model runs under the current implementation system. Additional data collection items were not made at this point in the study for this case, as each run was costing approximately $21.00 for computer

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1 C. W. Churchman, "An Analysis of the Concept of Simulation" Symposium on Simulation Models: Methodology and Applications to the Behavioral Sciences (Cincinnati, Ohio: Southwestern Publishing Co., 1969) pp. 1-2

2 Martin Phaff and Anita Pfaff, "Statistical Analysis of Simulations of Human Systems", Proceedings of Eighth Symposium of the National Gaming Council, Excelsior Springs, Mo., June, 1969, p. 2

3 Op. Cit. p. 7

4 G. S. Fishman and P. J. Kiviat "The Statistics of Discrete Event Simulation", Simulation, April, 1968, pp. 191.

time, and additional development work requiring considerable expenditures was being projected for the model. The applicable statistical test was conducted as follows:

Null Hypothesis:	Sample Mean (Computer Prediction) = Population mean (Actual System Value Obtained By Sampling)
Test Statistic:	$t = \frac{4.14 - 4.605}{2.918 / \sqrt{3}} = -.275$
Rejection Region:	For $\alpha = .05$, reject for $t > 2.920$
Conclusion:	Accept the Null Hypothesis

TABLE 21

VARIOUS COMPUTER MODEL SCHEMES BASED ON REALISM AND FORMALISM COMPONENTS

degree of realism ←

	All-Human Simulation	Man Computer Simulation (Game Simulation)		All-Computer Simulation		
Description	All Human Game	Hierarchical Man-Computer Game	Man Computer Game	Man-Computer Experiment	Complex All-Computer Experiment	Simple All-Computer Experiment
Feedback	very complex & important	multi-level, partly formalized	one-level partly formalized	one-level or multi-level formalized	multi-level all formalized	multi-level all formalized
Data Series	subject-generated	subject-and experimenter generated			experimenter generated	
Replication	not possible	difficult and not meaningful		possible	possible	possible
Experimental	not possible	not possible	not possible	possible	not possible	possible

degree of formalism →

SYSTEM RESPONSE TO AUTOMATIC VEHICLE LOCATOR (AVL) ACCURACY

The simulation study compared the effects of AVL accuracies in two important areas: the number of incorrect dispatches and the average distance travelled due to an incorrect dispatch.

The simulation model of the Automatic Vehicle Locator System was run with accuracies of ± 0 feet, ± 500 feet, and ± 1000 feet. Four runs of the model were made with each run processing 500 incidents. In order to insure steady state conditions, 1000 incidents were processed through the model prior to collecting performance statistics. It is well known that transient effects in a simulation model must be eliminated to permit reliable results from the model. As a further control on variability between runs, each set of four runs were averaged to obtain the results shown on the facing page.

The first graph, Figure shows the average distance traveled by an incorrectly dispatched unit as approximately 0.4 mile with an AVL of ± 500 foot accuracy. An incorrectly dispatched unit is defined as a unit which is not the physically closest available unit to the incident under process. Physical distance in the model is measured in horizontal and vertical (X,Y) distances. In the model design, it was assumed that X,Y travel most closely approximate actual travel of a vehicle through city streets. As an illustrative example, consider two points A and B with coordinates (X_1,Y_1), (X_2,Y_2) respectively. The following simple formula relates the distance between these points

$$\text{Distance} = |X_1 - X_2| + |Y_1 - Y_2|$$

where the vertical bars designate absolute value. In Figure 44, distances measured by this formula for incorrectly dispatched units averaged approximately one mile for the AVL System with ± 1000 foot accuracy. It will be noted that the distance travelled increases sharply with decreasing AVL System accuracy. Computer runs with ± 50 foot accuracy showed little difference from ± 0 foot accuracy but distance increases rapidly as accuracy is degraded to the ± 500 and ± 1000 foot levels.

For each of the accuracies in Figure 45 , the number of incorrect dispatches increases as the accuracy of the AVL System is decreased. An incorrect dispatch is defined as the selection of a unit for assignment which is not physically closest to the incident scene. The selection of this parameter relates to the assumption that incorrect dispatches obviously degrade overall system response time. In the second figure, the number of incorrect dispatches almost doubles as the accuracy goes from ± 500 feet to ± 1000 feet, increasing from 17 wrong dispatches at the ± 500 feet accuracy to 30 for the ± 1000 feet accuracy system. The parameters of wrong dispatches and average distances travelled due to wrong dispatches have been determined by Larson[1] as significantly important measures of system performance.

[1] Larson, Richard C., Urban Police Patrol Analysis; The Massachusetts Institute of Technology Press, 1972.

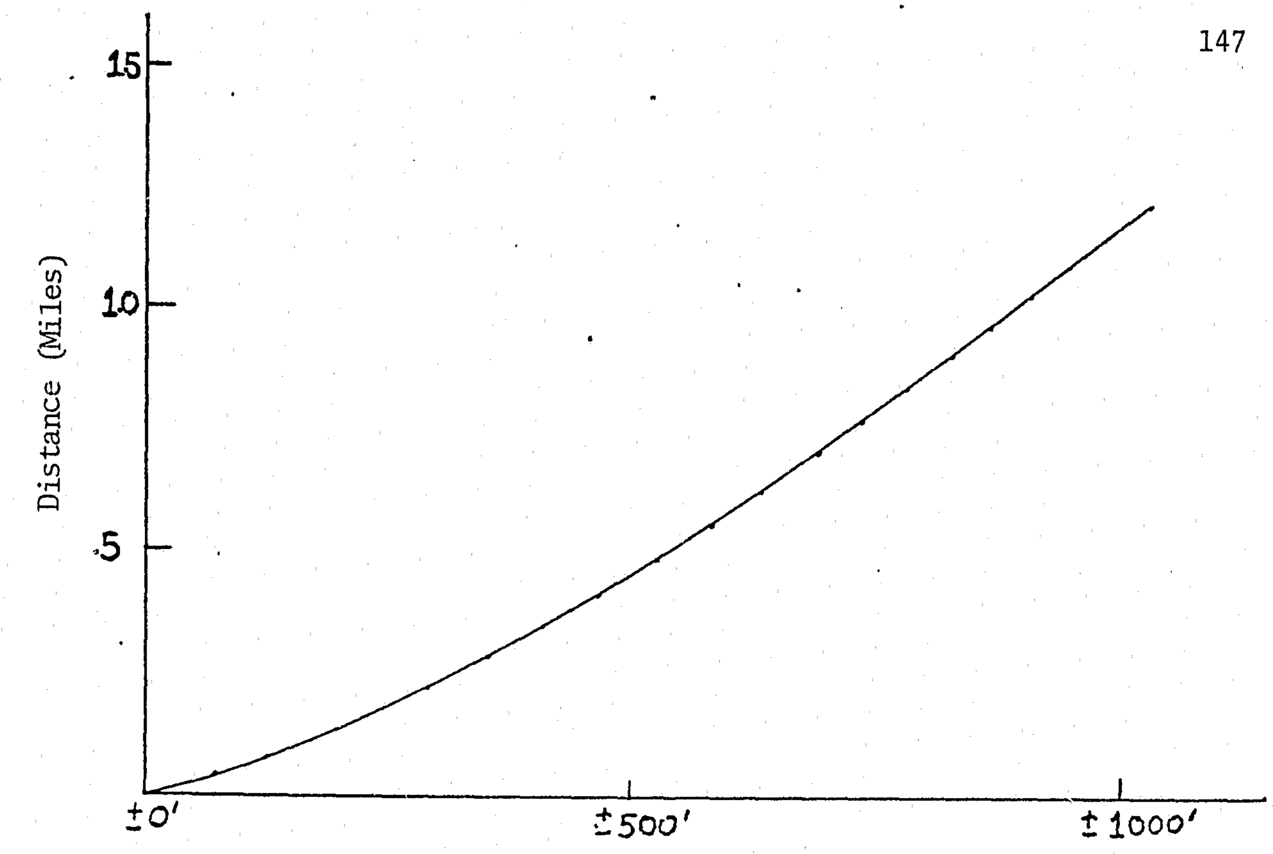

Figure 44 Average Distance Traveled Due To Wrong Dispatch

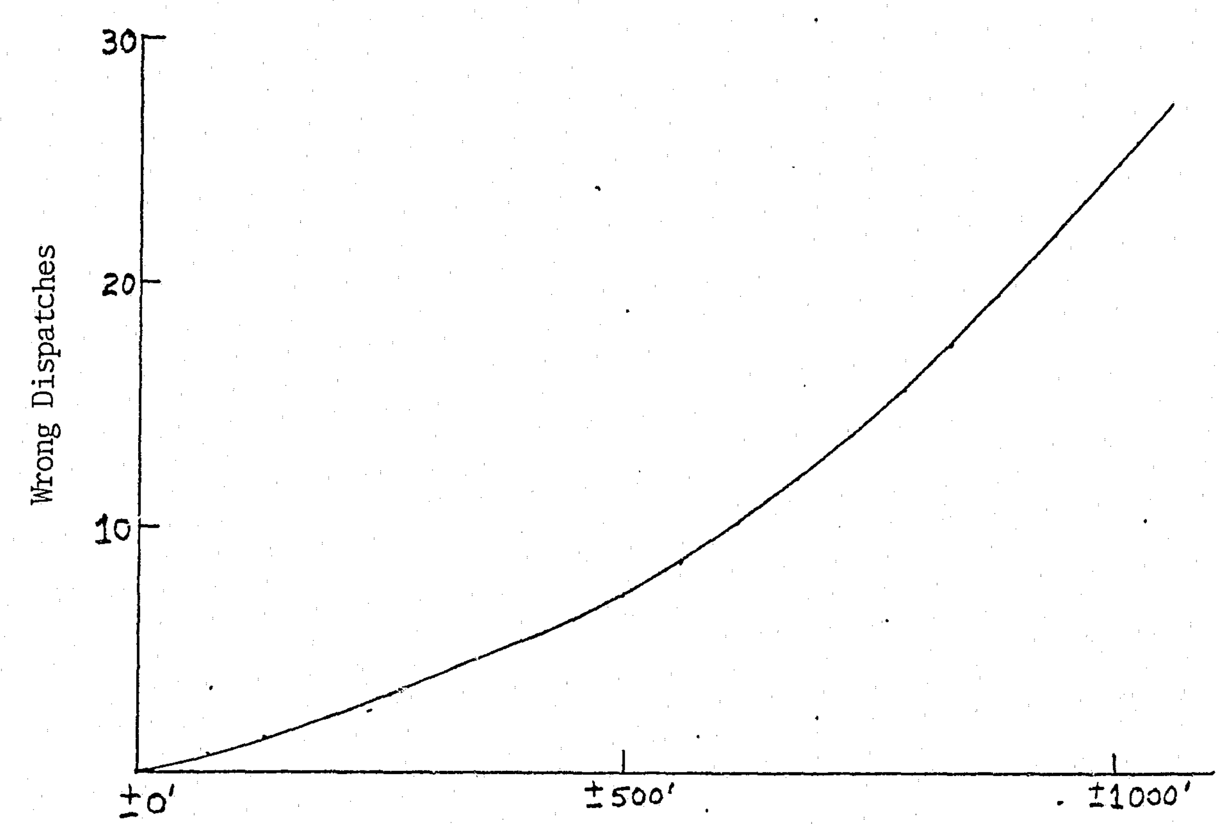

Figure 45 Number Of Wrong Dispatches

COMPARISON OF PRESENT AND AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

The computer simulation model was developed to permit an assessment of the value of an Automatic Vehicle Locator (AVL) System and the influence of the accuracy of such a system.

The two systems under comparison are the existing district dispatching system (without Automatic Vehicle Locator) and the proposed closest vehicle dispatch using automatic vehicle locators of varying accuracy. Comparison of the two systems is based primarily on the tabulated values of 10-6 time (time from receipt of call until a unit arrives at the scene of the incident) and impact of dispatching the incorrect patrol vehicle. The Automatic Vehicle Locator System model was run to obtain results for three different accuracies ± 0 feet, ± 500 feet, and ± 1000 feet. The specific results of these runs are included in a later section of this report.

To interpret the system behavior under various accuracies, a means of comparison to the present system was needed. For the purposes of this study, it was deemed appropriate to increase the number of units in the present system to a point where both systems were equivalent in response time. Thus if the AVL System response time were less than the existing District Dispatching System, more patrol vehicles would be added until the existing system obtained the same reduction in response time.

Under this procedure, the model of the present system was run with the same number of vehicles (34) as assumed in the Automatic Vehicle Locator System. More vehicles were added, one at a time, to the model of the present system. The simulation was run again and the results noted. This was carried out repeatedly until the 10-6 time equalled or was less than, the 10-6 time of the Automatic Vehicle Locator System. As vehicles were added to the present system, they were placed in districts showing the most activity in the previous run.

A graphic comparison of the two systems is shown in Figure 46 . Some of the results shown by the graph include:

1. A perfect Automatic Vehicle Locator System will operate as well as the present system with 37 vehicles.
2. A 500 foot accuracy Automatic Vehicle Locator System has the performance of the present system using 36 vehicles.
3. The two systems are approximately equal with an Automatic Vehicle Locator System of 800 feet and the present system with 35.8 vehicles.

On an overall basis, we may conclude that the cost of operating 1.8 vehicles (rounded off to 2 vehicles) may be compared with an AVL system with 800 feet accuracy. In general, then, we may assume that if the 800 feet AVL System is less costly then the operation of 2 additional patrol units its installation is justified.

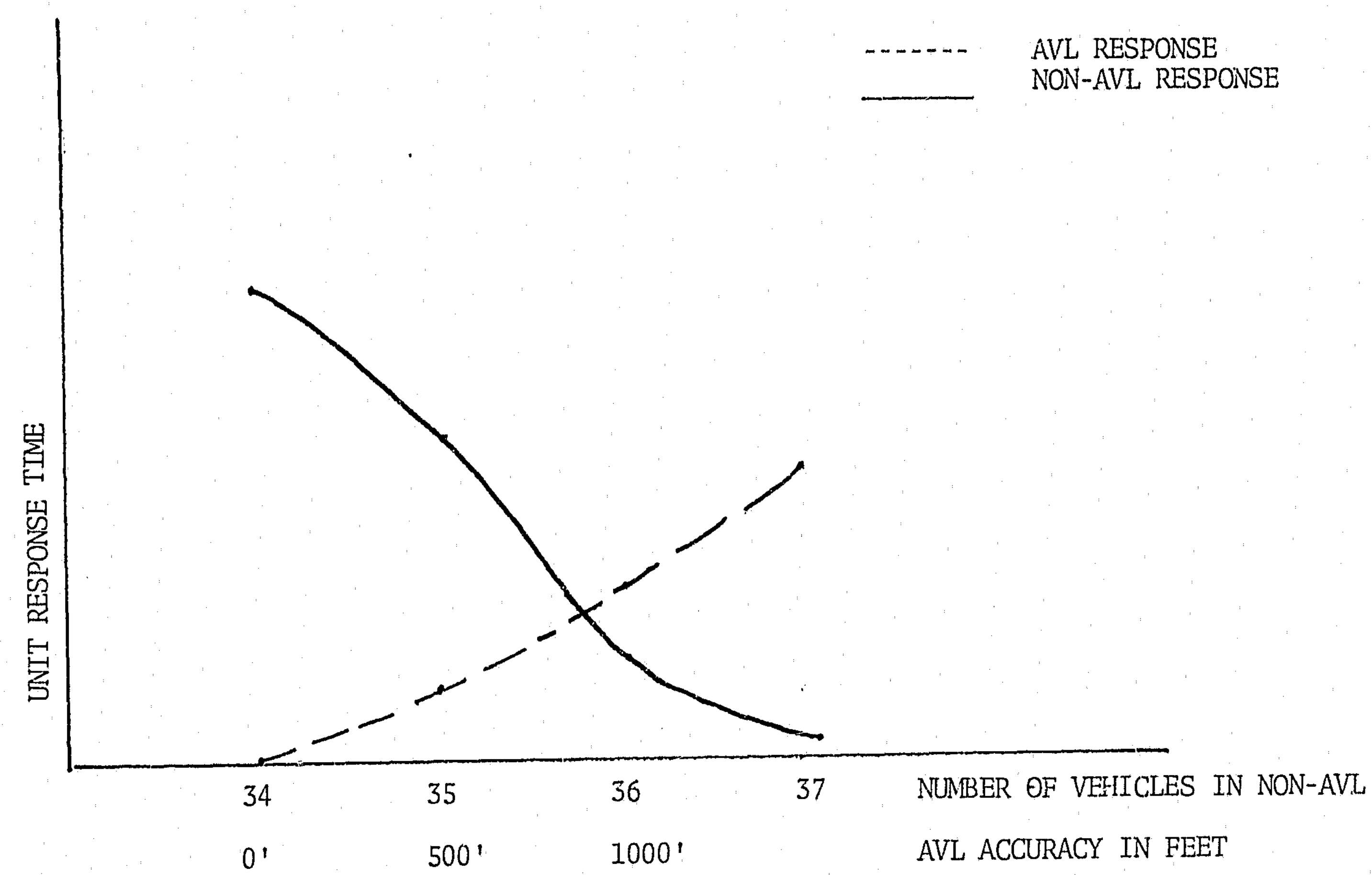

FIGURE 46

ECONOMIC JUSTIFICATION OF AVL SYSTEM

A basic engineering economics analysis was used to estimate the capital investment which could be justified for an AVL System based on its response efficiency expressed as equivalent patrol vehicles. The analysis showed that for each patrol unit so replaced $914,000 was justified.

The Orlando Police Department is currently experiencing expenses of $450 per month for the operation and maintenance of each patrol vehicle (car). This includes depreciation, gas, oil and maintenance. To estimate the personnel costs a single officer unit was assumed and an average salary of $10,500 per year for the officer. Three shifts per day, 7 day/week, including holidays and vacations would require 5 equivalent men and amount to $52,500 direct cost per year in operator salaries, for each unit in the field. If we include overhead and administrative support this would increase by an estimated 100%. The Orlando Police Department, therefore, experiences total costs per year of $115,000 including operator salaries overhead/support and operation and maintenance costs.

Although the initial cost of an Automatic Vehicle Locator (AVL) System is unknown at this time the capital outlay justified by a reduction in field units can be determined. This can be used to determine the threshold of capital outlay where an AVL System becomes a good investment. Examining the cash flow diagram in Figure , the cost of an AVL System has been labelled as "X". Annual operation and maintenance costs were estimated at 10% of first cost or .10X, as shown in the diagram. The investment of these amounts then will produce savings because of fewer patrol units in the field. For example, if one field unit is eliminated through the use of an AVL System an annual savings of $115,000 will result. This amount is shown as the upward (cash inflow) arrows on the diagram. The net "profit" from installing an AVL System eliminating one field unit is the quantity ($115,000 - .10X). We then wish to solve the equation

$$X = (\$115,000 - .10X)\ (PWF - 5\% - 10); \qquad (1)$$

where the quantity (PWF - 5% - 10) is the Present Worth Factor of an annual amount at 5% interest over five years. Five percent was assumed to be a reasonable return on investment for a municipality. Using a standard table of interest factors we have

$$X = (\$115,000 - .10X)\ (7.722) \qquad (2)$$

which may be solved for X as

$$1.722X = \$115,000\ (7.722) \qquad (3)$$

or

$$X = \$115,000\ (4.357) = \$501,000 \qquad (4)$$

Thus an elimination of one field unit justifies a capital investment of about $501,000. In a similar fashion, we can rapidly calculate capital investment justified for 2,3,4 etc. units eliminated from the field. This data is displayed in Figure 47 . This plot reveals that a straight line relationship exists where for each car eliminated an additional $501,000 in capital investment is justified.

In examining these figures it is necessary to consider the true "savings" of the reduction of field units. Certainly, patrolmen relieved from operating field units are not completely eliminated from OPD operations. In this sense manpower so released could be used in other OPD functions, such as Preventive Patrol.

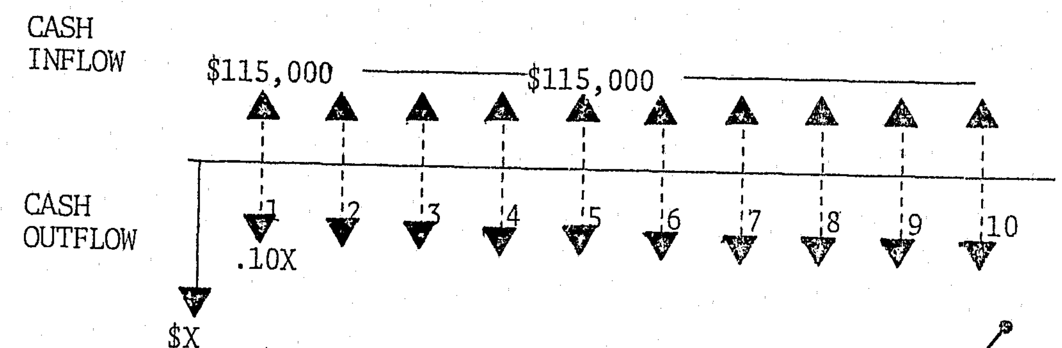

Figure Cash Flow Diagram

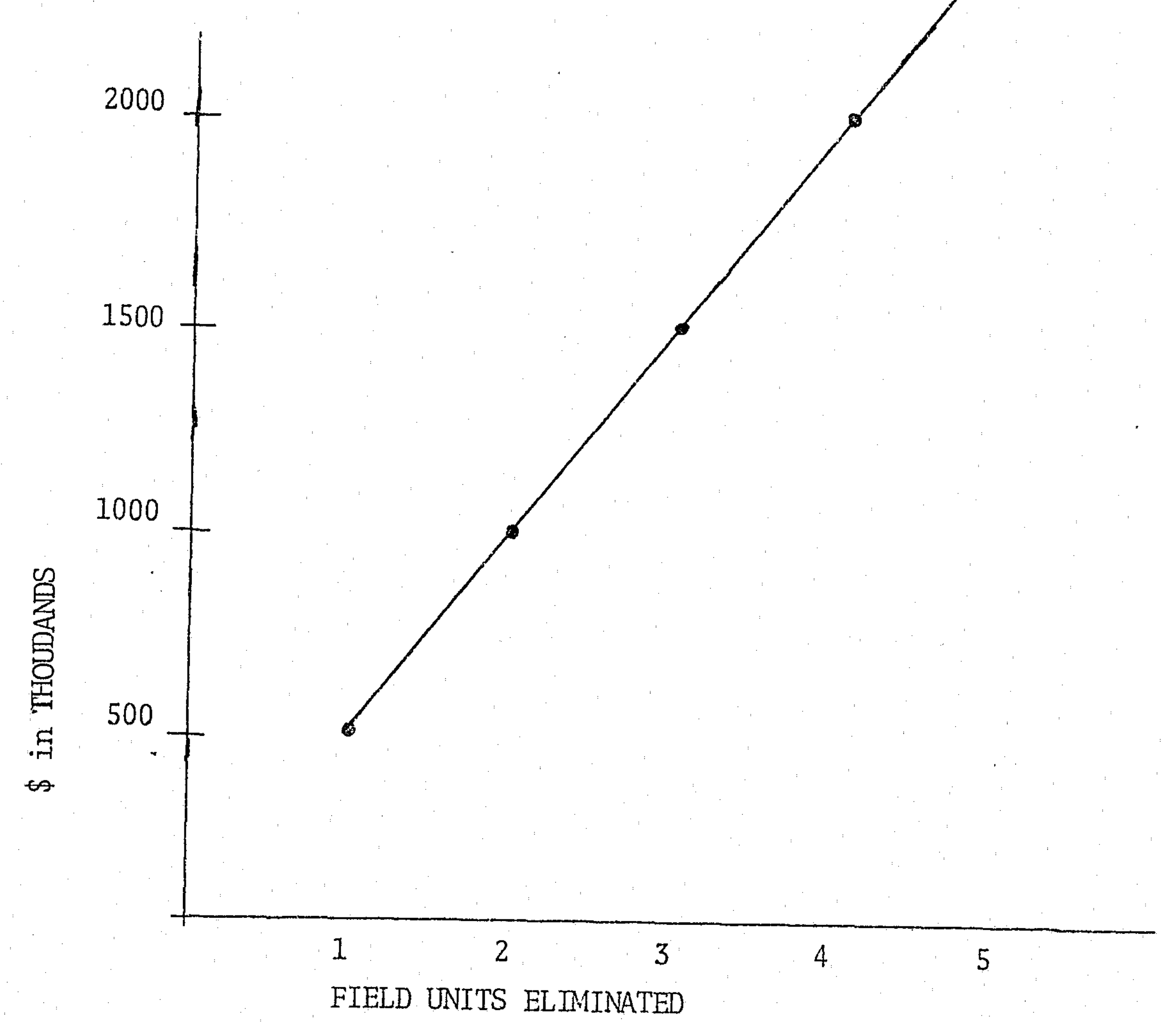

Figure 47 Capital Investment Justifed by Elimination of Field Units

APPENDIX A

FUNCTION FLOW DIAGRAM OF MAJOR SUBSYSTEM ACTIVITIES OF OPD COMMAND/CONTROL SYSTEM

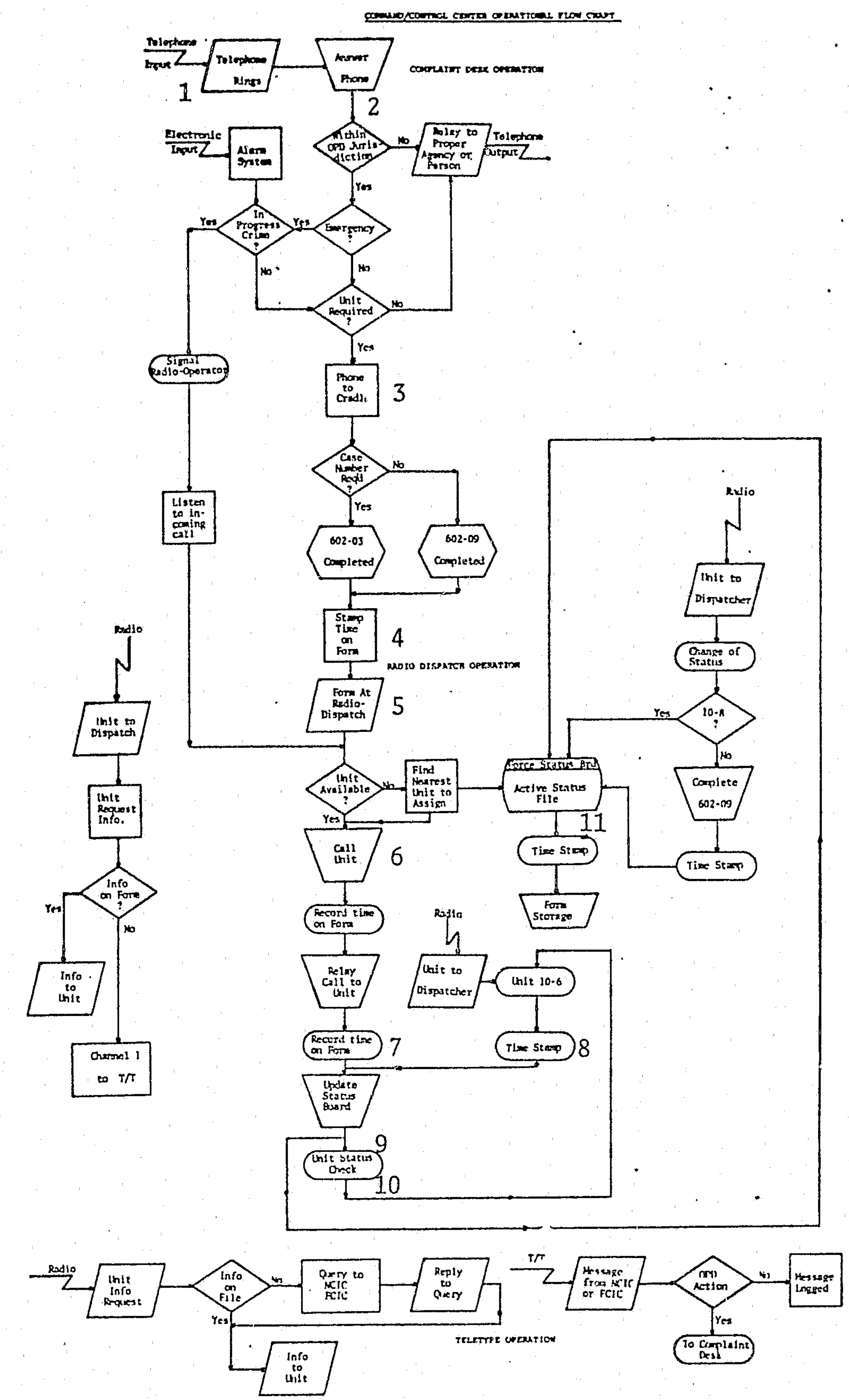

Figure 48: Function Flow Diagram of Major Subsystem Activities of OPD Command/Control System.

APPENDIX B

COMPLETED DATA COLLECTION SURVEY FORMS

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier (x)
Component Supplier ( )
Other ______

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research x
Design x
Prototype x
Operating Systems ______

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity ( )
- Dead Reckoning ( )
- Trilateration ( )
- Triangulation (x)
- Loran-Decca-Omega ( )
- Other) Sign-post

Vehicle Electronics uses car radio as coded beacon

Base Station Electronics three or four station DF system

Data Link phone lines for simplest configuration - slow speed, bidirectional data link for more advanced system

Base Station Display CRT situation display with text

Dispatchers CRT Console Display Similar to above

System Computer one of several mini's such as PDP-11

System Documentation not yet complete

Personnel Training minimal required

System Equipment Maintenance (annual) minimal required

Additional System Capabilities growth to complete status monitoring, information retrieval and command and control

Oth er Notes on System

4. SYSTEM PERFORMANCE DATA DESIGN (x) FIELD TEST (x) (Partial)

Accuracy better than 1,000 feet

Capacity Unlimited

Update Time 30 Vehicles/Sec.

Frequency shares police channels

Band Width 5 KC

Power Levels standard police radios

Sites 3 or 4 depending on terrain

Coverage Area depends on site geometry

Advantages 1) automatic, 2) reduced vehicle electronics, and 3) data link compatible

Limitations reduced accuracy in congested area with tall buildings

May we use this information in our report? Yes (x) No ( )

May we contact you for more details? Yes (x) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes ( ) No ( )

Comments We would be interested in discussing the program further to see if our developmental equipment could be used in your evaluation.

Name Harold Wing Title Mgr., Municipal Systems

Organization Sanders Associates, Inc.

Address 95 Canal Street, Nashua, N.H. 03060

Phone (603) 885-6457 Signature H. Wing

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier (X)
Component Supplier (X)
Other System Design and Checkout

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research X

Design X

Prototype X

Operating Systems None

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity (X)
- Dead Reckoning ( )
- Trilateration ( )
- Triangulation ( )
- Loran-Decca-Omega ( )
- Other

Vehicle Electronics Passive label

Base Station Electronics Teletypewriter or as desired by customer

Data Link telephone lines

Base Station Display to customer specified

Dispatchers CRT Console Display customer specified

System Computer HP 2100A

System Documentation Small manual

Personnel Training Two hours

System Equipment Maintenance (annual) Factory replacement

Additional System Capabilities See attached

Oth er Notes on System Must be designed to customer requirement. See attached

4. SYSTEM PERFORMANCE DATA DESIGN (X) FIELD TEST (x)

Accuracy To within signpost location plus deadreckoning
Capacity Unlimited
Update Time every signpost passing
Frequency C band
Band Width less than 500 Hz
Power Levels 1 milliwatt
Sites customer specified
Coverage Area signposts in grid
Advantages See attached

Limitations No extensive operating exprience
No limitations based on limited field tests.

May we use this information in our report? Yes (x) No ( )

May we contact you for more details? Yes (x) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes ( ) No ( )

Comments We will provide a system to your specification under contract We have available hardware off-the shelf. However, it would take us about 3 months to implement your requirements into a software program suitable for use in your application. See attached for system details.

Name James Constant Title President

Organization RCS ASSOCIATES, INC.

Address 1603 Danbury Dr., Claremont, CA

Phone (714) 624-1801 Signature [signature]

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier ( )
Component Supplier ( )
Other Software - Computer graphics

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research ____
Design ____
Prototype ____
Operating Systems ____

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity ( )
- Dead Reckoning ( )
- Trilateration ( )
- Triangulation ( )
- Loran-Decca-Omega ( )
- Other ____

Vehicle Electronics ____

Base Station Electronics ____

Data Link ____

Base Station Display static CRT and interactive CRT experience; extensive computer mapping.

Dispatchers CRT Console Display inter-active graphics experience

System Computer

System Documentation

Personnel Training

System Equipment Maintenance (annual)

Additional System Capabilities

Oth er Notes on System

4. SYSTEM PERFORMANCE DATA DESIGN ( ) FIELD TEST ( )

Accuracy

Capacity

Update Time

Frequency

Band Width

Power Levels

Sites

Coverage Area

Advantages

Limitations

May we use this information in our report? Yes (X) No ( )

May we contact you for more details? Yes (X) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes (X) ~~No (X)~~ → if cost reimbursable

Comments

Extensive experience in design & implementation of computer graphics displays for decision making; includes major data base manipulation (1970 census; County Business Patterns) and computer systems design + application

Name Thomas C. Miles Title VP Marketing

Organization Applied Urbanetics, Inc

Address 1701 K St NW Wash DC 20006

Phone 202-628-7800 Signature TC Miles

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

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Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier (✓)
Component Supplier (✓)
Other ______

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research: Transportation Control Laboratory

Design: yes

Prototype: yes

Operating Systems: Bendix Transportation Control Lab; Morgantown Personal Rapid Transit; Surface Transportation Test Facility

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity (✓)
- Dead Reckoning (✓)
- Trilateration ( )
- Triangulation ( )
- Loran-Decca-Omega ( )
- Other ______

Vehicle Electronics: Two types
1. Passive marker or car borne local transmitter
2. Dead reckoning position report

Base Station Electronics: Two types
1. Hardwired space division multiplexer
2. Serial data receiver and decoder

Data Link: 1. Hardwired
2. Inductive communications

Base Station Display: 1. Road mimic display
2. CRT

Dispatchers CRT Console Display
1. CRT
2. CRT

System Computer: 1. Bendix 9000 minicomputer
2. Bendix 9000 computer

System Documentation: 1 Drawings complete

Personnel Training: 1. We have faculty and prepare manuals

System Equipment Maintenance (annual): TBD

Additional System Capabilities ______

Oth er Notes on System ______

4. SYSTEM PERFORMANCE DATA DESIGN (✓) FIELD TEST (✓)

Accuracy	1. ± 9 inches	2. ± 12 ft
Capacity	1. 528 cars	2. 528 cars
Update Time	1. 1/2 sec	2. 1/2 sec
Frequency	1. NA	2. 95 and 121 KHZ
Band Width	1. NA	2. ± 10 KHZ
Power Levels	1. NA	2. 3 watts per antenna
Sites	1. Expandable	2. Expandable
Coverage Area	1. Expandable	2. Expandable
Advantages	Low cost, reliable	

Limitations: -

May we use this information in our report? Yes (✓) No ( )

May we contact you for more details? Yes (✓) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes (✓) No ( )

Comments You are invited to review our full scale test facility where automatic vehicle locators are under development and test

Name Thomas J. Trexler Title Manager Transportation Test Facility

Organization Bendix Aerospace Systems Division

Address 3300 Plymouth Road, Ann Arbor, Mich.

Phone 313-665-7766 Signature J. J. Trexler

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier (✓)
Component Supplier (✓)
Other ______

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research ______

Design ✓

Prototype ✓

Operating Systems ______

3. SYSTEM DESCRIPTION

Sensor Type
Officer Update ( )
Proximity ( )
Dead Reckoning ( )
Trilateration (✓)
Triangulation ( )
Loran-Decca-Omega ( )
Other ______

Vehicle Electronics
VHF FM Xmtr & antenna

Base Station Electronics
VHF Receiver

Data Link X-Band μwave

Base Station Display
X-Y Plotter

Dispatchers CRT Console Display
None

System Computer
Varian 520i

System Documentation
FER for DOT
see Sam Rondberg @ DOT

Personnel Training.
N/A

System Equipment Maintenance (annual)
Not Avail

Additional System Capabilities
Two-way voice &/or digital data transmission when used with existing communications eq.

Oth er Notes on System
Easily expandable for no. of vehicles & base stations

4. SYSTEM PERFORMANCE DATA DESIGN ( ) FIELD TEST ( )

* Accuracy 800-1250' CEP in Philadelphia DOT tests
Capacity ≈ 1,000 vehicle
Update Time ≈ 1 per min
Frequency VHF to UHF carrier (244 MHz used)
Band Width 12.5 KHz nominal
Power Levels 10 watt nominal
* Sites 4 or more
Coverage Area 10 x 10 mile area (or greater)
Advantages Minimum complexity. Low cost
Adaptable to use of existing communications eq. for polling etc.
Limitations
* Function of building densities etc.

May we use this information in our report? Yes (✓) No ( )

May we contact you for more details? Yes (✓) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes ( ) No ( ) Want more information

Comments The prototype system has been successfully tested in El Cajon, San Diego & Montclair California. Also Philadelphia Pa & Washington D.C.

Name Frank R. Brown Title Project Manager

Organization Cubic Industrial Corp.

Address 4285 Ponderosa Ave

Phone (714) 279 7400 Signature Frank R. Brown

for :
R.L. deKozan
Manager of Marketing
Cubic Industrial Corp.

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier ( )
Component Supplier ( )
Other See attachment

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research X

Design X

Prototype X

Operating Systems

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity (X)
- Dead Reckoning ( )
- Trilateration ( )
- Triangulation ( )
- Loran-Decca-Omega ( )
- Other

Vehicle Electronics See 3a of attachment

Base Station Electronics See 3b of attachment

Data Link See 3 c of attachment

Base Station Display Lighted display board with status and location light indicators.

Dispatchers CRT Console Display Standard computer inquiry keyboard with CRT display.

System Computer Almost any small commercially available computer.

System Documentation Primarily standard mini-computer and computer inquiry unit documentation.

Personnel Training No more than a few hours to operate.

System Equipment Maintenance (annual) Primarily emitter frequency and power output checks and sensor sensitivity checks.

Additional System Capabilities Officer in trouble silent alarm

Oth er Notes on System See 3k of attachment.

4. SYSTEM PERFORMANCE DATA DESIGN (X) FIELD TEST (X)

Accuracy See 4a of attachment.
Capacity Virtually unlimited.
Update Time Within a second after vehicle passes sensor.
Frequency 27 MHz preferably.
Band Width 25 KHz maximum.
Power Levels 50 to 100 milliwatts
Sites See 4g of attachment
Coverage Area Whatever area is equipped with sensors.
Advantages See 4i of attachment.

Limitations See 4i of attachment.

May we use this information in our report? Yes (X) No ( )

May we contact you for more details? Yes (X) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes (X) No ( )

Comments We would be interested in setting up a breadboard system provided our costs are covered. We would be willing to agree to an arrangement to reimburse the City later from profits out of sales of the system to other cities if they materialize.

Name E. Ray Knickel Title President

Organization CAPITAL SCIENTIFIC CORPORATION

Address 2607 Connecticut Avenue, N.W., Washington, D.C. 20008

Phone AC 202/667-3100 Signature

ATTACHMENT TO ORLANDO POLICE DEPARTMENT
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS QUESTIONNAIRE

Note: Answers to questions that require more space than was available on the questionnaire form are provided on this attachment. The answers are numbered to correspond with question numbers on the questionnaire form.

1. We would design and build the prototype units and we would prepare specifications for the entire system which could then be put out for bid.

3a. Vehicle Electronics consists of a very low power AM or FM transmitter (emitter) preferably operating in the 27 MHz band. The transmitter would be modulated by a discrete combination of audio tones that may be either continuous or pulsed depending on the system requirements.

3b. Base Station Electronics consists of tone filters and logic circuitry which make up decoder for decoding the emitter identification code and may also include a decoder for decoding the sensor identification code.

3c. Data Link would consist of very simple relatively insensitive receivers (sensors) installed on police or fire call boxes and at other locations as necessary, preferably connected to base station by land lines. In the case of radio call boxes, a radio link could be used for the data.

3k. System could operate in conjunction with intrusion detectors at certain locations or temporarily installed on premises that are suspected of being targets for burglary.

4a. Accuracy is determined strictly by the spacing of the sensors. Hence the system can be built to any desired accuracy and different areas of the system can have different accuracy capabilities as required.

4g. Police and or fire call boxes plus other sensor locations as required.

4i. The advantages of the system are as follows:

(1) Requires virtually no spectrum since only a few audio channels at most would be required for even the largest system and these same channels can be reused all over the country.

(2) Equipment in vehicle is extremely simple since no storage or logic is required in vehicle unit.

(3) If a call box system is in existance or a cable TV system with an available data channel is in existance, implementation of the system can be achieved at a minimum of cost per vehicle.

(4) Silent alarm for officer in trouble can be provided.

(5) Covert tracking of suspect vehicles could be achieved by means of microminiaturized emitter units.

(6) System could operate in conjunction with a burglar apprehension system with intrusion detection sensors tripping emitters to edentify location of the break-in.

(7) Accuracy can be varied in different parts of the system as required.

4j. The main limitation to this system is that the initial cost would be high if there is no existing call box system or if there is no CATV system in the city that has a data channel available for this use.

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier (X)
Component Supplier (X)
Other CONSULTING ACTIVITIES

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research X

Design X

Prototype X

Operating Systems X

3. SYSTEM DESCRIPTION

Sensor Type
Officer Update ( )
Proximity (X)
Dead Reckoning ( )
Trilateration ( )
Triangulation ( )
Loran-Decca-Omega ( )
Other

Vehicle Electronics PROVIDE FOR LOCATION (AND STATUS) INFORMATION RECEPTION, STORAGE, COMPARISON AND TRANSMISSION TO THE COMMAND CENTER.

Base Station Electronics PROVIDE FOR LOCATION (AND STATUS) INFORMATION RECEPTION/TRANSMISSION, STORAGE, COMPARISON, AND TRANSFER TO DISPLAYS & INFORMATION SYSTEM PROCESSING EQUIPMENT.

Data Link RADIO FREQUENCY AND/OR LAND LINES DEPENDING ON SYSTEM REQUIREMENTS.

Base Station Display SPECIALLY CONFIGURED FOR EACH APPLICATION. AUTOMATICALLY PROVIDES LOCATION & STATUS OF MOBILE UNITS WITHOUT OPERATOR INTERVENTION.

Dispatchers CRT Console Display PROVIDES FOR ALERTING DISPATCHER ON EXCEPTION BASIS; TOGETHER WITH CAPABILITIES FOR CALL-UP OF LOCATION, STATUS, AND/OR UNIT NUMBER.

System Computer VARIES WITH SYSTEM SIZE, & COMPLEXITY OF INFORMATION SYSTEM REQUIREMENTS. MINI-COMPUTER FOR C^2 SYSTEM.

System Documentation COMPLETE SYSTEM DOCUMENTATION IS PROVIDED, INCLUDING OPERATIONS MANUALS, MAINTENANCE MANUALS, SYSTEM TRAINING MANUALS, ETC.

Personnel Training PERSONNEL FULLY TRAINED IN USE OF SYSTEM. DISPATCHER AND OFFICER TRAINING EMPHASIZED.

System Equipment Maintenance (annual) DEPENDS ON SIZE & COMPLEXITY OF SYSTEM. SYSTEM ELECTRONICS CAN READILY BE MAINTAINED AT CARD LEVEL BY NON-TECHNICIANS.

Additional System Capabilities SYSTEM HAS CAPABILITY FOR TWO-WAY DIGITAL INFORMATION TRANSFER/DISPLAY, AS WELL AS FOR EMERGENCY SIGNALLING BY OFFICER AWAY FROM UNIT.

Oth er Notes on System SYSTEM IS FULLY OPERATIONAL AND CAN BE LEASED AT THIS TIME.

4. SYSTEM PERFORMANCE DATA DESIGN ( ) FIELD TEST (X)

Accuracy AS REQUIRED. 100 FEET MAXIMUM ACCURACY.

Capacity NO LIMIT ON MOBILE UNITS

Update Time NORMALLY 200 UNITS/MIN

Frequency NORMALLY 150MHZ; 450 MHZ

Band Width 3000 KHZ

Power Levels ALL POWER (INCLUDING RF) MEETS ORLANDO REQUIREMENTS.

Sites NOT REQUIRED WITH PROXIMITY SYSTEM

Coverage Area ENTIRE GEOGRAPHIC AREA

Advantages LOWEST COST SYSTEM AVAILABLE. LOCATION ACCURACY CAN BE VARIED THROUGHOUT GEOGRAPHIC AREA TO MEET OPERATING REQUIREMENTS. SYSTEM IS READY FOR IMPLEMENTATION.

CONTINUED

2 OF 3

May we use this information in our report? Yes (X) No ( )

May we contact you for more details? Yes (X) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes (X) No ( )

Comments SYSTEM IS READY FOR DEMONSTRATION, TESTING, EVALUATION, AND IMPLEMENTATION.

Name R. B. FLEMING Title VICE PRESIDENT

Organization PRODUCTS OF INFORMATION SYSTEMS

Address 225 PAULARINO AVENUE

Phone (714) 540-9772 Signature R. B. Fleming

ORLANDO POLICE DEPARTMENT SURVEY FORM
AUTOMATIC PATROL VEHICLE LOCATOR SYSTEMS
FLORIDA GOVERNOR'S COUNCIL ON CRIMINAL JUSTICE

PROJECT 72-14-09

ATTENTION: Dr. Robert D. Doering,
Florida Technological University
College of Engineering
P. O. Box 25000
Orlando, Florida 32816

1. INTEREST OF OUR FIRM IN AUTOMATIC VEHICLE LOCATOR (AVL) SYSTEMS

System Supplier (✓)
Component Supplier (✓)
Other ______

2. EXPERIENCE OF OUR FIRM IN AVL SYSTEMS

Research: Four Years Directly Related Research
Design: Signpost to Vehicle Sensor Systems
Prototype ______
Operating Systems ______

3. SYSTEM DESCRIPTION

Sensor Type
- Officer Update ( )
- Proximity (✓)
- Dead Reckoning ( )
- Trilateration ( )
- Triangulation ( )
- Loran-Decca-Omega ( )
- Other ______

Vehicle Electronics: Ultrasonic Receiver/Electronics

Base Station Electronics: Signpost Type Ultrasonic Transmitter Station

Data Link: Radio From Motor Vehicle To Central Station. Memory At Motor Vehicle Holds Info. On Last Signpost Passed Until Polled.

Base Station Display ______

Dispatchers CRT Console Display ______

System Computer ______

System Documentation ______

Personnel Training ______

System Equipment Maintenance (annual) ______

Additional System Capabilities: Compatible Technique For Transmitting From Vehicle to Signpost.

Other Notes on System: Uses Acoustic Propagation At Ultrasonic Frequencies For Controlled Coverage. Designed For Multiple Inexpensive Units On Signposts, etc.

4. SYSTEM PERFORMANCE DATA DESIGN ( ) FIELD TEST ( )

Accuracy: ± 25 Feet of Signpost
Capacity: No Limit
Update Time: Seconds
Frequency: 20 - 60 kHz
Band Width: 5%
Power Levels: Under 5 watts.
Sites: Telephone poles, Signposts, Buildings, etc.
Coverage Area: 100 Foot Length of Roadway
Advantages: Predictable Area Coverage Without Mutual Interference, Inaudible, Low Cost, Reliability
Limitations: Moderate Range Requires Multiple Units For Full Coverage [But Low Cost Each].

May we use this information in our report? Yes (✓) No ( )

May we contact you for more details? Yes (✓) No ( )

Is your firm interested in setting up a breadboard system for evaluation in Orlando Yes (✓) No ( )
If Paid For

Comments ARA, Inc. has been studying application of ultrasonics for AVL as company sponsored research program. Have discussed possibilities with DOT. Experimental results indicate feasibility of AVL using acoustics, for signpost type system with ultrasonic transmissions to moving vehicles which in turn radio data on post just passed to central storage center on command.

Name G. W. Renner Title President

Organization Applied Research Associates, Inc.

Address P. O. Box 138 Dorchester, Mass. 02125

Phone 617 288-8975 Signature G W Renner
3/9/73

APPENDIX C

FTU PROTOTYPE PROXIMITY SYSTEM DESIGN AND MAINTENANCE INFORMATION

LIST OF SYMBOLS

A	Ampere
mA	Milliampere (10^{-3} A)
AC	Alternating Current
AM	Amplitude Modulated
BCD	Binary Coded Decimal
C	Capacitor
D	Diode
DC	Direct Current
e	Exponential
f	Farad
μf	Microfarad (10^{-6} f)
pf	Picofarad (10^{-12} f)
I	Current
ID	Identification
K	Relay
L	Coil
ln	Natural Logarithm
NC	Normally Closed
NO	Normally Open
P	Power
Q	Transistor
RMS	Root-Mean-Square
R	Resistor

S	Solenoid
R	Transformer
t	Time (in seconds)
t_w	Time Interval
V	Voltage (volts)
V_b	Base Voltage
V_{be}	Base-Emitter Voltage
V_{ce}	Collector-Emitter Voltage
V_{cc}	Voltage Source
VR	Variable Resistor
w	Angular Frequency
Z	Impedance (ohms)
Ω	ohm (unit of resistance)
kΩ	Kilohm (10^3 ohms)
MΩ	Megohm (10^6 ohms)

THE ENCODER-TRANSMITTER POWER SUPPLY

The power requirements of the encoder-transmitter units are fairly flexible. The devices will function acceptibly at supply voltages ranging between nine and fifteen volts DC and only provide a current drain of approximately sixty milliamperes. In order to insure that the transmitter's output levels are relatively constant, some form of voltage regulation of the power supplies' output is required. A simple circuit to achieve this is shown in Figure 49.

This circuit provides zener-diode regulation of the output voltage to insure its stability at a level of twelve volts DC. The voltage supplied to the regulator circuit is provided by a capacitively-filtered full-wave rectifier arrangement connected to the secondary winding of a power transformer, as shown. The analysis and design of this type of circuit is straight forward.

It has already been established that the output voltage provided by the supply will be twelve volts DC. It is also known that the encoder-transmitters require a current of sixty milliamperes. The power supply, then, will see an effective impedance across its output terminals of

$$Z_o = \frac{V_o}{I_o} = 200 \text{ ohms} \qquad (1)$$

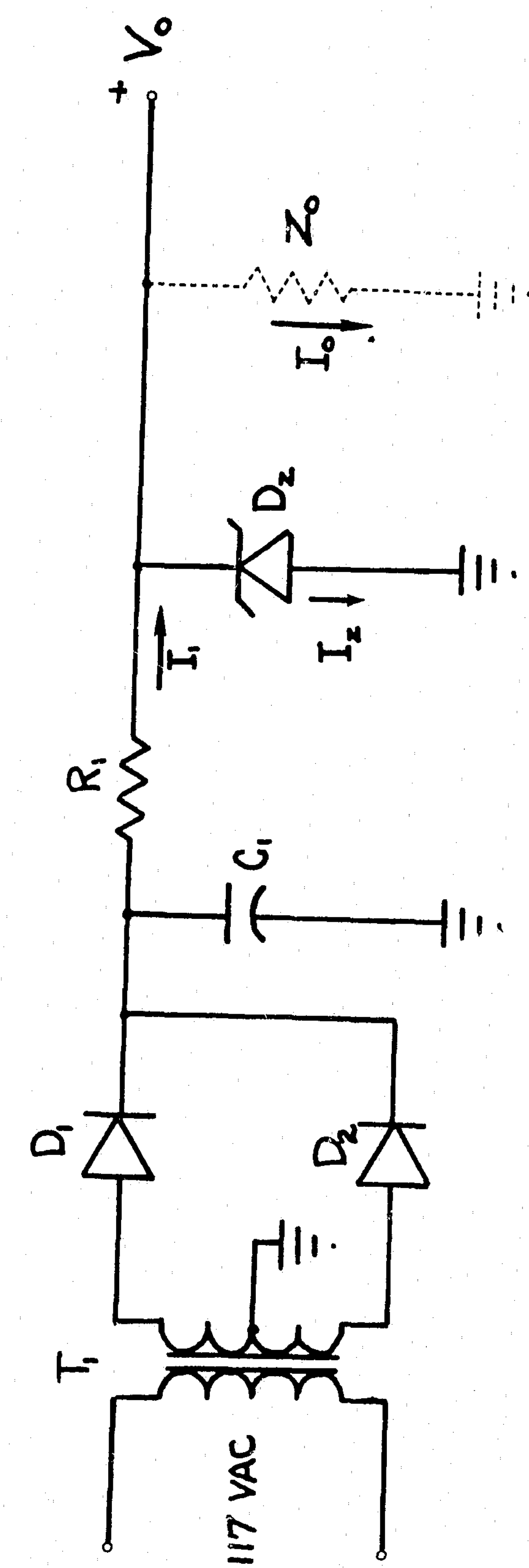


Figure 49 Encoder - Transmitter Power Supply

The selection of a zener-diode for the regulator circuit is also aided by knowledge of the current drain at the output. It can be estimated that the current sink for good regulation provided by the zener-diode, assuming negligible supply or load variation, need only be a few milliamperes. From this, the diode's power rating can be computed.

$$P_z = V_z I_z = V_o I_z = 120 \text{ milliwatts} \qquad (2)$$

Knowing this, the zener-diode selected for use in the circuit was a 1N963, which is capable of dissipating four-hundred milliwatts of power and will provide a constant output of twelve volts DC when its sink current is 10.5 milliamperes. At this given sink current the forward resistance of the diode is specified as 11.5 ohms. This resistance causes a small additional voltage drop across the diode, the value of which is

$$V_{rz} = I_z R_z = 0.121 \text{ volts} \qquad (3)$$

Since this value is small compared to that of the specified zener voltage, it will be neglected in the remaining calculations.

Resistor R_1 performs the function of dropping any additional voltage developed by the rectifier circuit that is above the twelve volt output level. In order to determine its value, the, the filtered output voltage of the rectifiers must be known.

The power transformer used is rated at a 25.2 volts AC center-tapped secondary voltage with a current drain of one ampere. It would be expected, the, that the anode of each rectifier would be supplied 12.6 volts AC with the transformer's center-tap grounded. This would indeed be the case of the current required by an encoder-transmitter were one ampere. Since its current drain is much less than this, however,

further consideration must be given the problem.

A transformer's performance is limited by a number of internal losses that grow more prominent at higher power output levels. It can therefore be expected that a transformer's output voltage will be slightly higher at low current drains than at high current drains. By placing a load across the secondary of this particular transformer which was similar to that provided by an encoder-transmitter unit and regulator circuit, it was found that the actual measured output of the transformer was fifteen volts AC with respect to its grounded center-tap. Using this voltage, then, the values of the rest of the components of the circuit may be computed.

If the small forward voltage drops across the rectifiers are neglected, it is seen that the voltage applied to the filter capacitor will be a full-wave rectified sine wave whose period is 1/120 second and whose RMS value is fifteen volts AC. From this the peak voltage can be computed as

$$V_p = V_{RMS}\sqrt{2} = 21 \text{ volts} \qquad (4)$$

This voltage, applied to a capacitor with no additional load, would provide a filtered output of 21 volts DC. With a load, however, the capacitor will discharge somewhat during the time interval between the peaks of the rectified sine wave, the extent of the discharge being related to the impedance of the load and the capacitance of the capacitor by the equation

$$V = V_p e^{-t/Z_L C} \text{ volts} \qquad (5)$$

where V is the voltage after a time interval of t seconds, Z_L is the load impedance and C is the capacitance of the capacitor.

From this equation it can be seen that if the product of Z_L and C is much greater than the value of t, the magnitude of V will be comparable to that of V_p, and little discharge of C will occur. In the given circuit,

$$Z_L = \frac{V_o}{(I_o + I_z)} \approx 121 \text{ ohms} \tag{6}$$

It is also known that the period of the rectified sine wave is 1/120 second; therefore, the value of t can not be greater than 1/120 second, which is the time interval between two successive voltage peaks. Assuming that if the product of Z_L and C is at least ten times the value of t it can be said that

$$Z_L C \gg t \tag{7}$$

and it is found that

$$Z_L C > 10(1/120) \text{ seconds}$$

Solving for C yields

$$C \approx 10(1/120)(1/121) \text{ farads} \tag{8}$$

or,

$$C \approx 690 \text{ microfarads}$$

The value of C used in the circuit was 1000 microfarads, so it can be assumed that the average DC voltage across the capacitor will be fairly close to the peak value of 21 volts.

The value of R_1, then, will simply be

$$R_1 = (V_p - V_o) / I_1 \tag{9}$$

or,

$$R_1 \approx 130 \text{ ohms}$$

The power supplies constructed using the component values computed here performed as expected, and provided fairly well regulated DC voltages of slightly greater than twelve volts DC to the encoder-transmitters. It should be noted here that the use of the multitude of approximations in the preceding calculations was directly due to the fact that the power demands of the encoder-transmitter units are quite flexible and any power supplies that approximate these demands could be used.

THE DISPLAY UNIT POWER SUPPLY

The power supply requirements of the map curcuitry are much more rigid than those of the encoder-transmitter devices, and hence a more elaborate form of power supply regulation is required. In order to eatablish just what these requirements are, some characteristics of the map curcuitry must be examined.

The control circuitry of the map is comprised to TTL integrated-circuit logic devices. The supply voltages required by some of these devices can be set between 4.50 and 5.50 volts DC, but others require a voltage closer to the five volt level, typically between 4.75 and 5.25 volts DC. It would therefore be logical to fix the power supply voltage as close to a constant 5 volts DC level as possible.

It is also necessary to remove any ripple or fluctuations in the output voltage of the supply. This is a consequence of the sensitivity of the devices used, since voltage fluctuations may be interpreted by these devices to be a presentation of data that would alter the logical sequence of their operations. For suitable operation of the map, this simply can not be allowed.

The last thing that must be known is the total current that will be required by the map circuitry. This is not too difficult to determine since the specification sheets of the devices used state both the typical and maximum supply currents required by the devices in normal operation. A summation of these individual currents indicates that the total map current will not be greater than approximately 1.1 amperes and will most probably be closer to a typical value of 657

milliamperes than to the maximum value of 1.1 amperes. Armed with this knowledge, the power supply can be designed, and its diagram is shown in Fig. 50.

The secondary winding of the power transformer selected is rated at 12.6 volts AC center-trapped with a current drain of 2.0 amperes. The actual output voltage with a load approximately equal to that presented by the map was 7 volts RMS AC, the peak value of which is close to 10 volts. If adequate filtering is provided, the output to the voltage regulator section will be close to 10 volts DC. Before a value for C_1 can be calculated, however, the requirements of the voltage regulator must be determined.

To simplify construction of this power supply and at the same time insure a stable, low noise output voltage, a Signetics LM109 regulator circuit was obtained. Some of the specifications are listed in the manufacturer's description of the device, as follows.

> The LM109 and LM209 are complete 5V regulators fabricated on a single silicon chip, They are designed for local regulation on digital logic cards, eliminating the distribution problems associated with single-point regulation. The devices are available in two common transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1A.
>
> The regulators are essentially blow-out proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating. (1)

The output voltage of this device is specified as being between 4.7 and 5.3 volts DC, these values being the limits for the worst possible operation of the device. Since it is assumed that the regulator will be used within the range of its normal operating conditions,

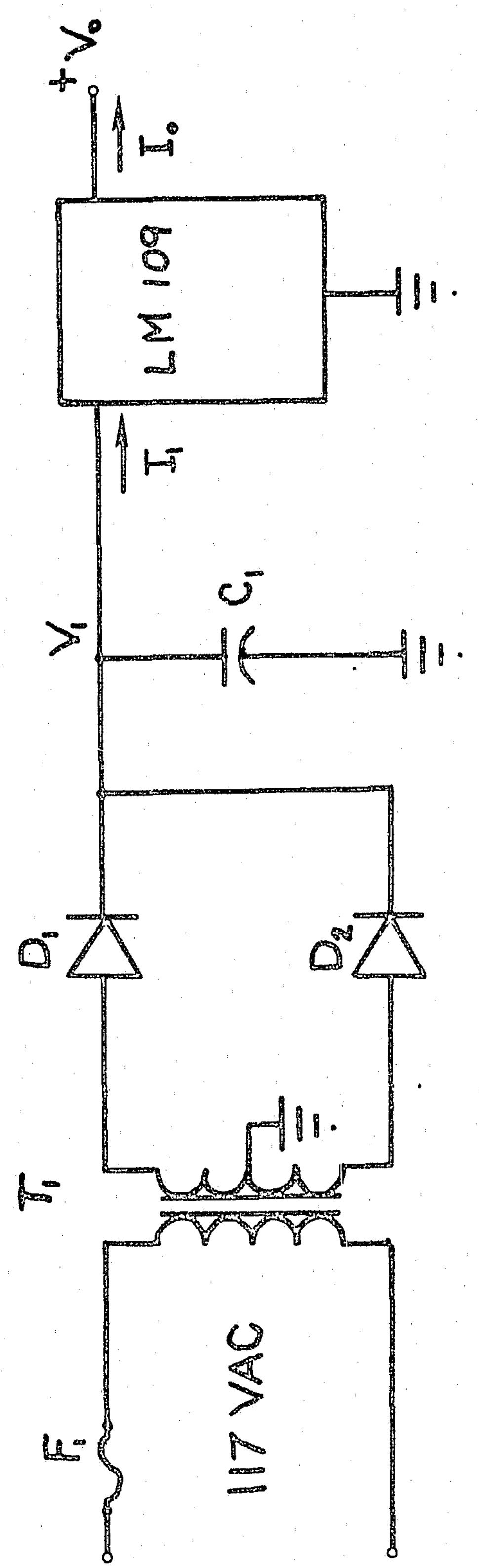


Figure 50: Visual Display Unit Power Supply

it may be further assumed that the device's output will be very near its typical value of 5.05 volts DC for inputs ranging between 7 and 25 volts DC. The quiescent current of the device will never exceed a value of 10 milliamperes and the output current is limited to a value slightly greater than one ompere, which makes it more than acceptable for use in this power supply circuit. (1)

The typical level of output noise for this device is specified as 40 microvolts for frequencies ranging between 10 hertz and 100 kilohertz. This level is sufficiently small so that it will never be interpreted as data by any of the TTL chips used in the map's logic circuitry. (1)

The value of the filter capacitor, C_1, may be determined using the parameters of the LM109 regulator circuit. Assuming that the regulator module is fairly effecient device, the current drain at its input should be very similar to the sum of its output current and quiescent current, or,

$$I_I \approx I_o + I_q. \qquad (1)$$

To determine the minimum value of C_1 the maximum output current drain must be used. This results in an input current of

$$I_I \approx (1.1 + 0.01) \text{ amperes},$$

or,

$$I_I \approx 1.11 \text{ amperes}.$$

For ease of calculation and because it is expected that the current required by the map will never actually reach a value of 1.1 amperes, this can be rouned off so that

$$I_1 \approx 1 \text{ ampere.}$$

This represents a load across C_1 of

$$Z_L \approx V_1/I_1 \qquad (2)$$

or,

$$Z_1 \approx (10/1) \text{ ohms} \approx 10 \text{ ohms}$$

In order to insure proper operation on the regulator, the input voltage may not be allowed to drop below 7 volts DC. To under-rate this power supply, it is assumed that the voltage input to the regulator will not be allowed to drop below 9 volts DC. The input waveform to the regulator, then, will resemble that of Fig. 51.

The amount of discharge per given length of time t is

$$V_1 = V_p e^{-t/Z_L C_1}, \qquad (3)$$

or, taking the ln of each side,

$$\ln(V_1/Vp) = -t/Z_L C_1. \qquad (4)$$

The only undetermined quantities in this equation are t and C_1. So, in order to establish a value for C_1, t must be determined. Considering one peak of the original sine wave of Fig. 51, it is seen that

$$V_1 = V_p(\sin wt_2) \qquad (5)$$

where

$$w = 2\pi f = 120\pi \text{ rad/sec.} \qquad (6)$$

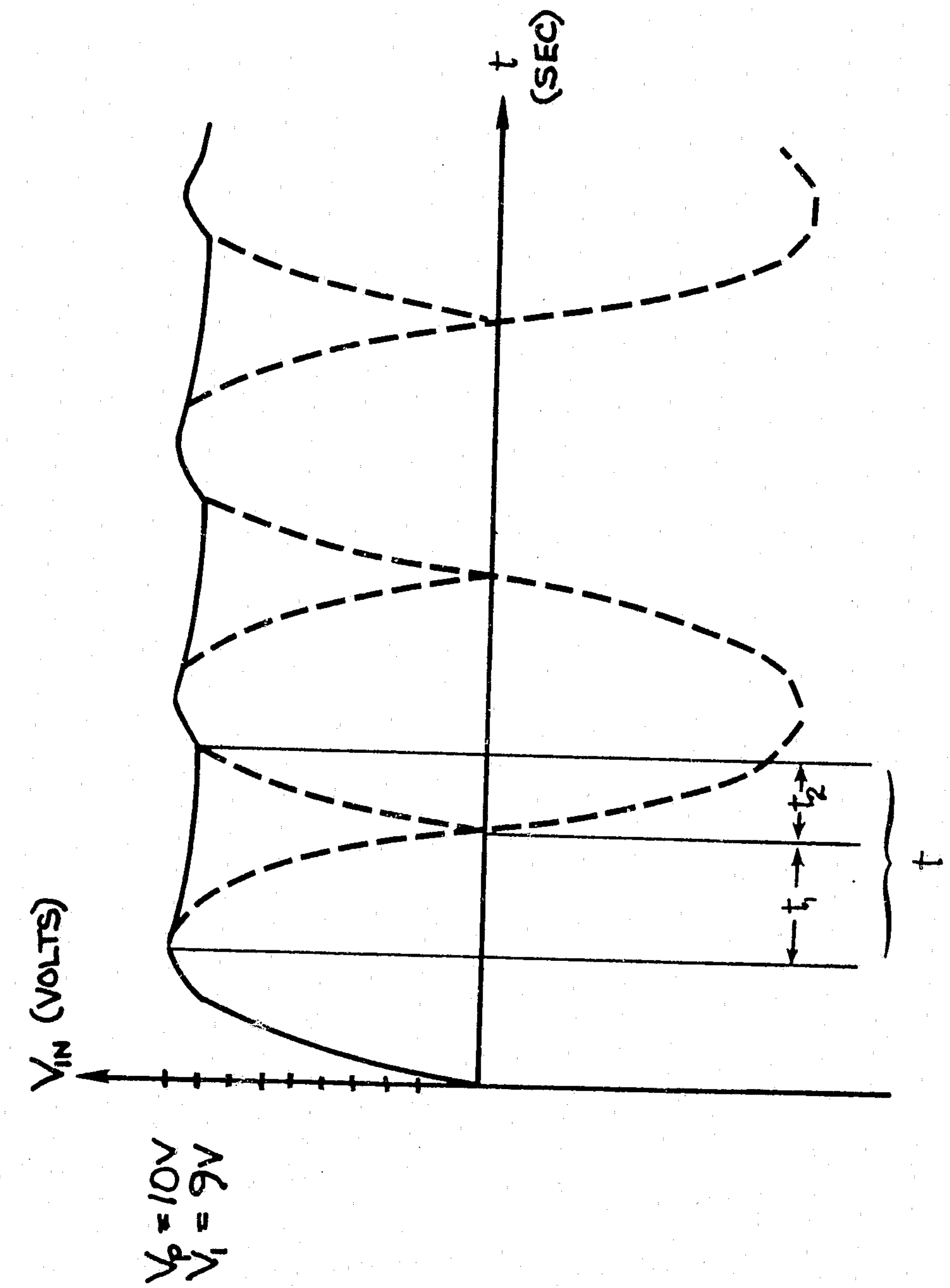


Figure 51: Power Supply Output Waveform

Subtituting the desired results into this yeilds

$$\sin wt = V_1/V_p = 9/10 = 0.9,$$

or,

$$wt_2 = 0.356\pi \text{ radians}$$

and,

$$t_2 = 0.003 \text{ seconds.}$$

Therefore it takes 0.003 seconds for the original sine wave to go from zero to nine volts. The discharge time of C_1 will be equal to the time it takes for the restified sine wave to drop from 10 volts to ground potential and rise back to nine volts, or

$$t = t_1 + t_2, \qquad (7)$$

Where t_1 is simply equal to the time required for the original sine wave to complete one-fourth of a cycle, or

$$t_1 = 1/4(1/f) = 1/4(1/60) = 1/240 \quad 0.004 \text{ seconds.}$$

Therefore,

$$t \approx 0.007 \text{ seconds.}$$

Substituting this value into equation (4) yields

$$\ln(9/10) \approx -0.007/10C_1,$$

or,

$$C_1 \approx 6{,}670 \text{ microfarads}$$

In the actual circuit a value of 10,000 microfarads was used and the output of the voltage regulator held constant at a level very close to 5 volts DC with the map circuitry in full operation. As a safety feature, the input to the power transformer was fused. The maximum current in the primary of the transformer may be determined to be

$$I_p = V_s I_s / V_p, \qquad (8)$$

where V_s is the secondary voltage, I_s is the maximum current in the secondary, and V_p is the primary voltage. Thus,

$$I_p = (7.0)(1)/117 \text{ ampere} \approx 60 \text{ milliamperes}$$

and the fuse used had a current rating of 0.1 ampere.

THE VISUAL DISPLAY UNIT

The most complex of the devices used in this project is the visual display unit (VDU), which performs a number of simultaneous functions in the process of converting data presented to it into a humanly-comprehensible visual-information display. Thanks to modern solid-state technology and the advent of integrated circuits, however, the design and construction of such a device is not as formidable as it might first appear. A basic working knowledge of the operation of TTL integrated-circuits and an examination of the configuration of the circuits used is needed to understand the operation of the VDU. The circuitry involved is shown in Figures 52-55 and will be discussed here in some detail.

The data input to the VDU, as has been previously mentioned, consists of high or low impedance levels on ten separate intersection lines and two separate car lines. The normal levels of the intersection lines are high, while the normal levels of the car lines are low, and it is desired to convert the information they carry when not in these states into a form compatible with the operation of the VDU's circuitry.

To facilitate the design of this system, it would be helpful to reduce the number of data lines. And, since there are only two car lines as opposed to ten intersection lines, the logical procedure would

be to leave the car lines as they are and find some way to reduce the number of intersection lines. An easy way to accomplish this is to encode the data on the intersection lines into a binary code, as shown by Table 1.

TABLE 1

LINE NUMBER REDUCTION CODES

Input Lines Active	Intersection Levels 1 2 3 4 5 6 7 8 9 10	Output Levels a b c d
.....	1 1 1 1 1 1 1 1 1 1	1 1 1 1
1	0 1 1 1 1 1 1 1 1 1	1 1 1 0
2	1 0 1 1 1 1 1 1 1 1	1 1 0 1
3	1 1 0 1 1 1 1 1 1 1	1 1 0 0
4	1 1 1 0 1 1 1 1 1 1	1 0 1 1
5	1 1 1 1 0 1 1 1 1 1	1 0 1 0
6	1 1 1 1 1 0 1 1 1 1	1 0 0 1
7	1 1 1 1 1 1 0 1 1 1	1 0 0 0
8	1 1 1 1 1 1 1 0 1 1	0 1 1 1
9	1 1 1 1 1 1 1 1 0 1	0 1 1 0
10	1 1 1 1 1 1 1 1 1 0	0 1 0 1

As can be seen from Table 1, each intersection has been given a number that can now be used to identify that particular intersection. The intersection numbers range from one to ten and, from Boolean Algebra, it is known that any one of these numbers can be represented by a four-bit binary code. In this case, since the line levels are normally characterized by a high impedance, the non-active lines will be represented by 1's, while lines carrying information will be represented by 0's. Thus, if a 0 appears on intersection line 5 the output code (with the least-significant-digit at the right) will be 1010, while a 0 on line 7 will provide the output code 1000, and so on.

A physical means of converting the ten inputs to four outputs in the coded form indicated is required. This is accomplished through the use of the diode encoding matrix of Figure 52.

This matrix can be designed directly from the information presented in Table 1 if the 0's are interpreted as shorts to ground and the 1's are interpreted as open lines. Then Table 1 indicates that if an input line is shorted to ground, its corresponding output lines must also be shorted to ground. This can be accomplished by placing diodes between the input lines and their corresponding output lines, as shown. Thus, if a 0 appears under a certain input line in the table, the output lines in that same row represented by 0's must be connected to the input lines through the diodes. If this is done systemmatically, the diode matrix of Figure 52 will be obtained.

It should be noted here that thus far a zero level on a data line has represented significant information. Unfortunately, the logic circuitry used in the bulk of the VDU requires that high levels be used to represent significant data. This means that the information on the output lines of the diode matrix must be inverted. This is accomplished simply by feeding each line into both inputs of four separate nand-gates. Since the output of each gate is the inverse of its inputs when both inputs are the same, their outputs represent data which is compatible with the rest of the VDU circuitry.

The inverted output lines of the diode matrix are connected directly to the parralleled inputs of the two quadruple bistable latches that serve as the system's memory unit. The operation of these

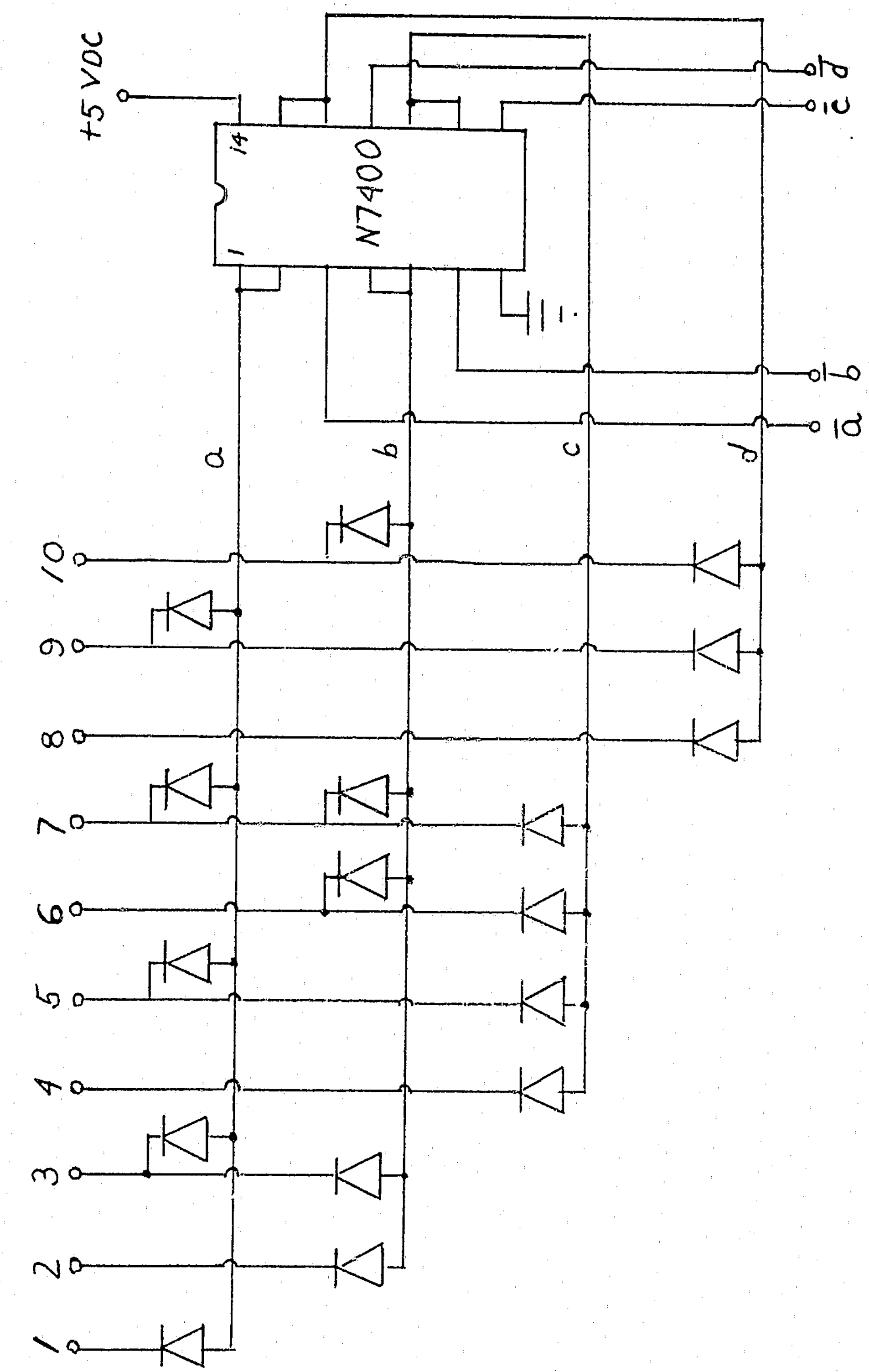


Figure 52: Diode Encoding Matrix

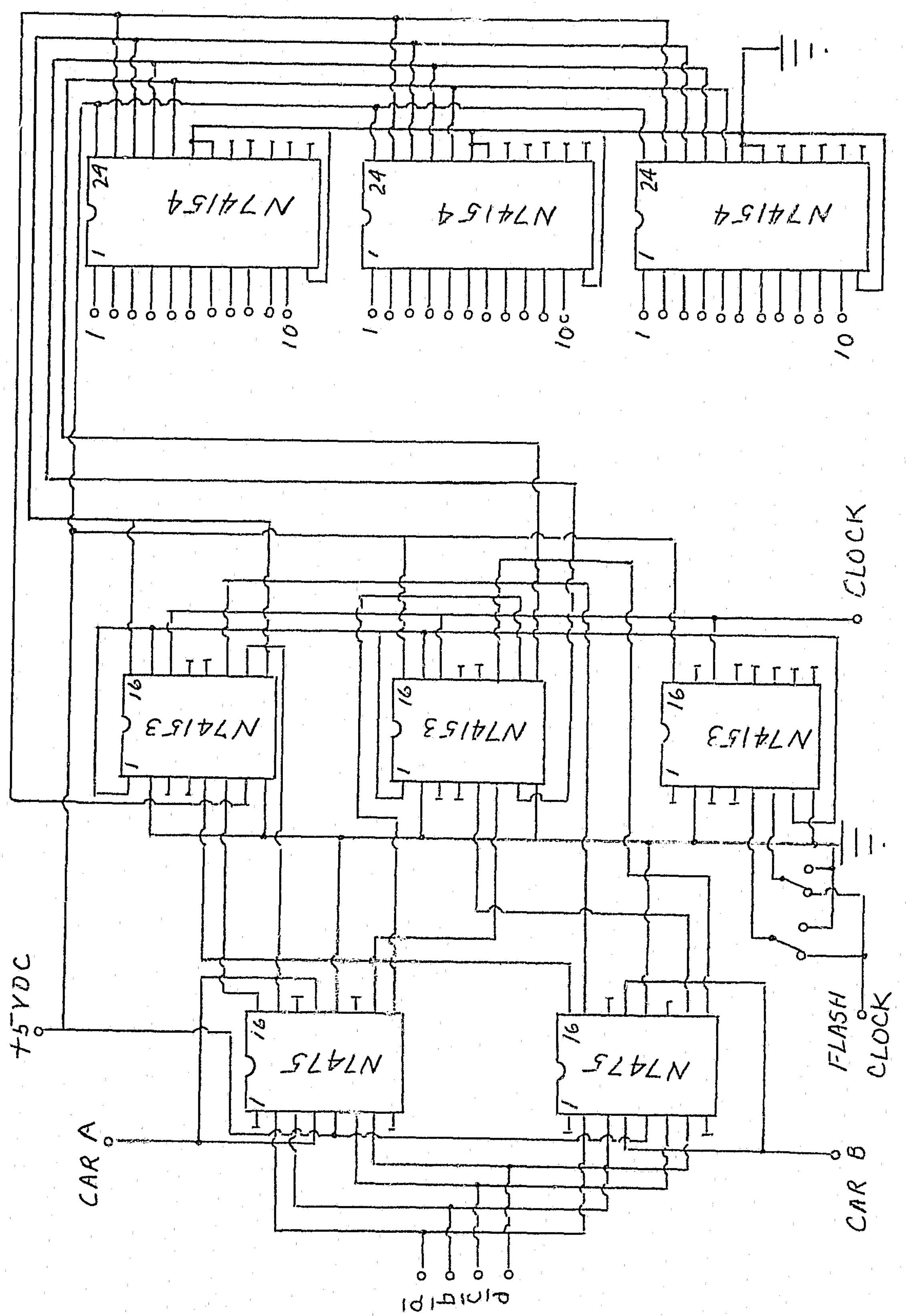


Figure 53: Intersection Location Logic Circuitry

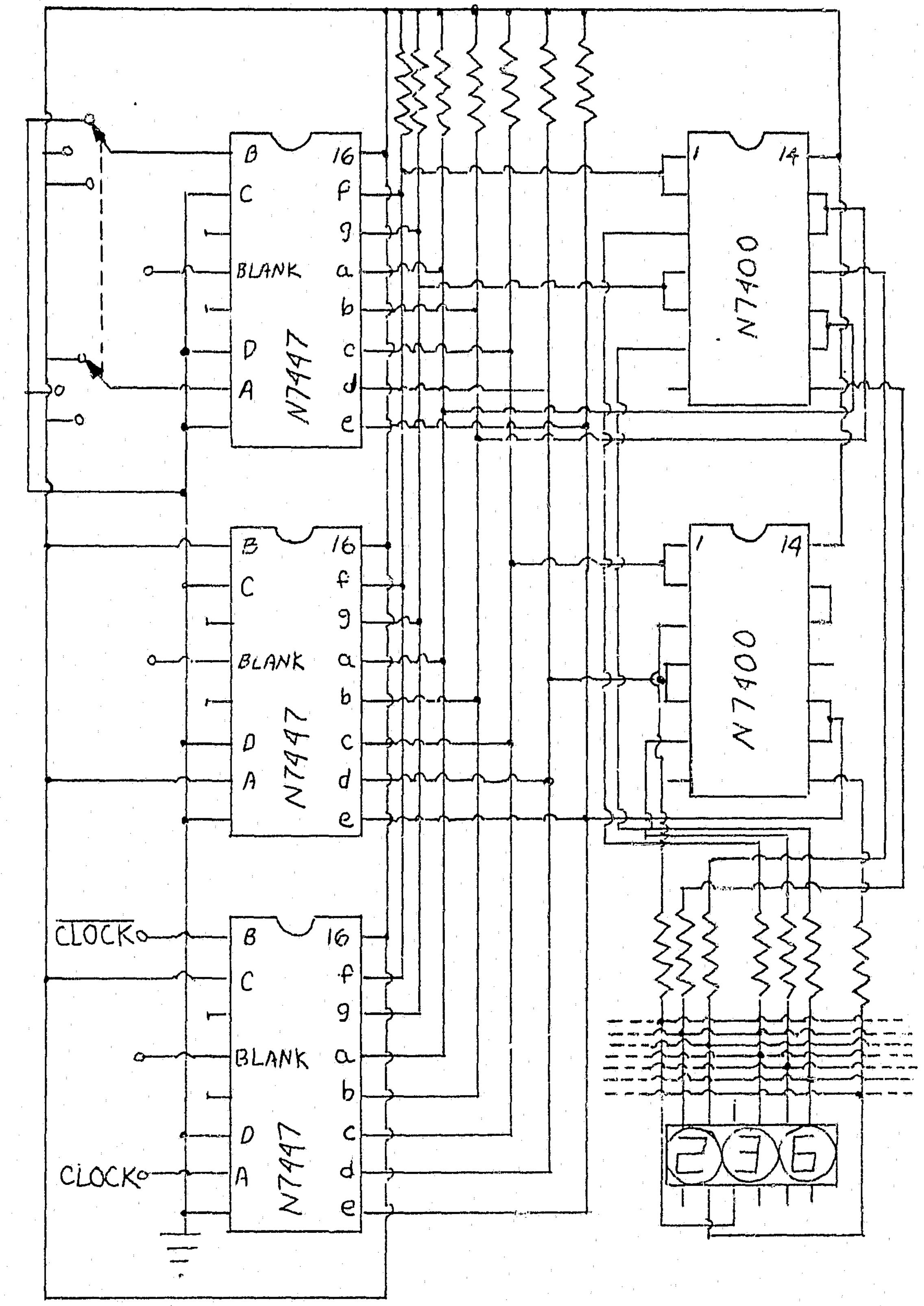


Figure 54: Number Generating Circuitry

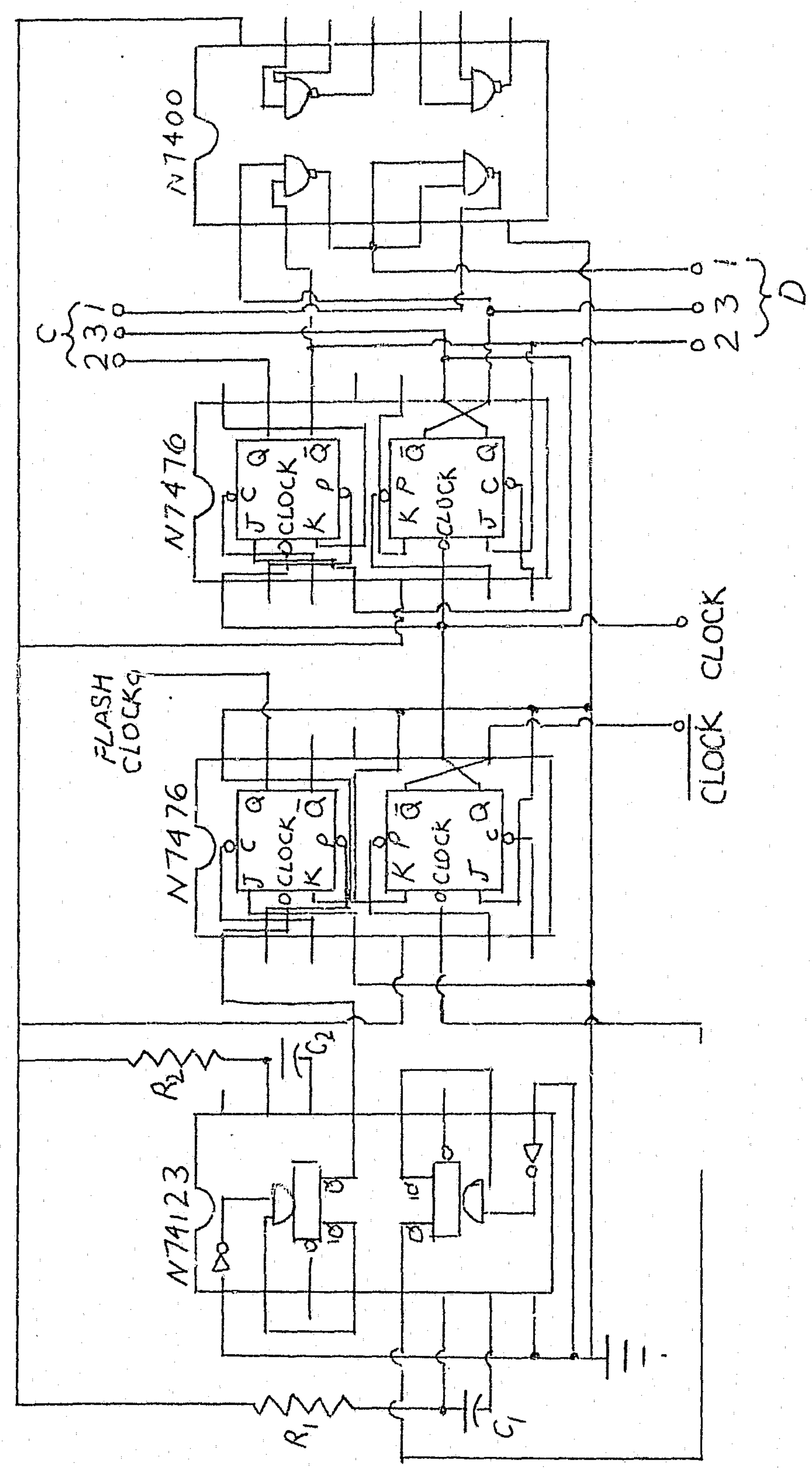


Figure 55: Pulse Train Generator

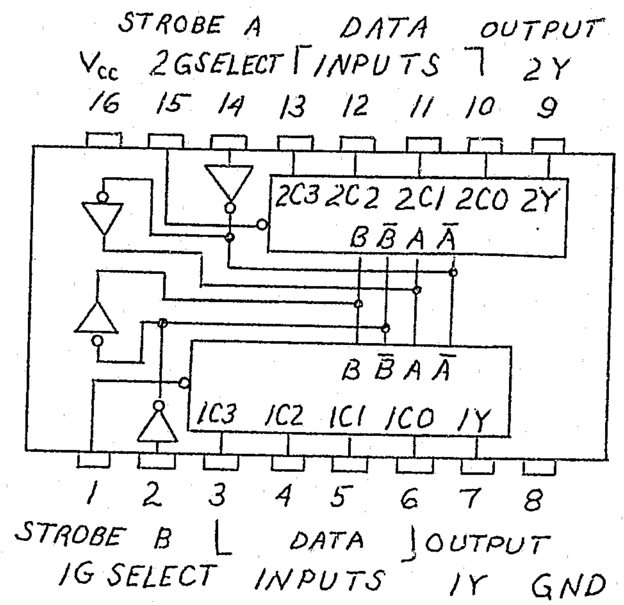
latches is outlined in the manufacturer's description of the devices.

The N7475 is a nomolithic, quadruple bistable latch with complementary Q and $\overline{Q}$ outputs. Information present at a data (D) input is transferred to the Q output when the clock is high, and the Q output will follow the data input as long as the clock remains high. When the clock goes low, the information (that was present at the data input at the time the transition occurred) is retained at the Q output until the clock is permitted to go high. (2)

Thus if one car data line is connected to each latch package's clock input, a pulse on a particular car line will enable that package to store the four bits of information present at its inputs. This information will then be present at the Q outputs of the package until the next clock pulse occurs.

The next section of the VDU's circuitry performs the function of multiplexing the information at the outputs of the two memory packages so that it can be alternately displayed on the map. This is done through the use of two dual four-line-to-one-line data selector/multiplexer packages. Each multiplexer is a device that has four inputs and one output plus two additional lines, the data on which determines which input will be made available at the output. The internal configuration of a multiplexer package is shown in Figure 56 along with a truth table describing its operation. (5)

To achieve the desired results, the output lines from the car A memory were fed into the devices' C0 inputs while the output lines from the car B memory were fed into the C1 inputs. From the truth table it can be seen that if the devices' B select lines are tied to ground, a pulse train of alternating high and low levels at the A seleect lines will cause the C0 and C1 inputs to alternately appear



TRUTH TABLE

ADDRESS INPUTS		DATA INPUTS				STROBE	OUTPUT
B	A	C0	C1	C2	C3	G	Y
X	X	X	X	X	X	H	L
L	L	L	X	X	X	L	L
L	L	H	X	X	X	L	H
L	H	X	L	X	X	L	L
L	H	X	H	X	X	L	H
H	L	X	X	L	X	L	L
H	L	X	X	H	X	L	H
H	H	X	X	X	L	L	L
H	H	X	X	X	H	L	H

L → LOW LEVEL, H → HIGH LEVEL, X → IRRELEVANT

Figure 56: Multiplexer Configuration and Truth Table

at the devices' outputs. This is the desired result, and all that is necessary to achieve it is to provide a pulse train as specified to the A select lines. The pulse generator will be discussed later; right now, however, it might be interesting to notice how the flashing function, also a part of the multiplexing section, is performed.

From the truth table of the multiplexers it can be seen that the strobe input must be at a low, or ground, level or the outputs will all be low rather than identical to the selected data inputs. Suppose that the strobe inputs are connected to the data output of another multiplexer whose C0 and C1 inputs can either be switched to ground level or to a pulse train of alternating high and low levels. This multiplexer must also have its A select line connected to the clock that drives the other devices' A select lines, so that its output will be synchronized with theirs. Then, if both its C0 and C1 lines are switched to ground, the devices output will be a continuous low-level, enabling the information multiplexers to function continuously. If, however, one or both inputs are switched to a line carrying a pulse train, the device's output will alternate between high and low levels, which will, in turn, cause the outputs of the information multiplexers to drop from their normal data levels to a low level, which represents a zero output for that device. Thus, if the C0 line were tied to the pulse train line, the multiplexers would output their C0 data while the pulse is at zero level, but when it goes to a high level, the devices' outputs would be zero. It can be seen, then, that if the driving pulse train is very slow, say in the neighborhood of one pulse per second, the outputs will flash at a rate that will be noticable when the information is displayed on the map.

The next important section of the VDU's circuitry is that which decodes the information on the four multiplexer output lines and transforms it back to a single low level on one of ten separate output lines. The devices that perform this function are called four-line-to-sixteen-line decoder/demultiplexers, and it is necessary to have three of these, one for each digit of the cars' identification numbers, in the circuit.

The operation of these devices is very simple. Each package has four inputs, so the four lines from the multiplexer section are paralleled into each of the three packages. The output of each package, then, will be a low level on one of ten lines corresponding to the coded information presented to the device's inputs. Since all packages have the same input information, they will have low levels on the same output lines. Corresponding output lines from each package go to each of the three digits at each intersection on the map. Thus, the original intersection location information has been routed to the proper location on the Orlando area map.

At the intersection locations the three leads from the decoders are connected to the three cathodes of the three-digit seven-segment LED readouts. These readouts are manufactured by Hewlett-Packard and are specified as the 5082-7402 series, which are 0.11 inch high, seven-segment Gallium-Arsenide-Phosphorous readout devices. (3)

These devices have three cathode connections, one for each digit, and seven data lines that are common to each digit. Therefore, if it

is desired to display three different digits on the devices, they must be multiplexed in such a way that the cathodes are sequentially dropped to ground level so that only one cathode may be grounded at a time. Also, the information present on the seven data lines must be changed each time a cathode is grounded. If this is done rapidly enough, the visual effect will be that three different digits are being displayed simultaneously.

The accomplishment of this process is fairly simple. Each of the three decoder/demultiplexer devices has a pair of inputs which, when presented with a high level, will cause all its outputs to go to a high state. Therefore, if these inputs of only one decoder at a time are grounded, only that decoder will function and output a low level on one of its data lines. By sequentially causing this condition for each decoder, the result will be that the three LED cathodes at a particular intersection will be consecutively grounded, allowing the input data to be displayed separately for each digit. This is accomplished by applying three synchrous pulse trains to the three decoders, the time sequences of which are shown in Figure 57. The means of generating these pulses will be discussed later, along with the clock circuitry.

It is now necessary to examine the circuitry that presents data to the seven input lines of the LED readouts. The basic unit involved consists of three N7447 seven-segment decoder/driver integrated-circuits. These devices have four data inputs which receive binary coded information in high level significant form and convert it to

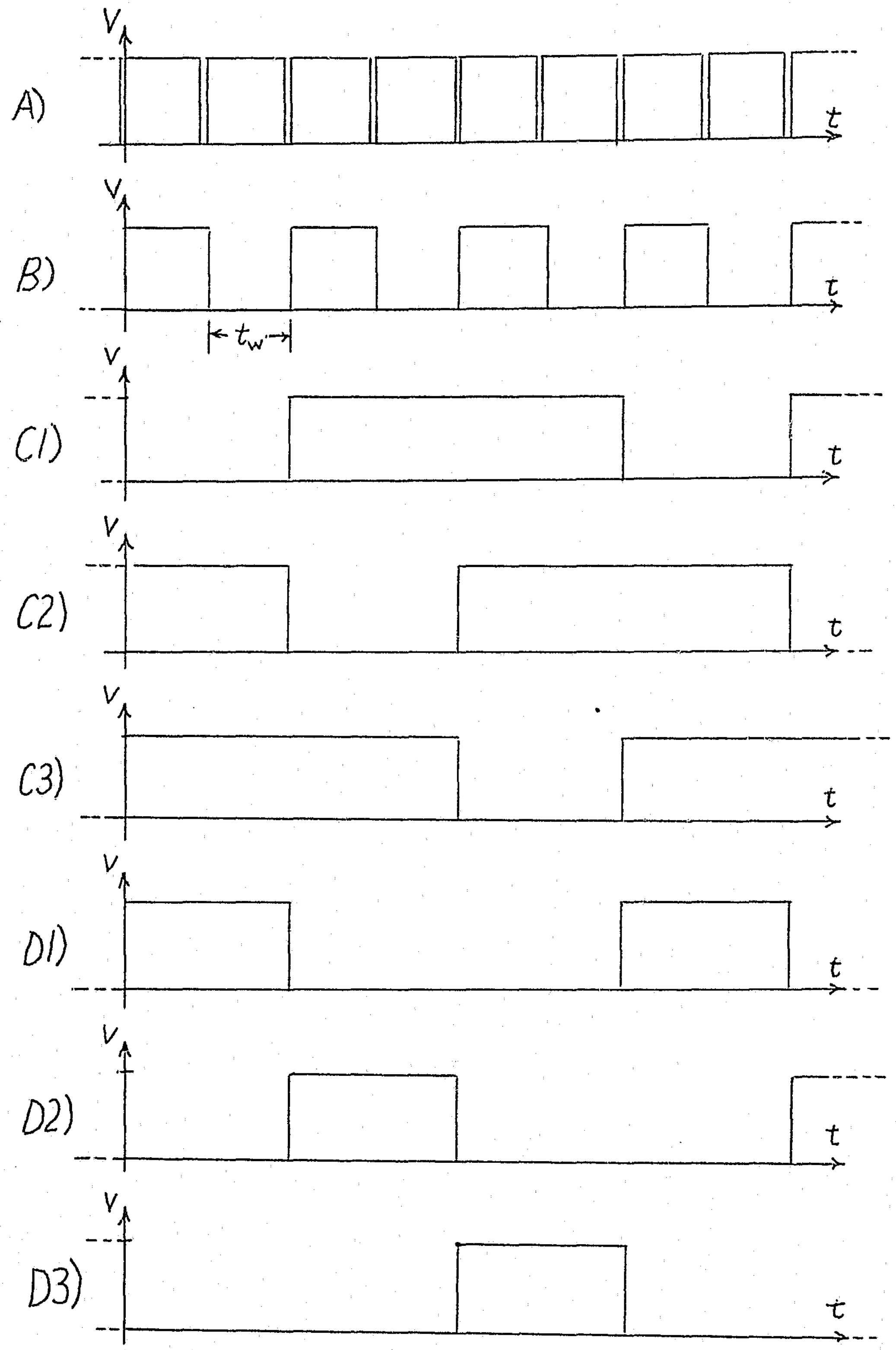


Figure 57: Pulse Trains: A) N74123 output, B) clock waveform, C) decoder/demultiplexer enabling waveforms, D) decoder/driver blanking waveforms.

a code on their seven output lines that causes a seven segment LED readout to display the arabic numerals 0 through 9. Also of importance to the operation of these units are their blanking inputs which, when a low level is applied, allow all the outputs to rise to a high state. It should also be noted here that these units have open-collector outputs, which means that the output lines must be connected to the positive voltage source through some value of limiting resistor before any data can be output. This restriction will be shown to be quite useful very shortly. (5)

The N7447 presents output data in low level significant form. Since, however, the LED readouts can only accept high level significant data, its outputs must be inverted. This is accomplished as shown in Figure 54.

The resistors shown are used to limit the current through each of the LED segments. If not for these resistors, the readouts would burn out quickly, since they have a very low forward resistance. The values of the resistors are determined by the maximum amount of current that the LED's will be allowed to conduct for the applied logic voltage of five volts DC. The resistances, then, were found to be

$$R = V/I_{max} = 5/(5x10^{-3}) \text{ ohms} = 1 \text{ kilohm}. \quad (1)$$

The method used to provide three different sets of data to the inputs of the LED's is a direct consequence of the fact that the decoder/drivers are open-collector devices. Realizing this, it is possible to parallel the outputs of the three units, if sufficient current limiting is provided by the collector resistors, as shown in Figure 54. The values of these resistors is determined by considering the current drain of each output of the decoder/drivers and the supply voltage. Or,

$$R = V/I_d = 5/(15x10^{-3}) \text{ ohms} = 333 \text{ ohms}. \qquad (2)$$

Now, if each of the three decoder/drivers has information at its input representing a different number, and two out of three of the devices are blandked at any given time, each of the three digits may be separately displayed. Since the devices require low level blanking signals, a set of three pulse trains like those shown in Figure 11 will produce the desired results. It should be noted that the pulse that brings each digit out of blanking occurs at the same time as the pulse that causes the intersection selection line for that same digit to drop to a ground state, but that the pulses are the inverse of each other. Therefore, these pulses can be provided by inverting the outputs of the pulse generator that provides the pulses for the intersection decoder/demultiplexers. This will be discussed more fully later.

Assuming, for the moment, that a black box is available to provide the necessary pulses for proper operation of the system, a method of differentiating between the numbers that identify car A and car B remains to be determined. This allows them to be alternately displayed. It is obvious that since only three decoder/drivers are being used, and are shared by both cars A and B, the information present at their inputs must be altered depending upon whether car A or car B is

being displayed. In this particular case this is easy to achieve since each car number only differs in the third digit. The first digit, as previously mentioned, is the shift digit, either a 1, or 2, or a 3. A simple switching arrangement, as shown in Figure 54 can be used to change these numbers. The second digit in each car number will be a 3, which is represented in four-bit binary-code as 0011, with the 1's representing high levels and the 0's representing low levels, the least-significant-digit again being at the right. By connecting the correct inputs to either ground or V_{cc} , this number can be permanently supplied to the decoder/driver.

In the case of the third digit, either a 5, represented by 0101, or a 6, represented by 0110, must be displayed. It is seen that the last two data bits are the same for each number, so they can be connected to V_{cc} and ground permanently. The first two digits must be changed, however, depending on which car number is being displayed. Therefore, when car A is being displayed, the first data bit must be a high level and when car B is being displayed it must be a low level. This can be accomplished by tying this input line directly to that which carries the clock pulses, since the clock line is high when car A is displayed and low when car B is displayed. The second data input bit must be low when car A is displayed and high when car B is displayed. This is the inverse of the clock pulse train, and is also available from the black box pulse generator. Thus, the numbers for car A and car B can be alternately displayed, as desired.

This completes the description of the logic circuitry that operates on the data presented to the inputs of the VDU. It should be noted that many of the important parameters of the individual devices used, such as fan in, fan out, rise time, and so on, have been neglected. This can be done by assuming that the devices will always be operated within the limits of their restricting conditions, since the most important information needed here was that concerning the most important information needed here was that concerning the actual operations of the devices. It is necessary now to examine the unit that provides the sequences of pulse trains required by the map circuitry, and the discussion of the VDU will be complete.

The basic sequence of operations that enables the pulse generator to create the necessary pulse trains is composed of three different but related steps. First, an impulse generator provides a series of equally spaced pulses, as shown in Figure 57. Next, these pulses are input to a JK flip-flop that converts them to a square wave whose period is equal to two of the individual pulse peridos. This square wave is, as has been previously mentioned, the clock signal that differentiates between cars A and B, and will be coupled to a synchronous divide-by-three network which provides the pulse trains required by the decoder/drivers and decoder/demultiplexers.

The impulse generator was constructed from an N74123 retriggerable monostable multivibrator, as shown by Figure 55. When this device is connected as shown, the values selected for R_1 and C_1 determine the time interval between the spikes in its output wave form. The equation for this time interval is given by the manufacturer as

$$t_w = 0.32R_1C_1(1 = 0.7/R_1) \tag{3}$$

where 0.32 and 0.7 are constants evaluated specifically for the N74123 integrated-circuit. (5)

It can be seen that for any large value of R_1, this will be approximately

$$t_w = 0.32\ R_1C_1 \tag{4}$$

so that if the period of the clock waveform is to be one millisecond,

$$t_w = (1x10^{-3})/2 = 0.5 \text{ millisecond}$$

and, selecting C_1 as one microfarad,

$$R_1 = t_w/0.32C_1 = 1.56 \text{ kilohms} \tag{5}$$

The functioning of the multivibrator itself can be seen by examining its configuration, also shown in Figure 55. Essentially, it is no more than a flip-flop driven by an AND-gate such that when the AND-gate receives two high signals the flip-flop will have a logical 1 at its Q output. It will remain in this state for the length of time t_w, and will then change state so that the logical 1 appears at the $\overline{Q}$ line, The $\overline{Q}$ line, however, is coupled back to one of the AND-gate's inputs, the other input being tied to ground through an inverter so that it always maintains a high level. Therefore, when the 1 appears at $\overline{Q}$, the AND-gate causes the flip-flop to return to its original state, for which the 1 appears at Q, with the result that the $\overline{Q}$ line stays in the logical 1 state for a very short period of time. Thus the impulse spike has bee produced, and the continuation of the process will result in the impulse train shown in Figure 57.

The conversion of this impulse train to the clock pulse train is quite simple and only requires the use of one JK flip-flop. The operation of the JK flip-flop is such that when its J and K inputs are tied to ground its output state will change each time the clock signal input to the device goes from a high level to a low level. Thus, if the Q output is high when one impulse appears it will go to a low level and remain there until the next impulse occurs, at which time it will return to a high level. This causes the clock pulse train, also shown in Figure 57.

The remaining circuitry of Figure 55, composed of two flip-flops and two NAND-gates, performs the function of producing the three synchronous pulse trains required by the decoder/drivers. The inverse of these signals, required by the decoder/demultiplexers, is also produced by this circuitry.

The design of this network can be derived from a knowledge of the demands that will be placed on it. First, it must have three separate and distinct sequential outputs. Realizing this, it can be seen that only two flip-flops will be required since each flip-flop has two such outputs and some combination of these outputs can be used to produce the desired three outputs. In this particular case it is assumed that one output will occur when both $\overline{Q}$ states are high, another when Q_1 is low and Q_2 is high. This is shown in Table 2 in relation to the clock pulses that will cause the state changes.

TABLE 2

FLIP-FLOP OUTPUT STATES

Clock Pulses	Q_1 Q_2	$\overline{Q}_1$ $\overline{Q}_2$
Before First Pulse	0 0	1 1
After First Pulse	1 0	0 1
After Second Pulse	0 1	1 0
After Third Pulse	0 0	1 1

Since the required sequence of outputs is now known, they can be made to occur by causing the J and K inputs of the two flip-flops to be in the correct states at the time each clock pulse occurs. These states are determined from the flip-flop's truth table, designated as Table 3.

TABLE 3

JK FLIP-FLOP TRUTH TABLE

t_n		$t_{n\ 1}$
J	K	Q
0	0	$\overline{Q}_n$
0	1	1
1	0	0
1	1	Q_n

Examination of this table allows the construction of another table, Table 4, which shows the J and K input conditions at the time of each clock pulse necessary to obtain the proper outputs after the clock pulses. From this table it can be seen that the K inputs must always maintain a zero level; therefore, they will be connected directly to ground. The J inputs, however, must be changed sequentially with each clock pulse.

TABLE 4

REQUIRED JK INPUTS

Pulse At Time t	Inputs At t	
Sequence	J_1 J_2	K_1 K_2
First pulse	0 1	0 0
Second pulse	1 0	0 0
Third pulse	0 0	0 0

At the time of the first clock pulse it will be assumed that Q_1 and Q_2 are both at zero level. After the pulse, the required output comditions of Q_1 and Q_2 are 1 and 0 respectively. To accomplish this J_1 must be at a zero level and J_2 at a high level. Since the levels of Q_2 and $\overline{Q}_1$ meet these requirements at the time of the pulse, J_1 and J_2 will be tied to them as shown. A continuation of this process shows that these two connections are all that is necessary to meet the requirements placed on the circuit. Thus, the Q output of the first flip-flop will provide one output line, that of the second flip-flop will provide another, and an AND operation on $\overline{Q}_1$ and $\overline{Q}_2$ provides the third. Since the $\overline{Q}$ outputs are the inverse of the Q outputs, the pulse trains required by the decoder/demultiplexers can be obtained directly from this circuit, as shown.

THE CAR UNIT

The radio relay unit mounted in the patrol car is the connecting link between the intersections and the radio dispatch room at police headquarters. As has been previously mentioned, it serves a double purpose. First, it receives the tones transmitted from the intersections and re-transmits them back to the police station. Secondly, it generates and transmits a tone that identifies the mobile unit in which the device is mounted.

Before actually designing the circuitry to accomplish these objectives, it is necessary to take a close look at the restrictions that will govern its operation. First of all, the control circuitry constructed must be compatible with that of the commercially made devices already obtained for use in the project. These devices, listed again here for convenience, are the Pace receiver, the tone encoder, and the police channel-four hand-transmitter. It is desired, then, that the circuitry designed will in no way alter the normal operation of these devices.

In order to avoid unnecessarily long interruptions of the traffic on channel four, it is also required that the radio relay unit's transmission time be kept within a time interval of one to two seconds. This length of time will enable the transmitted data to be available at the decoders in the radio dispatch room long enough to ensure their proper operation but will not seriously hamper communications on police channel four.

It is also desired that the radio relay unit only transmit data once while the car is in the proximity of a particular intersection. This is primarily an extension of the restriction concerning the interruption of channel-four transmissions, but is also warranted by the fact that the map circuitry only needs one signal from an intersection in order to establish a car's location and will store that location in memory until another signal is received. Therefore, another signal from the same intersection may be considered useless information and need not be transmitted.

Keeping all these restrictions in mind, it can be seen that a possible means of providing the desired functions would be to cause the presence of an intersection signal in the Pace receiver to trigger the tone generator and timing circuitry simultaneously. By this means both the intersection and car identification signals will be available to the hand transmitter at the same time, and will both be transmitted when the timing circuitry triggers the solenoid that actuates the press-to-talk switch. The necessary circuitry can now be designed.

The tone encoder, shown in Figure 58, has an internal relay that may be used to cause the device to begin oscillation; thus, if some means is provided to actuate this relay when an intersection signal is received, the encoder will begin to function and continue until the signal is removed. An examination of the Pace receiver's squelch circuitry, shown along with its pre-amplifier section in Figure 59, suggests a possible solution to the problem. (4)

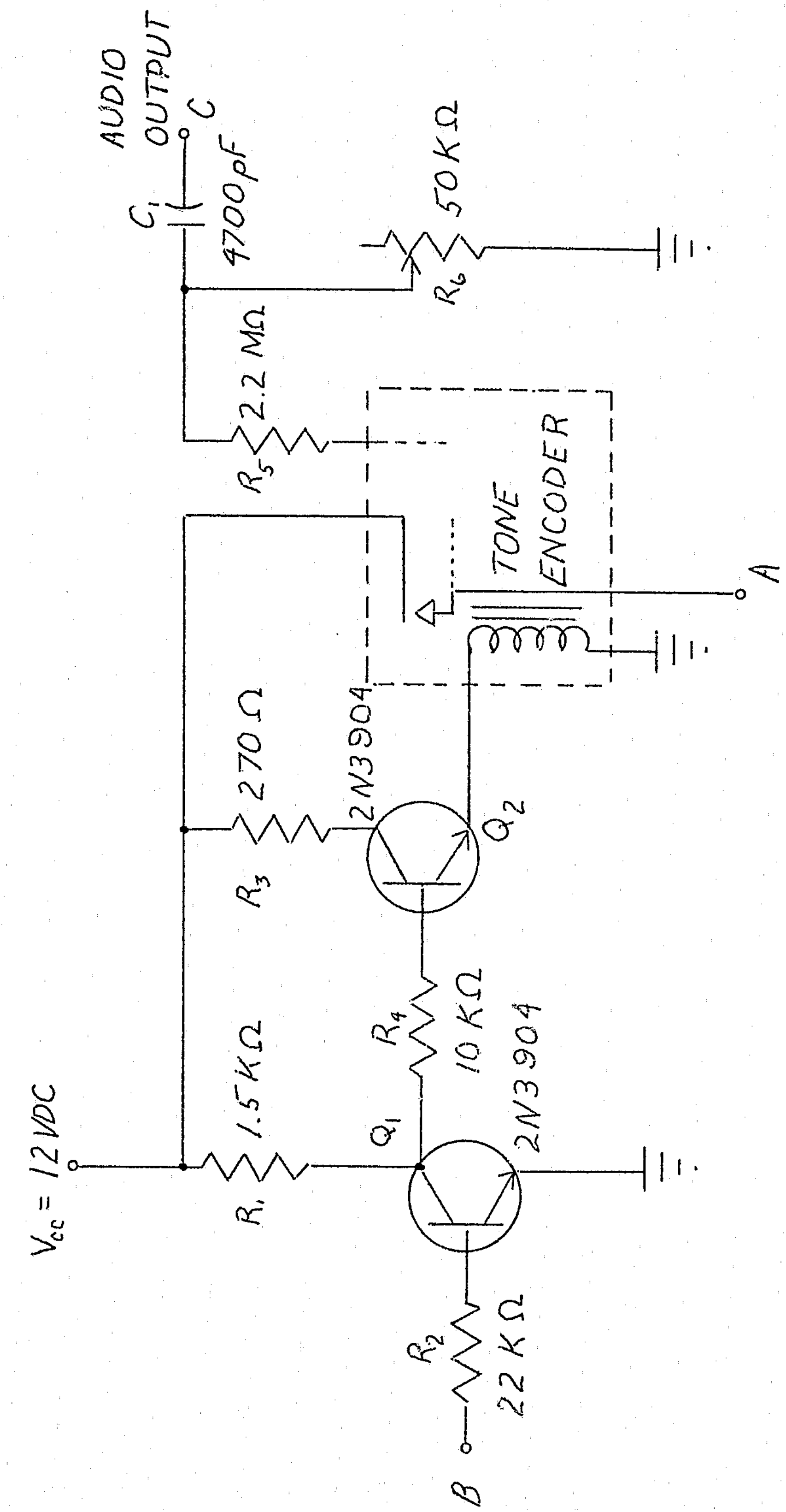


Figure 58: Encoder Trigger Circuitry

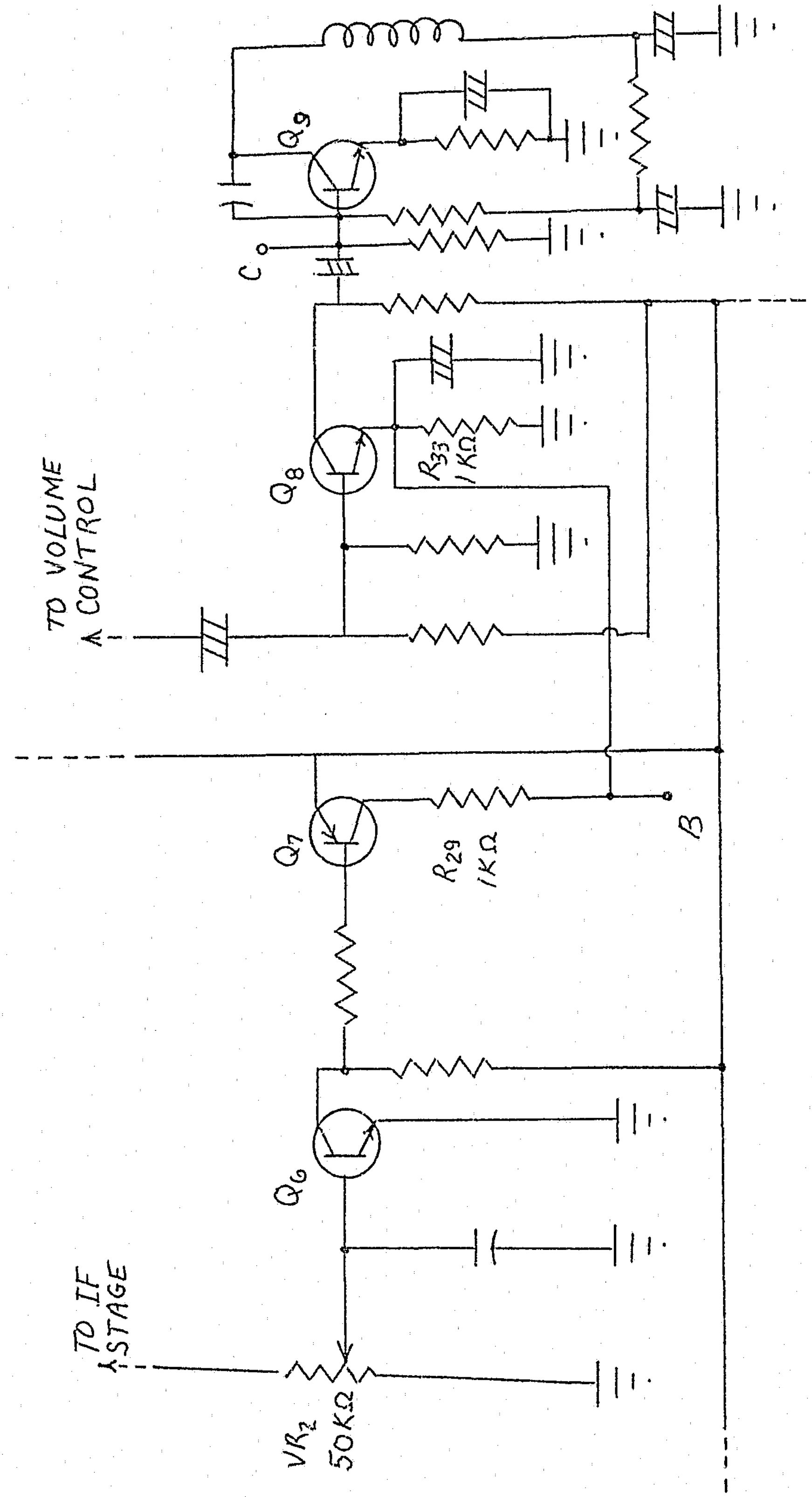


Figure 59: Pace Squelch and Audio Circuitry

The squelch section consists of Q_6 and Q_7 and receives a signal from the receiver's IF amplifier when a transmission is received. This signal, applied to the base of Q_6 by squelch control VR_2, causes Q_7 to cease conduction, which causes the voltage at the emitter of Q_8 to drop from a squelched value of 6 volts DC to a non-squelched value of approximately 0 volts DC. Thus, the circuitry that triggers the encoder must provide an output to actuate the encoder's relay when its input is 0 volts DC. A simple circuit to accomplish this is shown in Figure 58.

Terminal B is the circuit's input and it is connected to the emitter of Q_8 of the receiver's audio pre-amplifier section. When the input voltage is 6 volts DC Q_1 conducts heavily since it is biased in its saturation region, and thus, the base of Q_2 is at approximately ground potential, a condition which prevents its conduction. This means no voltage will appear across the encoder's actuation relay and the encoder will not function. When the input at B drops to 0 volts DC, however, Q_1 ceases conduction and voltage appears at the base of Q_2. This causes Q_2 to saturate and creates a path by which current may flow to ground through the coil of the encoder relay, triggering the relay and causing the encoder to begin oscillation.

Both transistors used in the circuit are 2N3904's, and the values of the necessary resistors may be determined by examination of the transistors' saturation curves. These curves may be found in any good transistor reference book, and will not be shown in this paper.

From the transistors' saturation characteristics it is found that they may successfully perform their switching functions for collector currents ranging between one and one-hundred milliamperes. Thus, the value of R_1 was chosen as 1.5 kilohms. Knowing this, the collector current of Q_1 can be determined to be

$$I_{c1} \approx V_{cc}/R_c \qquad (1)$$

if V_{cc} is negligible. Therefore,

$$I_{c1} \approx 12V/1.5 \text{ kilohms} \approx 8 \text{ milliamperes}$$

Knowing this, the saturation curves show that Q_1 will be saturated for base currents greater than approximately 0.2 milliamperes. Therefore, neglecting the transistor's base-emitter resistance,

$$R_2 \angle V_{in}/I_b \angle 6V/2x10^{-4} \angle 30 \text{ kilohms} \qquad (2)$$

The value selected for the circuit was 22 kilohms.

It should be noted that, since this value is much greater than that of the emitter resistor of Q_8 in the Pace circuitry, the input of this circuit will not cause an appreciable change in the bias levels of the receiver circuitry, and will, therefore, not alter its normal operation.

To determine the value of R_3, the resistance of the encoder relay's coil must be known. It was measured to be 500 ohms and it was also found that a minimum current of 10 milliamperes is required to trigger the relay. The saturated collector current of Q_2 to trigger the relay, then, must be greater than 10 milliamperes, and R_3 can be found to be

$$R_3 + 500 \angle V_{cc}/I_{c2} \qquad (3)$$

or,

$$R_3 \angle 12/10x10^{-3} - 500$$

so that

$$R_3 \angle 700 \text{ ohms}$$

thus, R_3 was chosen as 270 ohms.

The actual collector current, then, will be

$$I_{c2} \approx V_{cc} / (R_3 + 500) \approx 12/0.770 \text{ milliamperes} \qquad (4)$$

or,

$$I_{c2} \approx 15.6 \text{ milliamperes}$$

From Q_2's saturation characteristics, this requires a base current of

$$I_{b2} > 0.5 \text{ milliamperes} \qquad (5)$$

or,

$$R_4 + R_1 + 500 \angle V_{cc} / I_{b2} \qquad (6)$$

thus,

$$R_4 \angle (12/5)x10^4 - 0.2x10^4 \text{ ohms}$$

and,

$$R_4 \angle 22 \text{ kilohms}$$

The actual value of R_4 used, as shown in Figure 58, is 10 kilohms.

The remaining circuitry of Figure 58, consisting of R_5, R_6, and C_1, is used to adjust the level of the audio output of the encoder and provides coupling between the encoder's output and the base of the second audio pre-amplifier transistor (Q_9) of the Pace receiver. The values of these components were determined experimentally as those which provided the best tone, in both level and purity, at the output of the receiver. A detailed derivation of their values is therefore unnecessary and will be omitted.

It can also be seen from Figure 58 that a connection has been made to the contacts of the encoder relay. This connection, leading to terminal A, provides 12 volts DC to the timing circuitry when the relay is activated. The timing circuitry is shown in Figure 60.

The operation of this circuit can be understood without elaborating on the mathematical intricacies that describe its exact performance. The basic functional sequence is that when 12 volts DC, supplied by the contacts of the encoder relay, appears at input A, power transistor Q_3 saturates and supplies approximately 12 volts DC to the rest of the circuitry. The major portion of the network is composed of two separate timing circuits that supply power to two relays, one with normally-open and the other with normally-closed contacts. These contacts are connected in series with the coil of the mechanical solenoid that actuates the channel-four transmitter so that when no signal is applied at A there is no current path from V_{cc} to ground through the solenoid's coil. When A receives a 12 volt DC signal, however, the timing circuits begin to function. After the 12 volts has been applied for approximately one and one-half seconds the normally-open contacts close and the solenoid is actuated. A short time later, the normally closed contacts open and the solenoid is released. The two relays will maintain this condition until the encoder relay deactivates (i.e., the car is no longer in the intersection), at which time they will return to their normal conditions.

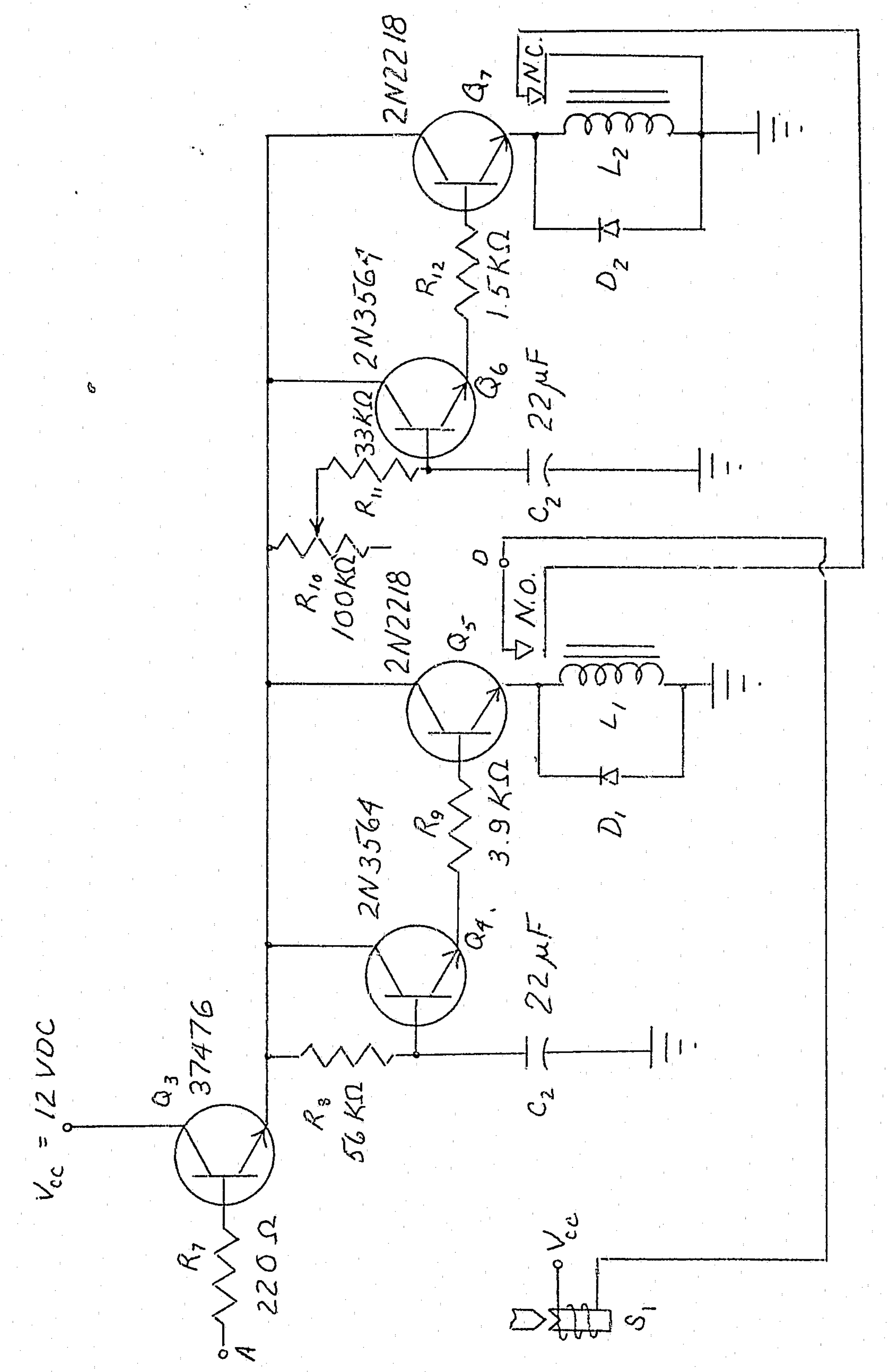


Figure 60: Solenoid Control Timing Circuitry

Brief consideration can now be given to the conditions that cause the delay times in the two relays. Since both time delay sections are essentially the same, it will only be necessary to examine one of the two, that consisting of Q_4, Q_5, and Relay 1 (the coil of which is designated as L_1). It should be noted, however, that the differences in the component values of the two sections arise from the fact that the current requirements to actuate the relays differ; hence, the biasing networks of the transistors will not be identical. The only other difference in the two circuits is that the second contains a variable resistor network composed of R_{10} and R_{11}. The combination of R_{11} and C_2 sets the minimum time delay for the normally closed relay. R_{10}, when added to R_{11}, allows adjustment of the time interval between the actuations of Relay 1 and Relay 2, thus regulating the on-time of solenoid S_1.

The operation of the timing circuit containing Q_4, Q_5, and L_1 may now be examined. From Figure 60 it can be seen that when Q_3 begins to conduct due to a signal at A, C_2 will start to charge through R_8 from its initial value of 0 volts DC towards the applied voltage of 12 volts DC. As it charges, the base voltage of Q_4 will rise and cause an increase in Q_4's collector current. This current, coupled to the base of Q_5 through R_9, will cause an increase in Q_5's collector current. When Q_5's collector current reaches the level required to trigger Relay 1, the contacts of the relay will close and the time delay process will have reached completion.

There are a number of difficulties that arise in attempting to

compute the actual time delay of this type of circuit, most of which stem from the nonlinearities inherent in the circuit. First of all, it should be noted that, since the base voltage of Q_4 is initially at a zero level, the transistor will not be operated within its linear region over the entire charging interval of C_2 and, hence, the relationship between base voltage and collector current will not be linear. Secondly, this also implies that the input resistance will vary as the base voltage of Q_4 increases, which means that the timing circuit will be based on an RC form with a non-linearly varying value of R. At this point it would seem that the difficulties in calculating the required time delay might be insurmountable; however, if a number of assumptions are made, an approximate time delay value may easily be computed.

Consider first the part of the delay circuitry composed of Q_5 and L_1. If it is assumed that the only important conditions on Q_5 occur at the time the relay is activated, Q_5 can be eliminated from the circuit. It is known that the relay will actuate when the voltage across its coil reaches a value of 7 volts DC. This, then represents a collector current for Q_5 of

$$I_{c5} = 45 \text{ milliamperes.}$$

It is also known (by curve-tracer measurement) that Q_5 will have a current gain factor (Beta) of 100. Therefore,

$$I_{b5} \approx I_{c5}/(\text{Beta}) \approx 45 \text{ mA}/100 \approx 0.45 \times 10^{-3} \text{ amperes} \quad (7)$$

Also, since I_{c4} is identical to I_{b5} it follows that I_{c4} must be 0.45 milliamperes.

Knowing the collector current of Q_4 at relay actuation allows the part of the network composed of R_9, Q_5 and L_1 to be replaced by a constant load in the emitter circuit of Q_4. The total voltage drop across this load may be calculated as

$$V_{load} = I_{c4}R_9 + V_{be5} + V_{L1} \qquad (8)$$

or,

$$V_{load} \quad (0.45x10^{-3})\ (3.9x10^{3}) + 0.7 + 7 + 9.45 \text{ volts}$$

For actuation of Relay 1, the, the base voltage of Q_4 must rise to a level of

$$V_b \approx V_{be4} + V_{load} \qquad (9)$$

or,

$$V_b \approx 0.7 + 9.45 + 10.15 \text{ volts}$$

If it is now tacitly assumed that the input resistance at the base of Q_4 is much greater than that of R_8, the approximate time delay can be computed using the basic equation

$$V_b = V_{cc}\ (1 - e^{-t/RC}) \qquad (10)$$

which may be rearranged for a direct solution of time as

$$t \approx -R_8C_2\ln(1-V_b/V_{cc}) \qquad (11)$$

Using the circuit values shown in Figure 60, the computed value for t may be found to be 2.34 seconds, which is relatively close to the actual value of the time delay which, by approximate measurement, was found to be one and one-half seconds.

The circuit described here could be greatly improved by making a minor change in its configuration. That is, the relay and its bypass

diode could be removed from the emitter circuit of Q_5 and placed instead in its collector circuit, allowing Q_5's emitter to be connected directly to ground. This configuration would aleviate some of the computational problems mentioned in the previous model. For one thing, the input impedance at the base of Q_5 would be extremely high, being approximately equal to

$$R_{in5} \approx (\text{Beta})R_2 \qquad (12)$$

or,

$$R_{in5} \approx 100(3.9) \text{ kilohms} \approx 390 \text{ kilohms}$$

This value is sufficiently high that it may be justifiably neglected in any calculation of the circuit's RC time delay.

Using this configuration would also reduce the voltage level at the base of Q_4 required to actuate the relay. In that the seven volts required for actuation would no longer be in Q_5's emitter circuit, the total base voltage on Q_4 at that time would be

$$V_b \approx 0.7 + 1.75 + 0.7 \text{ volts} \approx 2.14 \text{ volts}$$

This means that the base voltage required to trigger the relay would be reached during a fairly linear portion of C_2's logarithmic charging curve. This fact, when added to the previously mentioned increased input resistance, creates a considerably more accurate basis for calculation of the circuit's time delay.

actuate the collector circuit relay (K_2), the base of Q_2 will be supplied enough current to cause the transistor to saturate. It should be noted that, due to the time delay between the actuations of K_1 and K_2, Q_2 saturates a short time after the car tone has actually reached the decoder. This means that by the time Q_2 saturates, the output of an intersection line should already be in its low impedance state.

The saturation of Q_2, then, supplies twelve volts DC to the network composed of R_3, C_2, D_1 and K_3. At the instant this occurs C_2 experiences a heavy charghin current, which supplies approximately twelve volts to the coil of K_3, causing its actuation. This opens its normally closed contacts and provides the desired high impedance level at the VDU's input. As C_2 continues to charge, however, the voltage across the coil of K_3 will decrease until it drops below the level required to maintain actuation, at which point its contacts will return to their normally closed state. When the decoder relay's contacts open again C_2 will discharge through R_3 and D_1, assuring that the coil of K_3 will not be re-energized by the discharge current and will maintain its de-energized state until another signal appears at the decoder's input.

The mathematics involved in determining the component values of this circuit are quite similar to those used in the derivation of the component values of the car unit's timing circuitry, and will not be repeated here. Instead, it need only be re-emphasized that timing component values chosen must allow the contacts of K_3 to close

again before the intersection decoder de-activates, else the information on the intersection line will be lost.

SYSTEM ADJUSTMENTS AND ALTERATIONS

It would be unrealistic to assume that even the most brilliantly conceived and acrefully designed system would prove operational on the occasion of its initial trial. And thus it was that, in keeping with the laws of nature that seemingly govern such events, the Proximity Vehicle Locator System stubbornly resisted all early efforts to collect data substantial to prove the merit of the conception which ultimately gave it birth. An examination of the system's problems revealed that none seemed insurmountable; in fact, no major design alterations were indicated, and the solution of each problem led the system closer to the level of performance expected of it. The following material, then, deals with a number of the problems that have been, or should be, eliminated from the system.

Problems at the Intersections

The mounting of the transmitters in the traffic control boxes gave rise to no unusual difficulties other than in one instance, when the traffic engineer assigned the task chose the wrong power source, with the result that the transmitter at that intersection ceased transmission when the amber caution light was on. This condition, however, was easily remedied.

The most prevalent problems at the intersections resulted from the insufficient output levels of a number of the transmitters. In

the more extreme cases a car passing through the intersection on the side where the control box was located could pick up the transmitter's signal only if his receiver was lightly squelched, and passing through from the opposite direction the signal was completely undetectable.

Another undesirable offshoot of this problem was that, since the receiver had to be operated with minimum squelch, an approach to an intersection whose transmitter was stronger than usual would result in a fringing effect. That is, as the car entered the outer fringes of the transmitter's blanket of coverage, the car would pass through areas where the signal would be strong enough to bring the receiver out of squelch and activate the radio relay unit. Then the signal would die out briefly, allowing the radio relay to de-activate, only to be re-activated when another area of reception was entered. This resulted in numerous transmissions of varying signal levels from some of the intersections, a situation detrimental to communications on channel four.

The solution to this problem was quite simple. Originally, the transmitters installed at the intersections were equipped with one-quarter wavelength (approximately nine feet) of antenna wire. These antennas were fed through small holes in the traffic control boxes and strung along the outer surfaces of the boxes, which are made of iron and are well grounded. The problem, then, was one of loss of signal. The antennas were not long enough to be strung away from the metal boxes, and a great deal of a transmitter's output was lost to ground absorption. To solve the problem, another one-quarter wavelength of antenna was added to each transmitter, and was hung away from the control box to reduce absorption.

The result of this procedure was that a car could now pass through the intersections from any direction with its receiver heavily squelched and still pick up the intersection identification signals. Also, the use of more squelch requires a stronger signal to bring the receiver into operation. Thus, the weak fringe area signals were eliminated, ending the problem of premature triggering of the radio relay unit.

With the transmitters functioning as desired, one can only guess at problems that may crop up in the future. For one thing, it is not yet known how well the transmitters will endure the frequent lightning strikes that knock out traffic control units throughout the summer months. The transmitters are all well grounded, but so is the traffic control equipment, and it doesn't seem to do much good. Only time and several thunderstorms can provide data regarding this problem.

The Car Unit

The radio relay unit mounted in the patrol car performed its mechanical duties exactly as desired. That is, the timing circuits and actuator controls did indeed trigger the channel four transmitter to relay signals back to the police station. And once the ignition noise was filtered out of the receiver and the intersection transmitter's signal outputs were boosted, the signal to noise ratio of the received signals was adequate to provide relatively noise free tones at the decoders at the police station.

The major problem with the car unit was that since the receiver and transmitter must function simultaneously, some means had to be provided to keep the transmitters signal from entering the receiver. It would seem that the two units should not normally interfere with each other since the receiver operates at 27 megahertz and the transmitter at 450 megahertz, but with the transmitter mounted directly beneath the receiver, the signal from the transmitter easily leaked back into the receiver to create a feedback loop. The loop occurred when the intersection and car ID tones were coupled from the output of the receiver to the input of the transmitter, which then transmitted them right back into the receiver. The problem was solved by simply moving the receiver away from the transmitter. This required, however, that the receiver's speaker be mounted above the transmitter and that wires be run from the receiver to its now disjoint speaker.

The only remaining problem with the car unit is that the audible tones tend to wear on the nerves of the officers who have to listen to them each time a monitored intersection is passed. A possible solution to this would be to acquire a channel four transmitter that could be permanently incorporated into the unit. Then the receiver's output and transmitter's input could be electrically, rather than acoustically, coupled and the tones would no longer be audible to the officers in the patrol car.

The Decoders

The biggest problem with the decoders was one of adjustment of input levels. This became rather critical, because when the decoders are driven too hard, more than one at a time (usually those closest to the frequency of the incoming signal) may provide an output which causes inaccurate data to be supplied to the VDU. To remedy this situation, a network was placed at the input of the decoder unit that allowed adjustment of the incoming signal levels. Such a simple network need not be discussed here.

Once the input level was adjusted, it was found that some of the decoders were more sensitive than others, and would actuate when a strong signal close to their frequencies appeared at their inputs. This, too, caused erroneous data to be fed to the VDU. Minor alterations to each decoder's circuitry made the decoders' sensitivities adjustable, and they were finally set at a level that allowed the input to vary between one-half to twenty volts with only the correct decoder being actuated.

Another problem that can be dealt with at the decoder unit is that which occurs when a car ID tone arrives without an intersection ID tone. This can occur when a car passes through an area of radio noise strong enough to bring the receiver out of squelch, which causes generation and transmission of the car tone even though the car was nowhere near a monitored intersection. When this occurs, the car ID line to the VDU enters data without data on one of the intersection lines, which erases the map. To correct this situation, which rarely occurs anyway, a logic network could be installed on the decoder unit's output lines that would not allow the car data to reach the VDU if no data appeared on an intersection line.

The Map

The map circuitry functioned perfectly throughout all the tests. The only complaint that can be made about the map is that the LED's used for the numeric displays are a little too small to be read comfortably at distances of more than a few feet. Using larger readouts would solve the problem, but they would also require more space for mounting, which could cause problems when the intersections to be monitored are only about one inch apart on the map. This problem, one of human engineering, could be solved in a number of different ways, all of which are tacitly ignored in this paper.

CONCLUSIONS

The system described in this paper, admittedly, has a number of serious drawbacks. In order to obtain the best possible monitoring of a car's location in a large city, a great number of intersection transmitters would be required. Although the cost of each transmitter is relatively low, the man-hours required for installation and maintenance might prove prohibitive. For a smaller community, however, it might prove to be a worthwhile system. Not as many transmitters would be needed, and probably the knowledge of a car's approximate location would be sufficient for the police dispatch operator. In such a situation, the cost of such a small scale system would probably not be out of reach of the community's budget, as would some of the more sophisticated systems now available.

There are available at this time systems, ideal for large metropolitan areas, that promise a great degree of accuracy through computer data manipulation. These systems, already reduced in price through their acceptance and use, tend to make the system described here obsolete for large scale applications.

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