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EVALUATION

OF A

POLICE AVM SYSTEM

A Phase II

City-Wide Implementation

by

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ABSTRACT

An Automatic Vehicle Monitoring (AVM) system provides real-time location and status information for each vehicle in the system. Typically, the system would include a display showing a map of the city (presented in several scales) with cars, including their identification number, properly positioned on the map. This report is a Phase II evaluation of such a system implemented city-wide by the St. Louis Metropolitan Police Department. The Phase I evaluation covered only one district and utilized a prototype technology.

The principal goal was reduction in response time, which, it was believed, would increase the rate of criminal apprehension and possibly deter crime because of time saved by always dispatching the car closest to an incident site. Other objectives included improved officer safety, more effective command and control, less voice band congestion because of the digital communications included in the particular AVM system used, and better supervision of the force.

The evaluation results were unfavorable for response time reduction, favorable for improved operations due to digital communication and mixed in the realization of other objectives. Poor system performance had some influence on the evaluation results. During the process of evaluation it became clear that full system potential could not be assessed without some change in police procedures and operating methods. Such potential (which is yet to be verified) relates to the use of directed dispatch rather than the all points broadcast (APB) for extraordinary events such

as pursuits, burglaries, and disturbances; the dynamic reallocation of the force to maintain a patrol presence or to reduce queuing levels in areas where excessive calls for service have depleted the force availability; and better supervision of the force made possible by the new information that the AVM system supplies. Also AVM serves as a hidden supervisor producing better officer behavior. An outgrowth of these potentials can be improved effectiveness of the force, greater productivity, and a cost-effective system.

The evaluation methodology involves three separate analyses: technological, operational, and attitudinal. A cost-effectiveness analysis is included.

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PREFACE

This report covers an evaluation of an automatic vehicle monitoring (AVM) system that has been implemented city-wide by the St. Louis Metropolitan Police Department. St. Louis is the first metropolitan city in which such a system has been evaluated. The results of this study have significance because:

- They illustrate the effect of closest-car dispatching on response time. One of the principal benefits cited by AVM proponents has been the reduction of travel time (and thus, response time).
- They assess the value of digital communications in police operations.
- They examine the potential of AVM for improved officer safety, command and control, and supervision of the force.
- They address the influence of AVM on officer productivity and the basis whereby such systems can be cost-effective.

A complete evaluation of all AVM potential benefits was not possible. It became clear that some benefits were not attainable without changing some rather well established police policies and practices. Additional experiments to more fully explore such potentials are recommended. The following report summarizes the evaluation results and discusses those areas where potential benefits exist.

The evaluation methodology covers a broad range of issues. Recognizing that AVM is relatively new, the technology involved in several systems and the performance of the particular system is reported in Chapter II. The effect of AVM on police operations and the degree of achievement of system objectives is covered in

Chapter III. Introduction of such a new technology into a labor-intensive environment can cause attitudinal and organizational shifts, and these effects are assessed in Chapter IV. An introduction to the AVM evaluation is provided in Chapter I,and the evaluation conclusions together with an assessment of the potential value of AVM are summarized in the concluding chapter.

Included with the report are two important appendices. Appendix A is a paper entitled "Alternative AVM Technologies" which contains performance measures, system specifications, location techniques, methodsof transferring data and processing and display methods. It should be of interest to those who desire more knowledge on AVM technology and those who are contemplating purchasing a system. Appendix B is a paper entitled "Markov Models of Fixed-Post Sensor AVL Systems" which includes mathematical models showing the relationship between sensor density, layout, accuracy, and system cost. This paper should be of interest to system designers, and--because it contains newly developed models--to professionals in operations research as well as to mathematicians.

ACKNOWLEDGEMENTS

This AVM evaluation was conducted within the jurisdiction of the St. Louis Metropolitan Police Department, where, during three years of active participation, many St. Louis principals extended invaluable assistance and support to the program. Foremost was Police Chief Eugene Camp, who gave his support and many contributions to the program as did others of the command staff, especially Colonel Adolph Jacobsmeyer, Colonel David Walsh, and Captain Glenn Pauly (now retired); Mr. Herbert Bosch, FLAIR Program Director, provided important day-to-day assistance and interface between the evaluators and the various functions and services of the department; Lieutenant Joe Taszarek and Sergeant Jay Canada, under whose direction the communication division operates (and where much of the action took place), not only accommodated us but went out of their way to provide special tests and other services when requested; and Sergeant George Brinkman, planning and development, who generously gave of his time and knowledge.

Significant contributions were also made by the St. Louis Commission on Crime and Law Enforcement, particularly Mr. Otto Heinecke, Lieutenant Paul Herman, and Mr. Don Richardson, who managed and conducted regularly held evaluation meetings; the Boeing Company (Wichita Division), contractor for the FLAIR AVM System, whose representatives Messrs. Joe Henson (FLAIR Program Manager), Carrol Stevens, and Chuck Matthis provided valuable assistance.

The National Institute of Law Enforcement and Criminal Justice of the Law Enforcement Assistance Administration provided not only the financial support but also expert project monitoring and guidance by Messrs. Paul Lineberry and John Spevacek.

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Chapter I

INTRODUCTION

Automatic Vehicle Monitoring (AVM) systems use advanced technology to track the position of vehicles and to monitor their general status. Sometimes called automatic vehicle location (AVL) systems, they use one of several currently available technologies to estimate a vehicle's position. These technologies usually build around one of the following concepts: radio ranging ("trilateration"), proximity sensing (e.g., a vehicle passing a sensor at an intersection), or dead-reckoning (e.g., in-vehicle position updating, such as in submarines). Some systems--called hybrid systems--incorporate two or more of these concepts along with other concepts such as computer correction of tracking errors.

The "monitoring" aspect of an AVM system usually includes status information in addition to location. In police applications the status may describe whether the vehicle is responding to a police call-for-service, at the scene (servicing a call), or involved in routine preventive patrol, in hot criminal pursuit, or in need of emergency assistance.

The potential for AVM systems in law enforcement agencies was originally suggested by studies undertaken by the President's Crime Commission (1966) wherein it was suggested that AVM--by automatically dispatching the closest patrol car--could cause a significant reduction in travel time (and a corresponding reduction in overall response time). Some conjectured that AVM could be a deterrent to crime because more criminals would be apprehended. Even earlier though the need and application of

AVM was evident in public transportation, where as early as 1935 a crude form of vehicle monitoring was implemented by the Chicago Transit Authority leading eventually to a much more sophisticated system in the early 1970's (implemented by Motorola) which provided real-time data for an automatic schedule adherence system, an emergency alarm system, and other features permitting better supervision and safety.

A. AVM in Law Enforcement Agencies

The President's Crime Commission reports stirred considerable interest within the industry to develop systems that could meet the basic requirement for automatic selection of the police cars closest to an incident site with the expectation that such a system would reduce response time to the extent that more criminals would be apprehended. If this concept proved successful the market potential appeared attractive because a system that reduces crime--especially if paid for by federal funds--is difficult to refuse.

Over ten industrial companies invested their monies and talents in the early 1970's in an effort to develop an appropriate system. Most designs were variations of the three basic system types mentioned in the opening paragraph. The Law Enforcement Assistance Administration (LEAA), too, was following these developments with considerable anticipation. It was during this period of high expectation that the LEAA awarded the Boeing Company a contract to implement their AVM system in one police district in St. Louis,[1] and awarded Public Systems Evaluation, Inc. (PSE)

[1] Implementing the system in District 3 commenced in mid-1974.

a grant to evaluate the results. This was the first attempt to install a sophisticated AVM system in a major metropolitan area. After completion of the Phase I program--which yielded some successes and some disappointments--a Phase II program was initiated to implement the entire city. The evaluation results of the Phase II program are the principal subject of this report. The period covered by the Phase II evaluation was approximately June 1976 to January 1978.

Other noteworthy police-related developments in this interesting new technological field include the implementation of a proximity signpost system in Huntington Beach, California, by the Hoffman Company during 1975-76, and the implementation of a pulse-trilateration system by the Hazeltine Corporation in one of the large Dallas police districts during 1977-78. The Department of Transportation (DOT) has also shown keen interest in AVM, primarily in its ability to improve the safety and schedule adherence of their transport systems. DOT conducted a competitive test in the City of Philadelphia during 1977 involving four suppliers: Fairchild Industries, Hazeltine, Hoffman, and Teledyne. The Hoffman Company won the competitive test and was awarded a contract to implement their proximity signpost system in an area of Los Angeles. It is to serve both fixed and random route bus systems as well as other public agencies--such as the Los Angeles Police Department--and perhaps private industry--such as delivery truck systems and/or taxi cabs.

B. Evaluation Methodology

A new technology such as AVM is generally conceived for the purpose of improving the operations of a system and, to enhance the possibility of success, the new technology should be cost-effective. This then suggests that an evaluation program should include components that will (1) measure the technical adequacy and performance capability, and (2) measure the improvement that impacts the operating system, including its cost-effectiveness. Other reactions from urban planners and sociologists suggest that attitude towards and acceptance by police personnel to AVM systems will be among the most critical factors in implementing these systems in police departments today--in fact, they may be more critical than any particular technological problem. The evaluation methodology then builds on three prongs: technology, operations, and attitudes. These aspects of the AVM evaluation are presented in Chapters II through IV of this report.

C. AVM System Objectives

At the time that the AVM program was contemplated the St. Louis Metropolitan Police Department (SLMPD) established four major objectives for the system as follows:

1. Reduce response time
2. Improve officer safety
3. Reduce voice-band congestion
4. Enhance command and control capabilities

These four objectives, together with system costs, were to provide a framework for considering the overall cost-effectiveness of the system.

D. Evaluation Highlights

Evaluation results of the Phase I system failed to support the belief that closest-car dispatching using an AVM system would yield effective savings in response time;[2] the Phase II data substantiate the Phase I findings.

During Phase II emphasis was shifted from *saving response time* to *improving supervision of the force*, and, more important, an overall focus on *improved productivity* that may materialize from a properly utilized AVM system.

From the patrol officer's viewpoint, the greatest expectation from AVM was improved safety; the greatest fear was use of the system as an inspection tool leading to disciplinary action.

For the dispatcher, AVM improves the decision-making process and provides real-time data permitting a more organized operation. There is strong evidence that dispatchers have gained increased respect from police officers and management.

Better utility from AVM systems can be gained by instituting procedural, operational, and organizational changes. For example, the system can provide for a more directed dispatch process for some extraordinary events--such as pursuits--in place of the less efficient all points bulletin (APB) method.

E. Influencing Factors

System performance was below expectations for both Phase I and Phase II, including location accuracy and hardware reliability.

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[2] R.C. Larson, K.W. Colton, and G.C. Larson, "Evaluation of a Police-Implemented AVM System - Phase I, A Summary Report" (Public Systems Evaluation, Inc., Cambridge, 1976). Available from the U.S. Government Printing Office, Washington, D.C. 20401, stock no. 027-000-00525-0. See also R.C. Larson, K.W. Colton, and G.C. Larson, "Evaluation of an Implemented AVM System: Phase I" available from the National Institute of Law Enforcement and Criminal Justice Library in the Law Enforcement Assistance Administration.

The consequences were that the achievement of some system objectives were not realized, or in some cases were not adequately tested. For example, the use of the system for emergencies was not considered reliable, so officers still used voice radio, perhaps supplemented by the activation of the emergency button, and lack of confidence restricted use for command and control purposes.

F. General

The following chapters summarize the results of the city-wide AVM implementation. Chapter II covers AVM technology and system performance. Three systems--representing three basic types--are briefly described; data on location accuracy and the frequency of lost cars is given; reliability factors and measures are stated; and causes and corrective actions for poor performance are reviewed.

Chapter III reports the effect on police operations due to AVM and reviews the degree of achievement of system objectives. Chapter IV summarizes the results of city-wide attitudinal surveys conducted before and after implementation. Data sources include questionnaires, ride-alongs in patrol vehicles, and interviews. Chapter V presents evaluation conclusions and assesses the potential of AVM. System costs are shown together with possible return on investment due to improved productivity.

Chapter II

AVM TECHNOLOGY AND SYSTEM PERFORMANCE

Prospective users of AVM need to be informed of the benefits that can be expected for the particular application being considered, which type of system best suits their requirements and what performance objectives are needed for the applications. This section reviews two of these issues by (1) establishing the basis for performance objectives, and (2) describing some of the types of AVM technology that are available together with a listing of their favorable features and some possible negative aspects. System benefits will be discussed in Chapter III.

The principal focus of this report is on systems applicable to law enforcement agencies, and on a particular system implemented citywide by the St. Louis Metropolitan Police Department. This section, then, also reviews performance and reliability of this system and equipment. Factors that caused the performance to be below the desired level are discussed, as well as the steps being taken to improve the results.

A. Performance Objective

The need for location accuracy relates to the type of application. For example, the accuracy requirement for a cross-country trailer truck needs to be only one to two miles--if the purpose is to monitor its schedule and its route. A delivery vehicle or a taxi in a metropolitan area should be defined within perhaps one-half to one mile--if the purpose is to improve efficiency by dispatching one of the closer cars. For law enforcement vehicles--to which this report is addressed--the accuracy need be only about one quarter of a beat dimension,[3] or several blocks to perhaps a mile depending upon where in the city the beat is located, providing the *only purpose* is for dispatching the "closest car" in the interest of reducing response time.

Response time studies during Phase I and Phase II do not support the original popular belief that closest-car dispatching would substantially reduce response time. The actual saving in response time is, at best, marginal in terms of benefiting police operations. Therefore, achievement of response time saving is not considered a good basis for establishing AVM accuracy goals for law enforcement purposes.

The more critical requirement in the application of AVM involves its use for command and control, officer safety, and improved supervision

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[3] R.C. Larson, Urban Police Patrol Analysis (Cambridge: MIT Press, 1972), pp. 102-106.

of the force. For example, in a pursuit it is desirable to know the street the lead car is on and the location of cars in the path of the pursuit to perhaps one-half block of true position; when an emergency alarm is sounded by an officer in trouble, his location should be known to about one-half block (particularly in the more dense urban areas) if he is to be quickly found, and police cars that are bunched should be identifiable. A reasonable location accuracy for AVM systems used in law enforcement environments is considered to be that which shows the *indicated position within 300 feet of the actual location 95% of the time.*[4]

Location accuracy is determined by the performance of the AVM system and equipment, radio communication considerations, and the location *update* rate. With regard to the latter, if the update rate were only once a minute and the car was traveling 60 mph on an expressway, the error from this cause could be up to one mile. For a car traveling at 20 mph with location update at 5 second intervals, the error could be up to 146 feet or nearly half of the allowable error. For law enforcement purposes an update rate every 2 to 5 seconds is recommended.[5]

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[4] A typical rectangular block in St. Louis is approximately 600 feet by 300 feet. A system accuracy equal to one-half the short block dimension (or 150 feet) is desired and should be a longer range objective. An accuracy of 300 feet 95% of the time is considered to be a compromise favoring cost and present day technology.

[5] A more complete review of AVM performance considerations, location techniques for competing systems, methods for transfering location and status data from the vehicle to headquarters,and methods of processing and displaying the data are given in a paper entitled, "Alternative AVM Technologies," which is included as Appendix A of this report.

B. Types of AVM Systems

Several types of AVM systems are competing for the law enforcement application. The type of system used in St. Louis and evaluated in this report is known as a *computer-assisted, dead-reckoning* system; the one that has been implemented in Huntington Beach, California, is a *proximity signpost* type; and the system in process of implementation in Dallas, Texas, is a *pulse trilateration* type. While these three systems are not the only ones being considered, they do represent a fairly advanced state of development and each has been or is being implemented in an urban police environment. Brief system descriptions, together with suggested system advantages and possible disadvantages, are provided to generally inform the reader of their individual characteristics. Since a comparative evaluation of the systems has not been made, comparisons of performance, utility, cost-effectiveness, etc., are not intended nor implied.

1. A computer-assisted, dead-reckoning system, known as FLAIR,[6] is the type used in St. Louis, and evaluated in this report. Car location is determined by data supplied from each car involving distance traveled (from an odometer) and direction of travel (from a magnetic heading sensor). Such incremental data is transmitted to the base station each update period (about 1.2 second intervals) where the computer applies such up-dates to the previous data (and the car's original initialized position) to present continuous tracking of the vehicle's location on a color TV-type display. A characteristic of dead-reckoning systems is that the vehicle being tracked will eventually become "lost" due to the

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[6] FLAIR is a trademark of the Boeing Company, and stands for Fleet Location And Information Reporting. Patents have been applied for in the United States and in foreign countries.

accumulation of error. To delay this process the FLAIR system uses the computer to keep the car located on streets and corrects distance error when a corner is turned (through a map-matching process). The estimated vehicle location still can become lost, however, and when this happens the computer notifies the dispatcher to stop the real vehicle and verify its location. If the location is incorrect, the dispatcher will correctly locate it (this process is called reinitialization).

a. Some Positive Features

(1) Frequent update periods present a realistic real-time display of vehicles moving on streets--one that the dispatchers easily relate to.

(2) Only one UHF voice-type channel using two conventional 25KHz channels (for transmitting and receiving) is used for 200 cars.

(3) Up to 99 digital codes can be sent mobile to base over the AVM channel--thus supplementing communication capabilities.

b. Possible Negative Aspects

(1) Vehicles become lost requiring reinitialization. This process involves participation of both the patrol officer and the dispatcher--thus increasing their workload. System performance could be vulnerable to the acts of people whom it is trying to serve.

(2) System expansion may be constrained by the limitations of 200 vehicles per radio channel and 400 per computer system. Channel availability in the UHF band is getting scarce.

2. A pulse trilateration system is being implemented in one district in Dallas, Texas, by the Hazeltine Corporation. Its operation is based on radio propagation properties to identify vehicle location as a function of radio transmission time between the vehicle and three or more satellite

receivers. A synchronized fast-rise pulse emitted from the transmitter located in a vehicle is received by three or more satellite receivers whose demodulated signals are transmitted by land-lines to the base station computer where location is determined. The pulse leading-edge is used in computation to minimize errors that would result from radio-frequency reflections as may be caused by buildings in high-rise urban areas. System accuracy is dependent on the ability to identify the pulse leading-edge for computing the direct (shortest) path between the vehicle and the satellite receivers.

a. Some Positive Features

(1) The system has a high capacity and can accommodate fleets of vehicles having differing update rates, depending upon the accuracy requirements. Several thousand vehicles could be accommodated.

(2) The FCC has allocated two channels (8MHz each) in the (new) 900MHz band for AVM service on a temporary basis subject to final authorization. These channels should assure adequate service in most metropolitan areas.

(3) Digital communication is provided in both directions--mobile to base and base to mobile.

b. Possible Negative Aspects

(1) System performance has not been fully proven. In a competitive test conducted by DOT in Philadelphia, accuracy in an urban high-rise environment was unsatisfactory. The degree to which the condition has been corrected is yet to be demonstrated.

(2) Channel assignment in the 900MHz range does not have final FCC authorization. Also, near the allocated bands is a potential interference from commercial/industrial/consumer microwave devices (such as microwave ovens) of an unknown dimension.

3. A proximity signpost system has been implemented in Huntington Beach, California, by the Hoffman Company. The system uses a multiplicity of low power transmitters each located in fixed positions throughout the area being served. Each signpost transmits its individual code continuously so a patrol car receives its signal as it passes and relays the code to identify its location to the base station at the next update period. The greater the density of the signpost sensors, the better the accuracy and the higher the cost.[7] The Hoffman system uniquely uses a two signal-level system, which more than doubles the identifiable locations per signpost. It is noted that Hoffman was awarded the City of Los Angeles Transit Authority AVM contract after competitive testing in Philadelphia where the competitors were Fairchild Industries, Teledyne, and Hazeltine.

a. Some Positive Features

(1) Signpost systems appear to have a high order of flexibility. For example, accuracy can be a trade-off with cost (where applicable), and systems can be applied to small as well as large metropolitan areas. Systems such as Boeing's and Hazeltine's (previously described) are dependent on high-capacity computer processing of their signals. This generally involves substantial investment, and may make such systems non-competitive for smaller communities. Small signpost systems can operate with smaller computers or logic circuits and even a "wall" map rather than electronic displays.

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[7] The relationship of system accuracy and cost is not only a function of signpost density, but is also dependent on the signpost layout and turning probability of the vehicle. These relationships are developed, for several layout configurations, in a paper entitled, "Markov Models of Fixed-Post Sensor AVL Systems," which is included as Appendix B of this report.

(2) For smaller systems the location information may be able to utilize the voice-band channel and radio equipment saving both cost and valuable frequency spectrum.

(3) The signposts can be used by any number of services making it possible to reduce the "cost per car" for this portion of the system as the number of users increases.

b. Possible Negative Aspects

(1) Because accuracy is directly related to system cost, the accuracy requirements for law enforcement (300 feet, 95% of the time) may cause proximity signpost systems to be non-competitive, particularly in larger metropolitan areas.

(2) The signpost operation is based on the transmission of low-level signal. This could make the system vulnerable to external interference, decreasing the effectiveness of the system.

C. The FLAIR System

The FLAIR system and equipment for Phase II (city-wide) implementation differ from that in the Phase I pilot program [8] in a number of important ways: (1) basic system changes were necessary to comply with FCC requirements; (2) a number of changes were made to improve performance involving *location accuracy* and the *frequency of lost cars*; and (3) changes were made to improve reliability. The significant changes are briefly described, and the impact of these changes on performance and reliability is discussed under subsequent headings. A detailed description of the Phase II system and equipment is considered beyond the scope of this report, as it is well described elsewhere. [9]

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[8] R.C. Larson, K.W. Colton, and G.C. Larson, "Evaluation of a Police-Implemented AVM System - Phase I, A Summary Report" (Public Systems Evaluation, Inc., Cambridge, 1976). Available from the U.S. Government Printing Office, Washington, D.C. 20402, stock no. 027-000-00525-0.

[9] R.W. Lewis and T.W. Lezniak, A Report on the Boeing Fleet Location and Information Reporting System (FLAIR) (Wichita: Boeing Company [1976]).

1. Phase II changes. If a UHF voice channel is to be licensed for AVM use, the FCC requires that a minimum of 200 vehicles be accommodated. The Phase I system provided for only 100. The increase in capacity by a factor of 2 required substantial changes--the more important ones being the following:

	Phase I System	Phase II System
Number of Time Slots	100	200
Update interval	1 second	1.215 seconds
Bit rate	1600 bps	4800 bps

In addition, changes were made to improve performance--the principal ones being as follows:

Distance sensor resolution (odometer)	24 feet (4 bits)	6 feet (6 bits)
Heading sensor resolution (magnetic compass)	± 5.6° (5 bits)	± 1.4° (7 bits)

Changes were also made to provide better tracking in off-street areas (open-loop mode) such as parking lots and shopping centers; computer correction was added to the distance sensor data for errors due to speed; and entirely new computer software was developed to accommodate the changes and a system capacity of up to 400 cars. Then added to this was a new production packaging and the result was a major redesign program.

The consequence of such an extensive redesign was, unfortunately, a delay in the Phase II implementation by approximately 5 months. As one might expect (when a design is hurried into production) considerable debugging of the hardware and software became necessary. Extensive field tests throughout the city (other than District 3 where Phase I was implemented) revealed new locations having magnetic anomalies and roads intersecting at small angles that required special software programs for proper operation. The Phase II system became operational on March 15, 1977, instead of the originally scheduled date of October 15, 1976.

2. System performance. As previously stated, the most important performance measure for AVM systems is *location accuracy*. For dead-reckoning type systems--such as FLAIR--another perhaps equally important parameter is the *frequency of lost cars* or the *mean-time between losses*. Evaluation of these performance measures together with Phase I results will be addressed.

a. Location accuracy. As covered in Section A of this chapter, a reasonable accuracy requirement for AVM operating in a law enforcement environment is for the indicated location to be within 300 feet of the true location 95% of the time. Location measurements were made in District 3 during Phase I and in all districts in Phase II by the dispatchers in accordance with procedures developed and with results sample-checked by the evaluators. The dispatchers would stop patrol cars at random times during periods of low activity and ask for a "FLAIR check."[10] Only cars not indicated as being lost were stopped. The dispatcher then would measure--using a plastic ruler--the distance between the reported location and the indicated position to the nearest 1/8" (1/8" on the most magnified scale is approximately 90 feet). A tabulation of performance in each district (Phase II) and District 3 (Phase I) is shown in Exhibit 2-1. Plots of the Phase II city-wide results, and--for comparison--the Phase II, District 3, results are shown in Exhibits 2-2 and 2-3, respectively. For both Phase I and Phase II,

[10] This would signal the patrol officer to stop at the next convenient intersection and to identify his location via the voice radio.

Exhibit 2-1

Accuracy Measurements, Phase II

District	% of Observations within 1/8" *	Indicated Error (Feet) for Confidence of		
		80%	90%	95%
1	34%	1350	2100	2880
2	57	600	1800	3600
3	56	750	1950	3600
4	31	1950	2550	3300
5	34	1350	1950	3000
6	43	1350	2700	4050
7	64	375	1125	2850
8	57	675	900	1950
9	34	750	1425	2100
City	46	1005	1725	3000
Phase I/ District 3	80	90	400	700

* 1/8" equals 90 feet

Exhibit 2-2

Cumulative Error Distribution - Whole City

(Sample Size: 1,210)

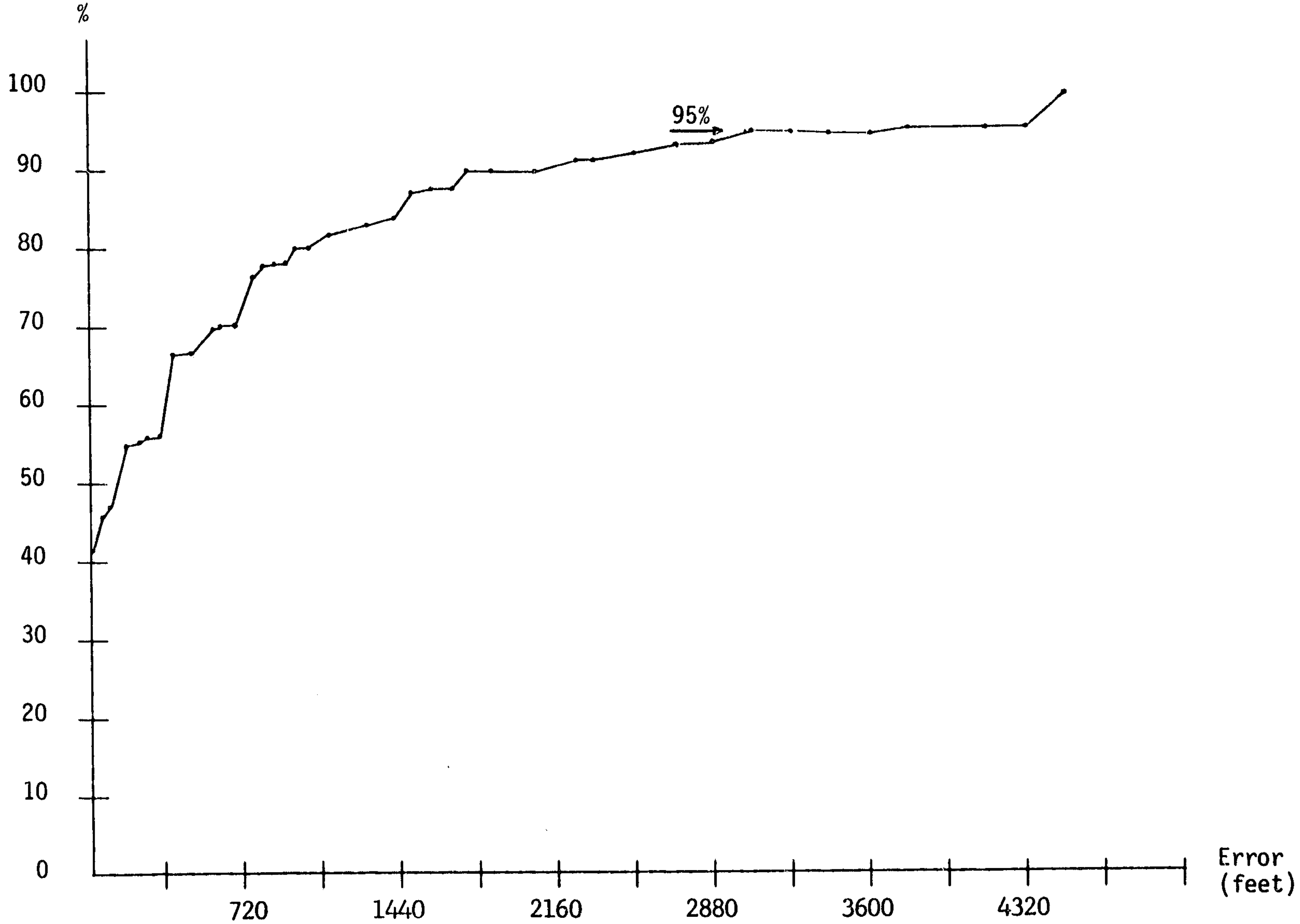


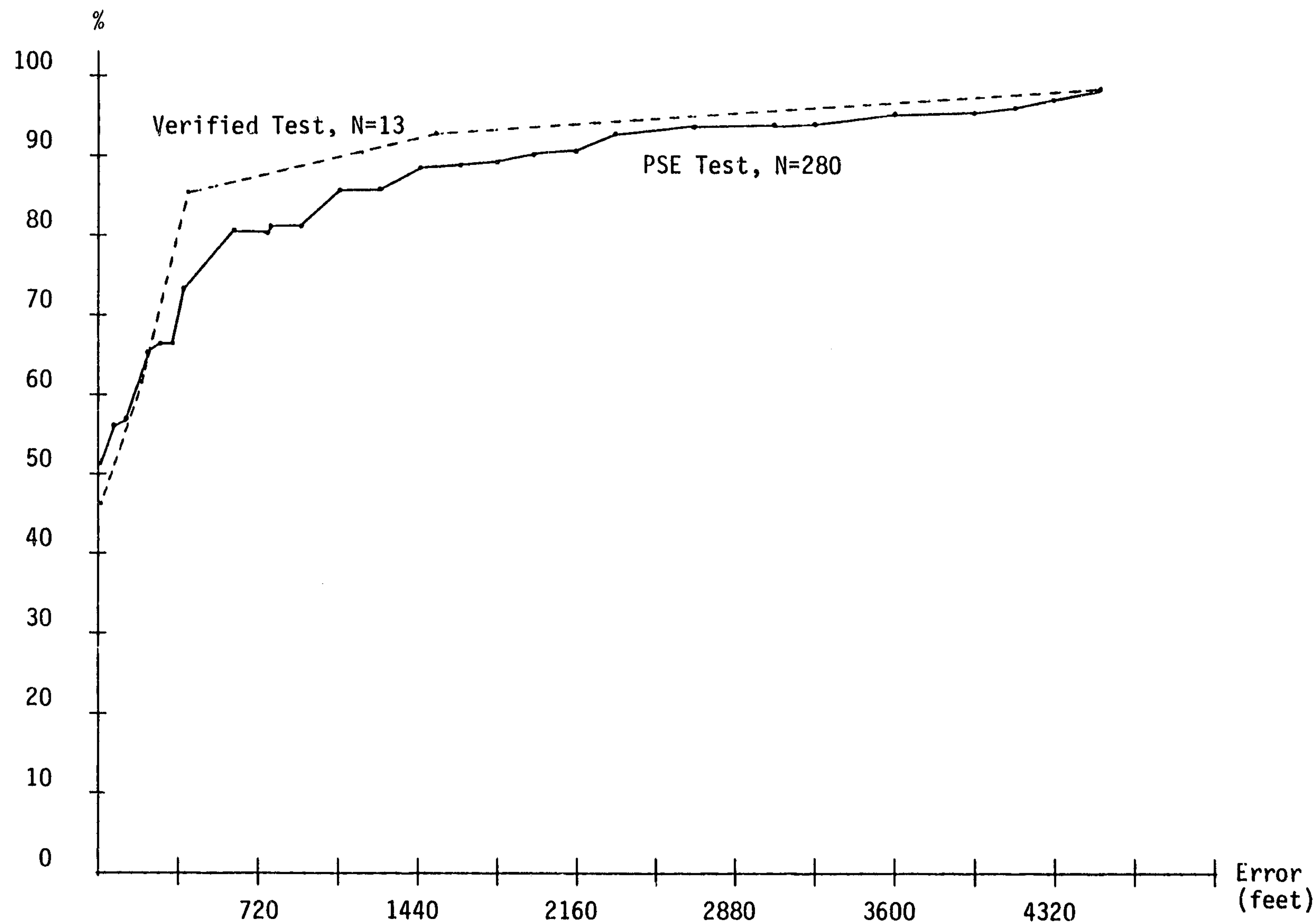
Exhibit 4-9

Cross-Tabulation of Concern About Dispatch Operations
versus
Effect of FLAIR on Dispatch Operations

	Effect of FLAIR on Dispatch Operations (N= 467 Officers)		
Concern About Dispatch Operations	Improved	No Effect	Worsened
Definitely Needs Improvement	8.1%	21.2	70.8
Needs Some Attention	24.8%	40.1	35.0
Okay As Is	35.1%	43.2	21.6
TOTAL	18.0%	31.0	51.0

Exhibit 2-3

Cumulative Error Distribution - District 3



measurements were made after the system had settled down (about two months after implementation).

Accuracy results are disappointing showing the 95% confidence levels ranging from 1950 feet (District 8) to 4050 feet (District 6), compared to 700 feet (District 3, Phase I). The 80% confidence levels are 1005 feet city-wide in Phase II, compared to 90 feet in Phase I. An obvious question is: What caused the poor Phase II performance, particularly in view of the many system improvements?

Some suggested that the officers might be deliberately subverting the system by incorrectly stating their location during a FLAIR check. This, it was conjectured, could be caused by a negative attitude resulting from the delay in system implementation or by fear of its use for inspection purposes. Therefore, a limited number of FLAIR checks were made (over a 5-day period) in District 3 with an evaluator riding in a patrol car and another observing the dispatcher. This test provided a verified accuracy measurement which is plotted together with "normal" District 3 results in Exhibit 2-3. Considering the relatively small sample size (13) for the verified test, correlation with the District 3 results is quite good and does not suggest improper results at least of any consequential proportion.

Other tests were made which helped to explain the poor accuracy. A number of "straight line" tests were conducted in which cars were driven on streets that were more or less straight. At the start of the test the car was initialized, and at the end the difference (in feet) between the actual and indicated position was noted. This type of test was conducted to determine the odometer error without the benefit of distance correction when a corner is turned.[11] The first test was made in a patrol car that was "roughly" calibrated by driving around the block at the police garage and noting on a test monitor the "bits" traveled (this type of calibration is believed accurate to only about 2%). Nine runs were made--ranging from 2.8 miles to 9.4 miles with an average length of 5.7 miles; errors were from 0 to 6240 feet with an average of 1860 feet or 6%. Another car, that had been accurately calibrated using the contractor-supplied fixture, completed seven runs ranging from 4.8 to 6.0 miles with an average of 5.4 miles; errors were from 0 to 1895 feet with an average of 373 feet or 1.3%. This illustrates that an accurately calibrated odometer produces vastly superior performance.

The above results and other tests demonstrate the importance of periodic calibrations of the equipment. During Phase I, for example, it was shown that worn Rayon-belted tires created a 2% error (106 feet per mile) if calibrated when new. A preventive maintenance program had not been initiated during the Phase II evaluation period, although one has since been activated.

Another travel environment that creates special accuracy consideration concerns driving in off-street areas, such as shopping centers, parking lots, industrial sites, etc. In such areas, the system operates in an "open-loop" mode and the vehicle's

[11] On normal patrol a turn (distance correction) may be expected on an average of every four blocks. However, driving on long straight streets can occur when responding to some calls for service or when driving to the district station.

location is determined solely from dead-reckoning data (direction and incremental distance). In contrast, when driving on streets a "closed-loop" mode is used where the computer recognizes the street being driven on and holds the vehicle's indicated position on the street center-line (by referencing to its stored digital map) rather than allowing it to wander off the street and in and out of buildings as would be the case if its direction were controlled only by the relatively noisy signal from the magnetic compass. The closed-loop mode also provides for distance correction when a corner is turned.

Patrol cars were driven through a variety of off-street areas where their travel and duration of stay represented normal patrol-type operation. For each test the cars were initialized at an intersection near the entrance to the off-street area and the difference between actual and indicated positions was checked upon leaving the area.

- For 17 large and small parking lots, 6 showed an error of 0 feet; 5 additional were under 300 feet; the remaining 6 averaged 860 feet.
- For 15 other types of open areas, 5 showed an error of 0 feet; 5 additional were under 300 feet; the remaining 5 averaged 900 feet.

The off-street results still show excessive error with results comparable to those in Phase I. For Phase I a smaller sample size was tested (eight areas) where 3 of the 8 had errors in excess of 300 feet (averaged 906 feet).

b. Frequency of lost cars. Another measure of performance for dead-reckoning type systems is the frequency with which a car gets lost. As mentioned previously the FLAIR system has features that are intended to reduce this frequency by using the computer to (1) locate the car on a street center-line (preventing its wandering from side to side), and (2) correcting for distance errors when a corner is turned. The computer can even correctly relocate a lost car, some of the time, through a map-matching process. However, when the computer cannot match the vehicle's indicated route with streets in the stored digital map, the vehicle number, followed by a "V", will be shown in the status column of the display console, indicating that the vehicle's location should be verified.

During Phase I the average frequency of lost cars was 11 per car per 24-hour day. This high rate was the major Phase I operational problem, causing an extra workload for the dispatcher and resentment and inconvenience to the patrol officer. Therefore the reduction of this occurrence was a principal Phase II objective. Some of the changes made to improve this characteristic were:

- Increased odometer and heading sensor resolution, automatic velocity correction, and many software changes for improved accuracy.
- Provisions for 22 self-initialization[12] points throughout the city, one in front of each of the 9 district houses and 13 at other well-traveled locations (such as the police garage). Phase I had one self-initialization point in front of the District 3 station.

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[12] A self-initialization point is a precise location that a FLAIR-equipped car can go to, where the address code of that location can be entered into the digital message panel and after 7 seconds the computer will locate the car precisely at that location without the assistance of the dispatcher.

- A new method for flagging a lost car, which provides more time between the first computer indication that a car may be lost until the "V" sign is displayed on the dispatcher console. The apparent purpose was to provide more time for the computer to relocate the car.

Lost car performance is plotted in Exhibits 2-4 and 2-5. The former plot shows total "V" requests, number of dispatcher reinitializations and number of self-initializations for a 24-hour day; during the period April through August the number of dispatcher reinitializations increased from about 900 to 1200, or 33%. The latter exhibit plots the number of reinitializations per car per day and the average miles driven between reinitializations; during the period the number of reinitializations increased from below 7 to above 9 per car per day (compared to 11 for Phase I).

Probable reasons for the increased rate of reinitializations, the relationship of the number of reinitializations per car per day to accuracy, the potential for improvement due to increased participation in self-initializations, and other methods for increasing accuracy and reducing the frequency of lost cars will be covered under paragraph C.4, Performance, potential for improvement.

3. Maintenance and reliability. The Phase II production styled system provided advantages and features, compared to Phase I, to enhance the reliability and to simplify repair and calibration. At the base station a standby computer with interface modules was added to reduce the likelihood of the whole system's collapsing in the event of computer failure. At the repair garage a rotatable car rack was installed to facilitate heading sensor calibration; a fixture was furnished

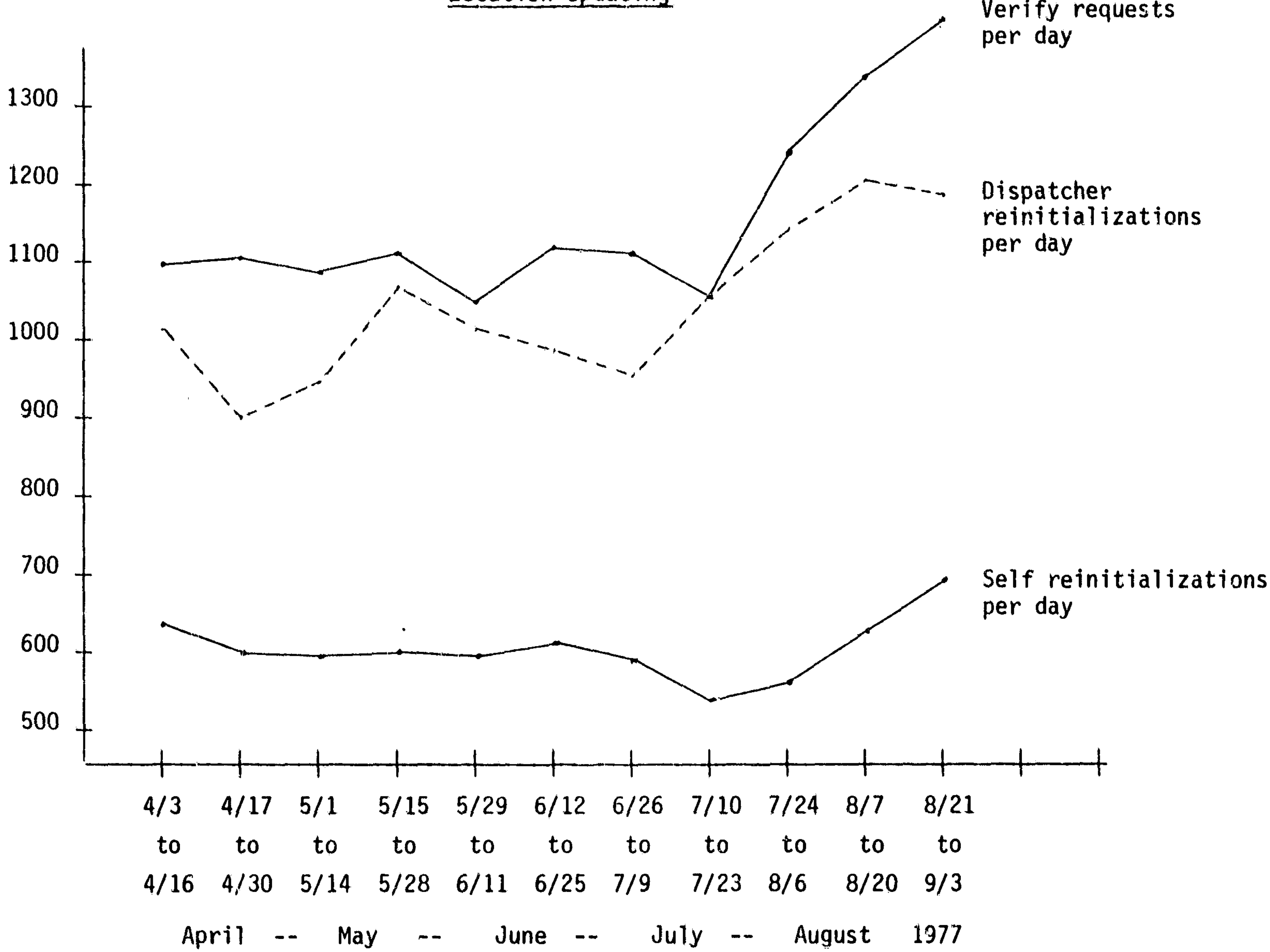
to observe the activities at the FLAIR console and to ask questions as to the operations of the system. All personnel wrote memoranda to their superior officers describing their experiences. A sampling of these memoranda by the evaluators showed that: Nearly all commented on the poor accuracy; many expressed concern about FLAIR's cost; many could see benefits in officer safety and command and control--if the accuracy were improved; many had new respect for the dispatch operation; and, suprisingly, most seemed to accept FLAIR based on expected performance improvement (see Exhibit 3-18). Unfortunately, the decision to send officers to observe the dispatching operation was made after the PSE questionnaires were distributed and the results tabulated, so the effect of this FLAIR training on their attitudes is not reflected in the quantified questionnaire results.

3. Involvement of departmental top management. Just as it is important to integrate and train police officers concerning innovation, it is essential that top police supervisors be deeply involved in the implementation of new technology. Experience in other police departments has shown that it is not enough to simply approve change and manage the evaluation. With FLAIR the Phase II results demonstrated that the response time benefits of the system are below expectations. Other potential benefits such as the opportunity for improved command and control or better management of resources must be further examined to determine the degree to which the benefits may justify the costs. To truly test the benefits of the system, it may be necessary to try new command and control or organizational relationships, at least on a temporary basis, such as assigning a high-level command person to the

Exhibit 2-4

System Use:

Location Updating



commitments seem to be on-going while solutions are being sought to technical problems which might affect accuracy. Even though performance to date has been a disappointment to most members of the MPD, they still hope for future improvements.

The most impressive display of support for the FLAIR system comes from the officers and dispatchers who use the system every day. When asked about a FLAIR system that was accurate and did not require periodic location updates, 83.8% of dispatchers and 71.0% of the officers said they would be more likely to accept such a system as compared to the current version of FLAIR.

Concerning the specific objectives of the system, the overall attitudes held:

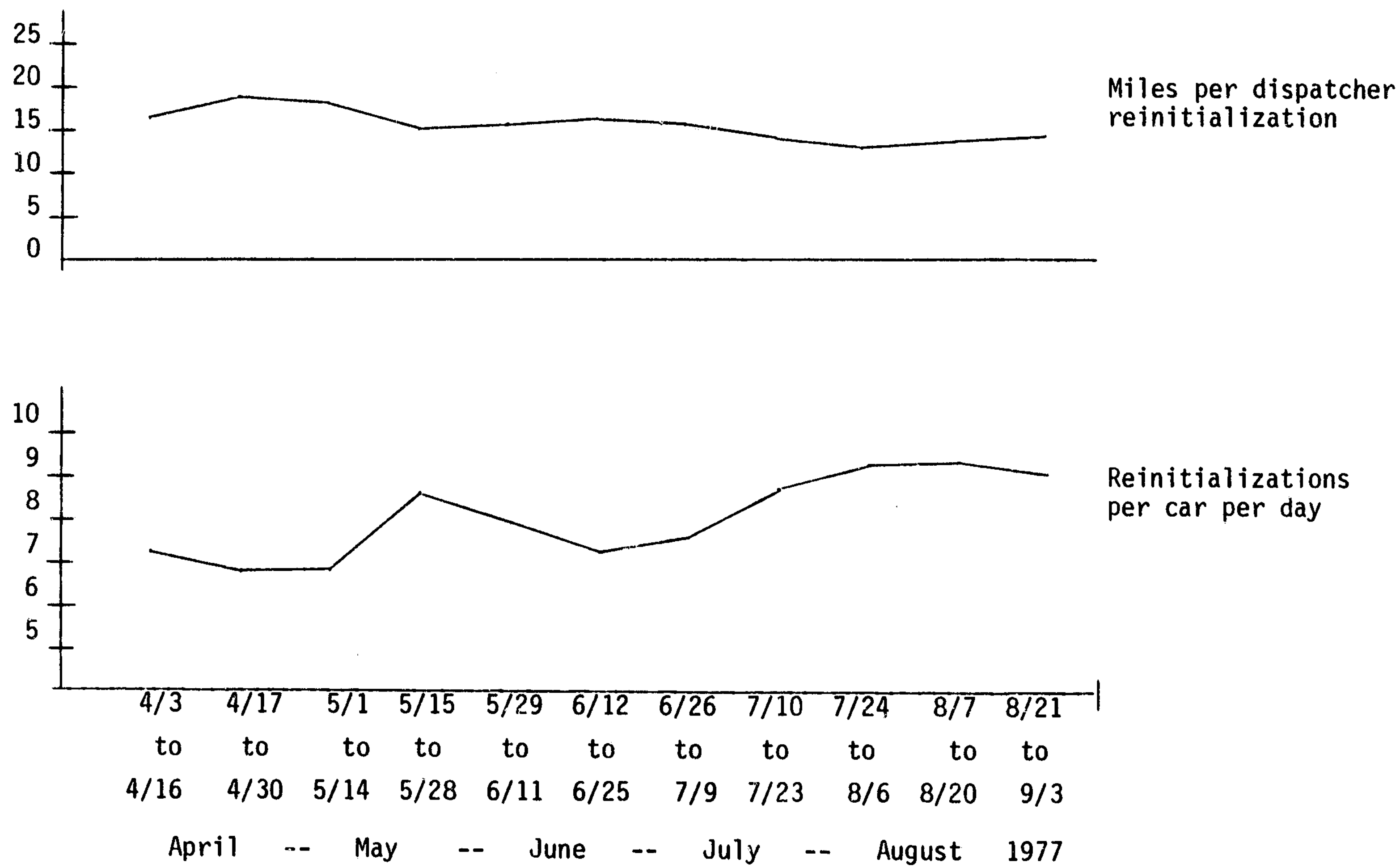
- That response time was largely unaffected by AVM, and even an accurate AVM system would not noticeably reduce response times.
- That officer safety could be usefully improved if an accurate AVM system and a skilled dispatcher were tracking a vehicle in trouble, and if a button on the belt were available for use outside the car.
- That digital communications produce smoother operations and are one of FLAIR's greatest benefits (due to problems with accuracy in achieving other objectives).
- That command and control applications of an accurate AVM system may be expected to yield increased departmental effectiveness if used appropriately.
- That improved supervision of the patrol force is a possible useful AVM application if disciplinary abuses of the system can be avoided.

In conclusion, there is still much to be done in terms of properly using the FLAIR system. Still, given the difficulties with respect to accuracy, the attitudes of the patrol and dispatch force are still somewhat positive toward the system. As one of the police supervisors indicated, the police officers have come to accept the FLAIR system as a reality in the St. Louis Police Department. At first they were resentful; they no longer have such resentment but accept FLAIR as a "fact of life." If the system could be easier for the officers in terms of automatic initializations and/or in terms of improved accuracy then St. Louis could well be in a position to fully test the potential of the system and to achieve further benefits. However, if the accuracy problems continue to persist then the use of the system may eventually be phased out.

Exhibit 2-5

System Performance:

Location Accuracy



Chapter V

EVALUATION CONCLUSIONS
AND
ASSESSING AVM POTENTIAL

The Phase II program extended the application of FLAIR from the Phase I, District 3, experimental application, to city-wide operation in all nine police districts using 200 patrol cars and six dispatcher display consoles. It was the first AVM system to be installed in a major metropolitan environment.

However, the Phase II implementation was faced with a number of problems. Debugging the equipment and the software caused delays, and once the system became operational, developing effective repair and maintenance programs and solving other operational problems took longer than expected, causing poor system performance during the entire evaluation period. This, of course, had an adverse influence on evaluation results, causing inconclusive results concerning the achievement of many system objectives. But, even with these problems, some interesting trends developed. For example, the poor performance had a negative impact on operating people so that only 28% of the patrol officers and 46% of the dispatchers thought FLAIR was a good idea (based on a city-wide survey near the end of the evaluation period). However, when asked if they would be more likely to accept the system if it were accurate and did not require reinitializations, 71% of the officers and 84% of the dispatchers responded favorably.

for odometer calibration; a custom-designed test set was provided for analyzing the performance of the AVM mobile equipment; and a maintenance/installation manual and spare parts were supplied. Inspite of all this some problems were still encountered.

a. Base station. From the time the city-wide system was made operational in March through the middle of May (1977), the FLAIR system went down ten times due to computer failure (even with a standby capability) for a total of 224 hours--averaging three hours per day. During this period the computer engineers made twelve modifications/corrections. This appears to have been a shakedown period because from mid-June to the end of September there was only one 4-hour period that the system failed because of the computers. Changeover from the prime to the standby computer is a manual operation involving cable changes and procedures requiring about 10 to 15 minutes. Since June the computers have been changed monthly so as to alternate between prime and standby functions and the system reliability has been at a satisfactory 99.95% level.

b. Mobile equipment. Two hundred patrol cars have been equipped with FLAIR--26 of which are designated as FLAIR spares. Cars that fail, whether for mechanical, radio, or FLAIR reasons, should be replaced with a FLAIR-equipped spare vehicle during repair to maintain as nearly as possible a 100% FLAIR operational presence in the field. During a heat wave in July as many as 34 non-FLAIR-equipped spare vehicles were used due to excessive failure rate--most failures being mechanical in nature. Such a high mix of non-FLAIR cars creates a serious dispatch problem where the non-FLAIR cars are likely to be overlooked because their number or location is not shown on the display console. To cope with this problem police management decided that a dispatcher can reasonably be expected to handle up to two non-FLAIR cars at anytime, but if there should be more the dispatcher would revert to pre-FLAIR dispatching practices. This, then, highlights the need for high reliability, not only in the AVM equipment, but also in the two-way radio and the car itself. Also emphasized is the need for an adequate number of fully equipped spare vehicles--their number is directly related to the overall reliability which in turn affects capital investment and the cost-effectiveness of the system.

The FLAIR mobile equipment consists principally of an odometer, a magnetic heading sensor, a vehicle data processor, a UHF two-way radio, and a control panel unit (for digital codes). Failures in these units during the period April 1, 1977 to August 31, 1977 were:

	Number of Component Repairs	Number of Non-Component Repairs
Vehicle Data Processor (main unit)	70	
five modules	36	
	106	
Two-way radio	81	
Control panel unit	66	
Heading sensor	3	
Odometer	67	
Fuse	150	
Other	9	
TOTAL (with fuses)	482	
TOTAL (without fuses)	332	
Heading realignment		356
Clean & lubricate module connectors		319
AVM two-way radio alignment		209
TOTAL		884

Assuming each of the repairs (except fuse replacement) took 8 hours (1/3 day) including officer travel time, then the total car days out of service for component repair (excluding fuses) was 111, and for non-component repairs (alignment, etc.) 295, for a total of 406 (excluding fuses) or 419 car days including fuses (assuming 2 hours repair and travel time each). During this period the total FLAIR car days on the road were estimated at 25,000 with the reliability percentages as follows:

For component failure:

$$\frac{25{,}000 - 111}{25{,}000} \times 100 = 99.56\%$$

For alignment and contact repair:

$$\frac{25{,}000 - 295}{25{,}000} \times 100 = 98.82\%$$

For all type repairs, the composite total:

$$\frac{25{,}000 - 419}{25{,}000} \times 100 = 98.32\%$$

If the above represented a true picture of equipment failure and reliability factors the results would be considered acceptable, but, unfortunately, this is not the case. Other considerations include:

- The bad contact problem between the Vehicle Data Processor modules (there are five) and the mother board is an intermittant condition and is not subject to a prescribed fix. The intermittant condition can and does occur in a random manner causing false emergency alarms and other data errors. It is difficult to identify a car with this problem and there is little assurance that a car identified as having the problem will remain "fixed" after the repair.

- Odometer failure, although infrequent, is a particularly difficult repair--requiring the garage's mechanical assistance to pull the left-front wheel to make a replacement. Failure of the odometer--mounted in close proximity to the front wheel brake--is believed caused by ice in the winter or high temperature due to frequent braking.

- The repairs made during the indicated period were those covering problems readily identifiable--either by the dispatcher or the officer in the car. Problems that could cause poor accuracy--such as poor calibration of the odometer or heading sensor or misalignment of the AVM two-way radio--are not detectable unless someone observes the tracking of each car (which is not practical) or unless the computer can detect poor tracking of cars. Actually, the computer does select 20 cars having the poorest performance due to data rejected for noise or program, for largest correction distance when a corner is turned, and for the fewest miles traveled per initialization. These data, available daily, have not been well utilized because their accuracy has been masked by cars undergoing tests at the garage, and because the technician workload has been filled with correcting the more easily identifiable problems.

The need for preventive maintenance is generally recognized as the preferred first step in improving overall tracking (and accuracy). This was not practiced during the evaluation period because of insufficient manpower. Since then, however, each FLAIR car is checked and adjusted (when necessary) every time it is sent to the garage for its 5,000 mile mechanical maintenance check.

4. Performance, potential for improvement. Operating results of the FLAIR system have been reviewed in considerable detail. Clearly, system performance as measured by *location accuracy,* and the *frequency of lost cars* is unsatisfactory. At this point one might be tempted to conclude that dead-reckoning AVM systems are not capable of adequate accuracy. However, allowance should be made for systems which involve major new technologies in which unforeseen problems can arise. Time is required to develop solutions to these problems and for adopting new operational and maintenance procedures that may be required.

System capability of the Phase II system can be illustrated by two tests made just prior to the system becoming operational. For the Phase II acceptance test 3 cars in close formation traveled 4 city-wide test routes of 20 miles each for a total of 80 miles for each car. During this run, totaling 240 car miles, 3 reinitializations were required--averaging 80 miles between losses. This compares to approximately 15 miles during the Phase II evaluation period. It should be noted that the test cars had been freshly calibrated, and that the test routes had been rehearsed.

The other test involved the monitoring of vehicle location of 3 patrol cars that were on normal patrol during an afternoon shift. The patrol officers were not aware that their cars were being tracked, and their locations could not be reinitialized. The path of these cars was recorded on tape over approximately a 6-hour period. An evaluator witnessed the performance of each of the 3 cars when re-played at "fast" speed with results as follows:

- One car appeared to travel more than the others--including one trip to the far corner of the city via the expressway, parkways, and city streets, plus some patrol and visits to the district station. This car was lost once and caused a "V" to be displayed, but was relocated by the computer and at the end of the period was correctly located at the district station.

- A second car displayed more or less normal activity--including preventive patrol, responding to three calls for service, and visiting the district station without getting lost.

- The third car moved very little during the 6-hour period and did not get lost.

a. Changes to improve performance. The above examples demonstrate a system capability far better than that experienced during the Phase II evaluation. Actions being taken to improve performance are stated below.

(1) Initiating a preventive maintenance program. This was not done during the evaluation period because of technician availability and budget constraints, but it was instituted during the first quarter of 1978. This will assure calibration of the heading sensors and odometers, proper AVM transceiver alignment, and proper system operations for all cars. Work will be performed every 5,000 miles when the patrol cars receive their routine mechanical preventive maintenance.

(2) Modifying connector assembly on the Vehicle Data Processor to correct intermittent contacts. The contractor has completed 10 modification kits for installation in operational units for testing during the first quarter of 1978.

(3) Changing method of flagging a "lost" car to reduce the time a car may remain in a "lost" condition. The flagging method was changed to that used in Phase I during the last quarter of 1977.

(4) Increasing the participation level of all officers to self-initialize, and developing incentives that will attain this objective. There were 22 self-initialization points throughout the city--9 located at the district stations and 13 at other strategic sites. Five of the 13 sites are seldom used so relocation of some of the self-initialization points to more favorable sites is under consideration; posting signs at the sites with initialization numbers is planned; and reporting (in the computer daily report) the number of initializations by car number has been accomplished during the first quarter of 1978.

b. Expected performance improvement. Accuracy is expected to improve as a result of all four modifications listed above. The frequency of lost cars, however, will worsen because of the change in flagging method (Item 3, above).

Referring to Exhibits 2-4 and 2-5, the miles per dispatcher reinitializations decreased from about 18 to 13 over the evaluation period; the reinitializations per car per day increased from about 6 to 9 over the same period; and the total number of dispatcher reinitializations increased from about 900 to 1200 per day. All of these indicators reflect poorer performance believed caused by deteriorating calibration and alignment and intermittent contacts which would be improved by Items 1 and 2, above.

The change in method of flagging a lost car notifies the dispatcher more quickly of a suspected lost car thus reducing the time a car remains lost before being flagged. This should have had high impact on accuracy; however, when this change was made the rate of reinitializations per car per day about doubled--from 10 to 20--resulting in an intolerable increase in dispatcher workload. Since the preventive maintenance program and the incentives to self-initialize were started, the rate has been reduced from 20 to 10 reinitializations per car per day (first quarter of 1978). Considering that these programs have not been fully implemented the performance trends appear encouraging.

c. Performance goals and achievability. As previously stated, AVM systems for law enforcement application should be accurate to within 300 feet 95% of the time, and, ideally, there should be no reinitialization required (to make the system independent of those it serves). Questionnaire surveys and interviews, however, indicate a modest number of dispatcher reinitializations--between 2 and 3 per car per day--would be acceptable. However, any dependence upon those the system serves increases the risk of subversion.

d. Other system options. As this report is being finalized the degree of improvement in accuracy and frequency of lost cars due to the aforementioned changes has not been determined. Should the results still be unacceptable the following options have been considered.

(1) Addition of automatic signposts which will reinitialize a car as it passes the electronic signpost without the assistance of the dispatcher or the patrol officer. This method obviously increases cost and creates a task of optimizing the number of signposts and their spatial distribution. If the system were to apply only to patrol officers location of automatic signposts at the district stations could be considered. Surveys indicate that a patrol car will visit the district station 3 to 4 times a shift, or 9 to 16 times a day, and records indicate travel of about 150 miles per 24 hours. This would indicate a need for maintaining accuracy for only 10 to 17 miles on the average between automatic reinitializations. The worst case would be one visit per shift, or approximately 50 miles between reinitializations. With reasonable system performance this method should nearly eliminate the need for dispatcher reinitialization and could improve accuracy to acceptable levels.

(2) Another option that has been discussed is to replace, or supplement, the magnetic heading sensor with a gyroscope. Here again cost is a factor. The gyroscope would not eliminate all sources of error, but could improve performance to acceptable levels.

Chapter III

IMPACT OF AVM ON POLICE OPERATIONS

The effect of FLAIR on police operations was not as pronounced as expected due to compromises in system accuracy and reliability. The greatest value of the system appears to lie in its impact on productivity rather than in potential response time reductions. In spite of disappointing hardware performance, a valuable assessment of the potential of AVM was obtained through careful attention to performance-related details during the evaluation.

The St. Louis Metropolitan Police Department made extensive preparations to ensure an adequate level of performance and integration of the FLAIR system into police operations during Phase II. In addition to the modifications to the physical system reported in Section C.1 of Chapter II (AVM Technology and System Performance), the following changes were made in the way the system was operated:

- Temporary dispatching personnel (including cadets and sworn officers) were replaced by permanent dispatchers.
- Sector maps were removed from the dispatch consoles to encourage the use of the FLAIR map displays.
- More self-initialization points were provided.
- A committee of top management held weekly meetings to resolve operational problems and policies relating to FLAIR.

Operational analysis begins by describing the goals of FLAIR and verifying that the system was used in day-to-day operations at a level sufficient to have an impact on performance. Then the degree to which each goal was achieved will be considered, along with a detailed discussion of the factors which tend to increase or decrease the value of FLAIR in achieving its specified goals. This discussion draws on the Performance Section in Chapter II and on the assessment of the system's capabilities described in the Attitudinal Analysis Section of Chapter IV.

The initial goals set for the FLAIR system were:

- To reduce response time,
- To improve officer safety,
- To improve command and control, and
- To reduce voice radio congestion.

Only the last goal (which did not depend upon FLAIR's locating abilities) showed promise during the Phase I test of the system in the Third District of St. Louis. As a result, each of the initial goals required additional testing during the Phase II city-wide implementation. Important new goals were also considered during Phase II--improved supervision of the patrol force, and the effect of FLAIR and objective achievement on improved productivity.

Achievement of the system's stated goals depends upon the two basic performance parameters considered in detail in Chapter II: accuracy and reliability. One should recall that accuracy was quite disappointing and that even the level of accuracy normally maintained interfered with dispatching operations. Dispatchers performed an average of 1064.7 re-initializations per day (one every 8.1 minutes for each dispatcher) from April through August of 1977. The principal reliability problem involved mechanical failure of the patrol cars which adversely affected system operation, e.g., 20 non-FLAIR cars had to be fielded each day during a two week heat wave in August.[13] Use of non-FLAIR cars interferes with the dispatch process as their location and status do not appear on the FLAIR display.

The interrelationship of accuracy and reliability with the various system goals are illustrated in Exhibit 3-1. Each of the goals depends upon the achievement of reliability. Response time, officer safety, command and control, and improved supervision depend upon accuracy. Each of these goals makes a potential contribution to productivity through faster response, decreased excess driving, and improved efficiency and effectiveness.

The FLAIR system received extensive use in St. Louis--as demonstrated by the high levels of FLAIR-equipped cars, the mileage they covered, and the number of digital communication messages--as indicated in Exhibit 3-2. An average of 136.2 cars were deployed to cover 136 regular patrol division vehicle assignments during April through August 1977. They covered an estimated 2,321,000 patrol miles during this 5-month period--well over 15,000 miles per day. This high level of FLAIR system use has helped to ensure meaningful evaluation results.

A. Response Time Results

On first analysis it seems obvious that the ability to select the closest car for dispatching should result in improved response time by reducing response distances. But even though such a closest car

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[13] 26 FLAIR-equipped spare cars are available for use when regular patrol cars are being serviced for mechanical, radio, or FLAIR reasons. Replacements in excess of 26 are not FLAIR-equipped.

Maintenance Cost

Computer contract	$ 32,000/year
Eleven technicians (average $9,000 at one-half time)*	85,500
Spare parts (estimated)	23,000
Total maintenance cost................	$ 140,500/year

*One-half time for FLAIR, one-half time for voice communication equipment

Operating & Maintenance Cost....................	$ 159,500/year
Operating & Maintenance Cost per Car...........	$ 800/year

	Straight-Line Depreciation	
	10 years	5 years
Amortization	$ 966	$1,932
Operating & Maintenance	800	800
Total Cost per Car per Year......	$1,766	$2,732

4. Return on investment. The total cost of a one-man police car is approximately $130,000 per year. This assumes five officers are assigned to each patrol car to cover three shifts, holidays, vacations, and sick time, and the proportionate share of vehicle and equipment cost. A two-man car is approximately twice the cost of a one-man car--$260,000 per year. Thus, percentage of productivity improvement needed to break even is calculated in the following.

	One-Man Car		Two-Man Car	
Amortization basis	10-year	5-year	10-year	5 year
FLAIR cost per car per year	$1,766	$2,732	$1,766	$2,732
Operating cost per car per year	$130,000	$130,000	$260,000	$260,000
% productivity improvement to break even	1.36%	2.1%	0.7%	1.05%

Exhibit 3-1

FLAIR System Goals

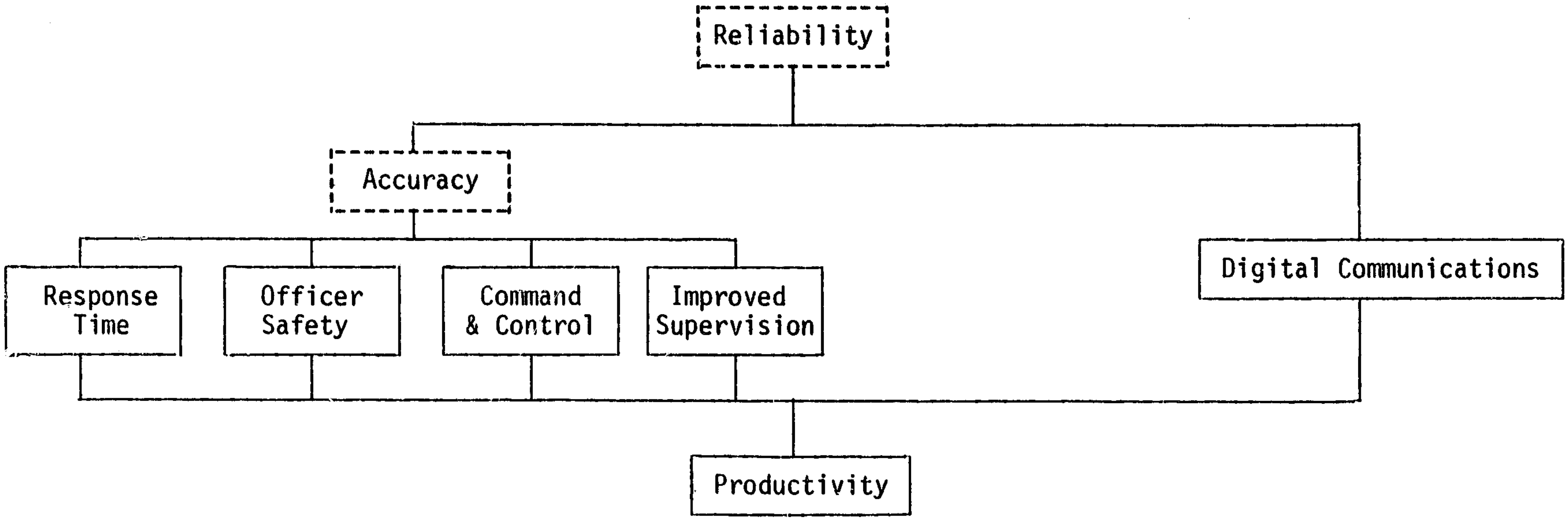


Exhibit 5-1

Return on FLAIR Investment
vs.
Productivity Improvement

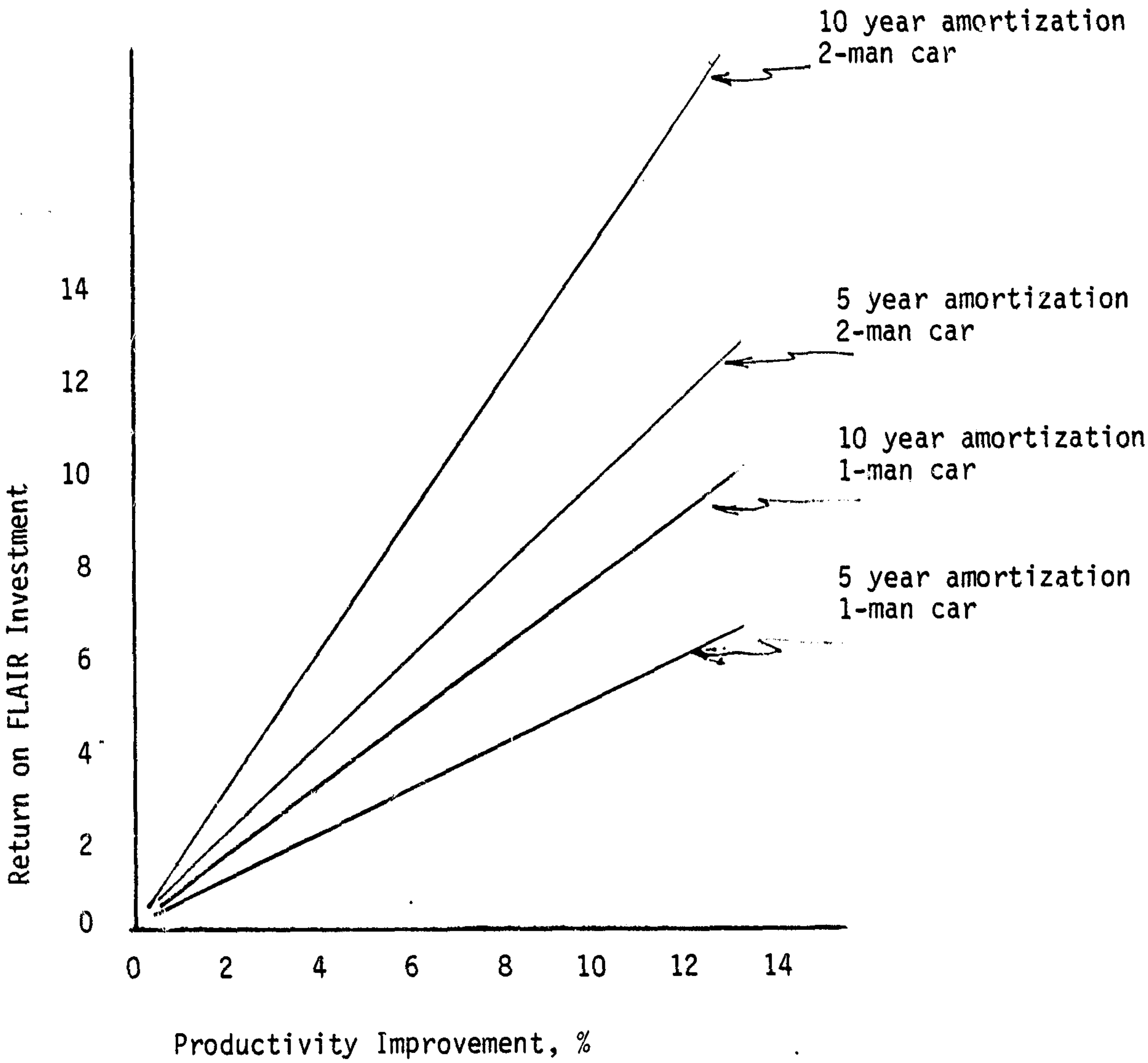
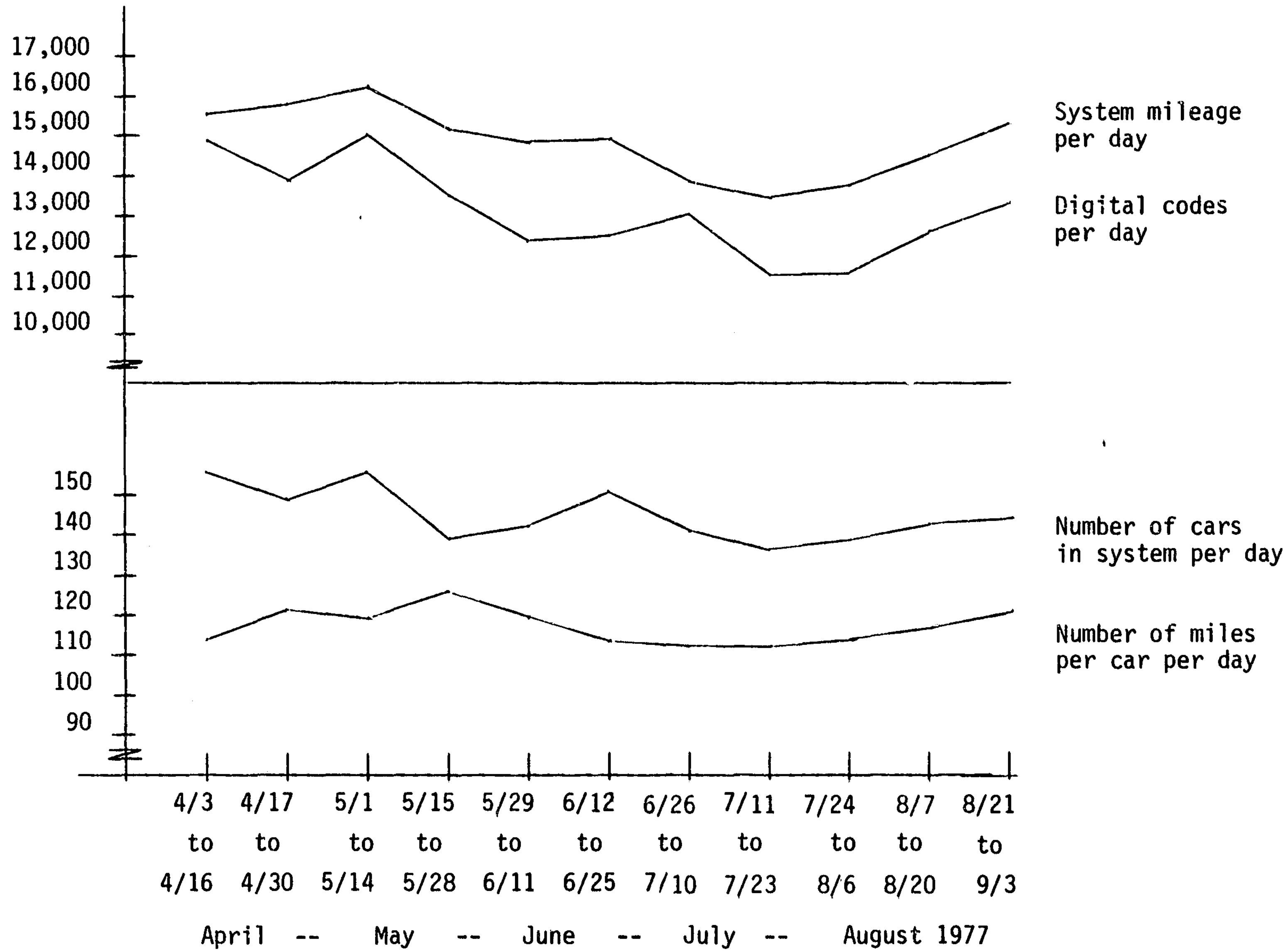


Exhibit 3-2

System Use:
Overall Indicators



dispatching plan was adhered to very closely during Phase II, *there was no significant improvement in travel times.* On the whole, response times seemed somewhat longer after FLAIR became operational, but there were many reasons besides the closest car dispatching process (e.g., less experienced dispatchers) which could have caused this pattern. In any case, response time reductions do not appear to be the popular benefit of AVM contrary to what many had expected.

Evaluation of response time performance is particularly important because response time is often a major design criterion for AVM manufacturers. For this reason this aspect of AVM has received extra emphasis in this evaluation. In order to assure the validity of evaluation conclusions, several different measurements of the effect of AVM on response time are included in this analysis:

- Simulation model of AVM impact on response time
- Detailed analysis of travel time by priority of call
- Detailed analysis of dispatch times by priority of call
- Overall Phase II response time results
- Phase I special test results

Every approach to AVM response time evaluation indicates that only limited improvements can be expected. When these are considered in the light of the results of the recently completed Kansas City Response Time Study,[14] it is apparent that response time will not be the area in which AVM has its greatest potential. The Kansas City study showed that the time taken to report an incident after its occurrence is comparable to or greater than travel time for most crime categories, thus diluting the influence of travel time savings on greater criminal apprehension and witness availability.

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[14] Marvin L. Van Kirk, "Response Time Analysis - Executive Summary" (Kansas City, Missouri Police Department, 1977).

1. Use of closest car dispatching. Observed levels of the use of closest car dispatching, shown in Exhibit 3-3, implied diligent and extensive use of AVM in dispatching. Any response time benefits available should have been revealed at this level of system use.

A benchmark value for closest car dispatching was set during a 3-week special test under the Phase I version of FLAIR. Specially selected dispatchers and special attention to dispatch policies meant a very high degree of adherence to the closest car dispatching policy. Phase II of FLAIR was operational on March 15, 1977, and it took time for many dispatchers--especially those who had not worked with the Phase I version--to learn how to use the system. Maximum effectiveness of closest car dispatching occurred during June and July, after most dispatchers had learned the use of the system, but before the very frequent deployment of non-FLAIR cars (during August) motivated them to revert to pre-FLAIR dispatching strategies. The shift can be seen clearly in Exhibit 3-3.

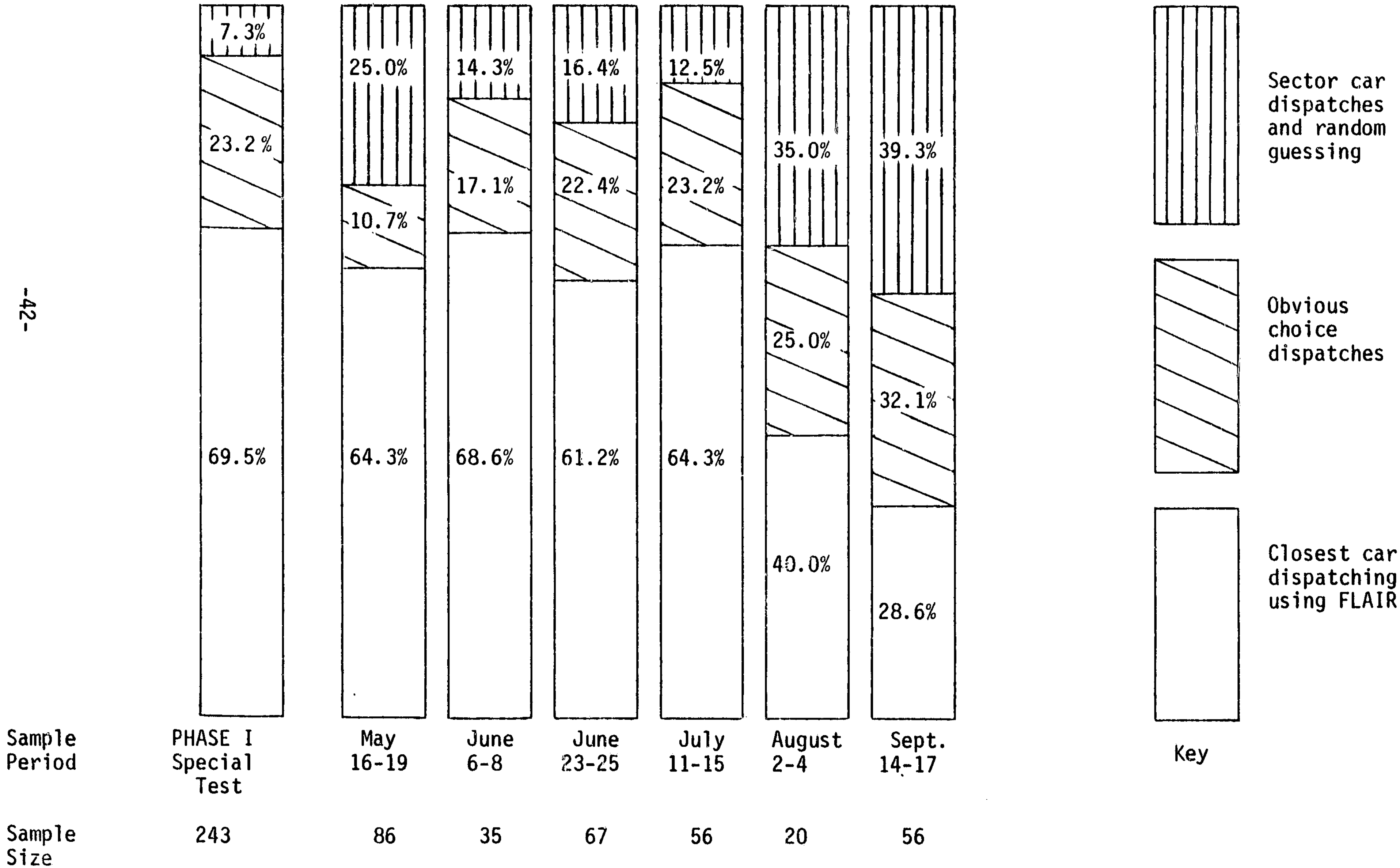
In addition, it is evident that dispatchers learned shortcuts to using FLAIR for closest car selection as shown by the steady growth of "obvious choice dispatches" during Phase II. The very busy periods of the summer months inspired this trend because many dispatches occurred when there was only one available car in a district.

2. Simulation analysis of the limits of response time reduction. Employing a specially developed simulation model of police patrol and dispatching,[15] mean travel time was estimated to be reduced by up to 25 percent by switching from pre-AVM dispatching procedures to closest car

[15] R.C. Larson, K.W. Colton, and G.C. Larson, "Evaluation of an Implemented AVM System: Phase I" (Public Systems Evaluation, Inc., Cambridge, 1976, pp. 203-209). Available from the National Institute of Law Enforcement and Criminal Justice Library in the Law Enforcement Assistance Administration, Washington, D.C.

Exhibit 3-3

Use of Closest Car Dispatching



APPENDICES

dispatching. However, a large fraction of this anticipated reduction in travel time is attributable to the relatively inefficient (from the perspective of dispatching the closest car) precinct-oriented dispatch strategy used prior to AVM.[16] Other modeling analyses indicate that about the most travel time reduction that can be expected from AVM is roughly 11 to 15 percent, not 25 percent, when compared to more conventional non-precinct oriented dispatch policies. The potential benefits of AVM, then, depend critically on the dispatching policy to which it is compared.

Closest car dispatching is of value principally during periods of intermediate workload. If most cars are available, the closest car is usually the sector car and no additional benefit is derived from using the closest car dispatching strategy. Similarly, if only a few cars are available the closest one will usually be obvious to the dispatcher without the aid of AVM.

By assigning the closest car to any given incident, the frequency of dispatching any given car to an assignment outside of its patrol area will be increased. The extent to which this occurs has been estimated through operations research modeling by Larson and Franck for various levels of patrol car utilization and is shown in Exhibit 3-4.[17] According to the officers this decreases their sense of unique responsibility for policing their sectors. Both the increase in intersector workload assigned by the dispatcher and the increase in officer-initiated workload outside of assigned patrol beats are shown in Exhibit 3-5.

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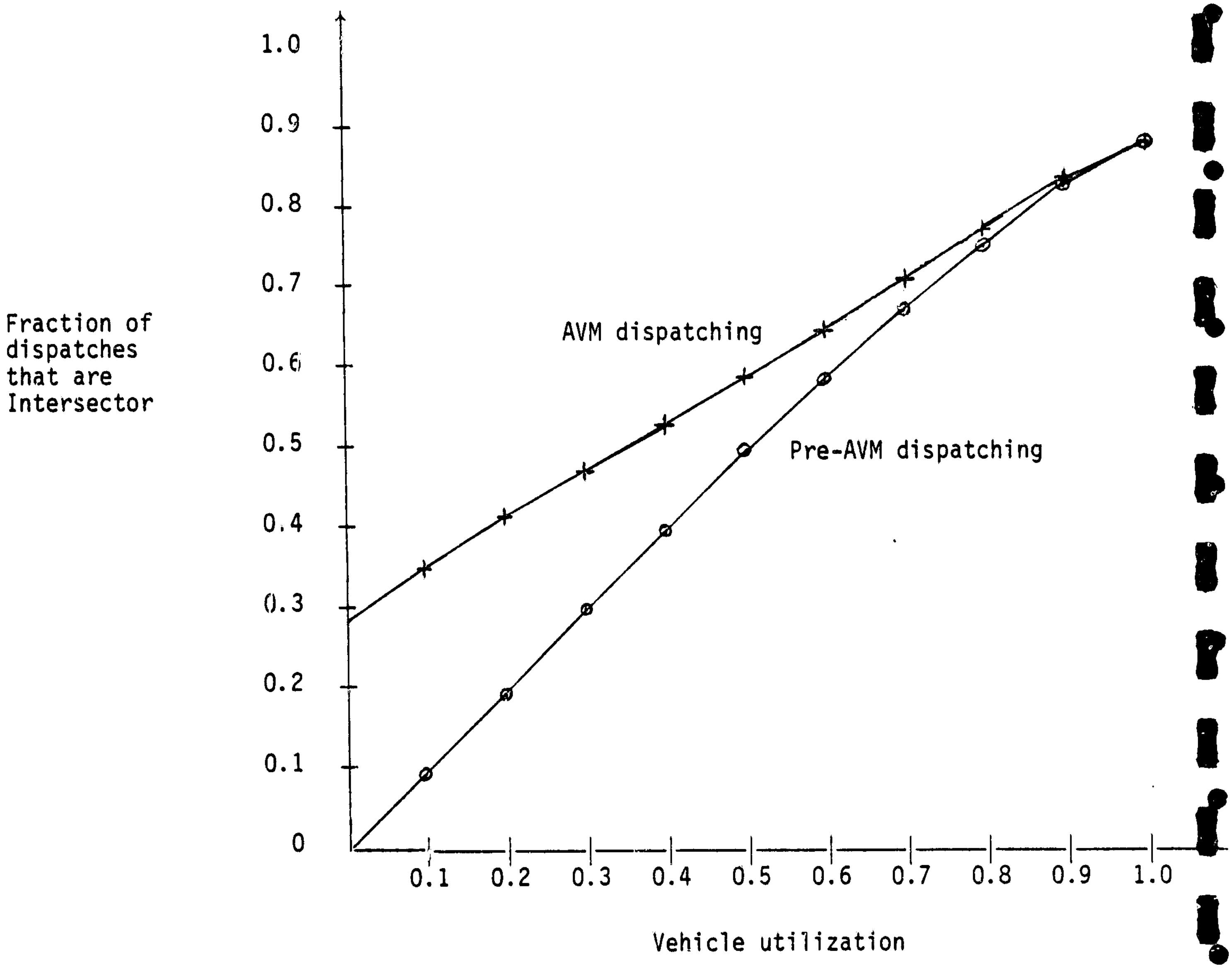
[16] In St. Louis a precinct is a small collection of contiguous beats, and each district contains two or more precincts. Dispatch preferences are given to precinct vehicles, even if a vehicle in the same district, but another precinct, is closer.

[17] R.C. Larson and E. Franck, "Evaluating Dispatch Consequences of Automatic Vehicle Location in Emergency Services," Journal of Computers and Operations Research, Vol. 5 (1978), pp. 11-30 (27).

Exhibit 3-4

Estimated Effect of AVM on Intersector Dispatching*

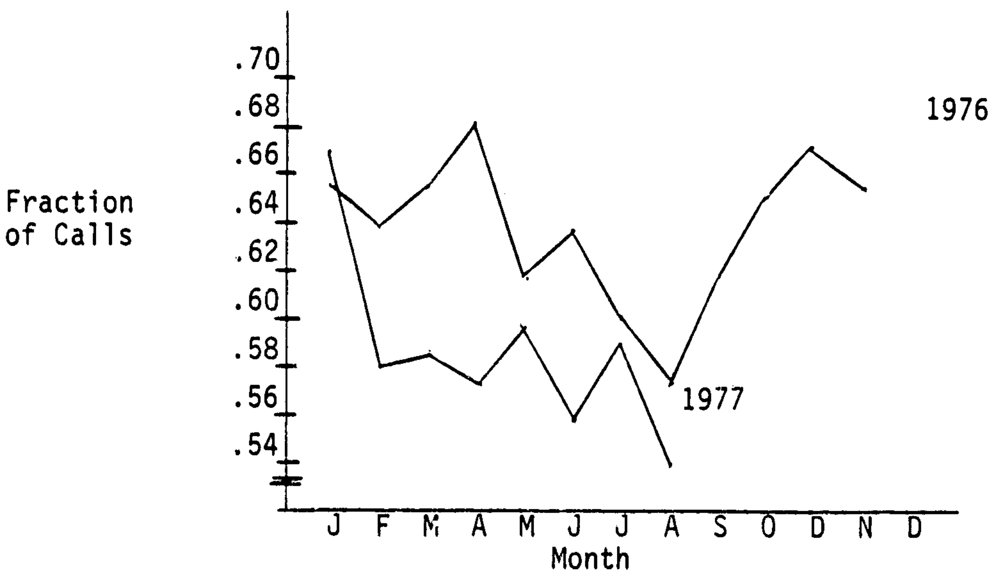


* Example for a 9-car square region, taken from "Evaluating Dispatch Consequences of Automatic Vehicle Location in Emergency Services," Journal of Computers and Operations Research, Vol. 5 (1978), pp. 11-30 (27).

Exhibit 3-5

Fraction of Activities within Beat in District 2

(a) Fraction of Calls for Service handled within beat



(b) Fraction of patrol-initiated activities handled within beat

3. Phase II response times. Response times during 1977 are often longer than those for 1975 and 1976, but the increase seems to be operationally insignificant. (A detailed breakdown of the elements of response time is shown in Exhibit 3-6.) Only two elements of response time were affected by FLAIR. While the changes in travel time are not uniform in pattern from district to district, it is clear, on the whole, that no useful decrease in response time has been obtained in St. Louis through the use of FLAIR.

a. Travel times. Overall travel time results for three test districts are shown in Exhibit 3-7. There was no operationally significant change in travel times in March and April of 1977, just after FLAIR became effective. Because of very large sample sizes statistically significant changes were observed when 1977 data were compared with that of 1976: a 12.6 second increase in District 2, a 3.0 second increase in District 3, and a 3.6 second decrease in District 5 for April.[18] Even the District 5 reduction was only a 1.2% improvement and it was an isolated area. In general, response times were higher during the later months of 1977 when FLAIR was fully operational.

Special investigation was made into the effect of priority on travel times to detect changes due to FLAIR. The overall travel times reflect the pattern for low priority calls fairly well because most of the police department volume (roughly 60%) consists of such calls. In Exhibit 3-8 the pattern for high priority calls is displayed. While higher priority call travel times are lower than overall travel times, high priority

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[18] Compare this improvement with the estimated 30-second savings due to the installation of a direct dial phone number for complaint evaluators.

Exhibit 3-6

RESPONSE TIME COMPONENTS

Events	Response Time Component	
1. Crime occurs		
	Reporting time	
2. Citizen calls police		
	Telephone delay time	
3. Complaint evaluator answers call		
	Complaint preparation time	
4. Written complaint to dispatcher		
	Dispatch time	Elements Affected by FLAIR
5. Officers dispatched		
	Travel time	
6. Officers arrive at scene		

AVM has an impact only on the last two response time components: dispatch time and travel time.

The magnitude of acceptable location error levels for law enforcement application may be developed from the following considerations:

- If reduction of travel time to the incident site were the only consideration, than the accuracy required to accomplish nearly all of this time, has been established as one quarter of a beat dimension.[2] Beats have various dimensions dependent upon urban density and other factors. In New York City, for example, a beat may be 2 to 4 blocks on a side in Manhattan, whereas in Kansas City a beat may be 1.25 miles on a side. For these examples, AVM accuracy required would range from one-half of a block, say, in Manhattan, to one-third of a mile, say, in Kansas City.

- Travel time, in the above illustration, assumes a continuous street pattern. Barriers, such as expressways, large hills, streams, etc. can influence the results. When such barriers influence travel time significantly,[3] the dispatcher should know on which side of the barrier the vehicle is located. For this purpose, accuracy in the order of one-half block may be required.

- Command and Control operations may require an area to be sealed off, or a vehicle to be chased. For maximum effectiveness, the dispatcher should know the street on which the vehicle is located (or travelling), to a tolerance of perhaps one-half block.

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[2]See Chapter VI.

[3]R.C. Larson, Urban Police Patrol Analysis (MIT Press, 1972), pp. 102-106.

> When an officer sounds an emergency alarm, the dispatcher should be able to direct other officers to the emergency site quickly. If the officer is located in an alley in a high-rise urban area, the response time may be considerably shortened if the location accuracy and resolution could define this location.

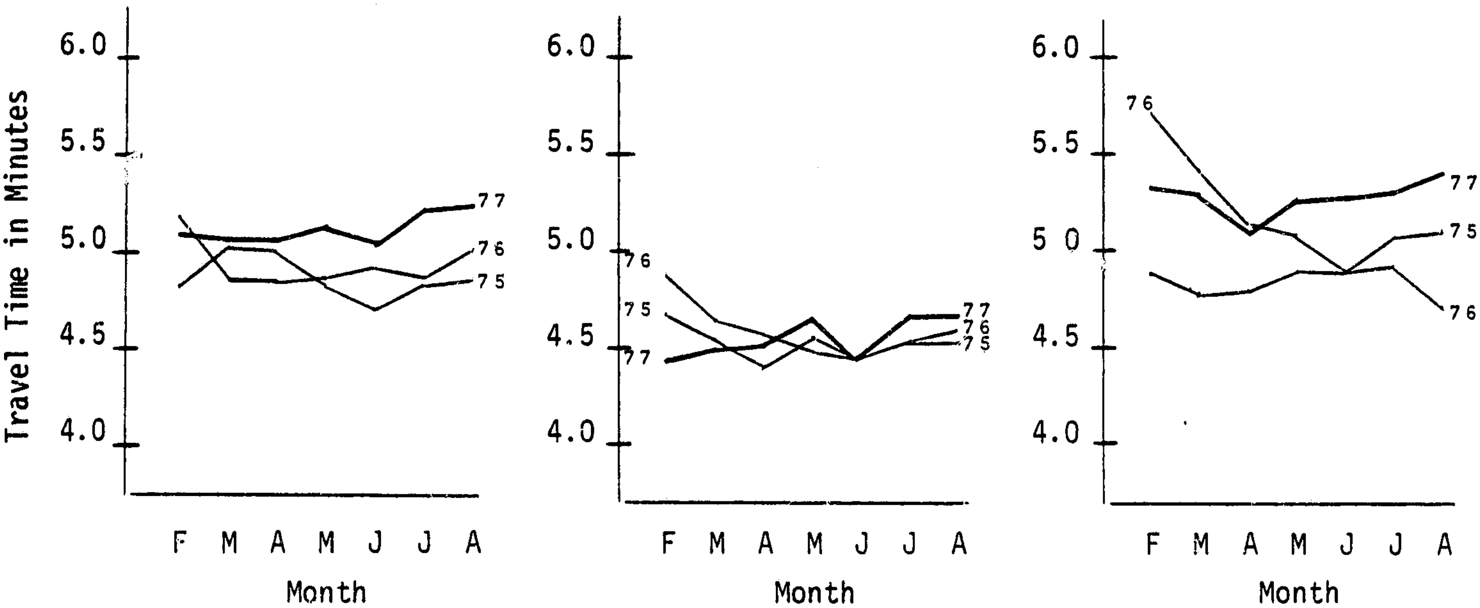
Considering the above situations, AVM system accuracy of one-third mile to one-half block may be required, depending on the system objective and implementation location. For systems in dense locations, or where significant barriers exist or when command and control operation and officer safety are system objectives, accuracies in the order of one-half block are desired. An average block is estimated at 440 feet. A system having 95% confidence that the error would not exceed 220 feet should be very acceptable for law enforcement application. However, it is also recognized that tradeoffs (such as cost) might make lesser accuracies in some police departments (perhaps to 400 feet) tolerable.

Acceptable levels of mean time between losses are more difficult to rationalize, as it relates to attitudes and workload of the dispatcher, and the patrol officer. Too frequent occurrence of lost cars will adversely affect attitude, the likely result being loss of confidence in the system. This subject is covered in more detail in Chapter V, "The Frequency of Lost Cars," and in Chapter IX, "Technological Analysis."

2. Update rate. This is the rate at which vehicle location (and other data) is sent from the vehicle to headquarters.

Exhibit 3-7

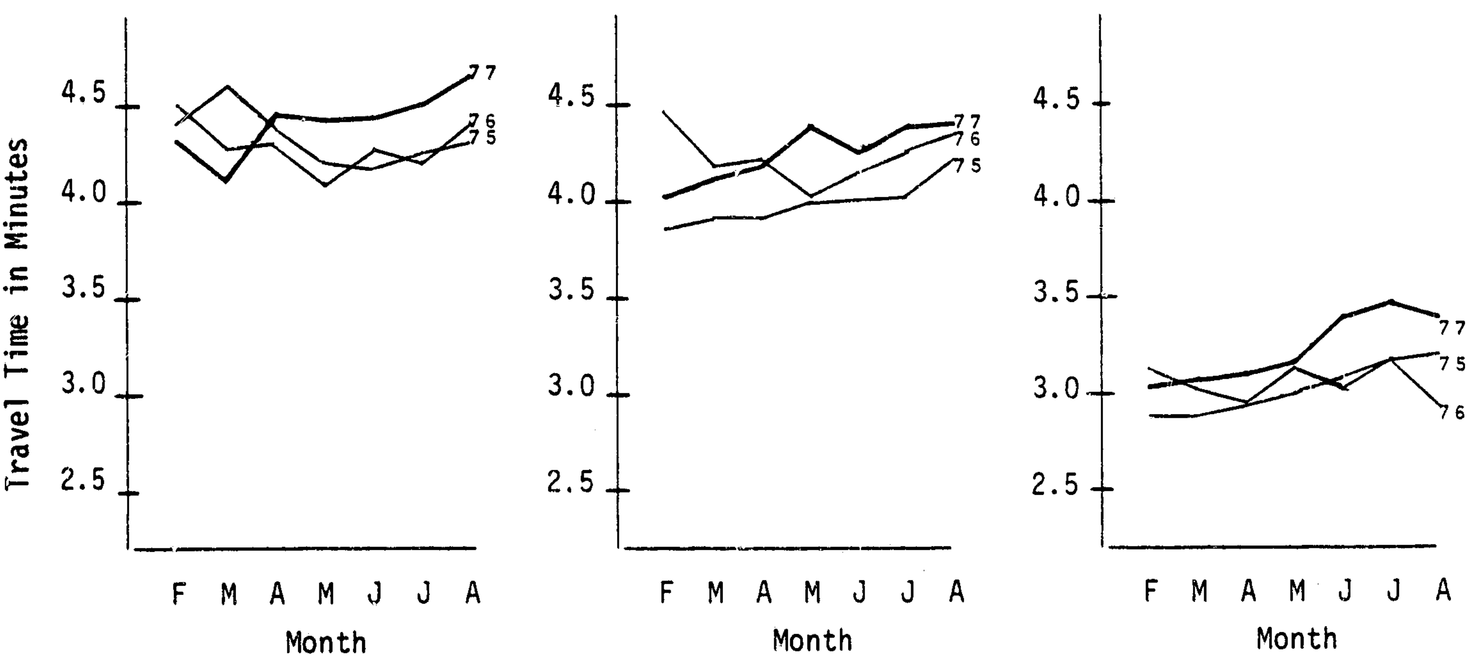
Overall Travel Time Results



(a) District 2 (b) District 3 (c) District 5

Exhibit 3-8

Priority I Travel Time Results



(a) District 2 (b) District 3 (c) District 5

travel times under FLAIR are higher than they were under pre-FLAIR dispatching. For high priority calls it is especially important that travel times be reduced and the lack of improvement here is disappointing. It is however incorrect to assign the responsibility for the observed increase to FLAIR--in May 1977,when the system was usually not in service, there is no improvement over other months.

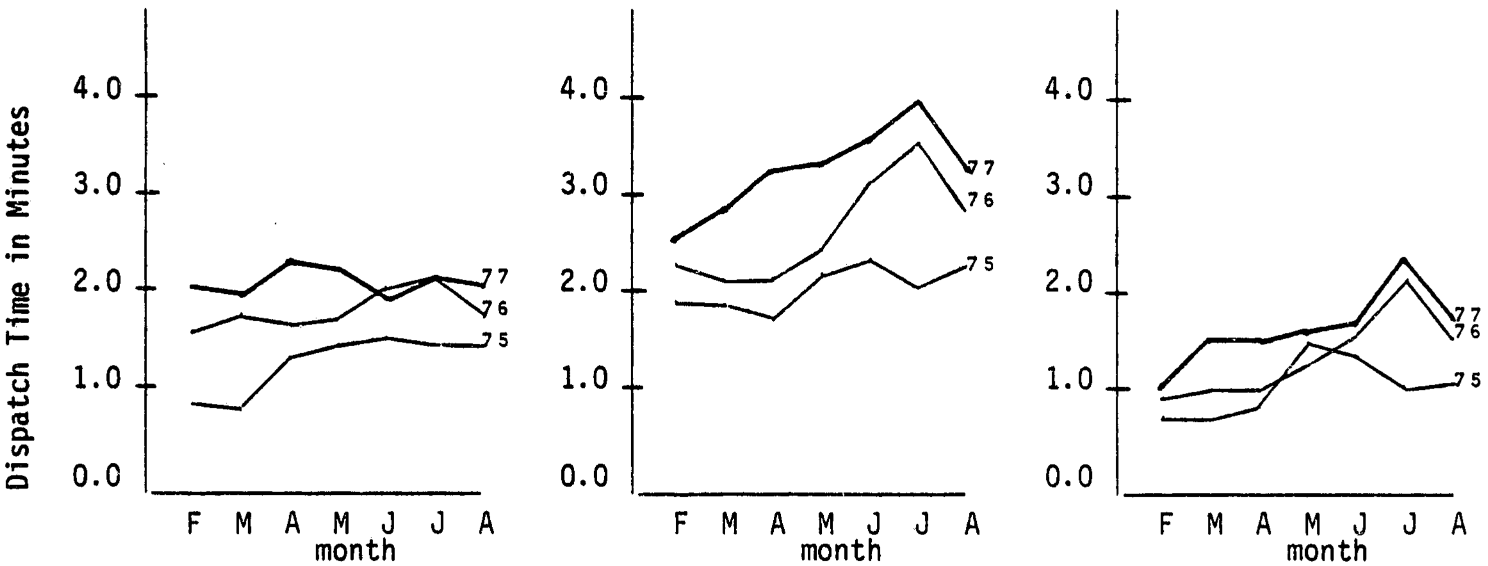
Overall, it is clear that FLAIR did not cause an operationally significant decrease in travel time. The system did not achieve the 11 to 15 percent decrease in travel time which was theoretically possible to achieve over normal dispatch policies. The effects of a myriad of other factors--workload, dispatcher experience, and officer motivation, in particular--can make a great enough difference in travel times to obscure any changes due to AVM.

b. Dispatch times. The dispatch time results for the same three test districts are shown in Exhibit 3-9. Dispatch times are consistently higher in 1977 than in the two previous years. This appears to be part of a trend, however. The dispatch times in 1976 are almost as consistently greater than those in 1975 as they are less than those of 1977. The sharp peaks in July show the effects of queuing when calls for service arrive at the dispatcher's desk faster than the cars can handle them. Dispatch times are strongly sensitive to workload fluctuations.

Examining the pattern for high priority calls reveals that the use of priorities does have some effect--in Exhibit 3-10 the pattern of increasing dispatch times from year to year is not as consistent for high

Exhibit 3-9

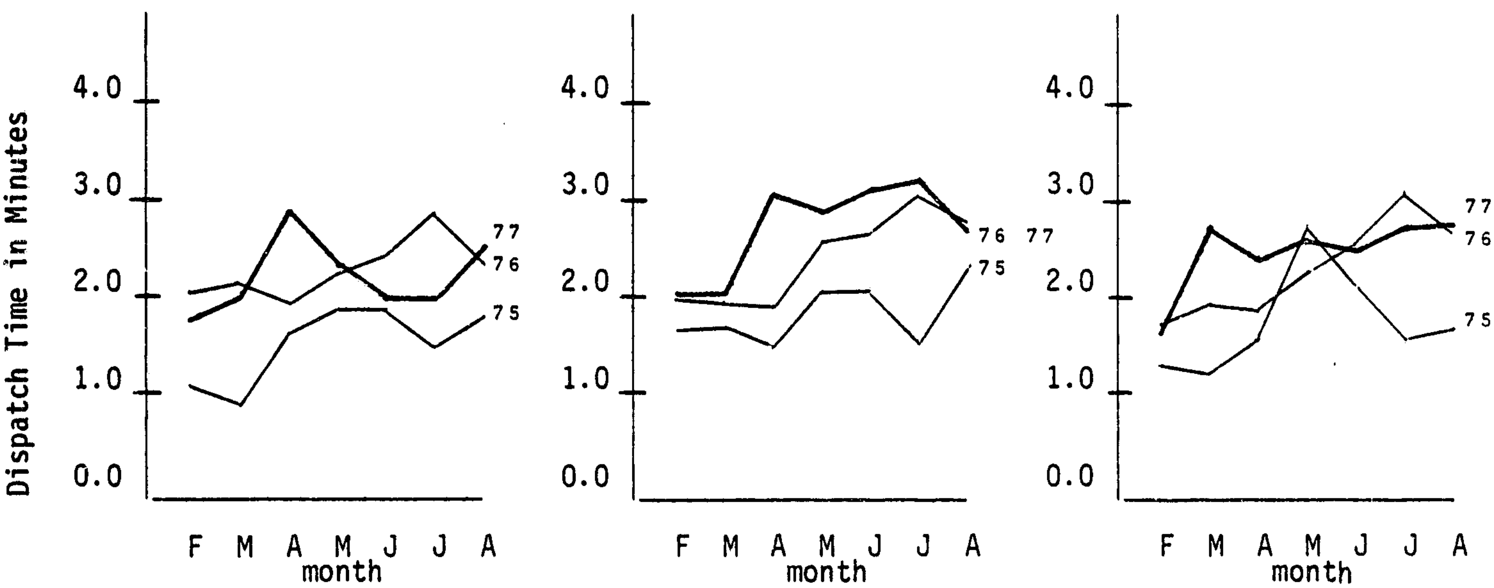
Overall Dispatch Time Results



(a) District 2 (b) District 3 (c) District 5

Exhibit 3-10

Priority I Dispatch Time Results



(a) District 2 (b) District 3 (c) District 5

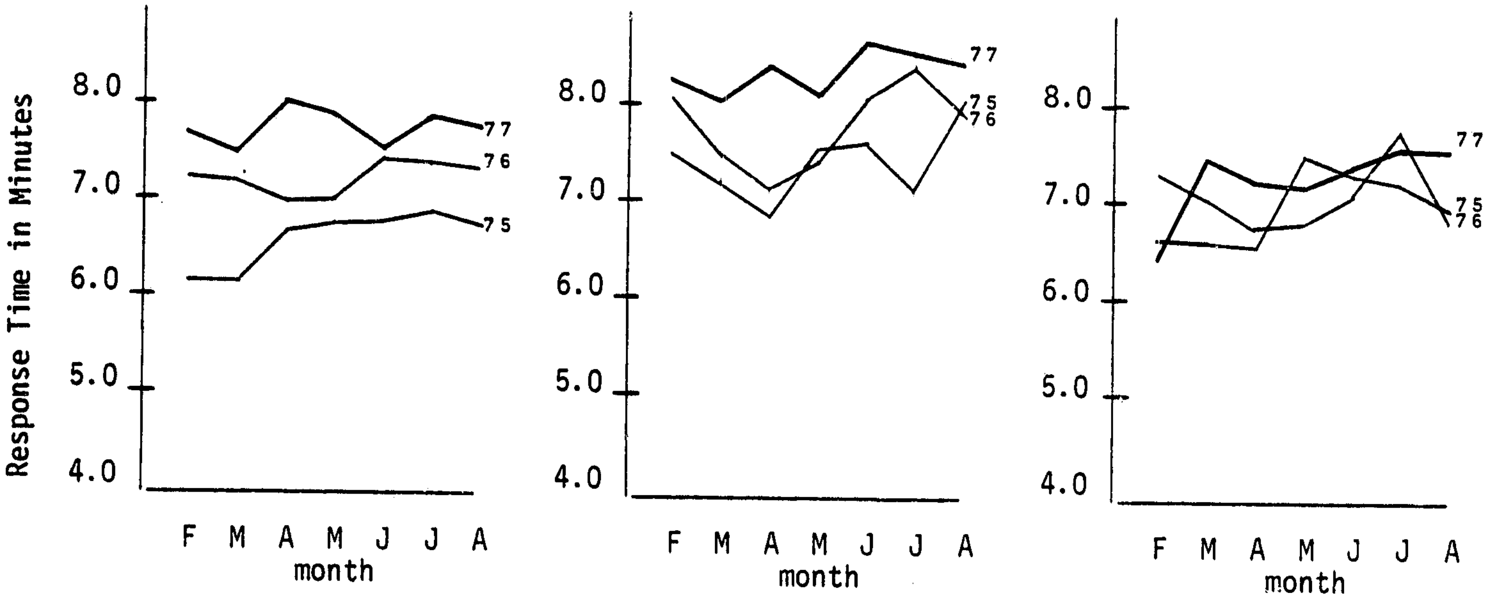
priority calls as it is for all calls combined. But 1977 dispatch times remain fairly high. Because there is no consistent month-to-month pattern, it appears that FLAIR's impact on dispatch times is not easily distinguishable from the impacts of higher workloads or in-experienced dispatchers.

c. Overall response time. Adding the impacts of FLAIR upon travel time and dispatch time to obtain those for total response time still does not reveal any operationally signficant change. The tendency for 1977 to be somewhat higher in total response time holds true for many of the sample months in the three sample districts, both for all calls together (Exhibit 3-11) and for high priority calls (Exhibit 3-12). Both the travel time and the dispatch time data exhibit patterns which suggest that FLAIR is not a significant factor in the response time changes that were observed.

4. Phase I special test results. Response times, particularly travel times, also received extensive attention in the Phase I special test. In order to determine the effect of FLAIR on travel times, the September 1975 test period was compared to its seasonally closest non-FLAIR counterpart, September 1974. Travel times were compared on a category-by-category basis, as shown in Exhibit 3-13, for 29 categories of incidents plus an overall total. Overall, the test district travel time dropped 15 percent from September 1974 to the September 1975 test period. This drop corresponded to a reduction in absolute travel times from 5.60 minutes to 4.74 minutes (or a drop of 52 seconds). While the test district figures may be impressive, it is noteworthy that non-AVM city-wide average travel time

Exhibit 3-11

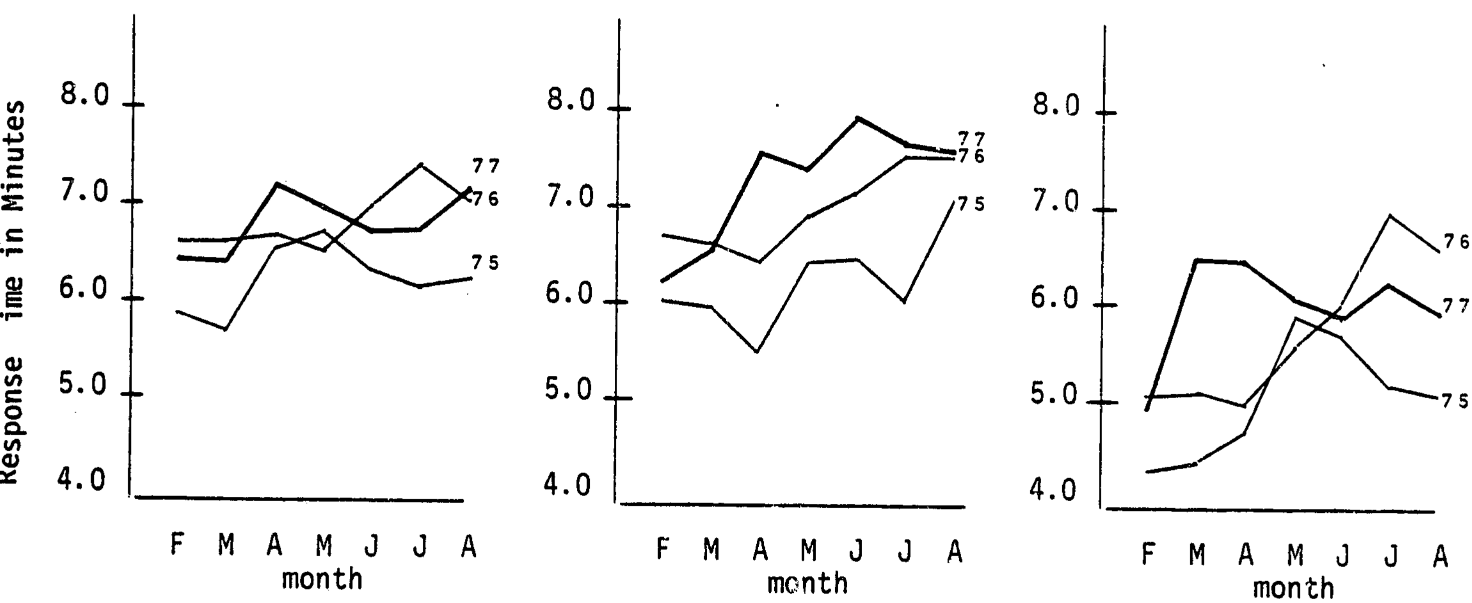
Overall Response Time Results



(a) District 2 (b) District 3 (c) District 5

Exhibit 3-12

Priority I Response Time Results



(a) District 2 (b) District 3 (c) District 5

Exhibit 3-13

PHASE I TRAVEL TIME CHANGES

(Travel time of September 1974 minus travel time of September 1975 test period [in minutes])

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Robbery	-0.71	-23	-0.16	- 4
Assault	1.16	27	0.83*	20
Burglary	0.28	6	0.55*	12
Larceny	1.16*	20	0.59*	11
Auto Theft	0.99	15	0.09*	1
Destruction of Property	1.47	23	0.58	10
Sex Offense	1.50	30	0.27	- 7
Flourishing	0.55*	14	0.47*	15
Person Down	1.25	24	0.65*	14
Disturbance	0.65*	13	0.50*	10
Traffic Violation	1.13	11	0.76*	10
Alarm Sounding	0.92*	20	0.45*	12
Injury	1.33	24	1.21*	23
Fire	0.50*	12	0.17	4
Accident	-0.11	- 2	0.39	7
Animal Case	-0.76	-11	0.32	5
Sick Case	0.56	13	0.49	10
Death	4.01	41	1.82	21
Assist	0.50*	10	0.82*	14
Miscellaneous Hazard	1.08	14	0.62*	10
Call for Police	1.11	34	0.48*	12
Suspicious	0.44	8	0.11	2
Additional Information	1.59	24	0.50	8
TOTAL	0.84*	15	0.57*	11

* Statistically significant at 90% level according to modified T-test.

also decreased in a statistically significant way during the same period. The drop was from 5.18 minutes (September 1974) to 4.72 minutes (test period), or a drop of 11 percent (34 seconds). Moreover, city-wide figures show statistically significant reductions in more specific response-type categories than the test district response times. Neither the test district nor the city as a whole showed any significant increase. Given these results it is difficult to attribute more than 4% of the 15% reduction (corresponding to 14 seconds) to the presence of FLAIR.

5. Response time as an AVM objective. The results of a careful examination of response time show no operationally significant reduction due to the use of FLAIR. This is in spite of comparatively careful adherence to the closest car dispatching policies through which AVM should have its effect on response time. As discussed previously, a simulation analysis of the potential benefits of closest car dispatching reveals that its effects are limited to an 11% to 15% improvement in travel time over the pre-AVM dispatching strategies. Even this limited benefit assumes complete compliance with the closest car dispatching policies and the use of an accurate system.

A recent study of the importance of response time to police operations in Kansas City found that in many cases a short response time is not a uniquely important objective for policing.[19] All of these factors lead to the conclusion that response time reductions are not the most important capability of an AVM system.

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[19] Marvin L. Van Kirk, "Response Time Analysis - Executive Summary" (Kansas City, Missouri Police Department, 1977), p. 23.

Even though FLAIR has not shown significant reduction in response time, and the Kansas City report indicates a response time reduction may not result in the apprehension of more criminals (due to reporting time and other considerations), these findings should not be interpreted to mean that rapid response has no value. The public expects quick response and for some extraordinary events rapid response can result in possible apprehension of criminals as well as finding more witnesses. This is particularly applicable to alarm-triggered and in-process events, such as pursuits and burglaries. For this reason, along with others, the St. Louis Metropolitan Police Department has elected to continue the use of closest car dispatching for high priority calls even though the sector car concept has been reinstated for dispatching the vast majority of routine calls.

B. Officer Safety Results

To facilitate the process of signaling the dispatcher in an emergency, FLAIR is equipped with a special button in each vehicle which will alert the dispatcher in three ways (two visual cues and an audible alert tone) without requiring the use of the voice radio. Unfortunately, the poor accuracy performance of the FLAIR system has meant that its location information is not reliable enough to use in the life-or-death situations which officer emergencies may often be. Most officers prefer to rely on the voice radio, but may also activate the emergency FLAIR button.

Three features of FLAIR contributed to possible officer safety improvements:

- accuracy,
- use of the special emergency button, and
- the availability of the digital code transmitter as a backup for voice radio communication.

There were some performance problems with the first two features; the digital code feature was generally quite reliable.

1. Accuracy. Accuracy was an important factor in FLAIR's contribution to officer safety. Should trouble occur, an officer could depend upon people knowing where to find him, or at least his car. If the accuracy objective of displaying 95% of the cars within 300 feet of their position was achieved, positions could still be as much as a block off for a few cars. But as it turned out, only 55% of the cars were shown by FLAIR within 300 feet of their actual positions. While the officers were not aware of this, they were aware of the large number of position updates that FLAIR required and they arrived at the conclusion that FLAIR's accuracy was of questionable value when considering their safety.

2. Use of the emergency button. The special emergency button provided in the car gave immediate audio and visual signals when pressed in order to command the dispatcher's attention. It was used with considerable regularity, as indicated in Exhibit 3-14. However, many of these uses represented tests, defective equipment, and false alarms. Genuine emergencies reported through FLAIR have included automobile accidents, pursuits, an officer who discovered a seriously ill person who seemed to have been shot, and (once during Phase I) when an officer was fired upon. During the period of June 22 to August 2, 1977, six genuine emergencies were relayed using FLAIR.

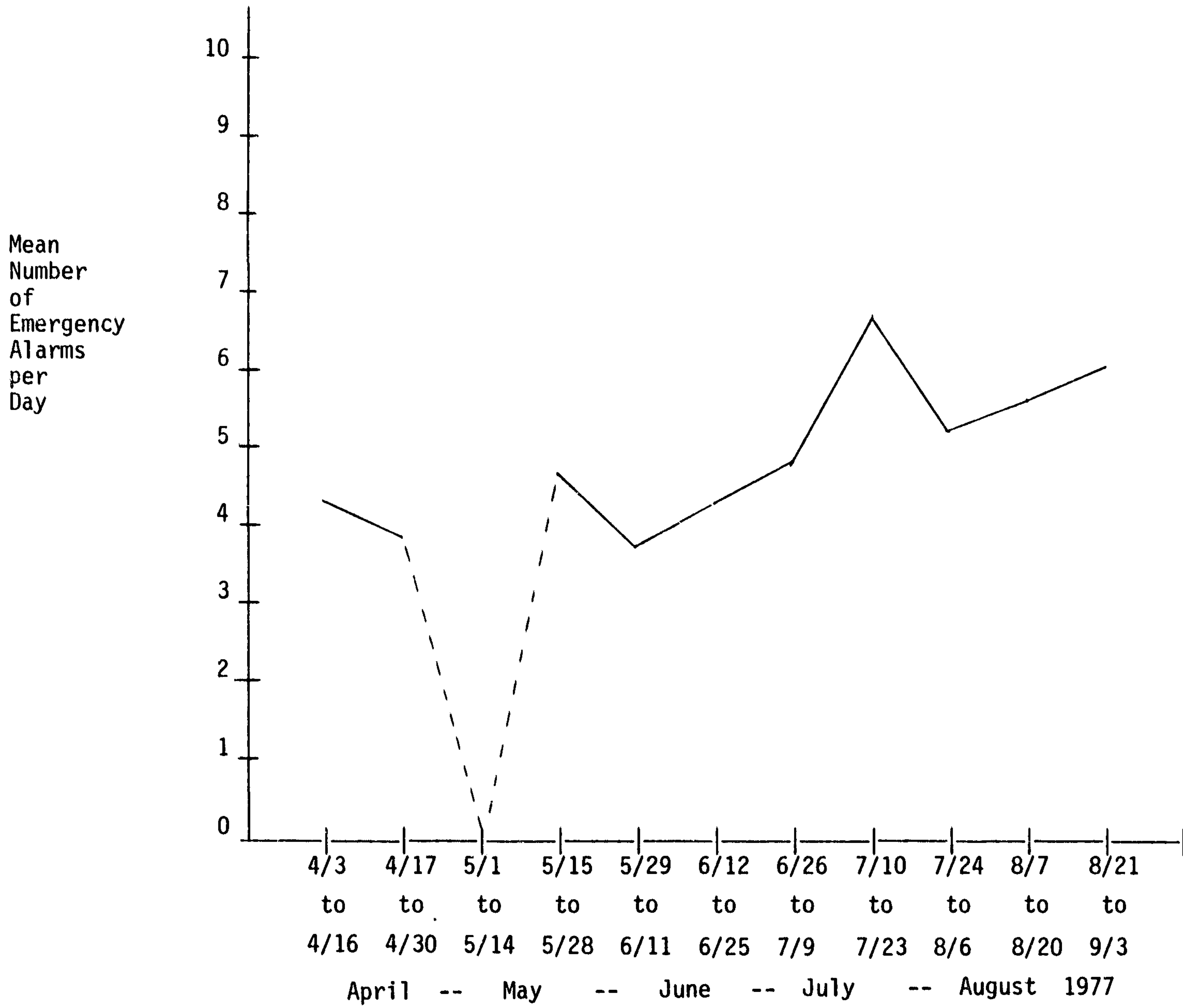
3. Use of digital communications. The digital communications feature did serve its function as an alternative to the voice radio system. When serious situations arose, officers could send a code indicating that they needed to talk to the dispatcher in order to get the dispatcher's attention

with other systems with regard to accuracy, update rate, cost and other features. Considering cost, the signpost portion of the system is directly proportional to the number used. If accuracy considerations require a signpost at each intersection, and if a city has block sizes averaging 550 feet by 300 feet, the number of signposts per square mile is approximately 170. If the price per signpost were $300, the cost per square mile for this portion of the system would be $51,000. For a city the size of St. Louis (67 square miles), the cost would be $3,417,000. This seems to illustrate that such systems may be attractive to small area communities (e.g., Montclair, California), but a method is needed to reduce cost by reducing the number of signposts or the cost of signposts if it is to be attractive to larger area cities.

An accuracy tolerance of one city block (300 to 500 feet) is not as good as one would like, particularly for such tasks as locating an officer in distress, or for command and control. Further, if the location information cannot be sent to headquarters exactly at the time when the vehicle passes the signpost, the tolerance increases. For example, if an update rate of once every five seconds is used, the added tolerance at 30 mph could be 220 feet. Another accuracy problem relates to the size of the activity area of the signpost. A radio-type signpost, that transmits or receives a signal, depends upon signal strength to activate the vehicle. See Figure 2-3. Typically, the coverage area is circular around the signpost,

Exhibit 3-14

Average Number of Emergency Alarms per Day



when the radio channel was busy. Other codes affecting officer safety can be sent when on a high speed chase or when checking an occupied car.

4. False alarms. The testing the system received as a result of the frequent false alarms was revealing. During the June 22 to August 2, 1977 period, 96 vehicle -reported emergencies were transmitted--93.8% of which were false alarms. In 56.4% of these false alarms and in three of the six genuine emergencies occurring during the sample period, the dispatcher felt that FLAIR reported the wrong location for the vehicle.[20] On a form filled out for each emergency, dispatchers were asked to report whether FLAIR was a help or a hindrance. Most of them reported the system was a hindrance when it did not report an accurate location during the emergency.[21]

5. Officer perceptions. On the questionnaire--distributed toward the end of the Phase II evaluation--both officers and dispatchers indicated that FLAIR could not locate a patrol car in an emergency most of the time and that officers should not rely on the FLAIR emergency button alone for emergency assistance. This can be seen in Exhibit 3-15. Such low levels of confidence and inclination to use the system constitute the assessment of FLAIR's value for officer safety by those whose safety will be most affected. Initial response to the system included the response "If it saves even one officer's life, it's worth whatever it costs." Poor accuracy

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[20] Data from the 6/22/77 to 8/2/77 sample. N=78.

[21] When the location was correct (N=20) 90% felt FLAIR was a help and 10% felt it was a hindrance; however, when the location was incorrect (N=43) 18.6% felt FLAIR was a help and 81.4% felt it was a hindrance.

Exhibit 3-15

Perceived Officer Safety with FLAIR

How much of the time do you think the FLAIR system would accurately locate a patrol car in an emergency?

Percent Answering	Officers (N=482)	Dispatchers (N=39)
Almost all of the time	4.4%	7.7%
Most of the time	10.0	5.1
Some of the time	38.6	30.8
Not much of the time	47.1	56.4

(a) Confidence in FLAIR

In the event of an emergency, should an officer activate the FLAIR emergency button, call the dispatcher on the voice channel, or both?

Percent Answering	Officers (N=480)	Dispatchers (N=38)
Activate FLAIR emergency button	4.2%	5.3%
Contact dispatcher on voice channel	35.8	34.2
Both	60.0	60.5

(b) Inclination to use FLAIR

In the search for lower cost approaches, and greater accuracy, other signpost concepts have evolved. A magnetic signpost[14], near street intersections, consists of a number of cylindrical magnets imbedded in a street such that when a vehicle passes over the area where the magnets are located, a current is induced in a pick-up coil on the vehicle, and the spacing between magnets and/or their polarity generate a binary code for identifying the intersection. This method appears to have certain advantages over radio signposts, in that the activity area of the magnetic signpost is a few feet. contrasted with 100 or more feet for the radio type (increasing the accuracy), and the magnets are passive, requiring no power for operations, presumable reducing operating and maintenance costs (radios require a battery or a-c power for operation).

Other passive and semi-passive arrangements are under development, involving for example, X-band radiation from the vehicle, and a coded reply from the signpost sensor. These approaches, too, are aimed at better accuracy, lower cost and less maintenance.

Acceptance of signpost systems by law enforcement agencies largely lies in industry's ability to solve the cost-accuracy problem. Lower cost signpost, passive signposts and hybrid systems involving a combinaton of dead-reckoning and signposts all appear to have promise. Final results will be dependent

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[13]Richard C. Furth, "A Magnetic Array Proximity AVM System," Novatek, Inc., 1974 Carnahan Conference Proceedings.

has fostered the opinion that the system is likely to cause more trouble than it prevents.

Situations threatening an officer's safety are most likely to occur in a fashion that limits the likelihood of a natural use of FLAIR's emergency button. Quite often such situations occur outside the car. Originally FLAIR was to have a button for each officer's belt that would trigger the emergency system in his car to alert the dispatcher, but that option was cut back because of cost. However, many officers feel that this emergency button on the belt would be the most important feature: "If you're on the 8th floor in one of those projects trying to handle a domestic dispute, you can't just send somebody down to the car to press the emergency button when things get hot."

Because officers are accustomed to relying on their radios and are aware that the radio is a proven source of help, it is natural to use the radio in stressful situations. Therefore, many of the emergencies observed by the evaluator were reported by voice radio rather than by FLAIR.

6. Officer safety results. No traumatic injuries of officers occurred in FLAIR-equipped cars that could have been prevented by better communications, and no officers lost their lives during the experimental period. These results reflect the care with which St. Louis officers approach their jobs and also indicate that FLAIR did not receive extensive testing in real life officer safety application.

With better accuracy, an AVM system could make a contribution to officer safety even though FLAIR in its current form does not seem to do so. It can be concluded that such benefits will be real but limited.

Closest car dispatching can do little to increase the speed of response to officer emergencies compared with the APB method of sending assistance. But, an accurate AVM system can help to identify the proper location of an officer who may be incoherent or incapacitated as a result of excitement or danger, and the digital code system is of some value as a backup for the regular voice channel. Any city that elects to install an AVM system should make careful provision for applying the system's capabilities to officer safety in recognized emergencies.

C. Digital Communication Results

A non-spatial feature of FLAIR is the digital coded message feature which has been integrated into the system. By sending such a message from a calculator-like panel in the car an officer can convey information to a status listing on the dispatcher's display without interrupting the dispatcher's current voice radio activities. Many of the coded messages affect the in-service/out-of-service designation of the car on the screen, including codes to indicate the priority of an assignment, time arrived at scene, and disposition upon clearing. A complete list is shown in Exhibit 3-16. Several codes are available to interrupt the dispatcher for an emergency or for pursuits so that officers are not at the mercy of the voice channel. Each of these coded messages serves to reduce the amount of information that has to be conveyed over the voice channel, and to provide an alternative to the voice channel when officers need immediate dispatcher attention.

1. Level of digital code use. The code system of communication was already in use on the voice channels before FLAIR was installed in St. Louis

Exhibit 3-16

Digital Code Messages

METROPOLITAN POLICE DEPARTMENT – CITY OF ST. LOUIS

DIGITAL CODES

[a] "E" EMERGENCY – OFFICER IN NEED OF AID
01 1st Dist. Sta. - Front Entrance
02 2nd Dist. Sta. - Parking Lot Exit
03 3rd Dist. Sta. - Front Entrance
04 Hdqtrs. Parking Lot - Entrance
05 5th Dist. Sta. - Front Entrance
06 6th Dist. Sta. - Garage Exit, Ruskin Ave.
07 7th Dist. Sta. - Parking Lot Exit
08 8th Dist. Sta. - S.E. Corner, Deer & M.L. King Dr.
09 9th Dist. Sta. - Rear Entrance
10 Laclede Garage - Front Exit
11 Grand & Meramec - All Corners
12 Hampton & Chippewa - All Corners
13 Grand & Magnolia - At Signalized Intersection
14 15th St. Garage - Gas Pumps
15 Jefferson & Chouteau - All Corners
16 Jefferson & N. Market (not Parnell) - All Corners
17 Zealand & Adelaide - All Corners
18 Fair & Natural Bridge - All Corners
19 Broadway & Baden - S.E. Corner Only
20 Laclede Garage - Gas Pumps
21 Goodfellow & M.L. King Dr. - All Corners
22 Cora & Labadie - All Corners
*23 Request Ambulance
*24 Request Cruising Patrol
*25 Traffic Violation
*26 Unoccupied Car Check
*27 Occupied Car Check
*28 Pedestrian Check
29 Building Check
30 Going On Information Channel
31 Going Off Information Channel
*32 Assist a Motorist
*33 High Speed Pursuit (criminal)
*34 High Speed Pursuit (traffic)
*35 Personal Relief
*36 Notification
37 School/Playground Signs Turned
38 Unassigned
39 Foot Patrol
*40 Meals
41 One-Man Car
42 Two-Man Car
*43 Bench Warrant Service
44 Unassigned
*45 Public Affairs Activity
46 Unassigned
*47 Prisoner in Custody
*48 Escort
*49 Road Block
50 Unassigned
*51 Detoxification Center
52 Unassigned
53 Unassigned
*54 Victim/Witness in Car
b*55 Emergency (Need to Talk to Dispatcher)
56 Business Interview
*57 Laclede Garage
*58 Radio Repair
*59 Washrack
*60 Bus Patrol
*61 - Auto Trouble
*62 City Court
*63 Warrant Office
*64 Prisoner Processing
*65 City Counselor
*66 Preventive Maintenance
*67 Gas
*68 Out-of-Service (Dispatcher action only can put car out of service in the system)
69 Unassigned
*70 Out-of-Service at Station
71 Unassigned
72 Arrived at Scene
73 In-Service
c 74 Voice Contact with Dispatcher
75 Unassigned
*76 Leaving for Scene - Low Priority
*77 Leaving for Scene - High Priority
*78 Leaving City
79 Miscellaneous (Dispatcher Use Only)

[a] To be used only for an officer in need of aid.
[b] To be used for emergency contact with the dispatcher other than above - ("E" EMERGENCY – OFFICER IN NEED OF AID).
[c] To be used for voice contact with dispatcher (e.g. additional information - reclassified coded incidents - returning to service requiring verbal disposition and C.N.

*These codes take a vehicle "out of service" – to return to service in the system a Code 73 must be transmitted.

On codes 1 through 22, 30, 31, 41, 42, 76 and 77, wait 7 seconds before clearing. All others must be acknowledged by dispatcher.

MPD Form BFO-6 (R-7) 12/76

(Radio Disposition Codes on Reverse Side) low-cost distance sensor (odometer) and heading sensor (magnetic compass). This tracking technique is called map matching whereby the computer keeps the vehicles on a street-even though the relatively inaccurate heading sensor might otherwise let it wander from one side to the other. In a similar manner, inaccuracies in the odometer can be overcome when a vehicle turns a corner, as the computer will correct the location to the nearest cross street, even though the indicated location is short of or beyond the intersection. If the computer should pick up the wrong intersection, it is likely that the vehicle will eventually encounter routes not on the map, and thus the computer can no longer track it. Under these conditions, the computer will search the map to find the location that corresponds to the vehicle route, and if successful, will relocate the vehicle.

If a vehicle does become "lost" (because the computer can no longer track it), a V is displayed on the video screen identifying the particular vehicle number whose location should be verified. To verify, the dispatcher asks the particular officer to stop at the next convenient intersection and identify the intersection. If the location is not correct, a cursor is placed, by the dispatcher, at the correct location, on the screen, and the car is reinitialized. Occasional lost cars will probably not detract from the effectiveness of the system, but too many lost cars could obviously negate the benefits intended.

so that it was relatively simple for the officers to switch to the use of the transmitter panel. This took a bit of extra concentration at first as compared to the voice microphone, but specific orders from the supervisors and reminders from the dispatchers encouraged compliance.

Extensive use of the FLAIR digital code feature is refected in Exhibit 3-17. Each car sent an average of more than 32 digital codes on every shift. This is not surprising since the cars send 3 codes for each of the incidents they handle, plus 2 more codes for each self-initiated or intradepartmental activity. Since it was more complicated for dispatchers to enter status information after a voice radio request than for them to tell the officers to use their code panels, use of the system was carefully enforced.

2. Digital communication results. Digital communications show promising potential for law enforcement applications in the following areas:

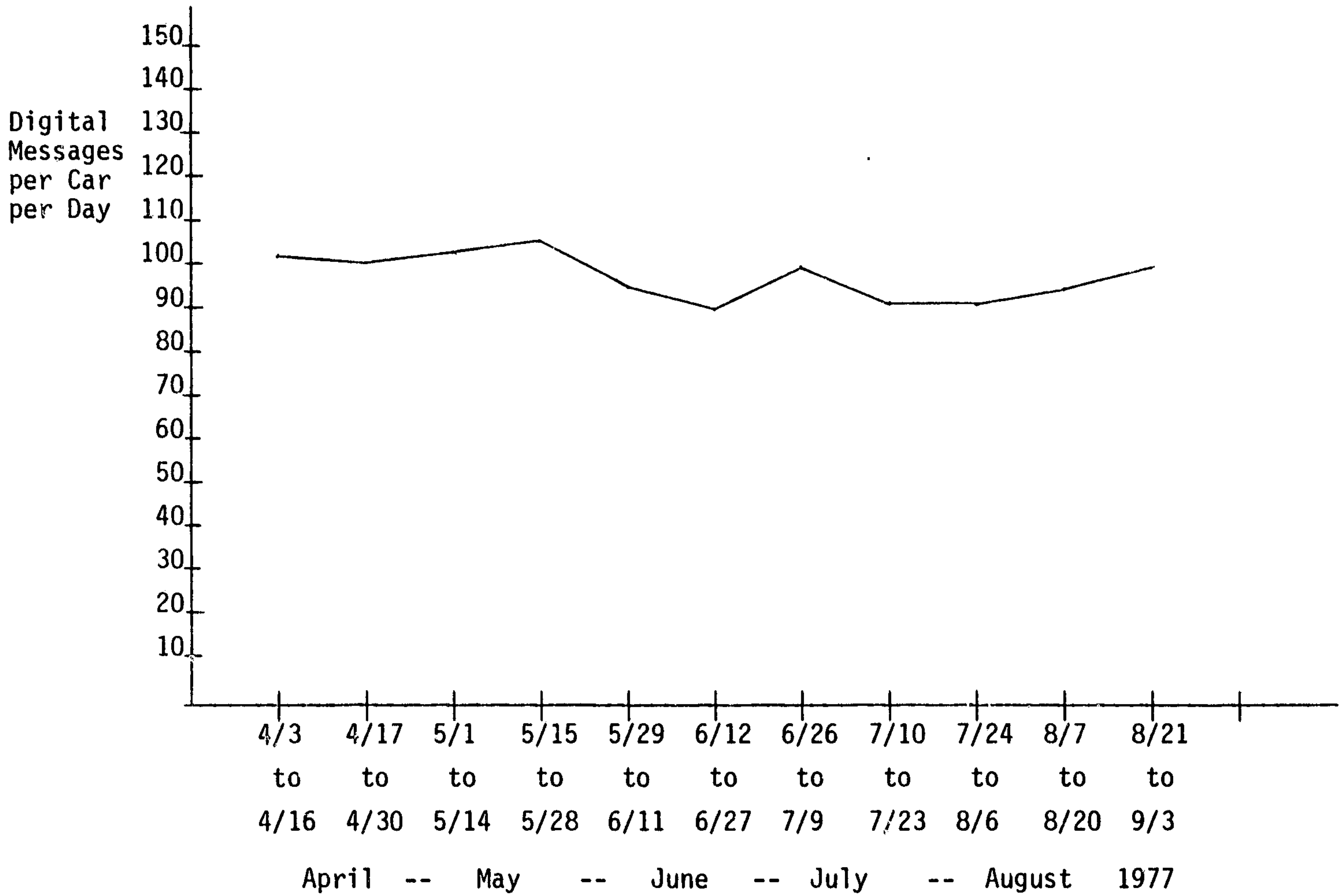
- dispatcher control of the voice channel,
- better communications during high volume periods, and
- reduced voice channel congestion.

Each of these potential benefits is important and contributes to efficient and professional communications practices.

a. Dispatcher control of voice channel. The display of digital messages appears on the dispatcher's screen when sent by the car and remains until it is acknowledged by the dispatcher before it is cleared. This means that dispatchers have an unprecedented increase in control over the traffic on the voice channels. Dispatchers now acknowledge calls requiring further

Exhibit 3-17

Digital Messages per Car per Day



location technique. The method of information transfer is by mobile transmitter, sometimes combined with dedicated telephone lines, and the type of communication is generally digital, whose numbers are transmitted using "bits" (0 or 1) in a binary code.

For systems involving digital radio communication, the capacity of a system may be determined by the number of vehicles that can be handled per r-f channel. Factors that will influence the number of vehicles per channel are:

- Number of bits per update period. The fewer required, the greater the vehicle capacity;
- The bit rate (bits per second). The higher rates produce the greater capacity (the high limit will be limited by band-width and noise considerations);
- The update rate. The less often an update is transmitted, the greater the capacity. Previous discussions of update rates indicate a rate of at least once per five seconds is desired if certain police benefits are to be obtained.
- The channel band-width. The voice channels in the VHF and UHF bands have 25KHz channel spacing and a nominal 3 KHz audio band-pass, and thus will accommodate proportionally fewer vehicles than the newly available 1 and 8 MHz channels in the 900 MHz bands (see following discussion on FCC considerations); and
- The method of communicating data from mobile to headquarters, such as random, polling and time-slots. These methods will be discussed more fully in the following.

1. Methods of communicating data. Small systems, such as the (transmitter) signpost system in Montclair, California, use

information in some priority order--for example, a dispatcher can elect to receive information from an officer who has stopped a suspicious vehicle before he responds to a request for a lunch break. Further, if a dispatcher needs to complete an off-the-air task or wants a brief rest break, he allows messages of minor importance to build up on the screen for a minute or two. An audible and visual signal will be actuated to alert him of any emergency messages received during such a period. This kind of use of the system occurred regularly and consistently during all evaluator observations. The dispatchers learn this naturally without any special training.

b. Better communications during high volume periods. Because the system can provide communication to the dispatcher at times when the radio channel is not available, it increases the productivity of the field units. The voice channel tends to become clogged when it is most needed during extremely busy periods. Digital communication allows the dispatcher to quickly recognize units as they become available for use in situations when they are most needed.

c. Reduced voice channel congestion. Congestion on the voice channel has been reduced by the use of digital transmissions. Not only have many verbal messages been eliminated entirely (arriving at scene, stopping for fuel, returning to headquarters, etc.), but the process of calling the dispatcher and establishing unit identity has been greatly curtailed. This means a reduction of 3 to 5 seconds per radio conversation on channels with many thousands of conversations per day. For a channel with 2188 digital conversations per day, [22] a 3-second reduction

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[22] April 3 to September 3, 1977 sample.

means an hour and 50 minutes of additional air time over the course of a day. This saving is somewhat reduced by the need to reinitialize positions of cars. At 22.9 seconds per reinitialization,[23] an hour and 8 minutes of air time is consumed by the average 177.5 reinitializations per channel per day.[24]

The use of digital communication means that officers no longer have to wait for a pause in the voice radio traffic in order to send messages to the dispatcher. This has brought a limited improvement in officer safety and it has been able to contribute to productivity by allowing cars to clear from an incident promptly without waiting for a break in voice radio traffic.

3. Digital communication as an AVM objective. Digital communication in FLAIR provides an additional means of communication from the officer to the dispatcher and permits a more orderly process for the dispatcher in responding to officer messages. Digital messages can be processed when the voice band is fully occupied, resulting in a more effective and efficient operation. An AVM system which does not require the frequent manual position updates needed by FLAIR would also make a very significant contribution to reduced voice channel occupancy. The configuration of the digital communication feature of an AVM system should be given careful consideration by any department that elects to purchase an AVM system.[25]

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[23] Page 298 of Phase I report, op. cit.

[24] April 3 to September 3, 1977 sample.

[25] Many of the results of the evaluation of FLAIR's digital communication features would also hold true for digital communications systems not integrated with an AVM system.

D. Command and Control

FLAIR provides dispatchers with a visual display of the spatial configuration of the patrol units responsible to them. This is the information that is necessary for the strategic deployment of units during a high priority operations such as a pursuit, sealing off an area around a crime site, or responding to a large disturbance. These are the dramatic situations first brought to mind by the mention of police command and control. More generally, police command and control includes all dispatcher-directed operations:

- Assigning cars to incidents either by directed dispatching or by means of an APB announcement.
- Controlling the response pattern as in pursuits or sealing off an area.
- Redistributing resources between patrol areas on a temporary basis.

Through improved command and control a department could hope to increase criminal apprehensions, increase general public safety, and improve efficiency in emergency situations.

1. Use of FLAIR to direct the placement of units. FLAIR's capabilities provide the dispatcher with new information thus enabling him to make better and quicker decisions which in turn will enhance patrol effectiveness. For the more ordinary events, some examples are:

- A deliberate dispatch of a non-closest car may be advantageous, if that officer's capabilities are a better match to the needs at the scene. For example, for a family dispute, an officer trained in handling these problems could be considered a favorable trade-off for somewhat longer response time.
- Certain types of incidents--such as an occupied car check--require a two-man response. The FLAIR display,by identifying location and identity of one- and two-man cars,enables the dispatcher to decide whether to dispatch 2 one-man cars or 1 two-man car.

For extraordinary events, some illustrations include:

- A pursuit: Using FLAIR a dispatcher selects available cars in the path of the pursuit and directs their placement for most probable intercept as compared to the now prevailing practice of using an APB for this type of event. The APB method is both inefficient and ineffective as practiced in St. Louis--too many cars respond, too many accidents occur, and too few chased cars are intercepted. Some limited success has been demonstrated in using the directed approach by a few of the better dispatchers who have shown the initiative to direct a chase for possible intercept. To date, there has been no departmental directive to discontinue the APB method. Before the directed approach can be successfully adopted, certain steps should be taken--such as, establishing a city-wide dispatch console where one dispatcher can cover the entire city for the type of events that can extend beyond district boundaries; the training of special dispatchers in techniques of tactical and strategic deployment of the force; and improved accuracy of the AVM system.

- Sealing off an area where a robbery or burglary is in process. The dispatcher selects cars near strategic intersections that surround the site for rapid deployment to those locations. In some police departments, not equipped with AVM, such as in Philadelphia, an extensive planning effort was used to design a system for surrounding any area of the city in which a high priority incident occurred. The increase in apprehensions which resulted from the use of the system was limited and many dispatchers felt the amount of manpower required was excessive given the benefits obtained. Any greater success by an AVM-controlled process would derive from more rapid placement of perhaps fewer vehicles made possible by their known location. Here again, a city-wide console would be required for incidents involving two or more districts. The dispatcher should be trained in methods of rapid and effective deployment.

CONTINUED

1 OF 3

CONTINUED

2 OF 3

- Dynamic allocation of patrol resources. On not so rare occasions, one or two police districts can become stripped of their available units due to a heavy call-for-service workload while other districts may be experiencing a comparatively light workload. AVM provides the means, not only of identifying such situations, but of locating available units in nearby districts for temporary assignment to the high workload area. Benefits that may accrue include the effect of maintaining a patrol presence and/or the reduction of the calls for service queuing level in the high workload area; adverse effects may develop because police commands could resist the sharing of their force with those in other districts, even if only temporarily. Implementation of this concept was not attempted during Phase II although several higher ranking officers indicated their awareness of the potential benefits that could develop.

2. Use of FLAIR to achieve efficiency. Alert dispatchers have shown the initiative to use FLAIR for selecting the closest few cars to an in-process incident and limit the assignment to those units. Previously, an All Points Broadcast would have been issued and all available units would have responded. This new practice allows distant units to remain effective as patrol cars. It also preserves a reasonable distribution of units throughout the district so that travel times are not greatly increased for subsequent incidents. An extreme example of what can happen, if such command and control is not exercised, occurred during Phase II: 26 cars were involved in an APB pursuit on an interstate highway, and several of them were demolished in accidents during a single chase in early Spring 1977.

In-depth interviews with patrol supervisors during Phase II revealed considerable support for FLAIR's potential in command and control situations.

One lieutenant mentioned that "an experienced patrol sergeant in communication can estimate the number of cars required for a major situation and the amount of on-site supervision which is likely to be needed." However, a widespread lack of supervisor awareness remains a problem.

3. Command and Control as an AVM objective. For the command and control potential to be realized, FLAIR accuracy must be improved and some modifications in police policies and organization should be made. Examples of such changes are:

(1) Create a city-wide console for use in directed dispatch for certain extraordinary events that may encompass more than one district.

(2) Undertake a dispatcher training program to develop dispatch techniques for pursuits, sealing off an area, disturbances, and temporary reallocation of the force. A training method that should be considered is hands-on experience in the conduct of directed dispatch of mock (fire-drill type) experiments, conducted perhaps in the early morning hours.

(3) Issue new directives on the use of APB and dynamic allocation of the force.

Extension of command and control by adopting police policies and methods to more fully utilize AVM capabilities can, it is believed, be effective in improving police results and in making the police force more productive. More testing of FLAIR is required to assess its effect on real-time command and control.

E. Supervision of the Patrol Force

The FLAIR displays of spatial deployment and status information can be used for supervisory purposes. Even the possibility of such a use causes officers to be more conscious of their patrol conduct. They are aware that their movements can be monitored. In a way, the poor accuracy of the FLAIR system was useful in developing this image, because when a dispatcher verifies a "lost" car's location (FLAIR check), the patrol officer--after stopping at the next convenient intersection--announces his location over the voice radio for all to hear. It can be embarrassing to be caught too often at some distance from one's assigned area, without reason.

1. The fear of AVM. Early in the evaluation there was general concern that officers would develop a fear of being watched (the "big-brother-is-watching" syndrome) and therefore would resort to acts of subversion or otherwise be uncooperative (e.g., reporting incorrect location at a FLAIR check). In fact, during Phase I and in the early stages of Phase II considerable evidence of such undesirable conduct occurred: a number of officers might simultaneously give the "raspberries sound" over the voice radio if the dispatcher should announce that a car is lost in the Mississippi River (the dispatchers quickly learned not to use that approach); or other officers might attack the FLAIR digital panel with a night stick (heard over the voice radio) if stopped too often for a FLAIR check. As confirmed by the questionnaires,[26] there is no question that the officers' greatest concern in the application of AVM was that it would be used as an inspection tool to obtain evidence of improper conduct leading to disciplinary action.

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[26] See Chapter IV of this report, pp. 82,83.

2. Police training in the dispatch process. The SLMPD management recognized the possible long range consequences of this AVM fear if left unattended. To help turn these attitudes around an open-door policy was established at the communication center so that officers could drop in and watch the dispatchers. A more positive action was to undertake a program where each lieutenant, sergeant, and officer in the force spent 6, 4, and 2 hours, respectively, with their dispatchers to learn first-hand the operation and use of AVM, after which each one wrote a (candid) memorandum to his superior stating reactions and comments.[27] This program proved very successful in exposing the real use of the system: some recognized that in various police situations it can be advantageous for the dispatcher to know officer locations; the officers witnessed the dispatch process and recognized the dispatcher had no time (nor inclination) to monitor the travels of any particular car; and perhaps the most universal response related to the job (under stress) that the dispatchers were performing in a very efficient manner. This program seemed effective in removing the mystery of the AVM system (and some of the fear), initiated more frequent use of the self-initializing feature, and increased the respect that officers (and command staff) have for the dispatcher.

3. AVM as a hidden supervisor. Officers and dispatchers opinions of how FLAIR has influenced the behavior of patrol officers is indicated by a questionnaire administered near the end of the evaluation period, and is illustrated in Exhibit 3-19. Both officers and dispatchers indicate that patrol cars leave their district less frequently, officers show fewer improper activities while dispatchers show a slight increase

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[27] A random sample of officer replies is included in Exhibit 3-18.

Exhibit 3-18

Random Officer Memoranda
AVM-Dispatcher Observations

Sir: The FLAIR operation appears to be a useful police tool. I hope the numerous FLAIR checks (verifications) can be eliminated. I am in favor of its present and continued use as long as the cost of same does not cause a reduction in manpower (allowed number of police officers) or in their salary or future pay raises.

Sir: Have attended the FLAIR training and found it informative. This system has many faults and still needs improvements. I can't see its usefulness to myself in its present stage. Would enjoy seeing it operate correctly and see its benefits to crime prevention and officer safety as I was informed in the beginning is its purpose.

Sir: Relative to my 2-hour training session of FLAIR this date wish to state that I found the training to be interesting and informative. Realizing the problems the dispatchers have in locating cars has made me realize the importance of initiating as often as possible. I personnally feel the system is a good one, however the malfunction of the equipment in the cars seems to be a major problem.

Sir: FLAIR seems to need more work. I also think it will take time and effort to perfect the FLAIR system. FLAIR needs the cooperation of the dispatcher and the officer working in the field working together. I like the code system, it seems to work out well, but the tracking system needs the bugs taken out. The dispatcher I worked with for two hours seemed to be very sharp. Two hours with a system as complicated as FLAIR doesn't teach you much except the concept of how it works. I feel it will be a very useful tool to the St. Louis Police Department when it is perfected.

Sir: I feel the FLAIR system has great potential in police work today and definitely in the future. However, I was extremely disappointed in the location mechanism of this instrument. This part is accurate only about one-half of the time and needs to be corrected before the officers on the street will have any confidence in the system. I feel the code system is of the utmost help and for this reason alone I think it makes FLAIR worthwhile.

Sir: Respectfully wish to state that I am not particularly impressed with the FLAIR program. What time is saved on the air on one end seems to be surrendered on the other by making constant verifications. I do like the capability to track a car during a pursuit assuming the computer is tracking correctly. I don't think it could ever justify the cost.

Sir: After viewing FLAIR via FLAIR training, it is my opinion that FLAIR is not serving any purpose other than codes sent. The system of sending codes is very good however, the tracking system simply does not work, therefore I think the whole program is a waste of money. Also too many cars with FLAIR down.

Sir: Respectfully wish to state for your information I believe that FLAIR is a good thing when it works. It is a good way to keep track of district cars and the closest car to an assignment. I do believe it would be liked by more officers if there were less FLAIR checks. My coming to communications today has given me a better idea of how FLAIR works. Any changes in the procedures should make another visit to communications necessary for all officers.

Exhibit 3-19

Effect of AVM on Officer Behavior

Remembering that FLAIR provides dispatchers with the location of all patrol vehicles, do you think that FLAIR has made a difference in the following areas?

Officer Responses

Percent Answering	Increased*	Decreased*
a. Patrol cars leaving their district	8.8%	21.6
b. Patrol cars leaving their beat	15.3%	15.7
c. Improper patrol activities	11.1%	20.5

*remainder of officers indicated "no change"

Dispatcher Responses

Percent Answering	Increased*	Decreased*
a. Patrol cars leaving their district	5.4%	24.3
b. Patrol cars leaving their beat	27.8%	13.9
c. Improper patrol activities	18.9%	16.2
d. Cars bunching up	10.8%	16.2
e. Cars remaining stationary for long periods of time	10.8%	16.2

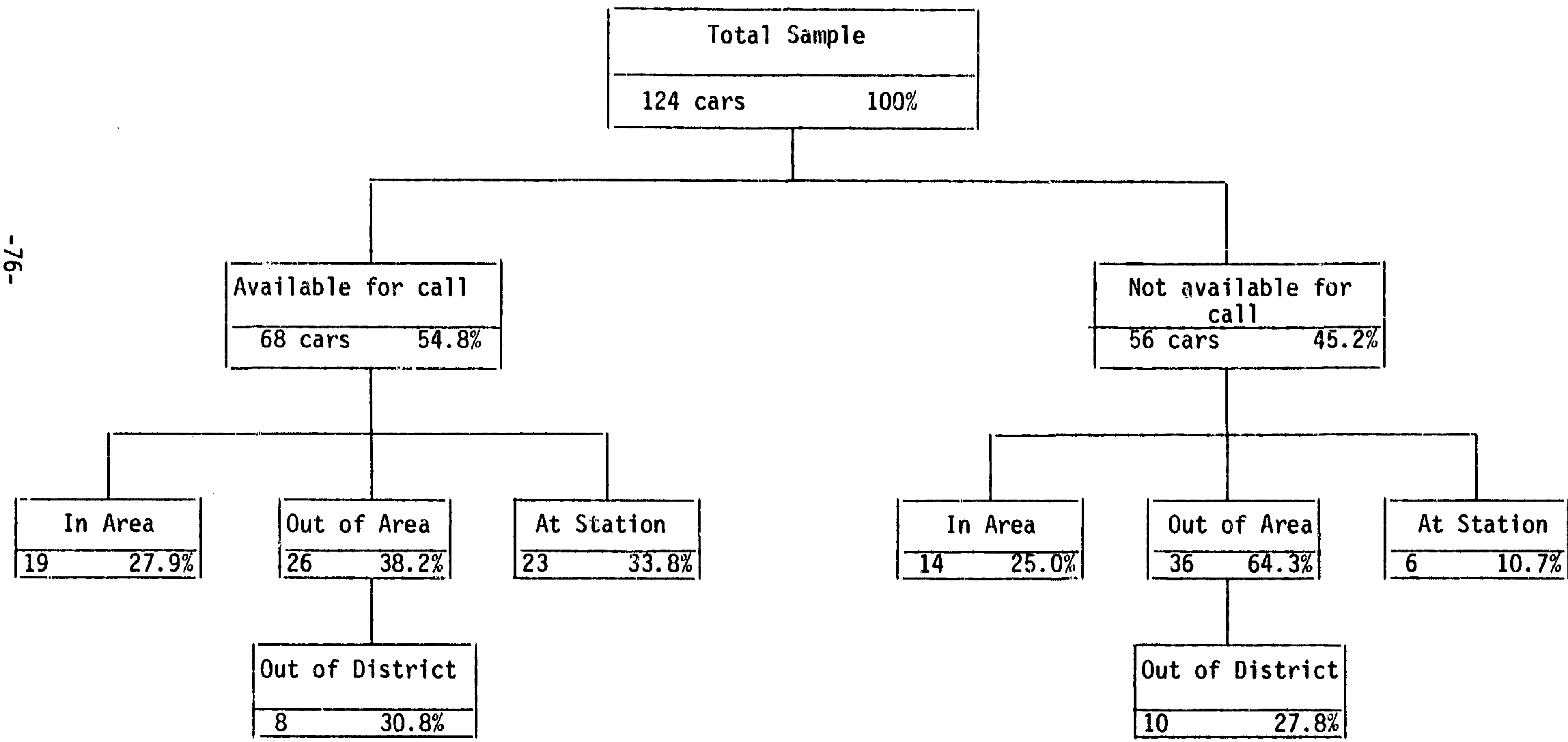
*remainder of dispatchers indicated "no change" or "don't know" (perhaps influenced by raspberry calls) and dispatchers show less bunching of cars and fewer cars remaining stationary for long periods. In all, this reveals that FLAIR performs the function of a hidden supervisor. It is probable that this effect will become more pronounced with a more accurate system and after implementing other programs to more effectively use AVM.

4. Monitoring vehicle status. The FLAIR system provides a wealth of information that can be used to develop measures of patrol effectiveness. By observing the display at the city-wide console, one can identify the cars *available for call* and those *not available for call*; those in their assigned area, out of the area or at the station; and those cars located out of their district. An example of such an observation, made by a PSE evaluator, is shown in Exhibit 3-20. The objective of such an analysis would be to relate the car status to measures of police effectiveness. For example, 14.5% of all cars (Exhibit 3-20) were out of the district and 38.2% of cars available for call were out of their assigned area. These indicators could be reflecting poor effectiveness. Measuring such status categories, perhaps by district, randomly taken several times a shift, can develop performance patterns and comparisons between districts. Such patterns (or trends) and comparisons can be useful to the supervisor for improving the effectiveness of his officers.

To maximize the benefits of such information more attention needs to be directed to the type of data that would best reflect the relative effectiveness of the force. For example, under the "not-available-for-call" category, those cars responding to or servicing a call are now

Exhibit 3-20

Sample Supervisory Status Information



visually identified on the screen by H (high priority) or L (low priority) codes, and can be tabulated separately as a percentage of the total. Extending such visual codes to reflect other status conditions is also possible.

As previously stated, AVM serves as a hidden supervisor, apparently causing (most) officers to be on their better behavior, because they know that they can be watched. What, then, would happen if they knew that they were being watched? If such awareness could be established without the implication of being spied upon, perhaps positive results would develop. The relatively poor performance of the FLAIR system has made it necessary for the dispatchers to request "FLAIR checks" when the computer suspects a car to be lost. This in turn requires the officer to announce, via the voice radio, his location, and creates an awareness that he is being watched. Perhaps such a low-key inquiry can be continued even after the system accuracy improves, and even for AVM systems not requiring reinitializations. The police department could establish a policy for continuous, though infrequent, accuracy checks on their system which perhaps could favor those cars that have been out of their area for an extended period, cars that are bunched, etc. Such an experiment could be conducted from the city-wide console. The results could be a more effective and productive force.

Chapter IV

ANALYSIS OF ATTITUDES TOWARDS FLAIR

The attitudes of the people in the St. Louis Police Department who have worked with the FLAIR AVM system are an important source of information about the value of the system and the way it is operated. The facts of their day to day experience with FLAIR have been summarized in the two previous chapters which addressed the technology of the system and its effects on MPD operations. This chapter reports on the opinions that developed from this experience.[28] It will

- indicate how well FLAIR has been accepted as a new idea,
- confirm the results of earlier discussions of the five operational objectives of FLAIR, and
- review FLAIR's future potential.

Relevant opinions were gathered by means of structured questionnaires, participant observations among patrol officers and dispatchers, from interviews with key command personnel, and from memoranda written by officers, sergeants and lieutenants after spending 2 to 6 hours with their dispatchers learning how FLAIR was being used.

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[28] The methods used to gather these opinions included:

- A questionnaire survey of 516 officers (54.5% of the force) and 49 dispatchers (67.1%) before Phase II of FLAIR.
- A questionnaire survey of 493 officers (52.1% of the force) and 40 dispatchers (54.8%) after Phase II of FLAIR had been operating for six months.
- A participant observer spent several hours riding in the patrol car of each of 15 officers and conducting informally structured interviews.
- A participant observer spent several hours observing the dispatching activities of about 50 dispatchers on all 6 dispatching consoles.
- Structured interviews were conducted with 13 sergeants and lieutenants.

The objective assessments of FLAIR's performance in the two previous chapters have indicated a number of disappointments. The opinions of the MPD personnel who have worked with the system also reflect these disappointments while at the same time indicating that the situation is not completely hopeless. Many people expressed the opinion that "FLAIR would be great if it worked the way it was supposed to." However, they also expressed a need for improved performance in essentially every aspect of FLAIR operations that depended on locations:

- response time,
- officer safety,
- command and control, and
- improved supervision.

The use of digital communications, which did not depend on locations, was well received. In essense, the personnel who relied upon FLAIR on a day to day basis felt strongly that continued use of the system would be beneficial if performance was improved.

A. Overall Attitudes Towards FLAIR

When asked to give an overall opinion of FLAIR, most of the dispatchers and police officers in St. Louis tended to be more negative than positive in their assessments. This opinion was widely held dispite an initial belief that the system would be a good idea. Performance simply did not meet earlier officer or dispatcher expectations. Nonetheless, many people felt that if the system showed better performance, particularly in terms of accuracy, it would be a valuable tool for policing. In the hope of providing satisfactory performance, changes to improve accuracy are being implemented as this report is being finalized and after the questionnaire survey was completed (see par. C.4, Chapter III).

1. <u>Summary opinion of FLAIR</u>. Near the end of Phase II, MPD officers and dispatchers completed a detailed questionnaire about the FLAIR system. They were asked "In general, do you think it is a good idea or not a good idea to have the FLAIR system in St. Louis?" Among the officers 72.0% said "not a good idea," and 53.8% of the dispatchers felt the same.

This evolution in the reaction of police officers to FLAIR is apparent in Exhibit 4.1. At the outset of the project, attitudes were generally positive, but as performance problems developed, this support declined during both Phase I and Phase II. Dispatchers and Third District officers were exposed to enthusiastic FLAIR training before Phase I, but actual performance did not live up to their expectations. Their opinion of the system declined, and toward the end of Phase I officers in the Third District held the same slightly negative opinions as the officers in the Fifth District who had no exposure to FLAIR until Phase II. During Phase II dispatchers and the the Third District officers showed an additional decline while the Fifth District control group showed no substantial change. *The primary reason for the difference in the initial opinions of Third and Fifth District officers was the encouraging explanation of FLAIR provided only to Third District officers in Phase I and fears among uninformed officers in the department that FLAIR's main purpose was to serve as a tool for inspection and discipline.*

It seems that attitudes toward FLAIR would have been much more negative if it had been used to gather evidence against officers for leaving their district, gathering in bunches, or engaging in other improper patrol activities. These fears dissipated and the percentage

Exhibit 4-1

Attitudes Toward FLAIR Over Time

In general, do you think it is a good idea or not a good idea to have the FLAIR system in St. Louis?

Dispatchers Percent Answering:	Before FLAIR Jan 1975 (N=32)	During Phase I July 1975 (N=45)	Before Phase II August 1976 (N=49)	During Phase II Sept. 1977 (N=40)
Good Idea	76.7%	58.5%	51.2%	46.2%
Not a Good Idea	23.3	41.5	48.8	53.8

Third District Officers Percent Answering:	Before FLAIR August 1974 (N=166)	During Phase I April 1975 (N=119)	Before Phase II July 1976 (N=128)	During Phase II Sept. 1977 (N=126)
Good Idea	64.4%	39.8%	35.2%	30.2%
Not a Good Idea	35.6	60.2	64.8	69.8

Fifth District Officers* Percent Answering:	Before FLAIR August 1974 (N=74)	Before FLAIR June 1975 (N=64)	Before Phase II July 1976 (N=63)	During Phase II Sept. 1977 (N=67)
Good Idea	36.4%	40.0%	29.6%	31.3%
Not a Good Idea	63.6	60.0	70.4	38.7

*control district during Phase I

All Officers			Before Phase II July 1976 (N=516)	During Phase II Sept. 1977 (N=493)
Good Idea	--	--	31.0%	28.0%
Not a Good Idea			69.0	72.0

of officers who thought disciplinary abuses would be a serious problem area for FLAIR dropped from 30.5% to 17.4% during Phase II. The officers decided that FLAIR was insufficiently accurate to be used in the ways they anticipated it would be used. Over the long run, accuracy problems have been the crux of attitude issues in St. Louis because poor accuracy has resulted in minimized effectiveness of the FLAIR system in many operational areas. In the words of one lieutenant, "The guys like FLAIR; it just doesn't work."

2. Perceived dependability of FLAIR. Specific results from the survey questionnaires indicate that officers and dispatchers have little confidence in the accuracy of the system. Fully 85.7% of the officers and 87.2% of the dispatchers did not feel that FLAIR could locate an officer in case of an emergency "almost all of the time" or "most of the time." This represents a significant loss of confidence from Phase I, when 28.6% of officers in both test districts (3 and 5) felt that FLAIR could locate them at least most of the time. The officers' opinions are a fairly appropriate assessment of the actual accuracy of the system indicated in Exhibit 2.1. Their estimations are developed from the frequency of FLAIR checks and the inaccuracy apparent when dispatchers tell them where FLAIR indicates their position for a traffic stop.

When asked about the roots of FLAIR's accuracy problems a consensus of officers and dispatchers held that equipment and computer difficulties were the largest area of concern, followed by lack of support and other problems both on the street and in communications. Disciplinary abuses and difficulty in operating the system were not thought to be such serious problems, as illustrated in Exhibit 4.2.

Exhibit 4-2

Perceived FLAIR Problem Areas

Question: Below are listed several problem areas the FLAIR system has encountered. Please indicate how much of a problem you think each has been.*

	Patrol Officers		Dispatchers	
Percent Answering "Serious Problem"	1976 (N= 385)	1977 (N= 493)	1976 (N= 49)	1977 (N= 40)
Equipment & computer problems	58.0%	68.0%	69.0%	77.5%
Lack of support from policemen on the street	36.6	29.9	27.5	53.8
Disciplinary abuses	50.3	17.4	8.3	23.7
Difficulty in operating the system	20.3	29.2	22.5	20.5
Dispatching & communications problems	31.1	47.6	29.7	32.4

* For officers who had not yet worked with FLAIR, the question was worded "Below are listed several possible problem areas the FLAIR system might encounter. Please indicate how much of a serious problem you think each might be."

The greatest perceived problem was maintenance: repairs were time-consuming, backup cars in short supply, and preventive maintenance virtually non-existent. Many MPD personnel simply felt that FLAIR units were inoperative all too often, and grouped their perceptions about maintenance and hardware problems as one concern for want of substantial distinguishing evidence. In addition, many officers felt that both the inaccuracy of the system and the constant need for re-initializations to update vehicle positions were mechanical reliability problems resulting from maintenance or design compromises.

Both officers and dispatchers perceive the number of reinitializations per car to be above the level they feel is acceptable,and also higher than actual levels,as indicated in Exhibit 4.3. Reinitializations are annoying to officers because they interrupt patrol activity by requiring the officer to stop for 7 seconds at an intersection, possibly disrupting the flow of traffic. Dispatchers dislike reinitializations because they add to the workload and accumulate during busy broadcasting periods, requiring that the reinitializations be completed during lulls in activity which were regarded as times for personal conversations prior to the coming of FLAIR. The importance of reinitializations is further demonstrated by the fact that many people felt that FLAIR could make a significant contribution to police operations if the need for reinitializations could be substantially reduced.

B. Perceived Impact of FLAIR on Operations

Officers and dispatchers of the SLMPD were asked which of a number of aspects of policing were in need of attention and what effect had FLAIR had on performance in each of these areas. Opinions were sought on each

Exhibit 4-3

Perceived Frequency of Reinitializations

Officer Perceptions:

On the average, how many times is a beat car stopped for a FLAIR check during an 8-hour tour of duty?

3 times of less	12.2%
4 to 6 times	43.6
7 to 12 times	31.4
13 times or more	12.8

What do you think should be the minimally acceptable level of FLAIR checks for an 8-hour tour of duty?

Once or less	27.6%
2 or 3 times	48.9
4 to 6 times	14.6
7 times or more	8.9

Dispatcher Perceptions:

How does the average level of FLAIR checks per car per tour compare to what you feel is the highest acceptable level for this problem?

Average level of FLAIR checks per tour:
median = 7

Highest acceptable level of FLAIR checks per tour:
median = 5

Actual Level of Reinitializations:

2.9 per car per tour

of the five FLAIR objectives for improving police operations:

- response time,
- officer safety,
- digital communications,
- command and control, and
- improved supervision of the patrol force.

Perceived accuracy problems and disagreement as to exactly how FLAIR would achieve each of its various objectives led many officers and dispatchers to doubt the value of FLAIR's contribution in all of these areas except digital communications.

1. Response time. Before FLAIR was tested in St. Louis, it seemed possible that AVM could contribute to decreased response time by making it easy for the dispatcher to select the closest car to each assignment. Of the officers in District 3, 65.1% said that dispatching the closest car was very important before they began to use FLAIR in Phase I. By the end of Phase II it was clear that most MPD personnel did not feel that response time was in need of great improvements as compared to other FLAIR objectives noted in Exhibit 4.4. Further, most officers indicated that the use of FLAIR in closest car dispatching had no effect on response time, as shown in Exhibit 4.5.

Officer perceptions accurately reflected the evaluation finding that essentially no decrease in response time had occurred, whereas dispatchers perceived some improvement. With the benefit of hindsight they suggested that the sector car when available is usually the closest car or one of the closest cars. The dispatching of cars other than the sector car caused officers to feel they were less able to identify with their own patrol sectors, and 52.9% of them indicated that performance

Exhibit 4-4

Perceived Usefulness of FLAIR Objectives

Below we have listed several areas of potential concern to MPD officers. As things stand now in the department, please indicate to what degree you feel these issues require attention:

Percent answering "definitely needs improvement" or "needs some attention"	Survey Conducted at the End of Phase II	
	Officers (N= 493)	Dispatchers (N= 40)
a. Reducing response time	50.9%	52.8%
b. Officer safety	87.4%	94.7%
c. Departmental disciplinary process	66.5%	62.2%
d. Dispatch operations	84.5%	78.4%
e. Increasing radio access and reducing frequency congestion	74.1%	83.8%

Exhibit 4-5

Perceived Effect of Closest Car Dispatching

The FLAIR AVM system automatically provides a listing of car numbers in the order of their distance from an incident site. This makes possible the selection of the closest available car by the dispatcher. What effect has this feature had on response time?

	Survey Conducted at the End of Phase II	
Percent Answering:	Officers (N= 493)	Dispatchers (N= 40)
Improved	19.0%	41.7%
No Effect	64.1	38.9
Worsened	16.9	19.4

would be improved if closest car dispatching were restricted only to high priority calls.[29] In general, it was felt that AVM was not likely to reduce response times even if accuracy problems were completely cured.

2. Officer safety. This was the most important objective of FLAIR to both officers and dispatchers, as can be verified from Exhibit 4.4 where it is described, by a dominant majority of officers and dispatchers, as in need of definite improvements or at least some attention. *Officer safety was the single largest "selling point" of the system as far as the officers on the street were concerned. When FLAIR was originally presented to them, an option was discussed in which there would be an emergency button on their belts in addition to the one in the cars in order to alert the dispatchers should an emergency occur. The button in the cars became a reality, but the emergency button on the belt was never implemented and many officers were disappointed at this limited capability.*

While the importance of officer safety was strongly and continuously emphasized, the perceptions of FLAIR's performance in this area show a pattern of continuous decreases. Before FLAIR was implemented in Phase I, a large majority (77.9%) of the Third District officers who would be using FLAIR felt that the new system would improve officer safety. Their opinions and those of all the officers in the city declined until only 21.9% felt that FLAIR could improve officer safety by the end of Phase II. In fact, many people felt that FLAIR decreased officer safety by providing false

[29] Almost all of the remaining officers said performance would be unchanged rather than worsened. In fact, 50.5% of the officers said that the effectiveness of dispatching would be improved if the procedure for dispatching prior to FLAIR were reinstated, while only 8.8% said effectiveness would worsen.

confidence to the officers, which led many of those who were particularly concerned about officer safety to feel that FLAIR had had no effect or worsened the situation (see Exhibit 4.6). The perceived poor accuracy of the system in emergencies and a lack of confidence in the FLAIR emergency button for calling the dispatcher can be seen clearly in Exhibit 4.7.[30] But the majority of officers feel that FLAIR has some merit since 60.0% of them indicated that it was worthwhile to use both the FLAIR emergency button and the voice radio in case of emergency. If FLAIR's accuracy were improved, it would be more likely to seem useful for upgrading officer safety .

3. Digital communications. This feature of FLAIR was the most highly regarded by officers and dispatchers alike. Digital communications helped both officers and dispatchers to get messages across crowded radio channels in normal working situations, as shown by the attitudes noted in Exhibit 4.8. Officers find it more convenient to send a message by means of digital codes if it means they do not have to wait for free air space. Because the codes alert the dispatcher if a non-routine message is waiting, officers find that their non-routine messages and requests get better service.

Digital communications allowed dispatchers to perform their regular work with fewer interruptions, since coded tasks could remain queued on the display. They felt, however, that their workloads were higher,

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[30] Officers who said the system "definitely needs improvement" were twice as likely (as those who said it was "OK as is") to feel that performance had worsened.

Exhibit 4-6

Cross-Tabulation of Concern About Officer Safety
versus
Effect of FLAIR on Officer Safety

	Survey Conducted at the End of Phase II Effect of FLAIR on Officer Safety (N= 476 Officers)		
Concern About Officer Safety	Improved	No Effect	Worsened
Definitely Needs Improvement	11.0%	48.1	40.9
Needs Some Attention	33.5%	51.4	15.1
Okay As Is	33.3%	48.3	18.3
TOTAL	22.3%	49.4	28.4

Exhibit 4-7

Perceived Usefulness of FLAIR in Emergencies

How much of the time do you think FLAIR would accurately locate your patrol car in an emergency?

Percent Answering:	Survey Conducted at the End of Phase II	
	Officers (N= 482)	Dispatchers (N= 39)
Almost all of the time	4.4%	7.7%
Most of the time	10.0	5.1
Some of the time	38.6	30.8
Not much of the time	47.1	56.4

FLAIR's Accuracy in an Emergency

In an emergency, should an officer activate the FLAIR emergency button, call the dispatcher on the voice channel, or both?

Percent Answering:	Survey Conducted at the End of Phase II	
	Officers (N= 488)	Dispatchers (N= 38)
Activate FLAIR emergency button	4.2%	5.3%
Contact dispatcher on voice channel	35.8	34.2
Both	60.0	60.5

Exhibit 4-8

Usefulness of Digital Communications

The digital communications aspects of FLAIR provide another way for the officers to communicate with the dispatcher. What effect has this had on each of the following areas?

	Survey Conducted at the End of Phase II Officers (N= 482)		
	Improved	No Effect	Worsened
a. On your overall ability to communicate with the dispatcher	45.0%	33.6	21.4
b. Access to dispatcher on voice channel	33.6%	44.7	21.7
c. Confidence in being able to reach the dispatcher in an emergency	21.6%	51.6	26.8
d. Your effectiveness as a patrol officer	14.6%	70.3	15.2

	Survey Conducted at the End of Phase II Dispatcher (N= 38)		
	Improved	No Effect	Worsened
a. Voice channel congestion	50.0%	28.9	21.1
b. Receiving information from officers	36.8%	39.5	23.7
c. Overall dispatcher workload	13.2%	7.9	78.9
d. Officers returning to service promptly after completing a call	21.1%	52.6	26.3

partially because of the need for location verifications and partially because the queued tasks filled gaps that they might otherwise have regarded as free time. The latter effect is mainly psychological since the messages from the officers would have filled those gaps whether or not the digital notification was received earlier. In compensation, the digital system allows the dispatcher to pick and choose the sequence of these conversations, giving them more control over the radio channels than the traditional voice schemes. Thus, digital communications have made radio traffic more responsive to the needs and work habits of the dispatchers. As a result of smoother operations, digital communications are thought to be one of FLAIR's greatest benefits since the location-dependent aspects of the system have functioned poorly.

4. Command and control. Officers and dispatchers were disappointed with FLAIR's effect on normal dispatch operations. But they seemed to feel that if dispatching talent was upgraded, FLAIR was more likely to increase departmental effectiveness. The strong feeling that FLAIR had contributed to dispatching problems can be seen in Exhibit 4.9 where officers who felt that the dispatch system needed improvement were more than 3 times as likely (as those who felt the system was "OK as is") to feel that dispatch performance had worsened.

The need for dispatcher training was strongly emphasized by the officers: 63.3% said better training in strategic deployment was needed, 67.0% said officers with years of experience should be available for dispatching and 45.9% said training exercises should be conducted on in-progress events. Less than 4% of the officers said that any of

Exhibit 4-9

Cross-Tabulation of Concern About Dispatch Operations versus Effect of FLAIR on Dispatch Operations

	Effect of FLAIR on Dispatch Operations (N= 467 Officers)		
Concern About Dispatch Operations	Improved	No Effect	Worsened
Definitely Needs Improvement	8.1%	21.2	70.8
Needs Some Attention	24.8%	40.1	35.0
Okay As Is	35.1%	43.2	21.6
TOTAL	18.0%	31.0	51.0

these alternatives might have an adverse effect on dispatching.[31] Participant observers have noted that good dispatchers have developed skills in using FLAIR which other dispatchers could be trained in, including:

- limiting the number of officers responding to an in-progress event based on the closest cars,
- limiting responses to a pursuit based on direction of travel and the position of officers,
- checking on all cars that are moving to be sure they are in service,
- other minor techniques to keep the force operating effectively.

In addition, interviews with supervisory personnel show considerable support for the idea of dynamic allocation of available patrol resources based on AVM information.

Officers can perceive the difference between a skilled dispatcher and a novice, and their experience with FLAIR as used by skilled dispatchers leads them to feel that the system could bring about improved MPD performance. By 36.6% to 17.4%[32] officers felt that FLAIR could improve the dispatcher's ability to keep track of the patrol force rather than worsen it, and by 28.7% to 22.1% they felt FLAIR could improve the directing and monitoring of a pursuit. While the officers did not feel that FLAIR would be of much assistance in directing the response to in-progress events such as robberies or burglaries, the dispatchers who worked with the system routinely indicated this area was the best opportunity for improvements

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[31] The dispatchers also favored better training by similarly large pluralities, but they were quite skeptial of the value of having sworn officers as dispatchers.

[32] The remaining officers said "no effect."

through FLAIR by a margin of 41.7% to 16.7%.[33] With improved accuracy and better trained dispatchers, MPD personnel expect FLAIR to increase the department's effectiveness through command and control improvements.

5. Supervision of the patrol force. FLAIR was not specifically used as a supervisory tool during the evaluation period, so the opinions as to its value for this application are the results of projections from current performance. Officers and dispatchers are continually reminded of potential disciplinary applications for FLAIR because of the frequent requests from dispatchers for officers to identify their locations for FLAIR reinitializations. For example, dispatchers are likely to request an officer's location if he appears out of his district on the display screen because such displayed locations are often inaccurate.

With this in mind, the officers feel that FLAIR has already tended to decrease rather than increase the frequency with which cars leave their districts or engage in improper patrol activities, as shown in Exhibit 4.10. Dispatchers also stated that cars were less likely to bunch up or remain stationary for long periods of time. It was felt that patrol cars were more likely to leave their beats because inter-beat dispatches under FLAIR increased officer activities outside their assigned beats. Interviews with supervisors corroborated the opinions of the officers and dispatchers. As noted in a series of interviews, the supervisors saw tremendous benefits in the use of FLAIR for supervisory purposes, especially after they had had a chance to sit with the dispatchers and observe the action at an AVM console in detail.

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[33] Again, the rest said FLAIR would have no effect.

Exhibit 4-10

Perceived Supervisory Usefulness of FLAIR

Officer Attitudes Reflected in the Survey at the End of Phase II

Remembering that FLAIR provides dispatchers with the location of all patrol vehicles, do you think that FLAIR has made a difference in the following areas?

	Officers*	
	Increased	Decreased
Patrol cars leaving their district	8.8%	21.6
Patrol cars leaving their beat	15.3%	15.7
Improper patrol activities	11.1%	20.5

*Remaining officers indicated "no change"

Dispatcher Attitudes Reflected in the Survey at the End of Phase II

Remembering that FLAIR provides dispatchers with the location of all patrol vehicles, do you think that FLAIR has made a difference in the following areas?

	Dispatchers**	
	Increased	Decreased
Patrol cars leaving their district	5.4%	24.3
Patrol cars leaving their beat	27.8%	13.9
Improper patrol activities	18.9%	16.2
Cars bunching up	10.8%	16.2
Cars remaining stationary for long periods of time	10.8%	16.2

**Remaining dispatchers indicated "no change" or "don't know"

The use of FLAIR as a supervisory tool brings up the highly emotional issue of whether AVM will result in disciplinary abuses. This is a major concern of officers who feel that the system may function as "an electronic cowbell." The percentage of officers who perceived this as an especially serious problem decreased from 30.5% to 17.4% during Phase II because no officers were singled out for punishment due to FLAIR information, and because accuracy was felt to be insufficient for disciplinary applications. Still these concerns remain important to a department seeking to develop supervisory applicationsof AVM. The officers recognized the benefits of supervisory applications but stressed the importance of the way supervisory uses were implemented.

C. Organizational Factors Affecting Attitudes

Just as attitudes depend upon the accuracy and reliability of an AVM system and its ability to achieve its objectives vis a vis police operations, attitudes also depend upon the way the police organization approaches the implementation of AVM. Four important factors have been identified during the evaluation of FLAIR:

- The interface between technological and human factors
- Involvement and training of police personnel
- Involvement of departmental top management
- Long-term commitment and continuity of personnel over time

These factors were identified during participant observations and interviews with key supervisory and management personnel. The reader will recognize that the opinions of the officers and dispatchers regarding FLAIR's performance support many of these observations.

1. <u>The interface between technological and human factors</u>. One of the most significant elements in determining success or failure in implementing any new technology is developing the proper human/technology interface. The point where this is especially vital with FLAIR is the link between the dispatcher and the new system. As pointed out by the officer opinions regarding command and control uses of FLAIR, capable people must be placed in the dispatching jobs. This may require an upgrading of the dispatcher's job description, qualifications, and salary. In addition, procedures for interactions between patrol cars and dispatchers should be clearly specified, and special training might be provided. For example, dispatchers seldom receive training on how to handle such "rare events" as responding to an officer-in-trouble call, handling pursuits, or handling civil disturbances.

2. <u>Involvement and training of police personnel</u>. There is a paramount need for effective training of both dispatchers and officers concerning FLAIR. However, this means more than just an initial training seminar. As highlighted in Exhibit 4.11, feeling at best "fairly well informed" about the system was one of the most important factors influencing attitudes toward AVM. Officers who felt they were "very well informed" were nearly 3 times as likely (as those who felt "not well informed") to say that FLAIR was a good idea. An "on-going" dialogue is therefore necessary to answer questions and to explain problems that may arise. An important contribution to supervisor and patrol officer awareness was made under a program of assigning everyone in the Patrol Division,up to the rank of lieutenant to sit in the dispatch room next to their dispatchers

Exhibit 4-11

Cross-Tabulation of Attitudes About FLAIR
versus
How Well Informed Officers Are

	Survey Conducted at the end of Phase II	
	Attitude About FLAIR (N= 477 Officers)	
How Well Informed Officers Are:	Good Idea	Not a Good Idea
Very Well Informed	27.6%	72.4
Fairly Well Informed	32.3%	67.7
Not Well Informed	10.9%	89.1
TOTAL	27.9%	72.1

to observe the activities at the FLAIR console and to ask questions as to the operations of the system. All personnel wrote memoranda to their superior officers describing their experiences. A sampling of these memoranda by the evaluators showed that: Nearly all commented on the poor accuracy; many expressed concern about FLAIR's cost; many could see benefits in officer safety and command and control--if the accuracy were improved; many had new respect for the dispatch operation; and, suprisingly, most seemed to accept FLAIR based on expected performance improvement (see Exhibit 3-18). Unfortunately, the decision to send officers to observe the dispatching operation was made after the PSE questionnaires were distributed and the results tabulated, so the effect of this FLAIR training on their attitudes is not reflected in the quantified questionnaire results.

3. Involvement of departmental top management. Just as it is important to integrate and train police officers concerning innovation, it is essential that top police supervisors be deeply involved in the implementation of new technology. Experience in other police departments has shown that it is not enough to simply approve change and manage the evaluation. With FLAIR the Phase II results demonstrated that the response time benefits of the system are below expectations. Other potential benefits such as the opportunity for improved command and control or better management of resources must be further examined to determine the degree to which the benefits may justify the costs. To truly test the benefits of the system, it may be necessary to try new command and control or organizational relationships, at least on a temporary basis, such as assigning a high-level command person to the

dispatch center in order to supervise command and control situations when they arise.

4. Long-term commitment and continuity of personnel over time In a study by the Rand Corporation published in 1976, it was found that efforts to implement technical projects in criminal justice agencies are often promoted by a single advocate or small group of advocates within the organization.[34] Although such people play an important role in spreading innovation, their presence also leaves the innovation vulnerable if the advocate leaves the agency or is transferred. In order to develop even the limited success of the FLAIR system in St. Louis, a long-term commitment based on a broad base of support was required. To broaden involvement and develop support for technological innovation, the department established a committee of top level command officers who met regularly to help monitor and oversee change. This provided a degree of stability and coordination which could not have been achieved otherwise. Such continuity and commitment is essential in the future.

AVM implementation is more than a technical experiment. As such it deserves important behavioral and command level attention. Even with such attention, difficulties will arise; but hopefully they will not prove to be insurmountable.

D. Conclusions

The St. Louis MPD has decided to renew its efforts to make FLAIR a viable and useful AVM system. Substantial management and organizational

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[34] J. Chaiken, T. Crabill, L. Holliday, D. Jaquette, M. Lawless, E. Quade, Criminal Justice Models: An Overview, Rand Corporation, National Institute of Law Enforcement and Criminal Justice, LEAA, April, 1976.

commitments seem to be on-going while solutions are being sought to technical problems which might affect accuracy. Even though performance to date has been a disappointment to most members of the MPD, they still hope for future improvements.

The most impressive display of support for the FLAIR system comes from the officers and dispatchers who use the system every day. When asked about a FLAIR system that was accurate and did not require periodic location updates, 83.8% of dispatchers and 71.0% of the officers said they would be more likely to accept such a system as compared to the current version of FLAIR.

Concerning the specific objectives of the system, the overall attitudes held:

- That response time was largely unaffected by AVM, and even an accurate AVM system would not noticeably reduce response times.
- That officer safety could be usefully improved if an accurate AVM system and a skilled dispatcher were tracking a vehicle in trouble, and if a button on the belt were available for use outside the car.
- That digital communications produce smoother operations and are one of FLAIR's greatest benefits (due to problems with accuracy in achieving other objectives).
- That command and control applications of an accurate AVM system may be expected to yield increased departmental effectiveness if used appropriately.
- That improved supervision of the patrol force is a possible useful AVM application if disciplinary abuses of the system can be avoided.

In conclusion, there is still much to be done in terms of properly using the FLAIR system. Still, given the difficulties with respect to accuracy, the attitudes of the patrol and dispatch force are still somewhat positive toward the system. As one of the police supervisors indicated, the police officers have come to accept the FLAIR system as a reality in the St. Louis Police Department. At first they were resentful; they no longer have such resentment but accept FLAIR as a "fact of life." If the system could be easier for the officers in terms of automatic initializations and/or in terms of improved accuracy then St. Louis could well be in a position to fully test the potential of the system and to achieve further benefits. However, if the accuracy problems continue to persist then the use of the system may eventually be phased out.

Chapter V

EVALUATION CONCLUSIONS

AND

ASSESSING AVM POTENTIAL

The Phase II program extended the application of FLAIR from the Phase I, District 3, experimental application, to city-wide operation in all nine police districts using 200 patrol cars and six dispatcher display consoles. It was the first AVM system to be installed in a major metropolitan environment.

However, the Phase II implementation was faced with a number of problems. Debugging the equipment and the software caused delays, and once the system became operational, developing effective repair and maintenance programs and solving other operational problems took longer than expected, causing poor system performance during the entire evaluation period. This, of course, had an adverse influence on evaluation results, causing inconclusive results concerning the achievement of many system objectives. But, even with these problems, some interesting trends developed. For example, the poor performance had a negative impact on operating people so that only 28% of the patrol officers and 46% of the dispatchers thought FLAIR was a good idea (based on a city-wide survey near the end of the evaluation period). However, when asked if they would be more likely to accept the system if it were accurate and did not require reinitializations, 71% of the officers and 84% of the dispatchers responded favorably.

From personal interviews with officers, sergeants, lieutenants, and captains, and from their written impressions of AVM following their training assignment with their dispatcher, there is evidence that the operational people generally have accepted AVM. They expect--in time--that performance will improve and that the system will become a permanent part of the police operations.

In the following sections, the evaluation results will be summarized; a refocusing of system objectives will be discussed; an assessment of AVM will be presented; and cost effectiveness factors will be reviewed.

A. Evaluation Results

The following lists AVM system objectives in order of the originally assigned priority, with a composite summary of Phase I and Phase II findings.

1. Objective: Reduce response time. The impact of AVM on response time was small, and not sufficient to materially influence apprehension rate or the effectiveness of the department. From a simulation model it has been estimated that under ideal conditions, potential savings in travel time of 11% to 15% were attainable (about one-half minute); in practice savings of 0 to 15-20 seconds were attained. There was no difference in response time savings between priority 1, 2, or 3 calls. Poor accuracy had some effect on the results, but in the opinion of the evaluators, not enough to change the above conclusion.

2. Objective: Increase officer safety. An emergency button is located on the push-button panel assembly in the patrol car that the officer can activate when he is in trouble. Evaluation of the emergency aspects were influenced by the poor accuracy of the AVM system, by equipment malfunction, and improper use by the officer. True emergencies were masked by too many false alarms, and about half were ineffective because of poor accuracy. In times of need the officers prefer to use voice radio, in combination with the emergency button activation. Emergency safety still appears to be a potentially positive aspect of AVM from the patrol officers perspective. At this point, though, the police are somewhat skeptical, and the impressions of the past several years must be modified if attitudes are to be changed. In fact, during interviews it became apparent that what the officer really wants is an emergency button on the belt, that can be activated when the officer is out of the vehicle. Boeing had originally proposed such an accessory, but it was never produced due to budgetary constraints.

3. Objective: Decrease voice-band congestion by digital communication. When city-wide FLAIR was made operational, many officers, dispatchers, and police managers commented on the decrease in voice-band usage. Digital communication offers an additional means (by coded messages) of officer communications to the dispatchers, via the AVM radio channel. It provides instant communication to the dispatcher; it allows the dispatcher to respond by priority of message (rather than by sequence of arrival); and it appears to be well-liked,

particularly by the officers. Most dispatchers, though, perceive the responding to digital codes via voice radio as an increase in workload. In general, the greatest benefit of digital communication is that it offers an additional means of communication that increases information transfer and the potential for increased police effectiveness and efficiency.

4. Objective: Improve command and control capability. Because FLAIR provides real time location and status of all patrol cars on the display console, the dispatcher is provided with information (not heretofore available) that facilitates a higher level of command and control of the forces. With this tool, the dispatcher can now direct strategic deployment of the force for pursuits, sealing off an area, burglaries in process, etc., rather than the less efficient process of issuing an all-points-bulletin (APB). Proper evaluation of this capability involves the implementation of new police methods and procedures, which unfortunately were not accomplished during the evaluation period because of the attention required on more pressing items (correcting for poor accuracy, training of personnel, etc.). On a few occasions, individual dispatchers would conduct a pursuit and other in-process events, by directing specific deployment, with encouraging results. Full assessment of this capability must await policy directives that will focus on this new methodology.

5. Objective: Improve supervision of the force. AVM itself serves as a *hidden supervisor* in that patrol officers know they can be watched, which tends to influence officers toward better behavior. Even with

poor accuracy, this purpose is served, because at any time the dispatcher can call for a "FLAIR check" which directs the officer to stop and state his location. If he responds over the voice radio with a location that is far from his beat area (and without cause), it would be normal for him to feel embarrassed and to reduce the frequency of such occurrences. Quantitative data on such performance is difficult to obtain, because data prior to AVM implementation are not available. However, FLAIR display viewings of numerous individual cars show performance behavior that often appears to be good, and questionnaires with dispatchers and officers, and interviews with officers and police management indicate support for this belief. Although little hard evidence exists, the indications allow us to hypothesize that AVM may lead to improved patrol performance.

Another supervision tool is to gather data at a city-wide console by observing and recording vehicle activity in each district at periodic intervals. Such data can include the number of cars moving and not moving; the number of cars available for call, on call, or unavailable; the number of cars out of the district ; and the number of cars at the district station. From these data, performance trends can be plotted and poorer than average results can be the subject for roll call discussions.

There may be a strong temptation to use AVM as an inspection device for catching an officer in some improper act, which then could lead to disciplinary action. Such use is believed wrong and may be counterproductive by causing acts of subversion, poor morale and possible labor disputes. AVM application to improve supervision may yield positive results, whereas application for spying and disciplinary purposes should be avoided.

B. The Changing Focus of System Objectives

The first four objectives listed in the prior section were the original system objectives of the St. Louis Metropolitan Police Department, and were the basis for the Phase I evaluation. The fifth objective, improved supervision, became apparent during the Phase II studies, and the potential results as covered by this report show it to be perhaps the most important objective, at least to those representing the Planning and Development functions of police departments. Improved supervision implies a more effective and efficient police force, *increased productivity*, and perhaps even a dent in the ever-increasing cost of the highly labor-intensive budgets of police departments.

Upon further examination of the other four objectives, *productivity* is a component of each. Some contributions from the other four objectives are illustrated in the following.

1. Response time. As noted above the impact on response time per se has been minimal. It is therefore suggested that the emphasis of this objective be changed from "saving response time" to "optimizing dispatch processes" for the dispatchers. This means establishing a more disciplined (and uniform) operating procedure that can increase effectiveness and efficiency, and for the officer, it means establishing an environment that produces more confidence in the conduct of his duties. Such expectations, though, require an accurate AVM system with few

reinitializations, a dispatching policy that favors use of beat cars serving their jurisdictions for lower priority calls, and closest-car dispatching applied only to priority 1 calls involving in-process incidents. The principal product of such changes could be improved productivity.

2. Officer safety. Again assuming an accurate AVM system, improved equipment and enforcement of strict operating guidelines, there should be fewer false alarms and the activation of the in-vehicle emergency button should supplement a voice radio alert, providing an audible signal at the display console and accurate location, which may not always be readily identifiable by the officer in trouble. If the AVM system is modified according to officers' desires by the application of an accessory that provides an invisible emergency button on the officer's belt for use outside the car, this would reduce the perceived risks of many encounters. The consequence of such a feature could be the saving of an officer's life, and more day-to-day benefits might result from officers feeling increased confidence and security possibly yielding more effective performance and productivity.

3. Digital communication. Digital codes are transmitted to the dispatcher, even when the voice radio is congested. FLAIR has 99 digital codes of which 77 are available for messages. Their use saves voice radio time and provides a more effective operation. Perhaps this can best be illustrated by code 73 "return to service." Before digital communications, a patrol officer completing a call for service (or returning from lunch) would notify the dispatcher by voice radio

of his availability for service. But, if the dispatcher is fully utilizing the voice radio, the patrol officer would wait for a pause--which could be a considerable time during peak load periods--when his availability is most needed. Again, the overall result is increased productivity, because service time is decreased.

4. Command and control. Use of an accurate AVM to strategically deploy cars for extraordinary events rather than using the APB method should produce better results, use fewer cars, minimize disruption of normal duties and cause fewer accidents--all adding up to improved productivity.

The AVM city-wide console can assess varying workloads by district and, when appropriate, reassign cars on a temporary basis to help those areas with more severe peak loads. This action improves the patrol effectiveness and may even reduce manning requirements to handle peak load conditions. In any case, the net effect is improved productivity.

In summary, until recently, the principal benefit of AVM was focused on *reducing response time*. This, proponents claimed, would result in more criminal apprehensions and even deter crime. Response time benefits as determined from the Phase I and Phase II evaluations of the FLAIR system implemented in St. Louis show only minimal gains, if any. Studies made using a PSE computer simulation model reveal that under ideal conditions, travel time savings of 11% to 15% may be attainable; such theoretical improvement in travel time would only affect total response time by about 6% to 7% or about one-half minute in most cases. An added diluting effect on response time savings is due to *reporting time* where LEAA's Kansas City Response Time Analysis shows the median time for reporting major felonies was six minutes and 17 seconds.

It may, therefore, be reasonably concluded that the purchase of an AVM system cannot be justified by the benefits resulting from savings in response time. The above conclusion does not imply that rapid response time is unimportant nor that AVM cannot be effective under some conditions; maximum benefit of AVM closest car dispatching results from alarm-triggered incidents and for in-process events such as pursuits.

The new focus for AVM justification is on *improved productivity* as illustrated in the foregoing. If it can be shown that an AVM system can pay for itself, or even create a return on the investment, then such systems will find applications in many law enforcement jurisdictions; and some non-cost benefits would be added, such as improved officer safety, improved morale, and a substantial boost in the level of professionalism, particularly in the dispatcher area.

C. The Potential of AVM

The potential of AVM is dependent upon the recognition by the law enforcement agency of the services it can render, and adopting methods and procedures where necessary to take advantage of these services. The measure of achievement can perhaps be best expressed by relating productivity improvement to AVM system and operating cost.

1. Adapting operations to AVM. Proper utilization of AVM to affect the cost and other benefits that can accrue requires more than just implementing the system; the methods, procedures, and organization

of the department should be carefully reviewed to accommodate the capabilities of the system. Examples follow.

a. Extraordinary events. Normally a dispatcher serves a district, or some prescribed area. In St. Louis, six dispatchers serve nine districts. Each dispatcher has an AVM display console to assist in the conduct of his duties. However, should some extraordinary event occur--such as a pursuit--the dispatcher would be unable to direct the pursuit beyond his/her own district. This gives rise to the need for a *city-wide console*, located in the dispatch area, that can take over such dispatch tasks.

b. Supervision. AVM can serve as a tool to improve supervision capability. The dispatcher at the city-wide console can establish a routine for recording the activity of all patrol cars by district at periodic intervals. Such information will develop trends of productive/non-productive activities which supervisors can use as a basis for improving performance.

The city-wide dispatchers can observe actions of individual cars, and when observations indicate probable non-productive actions, such as bunching or a patrol car located substantially far from his beat, the dispatcher can ask for his location (or other soft inquiry) that serves to signal the officers that the patrol force is being observed. The intent is to provide an awareness so that their behavior patterns improve. AVM should not be used for internal inspection and subsequent disciplinary actions.

2. Productivity improvement. During Phases I and II, the evaluation focus was principally on the four objectives common in both phases, and on a fifth objective, "improvement to supervision of the force", during Phase II. A method of measuring productivity improvement is desired, hopefully with a large component based on quantitative data, but recognizing some subjective analysis may be necessary.

During Phase II the assessment of productivity improvement relating to the four common objectives was not attempted because performance factors and other constraints caused the system to operate substantially below its potential. However, some information--mostly subjective--was acquired relative to the effect of AVM on improving supervision.

- The final questionnaire had a question, "Remembering that FLAIR provides dispatchers with the location of all patrol vehicles, do you think that FLAIR has made a difference in the following areas?" The officer replies were:

  Re: Patrol cars leaving the district: 21.6% indicated a decrease, 8.8% an increase, the remainder unchanged.

  Re: Improper patrol activities: 20.5% indicated a decrease, 11.1% an increase, the remainder unchanged.

- Although before-after information was not available, random observations made of numerous patrol cars (15 to 20) for an hour or more each at the city-wide console revealed behavioral practices that were generally good, showing essentially no evidence of abnormal practice (e.g., bunching, leaving the district, etc.)

- Interviews with police sergeants, lieutenants, and captains seemed to support the belief that attention to patrol duties has improved. Although most were hesitant on estimating the percentage of improvement, some were willing to estimate that the improvement could be 10% (or more).

Even with the poor performance of the FLAIR system during Phase II, there is enough indication to hypothesize that it might have served as a silent supervisor. Each officer knew his actions could be watched. However, the actual measure of Phase II productivity improvement--based on FLAIR operations--could not be determined. Better system accuracy, special programs for utilizing the AVM potential, and special programs for establishing productivity are necessary.

3. FLAIR system and operating cost. Productivity improvement should be balanced against the cost involved in improving the productivity. Such costs include the capital investment of the system plus the added operating and maintenance cost. The following system estimates are based upon Phase II costs as provided by the contractor, but do not necessarily reflect the ultimate production cost.

Capital Investment

Mobile equipment for 200 cars	$ 842,000
Base equipment for FLAIR system	908,000
Estimated value of usable Phase I equipment	140,000
Special test equipment	24,000
Total investment......................	$1,924,000
Cost per car	9,620
Installation cost per car	40
Total cost per car....................	$ 9,660

Operating Cost (estimated)

One FLAIR coordinator (with fringe & overhead)	$ 17,500/year
Operating supplies	1,500
Total operating cost..................	$ 19,000/year

Maintenance Cost

Computer contract	$	32,000/year
Eleven technicians (average $9,000 at one-half time)*		85,500
Spare parts (estimated)		23,000
Total maintenance cost................	$	140,500/year

*One-half time for FLAIR, one-half time for voice communication equipment

Operating & Maintenance Cost...................	$	159,500/year
Operating & Maintenance Cost per Car............	$	800/year

	Straight-Line Depreciation	
	10 years	5 years
Amortization	$ 966	$1,932
Operating & Maintenance	800	800
Total Cost per Car per Year.....	$1,766	$2,732

4. Return on investment. The total cost of a one-man police car is approximately $130,000 per year. This assumes five officers are assigned to each patrol car to cover three shifts, holidays, vacations, and sick time, and the proportionate share of vehicle and equipment cost. A two-man car is approximately twice the cost of a one-man car--$260,000 per year. Thus, percentage of productivity improvement needed to break even is calculated in the following.

	One-Man Car		Two-Man Car	
Amortization basis	10-year	5-year	10-year	5 year
FLAIR cost per car per year	$1,766	$2,732	$1,766	$2,732
Operating cost per car per year	$130,000	$130,000	$260,000	$260,000
% productivity improvement to break even	1.36%	2.1%	0.7%	1.05%

A one-man car amortized on a five-year basis requires only 2.1% improvement in productivity to pay for the FLAIR system; in contrast, a two-man car requires only 0.7% improvement when amortized on a ten-year basis. It would appear very unlikely that the productivity would not increase by these amounts. For higher levels of productivity improvement versus return on investment, see Exhibit 5-1. For "reasonable" levels of productivity improvement--such as five to ten percent, the return on investment appears very attractive, ranging from over 2:1 to 14:1. For a five percent improvement and a ratio of 3 one-man cars to 1 two-man car, the return would be 3:1 on a five-year amortization, or 4.5:1 for a ten-year amortization.

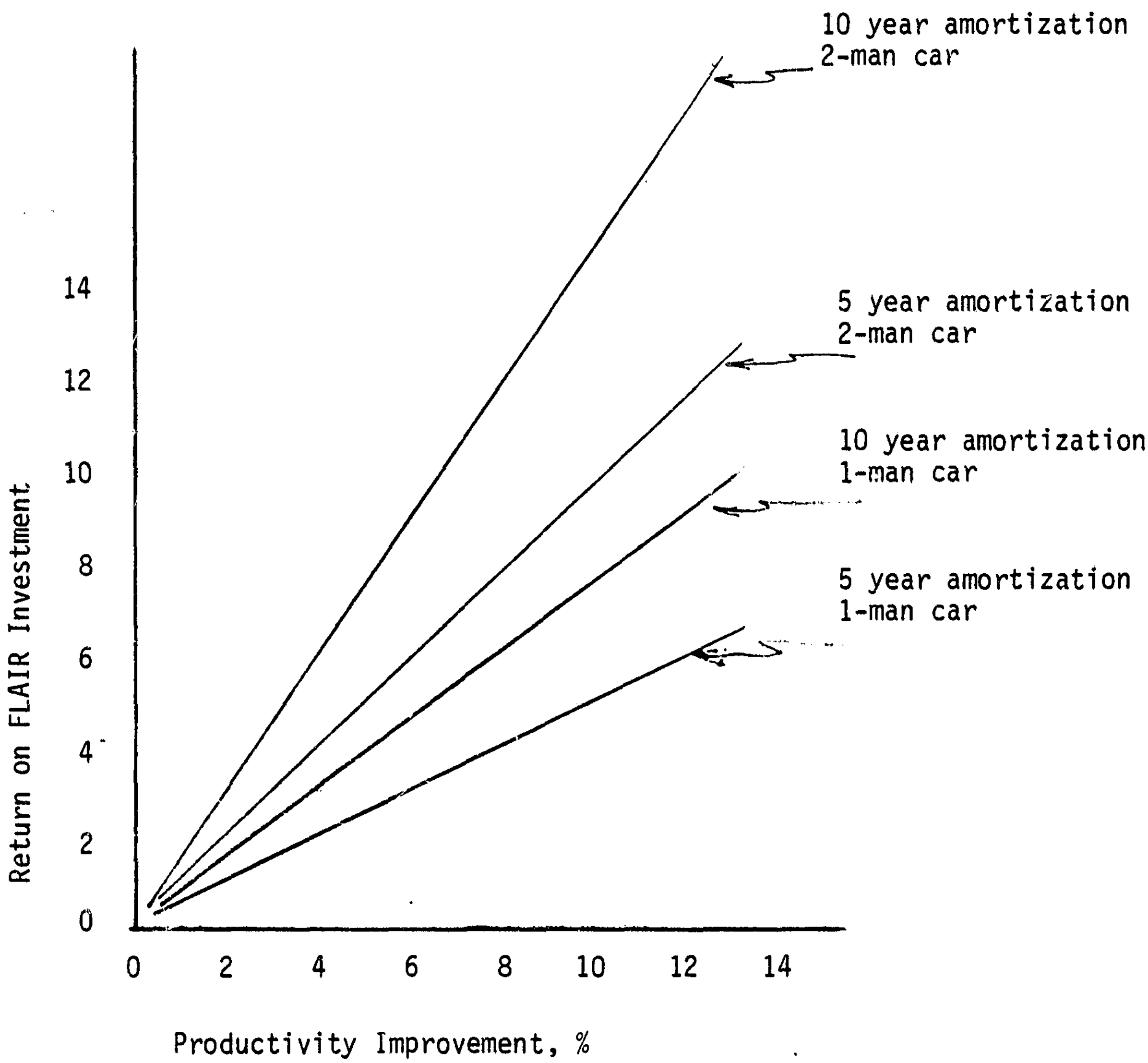
Still, the link between AVM and such returns has yet to be established. What remains is to demonstrate the effect on police operations of AVM when it is deployed in a manner to more fully use its capabilities and to develop measures that will determine a more definitive value of productivity improvement.

Exhibit 5-1

Return on FLAIR Investment

vs.

Productivity Improvement



5. Alternative technology cost considerations. The prior cost analysis was for a particular system implemented in a particular city. One might expect the cost-effectiveness and return on investment to vary depending upon the particular AVM technology, size of the city, physical layout and contour lines of the city, number of vehicles in the system, application, accuracy required, and, of course, the system cost. Of particular importance in analyzing system costs is the allocation of costs between equipment in the vehicle, fixed equipment in the city (e.g., signposts or trilateration receivers), and fixed equipment at the base station and/or headquarters (e.g., radio transmitters/receivers, computers, and display consoles). Systems requiring small fixed investment may have a cost advantage in smaller communities.

The process of determining the most cost-effective system for a particular community or city involves a detailed analysis of all the variables mentioned above. The possible result of such an analysis is illustrated in Exhibit 5.2, showing that system technologies will have differing costs dependent upon city and system size, implying differing optimal choices for various city sizes. For those contemplating an AVM system, such an analysis is recommended. The steps necessary prior to the analysis would normally involve (1) preparation of system specifications for the particular application, (2) preparation of a request for proposal, and (3) analysis of the bids received. A more comprehensive analysis of these considerations is contained in the report entitled "Evaluation of a Police Implemented AVM System: Phase I, A Summary Report."[35] Part II of this report is entitled "Recommendations for Other Cities" and illustrates the process for preparing specifications and reviews other AVM considerations.

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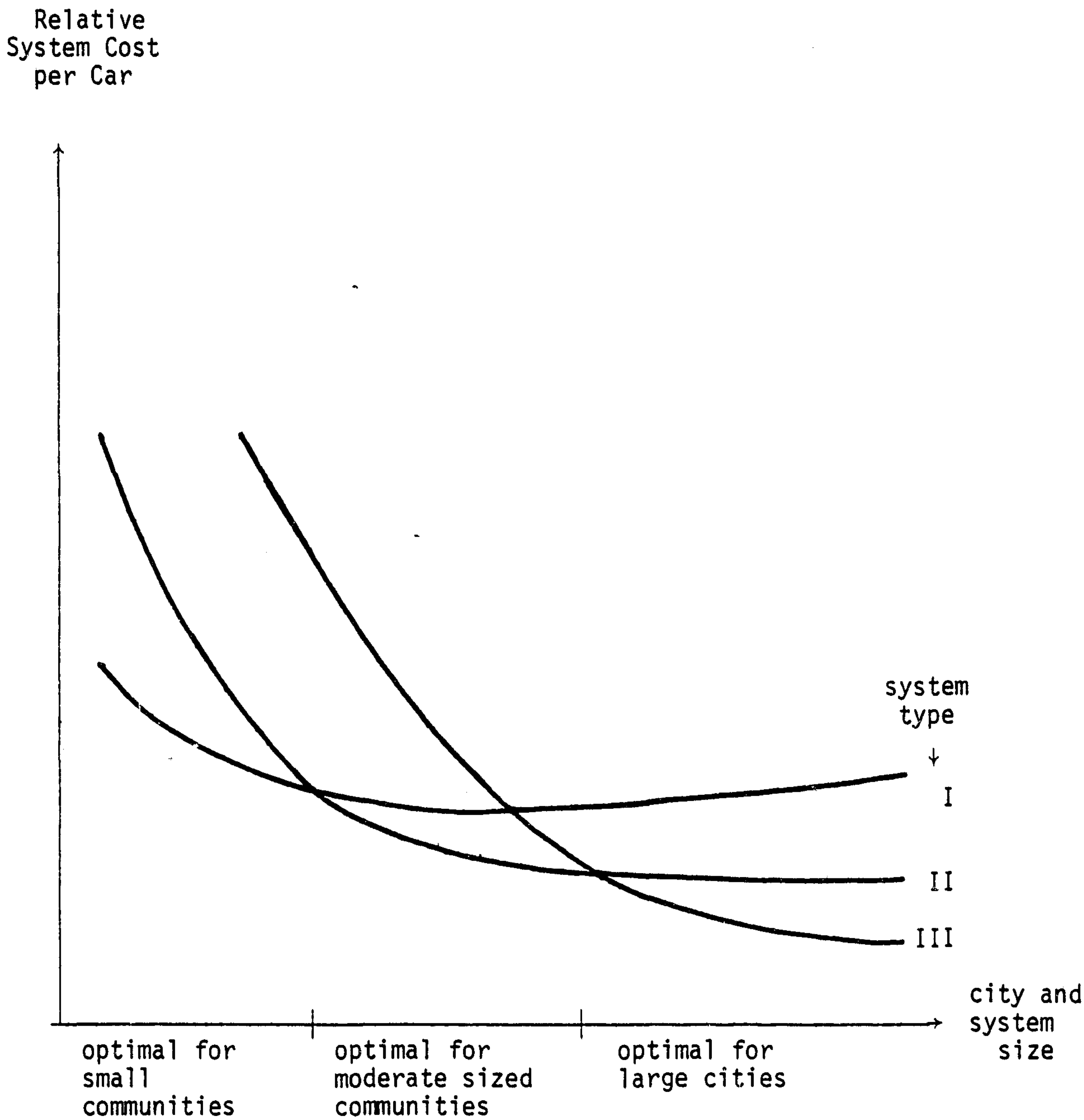
[35] See footnote [8] on page 14.

Exhibit 5-2

Possible Variation in AVM Cost
versus
Technology and City/System Size



6. <u>AVM as a research tool</u>. Conceptual uses for AVM originally envisioned improvement in response time, officer safety, and voice band congestion when applied to a conventional dispatch system. After implementation, other and perhaps greater benefits became apparent. These require modification on police practices and methods to accommodate the new technology (e.g., use of directed dispatch rather than the APB method, and improved supervision of the forces). As the use of AVM continues, more innovative applications are likely to develop.

An example of an unanticipated use occurred during the preparation of the paper "Markov Models of Fixed-Post Sensor AVL Systems." During the development of the mathematical models, it became necessary to determine the probability of a patrol car turning at the next intersection. The literature seemed void of such data; and acquiring reliable results using conventional methods appeared time-consuming and expensive. Using AVM, however, the results were easily, quickly, and accurately obtained simply by observing the behavior of random patrol vehicles on the display screen. A histogram of the number of blocks travelled between turns is shown in Figure 2 of Appendix B. The resulting curve showed a geometric distribution with the mean equaling 4.0 blocks between turns. For this application, AVM served as a *research tool*.

Additional research applications are apparent and other new ones undoubtedly will develop. Some of the apparent ones include:

- The total patrol car response to an APB (All Points Bulletin) message,
- The degree of conformity to established patroling routines,
- The spatial dependence between crime occurrences and patrol passings.

Some of the above applications would be greatly assisted by an AVM playback capability. Such a feature allows analysis of patrol operations after the occurrence at an efficient 10 to 50 times normal speed. A playback capability should be an important consideration for those planning an AVM system.

APPENDICES

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Appendix A

ALTERNATIVE AUTOMATIC VEHICLE TECHNOLOGIES

by

Gilbert C. Larson

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INTRODUCTION

An Automatic Vehicle Monitoring (AVM) System can be simply described as a system that provides at central headquarters the real-time location, identification and status of each vehicle in a fleet. AVM systems generally include: 1) a means of locating a vehicle; 2) the transfer of a vehicle location and status information from the vehicle to a central headquarters location; 3) the real-time processing of the data; and 4) the dispatcher terminal for display and analysis of the data.

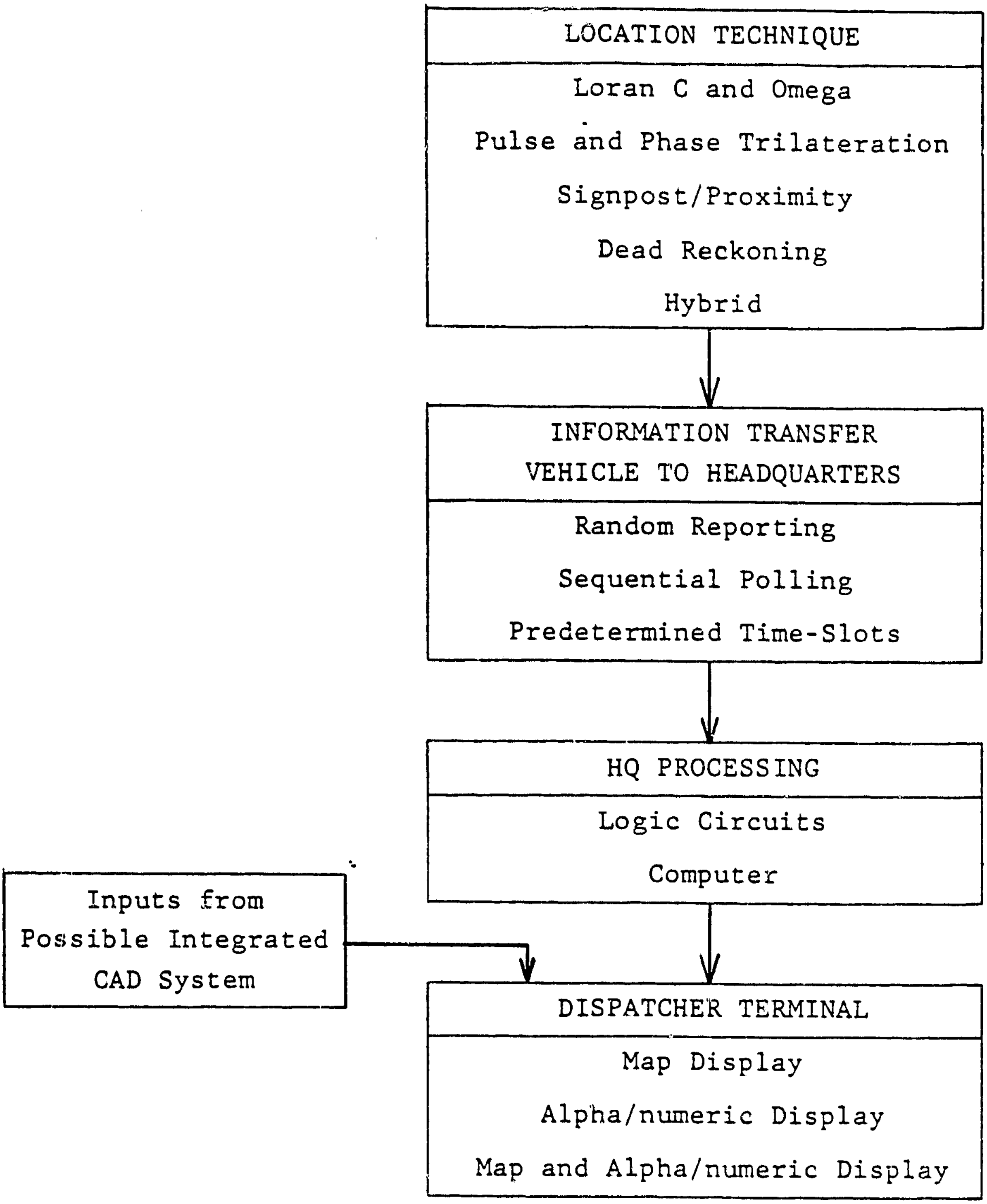
A number of methods have evolved to accomplish these separate functions. Figure 2-1 is a system block diagram which lists for each function the more popular methods currently being considered. This chapter will endeavor to describe each of these various systems and methods, with particular emphasis on their applicability to the requirements of law enforcement agencies. To assist in the understanding of these systems and subsystems, a general discussion of system objectives, performance considerations and an explanation of specific terms will first be undertaken.

A. System Objectives and Performance Considerations

An AVM system, to be effective, must be capable of locating a vehicle within acceptable tolerances. A ship at sea may be content to know its location within a mile--but an officer in need of help in an urban location would like to have his location known

Figure 2-1

AVM Subsystems



by the dispatcher to within a fraction of a city block. Various applications require different levels of performance. The following discusses the more relevant considerations, particularly as they relate to law enforcement applications.

1. System accuracy. The location accuracy of a system can be measured by comparing the known location of a vehicle with the indicated location. If numerous measurements are taken--to provide statistical significance--an error distribution will evolve which may be expressed in one of two ways.

- The average, or mean, error, can be derived by totalling the errors and dividing by the number of measurements.
- The error representing 95% confidence level is the error that a vehicle will not exceed 95% of the time. The error representing 95% confidence will be considerably larger than the mean error, and is the preferred method of indicating error for most urban applications.

To fully define accuracy for dead-reckoning and some hybrid systems, an additional measurement is necessary. For such systems, error can accumulate until the vehicle becomes "lost." When it is probable that such conditions exist, the car must be relocated by the dispatcher.[1] This measure of accuracy can be defined as:

- The mean time between losses, such as 4.2 hours per vehicle, or
- The frequency of losses, such as six times per vehicle per 24-hour day.

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[1]This process is known as "reinitialization."

The magnitude of acceptable location error levels for law enforcement application may be developed from the following considerations:

- If reduction of travel time to the incident site were the only consideration, than the accuracy required to accomplish nearly all of this time, has been established as one quarter of a beat dimension.[2] Beats have various dimensions dependent upon urban density and other factors. In New York City, for example, a beat may be 2 to 4 blocks on a side in Manhattan, whereas in Kansas City a beat may be 1.25 miles on a side. For these examples, AVM accuracy required would range from one-half of a block, say, in Manhattan, to one-third of a mile, say, in Kansas City.

- Travel time, in the above illustration, assumes a continuous street pattern. Barriers, such as expressways, large hills, streams, etc. can influence the results. When such barriers influence travel time significantly,[3] the dispatcher should know on which side of the barrier the vehicle is located. For this purpose, accuracy in the order of one-half block may be required.

- Command and Control operations may require an area to be sealed off, or a vehicle to be chased. For maximum effectiveness, the dispatcher should know the street on which the vehicle is located (or travelling), to a tolerance of perhaps one-half block.

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[2]See Chapter VI.

[3]R.C. Larson, Urban Police Patrol Analysis (MIT Press, 1972), pp. 102-106.

> When an officer sounds an emergency alarm, the dispatcher should be able to direct other officers to the emergency site quickly. If the officer is located in an alley in a high-rise urban area, the response time may be considerably shortened if the location accuracy and resolution could define this location.

Considering the above situations, AVM system accuracy of one-third mile to one-half block may be required, depending on the system objective and implementation location. For systems in dense locations, or where significant barriers exist or when command and control operation and officer safety are system objectives, accuracies in the order of one-half block are desired. An average block is estimated at 440 feet. A system having 95% confidence that the error would not exceed 220 feet should be very acceptable for law enforcement application. However, it is also recognized that tradeoffs (such as cost) might make lesser accuracies in some police departments (perhaps to 400 feet) tolerable.

Acceptable levels of mean time between losses are more difficult to rationalize, as it relates to attitudes and workload of the dispatcher, and the patrol officer. Too frequent occurrence of lost cars will adversely affect attitude, the likely result being loss of confidence in the system. This subject is covered in more detail in Chapter V, "The Frequency of Lost Cars," and in Chapter IX, "Technological Analysis."

2. Update rate. This is the rate at which vehicle location (and other data) is sent from the vehicle to headquarters.

This rate may vary--depending upon application--from, say, once per second to once per minute or longer. During the time between updates, the vehicles can be travelling, and in case of a vehicle on an expressway having a 60 mph speed, the distance travelled will be one mile if the update rate is once per minute. The dispatcher knows only the last reported position, so in this example an error of one mile can exist because of the slow update rate. This may be a very acceptable tolerance for distribution or service trucks, but unsatisfactory for police use.

The average speed of a police vehicle in an urban high-rise area has been estimated at 10 to 15 mph during normal patrol, and 25 to 30 mph when responding to a priority call. This would translate to travel of 15 to 22 feet/second for normal patrol and 37 to 44 feet/second for a priority call. If the update rate was once per second, maximum error caused by travel would be 20 to 40 feet and would be considered a reasonable contribution to the total tolerable error. For update rates of 5 and 15 seconds, the travel between updates (maximum error) would be 100 and 300 feet for patrol, and 200 and 600 feet for priority calls, respectively. Considering the various tradeoffs (e.g., system capacity versus update rate versus error), update rates with a frequency of not less than every five seconds appear necessary to satisfy certain law enforcement needs.

3. System capacity. The capacity of a system is measured as the number of vehicles that can be accommodated per some constraining influence. This could be a geographic constraint,

such as a system that is dependent upon a synchronizing pulse or data chain at UHF frequencies from a single base station, which may be limited to those vehicles operating under favorable line-of-sight signal conditions, which in turn may restrict the operating area to that contained in a circle of 15- or 20-mile radius around the base station. In contrast, the Omega system,[4] for example, can service an unlimited number of vehicles throughout the world from only eight base stations--assuming each vehicle determines its own position.

For AVM, a more common determinant of system capacity is the AVM data link between mobile and headquarters. This link is usually a radio channel, either of voice-grade type (in VHF or UHF bands) or special wide-band channels in the 900 MHz band, as recently provided by the FCC. Present system capacities vary from 200 to over 10,000 per channel. A system may expand to more than one channel, but the general scarcity of spectrum space favors systems that can accomodate more vehicles per channel. As already suggested, higher system capacity may involve tradeoffs between system accuracy, update rates and cost. More specific information is provided later in a section on Information Transfer Systems.

Other limiting constraints can be in data processing at headquarters. A computer may limit the amount of data--from the vehicles--that can be handled and processed. This subject is covered in the section II. D. on Headquarters Processing.

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[4]For a more detailed description of the Omega System see Section B.1. of this chapter and footnote   in section B.1.

4. System costs. For AVM to be warranted, the results must justify the cost. As discussed in Chapter I, expected benefits of AVM systems can be cost related (e.g., the improved effectiveness of the patrol force) or non-cost related (e.g., an officer's life was saved). Assuming that these benefits can justify AVM, then the question of concern is the relative cost of various systems as compared to their claimed benefits. An effective cost guide can be expressed as a cost per equipped vehicle considering system investment, operating and maintenance cost. More discussion on cost considerations follows in section II. F. of this chapter.

B. Location Techniques

A number of different methods have emerged for locating vehicles. The following will briefly describe the principal contenders and will endeavor to show the probable strengths and weaknesses of each system, particularly as applied to law enforcement use. The reader will realize that system and equipment development is a continuous process and that the current status of any of the systems described herein can have new technological advances inadvertently excluded, and in some cases, system description must be necessarily limited because of its proprietary classification.

1. Navigation (Hyperbolic) systems. The principal navigation type contender for AVM application is Loran C, which has been in successful use for nearly 20 years, primarily by ships

at sea (and also in aircraft on transoceanic flights). A more recently applied system is Omega[5], which is believed unsuitable for AVM (as applied to urban law enforcement) because of accuracy limitation (approximately one mile) and expected high cost.

Loran C, as presently implemented for ship navigation, uses high power stations (approximately 400 KW with 600 foot tower antennas) and can cover an area of up to 500,000 square miles with one chain of transmitters (minimum 3). Cities within the area of existing chains (approximately the eastern third of the United States) could use these signals, and thus save substantial cost. Cities not within the area of existing coverage can have lower powered and more closely spaced chain installed (1KW and 300-foot tower antenna with three transmitters spaced approximately 20 to 30 miles apart), covering a smaller area, perhaps 10,000 square miles. There is no frequency allocation problem involved for smaller chains, as all Loran transmitters operate on the same frequency (100KHz).

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[5]The operating principle of the Omega system is similar to that of Loran C, except that the frequency of transmission is very low, approximately 11KHz. The low frequency permits worldwide coverage from only eight fixed transmitters (four are now operating) and provides location signals to aircraft, ships, submarines, and land vehicles. Because of the low frequency and long transmission distance, the transmitted path length varies as a function of signal reflections from the ionosphere--which is dependent upon the distance from the transmitter, the season of the year, time of day, sun-spot cycle, etc. The measured path length must be corrected by applying appropriate correction factors which are available in prepared tables. For slow-moving vehicles, such as ships, this is a manual process; for faster moving vehicles such as aircraft, this is a computer process. Accuracies of one to two miles are considered normal.

A diagram of Loran C AVM system is shown in Figure 2-2. The chain of transmitters, XT_1, XT_2 and XT_3 emits a pattern of pulses, where the timing of each is precisely controlled. Pulse groups are repeated at a rate of ten to thirty times per second. The Loran C receiver, located in a vehicle, identifies the particular pulse group from XT_1 and XT_2 and measures the difference in arrival time of the pulse groups. A particular time difference locates a hyperbola between XT_1 and XT_2. A second measurement of the difference in pulse arrival time between XT_2 and XT_3 locates a second hyperbola. The intersection of the two hyperbolas defines the vehicle location. The Loran C receiver defines their locations with an output of two six-digit[6] numbers, which in turn is transmitted to headquarters at each update period over a communication-type transceiver--where the data is processed and displayed.

Accuracy is a function of Loran C transmitter power, noise environment and urban structures. Tunnels and overpasses can cause loss of signal or seriously reduced signal.[7] Accuracy tests conducted in the high-rise area of Philadelphia[8] produced a mean error of 588 feet and a 95% confidence accuracy of 1,390 feet; in the low-rise industrial area, the mean error was 383

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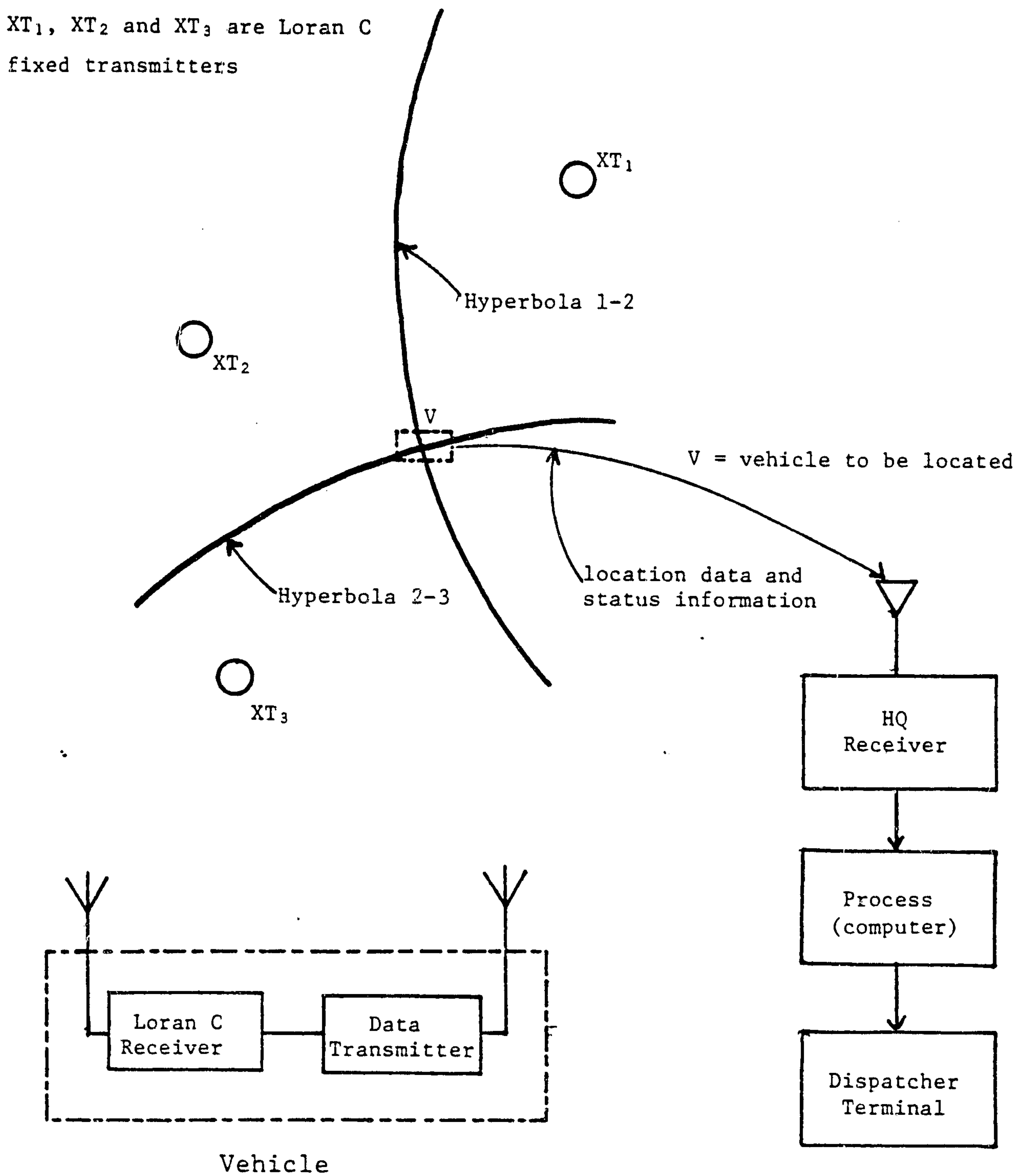
[6]For longitudinal and latitudinal positioning.

[7]W.K. Vogeler, "Vehicle Location with Loran C," Telecom, Inc., 1975 Carnahan Conference Proceedings.

[8]A comparison of Automatic Vehicle Tracking System by F.J. Chambers and R.S. Stapleton, Teledyne Systems Co., Northridge, California.

Figure 2-2

Loran C - Location Tracking Method



feet, with 95% confidence at 1,044 feet. In 1974, additional tests were conducted in Philadelphia[9] that revealed weak signal locations in the high-rise area had accounted for some of the 1971 error. To improve this, 20 signal augmentors[10] were used, reducing the mean error to 264 feet and the 95% confidence level to 506 feet (sensor only). It is also necessary to calibrate an urban area because of buildings and other structures. For the high-rise Philadelphia area, calibration was made at 24 locations.

a. AVM considerations. Special features of Loran C are the large area of coverage and the "free" use of existing transmitter chain facilities. Eastern installations now produce signal levels over many states, which should create an incentive for AVM applications (other than ships and aircraft) that involve intra- and inter-state travel. The missing element is a communication system over which location data can be transmitted from mobile to headquarters. There may be some services, such as state highway patrol, that have existing communication systems which may also have the capacity to handle the added data load.

Use of Loran C transmitter chains for urban law enforcement applications appears contingent upon acceptable signal levels,

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[9] 1974 Loran C Automatic Vehicle Monitor Testing by R.S. Stapleton, Teledyne Systems Company, Northridge, California.

[10] An augmentor simulates the actual signal and is synchronous with it for local weak signal areas of approximately 1,000 feet.

and as in Philadelphia, may require extensive field testing and application of "signal boosters" in weak areas. The surveys could be expensive, as well as the "boosters," and obtaining sites and permission to locate the "boosters" at these exact locations could be a problem.

New smaller powered transmitter chains may be designed to provide adequate signals in an entire city (or cities), to alleviate problems mentioned in the above paragraph, but this entails more capital expenditure, purchase of antenna sights, higher operating and maintenance costs, etc. It is also noted that the FCC, in its August 8, 1974 release (docket 18302 re: AVM) states "...authorization of non-government operation in this (90-110KHz) band is not permitted." Until this rule is changed, private stations cannot be licensed.

Loran C, as a basis for AVM applicable to law enforcement use, appears uncertain, mainly because of apparent excessive errors in urban environments. Further, the economic advantage in using existing transmitter chains is presently confined to the eastern third of the United States, and expansion to other areas by developing private transmitter chains appears thwarted by the FCC. Further (public) navigational expansion of Loran C by the U.S. Coast Guard (or others) may be delayed, awaiting perhaps preferred acceptance of Omega on a worldwide basis.

2. Signpost/proximity systems. Another technique for locating vehicles is electronic signposts that are positioned

in fixed locations throughout an area. When a vehicle comes within the proximity of a signpost, the vehicle location can be identified. A common form of electronic signpost is a radio, either a transmitter or a receiver, mounted on a utility pole or a street light fixture. If the signpost is a receiver (such as implemented in Stamford, Connecticut)[11], a vehicle with a corresponding transmitter will continually transmit its digital identification and when within the proximity of the signpost, the receiver will pick up the signal and relay the car identification to headquarters--usually over dedicated telephone lines. If the signpost is a transmitter (such as implemented in Montclair, California), it will radiate the signpost identification to the vehicle when it is within the proximity of the signpost--and the vehicle in turn will transmit the signpost (and vehicle) identification to headquarters over a communication-type transceiver. If there are a large number of signposts in an urban area (for example, one at every intersection), the dispatcher can locate vehicles throughout the area to an accuracy of one city block, assuming the vehicle and signpost data are sent back to headquarters at the time the vehicle passes the signpost.

a. AVM considerations. The practicality of signposts as a contender for AVM application depends upon its competing

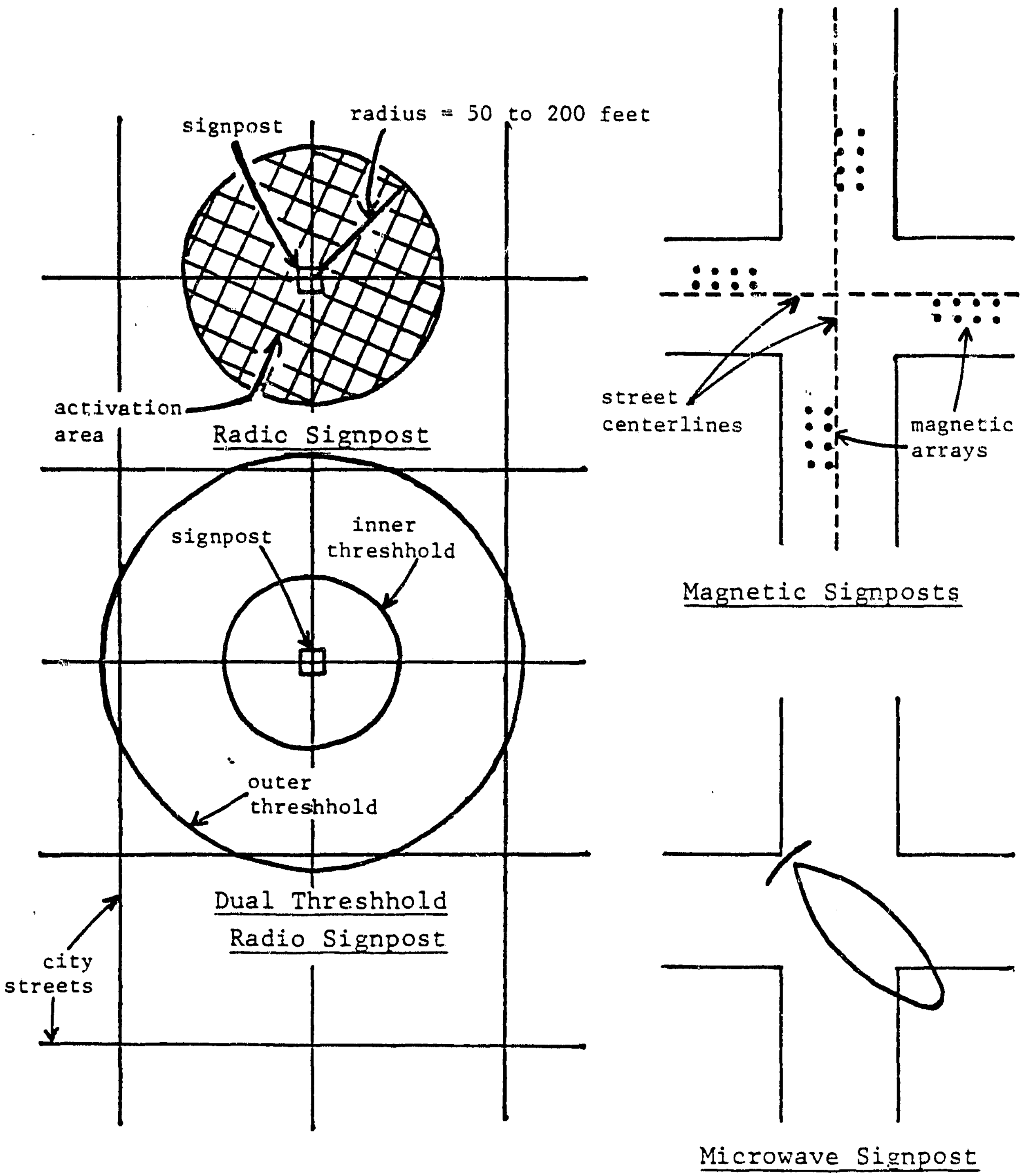
[11]Visits to Stamford, Connecticut (Police Department) and to Montclair, California (Police Department) were made during the course of this study. Both locations represented implemented AVM systems in a smaller urban environment.

with other systems with regard to accuracy, update rate, cost and other features. Considering cost, the signpost portion of the system is directly proportional to the number used. If accuracy considerations require a signpost at each intersection, and if a city has block sizes averaging 550 feet by 300 feet, the number of signposts per square mile is approximately 170. If the price per signpost were $300, the cost per square mile for this portion of the system would be $51,000. For a city the size of St. Louis (67 square miles), the cost would be $3,417,000. This seems to illustrate that such systems may be attractive to small area communities (e.g., Montclair, California), but a method is needed to reduce cost by reducing the number of signposts or the cost of signposts if it is to be attractive to larger area cities.

An accuracy tolerance of one city block (300 to 500 feet) is not as good as one would like, particularly for such tasks as locating an officer in distress, or for command and control. Further, if the location information cannot be sent to headquarters exactly at the time when the vehicle passes the signpost, the tolerance increases. For example, if an update rate of once every five seconds is used, the added tolerance at 30 mph could be 220 feet. Another accuracy problem relates to the size of the activity area of the signpost. A radio-type signpost, that transmits or receives a signal, depends upon signal strength to activate the vehicle. See Figure 2-3. Typically, the coverage area is circular around the signpost,

Figure 2-3

Signpost Systems



having an activation radius of as little as 50 feet, more typically 200 feet, and perhaps greater. When a vehicle approaches the signpost from the east, the mobile receiver will identify the signpost 50 to 200 feet east of the intersection; approaching from the west, the intersection will be correspondingly displaced to the west.

In summation, it would be desirable to have fewer signposts (to reduce cost), with an apparent contradictory need to improve accuracy, and with a desire to decrease the activity area of the signpost. These needs have been recognized by suppliers of signpost systems, and a number of approaches have been taken to solve the problem. Some of these are summarized below.

To reduce the number of signposts, one supplier, instead of having one activity area encircling a radio signpost, employs two.[12] This is done by using a receiver that recognizes two threshold levels--one a weaker signal threshold activated by an outer range circle, followed by a stronger signal threshold activated at the closer ring. By adjusting the levels, the coverage can encompass two blocks. This technique may permit a four-to-one reduction in the number of signposts, with an unknown effect on accuracy.

Some suppliers have developed a "low cost' dead-reckoning system that measures distance and direction, stores the

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[12] Dr. Charles C. Freeny and Otto A. Reichardt, "An Economic AVM System," 1974 Carnahan Conference Proceedings.

incremental data during the next update period. Such systems which combine two or more technologies are called "hybrid" systems. This not only removes the error that would devlop because the update time does not coincide with the time the vehicle enters the activity area, but also makes possible the use of fewer signposts. Obviously, the dead-reckoning equipment adds cost, so for this approach to be economically successful, the cost saved in reducing the number of signposts should be significantly larger than the cost of the dead-reckoning addition.

If, for example, such hybriding permitted signposts to be located at every fourth intersection, a 16 to 1 reduction would result; every tenth intersection would reduce the number 100 to 1! The success of this type of signpost plus a dead-reckoning system is yet to be proven; such reduced density permits vehicles to travel indefinitely between signposts to the point where reliance of system accuracy rests wholly on the capability of the dead-reckoning system. A possible solution to this dilemma would be to have the vehicle odometer accumulate distance since the last signpost identification, and when this distance has reached a magnitude that experience has shown will cause excessive error, a signal (audible and visual) will be activated advising the driver to seek a signpost as soon as it is convenient. This advisory signal would also be sent to headquarters warning the dispatcher that accuracy for the vehicle is questionable.

In the search for lower cost approaches, and greater accuracy, other signpost concepts have evolved. A magnetic signpost[14], near street intersections, consists of a number of cylindrical magnets imbedded in a street such that when a vehicle passes over the area where the magnets are located, a current is induced in a pick-up coil on the vehicle, and the spacing between magnets and/or their polarity generate a binary code for identifying the intersection. This method appears to have certain advantages over radio signposts, in that the activity area of the magnetic signpost is a few feet. contrasted with 100 or more feet for the radio type (increasing the accuracy), and the magnets are passive, requiring no power for operations, presumable reducing operating and maintenance costs (radios require a battery or a-c power for operation).

Other passive and semi-passive arrangements are under development, involving for example, X-band radiation from the vehicle, and a coded reply from the signpost sensor. These approaches, too, are aimed at better accuracy, lower cost and less maintenance.

Acceptance of signpost systems by law enforcement agencies largely lies in industry's ability to solve the cost-accuracy problem. Lower cost signpost, passive signposts and hybrid systems involving a combinaton of dead-reckoning and signposts all appear to have promise. Final results will be dependent

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[13]Richard C. Furth, "A Magnetic Array Proximity AVM System," Novatek, Inc., 1974 Carnahan Conference Proceedings.

upon completion of current development programs and further field testing. However, signpost systems are likely to be the most economical AVM type for small communities.

3. Trilateration systems. Trilateration systems are similar to Loran C and Omega Navigation systems in that the location determination is based on the difference in time of arrival using two pairs of fixed stations. As in navigation systems, the locus of a fixed time difference between a pair of stations is a hyperbola, and the intersection of two hyperbolas locates the vehicle. In trilateration systems a signal is emitted from the vehicle to be located and received by three (or more) fixed stations. The fixed receivers then relay the received signals via dedicated telephone lines to headquarters, where a computer locates the vehicle. It is possible to receive time-difference signals from more than two pairs of fixed stations which can reduce the mean error. Such systems are called multi-lateration systems.

Two types of trilateration systems have been developed and field tested. One, called phase trilateration, is a narrow band system, designed to operate over normal voice channels and detects time difference by comparing the phase of arrived signals. Unfortunately, this method is subject to substantial errors in an urban environment because of phase distortion caused by reflected signals (multi-path). In the 1971 Philadelphia tests, errors in the high-rise section were several thousand feet, and even in the low-rise industrial area, the 95% confidence factor was approximately 2,000 feet. This poor accuracy is considered unacceptable for law enforcement purposes.

The other system, called pulse trilateration, is a wide-band system and uses one of the two newly authorized 8MHz channels in the 900MHz band. The signal emitted for vehicle location is a fast-rise two-microsecond pulse, which is also subject to multi-path delays, but the pulse signal that arrives at the receiver sensor first has traversed the shortest distance so this leading pulse edge is used in calculating the time differences. The claimed location accuracy[14] with 95% confidence is 300 feet in random locations and 150 feet in select locations. Such accuracies, if confirmed by subsequent results in actual field usage, should be acceptable for law enforcement application.

The pulse trilateration system, being wide band, has an unusually high capacity that can accommodate over 10,000 vehicles, assuming this number is comprised of several different classes of vehicles requiring different update rates of from two or five seconds (such as police) to one minute (such as delivery trucks). If the vehicle mix involves proportionally more rapid update rates, the number of vehicles that can be accomodated will be reduced.

One supplier utilizes this technique in conjunction with two-way digital communication, where 16 bits of digital data

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[14] Jerome Zander, "Field Testing of an Automatic Vehicle Monitoring System," Hazeltine Corporation, April 2, 1970.

per time slot is transmitted from base to mobile, and another 16 bits from mobile to base (status information). This two-way digital communication capability is considered desirable in terms of decreasing voice-band congestion and increasing operational effectiveness.

4. Dead-reckoning systems. Dead-reckoning systems depend upon equipment within the vehicle to generate location information, in a manner similar to that of inertial guidance systems as used in missiles, aircraft, submarines, etc. For these systems to work, the initial vehicle location must be known, after which the instruments within the vehicle track its location through distance and direction sensors. To be commercially competitive, sensors other than the expensive precision gyroscopes should be used.

The system evaluated in this report is of this type. As mentioned in Chapter II the system is a Boeing development having a system trade name "FLAIR."*

Accuracy in position tracking is necessary in dead-reckoning systems[15], to avoid cumulative errors which eventually could lead to the vehicle becoming lost. The FLAIR system has a rather unique means to track a vehicle while using a rather

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[15]It is apparent that the Boeing FLAIR System operates on the dead-reckoning principle, but also uses the computer to reduce the possibility of accumulated errors. The FLAIR system should therfore more appropriately be called a computer-tracked dead-reckoning system, or, because it uses more than one location technology, a hybrid system.

*FLAIR is a trademark of the Boeing Company.

low-cost distance sensor (odometer) and heading sensor (magnetic compass). This tracking technique is called map matching whereby the computer keeps the vehicles on a street-even though the relatively inaccurate heading sensor might otherwise let it wander from one side to the other. In a similar manner, inaccuracies in the odometer can be overcome when a vehicle turns a corner, as the computer will correct the location to the nearest cross street, even though the indicated location is short of or beyond the intersection. If the computer should pick up the wrong intersection, it is likely that the vehicle will eventually encounter routes not on the map, and thus the computer can no longer track it. Under these conditions, the computer will search the map to find the location that corresponds to the vehicle route, and if successful, will relocate the vehicle.

If a vehicle does become "lost" (because the computer can no longer track it), a V is displayed on the video screen identifying the particular vehicle number whose location should be verified. To verify, the dispatcher asks the particular officer to stop at the next convenient intersection and identify the intersection. If the location is not correct, a cursor is placed, by the dispatcher, at the correct location, on the screen, and the car is reinitialized. Occasional lost cars will probably not detract from the effectiveness of the system, but too many lost cars could obviously negate the benefits intended.

Accuracy tests conducted during FLAIR Phase I implementation showed that the best 80% of position estimates (in terms of accuracy) averaged 45 feet error, with a maximum error (the 80% confidence factor) of 90 feet. In terms of other confidence factors, 95% confidence was 625 feet, 90% confidence 400 feet and 85% confidence 175 feet. These tests were based on 713 measurements taken by the dispatchers comparing actual with indicated locations over a one-month period. Separate tests conducted by Boeing, involving 12 tests runs, showed an average error of 72 feet and a 95% confidence of 224 feet. The frequency of lost cars, as recorded in a special three-week test[16], showed, on the average, that each car required re-initialization (location corrected) 11 times each 24-hour period, or the mean time between losses per car was 2.13 hours. This test was conducted at a time shortly after replacing previous Ford patrol cars with Novas, and the calibrations of some of the newly installed AVM systems had not fully stabilized. Boeing is making a number of changes in Phase II equipment to improve accuracy and reduce the incidence of lost cars.

The video display, as viewed by the dispatcher, shows the cars driving on streets, and with the location updated every second, presents a real-time view of the continuous movement of all vehicles. This is easy for the dispatcher to relate to

[16]Particular attention was given to factors influencing proper AVM operation.

(compared to other types of systems in which vehicles may appear to wander through buildings) and serves to assist the dispatcher in verifying the location of the computer selected closest car(s)--which could be located on one-way streets, or across a natural or man-made barrier (such as a river or expressway); assists the dispatcher in command and control operations (such as sealing off an area); and assists in identifying the location of a car that has activated the emergency alarm.

The FLAIR System provides digital communications from mobile to headquarters, having a capacity of 99 "canned" messages. The mobile operator can transmit a selected message by keying in the appropriate numbers. These codes are used for general messages, which the dispatcher must acknowledge (by voice); messages of another type perform an automatic function on the display (e.g., identifying one versus two-man car, leaving for incident scene, etc.) requiring no dispatcher acknowledgment and a third class that will automatically initialize the car at given locations when the operator keys in the appropriate number.

C. Information Transfer

Each location technique generates information that provides the basis for its location. Such location data and status information must be communicated to headquarters in a timely manner. The type and amount of information varies, depending upon the location technique. The method of information transfer is by mobile transmitter, sometimes combined with dedicated telephone lines, and the type of communication is generally digital, whose numbers are transmitted using "bits" (0 or 1) in a binary code.

For systems involving digital radio communication, the capacity of a system may be determined by the number of vehicles that can be handled per r-f channel. Factors that will influence the number of vehicles per channel are:

- Number of bits per update period. The fewer required, the greater the vehicle capacity;
- The bit rate (bits per second). The higher rates produce the greater capacity (the high limit will be limited by band-width and noise considerations);
- The update rate. The less often an update is transmitted, the greater the capacity. Previous discussions of update rates indicate a rate of at least once per five seconds is desired if certain police benefits are to be obtained.
- The channel band-width. The voice channels in the VHF and UHF bands have 25KHz channel spacing and a nominal 3 KHz audio band-pass, and thus will accommodate proportionally fewer vehicles than the newly available 1 and 8 MHz channels in the 900 MHz bands (see following discussion on FCC considerations); and
- The method of communicating data from mobile to headquarters, such as random, polling and time-slots. These methods will be discussed more fully in the following.

1. Methods of communicating data. Small systems, such as the (transmitter) signpost system in Montclair, California, use

the r-f channel assigned for voice communication to transmit location and status data from mobile to headquarters. This system may be called a random system in that each vehicle updates this information each time it approaches a new signpost (or a new status). If the channel is occupied, either by voice or other AVM data, transmission must be delayed until the channel is clear. In peak periods such delays could be substantial, during which time the vehicle trying to report could be traveling, and such distance travelled will be in effect an error. Random systems may be satisfactory for small AVM systems, but cannot accommodate larger systems, where voice channels are already congested.

Larger systems require separate r-f channels for communicating data from mobile to base. Two methods, sequential polling and time slots, are generally favored for this purpose.

a. Sequential polling. Each car in a fleet is sequentially polled, generally by computer command. For each vehicle, the headquarters AVM transmitter sends the vehicle address (selective call), to which that vehicle will respond with location and status data. After the response has been received at headquarters, the computer will step to the next car in the fleet and will repeat the interrogations procedure until all cars have been polled, at which time the cycle will repeat.

b. Time slots. This system divides the time during the update period into time slots, one for each vehicle in the system. The number of slots in a system is determined by the number of bits of information required (location and status), bit rate and the frequency of update. Thus, a system requiring 24 bits for location and status and having a 2400 bps rate can accommodate $\frac{2400}{24}$ = 100 vehicles per second or for a five-second update rate, 500 vehicles. This type of system requires that all vehicles be synchronized each update cycle and that all vehicles (as well as the headquarters receiver) have accurate timing circuits that control their assigned time slots. The time slot number assigned to each vehicle identifies this vehicle at headquarters. Boeing FLAIR and Hazeltine pulse trilateration AVM systems use the time slot method.

c. Time slots versus polling. A comparison of the two methods is shown in Table 2-1, where the location and status data are assumed to be identical, and typical of that which would be required in a law enforcement application. From examining the Table, it is evident that the polling method requires a longer time (19.25 versus 10.1 milliseconds - line h) to transfer this information because of the time required to transmit the mobile address, and the time involved for the mobile transceiver to switch from receive to transmit. System capacity for a five-second update rate is 495 vehicles for time slots and 260 for polling (line k). However, time slots are rather inflexible, and if a car is out of service (meals, at incident site, etc.) the time-slot time is reserved for that car even though not used. For polling, the

Table 2-1

Time Efficiency in Pollings versus Time Slots

		Polling	Time Slots	
a.	Interrogation address (bits)	10.00	0.0	(up to 1024 cars)
b.	Location data (bits)	10.00	10.0	
c.	Status data (bits)	7.00	7.0	(up to 128 codes)
d.	Total bits	27.00	17.0	
e.	Time at 2400 bps (ms)	11.25	7.1	
f.	Allowance for T/R switch operation* (ms)	6.00	0.0	
g.	Allowance for guard bands, synch signal, etc.	2.00	3.0	
h.	Total time (ms)	19.25	10.1	
i.	Number of time periods/ second	52	99	
j.	Number of seconds for 200 cars	3.8	2.0	
k.	Number of cars per five seconds	260	495	
l.	Number of cars per 15 seconds	780	NA	
m.	Number of cars per 15 seconds assuming 30% are out of service	900 (approx.)	NA	
n.	10% report each five seconds	750 (approx.)	NA	

* For polling systems, each vehicle must first receive its address (from HQ), after which the transceiver changes its mode from a receiver to a transmitter (T/R switch) to dispatch location and status data.

computer can step to the next car if the interrogated car reports "out of service," saving about one-half of the time in that polling period. Thus, if 30% are out of service (on the average) more cars (about 15%) can be accommodated per fixed update period. Further, if the update rate can be changed to 15 seconds (instead of five), the number of cars per system will increase from 260 to 780 (line l) and to 900 (line m) with 30% out of service. Polling at 15-second intervals does not satisfy police requirements for such operations as command and control, but the dispatcher can command specific cars to be interrogated three times as fast or every five seconds when required (or status--such as "on a chase"--can automatically increase interrogation rate). Thus, if a 15-second update rate is used, if 30% of the cars are out of service, if 10% of the cars require five-second update, then the polling method can accommodate 750 cars (line n) versus 495 for time slots.

The above illustration applies to a narrow-band voice-channel law-enforcement application. Wide-band high-capacity systems in the 900 MHz range can have a degree of flexibility using time slots. Various grades of applications can be programmed for different update rates depending on requirement. If delivery trucks and taxis require update every one minute, they would occupy one time slot per minute; if law enforcement application requires update every five seconds, 12 time slots would be occupied in a one-minute period. This type of time-slot flexibility requires that each vehicle be "permanently" programmed for its update class; in contrast, the flexibility of polling systems is more dynamic, under the control of the dispatcher or software programs.

2. System efficiency. A comparison of the efficiency in the use of narrow-band (voice) channels versus type of location system in shown in Table 2-2. Compared are Loran C, Signpost, Signpost with Dead Reckoning, and Computer-Tracked Dead Reckoning (FLAIR). This comparison is made using the time-slot method. All systems except for computer-tracked dead reckoning are shown with a five-second update rate; computer-tracked dead reckoning is shown with a one-second update rate which appears desirable to maintain the accuracy required to prevent excessive "lost car" occurrence. The number of cars per channel appears best for the signpost (615) and poorest for dead reckoning (103) (assuming that a five-second update rate proves satisfactory for the non-FLAIR type systems).

Wide-band systems have greater capacity per channel. Pulse trilateration systems operating in the 8MHz channel in the 900 MHz band can accommodate 5,000 to over 10,000 cars per system depending on class (and update rate) of vehicle in the system. Approximately 30,000 time slots are provided for each one-minute period. If all cars were required to have one-second update intervals, 500 can be accommodated; for a five-second update, 2,500 can be accommodated.

Large system capacity is desirable in terms of cost per vehicle, efficiency in the use of the frequency spectrum (see next section on FCC considerations), and for accommodating large customers.

CONTINUED

2 OF 3

Table 2-2

System Efficiency with Time Slots

(narrow-band systems)

	Loran C	Signpost	Signpost with Dead Reckoning	Computer-Tracked Dead Reckoning
Location Data (bits)				
--2 six-digit numbers	40			
--signpost addresses (to 1024)		10	10	
--x increment (to 640 feet)*			7	
--y increment (to 640 feet)*			7	
--odometer (to 640 feet)*				7
--heading sensor (2.8^{o})				7
Digital (status (bits)	7	7	7	7
TOTAL BITS	47	17	31	21
Times @ 2,400 pbs (ms)	19.6	7.1	12.9	8.7
Allowance, synch signal, guard bands (ms)	2.0	1.0	1.5	1.0
TOTAL TIME (ms)	21.6	8.1	14.4	9.7
Number of time periods/second	48.5	123	69	103
Update period (seconds)	5	5	5	1**
Number of cars per system	242	615	345	103

* Distance measured in five-foot increments

** Once per second update is required to maintain system accuracy

3. FCC considerations. Until recently the FCC had not authorized AVM use on existing VHF or UHF bands--so much of the development efforts on the various systems were done on the speculation that the FCC would authorize this service. On Docket No. 18302, involving use of AVM in the Land Mobile Radio Service, the FCC issued interim rules authorizing this service in FCC Report and Order dated August 8, 1974 and modified by Memorandum Opinion and Order dated December 18, 1974. In summary, this provides:

- Use of narrow-band 25 KHz band width channels in the low-band (25-50 MHz), high-band (150-170 MHz) and the UHF band (450-512 MHz) for AVM, providing frequencies are used that are presently assigned the applicant, or that frequencies be assigned where eligibility has been established.

  To be eligible, the applicant must accommodate location data for at least 200 vehicles per single frequency channel and 400 vehicles per paired frequency (UHF). This requirement has been modified by the December 18 release to 200 vehicles per paired channel--although suggesting that alternative solutions be found including the use of presently allocated voice channels for AVM and strongly recommending the use of channels in the 900-930 MHz band.

- Two new wide-band channels have been made available exclusively for AVM--904 to 912 MHz and 918 to 926 MHz. These channels are intended for pulse ranging/pulse trilateration systems that can accommodate a large number of vehicles (a licensee cannot apply for the second channel until the presently assigned channel provides location data for at least 5,000 vehicles).

It is noted that the industrial[17], scientific and medical (ISM) band is at 915 MHz so the wide band is subject to interferences from those services. The effect of this type of interference on AVM performance is not known.

- FCC also has provided two new medium-band channels (903 to 904 and 926 to 927 MHz) for systems that require up to 1 MHz of band width.

The above actions by the FCC illustrate that AVM has become an important and recognized service, and that frequency availability (particularly in the 900 MHz band), has been assured. The 1 MHz channels appear particularly attractive for increasing the capacity of systems now constrained by voice-channel limitations.

D. Headquarters Processing

The simplest forms of AVM systems, such as the signpost systems in Montclair, California and Stamford, Connecticut, take the location data information received at headquarters, and through logic circuitry, display the car location and identification on wall maps. This may involve turning on a light at the appropriate signpost location plus digitally displaying the car number at that location. From this map, the dispatcher can view the locations of all active patrol cars, can dispatch the one closest to an incident site, and observe the general movement and activity of the force.

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[17] This includes microwave ovens.

For larger and more sophisticated systems, computers are necessary to perform calculations, to store data and to provide inputs to the dispatcher terminal. Interface equipments are generally required, one to prepare data received from the field for computer use, and another to take computer output and process it for display at the dispatcher terminal. Also, an assortment of peripheral equipment is necessary, such as a teletypewriter, printer, card reader, magnetic disc, etc. The interface units are generally custom designed for the particular car location (and status) technique and the others can be standard purchased or leased items.

It is apparent that the investment in computer-related equipment can be considerable, particularly when stand-by units are required to achieve the desired reliability. This, in turn, requires an AVM system of sufficient size so that the allocated cost per car is reasonable. Consideration should also be given to combined AVM and CAD (Computer-Aided Dispatch) systems where the benefits can be greater than the sum of individual system benefits, and with the costs less than the sum of that for each system individually. It is probably that such a combined system can share in computer, peripheral and some interface costs.

E. Dispatcher Terminal

The dispatcher terminal is the most visible part of an AVM system. To a large measure, the method of display and the type of information displayed determine the effectiveness of the system.

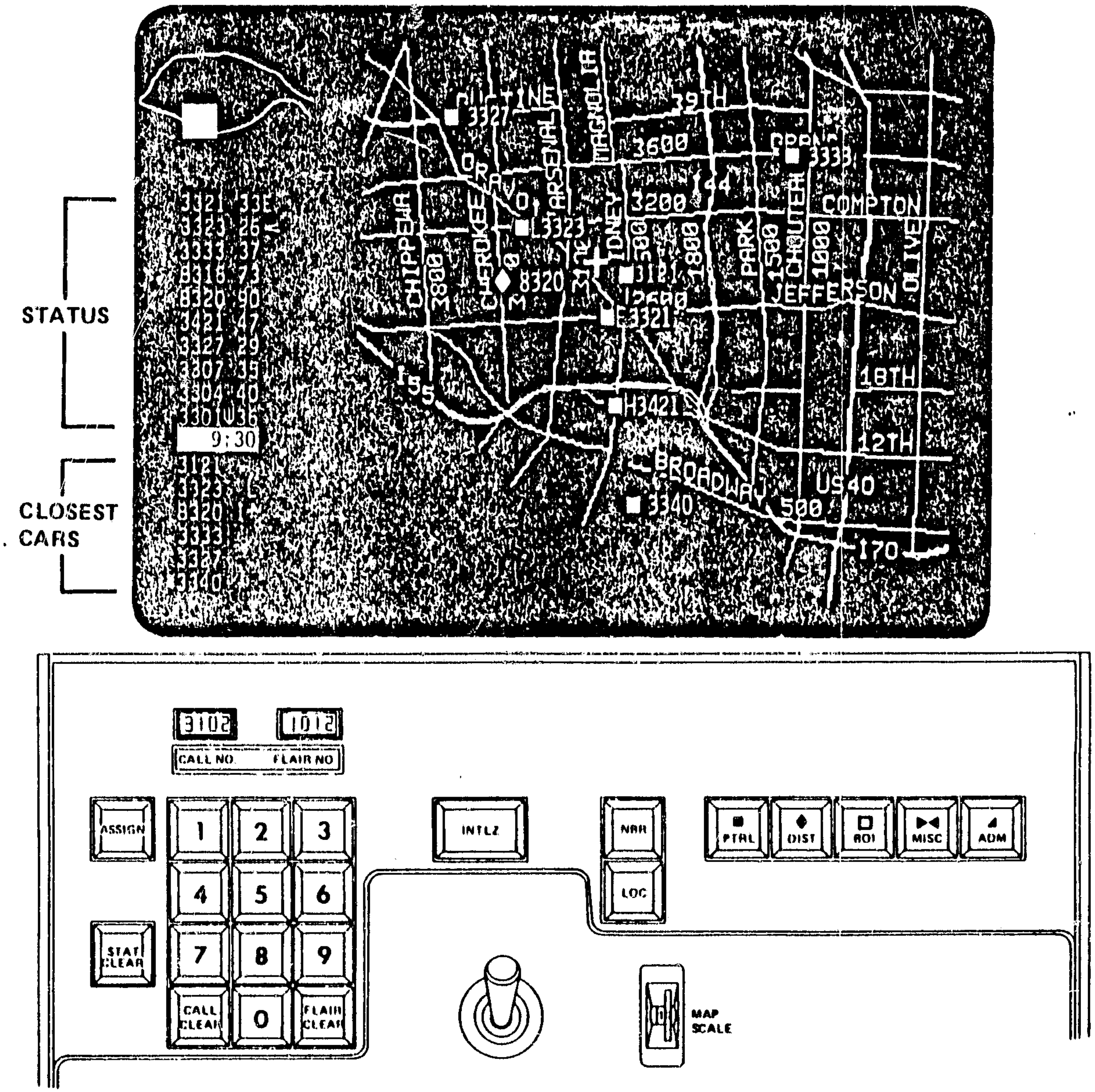
1. Alpha-numeric display. This display is of the type used in information retrieval systems and with computer-aided dispatching (CAD). It involves a Cathode Ray Tube (CRT) type screen on which numbers and words are displayed. It also includes a typewriter-type keyboard where the operator can enter information or instructions.

Information displays (e.g., identification of stolen cars, etc.) are now standard equipment in many police dispatch centers and CAD is being increasingly recognized as a valuable addition in improving the dispatching process. Therefore, there is considerable logic in an attempt to standardize on one display to serve the functions of Information Retrieval, Computer-Aided Dispatching and, if possible, Automatic Vehicle Monitoring. The alternative may be to surround each dispatcher with a number of CRT-type displays--which obviously would not be conducive to an efficient and effective operation.

If the principal value in AVM were to locate the cars closest to an incident scene or a car that has sounded an emergency alarm, combining the CAD and AVM display may have considerable merit. The CAD normally contains a geographic file which can convert specific addresses to x and y coordinate positions, so that the computer can quickly relate the incident address entered by the complaint evaluator (in the dispatch center) of the incident site to the police cars closest to the scene, and display their numbers--permitting dispatching of the cars closest to the scene, or the cars closest to the site of an emergency alarm.

<u>Figure 2-4</u>

<u>FLAIR Display</u>



2. Video or map display.[18] This is a color television-type display having a map of the city on the screen, with various magnifications available, showing drivable surfaces (streets, alleys, parking lots) and street names (Figure 2-4). The most magnified map (perhaps one square mile) would show all drivable surfaces and nearly all street names, while the less magnified maps would show proportionally fewer streets and names. All cars would be displayed on the map to an accuracy of the AVM system.

A video display can provide valuable information to the dispatcher, some not heretofore available. Examples are:

- Cars are displayed by different symbols to distinguish class of cars. Patrol cars may be represented by a small square, detective cars by a triangle, sergeants' cars by a bow-tie, etc. Each car can be identified by its number--which follows the symbol.

- Two-person cars are identified with two small dots that are associated with the car identification number--both on the map display, and on the listing of the closest cars.

- The car's status can be determined by the symbol brightness. A steady brightness indicates cars available for assignment; a slow blinking rate or a faster blinking rate identifies cars on a low- or high-priority assignment, respectively, either traveling to or at the incident scene. Such status identification can be controlled by the officer in the car by keying

[18] This description closely describes that used in Boeing's FLAIR System.

in the proper status numbers into his digital communication keyboard.

- To determine the cars closest to the incident site, the dispatcher moves a cursor (a cross on the screen) using a joy stick-type control to the site and the closest cars will automatically appear in order at the lower left of the screen.

- If the AVM system is used with CAD, this dispatcher operation would not be required, as CAD would perform the function of locating the incident site.

- Depending upon the AVM accuracy and the computer program for calculating the distance to the site, dispatcher verification of the computer-selected closest cars may be desirable. By looking at the map, the dispatcher can determine that such closest cars are not obstructed by barriers (expressways) or one-way streets.

- Any car in the system can be quickly located by keying in the car number and the "locate" button which will display the appropriate map and the car with a large square around it. As the car travels across the map, a new map automatically appears before the car is outside of the map area. This operation is particularly advantageous when a patrol car is in a chase or has sounded the emergency alarm.

- Digital messages are displayed with the car number at the left on the upper part of the screen.

- Any unusual distribution of cars may be quickly observed by viewing the less magnified map.

Compared to the alpha-numeric display, the video display permits:

- Verification of closest car location, so that obstructions such as expressways or one-way streets do not extend the travel time.

- Better execution of command and control operations by directing cars having known location to strategic positions to seal off areas; approach sites (from different directions) where a crime is in progress; or to give directions to supporting cars during a chase as to street location, change of direction, etc., by observing the lead patrol car in the chase.
- Continuous monitoring of police force activity. This capability, together with appropriate officer training and execution of orders, can assist in increasing the effectiveness and efficiency of the force.

When a dispatching operation faces the problem of separate displays involving information retrieval, CAD and AVM, some resolution may be possible by 1) maintaining the information retrieval function separate from dispatching and 2) possibly combining the alpha-numeric and video display into one unit permitting the dispatcher to select one or the other.

F. Economic Considerations

Accurate cost estimates for various AVM systems are not available. Literature published by various vendors has contained price "guestimates" based on assumptions of quantity production, incomplete considerations of operating and maintenance cost. Some published costs are available for complete systems, sold by Boeing to St. Louis and Hazeltine to Dallas. However, these costs are not considered representative of final pricing because the Phase I pricing covers only a trial system having relatively few vehicles and the Phase I and II pricing probably includes the effects of non-recurring costs (common to new products), pricing errors due to the newness of the technology, and consideration of the amount of available funds. The published prices are as follows:

Description	Number of Cars	Approximate Price	Cost per Car
Boeing (St. Louis) Phase I	25	$ 850,000	$ 34,000*
Hazeltine (Dallas) Phase I	43	761,000	17,700*
Boeing (St. Louis) Phase II	200	1,900,000	9,500
Boeing (St. Louis) Phase II Option (not awarded)	400	2,900,000	7,250

* For trial systems only.

The initial investment is not always the whole story, and to illustrate the probable effect of operating and maintenance costs, estimates are made relative to the Phase II FLAIR System in St. Louis as shown in Table 2-3. This example shows annual operation and maintenance costs at $205,000, exceeding the annual amortization charge of $190,000, based on ten year life and straight-line depreciation. Even with these relatively high costs, the annual cost per car is only about $2,000. A manned one-man patrol car costs in the vicinity of $100,000 per year. Related to this, AVM appears to add approximately 2% to the cost.

Table 2-3

Cost Analysis

(200-Car FLAIR System)

Initial investment	$ 1,900,000	
Cost per year based on ten-year straight-line depreciation	190,000	$ 190,000
Estimated operating costs (annual):		
AVM Coordinator*	30,000	
Space and utilities (500 sq. ft. @$6)	3,000	
Material and miscellaneous	2,000	
	35,000	
Estimated maintenance ccsts (annual):		
Computer maintenance contract**	34,000	
Service technicians* (1 for base station, 3 for mobile)	96,000	
Spare parts replacement	10,000	
Replacement modules	30,000	
	170,000	
Total operating and maintenance cost per year		205,000
Total cost per year		$ 395,000
Total cost per year per car		$ 1,975

* Including 100% overhead.

** 1% per month of cost of computer (with standby and peripherals).

As previously stated, the cost of AVM must be justified if it is to be implemented widely. Non-monetary benefits can include the possible saving of an officer's life (emergency alarm), apprehending more criminals in major crimes (bank robberies, chases, disturbance) through better command and control capability, and perhaps better morale. Cost effective benefits are likely to be most evident in the improved effectiveness of the force, where AVM allows better management of the patrol force by the supervisors of the police department. Adverse effects could result from lower officer morale or abuse of the system.

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Appendix B

MARKOV MODELS OF FIXED-POST SENSOR AVL SYSTEMS

by

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I. INTRODUCTION

An AVL (Automatic Vehicle Location) or AVM (Automatic Vehicle Monitoring) system provides estimated vehicle location information to a central controller (e.g., "dispatcher") who makes tactical assignment decisions based on the location information. These systems, because they provide more accurate vehicle position information than is currently available, should be important to transportation scientists in a variety of applications. At least five U.S. cities and several western European cities have already installed AVL systems.

Popular AVL technologies include radio trilateration systems,[1] dead-reckoning systems, and fixed-post sensor systems.[1-5] Each type of system is characterized by a particular operating characteristic for location estimation error. For instance, a radio trilateration system might yield a distance estimation error that has a circularly symmetric Gaussian distribution, centered at the vehicle's true location.[6] For such a system, one would desire such performance measures as the mean distance estimation error and the probability that the error exceeds some prespecified threshold. For a dead-reckoning system, such as Boeing's FLAIR[1] System,[7] one must resort to performance measures more closely related to the particular technology, such as the mean time between computer "losses" of a tracked vehicle.[8] Useful models for both radio trilateration and dead-reckoning systems have been developed in recent years. However, with the exception of the independently developed introductory work by Perlman,[9] no effort has been devoted to modeling fixed-post sensor systems. It is the purpose of this paper to introduce and develop a class of models suitable for modeling one important error characteristic of fixed-post sensor systems.

In our terminology, a fixed-post sensor system is characterized by a number of proximity sensors situated at a fraction ρ of intersections in a city ($0 \leq \rho \leq 1$). Each sensor or "sharp signpost," utilizing one of several available technologies (narrow beam optical scanner, a microwave transmitter, or in-road magnets), detects the presence of a vehicle once it enters the intersection. In this way, precise position information is provided at each of the sensor-equipped intersections. Between passings of these intersections no additional position information is available. A vehicle traverses the streets of the city in a random manner (at least as viewed by the system controller). At any given time the vehicle's estimated location is the last sensor-equipped intersection through which the vehicle has passed. An important random variable characterizing system performance is the time (or traveled distance) between successive passings of sensors; this time corresponds to the time between accurate updates of vehicle location. The longer this time, the less accurate is the last recorded sensor-equipped intersection as an estimate for the vehicle's current location. Thus, a major purpose of this paper is to develop procedures for analyzing alternative layouts to select the one that minimizes some measure of time between sensor passings.

We develop the key ideas of this paper first in terms of one specific example. Then we generalize the example and we consider a range of other examples.

II. EXAMPLE: $\rho=1/8$, ROTATED SQUARE LATTICE

Consider the city depicted as an infinite regular grid of two-way streets shown in Figure 1. In this city, it is proposed to place fixed-post sensors at $\rho=1/8$ of all intersections, arranged in a rotated square lattice pattern as shown in the figure. Should such a sensor density and configuration provide adequate position update characteristics, then it would save the city 50 percent of the sensor-related cost of a $\rho=1/4$ system and 87.5 percent of that of a $\rho=1.0$ system.

We define the location update rate according to the distance (in block lengths) traveled between successive passings of sensors. Obviously this distance could be converted to time by employing the average speed of travel. Our key probabilistic (random) variable of interest is

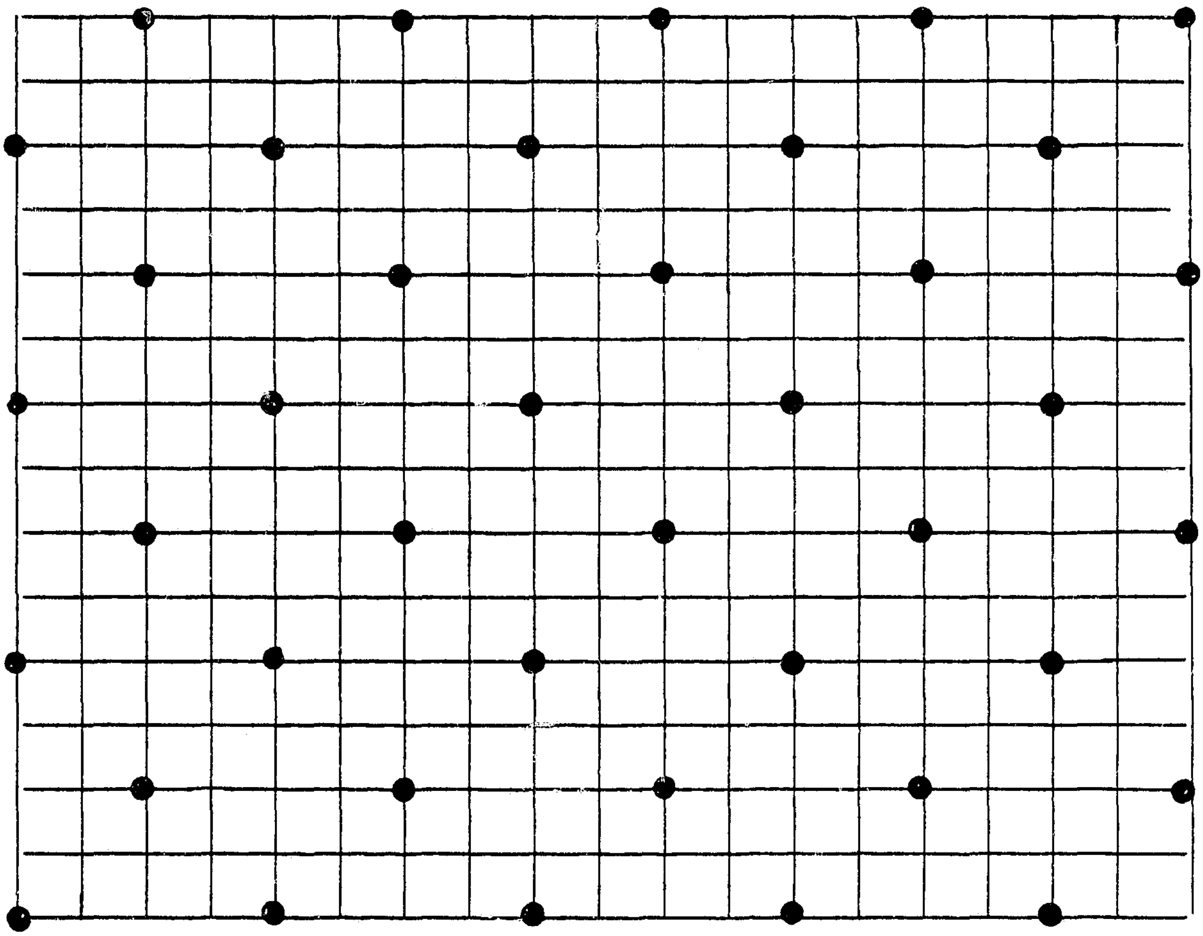
$\nu \equiv$ number of block lengths traveled between sensor passings

From examining Figure 1, we notice several properties of ν: a) it cannot be less than 4; b) it can become infinitely large; c) it can only take on *even* integer values (e.g., 4, 6, 8, ...).

Our evaluation of the lattice shown in Figure 1 will focus on the probabilistic behavior of ν. For instance, we will be interested in its expected or average value ($\bar{\nu} \equiv E[\nu]$), its variance ($\sigma_\nu^2 \equiv E[(\nu-\bar{\nu})^2]$), and in general in the probability that it exceeds some threshold value (say 20 blocks).

Figure 1

Rotated Square Lattice, $\rho = 1/8$



ρ = function of intersections having sensors

 corresponds to an intersection having a sonsor

A. Mean Number of Blocks Traveled Between Sensor Passings

To determine the probabilistic behavior of ν, we must specify the laws of movement of a vehicle whose position is to be "sensed" by the system. For the moment, we can just say that the vehicle moves in a random manner whose net outcome is equal coverage of all intersections in the grid. That is, at a random time, the next intersection to be visited by the vehicle is equally likely to be any of the intersections. If this is the case, then we have the (perhaps surprising) result that the expected value of ν is simply the inverse of the sensor density, regardless of the particular configuration of sensors. That is,

$$E[\nu] = \bar{\nu} = 1/\rho, \quad (1)$$

independent of the positions of sensors (assuming no more than one is at any particular intersection). Thus, in this example, $\bar{\nu} = 1/(1/8) = 8$ blocks (= average distance traveled between sensor passings). However, $\bar{\nu}$ would be equal to 8 blocks with any other configuration of the same number of sensors, even if their locations were selected randomly! We see this as follows: consider that the vehicle has driven very many block lengths N, thus passing through (roughly) N intersections. Since a fraction ρ of the intersections have sensors, the vehicle will have passed about ρN sensors. Thus, the average number of block lengths traversed between sensor passings is $N/\rho N = 1/\rho = \bar{\nu}$, as we have claimed.

Immediately we have an important evaluation criterion for fixed-post sensor systems. If the cost of the system varies linearly with the number of sensors, then the system performance (as measured by $\bar{\nu}$)

varies inversely with the cost. For instance, a halving of the sensor cost (implying a halving of the number of sensors) results in a doubling in the mean distance (time) between location updates (sensor passings). This simple relationship should be valuable in performing cost-effectiveness analyses of alternative fixed-post sensor systems.

B. Variance of the Number of Blocks Traveled Between Sensor Passings

The fact that $\bar{\nu}$ is invariant over all sensor configurations (at a fixed ρ) implies that we shall have to resort to other performance criteria to evaluate alternative sensor configurations at a fixed ρ. Throughout most of this paper we shall focus on the variance σ_ν^2, which is the most popular measure of the spread of a distribution about its mean value. In general, we would prefer configurations with smaller values of this variance. The situation is analogous to queueing theory, in which the mean wait in queue (W) is invariant under a large class of alternative queue disciplines, such as FIFO (first-in, first-out), LIFO (last-in, first out), or RANDOM; however, the variance of the waiting time in queue is quite sensitive to queue discipline.[10] To normalize for effects on the variance due solely to changes in ρ, we shall often use the *coefficient of variation* of the distance traveled between sensor passings,

$$c_\nu \equiv \frac{\sigma_\nu}{\bar{\nu}} = \rho\sigma_\nu \qquad (2)$$

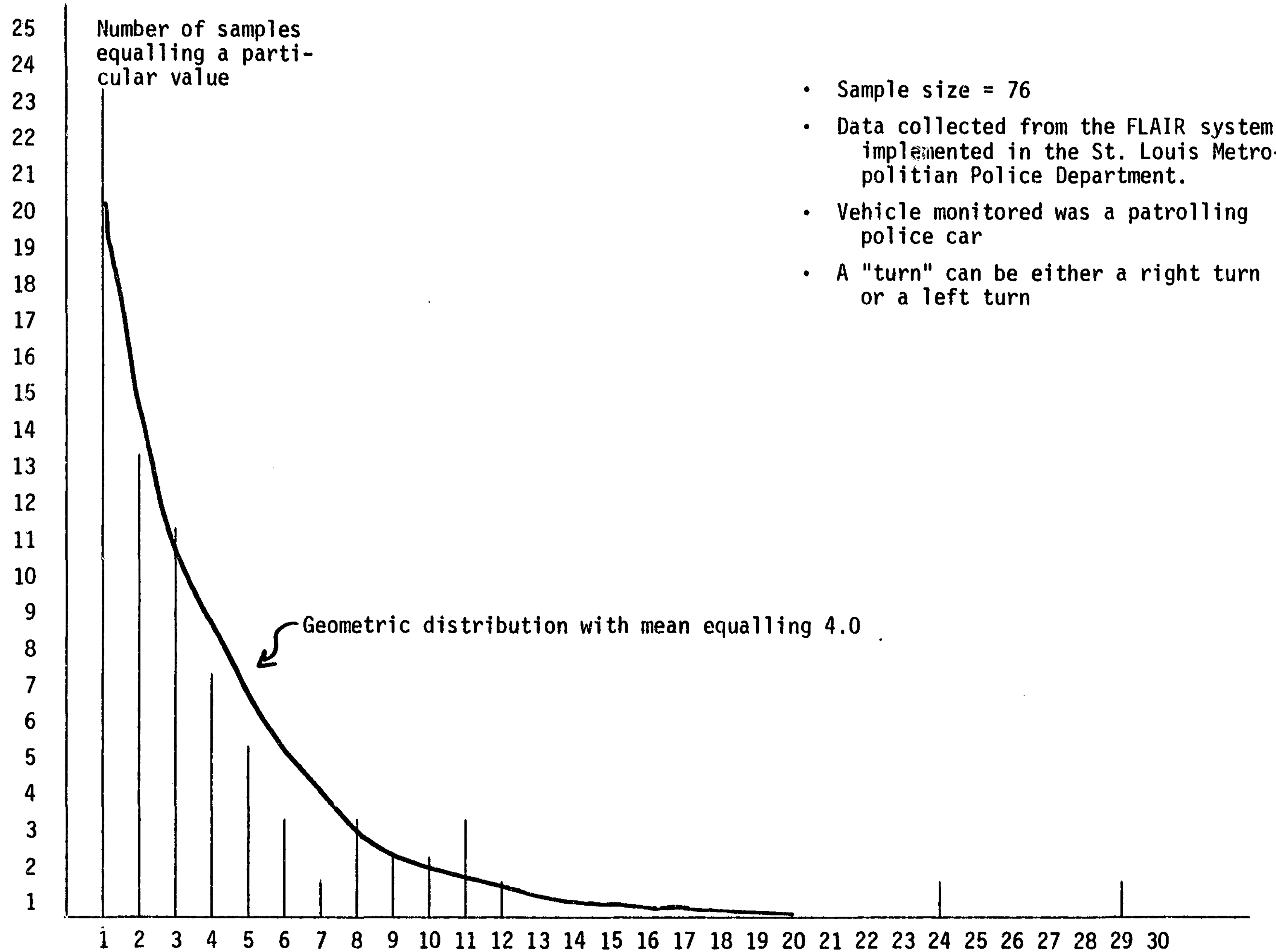
Such second moment measures are not entirely satisfactory, particularly if one is concerned with the probability of the distance between sensor passings exceeding some threshold. The models herein allow computation of the entire distribution, thus providing such threshold probabilities, however, the computation usually entails inversion of a complicated geometric transform.

C. Turning Probabilities

To obtain the variance of ν and, in general, its entire probability distribution, we must model the dynamics of vehicle turning behavior. In Figure 2, we show data from a limited vehicle-tracking sample obtained from the FLAIR System in St. Louis. Here, randomly selected patrolling police vehicles were tracked through 76 turns, and the number of blocks traveled between successive turns was recorded. As shown in Figure 2, the histogram depicting the number of blocks traveled between turns resembles closely the geometric distribution with mean approximately equal to 4.0. In applying a Chi-square test of significance (with 7 degrees of freedom), the Chi-square value is $\chi^2 = 2.20$, which is smaller than 90% of the equivalent χ^2 samples if the null hypothesis (the geometric distribution) were true. Thus, the histograms could reasonably have been generated by the hypothesized underlying geometric distribution. As is well known, the geometric distribution can arise from a sequence of independent (Bernoulli) trials, each trial having "success" probability equal to the inverse of the mean of the geometric distribution. The geometrically distributed random variable represents the number of trials (blocks, in our case) until the first success (turn). While histogram resemblance to the geometric distribution does not constitute proof of

Figure 2

Histogram of the Number of Blocks Travelled Between Turns



the "independent trials" assumption, it does suggest that such an assumption is plausible. This is analytically appealing because it implies we can analyze vehicle turning using discrete-state, discrete-trial Markov processes.[11]

First we specify a turning probability vector $\vec{P}_T = (P_S, P_R, P_L, P_U)$ where

P_S = probability that a vehicle will move straight through any particular intersection, without turning

P_R = probability that a vehicle will turn right at any particular intersection

P_L = probability that a vehicle will turn left at any particular intersection

P_U = probability that a vehicle will make a U-turn at any particular intersection

We assume that the turning behavior of the vehicle is determined entirely by $\vec{P}_T$, which is the same for all intersections, and, invoking the independent trials assumption, that turning behavior at any intersection is independent of all other turns.

For all of our work, we wish to select a form of $\vec{P}_T$ that both resembles actual moving vehicles and yields to relatively simple parametric analysis. Since U-turns are relatively rare, we set $P_U = 0$. For many vehicle types, the probability of turning right is approximately the same as turning left.[2] Thus, we set $\vec{P}_T = (1-2\beta, \beta, \beta, 0)$, reflecting an equal likelihood β $(0 \leq \beta \leq \frac{1}{2})$ of turning right or turning left and probability $1-2\beta$ of going straight ahead at any intersection. From the data reported earlier, it appears that the turn probability of a patrolling police car in St. Louis is approximately $2\beta = 1/4$ or $\beta = 1/8$. As the analysis will indicate, the variance σ_ν^2 depends significantly on the particular values assumed by β.

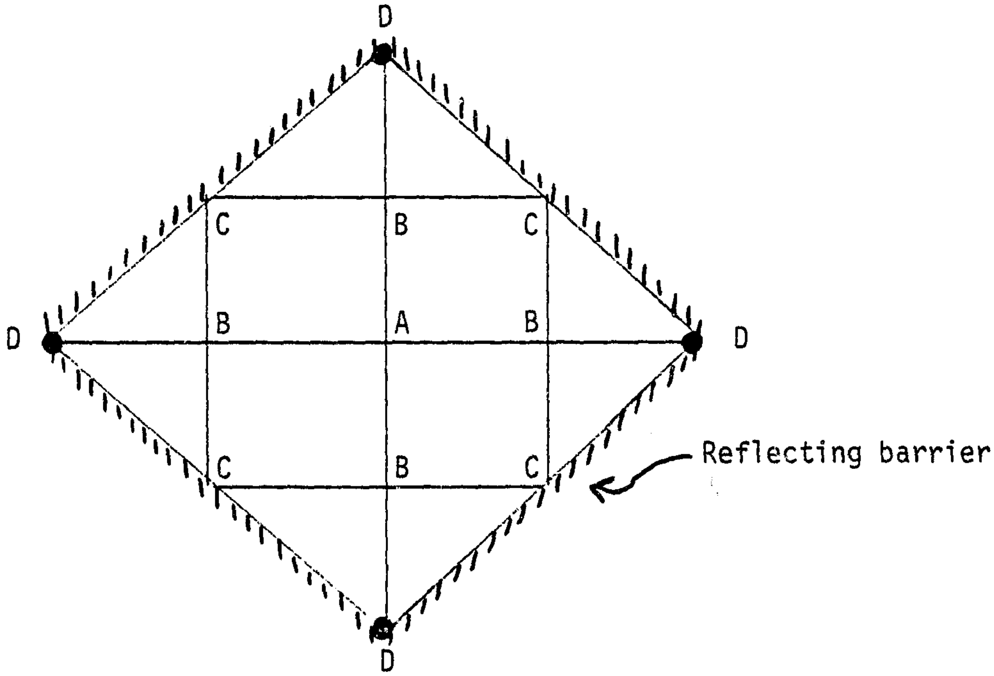
D. Lattice Kernel

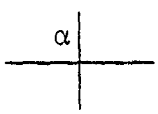
We wish to model the driving behavior over the infinite lattice of Figure 1 as a *finite*-state Markov process. To do this, we consider a *kernel* of the infinite lattice, shown on Figure 3. A kernel is a subset of the lattice having finite area that can be used to reconstruct the lattice; the lattice is composed of a countably infinite number of (identical) kernels. For any given lattice, the definition of a kernel is not unique, but depends in large part on the tractability of the resulting model. Any intersections or street links located on kernel boundaries "belong to" all kernels sharing that boundary. Thus, in the infinite lattice, kernels are not mutually exclusive (since they share boundary points) but they are collectively exhaustive. In counting sensors per kernel and vehicle traversals, care must be taken to apportion sensors and movements on the boundaries equally to all appropriate contiguous kernels.

A kernel contains a finite number of intersections, which in modeling can usually be reduced further by symmetry considerations. Of the 13 intersections shown in Figure 3, there are only four different types, labeled A, B, C, and D. The four B (or C or D) intersections are clearly equivalent because of symmetry.

Figure 3

Lattice Kernel for Rotated Square Lattice, $\rho = 1/8$





denotes a "type α" intersection

By appropriately apportioning intersections on the kernel boundary, we can verify that $\rho=1/8$. We let n_α = number of type-α intersections in the kernel and N = number of equivalent kernel intersections. By "equivalent kernel intersections," we mean the total number attributable to the kernel after apportioning boundary intersections among contiguous kernels. Clearly for our example

$$N = n_A + n_B + \tfrac{1}{2}n_C + \tfrac{1}{4}n_D,$$

where the factors ½ and ¼ arise because type C and type D intersections are shared with one and three additional kernels, respectively.

The boundary of a kernel acts as a *reflecting barrier* in the following sense: any driving path leaving the kernel from a particular intersection type and in a particular direction must enter a known-type intersection in a contiguous kernel. In this sense, then, driving to an adjacent kernel is equivalent to reflecting back into the original kernel to an intersection of known type. In our example (Figure 3) any driving path leaving the kernel (and not including a sensor-equipped intersection) must leave through a type C intersection and next enter a type B intersection in an adjacent kernel. Thus, all exits from C intersections result in entrances to B intersections. For this particular example, the reflecting back has an analogue in optics: each entry to C on the kernel is reflected at a 45° angle--the same as the angle of incidence--to the next B intersection (regardless of the values assumed by $\vec{P}_T$).

E. Markov Process

By examining the kernel and invoking the turn probabilities, we can generate a finite-state Markov process governing the vehicle's movement. This process is shown in Figure 4, with the states of the process defined as follows:

- A: the current intersection is type A
- C: the current intersection is type C
- BA: the current intersection is type B and the most recent was type A
- BC: the current intersection is type B and the most recent was type C
- T: the current intersection is type T, containing a sensor (T denotes trap state)

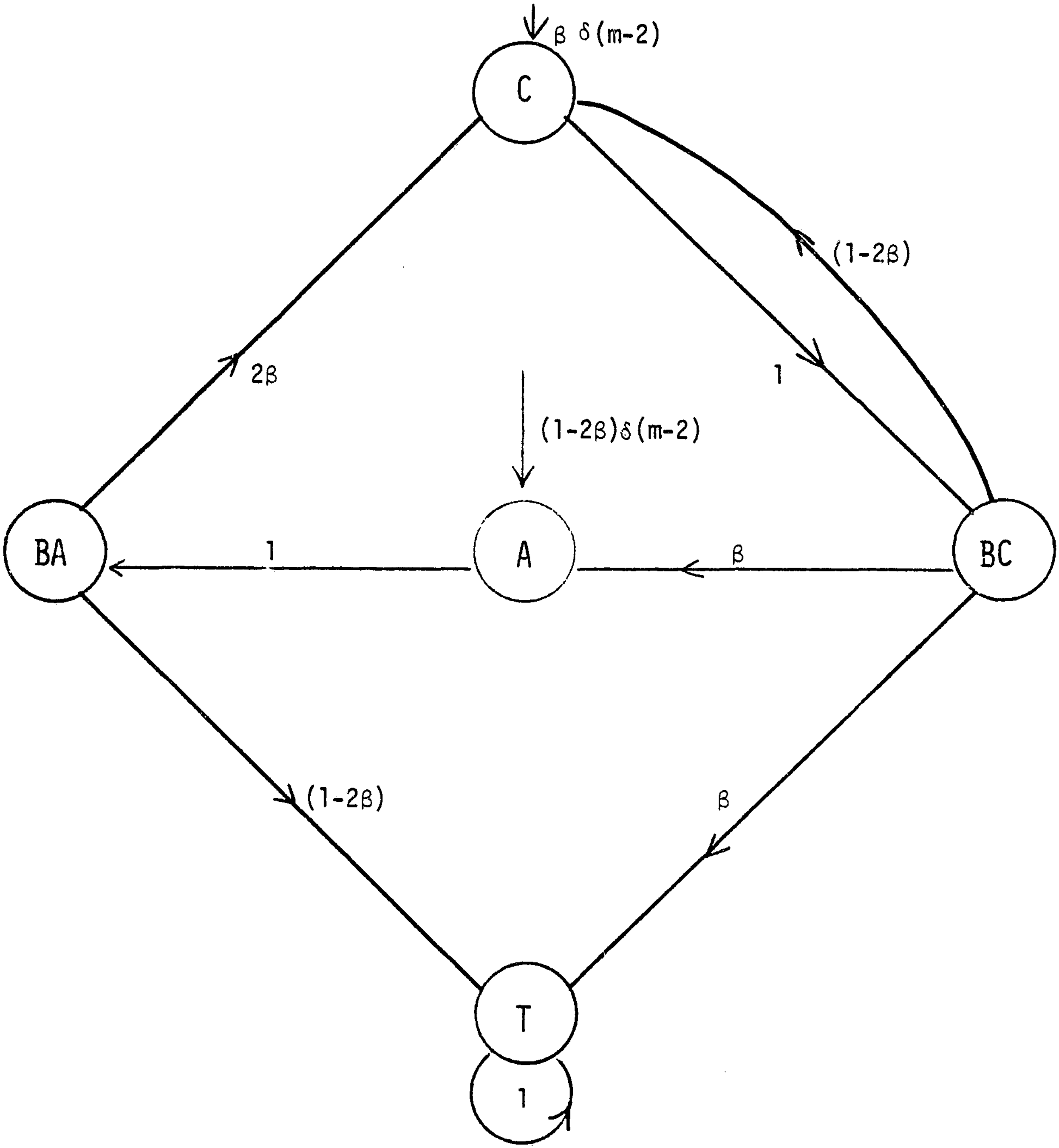
Since the direction of entry to a type B intersection influences the outcomes of leaving the intersection, the state depiction in this case includes the most recent state (intersection type). Thus, the process is a *second-order* Markov process.

For a general kernel, the movement to the next intersection type depends not only on the current intersection type but also on the direction of entry. Thus, in general, the Markov process implied by a kernel will be a second-order process.

The state-to-state transition probabilities for the example are shown on the state transition diagram. We give examples of their derivation: a) any entrance to state A must be followed by a type B intersection, thus the one-step transition probability from A to BA is unity; b) any entrance to state C must be followed by a reflection to

Figure 4

Markov State Transition Diagram for $\rho = 1/8$



β = probability of turning $\binom{\text{right}}{\text{left}}$ at an arbitrary intersection a type B intersection, thus the unity transition probability from C to B; c) any entrance to state BC will be followed by an intersection having a sensor (a type T intersection) with probability β, thus the β probability from BC to T. Since we are focusing on the event of passing the next sensor, given that the vehicle has just passed one, we define state T to be an *artificial trap state.* We are interested in the number of transitions the Markov process undergoes *until* entering the trap state. *Each transition corresponds to a block length traversed,* so the number of transitions until entry to the trap state is equivalent to the number of blocks traveled between sensor passings.

F. Probabilistic Starting

Consider the process when it starts to undergo transitions, corresponding to the vehicle leaving a type T intersection. Referring again to Figure 3, we see that state B is the first state entered, but from D (not C or A). We have no state TB. The second state entered is C (with probability 2β) or A (with probability $1-2\beta$). We can summarize this behavior by saying that after a *delay* of two transitions, the process starts in C with probability 2β or A with probability $1-2\beta$. In general, we characterize the random starting condition with a delayed starting state probability vector $\underline{\pi}(k) = (\pi_1(k), \pi_2(k), \ldots)$, where

$\pi_i(k) \equiv$ probability that the process starts in state i at time k (i.e., immediately after the kth transition)

The vector $\underline{\pi}(k)$ depends, in general, on the particular sensor configuration being analyzed and on the turn probability β. In most applications, it is convenient to use k=2.

To determine $\underline{\pi}(k)$ for an arbitrary kernel, suppose we know that a sensor somewhere on the infinite lattice has just been passed. That is, we have selected a sensor at random from the population of sensor passings. Due to steady state spatial homogeniety, the probability measure for the selected sensor is uniform over all the sensors. Moreover, the direction of exit from the intersection just passed is equally likely to be any of the four possible directions. Relating these observations to a kernel, each of the possible exit routes from a sensor-equipped intersection *that remains within the kernel* represents an equally likely starting condition.[3] Exit routes that lie on kernel boundaries are, by apportioning arguments above, half as likely as those lying entirely within a kernel. These observations, used in conjunction with the state depiction for the kernel, are sufficient to determine $\underline{\pi}(k)$. To include $\underline{\pi}(k)$ in a state transition diagram, we use the 0-1 operator,

$$\delta(k-j) \equiv \begin{cases} 1 & \text{if } k=j \text{ otherwise} \\ 0 & \end{cases}$$

As an example, we denote $\pi_A(2) = (1-2\beta)$ by writing $(1-2\beta)\delta(k-2)$ next to an exogenous input branch to state A (as shown in Figure 4).

G. Number of State Occupancies

The Markov process of a lattice kernel, such as the one shown in Figure 4, is a *transient process* with state T, the trap state, having unity probability of occupancy after infinitely many transitions. Transforming the lettered states to an index i=1,2,...,M, with state M being the trap state, we define the counting random variables

ν_{ij} ≡ number of occupancies of state j in an infinite number of transitions, given the system started in state i

ν_i ≡ number of occupancies of transient states in an infinite number of transitions, given the system started in state i

Now the mean number of transitions until entering the trap state, given the system started in state i, is

$$\bar{\nu}_i = \sum_{j=1}^{M-1} \bar{\nu}_{ij} \tag{3}$$

By using state indicator random variables, one can verify[11] that the second moment of ν_i can be obtained simply from the first moments of ν_{ij},

$$\overline{\nu_i^2} = \sum_{j=1}^{M-1} \bar{\nu}_{ij} \, \bar{\nu}_j - \bar{\nu}_i \tag{4}$$

Since the process undergoes a delayed starting according to $\underline{\pi}(k)$, corresponding to a delay of k transitions, the variance for the quantity of interest ν is

$$\sigma_\nu^2 = \sum_{i=1}^{M-1} \overline{\nu_i^2} \, \pi_i(k) - [\frac{1}{\rho} - k]^2 \tag{5}$$

This fundamental result is used in the remainder of the paper to compute the variance of the number of blocks traveled between sensor passings.

To obtain the matrix of mean numbers of state occupancies,

$$\underline{N} \equiv (\bar{\nu}_{ij}),$$

we need only work with the one step transition probabilities,

$p_{ij} \equiv$ probability the next transition is to state j, given that the process is currently in state i.

If we define the transient transition probability matrix,

$\underline{P}_{-} = (p_{ij})$ = one-step transition probability matrix with the column and row associated with the trap state *removed*; i,j= 1, 2, ..., M-1,

then it is well known[11] that

$$\bar{N} = [I-P_{-}]^{-1} \tag{6}$$

We now apply these results to our continuing ρ=1/8 example. Inversion of the transient transition probability matrix according to Equation (6) yields

$$\underline{N} = (\bar{\nu}_{ij}) = \frac{1}{1-(1-2\beta)-2\beta^2} \begin{array}{c} \\ A \\ BA \\ C \\ BC \end{array} \begin{array}{c} \begin{array}{cccc} A & BA & C & BC \end{array} \\ \begin{bmatrix} 2\beta & 2\beta & 2\beta & 2\beta \\ 2\beta^2 & 2\beta & 2\beta & 2\beta \\ \beta & \beta & 1 & 1 \\ \beta & \beta & 2\beta^2+1-2\beta & 1 \end{bmatrix} \end{array} \tag{7}$$

Recalling that ν is the number of transitions (blocks) between entries to the trap state T, and that a delay of 2 occurred before starting,

$$\nu = \begin{cases} 2 + \nu_A & \text{with conditional probability } 1/3 \ (=\pi_A\ (2)) \\ 2 + \nu_C & \text{with conditional probability } 2/3 \ (=\pi_C\ (2)) \end{cases}$$

Thus, for instance,

$$\bar{\nu} = 2 + 1/3\bar{\nu}_A + 2/3\bar{\nu}_C \qquad (=1/\rho=8)$$

or

$$\overline{\nu^2} = E[(2 + \nu_A)^2]1/3 + E[(2 + \nu_C)^2]2/3$$

Carrying out the computations implied by Equations (3), (4), and (5), we obtain for the variance

$$\sigma_\nu^2 = 2 \cdot \frac{4 + 2\beta - 6\beta^3}{\beta(1-\beta)^2} - 36 \qquad (8)$$

Interestingly, σ_ν^2 increases without bound as β becomes small. Intuitively this is explained by the fact that as the vehicle is less and less likely to turn, once it does turn away from a street having sensors, its position is likely to go undetected for a very long time. (Recall that regardless of the value of β, $0<\beta\leq 1/2$, the mean number of blocks between detections remains fixed at $\bar{\nu}=8$.)

A question of interest is the following: "Is there a value of the turn probability β that minimizes the variance σ_ν^2?" One can answer this question by differentiating (8) with respect to β and setting the result equal to zero; the resulting equation is

$$3\beta^4 - 4\beta^3 - 2\beta^2 + 4\beta - 1 = 0$$

which factors as follows

$$(3\beta-1)\ (\beta^3-\beta^2-\beta+1) = 0$$

indicating that a minimum[4] is reached at $\beta=1/3$. The second factor has no roots in the interval $0\leq\beta\leq 1/2$, and thus $\beta=1/3$ yields an absolute minimum, which is

$$\sigma_\nu^2\ \Big]_{\beta=1/3} = 24$$

One can speculate that the optimal layout of sensors (optimal in the sense of minimizing σ_ν^2) will depend on the driving behavior of the vehicles, as reflected by β. Indeed, as later examples will verify, this conjecture turns out to be true.

Discrete transform theory can be used to determine the transforms of the probability mass function of the time to trap.[11] If we define

$f(n) \equiv$ Prob {system enters trap state on transition n, given random starting on transition k according to $\underline{\pi}(k)$},

then the discrete or geometric transform of f(n) is

$$f^g(z) \equiv \sum_{n=0}^{\infty} f(n) z^n \qquad |z|<1$$

The resulting transform for our example is

$$f^g(z) = z^2\ \frac{z^2(1-4\beta+6\beta^2) + z^4[4\beta^2(1-2\beta)-(1-2\beta)^3]}{1-z^2(1-2\beta)-z^4 2\beta^2} \tag{9}$$

It is instructive to set β equal to a particular value in (9) and then to invert; in this way we obtain an intuitive idea of system behavior for a particular value of the turn probability. Since we have already determined that σ_ν^2 is minimized when β=1/3, we set β=1/3, in which case (9) reduces to

$$f^g(z) = \frac{1/3z^4}{1-2/3z^2} \qquad [\beta=1/3] \tag{10}$$

This result can easily be inverted by noting that

$$f^g(z) = 1/3z^4(1+2/3z^2+4/9z^4+\ldots).$$

Thus,

$$f(n) = \begin{cases} 1/3(2/3)^{(n-4)/2} & n = 4,6,8,10,\ldots \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

This relatively simple result has an intuitive interpretation: the Markov process is a periodic process that offers a "1/3" probability of trapping on each even transition (starting on the 4th transition). In terms of the moving vehicle, as the result of each odd-numbered trial (prior to trap) the vehicle is situated at a type B intersection; regardless of the direction of entry to the intersection, there is a 1/3 probability of choosing the sensor-equipped intersection (type T) as a result of the next trial. Thus, Equation (11) is simply a modified geometric probability mass function which says that for the system to enter the trap state for the first time on the n^{th} trial (block) there must be (n-4)/2 "failures" (each occurring independently with probability 2/3) followed by a success on trial n (which occurs independently with probability 1/3).

If we select $\beta=1/2$ (implying that the vehicle *always* turns either left or right at an intersection), Equation (9) becomes

$$f^g(z) = \frac{1/2z^4}{1-1/2z^4} \tag{12}$$

Straightforward inversion yields

$$f(n) = \begin{cases} (1/2)^{n/4} & n = 4,8,12,\ldots \\ 0 & \text{otherwise} \end{cases} \tag{13}$$

This result, too, has an intuitive interpretation which is easy to deduce by considering possible vehicular paths through the lattice kernel.

For most lattice kernels, the transform inversion required to obtain f(n) is difficult to perform parametrically as a function of β. Thus, particular numerical values of β must be used in conjunction with partial fraction expansion.

III. RANDOM PLACEMENT OF SENSORS

One can compare the variance σ_ν^2 obtained for any particular sensor configuration and turn probability β with that obtained from a totally unplanned system. By "unplanned," we mean that sensor locations are determined entirely at random, subject to the requirement that the average density of sensors remains fixed at ρ. We will discover that some planned systems are, in this respect, worse than unplanned systems.

In modeling an unplanned placement of sensors, we assume that any particular intersection will contain a sensor with probability ρ. The placement (or nonplacement) of a sensor at an intersection is independent of the locations of nearby (or any other) sensors. Thus, a moving vehicle, each time it enters an intersection, happens upon a sensor with probability ρ. Successive intersections give rise to successive independent Bernoulli trials each having "success" probability ρ. Note that the outcomes of these Bernoulli trials are independent of the turn probability β.[5]

The random variable ν, the number of blocks traversed between sensor passings, is now the time until the first "success" in a sequence of independent Bernoulli trials. As is well-known, its probability mass function is geometric,

$$P\{\nu=n\}=f(n)=\rho(1-\rho)^{n-1} \qquad n = 1,2,3,\ldots \qquad (14)$$

The Z-transform, mean, and variance of the geometric distribution are well known,

$$f^{g}(z) = \frac{\rho z}{1-(1-\rho)z} \qquad (15)$$

$$\bar{\nu} = 1/\rho \qquad \text{(as expected)} \qquad (16)$$

$$\sigma_{\nu}^{2} = \frac{1-\rho}{\rho^{2}} \qquad (17)$$

We emphasize that these results are not dependent on the turn probability β.

As discussed earlier, an important index of randomness of any distribution is the ratio of its standard deviation to its mean, or *coefficient of variation*; here, this quantity is

$$c_{v} = \frac{\sigma}{\text{Mean}} = \sqrt{1-\rho} \qquad (18)$$

Equation 18 represents a useful yardstick against which we can evaluate proposed sensor configurations. Any configuration yielding a coefficient of variation value greater than $\sqrt{1-\rho}$ could be improved by replacing the planned configuration with an entirely random placement of sensors.

As an example of the use of (18), consider again the $\rho=1/8$ example of the previous section. At $\rho=1/8$, a random placement of sensors will yield

$$c_{v}\Big]_{\text{random}} = \sqrt{1-1/8} \simeq 0.9354$$

For arbitrary β, the planned configuration of the previous section yields

$$c_v \Big]_{planned} = 1/8 \sqrt{2 \frac{4 + 2\beta - 6\beta^3}{\beta(1-\beta)^2} - 36} \qquad (19)$$

These two functions are plotted in Figure 5. As seen in the figure (and derived previously), the minimum value for the planned system occurs at β=1/3,

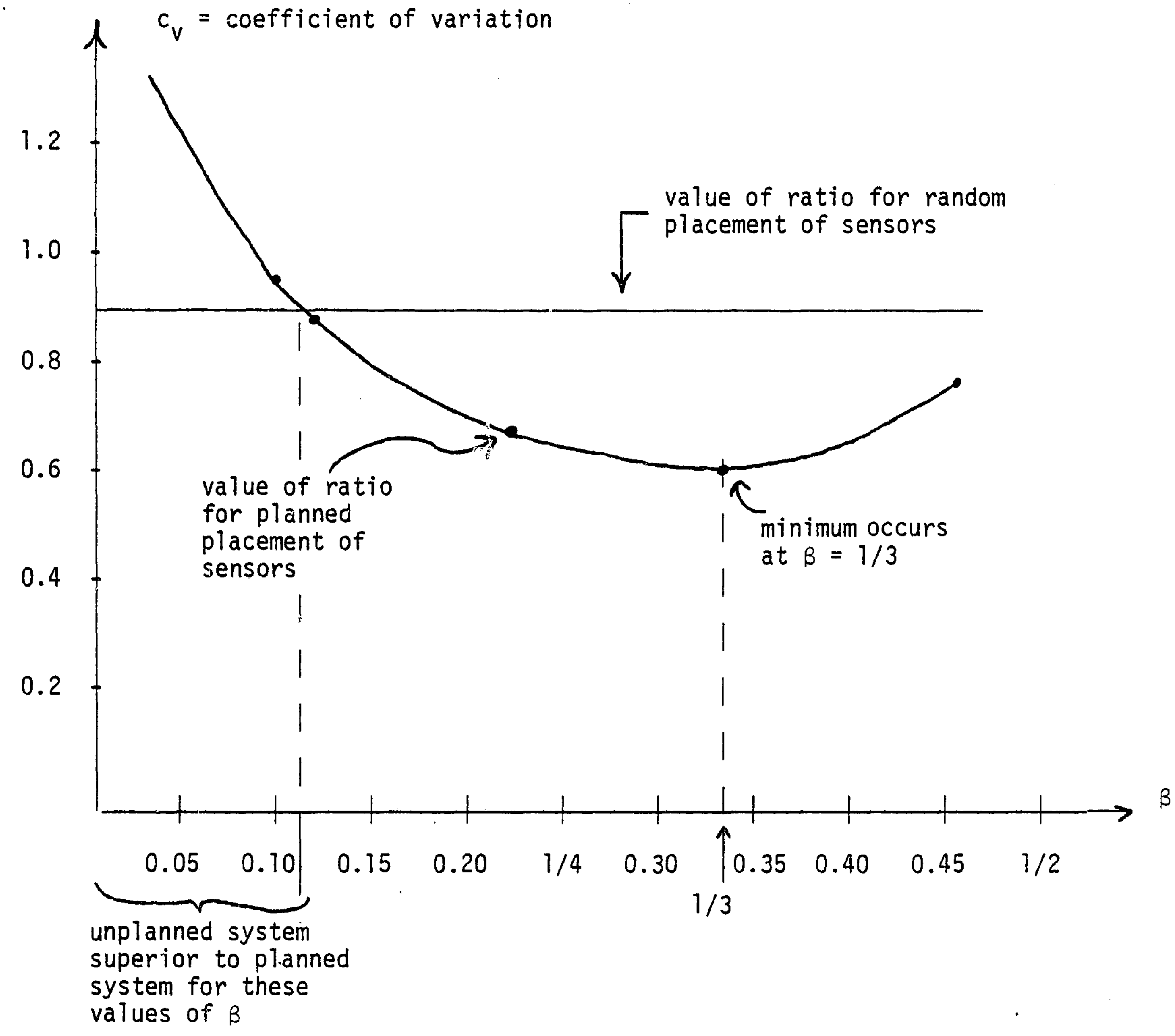
$$c_v \Big]_{\substack{planned \\ =1/3}} = \frac{\sqrt{6}}{4} \simeq 0.6124$$

representing considerably better performance than the unplanned system. However, the planned system deteriorates without bound as β becomes small, with the unplanned system becoming superior for values of β below approximately 0.119. Intuitively this can be explained by the probabilistic absence in the unplanned system of indefinitely long straight "corridors" having no sensors; it is the presence of such corridors in the planned system that causes poor system performance for small β.

Figure 5

Comparison of Planned and Unplanned System

(ρ= 1/8 example)



IV. Analysis of the Case $\rho=1/4$

We now utilize the methods of the previous sections to analyze several alternative configurations having an average of one sensor every four intersections (i.e., $\rho=1/4$). This case is important in applications, yielding a 75-percent sensor-related cost savings over a $\rho=1$ system and a 50-percent savings over a $\rho=1/2$ system. Also, the $\rho=1$ and $\rho=1/2$ systems have $\sigma_{\nu}^{2}=0$, thus negating the need for Markov analysis.

First we describe the sensor layouts to be analyzed, then we develop the corresponding Markov models, and finally we compare system performance using the coefficient of variation as the performance measure.

A. Six Sensor Layouts Having $\rho=1/4$

The sensor layouts to be analyzed are as follows:

(1) Regular Square Lattice. This is the "most natural" sensor configuration, with every other street (both North-South and East-West) having a sensor at every other intersection (Figure 6). Infinitely long corridors having no sensors exist in both the North-South and East-West directions.

(2) Diagonal "Walls of Sensors". This configuration places sensors in 45-degree-angle "walls" extending from "Southwest" to "Northeast" throughout the city (Figure 7).

(3) Diamond Lattice. This system combines elements of (1) and (2) above, yielding infinitely long corridors having no sensors only in the North-South direction (Figure 8).

Figure 6

Regular Square Lattice of Sensors, $\rho = 1/4$

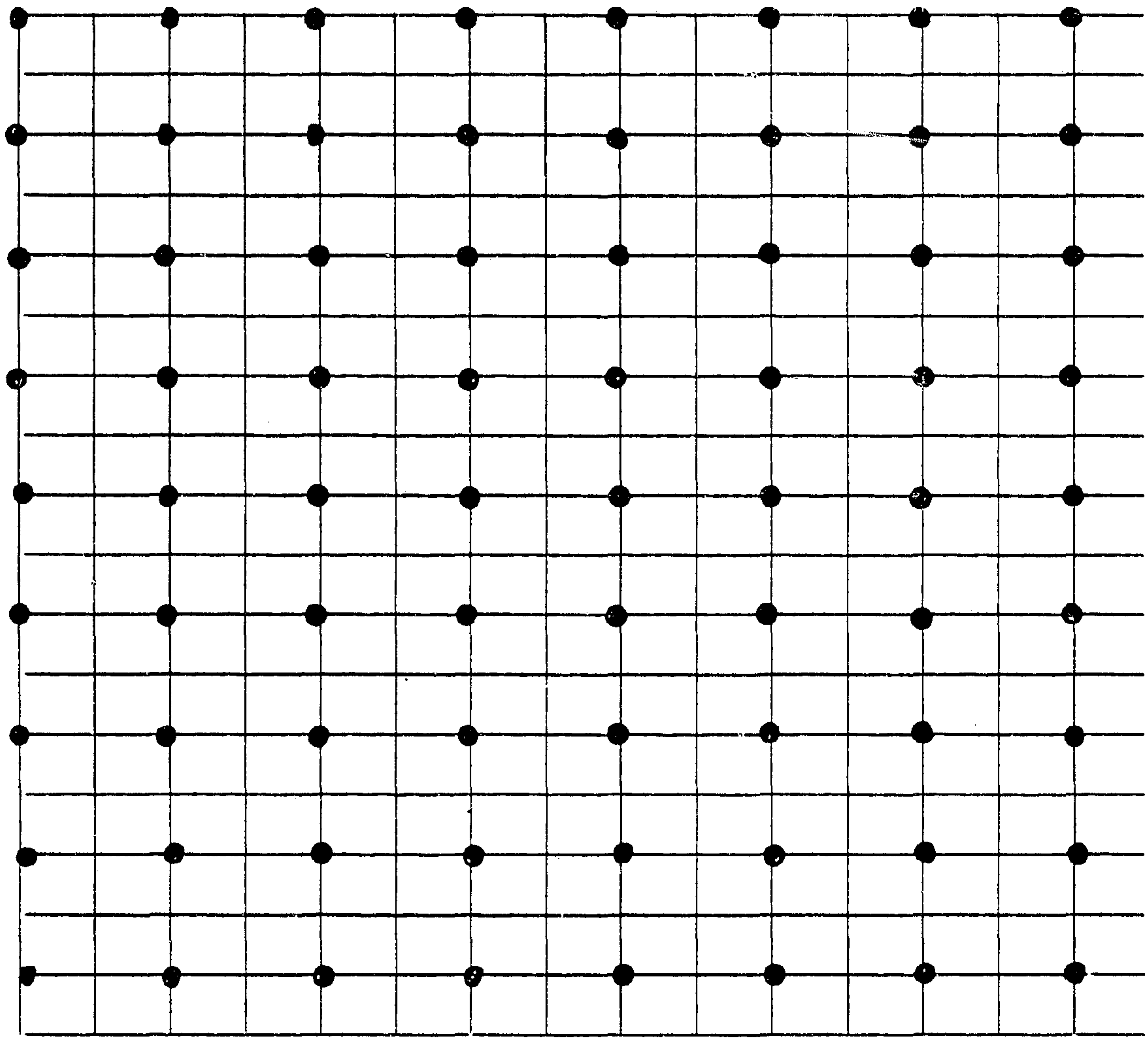


Figure 7

Diagonal "Walls of Sensors", $\rho = 1/4$

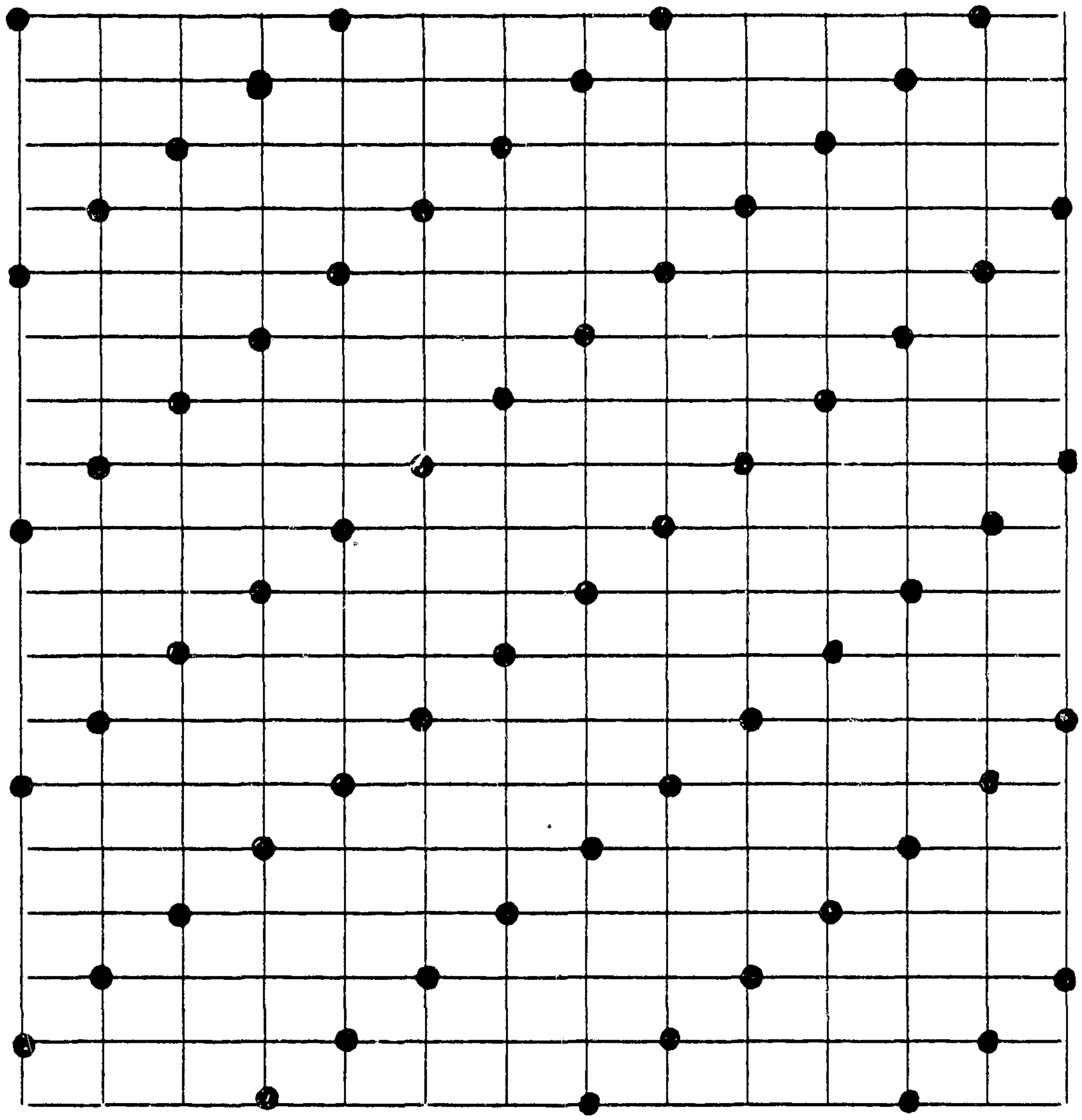
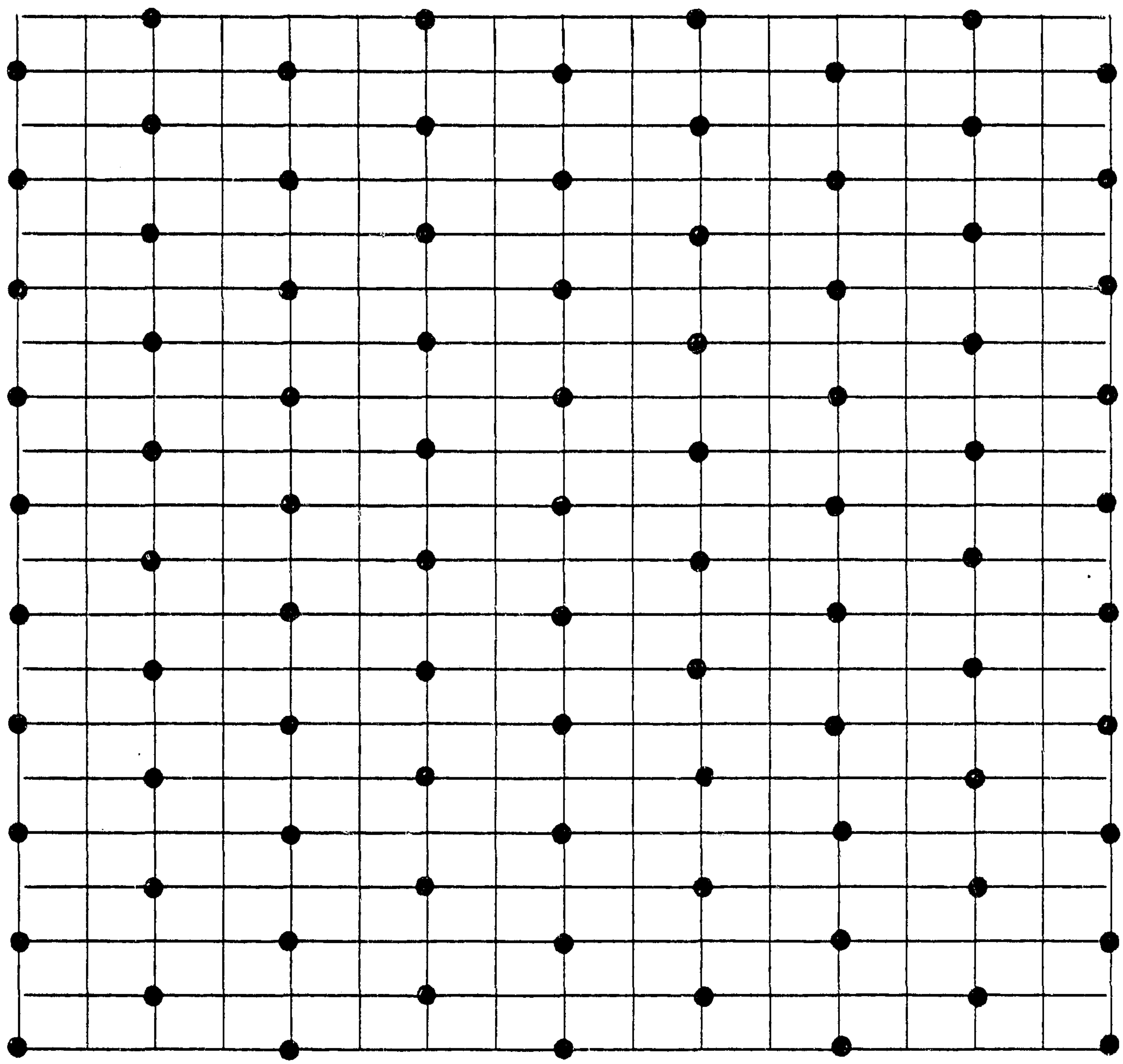


Figure 8

Diamond Lattice of Sensors, $\rho = 1/4$



(4) Vertical "Walls of Sensors". This layout places sensors on every intersection of every fourth North-South street (Figure 9).

(5) Square-Center System. This system places sensors repeatedly in a rotated-square configuration, with one additional sensor in the center of the square (Figure 10).

(6) Random. This is the familiar unplanned system in which each intersection has a sensor with probability $\rho=1/4$. Using Equation (18), the coefficient of variation for this case is

$$c_v = \sqrt{3/4} \approx 0.8660 \qquad (20)$$

B. Lattice Kernels and Associated Markov Processes

Using the ideas of the previous sections, it is fairly straightforward to construct lattice kernels and associated Markov processes for each of the five deterministic sensor configurations above. In Figures 11-15 are shown all five lattice kernels and in Figures 16-19 are shown four associated Markov state transition diagrams (the square-center case is omitted due to its large number of states). The random starting conditions are shown on each of the state transition diagrams using the $\delta(k)$ notation.

Figure 9

Vertical "Walls of Sensors" Configuration $\rho = 1/4$

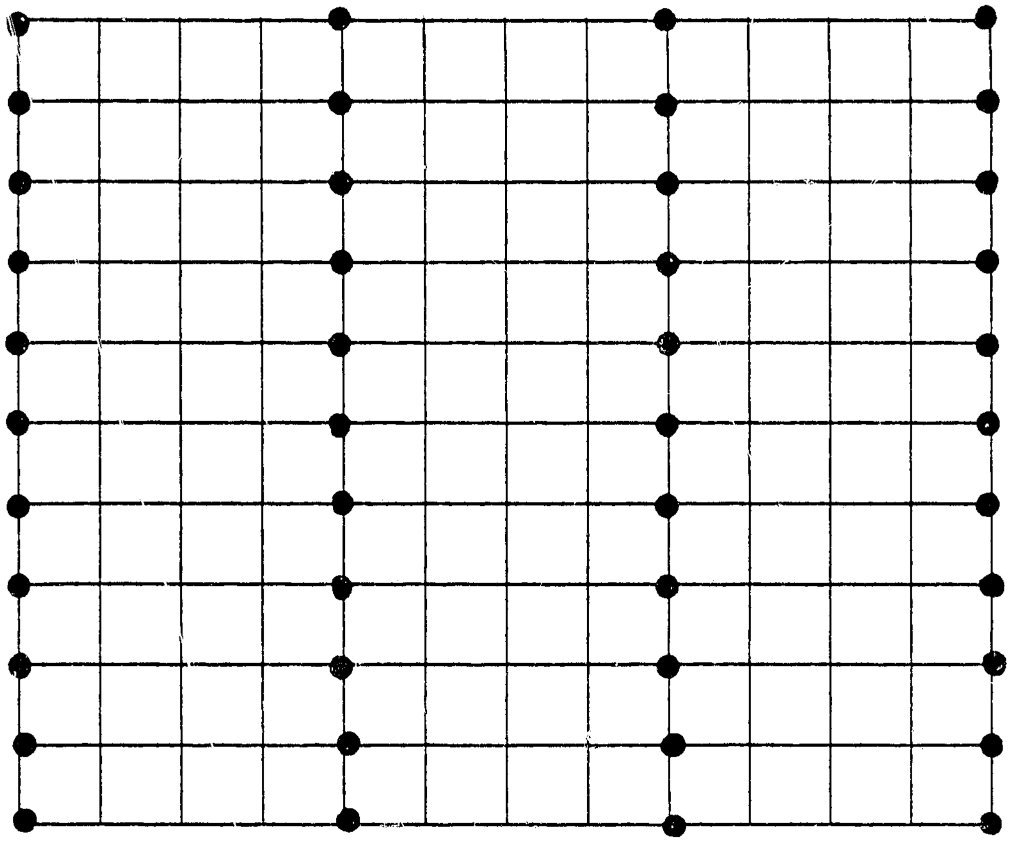


Figure 10

Square-Center Lattice $\rho = 1/4$

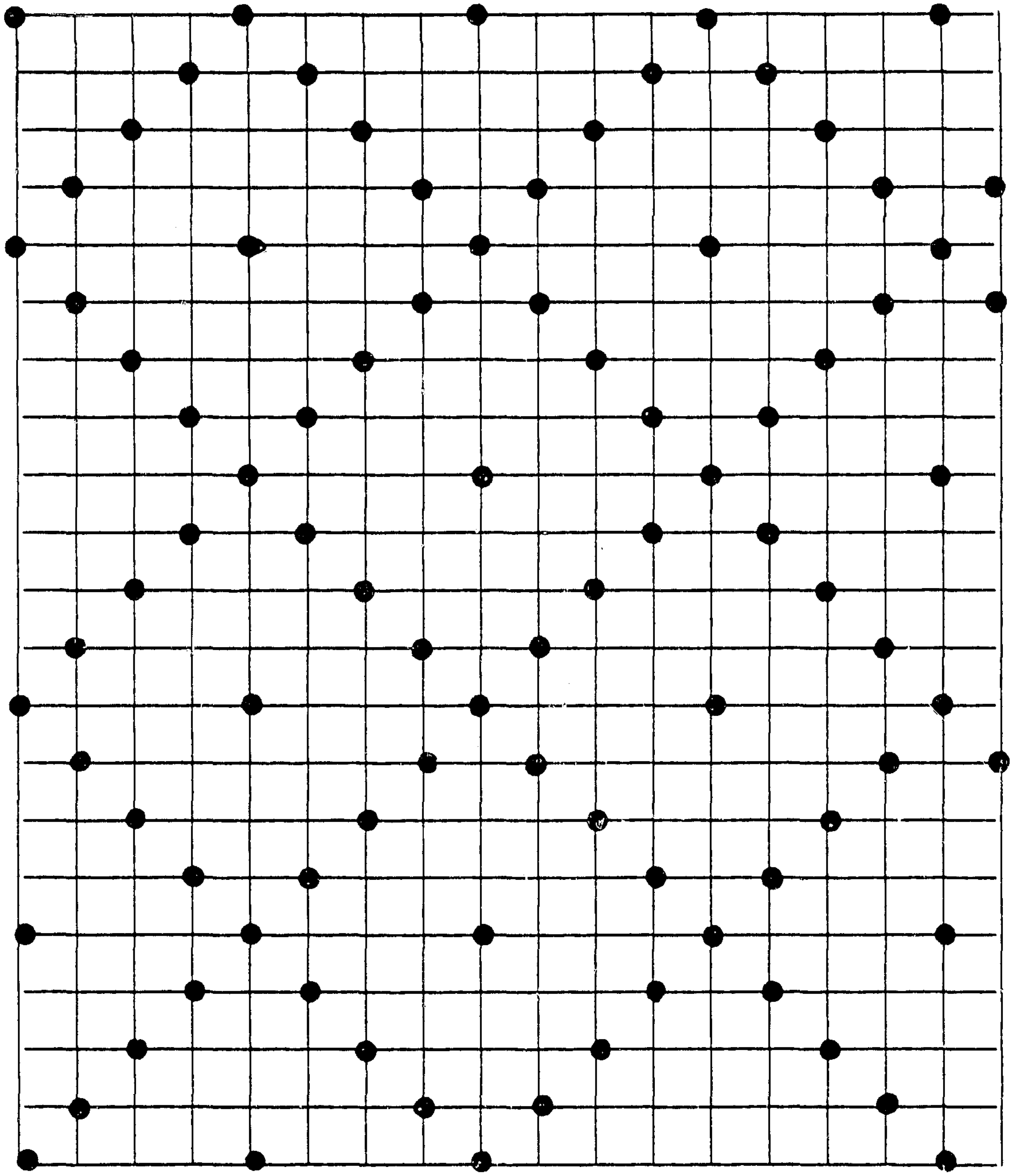


Figure 11

Lattice Kernel for ρ = 1/4 Regular Square Lattice

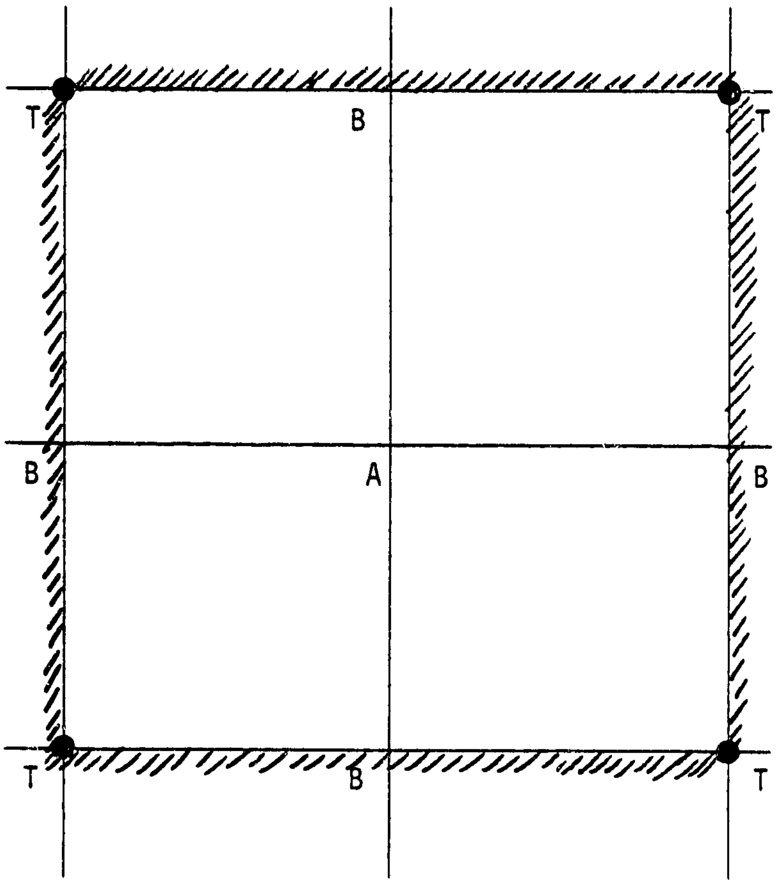


Figure 12

Lattice Kernel for ρ = 1/4 Diagonal "Walls of Sensors"

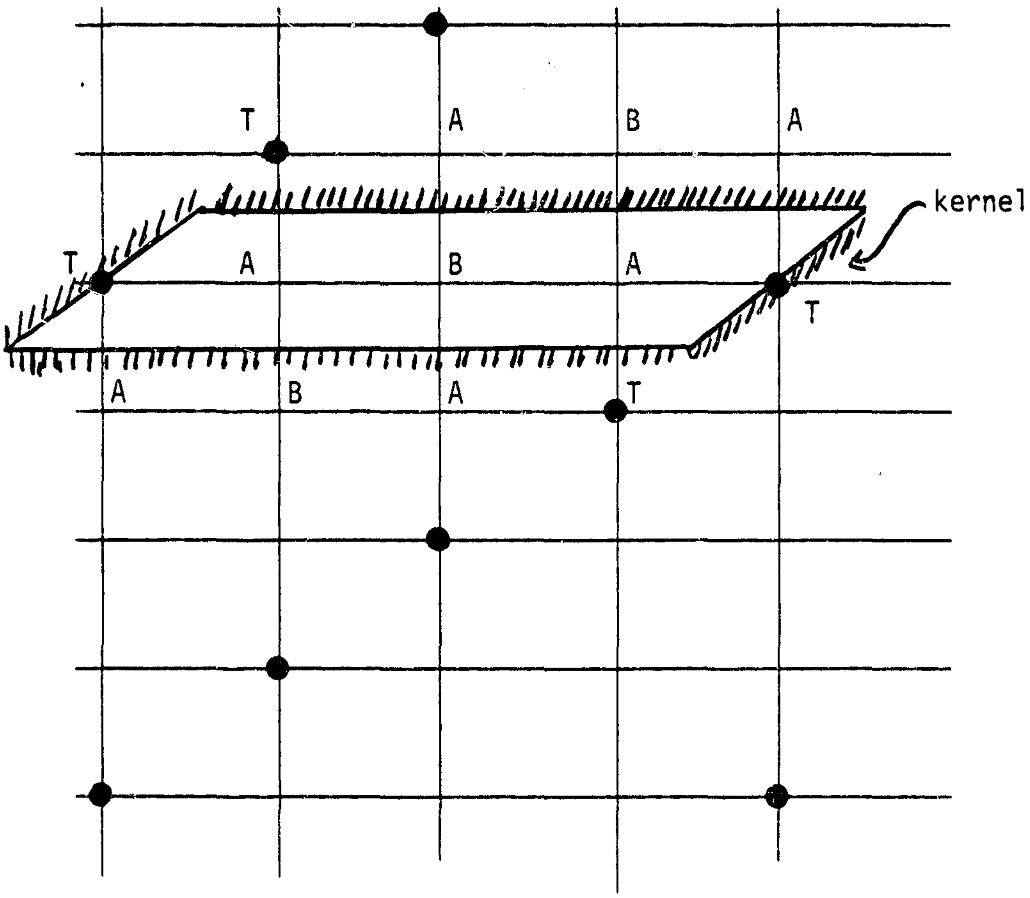


Figure 13

Lattice Kernel for Diamond Lattice, $\rho = 1/4$

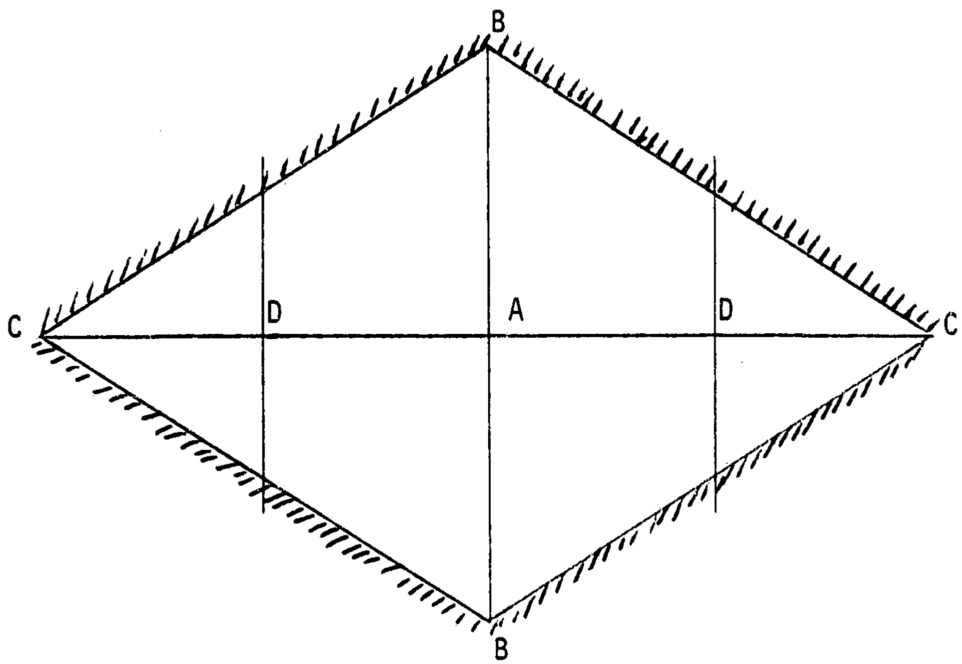


Figure 14

Lattice Kernel for Vertical "Walls of Sensors," ρ = 1/4

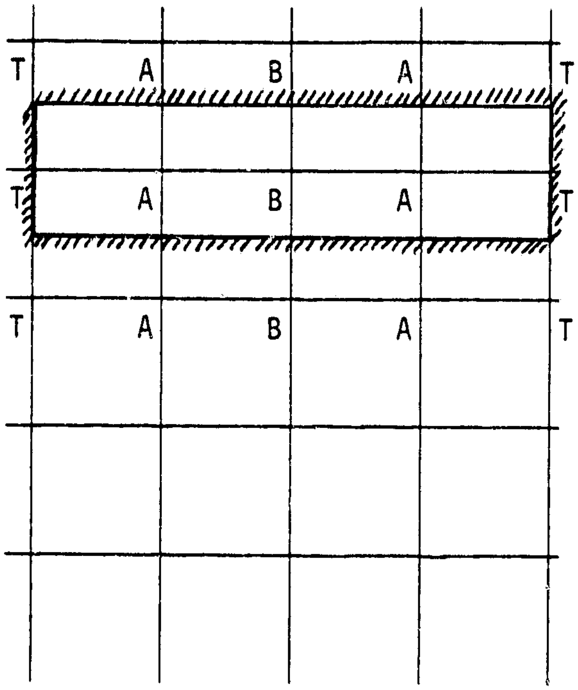


Figure 15

Lattice Kernel for Square-Center Lattice

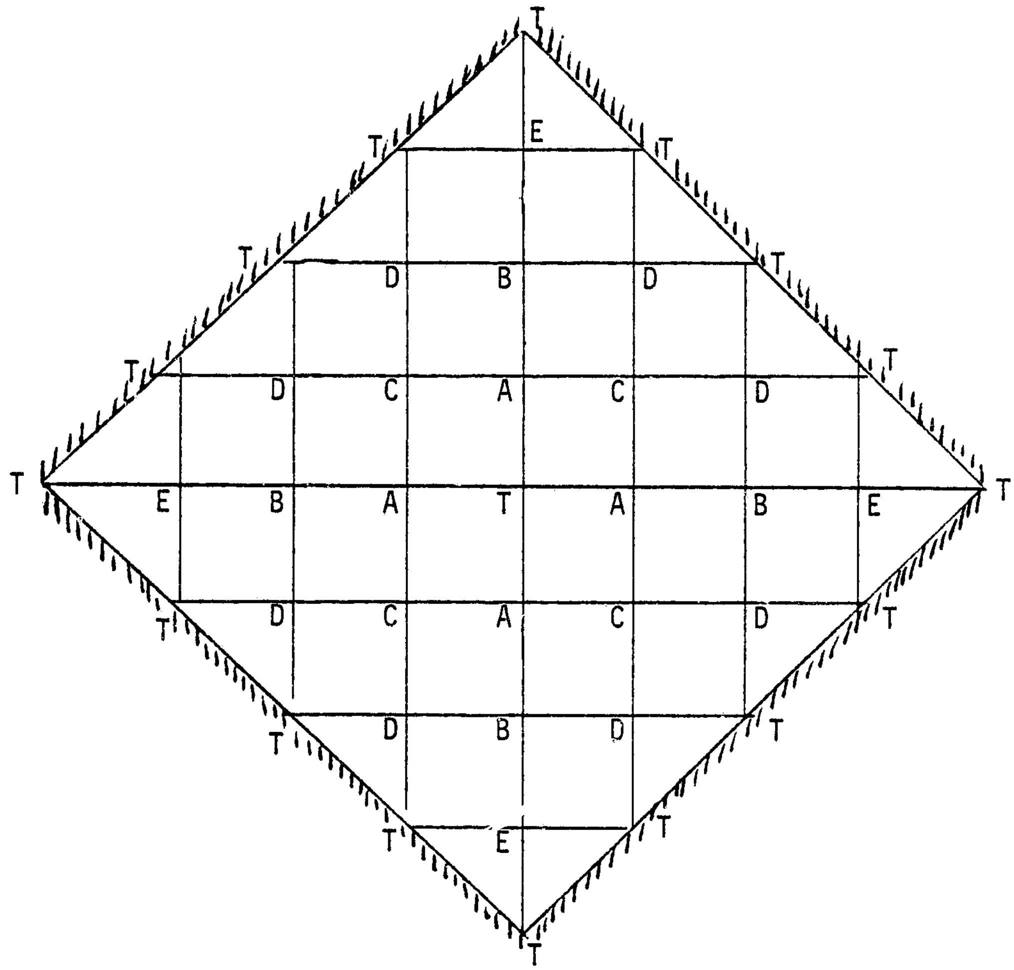


Figure 16

State Transition Diagram for ρ = 1/4 Square Lattice Configuration

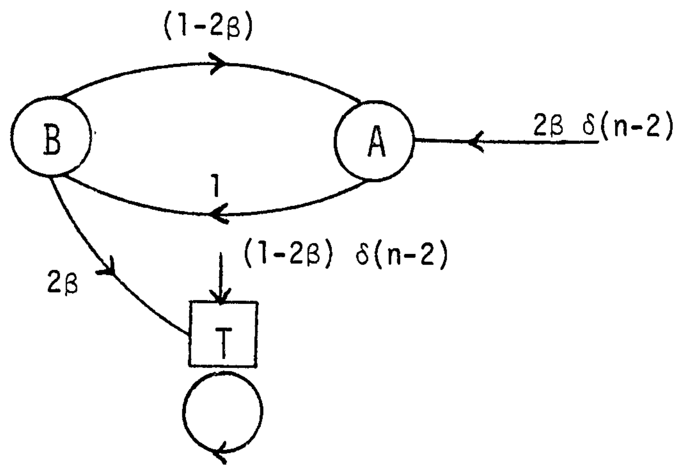


Figure 17

State Transition Diagram for ρ = 1/4 Diagonal Walls of Sensors

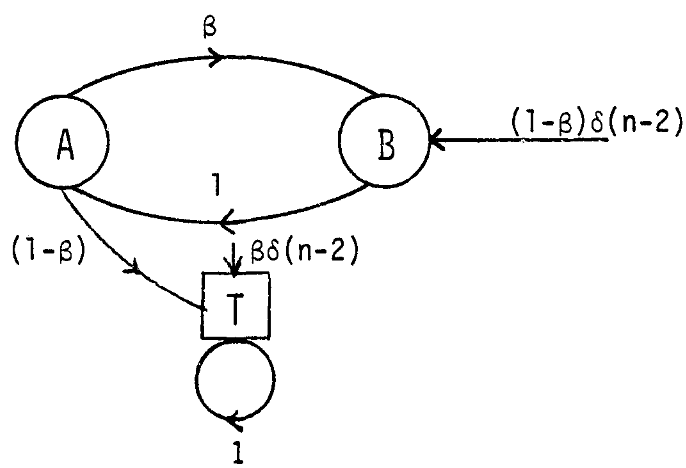


Figure 18

State Transition Diagram for ρ = 1/4 Diamond Sensor Configuration

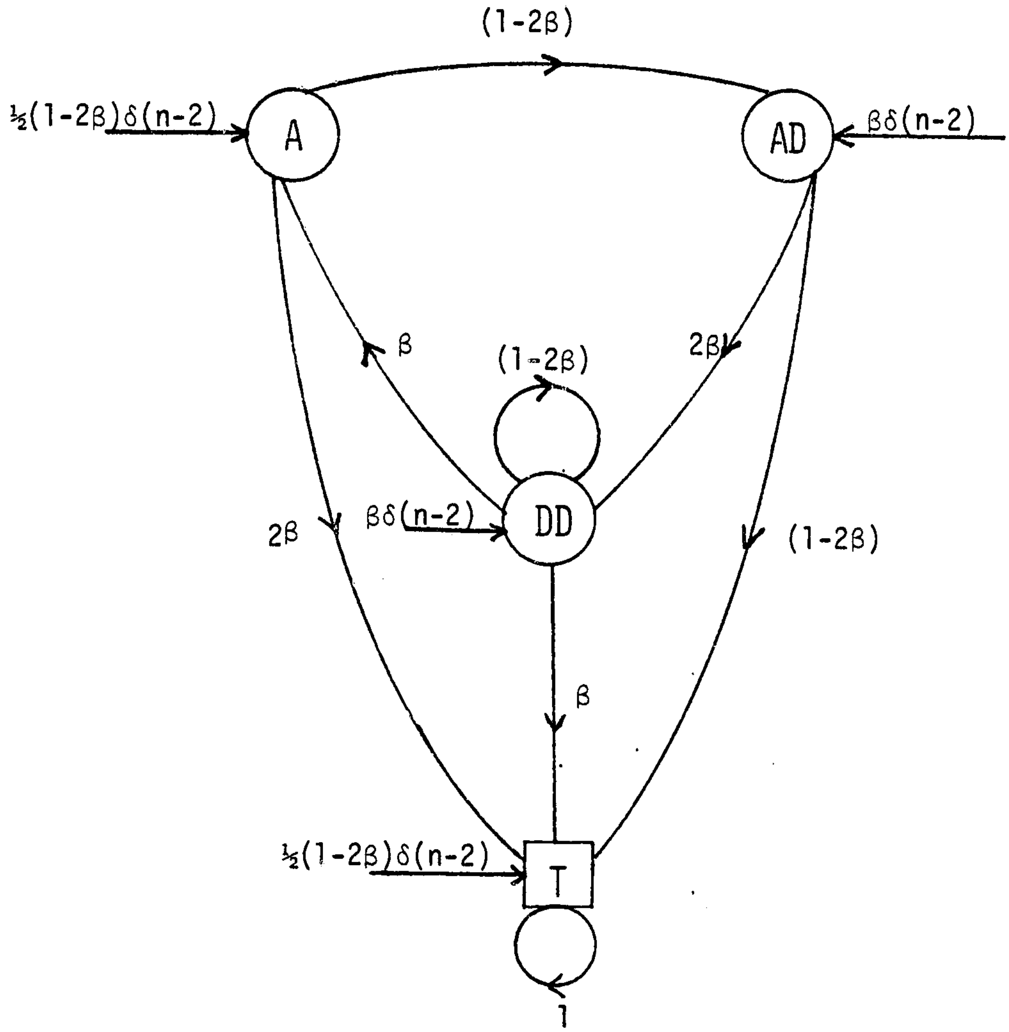
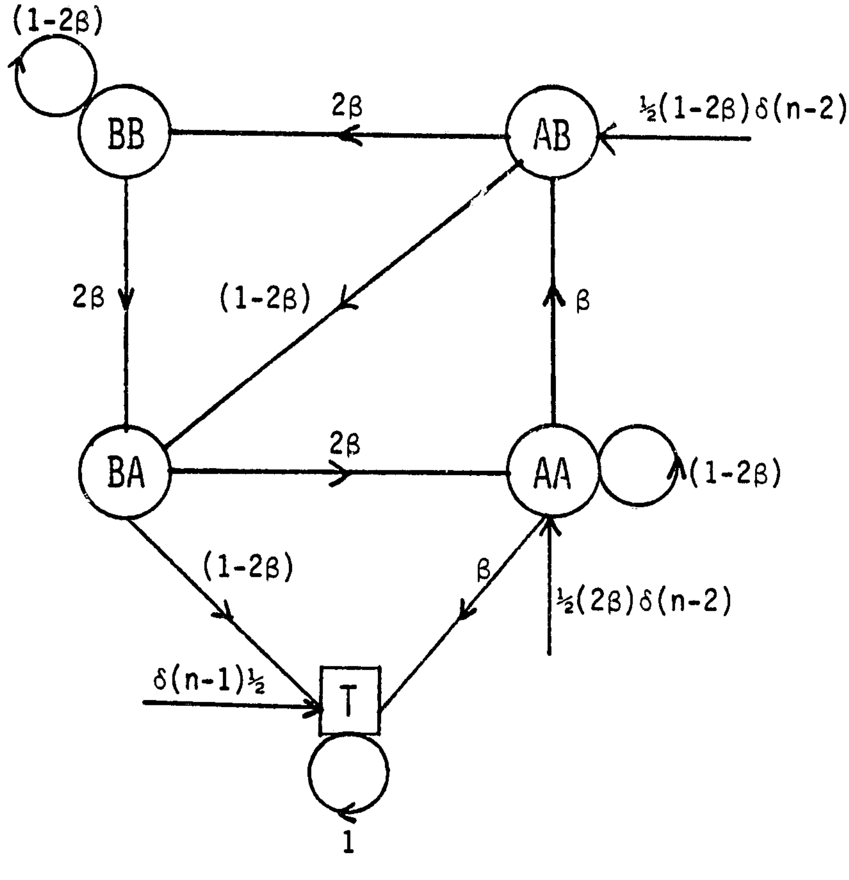


Figure 19

State Transition Diagram for ρ = 1/4
Vertical Walls-of-Sensors Configuration



C. Analysis

(1) Regular Square Lattice

This most obvious $\rho=1/4$ situation yields the simple two-state Markov process whose transition diagram has been shown in Figure 16. Following the methods of Section II, we obtain for this model

$$\underline{N} = (\bar{\nu}_{ij}) = \frac{1}{2\beta} \begin{array}{c c} & \begin{array}{cc} A & B \end{array} \\ \begin{array}{c} A \\ B \end{array} & \begin{bmatrix} 1 & 1 \\ 1-2\beta & 1 \end{bmatrix} \end{array}$$

$$\bar{\nu}_A = 1/\beta \qquad\qquad \bar{\nu}_\beta = \frac{1-\beta}{\beta}$$

Employing Equations (2) and (5), we obtain for the coefficient of variation of the time between sensor passings

$$c_v = \frac{1}{2}\sqrt{\frac{1-2\beta}{\beta}} \tag{21}$$

We note two interesting properties of c_v: a) it is equal to zero at $\beta=1/2$ (which is understandable intuitively by considering possible vehicle paths with $\beta=1/2$), and b) it increases without bound as β becomes small. Since we know that the corresponding coefficient of variation for the random case is $\sqrt{3/4} \approx 0.8660$ (see Equation (20)), there exists a "cross-over point" for the planned and unplanned systems at $\beta=1/5$; for values of β less than 1/5 the unplanned system is superior to the planned system.

The coefficients of variation for the regular square lattice, random positioning, and the other four cases are all displayed as a function of β in Figure 20. We now proceed to discuss each of the other four systems.

(2) Diagonal "Walls of Sensors"

For small values of β, one would like to have a sensor configuration whose variance of the time between sensor passings does not increase without bound. Intuitively, imagining a moving vehicle that rarely turns, we can virtually guarantee that the vehicle will pass a sensor every four or so blocks by arranging them in "diagonal walls," as already shown in Figure 7. Analyzing the corresponding Markov process (Figure 17), we obtain

$$\underline{N} = (\bar{\nu}_{ij}) = \frac{1}{1-\beta} \begin{array}{c} \\ A \\ B \end{array} \begin{array}{c} \begin{matrix} A & B \end{matrix} \\ \begin{bmatrix} 1 & \beta \\ 1 & 1 \end{bmatrix} \end{array}$$

$$\bar{\nu}_A = \frac{1+\beta}{1-\beta} \qquad \bar{\nu}_B = \frac{2}{1-\beta}$$

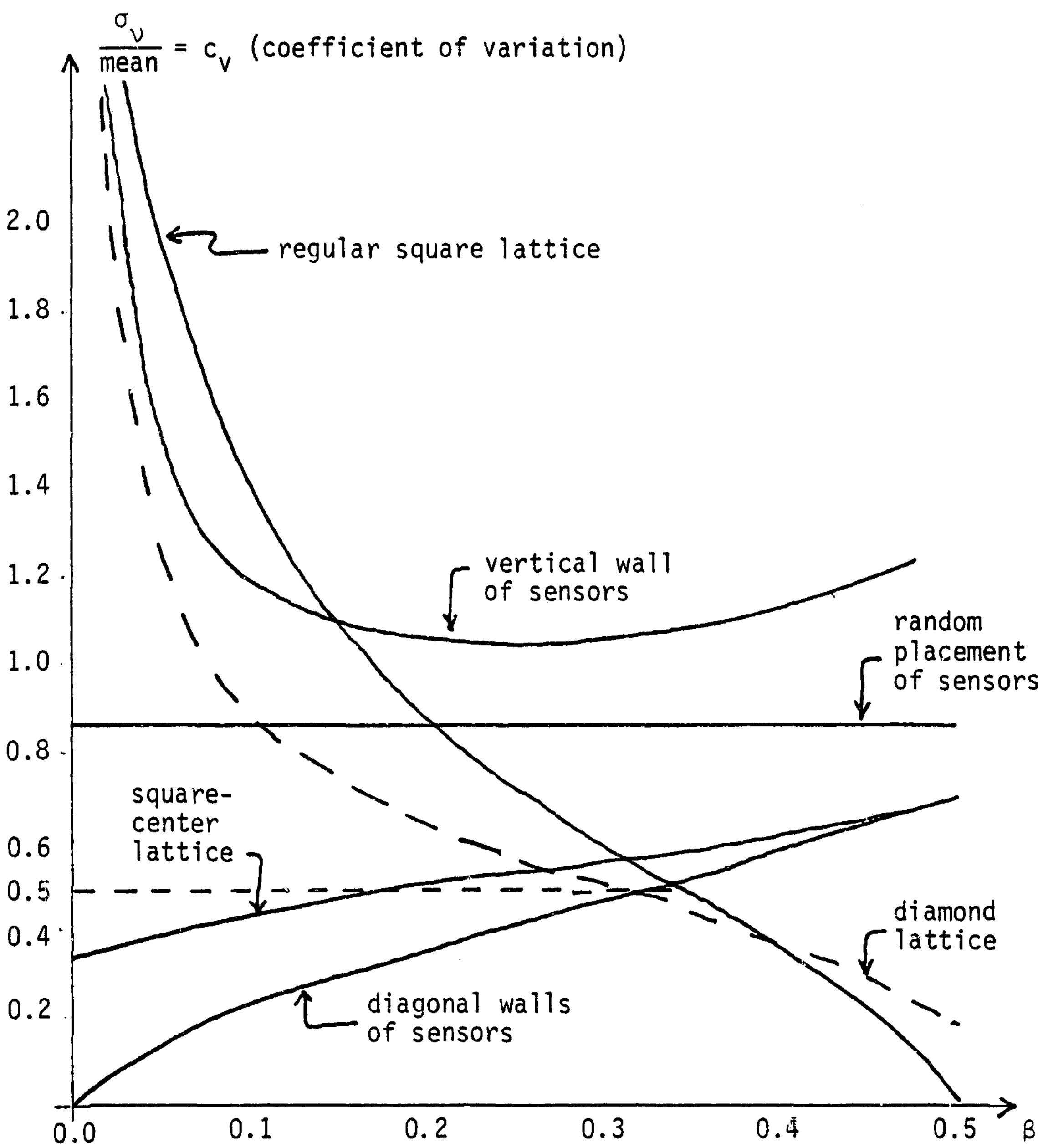
Employing Equations (2) and (5), we find for the coefficient of variation

$$c_v = \frac{1}{2}\sqrt{\frac{2\beta}{1-\beta}} \qquad (22)$$

which is plotted also in Figure 20. Note that, as expected, $c_v=0$ at $\beta=0$; in fact, c_v never exceeds $\sqrt{2}/2 \simeq 0.707$, which is less than the

Figure 20

Comparison of Six Different Systems, $\rho = 1/4$



value associated with a random placement of sensors. Thus, the diagonal-walls-of-sensors configuration is always better than random placement of sensors. Comparing this planned system to the regular square lattice, we see that the cross-over point between the two systems occurs at $\beta=1/3$; below this value, the diagonal-walls-of-sensors configuration is superior; above this value, the regular square lattice is superior.

Interestingly, the design that appears "most natural" is probably the square lattice design. The analysis shows that an alternative design is superior for a range of values of turn probabilities that probably characterizes most operating urban systems.

(3) Diamond Lattice

Is there a $\rho=1/4$ system superior to both of the two planned systems considered thus far? For a limited range of values of the answer is "yes." It is the diamond-lattice configuration, shown in Figure 8. Its lattice kernel is shown in Figure 13 and its associated Markov process is shown in Figure 18. Using by now standard methods, the coefficient of variation is

$$C_V = \frac{1}{4}\left[\frac{1+\beta+\beta^2-12\beta^3}{2\beta^3-\beta^2+\beta}\right]^{1/2} \tag{23}$$

(Again, see Figure 20.)

As expected, the system performance deteriorates without bound as β approaches zero. At β=1/3 (the crossover point for the previous two ρ=1/4 systems) we find

$$C_V \Big]_{\substack{\beta=1/3 \\ \text{diamond} \\ \text{lattice}}} = 0.4593$$

which is about 8 percent less than the ratio (0.5) for the first two systems at β=1/3. In fact, the diamond lattice is superior to the regular square lattice and the diagonal wall of sensors for values of β between approximately 0.32 and 0.38.

(4) Vertical Wall of Sensors

This configuration (Figure 9) may appear attractive because at every fourth North-South street a vehicle is assured of passing a sensor. However, analysis of the corresponding Markov process (Figure 19) yields a coefficient of variation for the time between sensor passings,

$$C_V = \frac{1}{4}\left[\frac{3 + 9\beta + 20\beta^2}{2\beta - 2\beta^2}\right]^{\frac{1}{2}} , \qquad (24)$$

which is greater than that for the random-placement system for *all values of* β (see Figure 20). Thus, this apparently plausible planned system is inferior to the unplanned system for all feasible values of the turn probability. This is due to the three parallel infinitely long vertical corridors between each wall of sensors.

(5) Square-Center Configuration

The final configuration to be analyzed is the square-center pattern shown in Figure 10. Its attractiveness lies in the fact that a certain amount of absolute position information can be easily maintained. Whenever the last sensor passed is one in a square's center, then regardless of the time from that passing, the system controller knows with certainty that the vehicle is still within the same square. If the last sensor passed is on a boundary between two squares, then with certainty the vehicle is within one of the two squares. In the worst case, if the last sensor passed is a "corner" sensor (shared among four squares), the vehicle would be in any one of the four. But in any case, there is zero probability that the vehicle could wander indefinitely long distances from the last passed sensor (which is possible with each of the other systems analyzed).

The 10-state Markov process arising from the kernel of this layout (Figure 15) requires much computation to derive the coefficient of variation as a function of β. Instead, the matrix inversion indicated by Equation (5) was performed numerically for a range of values of β and the resulting coefficient of variation is plotted in Figure 20. As can be seen, C_V for this system increases monotonically with β, starting at $C_V \simeq 0.36$. For values of β between 0 and 1/4, it is superior to all other systems except the diagonal wall of sensors. For these (realistic) values of β, the system designer is faced with a tradeoff involving the coefficient of variation, on the one hand, and the absolute position information afforded by the square-center system, on the other.

V. POSSIBLE FURTHER RESEARCH

The author sees basically three directions in which further research might proceed. The first continues to model the city as a perfectly homogeneous infinite grid and builds directly on the methods and results of this paper. Promising directions include sensor densities other than $\rho=1/4$, including analysis of the diagonal wall of sensors for $\rho=1/n$, for a range of positive integer values of n; systems utilizing vehicle direction information at sensor passings, thereby providing more information for estimating absolute vehicle position; and methods for determining the entire distribution of blocks travelled between sensor passings, thus perhaps basing design decisions on probability of exceeding some threshold.

The second direction focuses on modeling the actual street and vehicular flow patterns of a city, taking relevant spatial inhomogeneities into account. The question of sensor layout design in this case is complicated by the lack of reproducible kernels; most likely a mathematical programming formulation would be appropriate.

The third direction would focus on models of the performance of the dispatching or control system in which the AVL system is embedded. Several models linking AVL to closest vehicle dispatching have been developed in the police area [12-14], but these have not included the type of location error characteristics typifying a fixed-post sensor system or a dead-reckoning system; even less is known of the effects of AVL on bus operations and other transit systems.

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FOOTNOTES

1. FLAIR is a registered trademark of the Boeing Company.

2. Right turns are probably somewhat more prevalent due to restrictions on left turns and the newly popular "right turn on red" laws.

3. One can prove this assertion using an alternative Markov process. Given a lattice kernel with q block faces (street segments), one can construct a recurrent Markov process with 2q states, each state corresponding to a particular block face and direction of travel. As one can verify, this process is doubly stochastic, implying that the steady state probabilities of all of the states are equal (to 1/2q). Thus, given that the system (in equilibrium) is in a subset α of the states (e.g., the set of states originating from sensor-equipped intersections), each of the states in the subset is equally likely. This proves that each of the exit routes from a sensor-equipped intersection that remains in the kernel is an equally likely starting condition.

4. One can verify that a minimum (not a maximum) is obtained by noting that the second derivative at $\beta=1/3$ is positive.

5. This is not precisely true. Vehicular paths that form closed loops may encounter the same sensor more than once, thus causing small correlations.

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