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 1) 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. <u>System efficiency</u>. 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.

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°)				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. <u>FCC considerations</u>. 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.

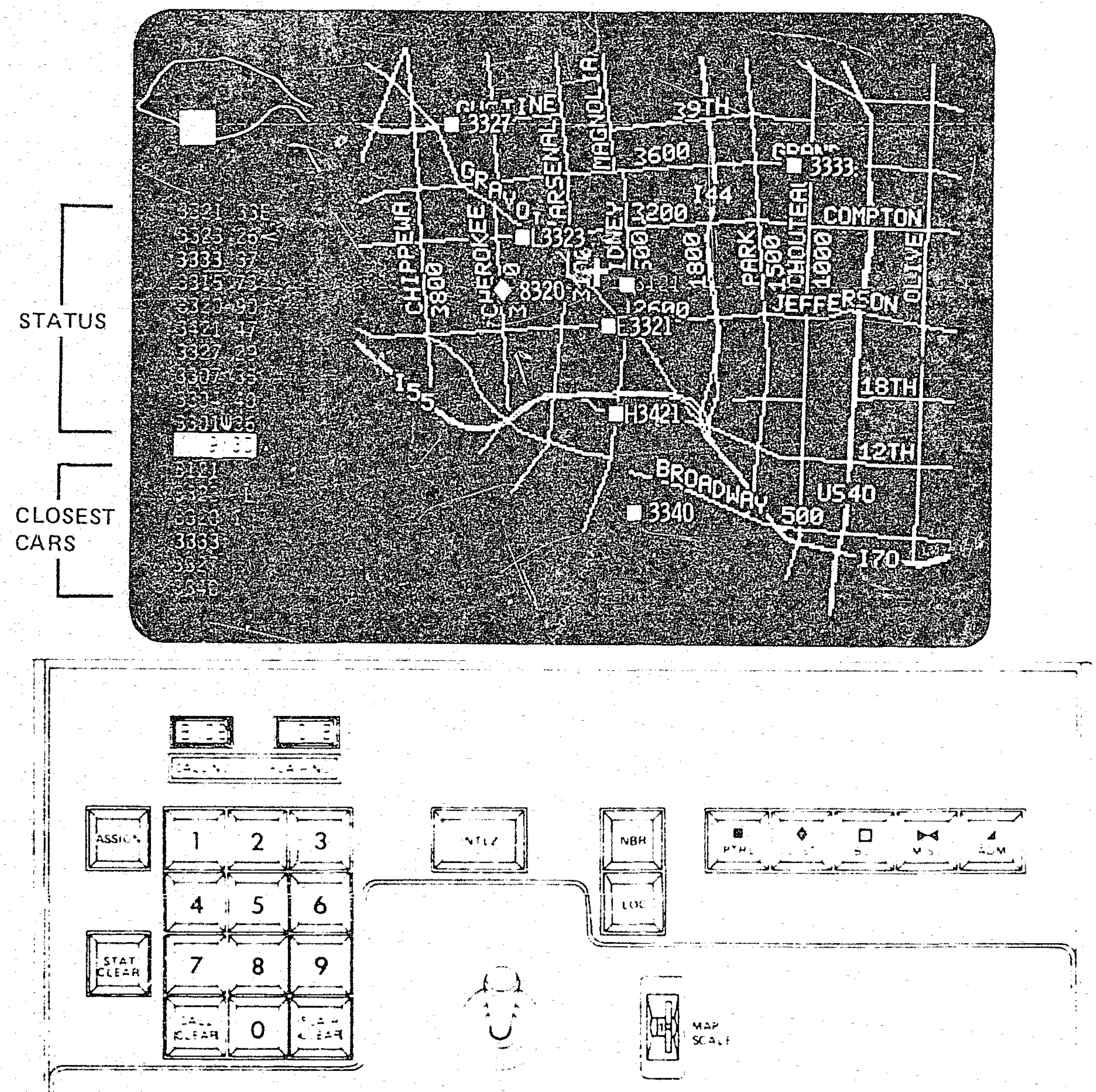
1. <u>Alpha-numeric display</u>. This display is of the type used in information retrieval systems and with computer-aided dispatching (CAD). It involves a Cathode Ray Tube (CRT) type screen on which numbers and words are displayed. It also includes a typewriter-type keyboard where the operator can enter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

Figure 2-4

FLAIR Display



2. <u>Video or map display.</u>[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

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[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 costs (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

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* 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.

Obviously it is not possible to reach any final conclusions regarding cost effectiveness and other benefits based solely on the Phase I FLAIR implementation. Such analysis is essential, and further analysis of these issues is proposed during the city-wide implementation in Phase II.

SCOPE

CHAPTER III: ST. LOUIS AND THE AUTOMATED RESOURCE ALLOCATION CONTROL (ARAC) PROJECT

A. Brief Background Concerning St. Louis. B. Implementation of the Phase I FLAIR System. C. Phase II of the FLAIR System.

Reader's Guide to Chapter III: The purpose of this chapter is to provide the reader with a brief background concerning the city of St. Louis and the Phase I implementation of the FLAIR System. The chapter is divided into three sections: the first discusses St. Louis, the second describes the Phase I implementation, and the third outlines the tentative timing for implementing Phase II. (This chapter will not provide a detailed technical description of the FLAIR System. Such discussions are found in Chapters II and IX.)

CHAPTER III: ST. LOUIS AND THE AUTOMATED RESOURCE ALLOCATION CONTROL (ARAC) PROJECT

A. Brief Background Concerning St. Louis

St. Louis, the traditional Gateway to the West, is a city that has experienced, and continues to undergo, major changes in its demographic and economic structure. It is deeply involved in a process of economic and residential flight to the surrounding suburbs. Population within the city of St. Louis dropped 17% between the 1960 and 1970 census, and economic growth within the St. Louis Standard Metropolitan Statistical Area (SMSA) has been below the national average.[1] This has left St. Louis facing a set of major problems: a declining tax base, rising costs for providing services, a high crime rate, a problematic school system, high unemployment, racial inequities, and a high rate of building and neighborhood abandonment.[2]

Several factors contributed to the city's weakening position. The post-World War II attraction of living in the suburbs resulted in a transfer of housing stock from middle and upper to lower income families. This was encouraged even further by the introduction

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[1] Charles L. Leven, Urban Decay in St. Louis, Institute for Urban and Regional Studies, Washington University, St. Louis, Missouri, March 1972, p. 23. (Distributed by NTIS, U.S. Department of Commerce, Report #PB-209 947.)

[2] Barbara R. Williams, St. Louis: A City and its Suburbs, The Rand Corporation, R-1353-NSF, August 1973, p. 1.

of major high-speed freeways between surrounding areas and the central city. Also, the demolition of one portion of the city, the Mill Creek area, for urban renewal purposes placed several thousand blacks in the housing market at a time when court decisions regarding school desegregation were motivating increased migration of the white population to suburbia.[3] The presence of vandalism, crime, and deteriorating city services within the transition neighborhoods attracted even more of the white middle class from the city to the county. Although St. Louis is not unique in the presence of these factors, it is unique in that these factors have combined in unusual strength.[4] Encouraged by the availability of large amounts of nearby farm lands for residential and industrial development, business and middle-class residents left the city.

The low-income blacks remaining in the city were joined by a heavy influx of low-income rural families, both black and white. The percent of non-white population in St. Louis jumped from 28.8% in 1960 to 41.3% in 1970. These population shifts have left St. Louis with a disproportionately small fraction of higher income families than the rest of the SMSA, and a disproportionately large portion of the area's low-income group. The 1970 census reported a median family income of $8,326 for St. Louis, which ranked the

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[3]C.L. Leven, <u>Urban Decay in St. Louis</u>, p. 103.

[4]B.R. Williams, <u>St. Louis: A City and its Suburbs</u>, p. vi.

city 41st in a group of 48 U.S. cities of over 300,000 population.[5] The magnitude of the problem becomes apparent when one realizes that the low tax base represented by these people must pay for the expanded municipal services they require.

The St. Louis Metropolitan Police Department (MPD) feels the pressure for increased service as much as any city agency. Despite a declining city population, service demands have increased 207% in the past 20 years while the number of policemen has increased only 19.4% over the same time period. Sworn personnel remained at a constant value of 2,232 officers in 1972 and 1973, a time when calls for service jumped 25% and the budget increased only 10.7%.[6] During 1973, the year that the Automated Resource Allocation Control (ARAC) Project was being drafted, St. Louis was the only city of 300,000 or more population to rank among the top ten cities in terms of incidence of ll seven Part I crimes, with the exception of auto theft. St. Louis ranked second in forcible rape (90.8 per 100,000 population), sixth in burglary (3.058 per 100,000) and larceny over $50 (4,167 per 100,000), seventh in murder-manslaughter (34.55 per 100,000) and aggravated assault (532.6 per 100,000), and eighth in robbery (832 per 100,000).[7]

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[5]U.S. Department of Commerce, 1970 Census.

[6]St. Louis Metropolitan Police Department, Annual Report, St. Louis, Missouri, 1973.

[7]Uniform Crime Reports, 1973, FBI.

In 1972, St. Louis had a ratio of 3.58 policemen per 1,000 persons, a figure that placed them ninth among major U.S. cities.[8] Sixty-seven percent were assigned to the nine police districts, 13% to special operations (juvenile, prisoner processing, mobile reserve, etc.), 6% to the Bureau of Investigation, and the remaining 14% were distributed among the Chief's Office, Communications, the Bureau of Inspections, and so forth. Of the districts, District 3 ranked highest with 233 commissioned personnel. The MPD had 478 automobiles in 1974. Two hundred and eleven were assigned to the districts, 68 were assigned to tactical deployment, 53 to the Bureau of Investigation, 43 to the garage as an "extra pool," and the remaining 103 were distributed throughout the rest of the Department. In addition, each district was assigned two cruising patrol vehicles to transport people. This averages out to one vehicle per every 4.50 officers.

B. Implementation of the Phase I FLAIR System

In order to respond to the increasing demands for police service which they faced, the Metropolitan Police Department saw three avenues of response: manpower, mobility of the force, and command and control. In their analysis proposing the ARAC Project

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[8]George L. Kelling, Tony Pate, Duane Dieckman, Charles E. Brown, The Kansas City Preventive Patrol Experiment: A Technical Report, Police Foundation, 1974, p. V-10.

and the FLAIR*System, they stated:

> Manpower is subject to budget limitations or restraints. Mobility is limited to the type and number of vehicles available, and the efficiency of travel in an urban environment. Command and control is the third problem and can be corrected for lesser dollar amounts than the other two....[9]

The effort to improve command and control through the introduction of technical and managerial innovation is not new to the MPD. They have been leaders in the past in the implementation of several technological innovations. In 1964, the Department installed the first real-time police computer system in a major city in the United States. Shortly thereafter, the Department developed a sophisticated resource allocation program for assigning personnel on the basis of projected workload, preventive patrol requirements, and acceptable response delays. The initial success of the system is reflected in the fact that IBM put its LEMRAS package together using the MPD program as a model, although the system now receives only very modest use.[10] In June of 1971, Glenn Pauly, then Lieutenant in charge of the Planning and Development Division, and a key individual in earlier implementation of the

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[9] St. Louis Metropolitan Police Department, "ARAC-Automated Resource Allocation Control," Narrative Work Program, June 15, 1973.

[10] Kent W. Colton, "Computers and the Police Revisited: A Second Look at the Experience of Police Departments in Implementing New Information Technology," Urban Data Service, Vol. 6, November, 1974.

*FLAIR is a trademark of The Boeing Company.

resource allocation program, was approached by representatives of the Boeing Company about a vehicle monitoring system they were developing. After a site visit to Wichita, the St. Louis Police Department, convinced that an AVM system would be beneficial, requested funding from the LEAA High Impact Cities Program through the Missouri Law Enforcement Assistance Council (MLEAC) in mid-1972. The Council, a state LEAA agency, approved funding in 1973 and a contract for the Phase I experiment was put out for bids. The proposal by Boeing was selected, and the contract was awarded on October 25, 1973 and signed on November 7. A cost of $850,000 was agreed upon by both parties.

In its original request for funding to MLEAC, the MPD listed six specific objectives in requesting an AVM experiment:[11]

- To reduce the response time of the patrol units to crime and service request to increase the probability of apprehension.
- To provide an alarm system for officers in trouble to increase their security in the field. (During 1972 two MPD officers were killed and 306 injured in 792 assaults on police officers.)[12]
- To simplify the operation of the dispatcher in routine matters.
- To reduce radio channel congestion through digital communication by use of canned messages.

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[11] St. Louis Metropolitan Police Department Narrative Work Program (ARAC), pp. 4-6.

[12] Ibid., p. 2.

- To provide security of messages and location of vehicles by eliminating cars reporting their position.
- To provide real-time management systems and operation monitoring.

The same document stated that a goal of the ARAC Project was to establish a program "...by which the effectiveness of an automatic vehicle monitoring system can be evaluated, as to its impact upon improvement of the nation's law enforcement and crime prevention capabilities."

The St. Louis MPD and LEAA both recognized the need and importance of an independent evaluation of the AVM experiment, and in July, 1974 the National Institute of Law Enforcement and Criminal Justice awarded a grant to Public Systems Evaluation, Inc. (PSE) to design, organize and conduct such an evaluation. This report is the product of this evaluation which was carried out with full cooperation with the St. Louis MPD, the Region 5 LEAA office and Boeing.

As a component of Phase I, 25 mobile FLAIR units were to be delivered and installed in District 3 vehicles by August 5, 1974. By the same date, all software, console and base station equipment were to be installed and in operating condition. By agreement of both parties, the installation of some equipment was delayed and a new deadline of September 3, 1974 was set for the time an operational system was to be turned over to the MPD. As this date approached, it became apparent that the system was not operating up to standards and an interim two-week period

was agreed upon to allow Boeing to monitor the dispatcher console and permit testing to improve system accuracy. An operating system was turned over to the Police Department on December 16, 1974.

District 3 was selected by the MPD to be the test area. In 1974, the Third District was assigned 253 commissioned officers, 34 automobiles, two cruisers, and two tricars (for traffic). It has an area of 9.78 square miles, one-sixth of the city's area, and 20% of the city's total population. 17.7% of the city's index crimes took place within its boundaries. It is a diverse area containing not only an industrial area but residential sections with both a high proportion of low-income residents and sections with high-income residents. Essentially every type of demand for police services found throughout St. Louis is found in District 3. It was felt that if the FLAIR System could operate successfully in the Third District, it could work anywhere else in the Department. At about the time of implementation, Lieutenant Glenn Pauly, the ARAC Project Director, was promoted to Captain and placed in command of District 3. At the same time, the MPD designated the Fifth District as a control area for purposes of experimentation and evaluation. District 5, although smaller than District 3, presents a similar pattern of requests for police services, primarily due to its large proportion of low-income and minority residents.

From December 16, 1974, the system operated almost continuously under joint responsibility of the MPD and Boeing on-site personnel. On February 25, 1975, the MPD accepted the Phase I equipment and made final payment to Boeing. Although it turned the system over to the MPD at that time, Boeing continued to

maintain a site engineer in St. Louis for the FLAIR System. Except for brief periods of computer failure and fleet turn-over, the system has operated continuously to date.

C. Phase II of the FLAIR System

The close of 1975 found the ARAC Project in an extended Phase I status. Although the original project plan called for the implementation to be complete by the end of 1975, tracking problems and a resulting hardware redesign set the time scale back for more than a year. The Phase I equipment includes 25 mobile units, 22 of which are currently used in Third District patrol and sergeant cars, leaving three as spares. The spares were taken from detective and auxiliary watch units during September, 1975 to allow for uninterrupted fielding of FLAIR-equipped beat cars.

The prototype display console is located at MPD Headquarters along with a radio base station for digital communications, and a computer with the associated peripheral equipment for computation and display. A console is installed at the District Three dispatcher station and is used for dispatching units whenever the system is operational. It is also being used, when necessary, for the training of dispatch personnel in anticipation of city-wide implementation. An observation screen is located elsewhere in Headquarters and allows for the monitoring of command console activities.

During the Phase I implementation, an evaluation group was formed with representatives from the Metropolitan Police Department, the St. Louis Commission on Crime and Law Enforcement, the Boeing Company and PSE. The purpose of this group is to coordinate evaluation efforts to reduce redundancy and increase inter-agency cooperation. The organization will be extended through the implementation of the Phase II system. To date, the group has facilitated the transfer of information and played a major role in preparing the special three-week test begun in the middle of September, 1975. Agreements were also made for the handling of proprietary information concerning system configuration, performance and evaluation findings.

Based on Phase I findings, several hardware and software changes are being made by Boeing on the FLAIR System. The Phase II FLAIR System will have an entirely new digital transmission format to provide increased accuracy and 200 cars per r-f channel (97 in Phase I); an entirely new software package providing greater system capacity and improved methods for vehicle tracking; and many equipment changes to improve system accuracy and reliability. A more complete description of these changes is included in Chapter IX.

As of this writing (May, 1976), Phase II implementation plans appear somewhat tentative, but expectations are that delivery of vehicle hardware will begin early in the summer of 1976. Also planned is a series of training seminars by MPD personnel for street officers in all districts. The first district to get Phase II equipment is expected to be the Third District. Phase I hardware is scheduled to be replaced in June after which tests will be

performed to debug the system and calibrate system performance. It is anticipated that the remaining districts in Area I (Districts I and II) will receive equipment before the rest of the city. Phase II installation is scheduled to be completed by the end of 1976.

SCOPE

CHAPTER IV: EVALUATION PLAN

A. Evaluation Approach. B. Operations Analysis: *Empirical Analysis; Modeling Analysis.* C. Attitudinal Analysis and Organizational Impact. D. Technological Analysis. E. A Special Test of the FLAIR System Under Optimal Conditions. F. Phase II Evaluation.

Reader's Guide to Chapter IV: Chapter IV provides an overall outline of the evaluation approach and plan. The evaluation framework was established to examine the experience in St. Louis in detail, and also to provide a general methodology and specific products which could be applied to other AVM systems or new technologies in other cities. Three interrelated tasks comprise the thrust of the evaluation and will be described in this chapter: operations analysis; attitudinal and organizational analysis; and technical analysis.

CHAPTER IV: EVALUATION PLAN

A. Evaluation Approach

Automatic vehicle monitoring (AVM) systems have been receiving continued attention in the police community since their potential utility and technological feasibility were argued by the President's Crime Commission (1966-1967). However, studies by engineers, operations researchers, and others have reached conflicting conclusions as to the likely cost effectiveness of these systems. Related analysis by urban planners and sociologists suggests that attitude 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.

To date, all analyses have been somewhat speculative since no AVM system has been implemented in any major urban police department in the U.S. (excluding "voluntary" location systems such as "Digimap," developed in Oakland, California and formerly marketed by Sylvania). Now with the implementation of an AVM system in St. Louis it is possible to go beyond speculation.

The St. Louis experience is the first major full-scale implementation of an AVM system in an actual police operating environment. This experiment provides an ideal, timely setting in which to conduct a thorough evaluation of the technical performance characteristics of the system; the resulting effects and benefits,

if any, on police operations; and the response and acceptance of police patrolmen and their supervisors.

In order to provide for an independent evaluation of the St. Louis AVM experience, Public Systems Evaluation, Inc. was funded by the National Institute of Law Enforcement and Criminal Justice of LEAA to design, organize and conduct such a review. In preparing for the evaluation, visits to the St. Louis MPD were made in order to become aware of the operational details of the AVM system and the physical and institutional environments for the trial implementation. The enthusiasm and cooperation were impressive, and the design of the evaluation was built upon a solid background which included the following:

- The potential importance and impact of AVM systems on police operations in the United States;
- The independence of the evaluation team from the St. Louis Police Department, the LEAA and any hardware manufacturer; and
- The thorough support and cooperation offered by the St. Louis MPD and other St. Louis officials.

In establishing the evaluation framework, it was anticipated that the work would not only provide valuable information regarding the St. Louis experience, but in addition, it was intended that the effort should provide a "model" or illustration of a methodology for evaluation which could be applied when examining the implementation of other AVM systems or the application of additional new technologies in other cities. With this in mind, three distinct

yet interrelated task areas were delineated in performing the evaluation:

- operations analysis
- organizational impact and attitudinal analysis; and
- a hardware systems analysis.

Each of these areas will be discussed below. In addition, specific products with broader application--such as computer models, survey instruments, and technological tests--have been developed as a part of the project. They are now in the public domain so they can be used by additional cities and police departments in other evaluation efforts.

B. Operations Analysis

This component of the evaluation was directed by Dr. Richard C. Larson and is described in detail in Chapters V, VI, VII and VIII. It includes both empirical and modeling analysis.

1. Empirical analysis. The empirical evaluation was designed to analyze the operations and performance of the FLAIR System as a part of the St. Louis Police Department. The details of the empirical analysis were worked out jointly with Captain Glenn Pauly, Dr. Otto Heinecke, Executive Director of the St. Louis Commission on Crime and Law Enforcement, and the Boeing Company. Included was a review of the following kinds of information:

- Response times--by type of call, by component of the emergency response

system (e.g., the dispatcher queue delay, travel time), and by time of day;

- Workloads of the individual patrol units; and
- Actual position estimation error (measured in the field by a monitoring unit).

This subcomponent provided the point of maximum information exchange and cooperation among the three groups which are monitoring the project: 1) our independent evaluation team; 2) Dr. Heinecke's LEAA impact evaluation group; and 3) Boeing's evaluation engineers. To some extent, each has been interested in the same core data, but each has had unique data requirements reflecting a specific evaluation focus. For instance, Boeing engineers were particularly concerned with human factors, including dispatcher fatigue accruing from prolonged work at the AVM display console. Dr. Heinecke's group included a special emphasis on crime rate increases and decreases that could be attributed to the AVM system. Our major concern focused on an overall evaluation of the system, excluding effects on crime, and provided the three task areas of our evaluation with the appropriate field-derived data.

2. Modeling analysis. This subcomponent focused on constructing a new, realistic and detailed simulation model of the trial system implemented in St. Louis, including those aspects of the street network and related travel times that were required to analyze effects of the AVM system, the AVM positional accuracy

characteristics, the dispatcher's strategy for selecting and assigning particular patrol units, the spatial distribution of calls for service, the service time distribution, and several other related factors. The model--described in Chapter VIII--is an important product in and of itself, and although specific to St. Louis, it has been designed so as to have application to other cities. In addition, from the model we have attempted to predict travel times (and compare the results with travel times without AVM information); workloads of the individual units; and inequities in the "coverage" provided by the units (coverage is some measure of neighborhood-specific travel time). These results are discussed primarily in Chapter VI, the response time chapter.

The methodology employed built on the simulation work of Dr. Larson (Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972; Chapters 6 and 7) and his more recent analytical work (see, for example, "A Hypercube Queuing Model for Facility Location and Redistricting in Urban Emergency Services," Computers and Operations Research, Vol. 1, March, 1974, pp. 67-95).

A second related modeling project has also been undertaken as a part of this evaluation. The second effort has been devoted to creating a model to depict the error characteristics of the FLAIR System. Previous AVM technologies utilized radio trilateration techniques, fixed-post sensor techniques and other location estimation methods for which it is typical to describe accuracy in terms of "the mean distance estimation error is 100 feet," or,

"at least 95% of all position estimations are within 50 meters of the true position."

Computer-tracked vehicle location systems pose new problems, however, in analyzing, modeling, and interpreting system errors. These systems, such as Boeing's FLAIR System, use an in-car odometer and compass to provide a crude form of inertial guidance information. This information is transmitted periodically (say every two seconds) to a central receiver where it is processed by a computer algorithm with the purpose of updating the estimated position of the vehicle. (The physics of this is discussed in Appendix A.) In essence, if the computer "knows" the street segment on which a vehicle is traveling, the average distance estimation error may be on the order of 50 feet (a fairly insignificant error for most police applications). The major system error occurs when the computer can no longer track the vehicle--due to accumulated errors that cause the computer to "place" the vehicle on an incorrect street. Such a vehicle is said to be "lost," and a major system error performance measure is the <u>mean time between losses</u> of a vehicle.

As a part of this task, a model has been developed for predicting mean time between losses as a function of 1) odometer errors; 2) geographical descriptors of the city; 3) vehicle speed; and 4) driving habits of the police officer. A formula is derived that predicts the mean time between losses in terms of these

factors, and these predicted numbers are then compared with the actual results in St. Louis. (The model and its implications are examined in detail in Chapter V and in Appendix A and Appendix B.)

C. Attitudinal Analysis and Organizational Impact

One of the important concerns regarding AVM systems is the impact they will have on police operations and behavior and how they will be accepted by the police. The question is a delicate one. On the one hand, with such technical innovation, it is essential to be sensitive to the needs and perceptions of the "patrol officers on the street." Without their understanding, and at least partial support, the long-run success of the system may be in danger, and the risk always exists of sabotage, whether direct or indirect. On the other hand, if possible resistance from police officers is given too much emphasis, all innovation might be stopped.

The purpose of this part of the evaluation, then, was to measure the attitude and acceptance of the men in the Department, at all levels, towards the AVM system, and where possible to utilize this information to point out important considerations in designing and modifying the operation of the system for the future. The work has been carried out under the direction of Dr. Kent Colton and Mr. Mark McKnew, and is reported in depth in Chapter X of this report.

During the Phase I implementation of FLAIR in District 3, a number of surveys were conducted. Questionnaires were developed and administered to police personnel in the Third District (the experimental area) and the Fifth District (a control district) both before and after the implementation. The first set of "before" surveys was completed prior to the operational installation of the first demonstration car. It was designed to gauge the initial perceptions of police officers in District 3 and District 5. Following the implementation of Phase I, a second set of interviews was conducted in order to obtain a second view of the implementation of the system.

The surveys were designed to evaluate officer characteristics and perceptions. Demographic-type data were obtained, such as prior level of education and years as a policeman. Also, questions were asked to obtain general impressions of police work and the FLAIR Program. Such questions focused on the officer's subjective response and acceptance of the AVM system, including perceptions of such issues as:

- Improvements in officer safety;
- Reduction in response time;
- Improved service to the public;
- Psychological impact of positional monitoring;
- Increased supervision, or control from above;
- Changed police behavior;

- Methods of implementing the AVM system and any improvements that could have been made; and
- Relation or conflict between such technological innovations to more social or behavioral alternatives in police work.

Other questions were designed to gauge perceptions and impressions of other operating characteristics and objectives of the system. Dispatchers play an obvious and important role in the FLAIR System. Therefore, in addition to interviews with the policemen in the Third and Fifth Districts, a survey was also made of St. Louis dispatch personnel. Further, in an effort to relate the FLAIR System to the overall operations and management of the St. Louis Police Department, initial discussions were held with the top management officers in the Department. Continued dialogue with the management of the Police Department will be an essential component of the Phase II evaluation in order to examine the potential of an AVM system in the area of command and control.

D. Technological Analysis

The third and final task, under the direction of Mr. Gilbert C. Larson, focused on the technology of AVM systems, in general, and the Boeing system being implemented in St. Louis, in particular. The task coupled the general analysis of on-going AVM hardware developments throughout the United States (discussed in Chapter II) with a more detailed and comprehensive evaluation of the Boeing

AVM hardware (see Chapter IX). Tasks included:

1. Analysis of AVM hardware developments. On a broad scale we felt that it was part of our task to maintain reasonable contact with many of the potential AVM hardware vendors in order to follow their progress. While this effort was not the main component of the hardware systems analysis, it was felt to be necessary to place the specific results of testing the Boeing equipment in an appropriate context. Chapter II therefore discusses alternative AVM technologies and provides a basic context for the remainder of the report.

2. St. Louis-Boeing-AVM equipment evaluation. This component focused on the technical evaluation of the Boeing AVM system and equipment to determine its operational adequacy in a law enforcement environment. The results of this work are reported primarily in Chapter IX. Equipment limitations, if any, were examined through special field tests. Included were studies and recommendations with regard to accuracy, reliability, repairability, and operating efficiency and convenience. The evaluation was conducted under actual field conditions and in a manner to minimize disruption of the normal operation of the St. Louis Police Department. The technical evaluation program included:

- Visual inspection of the equipment, with emphasis on the mobile equipment;
- Field tests in potentially unfavorable signal areas that could affect location accuracy and message/status transfer;

- Field tests to determine accuracy of the AVM mobile equipment;

- Observation of performance of the display console, including such factors as resolution, accuracy, display clarity, operational ease and human engineering factors;

- A review of Headquarters processing (computer) equipment and software programs, particularly with regard to ease of operation, ability to make changes (roads, detours, one-way streets, etc.), reliability, expandability and cost factors;

- A study of systems expandability and flexibility with regard to number of cars, dispatchers, radio channels and types of vehicle; and

- An analysis of system/equipment failures and their causes. An estimation of MTBF (mean time between failure), MTTR (mean time to repair) and projected service requirements in equipment and manpower.

E. A Special Test of the FLAIR System Under Optimal Conditions

Because of the various problems which developed in implementing the FLAIR System, it seemed that a special test was required in order to examine FLAIR under "more ideal" conditions. As such, a special three-week test was designed and carried out by PSE in September and October of 1975, in close cooperation with the St. Louis Police Department and the St. Louis Commission on Crime and Law Enforcement. The results of this test provide important information, particularly concerning the operational and technical aspects

of the system, although they also have significant attitudinal implications as well. A detailed description of the special three-week test and the results are included in Chapter VII.

F. Phase II Evaluation

Although the original project plan for FLAIR had called for a city-wide implementation to be complete by the end of 1975, tracking difficulties and necessary hardware redesign have caused substantial delays and the time scale for implementation was set back for more than a year. These problems make it impossible for this report to provide a complete and conclusive appraisal of the St. Louis AVM experience. A Phase II evaluation will therefore be conducted in order to assess the results of implementing the modified FLAIR System on a city-wide basis.

The Phase II evaluation will continue the three-part evaluation methodology utilized in Phase I: operations analysis; attitudinal and organizational analysis; and technological analysis. In addition, the extended time period will allow the continued evaluation of the St. Louis AVM project to broaden the scope of the first effort in two ways. First, the experience gained with FLAIR will provide an excellent background to go beyond the experience in St. Louis to begin to identify the overall costs, benefits and implications of AVM technologies for law enforcement. Chapters XI and XII of this report begin to do this by listing conclusions concerning the Phase I FLAIR System, and outlining

recommendations for other cities interested in examining AVM technology. However, the Phase II evaluation will be able to reach beyond this initial work. Second, the continued Phase II evaluation will provide the opportunity to expand and improve on the general evaluation framework that has been developed as a part of this project. The independent products developed in Phase I (such as the computer models, survey instruments and technological tests) will receive further refinement and will be made available to interested parties who are desirous to utilize either the products or the philosophy of the evaluation approach outlined in this report.

SCOPE

CHAPTER V: FLAIR SYSTEM ACCURACY: THE FREQUENCY OF LOST CARS

A. Empirical Test Results: *FLAIR Lost Car Procedures; Data Sources; Establishing Acceptable Levels of Initialization Rates; Initialization Rates by Watch and by Platoon; Self-Initialization; Two Measures of Lost Car Frequency.* B. Modeling Mean Time Between Losses: *Motivation; Outline of Mathematical Model; Procedure; Measuring Systematic Errors; Estimating Random Errors; Application to St. Louis; Illustrative Computations; Other Error-Producing Factors.* C. Concluding Remarks.

Reader's Guide to Chapter V: This chapter deals with an accuracy issue that is peculiar to dead-reckoning and computer-assisted dead-reckoning systems. Involved is the frequency of losing a car because the computer can no longer reliably track it. This performance measure, being relatively new to AVM systems, is discussed in considerable depth, first regarding empirical results and second describing a computer model used in predicting mean time between losses. Mathematical and technical support are contained in Appendices A and B. The non-technical reader should find Section A, covering the empirical results, of particular interest. The computer model provides insight into factors causing location errors and predicts the frequency of lost cars. This model is considered particularly valuable in assisting the designer when attempting to improve system performance. The reader should be cautioned not to use the model to predict performance in a particular city, especially since city-specific software affecting this performance parameter may be installed in the FLAIR system.

CHAPTER V: FLAIR SYSTEM ACCURACY: THE FREQUENCY OF LOST CARS

The most important performance characteristic of AVM systems is the accuracy of locating the vehicle. One method for determining accuracy is to compare the vehicles known position with its estimated position, using a sufficient number of randomly selected measurements to be statistically significant. From these measurements, accuracy is most often stated in one of two ways: 1) the average or mean error is less than 100 feet (for example), or 2) system accuracy with 95% confidence is 400 feet (for example). This latter method would indicate that 95% of the test measurements were correct to within 400 feet.

While distance-oriented accuracy measures fully describe the accuracy of most AVM systems, they do not adequately depict accuracy for computer-tracked dead-reckoning systems such as Boeing's FLAIR* system. These latter systems tend to be either very accurate (plus or minus a few car lengths) or--much less frequently--very inaccurate, a condition which occurs when the computer can no longer track the vehicle and the vehicle can be considered <u>lost</u>. When this condition has occurred, it is necessary to re-establish the vehicle's position by stopping the vehicle and placing the AVM display-indicated position at the known site. This process is known as <u>initialization</u>. The less frequency initializations are required, the better the accuracy

*FLAIR is a trademark of The Boeing Company.

performance of the system (and the less irritation to the dispatchers and patrolmen using the system). There are two ways for stating a performance measure focusing on loss frequency: 1) the mean time between losses, or its inverse, 2) the frequency of lost cars in terms of "X" initializations per car per unit of time (say a 24-hour day).

This chapter deals with the "lost" car aspect of accuracy. Location accuracy is covered in Chapter IX. The first section of this chapter entitled "Empirical Test Results" reports on the "lost" car results obtained during the Phase I trial period. The second section, entitled "Modeling Mean Time Between Losses", develops a probabilistic model to predict "mean time between losses" based on random driving and mapping errors, systematic errors resulting from such causes as tire wear and speed and other variables. For the reader's convenience, a glossary of frequently used terms is contained in Table 5-1.

A. Empirical Test Results

1. FLAIR Lost Car Procedure. Two types of lost vehicles are identified by the FLAIR software. One is denoted by the letter "V" and the other by "W." The "V" stands for "verification required" and is intended to signal the dispatcher that one of two conditions has been recognized by the computer: first, that a computer recognized error exceeding 250 feet has been encountered under normal tracking conditions, or second, that a vehicle has traveled more than 1800 feet in an off-street parking

Table 5-1

Glossary*

Basic Model	Model predicting mean time between losses that does not include effects of quantization.
Initialization	The process of the dispatcher repositioning the estimated vehicle location at the correct location.
Mean Time Between Losses	Average time between successive occurrences of the computer displaying a *V* or a *W* for a vehicle.
Platoon	There are three platoons: A, B and C and each is assigned to a particular watch for a shift period.
Polling Rate	Number of times per minute that the computer receives updated mileage and heading information from a tracked vehicle.
Quantization	Process of "rounding off" a number to one of a (usually small) number of possible values.
Random Error	That error due to unpredictable and uncorrectable factors such as tire slippage, lane switching, map errors, and speed changes (when latter viewed as uncorrectable).
Right-Angle Distance Metric	A mathematical formula for estimating the travel distance in a city between two points as the sum of the East-West distance and North-South distance (assuming streets run E-W and N-S).
Shift Period	A continuous three-week period during which the platoon assignments to watches remain constant.
Systematic Error	That error due to predictable and uncorrectable factors such as tire wear, temperature, and speed (when latter viewed as correctable).

* Underlined words appear elsewhere in the glossary.

Table 5-1
(continued)

Glossary*

V	Verification required (error exceeds 250 feet under normal tracking or 1,800 feet in open-loop tracking).
W	Position check required (due to uncharted open-loop tracking, magnetic anomalies. or leaving tracking area of the system).
Watch	A continuous eight-hour tour of duty.
Watch Period	A continuous nine-week period containing three complete shift periods, thus allowing a complete rotation of platoons.
"22 code"	Self-initialization that takes place in front of the district station house.
d_Q	Unit of distance quantization.
t_Q	Unit of time quantization.
γ	Mean systematic error per unit of distance travelled; summary parameter for systematic error.
$\overline{\ell}$	Mean block length.
p	Probability that vehicle will become lost on any random turn that it executes.
r	Probability that the vehicle executes a turn at any random intersection.
s	Average speed of a tracked vehicle.
σ^2	Incremental variance; summary parameter for random error.
$\overline{T}_L$	Mean time between losses.

* Underlined words appear elsewhere in the glossary.

lot which the computer recognizes. The "W" appears if any one of three conditions is met. The first is when a vehicle travels more than 600 feet in an off-street area which the computer doesn't recognize, such as driving around an industrial building. The second occurs when the vehicle travels in an area with a known magnetic anomaly like the large flood wall along the riverfront of the Third District. The third condition is met whenever a FLAIR-equipped car leaves the Third District. This condition will obviously not be a problem during Phase II because the whole city will be included as a part of the system. However, it most likely will be replaced by the analogous condition of a car leaving the City of St. Louis.

In Phase I three types of actions were available to a dispatcher in order to remove a "V" or a "W" from the status column. The first is just to "erase" the code from the console by use of a "status clear" button without checking the unit's actual location. This was heavily discouraged by the department because it would, if followed for even a short length of time, create a situation where there could be no confidence in displayed locations.

A second and proper response to remove a "V" or "W" is for the dispatcher to contact the unit at the earliest convenient moment and to ask for its location. The "earliest convenient moment" takes into account the fact that the dispatcher has other tasks to complete first, or that the unit is out of service handling a call. Once contacted and asked by its "21" (location), the unit is supposed to stop at a nearby intersection and give

that location over the voice channel. If the displayed location matches the given location, the dispatcher is allowed simply to clear the "V" from the screen without initializing. If the displayed location does not correspond to the actual location, then the vehicle stands by until the dispatcher goes through the initialization procedure. Using the joy-stick on the FLAIR console, the dispatcher guides a small red cross (cursor) to the intersection given by the field unit. Sometime during or after this process, the dispatcher enters either the radio call number of FLAIR number of the vehicle into the console to inform the computer which unit is being updated. Once both tasks are complete, the initialization button is pushed and the vehicle initialization is complete.

The third possible way for initialization gives field personnel the ability to update the location of their vehicles from the field without dispatcher assistance. This "self-initialization" process utilizes a special digital code, the number "22." Activating this code causes the computer to display the unit's location as directly in front of the Third District station house, independent of where the unit was previously displayed. If, prior to the 22 code, the vehicle was displaying a V or a W, it is cleared automatically from the screen and the system begins tracking the vehicle just as if the dispatcher had performed the initialization. The purpose of the 22 code was to increase average system accuracy and reduce the time spent by dispatchers initializing vehicles.

2. Data Sources. Two data collection procedures were used to measure frequency of lost cars. The primary source was a computer program within the FLAIR mini computer that each day tabulated the number of times a dispatcher used the initialization button and the number of times patrol officers sent self-initializing codes. Both are aggregated by the watch on duty (whether it be the day watch, the afternoon watch, or the night watch) at the time it occurred. These data are available for the 39-week period from January 6 to October 15, 1975, thereby presenting a long-term data stream on lost cars. With these data, one is able to compute both the mean number of times the initialization button is pushed and the mean number of self-initializations for each eight-hour tour of duty.[1]

A secondary source of data was a dispatcher log prepared by the Boeing Company, and used from January 6 to February 6, 1975. The dispatcher on duty at the FLAIR console was instructed to record several pieces of information when a *V* or *W* appeared: the date, call number, time, whether it was a *V*, *W* or no display, the update distance in inches on the console, and any comments thought appropriate.

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[1]The daily summaries record the number of times someone pushes the initialization button at the dispatcher console. Besides actually locating cars, the button was used on occasion to train dispatchers new to the FLAIR operation, although it is probably safe to assume that some actual initializations were performed during the training process. Early in Phase I several dispatchers were observed having to occasionally hit the initialization button more than once before a car is properly located. Each attempt is reported on the summary so the totals may include some modest "over-counting."

While the daily summaries and dispatcher logs provide a significant amount of data for analysis, they are both limited in certain ways. Detailed records were not maintained recording the number of working FLAIR-equipped cars in the field during each eight-hour watch. Thus, one must estimate the number of FLAIR-equipped vehicles to obtain an estimate for the average frequency of losses per car per day. The principle problem with the dispatcher's log was a significant under-reporting of lost cars in the logs. As a result, the absolute number of lost cars in the log was found to be a significant underestimate of actual performance (as measured in the daily summaries and by on-site observations). It seems that the dispatchers recorded *V*'s and *W*'s on the logs only when time permitted, so this record cannot be depended upon as an absolute measure of the frequency of lost cars.

3. Dispatcher log data analysis. Unlike the daily summaries the dispatcher logs provide data on the fraction of *V*'s and *W*'s that do not require an initialization and they also demonstrate the distribution of distance errors experienced by the various police vehicles. The absolute error (from under-reporting) should not bias these estimates. For the period January 6 to February 6, 1975, the number of *V*'s and *W*'s was counted for each FLAIR-equipped unit.[2]

[2]A unit was defined to be FLAIR-equipped if it had working FLAIR hardware for at least ten days of the thirty-day test period.

Even though the number of *V*'s and *W*'s reported represents only a fraction of those actually occurring, the errors recorded demonstrate that the frequency of *V*'s and *W*'s varies significantly among individual beat cars. Such variation cannot reasonably be attributed to random fluctuations alone. They also constitute a reasonable sample from which to calculate average distance errors under "lost" conditions. The instructions for completing the log directed the dispatchers to record as the error any distance between the actual location and the displayed location.[3] Errors encountered for *W*'s are on the average larger than those reported for *V*'s. *V*'s required an average update of 1,353 feet (or approximately .25 miles) while *W*'s resulted in an average error of 1,685 feet (or approximately .32 of a mile).

One very interesting statistic available from the logs is the fraction of *V*'s and *W*'s that required "zero update." Although a *V* or a *W* is a statement that the computer no longer has confidence in the location of a unit, there are situations where the *V* or *W* will appear and the system is still tracking the vehicle correctly. In such cases, a *V* or *W* with a zero error still represents a time investment on the part of the dispatcher to verify locations with the field units, but it does not require actually pressing the initialization button to clear, and is therefore an easier

[3]Distance was recorded on a 16x scale map. Dispatchers sometimes recorded the distance in blocks, a dimension of undependable length. The majority of the errors were recorded correctly, however.

transaction to handle. Based on the dispatcher's log, it was found that on the average, 13.8% of the *V*'s and *W*'s required no relocation on the part of the dispatcher.

4. Daily summary data analysis. Each day during Phase I, Boeing and MPD personnel issued a summary of the number of initializations and 22's (automatic field self-initializations) performed during the previous 24-hour period for each of the three watches: day watch (0700 to 1500 hours); after noon watch (1500 to 2300 hours); or night watch (2300 to 0700 hours). Before examining the data, it is appropriate to explain the way watches operate in St. Louis. Patrol officers are assigned to one of three platoons: A, B or C. The platoons are of approximately equal length and each one is assigned to a particular watch for a three-week "shift period." Every third Monday the watches rotate counterclockwise (day to night, night to afternoon, afternoon to day), so that every platoon works each watch once in a nine-week period, comprising three shift periods. Dispatchers also rotate watches in the same way every three weeks. (In other words, dispatchers essentially work with the same platoon and will rotate watches to stay with the platoon.)

The average number of initializations per watch over the thirteen shift periods between January 6 and October 5, 1975 was about the same for each watch: 66.0, 63.8, and 64.4 for day, afternoon and night watches respectively. Table 5-2 gives the average number of initializations per watch for each watch and three-week shift period. For instance, Table 5-2 yields the

result that the initialization button was used an average of 146.9 times per day during the shift period beginning January 6, 1975. Assuming that roughly 18 FLAIR-equipped vehicles per day were fielded during this period, one arrives at a rough estimate of eight initializations per car per day.[4]

a. Initializations per car per day. As stated earlier, due to a lack of FLAIR-car fielding data, the daily summaries do not provide sufficient data to calculate directly the number of initializations per car per day. However, an approximation involving a sample of fielding data can yield a set of reasonable values. Critical to the accuracy of the estimate is the ability to determine the effective average number of FLAIR-equipped vehicles on the street over any given shift period. This can be done by using a sample of "assignment logs" completed by each officer at the beginning of each watch. Each time an officer begins a watch, he places on the assignment log the mileage of the vehicle he is assigned to, the beat number he is assigned, and the number the department has given to the vehicle for record-keeping purposes. It is possible, through the department vehicle numbers, to determine which vehicles were FLAIR equipped. Only patrolmen (not sergeants) complete this log, so any number derived represents only the fraction

[4]By way of comparison, the dispatch log reported 2.43 *V*'s and .93 *W*'s per car per day, for a total of 3.36 losses per car per day. The discrepancy between 8 and 3.36 losses per car per day is an indication that the dispatcher logs recorded only a fraction of the initializations actually performed.

Table 5-2

Tabulation of Initializations and 22's by Platoon on Duty and Shift Period

Shift Period	Day Watch			Afternoon Watch			Night Watch			Total	
	Initial-izations	22*	Platoon on Duty	Initial-izations	22*	Platoon on Duty	Initial-izations	22*	Platoon on Duty	Initial-izations	22*
1/6-1/26	53.4	47.9	A	44.7	35.2	B	48.8	48.0	C	146.9	131.1
1/27-2/16	41.6	33.4	B	43.7	46.4	C	59.0	43.6	A	144.3	123.4
2/17-3/9	49.8	50.2	C	62.6	41.5	A	43.1	25.8	B	155.5	117.5
3/10-3/30	64.6	39.4	A	51.6	26.8	B	66.1	43.5	C	182.3	109.7
3/31-4/20	47.6	33.6	B	58.1	47.8	C	65.6	35.8	A	171.3	117.2
4/21-5/11	57.8	43.0	C	68.3	33.2	A	57.0	26.4	B	183.1	102.6
5/12-6/1	72.5	32.2	A	76.1	27.6	B	75.8	37.9	C	224.4	97.7
6/2-6/22	53.8	35.7	B	61.8	32.2	C	56.3	26.4	A	171.9	94.4
6/23-7/13	84.3	41.0	C	64.8	29.0	A	54.9	19.3	B	204.0	89.3
7/14-8/3	70.6	24.4	A	51.4	17.1	B	66.1	17.2	C	188.1	58.7
8/4-8/25	67.0	20.1	B	67.8	19.0	C	67.7	20.0	A	202.5	59.1
8/26-9/14	119.5	34.9	C	107.7	33.5	A	94.1	24.6	B	321.3	93.0
9/15-10/5	76.0	47.0	A	70.3	37.2	B	83.0	47.6	C	229.3	131.8
AVERAGE	66.0	37.1		63.8	32.8		64.4	32.0		194.2	101.9

A Platoon		B Platoon		C Platoon	
Average Initializations	68.4	Average Initializations	57.9	Average Initializations	67.9
Average 22's	34.9	Average 22's	27.9	Average 22's	39.1

* A "22" is a field-generated initialization.

of nonsupervisory patrol vehicles that were FLAIR equipped. However, if sampling indicates that a certain fraction of the nonsupervisory patrol vehicles are FLAIR-equipped over a shift period, one can assume that roughly the same fraction of the sergeant cars are FLAIR-equipped over the same period. Since patrol and patrol supervisor (sergeant) cars represent almost all of FLAIR's tracking time in the Third District, one can assign 20 vehicles (16 patrol plus four sergeant) as the value for a full contingent of FLAIR-equipped cars. Therefore, the average number of FLAIR-equipped cars can be estimated as 20 times the fraction of fielded patrol cars that were FLAIR-equipped.

As for the sample, assignment logs were tabulated for all watches for the middle week of each three-week shift period. The average fraction of patrol cars that were FLAIR-equipped was 0.88 over all the shift periods. The estimate of the average number of FLAIR-equipped cars is therefore 20 times that fraction. The value for each shift period is given in Table 5-3 along with the average total number of initializations performed per day during the same period. The number of initializations per car per day is obtained by dividing the total initializations per day by the average number of FLAIR-equipped cars fielded during the same 24-hour period. This average over all shift periods is 11.0 initializations per car per day, ranging from a low of 8.1 to a

Table 5-3

Initializations Per Car Per Day

(Tabulation of total initializations, fraction of FLAIR-equipped beat cars, and derived number of initializations per car per day, by shift period)

Shift Period	Total Initializations	Fraction of FLAIR-Equipped Beat Cars	Estimated Average Number of FLAIR Equipped Vehicles	Initializations Per Car Per Day
1/6-1/26	146.9	.91	18.2	8.1
1/27-2/16	144.3	.87	17.4	8.3
2/17-3/9	155.5	.84	16.8	9.3
3/10-3/30	182.3	.90	18.0	10.1
3/31-4/20	171.3	.79	15.8	10.8
4/21-5/11	183.1	.77	15.4	11.9
5/12-6/1	224.4	.80	16.0	14.0
6/2-6/22	171.9	.78	15.6	11.0
6/23-7/13	204.0	.86	17.2	11.9
7/14-8/3	188.1	.85	17.0	11.1
8/4-8/25	202.5	.70	14.0	14.5
8/26-9/14	321.3	.89	17.8	NA
9/15-10/5	229.3	1.00	20.0	11.5
AVERAGE	194.2	.88	17.6	11.0

high of 14.5[5] initializations per car per day.[6]

b. Variations in the rate of initializations. One impression gained from the trend of initializations per car per day given in Table 5-3 is the apparent degradation in the quality of system performance over the implementation time period. The number of initializations per car per day increases from a minimum of 8.1 to 14.5 in August. One may be tempted to attribute the increase in initializations per car per day to some decline in system performance, but another cause seems more likely. During January and February, several dispatchers developed the bad habit of clearing *V*'s and *W*'s off the board "en masse" by the use of the "status clear" button. It is proper to use this button to clear a *V* or *W* when the unit's location has been verified as the

[5]A value of 18.1 was found for the period August 26-September 14. This is not representative of normal system operation. At this time the MPD was turning over its fleet of patrol vehicles for new Novas. Contractual obligations required that the exchange of vehicles take place over a short period of time and that allowed very little time to reinstall and calibrate the FLAIR hardware. Consequently, due to the vehicle problems, many FLAIR-equipped units were on the street without properly calibrated tracking equipment. In an effort to compensate for these problems, dispatchers and field personnel alike had to maintain a higher than normal level of initializations.

[6]During the shift period of September 15 to October 5, PSE and MPD personnel conducted a special test of the system. The test, which will be explained in depth in Chapter VII, was an attempt to insure the best operating conditions for the AVM system. Efforts were made to have every patrol and sergeant car FLAIR-equipped and the best dispatchers on duty at the Third District console. During the test, data was specifically collected to enable an exact calculation of the initializations per car per day. The resulting figure, 11.28 initializations, corresponds favorably with the estimate of 11.5 found in Table 5-3 for that same period and helps to substantiate the accuracy of the estimates in Table 5-3.

same as that which is displayed. However, in this case, *V*'s and *W*'s were being cleared without any attempt to verify locations and to correct tracking errors. Not only did the use of this "status clear" capability mean that the number of initializations was low and that the system accuracy was severely decreased, it also meant that *V*'s and *W*'s appeared again much sooner than if they had been properly corrected. On March 19, 1975, the commander of the Communications Division issued a stern memo condemning this behavior, and initializations began to be treated in their proper manner. Presumably, the increased number of proper initializations, starting in the middle of the fourth shift period, played a major role in pushing the average number of initializations per car per day up to approximately 11 where they remained for the rest of Phase I.

5. Establishing acceptable levels for initialization rates. What type of inconvenience does the average of 11 initializations per car per day represent? Studies during the special test period indicated that the better dispatchers took, on the average, about 23 seconds to initialize a car. Over the Phase I test period, the 11 initializations per car per day represented an average of 84 minutes per day spent by District 3 dispatchers initializing cars for a 20-car fleet. In other words, approximately 5.8% of the dispatchers' time was spent correcting vehicle locations. This percentage may not affect dispatcher queuing times during slack periods, but it could become a problem during moderate to heavy workload periods.

In addition, such a large number of initializations presents an inconvenience and irritation to both dispatchers and patrolmen. If the same number of initializations were required when Phase II is implmented city-wide, it could mean up to 14 hours per day of dispatcher time could be required to initialize the 200 patrol cars[7]. Such a burden represents more than just an irritant, though. It is perceived by dispatchers and patrolmen to be a weakness of the system and influences the attitudes of those in the field towards the effectiveness of the FLAIR System. If the accuracy of the system is seriously questioned by the "men in the street" it will become more difficult to encourage them to use the system properly.

The present level of initializations required is considerably higher than was originally anticipated. Boeing has recognized the need for improvement and substantial changes are being made in the Phase II FLAIR System in the hopes of rectifying these problems. (These system modifications are discussed in Chapter IX.) However, in order to monitor accuracy performance in the future it is essential to establish a standard to measure the performance for the system. Eleven initializations per car per day is obviously very high and undesirable. On the other hand,

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[7] Calculated as follows:

[23 seconds (per initialization) ÷ 60^2 seconds (to convert to hours)] x 11.3 (initializations per day) x 200 patrol cars = 14.44 hours per day

it is probably unrealistic to hope for a standard as low as two initializations per car per day.[8] Perhaps a compromise in the range of four or five initializations per car per day is more realistic. (This would require approximately a two-or-three-to-one improvement in current performance.) We do not consider it the role of evaluators at this point to set an absolute standard. However, it is essential that some standard be set for the future and careful study is required by the St. Louis Police Department and Boeing in order to arrive at what level of performance is both reasonable and acceptable.

6. Variations in initializations by watch and by platoon. Over the Phase I implementation, the number of initializations per watch fluctuated greatly. However, an attempt to identify a pattern based on the time of day as represented by the watch on duty (day, afternoon, or night) failed. There was no indication that a busy watch (afternoon) had a consistently different pattern of initializations than the slowest (night) watch. As pointed out earlier, the average number of initializations for the thirteen shift periods between January 6 and October 5, 1975 was about the same for each watch: 66.0, 63.8, and 64.4 for day, afternoon and night watch respectively.

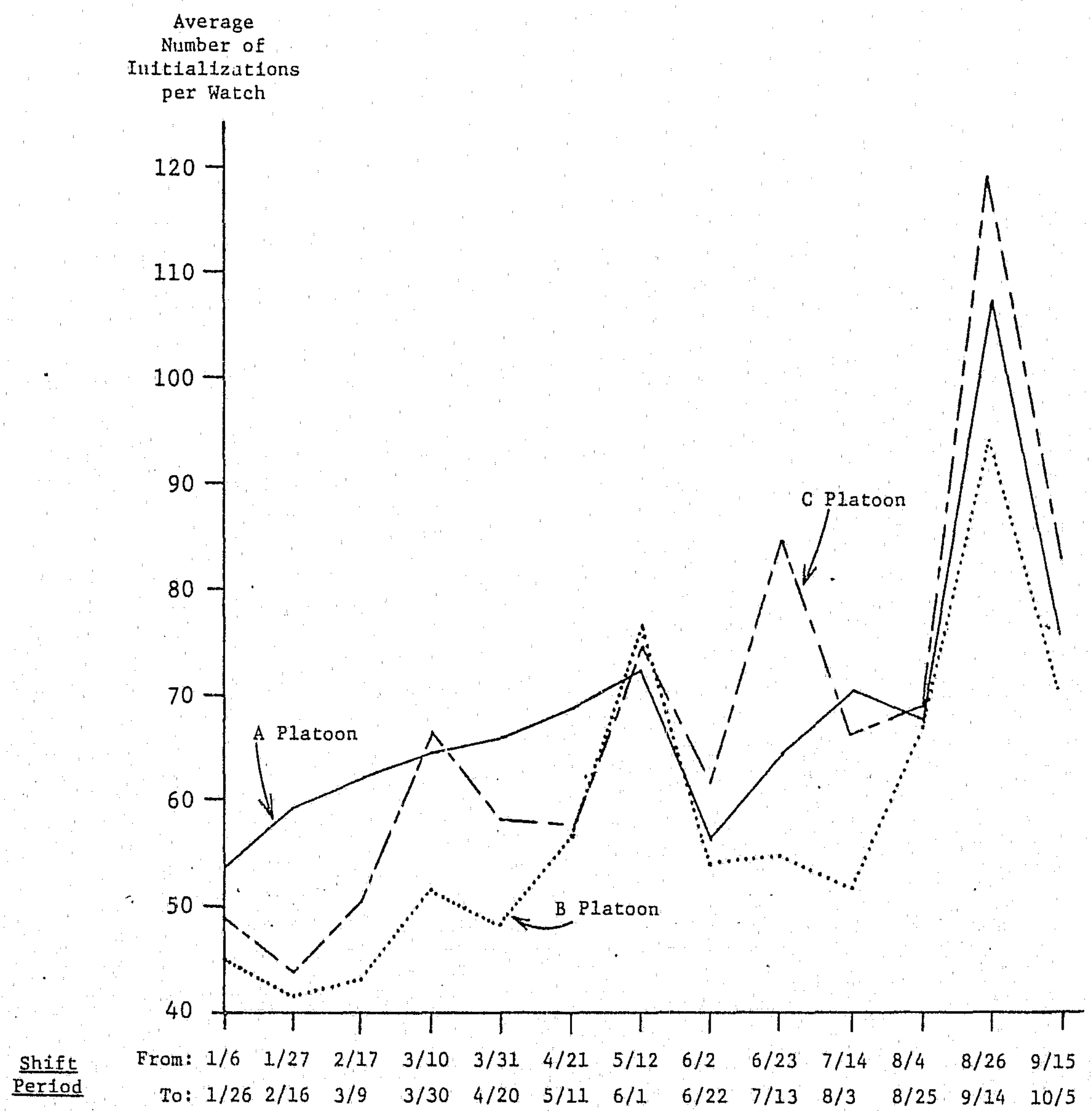
[8]This number was initially suggested as a "safe" level by some members of the evaluation committee early in the evaluation program.

However, it seems that a clearer pattern emerges when the average number of initializations per watch is compared to the platoon on duty. B platoon averaged 57.9 initializations per watch, whereas C platoon averaged 67.9 and A platoon averaged 68.4. This is further demonstrated by plotting the pattern of initializations by platoon (see Figure 5-1). In all but one shift period, fewer dispatcher initializations were performed when B platoon was on duty than when either of the other two platoons were on duty. Up until the end of May, A platoon usually performed the most initializations, but this pattern changed in the beginning of June, when C platoon began to perform more.

Since the same platoon of dispatchers always works with the same platoon of field personnel, it is difficult to completely attribute the cause of this pattern to either field personnel or dispatchers. However, this pattern seems to highlight the importance of behavioral, organizational and attitudinal factors in influencing the operational performance of the FLAIR System. For some reason the field personnel and dispatchers working with the B platoon have a consistently lower average number of initializations. It is unlikely that the FLAIR equipment performed better when B platoon was fielded. Thus, since the same equipment was being used by all three platoons and since the pattern seems to hold independent of time of day, it appears that other factors besides equipment--namely, some combination of the behavior, training, attitude, and/or organization of the dispatchers and patrolmen of

Figure 5-1

Average Number of Initializations per Watch by Platoon on Duty

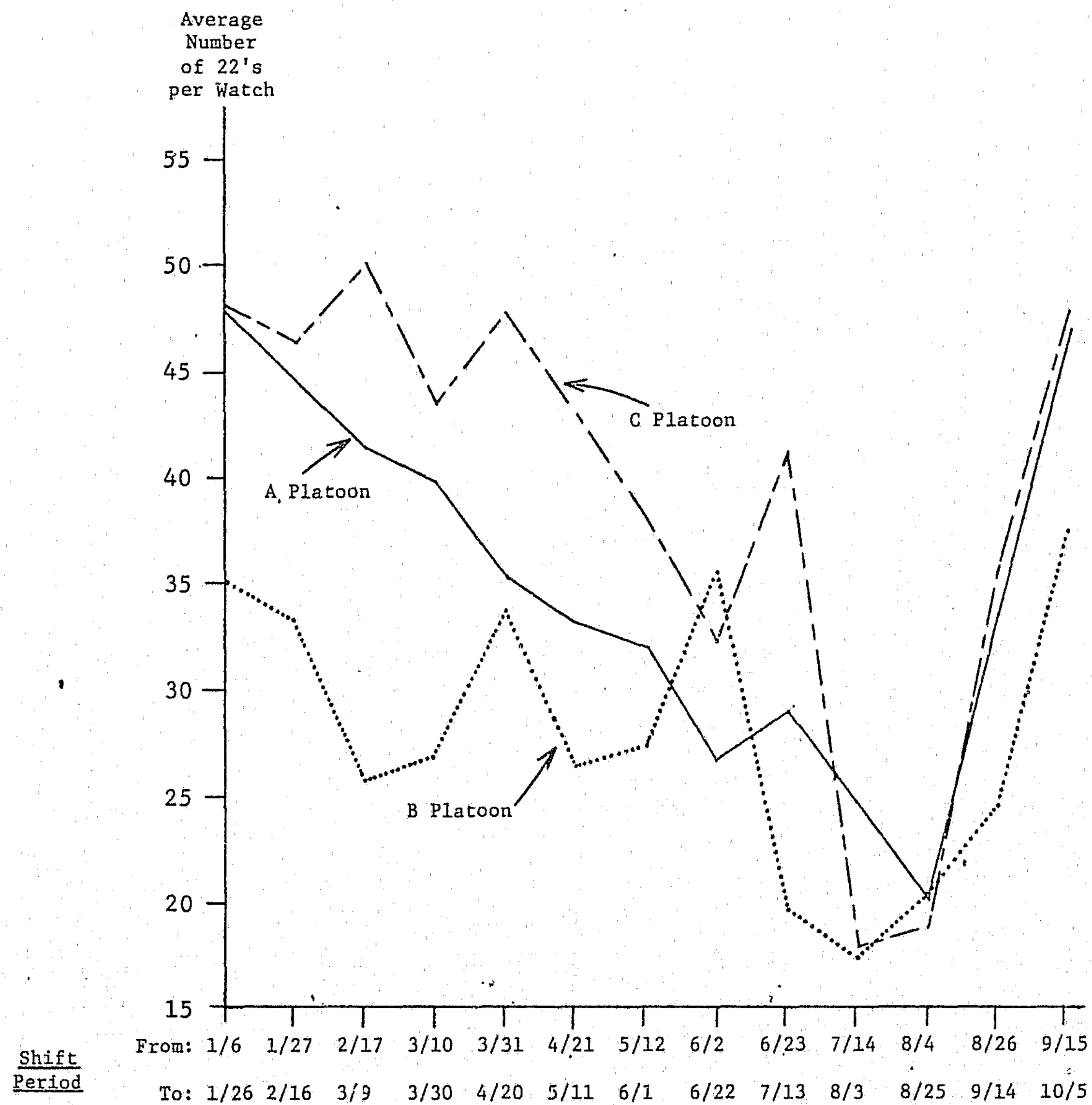


the various platoons--has an important influence on the operations of the FLAIR System as reflected in the number of initializations performed.

7. The influence of self-initializations. In order to reduce the number of initializations that dispatchers were called on to perform, a field initialization code was added to the FLAIR System. Field personnel were told to transmit a digital "22" code whenever they were directly in front of the district station. This signalled the computer to place the unit's image in front of the Third District station no matter where it thought the unit was previously. It was hoped that the introduction of this feature would lead to better system tracking, and consequently, less dispatcher workload. Data presented in the daily summaries suggest that this is a valid assumption. Figure 5-2 shows that the platoons behave differently in the number of times they will transmit 22 codes. During Phase I, B platoon consistently transmitted fewer 22 codes than either A or C platoons. C platoon appears to be the most conscientious in its use of the self-initialization code. The general decline in the number of 22's sent during Phase I could be a reflection of a decreasing interest in the experiment as it progressed through the summer. The jump in September can be attributed to renewed interest and attention due to the special three-week test conducted by PSE from September 15 to October 5, 1975. Once again, the variation in patterns between the three platoons reflects the importance of "people" influences on the system. In

Figure 5-2

Average Number of 22's per Watch
by Platoon on Duty



addition, the jump of self-initializations during the three-week test demonstrates the importance of special concern and training. During the test, FLAIR received special emphasis and patrolmen were encouraged to use the "22" code. The additional attention seems to have had a positive influence.

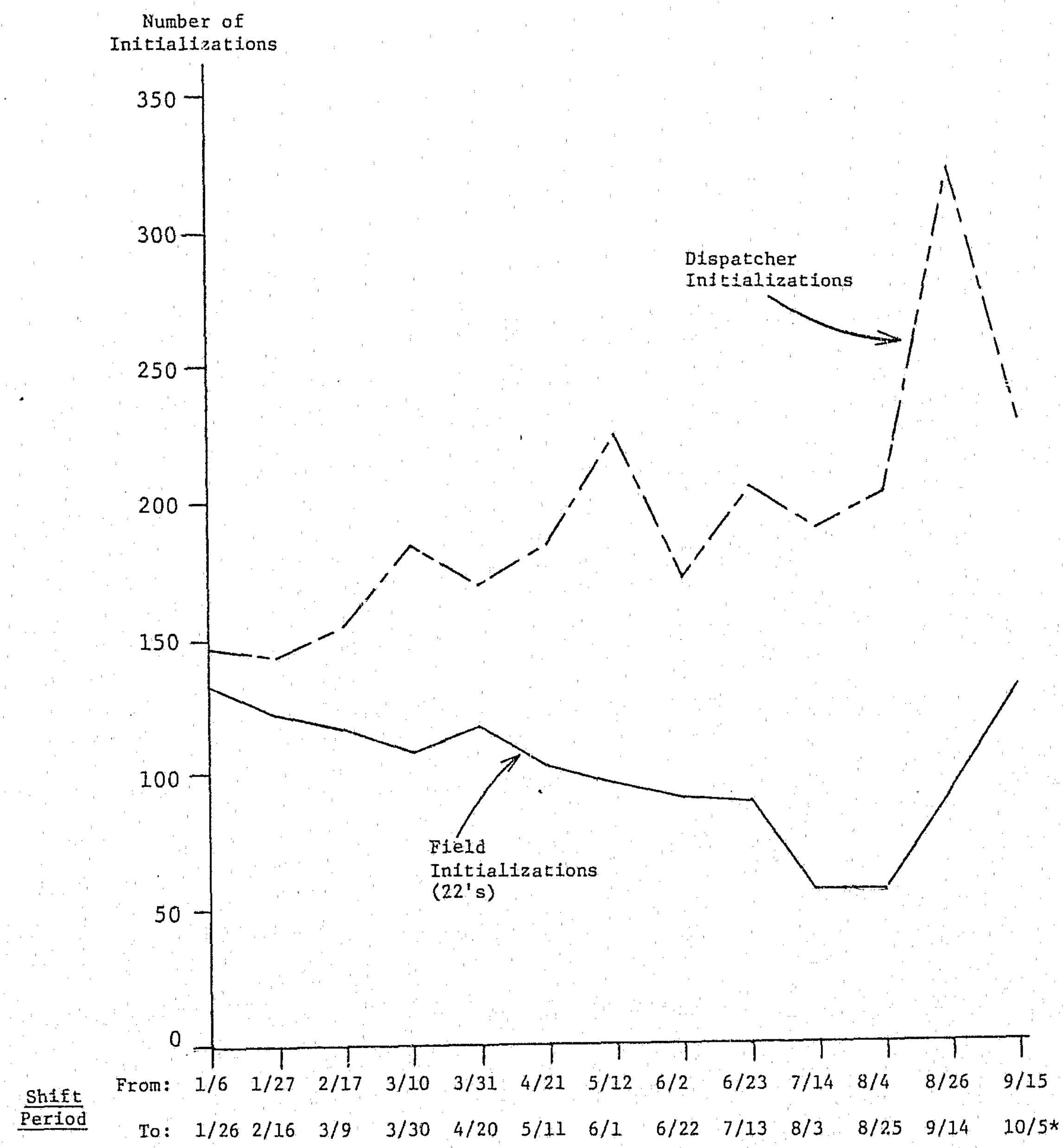
Does the use of the self-initializing code affect the number of initializations a dispatcher is called upon to perform? Data summarized in Figure 5-3 suggests that it does. In this figure, both average dispatcher initializations per day and field initializations (22's) per day are plotted. As the number of 22's decreased, the number of required initializations increased. Statistical correlations also confirm this visual perception. A Pearson's correlation coefficient was calculated using data from all thirteen shift periods.[9] The distribution of dispatcher initializations correlated at r = -.28 field initializations. When the August 28 - September 14 fleet turnover period is removed because of the special problems discussed earlier, this value increaed to r = -.66. This confirms the pattern that as 22's decrease, initializations increase in a roughly linear manner.

8. Two measures of lost car accuracy. The average number of initializations per car per day could be reported in another form.

[9]The Pearson's correlation coefficient is a measure of linear association between two data streams. An r of +1 indicates complete positive correlation and an r of -1 indicates a perfect negative correlation. A value for r whose absolute value is close to zero indicates no correlation.

<u>Figure 5-3</u>

<u>Plot of Dispatcher Initializations and</u>
<u>Field Initializations (22's) by Shift</u>
(Period for January 6 to October 5, 1975)



* Period of three-week test.

This other measure is the mean time between losses, which is simply the inverse of the frequency of lost cars. The mean time between losses indicates how often, on the average, an individual car is lost by the system. For instance, the Phase I average of 11.0 initializations per car per day represents an average of 11 losses in 24 hours for each car. This is the same as losing the car once every two hours and eleven minutes, or every 2.18 hours. Since this figure is the average value for time between losses of a particular vehicle it is called the mean time between losses. This type of measure will be the basis of a model developed in the next section to predict system performance as a function of tracking accuracy and local city geographic configuration.

B. Modeling Mean Time Between Losses

1. Motivation for this performance measure. As discussed in the introductory part of this Chapter, until recently common measures of system error for AVM systems have been given in feet or meters in statements such as "the mean error is 500 feet" or "at least 95 percent of all position estimations are within 200 meters of the true position." Computer-tracked AVM systems pose new problems, however, in analyzing, modeling, and interpreting system errors. In such systems, if a vehicle is being tracked properly, then the mean error is typically rather small, say on the order of a few car lengths rather than 100 or more meters. And, the estimated location of a properly tracked vehicle includes the direction of travel and almost always coincides with the vehicle's actual street of travel. So, for most police applications, the position estimation error of a properly tracked vehicle is not a significant factor.

However, virtually all vehicles on occasion execute a turn or pass through a magnetically active region or perform some other action that is not correctly interpreted by the tracking computer. If the computer cannot soon thereafter correct its "mistake," then the vehicle can no longer be tracked; it is said to be "lost." There is virtually no positional estimation information available for a lost car, and thus the region of uncertainty of its position (the maximum possible error) is usually large, say equalling a beat or sector or district or perhaps even the entire city (and certainly more than a few hundred meters).

Thus one is motivated to define a nondistance-oriented performance measure that captures the essence of the "being lost" phenomenon, and this is the <u>mean time between losses</u> of a vehicle. When considering the appropriateness of this performance measure, it is helpful to realize that a FLAIR-equipped vehicle repeatedly experiences the following three states in succession:

<u>State 1</u>: Vehicle is properly tracked.

<u>State 2</u>: Vehicle has executed a turn or other action that has not been correctly interpreted by the tracking computer (and which the computer cannot later correct). However, the computer does not yet "realize" that the vehicle is lost.

Initialization

<u>State 3</u>: Computer has indicated that it "believes" the vehicle is lost. However, the dispatcher has not yet initialized and no "22" has been transmitted (for automatic initialization).

Our performance measure--the mean time between losses--is the mean time between successive entries to State 3. In modeling this performance measure we assume that the mean time in State 1 (being properly tracked) is rather large--say greater than two hours--and the times in each of the other two states is comparatively small--say on the order of several minutes. So, the model for mean time between losses focused on in-the-field performance of the FLAIR System and ignores delays due to States 2 and 3. Time spent in these two states would tend to increase mean time between losses but drastically decrease system accuracy by allowing a significant amount of time during which no reliable position estimation information is available

for the vehicle. If the assumption of little time in States 2 and 3 is to be valid, the tracking software would have to "recognize" tracking errors quickly (a good assumption for most cities[10]) and dispatchers would have to initialize lost cars quickly (an assumption that depends upon training, motivation and workload).

This part of Chapter V focuses on a model that predicts the mean time between losses as a function of parameters that vary by city and by design specifications of the AVM system (assumed to be a computer-tracked, dead-reckoning system).[11] Our discussion is to the extent possible non-technical, relying heavily on the mathematical results of Appendix A, Operational Model for Predicting Time Between Losses of a FLAIR-Tracked Vehicle, and Appendix B, Mathematical Analysis for Implementing Mean Time Between Losses Model. As illustrated in Figure 5-4, we first outline the basic model derived in Appendix A, then describe heuristically the effects on error due to quantization (in distance, angle and time). A five-step procedure will then be developed that is applicable for estimating the loss probability. This procedure requires, among other things, estimates of the magnitudes of systematic error and random error, which are developed for District 3 in St. Louis. Then the five-step procedure is applied to St. Louis, recognizing that several of the parameters will change significantly in value during

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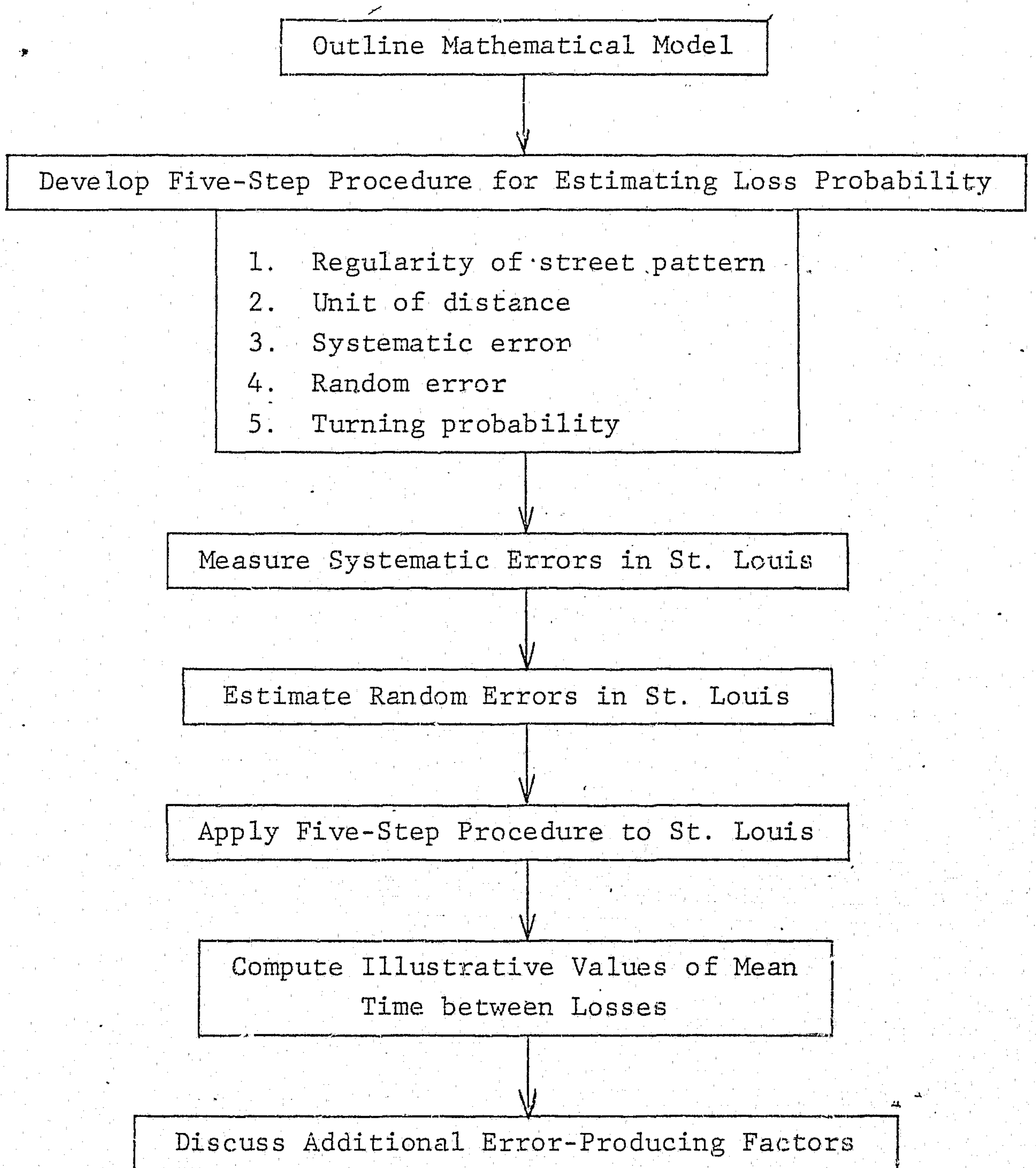
[10] For cities having perfectly regular street patterns (such as Wichita, Kansas and Phoenix, Arizona), the FLAIR software may require significant time before recognizing a tracking error.

[11] When applying this model to other cities, the reader should be mindful that city-specific software may be applied that could alter the results.

Figure 5-4

Organization of Chapter V, Section B



Phase II. An attempt is made to tie these calculations back to the empirically measured frequency of lost cars discussed in the first part of this Chapter.

As a result of developing the model and simultaneously performing the evaluation in Phase I, we have found that there are at least four additional error-producing factors <u>not</u> included in the model: Open-loop tracking, missed radio transmissions, magnetic anomalies, and proneness to subvertability.[12] Thus, much as the FLAIR System evaluated here represents work in progress, so too does the model which at this time can be considered to be a lower-bound model for predicting frequency of lost cars. The effects of the additional error factors and plans for their inclusion in Phase II conclude the Chapter.

2. Outline of mathematical model. Several mathematical models for predicting the mean time between losses of a FLAIR-equipped vehicle are developed in Appendix A. The first is a basic model which ignores effects on error due to quantization, and the others represent additions to the basic model that incorporate effects of time, distance, and angular quantization. Their purpose is to allow potential consumers of computer-tracked AVM systems to examine the probable first-order effects on system performance of certain design features and certain geographical characteristics of the city in question.

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[12] These terms are precisely defined later in the chapter and elsewhere in this report.

a. Basic model. The simplified version of system operation depicted by the basic model focuses solely on continuous tracking of a vehicle traversing the city's streets. Suppose a tracked vehicle leaves an intersection (at which it has turned) at a particular point in time. At that intersection its exact position is known with certainty. It continues to travel along the same street through a number of intersections, making no turns. As it travels, it accumulates an error in position estimation only along the street of travel; the fact that the tracking algorithm automatically places the vehicle back on the street, should it drift off due to heading sensor errors, means that the position estimation error is a one-dimensional rather than a two-dimensional error. This one-dimensional error is caused by two factors: 1) random error due to tire slippage, irregular driving patterns, computer map inaccuracies, etc.; and 2) systematic error due to tire wear, temperature, or other factors that could change the circumference of the tire and thus alter the accuracy of the odometer in a systematic (persistent) way.

Both types of error tend to become larger in magnitude as the vehicle drives farther from the last intersection at which it turned. With the systematic error, the bias from the true position (the average value of the systematic error) increases in direct proportion to the distance from the last intersection of a turn. Thus, if this bias is 40 feet after driving 1,000 feet, it would be 400 feet after driving 10,000 feet. With the random error, the

variance of the position estimate grows in direct proportion to the distance from the last intersection of a turn. If this variance is 100 $(\text{ft.})^2$ after driving 1,000 feet (indicating a deviation about the mean or standard deviation of 10 feet), then it would be 1,000 $(\text{ft.})^2$ after driving 10,000 feet (indicating a standard deviation of $\sqrt{1,000} = 10\sqrt{10} \approx 31.4$ feet).

Since these two measures of error grow in direct proportion to distance travelled since the last turn, the system tends to operate best when turns are made frequently. The greater the frequency of turns, the less the one-dimensional error can build up.

After traveling a certain distance from the last intersection of a turn, the vehicle finally turns at a new intersection. This action is the key event in the operation of the FLAIR System or any computer-tracked vehicle location system. The computer-tracking algorithm will detect that a turn has occurred due to the sudden change in the reading of the heading sensor. The key question which the algorithm must answer is this: "Onto which street did the vehicle turn?" The correct answering of this question would be no problem if error did not build up since the last turn. And, if the correct street is selected by the algorithm, all of the accumulated error since the last turn is washed away[13], as the turn has effectively initialized the vehicle's location.

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[13] As shown in Appendix A, time and distance quantization can cause a limited amount of position uncertainty immediately following a correctly interpreted turn. But this error is not a cumulative error.

However, if a significant error has built up, then the vehicle could be estimated to be closer to a street other than the one it has turned onto. Then the algorithm will "place" the vehicle on an incorrect street and resume (incorrect) tracking from there. Such an error, if not corrected, results soon thereafter in the vehicle executing turns that appear infeasible to the algorithm (the infeasibility deriving from the particular street patterns of the city). The algorithm then flags that the vehicle is <u>lost</u>; this is the major event in the system.

The mathematical model portrays this event by a probability, p, of vehicle loss at a random intersection at which a turn occurs. For instance, if p is found to equal 1/200, then (on the average) the vehicle becomes lost once every 200 turns.

Appendix A derives a basic model along the lines outlined above and a number of additions to the basic model to incorporate quantization aspects of system operation.

In order to compute the mean time between losses, the estimation of p from the basic model (or any of its variants) is used in the following equation:

$$\overline{T}_L = \frac{\overline{\ell}}{srp} \tag{1}$$

where

$\overline{T}_L$ = mean time between losses of a FLAIR-equipped vehicle

$\overline{\ell}$ = mean block length

s = average speed of tracked vehicle

r = probability that the vehicle executes a turn at any random intersection

p = probability that vehicle will become lost on any random turn that it executes.

As an example, suppose

$$\bar{\ell} = 528 \text{ feet} = 0.1 \text{ mile}$$

$$s = 10 \text{ mph}$$

$$r = 1/5$$

$$p = 0.01$$

These values imply that the average block has length 0.1 miles, that vehicles travel 10 mph (on the average), that vehicles execute turns at one out of five intersections (on the average) and that the probability of becoming lost on any given turn is one out of 100. (In practice, this latter value depends on the values of the first three quantities plus some other factors such as the variance of block lengths.) Then, the estimated mean time between losses of a vehicle is

$$\bar{T}_L = \frac{0.1}{10\ (\frac{1}{5})\ (0.01)} = 5 \text{ hours.}$$

In applying Equation (1), the most difficult task is to obtain an estimate of p, the loss probability at a random turn. As indicated above, the Appendix develops one basic model for estimating p, and then discusses ways in which p would be increased over that predicted by the basic model due to the finite <u>polling</u> rate of the

vehicle's status and such complications as quantizing direction of travel and distance travelled. It is important to note, however, that whatever one's procedure for estimating p, Equation (1) holds in general.

To summarize our discussion to this point, the basic model incorporates the following factors.

- A component of vehicle drift from its true position due to random error. This type of error is due to many factors including slippage on the road, irregular (non-straight line) driving patterns, inaccuracies in the computer map, and, if uncorrected in the tracking algorithm, speed variations which change the tire circumference. The net effect of such random error is summarized in the parameter σ^2 which is the mean square random displacement per unit of distance travelled.

- A second, often dominating component of vehicle drift called systematic error. This type of error creates a bias in the odometer readings and its magnitude is determined by temperature, tire wear and pressure, and speed (when the effect of speed on drift is viewed as correctable). The bias term is γ, which is the mean systematic displacement per unit of distance travelled.

- A simple description of how the vehicle is driven, as summarized by the average speed of travel and by the probability that the vehicle will execute a turn at a random intersection. The lower this probability, the greater the accumulated drift is likely to be at the next turn (due to the longer distance for error to build up) and thus the higher the probability of loss.

b. Effects of quantization. The basic model assumes continuous tracking of the vehicle in time and space. In practice

the time and space tracking are quantized (that is, continuously distributed variables are assigned one of only a given number of possible values). The time quantization interval corresponds to the inverse of the polling rate per vehicle and the spatial quantization occurs both in the odometer (distance) and the heading sensor (angle). Appendix A discusses the ways in which these three types of quantization increase the error probability predicted by the basic model.

Very briefly summarizing some of the results on quantization from Appendix A, we have the following:

- Angular quantization. This information is transmitted by a binary code, such as 1011, which might signify a heading angle of 280.5°. The number of binary digits (bits) used to transmit this information (four in the case of 1011) can markedly affect vehicular loss probability. One can virtually guarantee no increase in loss probability due to angular quantization if the corresponding number of bits is sufficiently large so that there is no possible ambiguity in interpreting a turn at any intersection of the city.[14] Thus, the number of bits has to be large enough to be able to distinguish between streets in the city diverging at small angles.

- Distance quantization. In a manner paralleling angular information, distance information is also transmitted digitally, therefore necessitating a distance quantization interval (d_Q). Thus, in a moving vehicle, if the odometer reading has just changed (say from 1010 to 1011, an addition of 1 bit to the previous reading), then the next odometer change will occur after the vehicle has travelled a distance equal to d_Q. If d_Q is about the same size as a block length, then this type of quantization could severely increase loss probability. However, typically

[14] This statement ignores errors in the heading sensor itself, such as those caused by random magnetic noise.

d_Q is 25 feet or less (and there are few blocks less than 100 feet in length). In such a case, the effect of distance quantization is to add to the variance of the random error a term proportional to the square of d_Q.

- Time quantization. Like angular and distance quantizations, time quantization too causes additional uncertainty in the estimate of a vehicle's location and this increases the loss probability p. The unit of time quantization is t_Q, which means the vehicle is polled every t_Q seconds to obtain new distance and heading readings. In the FLAIR system t_Q has been either one or two seconds. For those turns that are tracked correctly, the magnitude of t_Q determines the size of a "window of positional uncertainty" which characterizes the vehicle's estimated position until it next turns; this can often be crudely characterized as an increase in the variance of the estimate of position. However, the window of positional uncertainty can also have a direct effect on contributing to an incorrect interpretation of a turn; the larger the window (which means the larger the sampling interval), the larger is the probability of incorrect decision.

3. Procedure for estimating the loss probability. In this section we outline how one would utilize the mathematical model(s) developed in Appendix A together with empirical data to obtain an independent estimate of vehicle loss probability p. Once obtained, this number can be entered into Equation (1) to provide an estimate of the mean time between losses of a vehicle. We illustrate the procedure with initial data from St. Louis (District 3), but since the data were derived from only a Phase I implementation, we must await the Phase II (final) implementation for more

conclusive results. In addition, the Phase II model will include in some way the additional error-producing factors discussed in the introduction to this section.

Precalculated tables of the loss probability are given as Table A-1 in Appendix A. We use that table in our estimation of the loss probability.

a. Regularity of street pattern. Each page in the Table is calculated for a particular value of q, which is a measure of the regularity or irregularity of the street pattern. The parameter q can take on values between 0 and 1. A value of q=1 corresponds to a situation in which the streets are designed in a regular square grid pattern, each block being the same length. This might be an accurate depiction of the streets in Wichita, Phoenix, Tucson and several other midwestern and far-western cities. At the other extreme, suppose q were very small, say q=0.05 (it is impossible for q to equal zero exactly). This would correspond to an almost totally random positioning of streets, with adjacent intersections positioned almost as randomly in space as the arrivals of police calls for service in time. Intermediate values of q correspond to intermediate degrees of regularity or irregularity in the street pattern, with higher values indicating greater regularity.

A key question is "How do we obtain a numerical value for q?" The procedure, as shown in Appendix A, is simple and straightforward. We measure (on a map) the mean $\overline{\ell}$ and variance σ_{ℓ}^2 of a representative

sample of block lengths in the city. Then, the regularity of the street pattern q is found to depend on the ratio of the standard deviation σ to the mean $\overline{\ell}$, according to the following equation.

$$q = 1 - \left(\frac{\sigma_\ell}{\overline{\ell}}\right)^2. \qquad (2)$$

Thus, when there is no variability in block lengths, $\sigma_\ell=0$ and q=1. When the variability is "moderate," the standard deviation being say 50 percent of the mean, then $q=1-(.5)^2=.75$. When the variability is large, the standard deviation reaching 90 percent of the mean, then $q=1-(.9)^2=0.19$.

b. Unit of distance. The second step in using the tables of Appendix A is to define the unit of distance for the situation in question. We call this parameter b. The tables are not computed on a standard unit of distance such as feet, meters, miles, or kilometers. Rather, the unit of distance b depends on $\overline{\ell}$ and σ_ℓ^2 by the following equation:

$$b = \overline{\ell}\left(1 - \left(\frac{\sigma_\ell}{\overline{\ell}}\right)^2\right).$$

or,

$$b = \overline{\ell}q.$$

With no variability in block lengths, $\sigma_\ell = 0$ and the unit of distance equals the block length $\overline{\ell}$ (say $\overline{\ell}$ = 500 feet). With moderate variability, where $\sigma_\ell = 0.5\overline{\ell}$, then q = 3/4 and $b = (3/4)\overline{\ell}$ (say (3/4) (500) feet = 375 feet). With large variability, with $\sigma_\ell = 0.9\overline{\ell}$, then q = 0.19 and $b = 0.19\overline{\ell}$ (say 0.19(500) feet = 95 feet).

While computation of b is important, some of the linear modeling work can be carried out in terms of percentages (such as the percent of systematic error per unit of distance travelled), thereby avoiding the need to identify the unit of distance.

c. Systematic error. The first column in the Table contains a numerical value for the parameter

γ = Mean systematic displacement from the true position (the bias) per unit of distance travelled.

As discussed previously, this systematic error parameter is due to temperature, tire wear and pressure, and speed (when the effect of speed on displacement is viewed as correctable). In most implementations the value of γ could vary by vehicle, time of day, and (as indicated) even speed. Thus the loss probability p should most likely be calculated for a range of values of γ.

How does one estimate a value for γ in a particular situation? One way is to drive the test vehicle repeatedly (under identical conditions) over a straight line test course of premeasured length. Record the odometer reading resulting from each run. Then an estimate of γ, say $\hat{\gamma}$, is obtained as follows:

$$\hat{\gamma} = \frac{\text{average of odometer readings - true length of test course}}{\text{true length of test course}}$$

As an example, if the test course were 10,000 feet in length and the average of the odometer readings (when converted to feet) were 10,050 feet, then

$$\hat{\gamma} = \frac{10{,}050 - 10{,}000}{10{,}000} = \frac{5}{1{,}000} = 0.005.$$

An odometer with $\hat{\gamma} = 0.005$ has a consistent bias of one-half of one percent (in the positive direction).

d. Random error. The second column in the Table in Appendix A contains numerical values for the parameter

σ^2 = variance of the random displacement from true position per unit of distance travelled.

We call this the incremental variance. As outlined earlier, the value of this error parameter reflects random error in both the odometer and the computer map. The odometer error is caused by tire slippage on the road, irregular (non-straight line) driving patterns and, if viewed as uncorrectable, speed variations that change tire circumference. Random error caused by the computer map is due mainly to the computer's "model" of the street grid. Basically each street, no matter how straight or winding, no matter how narrow or wide, is modelled in the computer as a sequence of connected straight-line ("center-line") segments. Because of this, the travel distance as measured in the computer by adding the lengths of the straight-line segments may not equal the actual travel distance experienced on the street. Errors can occur because of the following reasons:

- Approximating any smoothly winding street (say in the Tower Grove Park area in St. Louis) by a sequence of straight-line segments results in measured travel distances different from actual distances;

- Approximating any road by a one-dimensional model (a line) neglects the two-dimensionality[15] of the road. Especially along a wide non-straight road (say Interstate 44 or even Gravois Avenue) the travel distance in one direction is likely to differ from that in the other direction. Even in the same direction on a non-straight road, travel distance is likely to depend on lane of travel.

- Corners can be turned sharply or broadly, yielding travel distances different from those estimated by the straight-line model.

Because of all these possible sources of random error within or due to the computer map, the random error term σ^2 combines random error of the odometer and of the computer map.

Like γ, the value of the parameter σ could vary by vehicle, time of day, and driving patterns of the occupants. Thus, the loss probability should also be calculated for several plausible values of σ.

To measure σ, one should identify several nonoverlapping test courses within the city whose traversal would be "typical" of the driving that a police vehicle would experience. The courses should include turns, both right angle turns and other types that may be experienced in the city; they should include straight streets and winding streets, in approximately the same proportion as found in the city. The "actual length" of the courses should be computed by summing the lengths contained in the computer map, which models any particular course as a sequence of straight-line segments.

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[15] Some cities have a significant number of hills that would add a third dimension to any accurate street grid model. These cities include San Francisco, Seattle and Pittsburgh.

Define the parameters of this measurement process as follows:

N = total number of test courses

d_i = actual length of i^{th} course, as computed by summing the lengths of the corresponding individual straight-line street segments of the computer map

$$D = \sum_{i=1}^{N} d_i$$

$L(d_i)$ = measured length of i^{th} course (as measured by the odometer)

γd_i = systematic error term (bias), which must be subtracted from the measured length

$L(d_i) - \gamma d_i$ = unbiased measured length

Using these definitions, there is a simple formula (derived in Appendix B) for obtaining an estimate of σ^2. Calling the estimate $\check{\sigma}^2$, the formula is

$$\check{\sigma}^2 = \frac{1}{D} \sum_{i=1}^{N} (L(d_i) - \gamma d_i - d_i)^2 \tag{3}$$

An example using hypothetical data with $N = 12$ test courses is illustrated in Table 5-4. The column entries in the Table, left to right, are test course number (i), actual length of course d_i, measured length of course $L(d_i)$, the bias term γd_i (assuming a one-half of one percent bias; i.e., $\gamma = 0.005$), the unbiased measured length $(L(d_i) - \gamma d_i)$ and squared deviation $[(L(d_i) - \gamma d_i - d_i)^2]$. The sum of all the numbers of the last (right-most) column, divided by the total distance $D = 62.236$ miles, gives us an estimate for σ^2:

$$\check{\sigma}^2 = \frac{0.148471}{62.236}$$

$$\check{\sigma}^2 \approx 0.00239$$

Table 5-4

Illustrative Hypothetical Data Used for Estimating σ^2

Course Number (i)	Actual Length (mi.) (d_i)	Measured Length (mi.) $L(d_i)$	Bias* (γd_i)	Unbiased Measured Length ($L(d_i)-\gamma d_i$)	Squared Deviation $(L(d_i)-\gamma d_i-d_i)^2$
1	2.603	2.585	0.013	2.572	$(0.031)^2$ = .000961
2	5.242	5.142	0.026	5.116	$(0.126)^2$ = .015876
3	4.051	4.103	0.020	4.083	$(0.032)^2$ = .001024
4	10.373	10.379	0.052	10.327	$(0.046)^2$ = .002116
5	9.639	10.030	0.048	9.982	$(0.343)^2$ = .117649
6	1.974	2.010	0.010	2.000	$(0.026)^2$ = .000676
7	2.812	2.780	0.014	2.766	$(0.046)^2$ = .002116
8	5.009	4,932	0.025	4.907	$(0.102)^2$ = .010404
9	2.300	2.210	0.012	2.198	$(0.102)^2$ = .010404
10	1.592	1.502	0.008	1.494	$(0.098)^2$ = .009604
11	9.277	9.103	0.046	9.057	$(0.220)^2$ = .048400
12	7.364	7.230	0.037	7.193	$(0.171)^2$ = .029241
	62.235**				0.148471

* The bias is assumed to be one-half of one percent; i.e., $\gamma = 0.005$.

** Total actual mileage.

Thus, the standard deviation is estimated to be

$$\check{\sigma} \approx 0.049 \text{ (mi.)}$$

One must convert $\hat{\sigma}$ to units of distance b before consulting the Table in Appendix A. This conversion is straightforward and is done in the following way: Suppose we have two units of distance, d_1 and d_2, which we measure in feet. For instance, we could have $d_1 = 5{,}280$ feet and $d_2 = 500$ feet. Associated with the units of distance are incremental variances $\sigma_1{}^2$ and $\sigma_2{}^2$, respectively, each describing the same system. The conversion process corresponds to expressing $\sigma_2{}^2$ in terms of $\sigma_1{}^2$. Suppose the tracked vehicle travels x_1 units of d_1-distance, which is equal to x_2 units of d_2-distance. Expressing both distances in feet, we must have

$$x_1 d_1 = x_2 d_2$$

or

$$x_2 = x_1 (d_1/d_2).$$

The corresponding variances are $\sigma_1{}^2 x_2$, which are in units of $d_1{}^2$ and $d_2{}^2$, respectively. When converted to feet, we must have the two variances equal,

$$\sigma_1{}^2 x_1 d_1{}^2 = \sigma_2{}^2 x_2 d_2{}^2$$

or

$$\sigma_1{}^2 x_1 d_1{}^2 = \sigma_2{}^2 x_1 \left(\frac{d_1}{d_2}\right) d_2{}^2,$$

which simplifies to

$$\sigma_2{}^2 = \frac{d_1}{d_2}\, \sigma^2$$

or

$$\boxed{\sigma_2 = \sigma_1 \sqrt{\frac{d_1}{d_2}}} \qquad (4)$$

For our example, with d_1 = 5,280 feet and d_2 = 500 feet,

$$\sigma_2 = \sigma_1 \frac{5,280}{500} = \sigma_1 \; 10.56$$

$$\approx 3.25\sigma_1$$

Thus, if $\sigma_1 \approx 0.049$(mi.), then in units of 500 feet

$$\sigma_2 = (3.25)().049) = 0.15925.$$

e. Turning probability. The last parameter required to use the Table for the loss probability p in Appendix A is r, the probability of a vehicle turning at a random intersection. One could actually obtain empirical estimates of r by driving with the officers in a police vehicle and counting both the number of intersections driven through and the number of turns executed. The estimate for r would be

$$\check{r} = \frac{\text{number of turns executed}}{\text{total number of intersections driven through}}$$

However, the value for r will probably depend on the driver, the weather conditions, the local crime conditions, and the local street layout. So, it is probably a good idea to calculate p for a range of values of r.

f. Summary of five-step procedure. We now summarize the steps required to estimate the vehicle loss probability:

Step 1: From a city map, compute the mean $\bar{\ell}$ and the variance σ_ℓ^2 of the block lengths in the city (or part of the city in question). Use these numbers to compute a value for the regularity of street spacings, $q = 1 - (\frac{\sigma_\ell}{\ell})^2$.

Step 2: Compute the unit of distance to be used in the calculations, $b = \bar{\ell}q$.

Step 3: By driving repeatedly over a straight-line test course, obtain an estimate of the systematic bias (error) for a given car per unit of distance travelled:

$$\hat{\gamma} = \frac{\text{average of odometer readings-true length of test course}}{\text{true length of test course}}$$

Step 4: By driving over N different test courses, representing typical driving patterns, obtain an estimate of the mean square deviation (from the mean) per unit of distance travelled:

$$\check{\sigma}^2 = \frac{1}{D} \sum_{i=1}^{N} (L(d_i) - \gamma d_i - d_i)^2,$$

where the parameters are defined in the text. (Here σ must be converted to units of b, according to Equation (4).)

Step 5: Obtain an estimate for the value of r, the turning probability at an intersection. Monitoring the movements of one or more vehicles, the estimate for r is

$$\check{r} = \frac{\text{number of turns executed}}{\text{total number of intersections driven through}}$$

4. Measuring systematic errors in St. Louis. Step 3 in the five-step procedure requires estimation of the systematic error one is likely to encounter in the AVM system. This section reports on some empirical measurements whose purpose was to obtain the range of plausible values of systematic error for the FLAIR

System (Phase I version). Two sources of systematic error are examined: that due to tire wear, and that due to speed changes.

a. Old versus new tires. The FLAIR mobile odometer operates by counting the number of brake cooling fins which pass by on the left front wheel, dividing this by the appropriate number of fins which would pass in 25 feet of travel, and reporting a "count" each time the division indicates that another such group of fins has accumulated. Calibration factors for each vehicle are implemented in software to inform tracking routines as to exactly how much distance is travelled per count. FLAIR printouts list odometer counts (mod 16) in each group of transmitted data. Several situations encountered in normal driving could affect the number of counts per mile (ct/mi) reported by the mobile odometer; one of these is tire wear which intuitively should increase counts per mile since tire radius is reduced.

On August 13 and 14, 1975, studies were undertaken to quantify this effect on FLAIR vehicles with tires of two differing constructions--steel radials and rayon belted. A section of Arsenal Street between Seventh Avenue and Maury Avenue in District 3 was selected for six test runs (three in each direction) with both new and old tires of the two types fitted on front wheels. Total FLAIR odometer counts for each run were obtained from system printouts, and actual driving distance was recorded to within ± .001 mile by a fifth wheel odometer, allowing accurate calculation of counts per mile. See Table 5-5 for test data.

Table 5-5

Systematic Tests

Indicated travel distance, old versus new tires*

	Rayon Belted		Steel Radial	
Tire type	Tread depth	FLAIR counts per mile**	Tread depth	FLAIR counts per mile**
New tires	13/32"	212.05	12/32"	213.58
Old tires	5/32"	216.27	3/32"	216.20
% change in indicated mileage	2% (106 ft/mile)		1.2% (63 ft/mile)	

Old tires, with smaller wheel diameter, will show more indicated travel distance than new tires.

Indicated travel distance versus speed***

		Rayon Belted		Steel Radial	
Speed, mph	Direction	FLAIR counts per mile**	% change	FLAIR counts per mile**	% change
30	east	214.36	ref.		
30	west	214.66	ref.		
35-40	east	213.32	.5	213.85	ref.
40-45	west	212.21	1.15		
47-50	east	211.95	1.4	213.85	0
48-55	west	210.92	1.8	213.62	.1
53-60	east	210.39	1.9	213.40	.21
53-65	west	209.98	2.2	213.25	.28
62-70	east	208.72	2.7		
64-75	west	208.94	2.7		

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*Test made in Arsenal Street, between Seventh Avenue and Maury Avenue, District 3. Speed was under 30 mph.

**Distance travelled was between fixed points. From a standing start cars accelerated to indicated speed and then came to a quick stop. FLAIR counts per mile were determined from total FLAIR odometer reading (from computer print out) divided by distance travelled (from 5th wheel).

***Test made on Interstate Highway 44 between Mississippi and Kings highway.

The average counts per mile for worn rayon belted tires exceeded that for new tires of the same brand and type by 2%. Pressures were 28 psi for both old and new tires; tread depth was 5/32 inch for the old set and 13/32 inches for the new set on the left front tire. Comparing old and new steel radials of the same brand and type, it was found that the worn set generated 1.2% more counts per mile than the new set. Tire pressures were 29 psi in both cases, with a tread depth of 3/32 in. and 12/32 in. on the old and new left front tires, respectively. In general, then, if software calibration factors were entered for new tires and not subsequently updated for tire wear, one could expect persistent overestimates on the order of 65 to 105 feet (depending on tire type) per mile in FLAIR odometer reports near the end of the tire's lifetime. Given observed tracking accuracies of 50 to 100 feet, and considerable daily vehicle mileage, this systematic error is significant and should be resolved, perhaps through regular odometer recalibration.[16]

To verify the reasonableness of these experimental results with those expected from simple geometrical considerations, consider that the "average" tire is circular with diameter D (inches) or circumference πD. A reduction in tread depth of Δ inches reduces

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[16] Such recalibrations could be performed automatically by the tracking software. The computer could store the average distance "overshoot" or "undershoot" experienced with each car at the moment of making a turn. When either is appreciably different from zero, its value could be used to update the current value of the calibration factor.

tire diameter by 2Δ inches, thereby reducing the circumference by $2\Delta\pi$ inches. The fractional change in circumference, which corresponds to the fractional change in rate of rotation, is then

$$\frac{2\Delta\pi}{\pi D} = \frac{2\Delta}{D}$$

Suppose the typical tire is 28 inches in diameter. The difference in tread depths for new and worn rayon-belted tires was 8/32 = ¼ inch. Thus the percentage change in "measured" mileage should be about

$$\frac{2(1/4)}{28} \times 100\% = \frac{1}{56} \times 100\% \approx 1.8\%$$

So, the first result checks with geometrical considerations (within the tolerances of the measurement devices employed). The second result, for steel belted radials, also implies a change in odometer readings by about two percent, but the measured change was somewhat less (1.2%). Perhaps there is some other characteristic of steel belted radials (e.g., riding "flatter") that makes the measured change slightly less than that predicted by our simple geometrical arguments.

b. Speed effects. Since tires are elastic, one might expect them to expand as speed goes higher, due to increasing centrifugal force and hotter temperatures within the tire. The implication for the FLAIR odometer is then decreased counts per mile due to increased tire radius. To investigate this effect, runs were made on August 13 and 14, 1975 at various speeds on a stretch of Interstate 44 between Mississippi and Kings Highway

with starting and stopping landmarks chosen as in the previously described test. For each run, a target speed was set to which the vehicle was accelerated as quickly as practical from a standing start. Throughout the duration of that run, speed was maintained as near the target speed as traffic conditions allowed; then braking started at the minimum safe distance from the endpoint. Fifth wheel mileage and counts per mile were obtained as before. Data were analyzed by determining the dependence of counts per mile on average cruising speed as determined from fifth wheel mileage and a portable timer. Also noted was the interval during which target speed was maintained (after acceleration and before braking). Table 5-5 is a tabulation of data gathered for two sets of new tires, steel radials and rayon belteds. Figure 5-5 illustrates linear regressions of counts per mile versus average speed in each case.

Two qualitative aspects of the results are the linearity of the trends for both tire types (coefficients of determination are .73 and .98 for steel radials and rayon belteds, respectively) and the marked difference in slopes between the two lines (seven times greater for rayon belteds than steel radials). For steel radials the variation in counts per mile over a range of 35 to 60 mph is 0.28% or about 14 feet/mile, while for rayon belteds it is 2.0% or about 100 feet/mile. It appears from these figures that variations in speeds in these intervals would little affect system tracking for steel radial tires, but potentially significant errors

Linear Regression of Odometer Readings versus Speed

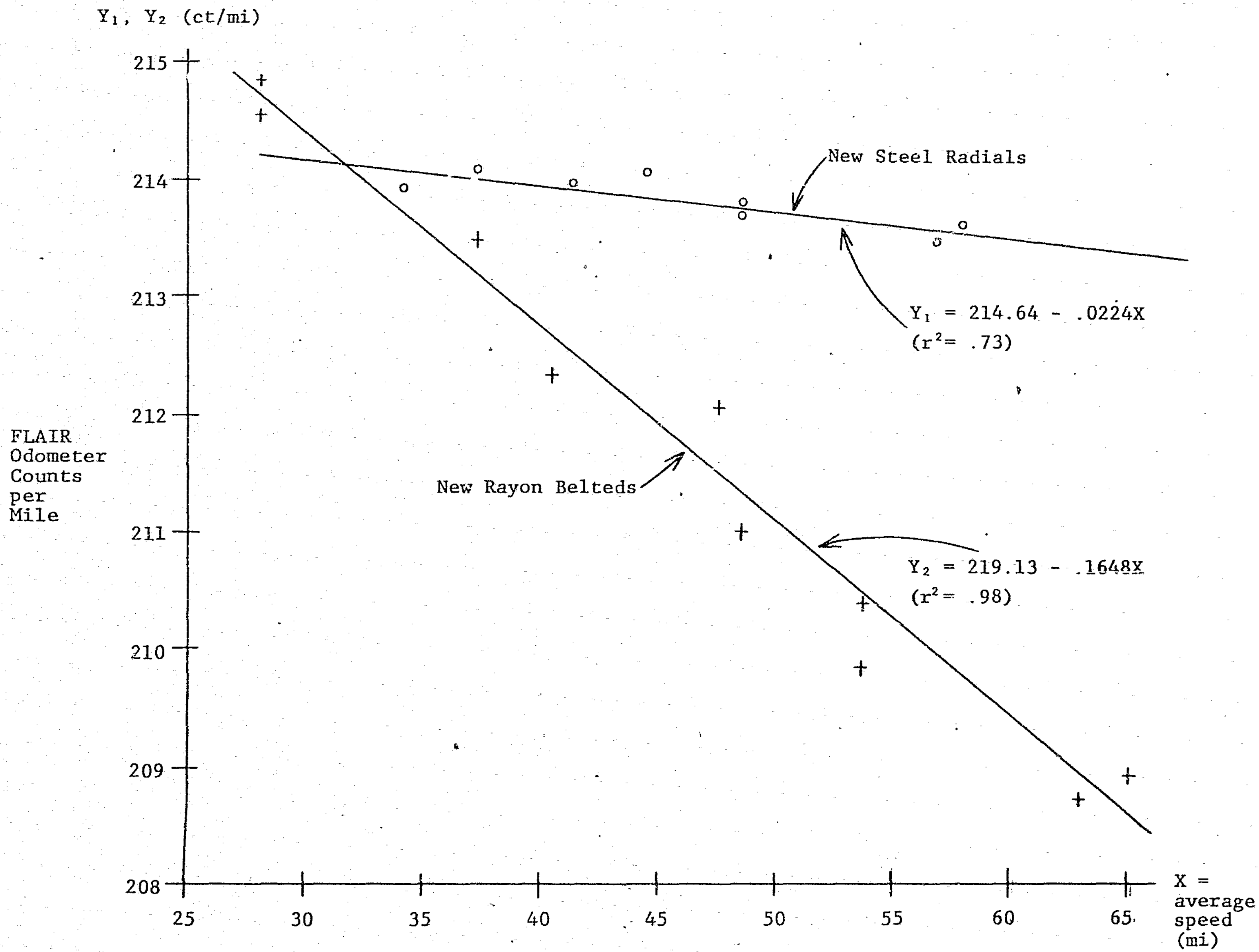

Figure 5-5

lie in use of rayon belted tires particularly if one expects speeds to deviate often and widely from calibrated speeds. The possibility for real-time calibration by FLAIR software according to iterative speed estimation and implementation of linear models such as these definitely exists.[17]

Summarizing the experimental outcomes as they pertain to γ, the systematic error term, γ has been measured between -0.0026 and +0.012 for steel radials and between -0.0193 and +0.02 for rayon belteds. Depending on the value of the FLAIR calibration point, the magnitude of the systematic error γ could reach as high as about 0.04 during the lifetime of a set of rayon belteds on a vehicle. Thus, in examining plausible values of p for a system, using rayon belteds, γ should take on a range of values between -0.04 and +0.04. For a system with steel radials only, γ should take on values between about -0.015 and +0.015 (almost all the variation due to tread depth changes).

5. Estimating random errors in St. Louis. Estimation of the random error performance of the system is perhaps the single most difficult task in fitting a model to the real situation. This is due to the fact that random error can be caused by so many different factors.

The random error parameter σ^2 can be used to incorporate those random error factors that cause the variance of the estimated

[17] See Section B.9 of this chapter for additional discussion of this point.

position to grow linearly with travel distance. These factors correspond to tire slippage, different driving patterns, speed variations (if viewed as uncorrectable), and mapping inaccuracies. If one can identify N subsets of factors (F_1, F_2,...,F_N) that are <u>independent</u>, for instance (for N=2) "mapping inaccuracies" being one subset and everything else (all related to driving behavior) being the other, then σ^2 can be viewed as the sum of individual variances, one for each subset,

$$\sigma^2 = \sigma^2_{F_1} + \sigma^2_{F_2} + \ldots + \sigma^2_{F_N}.$$

Thus, in attempting to estimate σ^2, it may be convenient to try to estimate individiually each of its (independent) component parts. However, the test identified as Step 4 (see Equation (3)) attempts to combine the effects of all of these factors into one test.

Since the FLAIR computer maps were being changed during Phase I (and they will be changed appreciably again for Phase II), no attempt was made to include an empirical estimate of the component of σ^2 due to the maps. Thus, the test implied by Equation (3) has been delayed until Phase II. Empirical tests were carried out, however, to estimate that component of σ^2 due to various driving behaviors along straight-line routes, and these are reported in this section. To obtain a preliminary estimate of plausible magnitudes of the component of σ^2 due to map error, several "back-of-the-envelope" models have been constructed (Appendix B) and the general nature of these results is reported in this section.

CONTINUED

2 OF 10

As indicated in these analyses, "map error" does not necessarily have to mean literal errors in the street map, but only errors in the use of any mapping procedure that attempts to model real-world travel paths as sequences of straight-line segments.

In dealing with random error in an actual system, one must also remember that quantization (particularly in time and distance) creates a component of variance that does not grow with distance. Thus, in an actual setting, given that the vehicle has travelled d (miles) since the last turn (which is assumed to be correctly interpreted), the total variance of the position estimate is the sum of a "fixed" variance and one that grows linearly with distance,

$$\text{(actual variance)} = \text{(fixed variance)} + d\sigma^2 .$$

The two primary components of the fixed variance--due to time and distance quantization--are discussed in Appendix A.

a. Measurements of effects of lane switching. To measure the effects of different driving patterns, several different routes--each approximately straight-line--were selected for repeated tests. To estimate the range of plausible values of the component of σ^2 due to different driving patterns, each route was driven in a "standard" manner and in a manner incorporating exaggerated lane switching.

We outline typical experiments performed in August, 1975, with data recorded in Table 5-6 . A section of Broadway in District 3 between LaSalle and Chippewa was chosen as a test route (test #2 in Table 5-6) on which six runs, in each direction

Table 5-6

Random Tests

Test location		Distance miles	Maximum variation* feet	% variation	Notes
Arsenal	- east	3.0	0	0	single lane
	- west	3.0	10.5	.07	each direction
Broadway	- south	2.8	21	.14	3 lanes
	- north	2.8	26.4	.18	each direction
exagerated lane switching	- south	2.8	37	.25	
	- north	2.8	42	.28	
Grand	- south	2.6	16	.12	2 lanes
	- north	2.6	26	.19	each direction
Gravois	- south-west	2.5	16	.12	2 lanes
	- north-east	2.5	16	.12	each direction
Tire pressure					
30 pounds pressure					
Arsenal	- east	3.0	10	insignificant	
	- west	3.0	5	insignificant	
20 pounds pressure					
Arsenal	- east	3.0	10	insignificant	
	- west	3.0	0	insignificant	
30 pounds compared to 20 pounds					
Arsenal	- east	3.0	10	insignificant	
	- west	3.0	5	insignificant	

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* To determine effects of driving habits and road conditions on indicated travel, test car was driven between fixed landmarks, 3 times in each direction, using a fifth wheel (accurate to 0.001 mile). Maximum variation in the indicated mileage of the 3 runs is shown. For the Broadway test, six runs were made in each direction.

were completed. Precise landmarks were chosen as endpoints to ensure consistent starting and stopping among runs in a given direction. Three runs were driven in a "normal" fashion; i.e., minimized lane switching so as to follow the most direct path between the endpoints. The other three were driven in an "exaggerated" fashion, frequent lane switching, so as to increase as much as possible the driving distance between the endpoints, while yet always maintaining positive progress along the route. Driving distances were recorded with a fifth wheel odometer accurate to ± .001 miles.

On the average for the southbound course (A-B), exaggerated driving was only .25% longer than normal driving, while on the northbound route the excess was .28%. Comparisons between northbound and southbound data are impossible, since the endpoints differed. Overall, the maximum excess of exaggerated distance beyond normal distance was about .4% and the minimum was .14%.

Other tests as shown in Table 5-6 were performed in a manner similar to test #2 on Broadway, described above. Even though three miles in length, test #1 showed remarkably little variation (.07% maximum). This test was made on a two-lane road, one lane in each direction, and the road was straight. Tests #3 and #4 were on two-lane roads (part of Gravois was three-lane), and showed variations of .12% to .19% for Gravois and .12% for Grand. These data show that driving on single-lane roads, where the driver has little choice, causes little variation. Variation increases as the number of lanes increases (and curves in the road

increase). Exaggerated lane switching produces maximum random variation, being somewhat more than that experienced in normal driving.

Data taken on Arsenal, with 20 and 30 pounds of tire pressure show insignificant variation due to differences in tire pressure, indicating that reasonable changes in pressure should not contribute to error.

The reasonableness of these empirical results can be verified by simple geometrical considerations. As shown in Appendix B, if a vehicle traveling on a roadway of lane width w smoothly changes lanes n times while traveling one mile of roadway, then the extra distance (beyond one mile) travelled by the vehicle is approximately

$$e = n^2w^2/10{,}560 \quad \text{(feet)} \tag{5}$$

As a plausible example, suppose n=20 lane changes per mile and w=15 feet (width of lane), corresponding to lane switching on a roadway with two (15-foot) lanes in each direction. Then,

$$e = (20)^2(15)^2/10{,}560 = (400)(225)/10{,}560$$
$$= 90{,}000/10{,}560 \simeq 9 \text{ feet.}$$

Thus, even switching lanes twenty times per mile results in an increased travel distance of only nine feet. In percentage terms, this corresponds to (9/5,280) x 100% ≃ 0.17%. Such a figure is compatible with our empirical results which ranged typically between 0.2% and 0.3% (Broadway test).

If the maximum measured deviation of 0.3% is equated to "two standard deviations," then we would have for the component of σ^2 due to driving patterns (along straight roadways),

$$\check{\sigma} \approx 0.0015$$

or

$$\check{\sigma}^2 \approx 0.00000225,$$

which represents a very small contribution to the random error, ($\check{\sigma}^2$ here is measured in units of $(\text{mile})^2$).

b. Approximating random errors due to the mapping method. The other source of random error contributing to the value of σ^2 is approximation errors in the computer map. While field testing in this area will not occur until Phase II, we can get a rough idea of the possible magnitudes of map approximation errors by simple geometrical considerations. Recall that the three major types of map approximation error are as follows:

- Approximating smoothly winding streets by sequences of straight-line segments.
- Approximating streets, which are two dimensional, by a one-dimensional model (a line).
- Approximating corners as the intersection of two or more straight lines since corners can be turned in many different ways.

We briefly consider each of these three sources of error. The mathematical derivations are contained in Appendix B.

(1) Effect of straight-line approximations. By approximating a smoothly curving street by a sequence of connected

straight-line segments, one usually obtains errors in estimating the true distance travelled. The FLAIR mapping system utilizes a method that places an approximately equal proportion of the straight-line segments on either side of the center line of the street, thereby minimizing the effect of this type of error. A simple geometrical model developed in Appendix B shows that it is highly plausible that errors in the one-to-three percent range could occur over short distances because of the straight-line approximation method. The actual magnitude experienced depends on the radius of curvature and length of the curve, as well as the number of straight-line segments used to approximate the curve.

(2) Effect of a one-dimensional model. Since FLAIR models two-dimensional streets as one-dimensional entities, additional errors are possible. One such type of error was already discussed, namely that due to frequent lane switching. Another is due to the way in which curving streets are traversed. Traveling in the inside lane of a curve yields a smaller travel distance than traveling in the middle or outside lane. For smooth curves, Appendix B derives a plausible example in which lane of travel can change travel distance by about two percent over a distance of 1,500 feet. Sharp curves can cause higher percentage errors (accrued over shorter travel distances).

(3) Corners. There are many different configurations for corners that could affect FLAIR accuracy. A possible

worst case would involve a driveable area at a street corner (perhaps a service station or parking lot) which the tracked vehicle could "cut through," perhaps on a high-speed chase. Appendix B discusses an example in which the distance estimation error due to such corner cutting could be as great as 80 or 90 feet.

While it is difficult to combine all of these analyses in order to obtain a "unique" estimate of σ^2, several different (plausible) values will be proposed in Step 4 of the next section.

6. Applying the five-step procedure to St. Louis. We now use preliminary data available from the Phase I implementation in District 3 in St. Louis to illustrate the five-step procedure presented above.

Step 1: Regularity of Street Pattern

First we must estimate

$\overline{\ell}$ = mean block length (in feet)

σ_ℓ^2 = variance of block lengths ($feet^2$).

From a map of St. Louis,[18] we approximate police District 3 as a 13,200 foot by 20,460 foot rectangle, or 2.5 miles by 3.88 miles, implying an area of 9.69 square miles.

[18] Official map of the City of St. Louis, prepared under the direction of C. Larry Unland, Director of Streets, 1965. Scale = 1,320 feet per inch.

According to the St. Louis Metropolitan Police Department,[19] there are 203.02 street miles and 104.83 alley miles in District 3, summing to a total of 307.85 miles. In our calculations, since alleys are included in FLAIR, we lump together streets and alleys.

Combining the two calculations so far, we see that there are (307.85/9.69) ≈ 31.77 street miles (including alleys) per square mile in District 3. As an approximation (which is quite good in St. Louis) assume that one-half of the 31.77 street miles in a square mile are all parallel, directed say East-West, and the other half are perpendicular to those in the first half, directed say North-South. Then, there are about 31.77/2 blocks per linear mile, yielding an average block length of 1/(31.77/2)(5,280) feet ≈ 330 feet = $\bar{\ell}$. (Recall that blocks can be defined by alleys as well as regular streets). This result checks with calculations made visually and independently from a map of District 3.

Similar procedures were used to calculate the variance, or equivalently, its square root, the standard deviation. Utilizing a map of St. Louis block length was modelled

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[19] One-page flyer produced by the St. Louis Metropolitan Police Department, "Mileage of Streets and Alleys in City of St. Louis" (by Police District), where source is "Map measures applied to St. Louis City Plan Commission Base Map; measurements made by Planning and Research Division, St. Louis Metropolitan Police Department, 1963."

as a discrete random variable taking on one of five possible values, ranging from about 120 feet to about 825 feet. The result of the calculation was that the standard deviation of block lengths equalled about 55 percent of the mean, corresponding to

$$\sigma_\ell \approx 183 \text{ feet.}$$

From the estimates of $\bar{\ell}$ and σ_ℓ^2, we have that the regularity of street spacings in District 3 is

$$q = 1 - \left(\frac{\sigma_\ell}{\bar{\ell}}\right)^2$$

$$q = 1 - (0.55)^2 = 0.6957 \approx 0.7$$

This value for the index indicates a fairly regular street pattern in District 3.

Step 2: Computing the Unit of Distance

The unit of distance is

$$b = \bar{\ell}\, q = 330(0.7) = 231 \text{ feet.}$$

Step 3: Estimating the Systematic Bias

Field tests to estimate systematic bias were performed and their results were reported in Section B.4 of this chapter.

From those results we see that, if biasing effects due to speed changes are viewed as correctable, the systematic error term γ should be allowed to take on values between -0.015 and +0.015 for steel belted radial

tires and between -0.04 and +0.04 for rayon belted tires. However, the variation for rayon belted tires decreases to ± 0.02 if biasing due to speed changes is not viewed as systematic and thus correctable.

Step 4: Estimating the Random Error

The random error term (the incremental variance) is, as of this writing, still relatively unknown due to the changes in Phase I FLAIR maps which precluded a conduct of the test summarized in Equation (3). We do know that the component of σ^2 due to exaggerated lane switching is so small that it can be effectively ignored in most urban settings. We also know from theoretical analyses that the map method can cause (random) errors in distance estimation on the order of one-to-three percent over distances of about 1,000 feet. Thus it is not unreasonable to tentatively set the standard deviation due to this component of random error to some value in this range, say $\sigma = 0.015$ for a unit of distance equalling about 1,000 feet.

Finally, we know that during Phase I variations in tire circumference due to speed changes were viewed as uncorrectable, thereby causing a maximum of ± 0.02 percent error for rayon belted

tires over indefinitely long distances.[20] Thus, an additional component of σ equalling about 0.01 would be appropriate to reflect random variations due to speed changes with rayon belted tires.

Summarizing, given the known (independent) sources of random error, we have the following reasonable estimates for components of σ:

<u>Lane Switching</u>: $\sigma_1 = 0.0015$
(Unit of distance = mile)

<u>Map Error</u>: $\sigma_2 = 0.015$
(Unit of distance ≃ 1,000 feet)

<u>Speed Variations</u>: $\sigma_3 = 0.01$
(Unit of distance = mile)

To convert to the standard unit of measurement derived in Step 2 (b=231 feet), we use Equation (4),

$$\sigma' = \sigma\sqrt{\frac{d}{d'}},$$

where d'=231 feet in all cases and d equals 5,280 feet, 1,000 feet, and 5,280 feet, respectively, for the three cases above. We have $\sqrt{5,280/231} \simeq 4.8$ and $\sqrt{1,000/231} \simeq 2.1$, implying that in units of b=231 feet,

$$\sigma_1 \simeq 4.8(0.0015) = 0.0072$$
$$\sigma_2 \simeq 2.1(0.015) = 0.0315$$
$$\sigma_3 \simeq 4.8(0.01) = 0.048$$

[20] As discussed in Section B.9 of this chapter, this assumption is being changed in Phase II, where such speed-related changes are to be monitored in real time and "corrected" according to a calibration curve similar to those shown in Figure 5- .

Thus, the total incremental variance σ^2 is the sum of the component variances,

$$\sigma^2 \simeq \sigma_1{}^2 + \sigma_2{}^2 + \sigma_3{}^2$$
$$= 0.00005184 + 0.00099225 + 0.002304$$
$$\simeq 33.48 \times 10^{-4}$$

Thus,

$$\sigma \simeq 5.8 \times 10^{-2} = 0.058.$$

It is instructive to note that the major contributor to this value is due to speed changes (assuming rayon belted tires). The variability is predicted to be considerably less with steel belted radials.

Since the above estimate for σ is based on such tentative assumptions at this time (awaiting more definite measurements in Phase II), a range of values (including those near $\sigma \simeq 0.06$) will be used in the model.

Step 5: Estimating r, the Turn Probability

This varies considerably by vehicle, location, driver, time of day, and the recent situation regarding police matters. For our illustrative purposes, we use these values of r: 0.125, 0.250, and 0.500. However, for District 3 in St. Louis, a simple model of uniformly distributed random patrol (Appendix B) suggests that 0.250 is a reasonable lower bound for r. Over 100 hours of evaluators driving with police officers in District 3 tend to confirm that for most patrol situations $0.25 \leq r \leq 0.50$. Thus, we consider more seriously those values

of mean time between losses arising from r in this "moderate" range, rather than the very small value of $r=0.125$.

7. <u>Illustrative computation of mean time between losses</u>. We now apply all of these estimates to the computation of p from the tables in Appendix A. Using Equation (1), this is equivalent to computing estimates of the mean time between losses, or using the inverse, the mean number of losses per car per day. Since we found the street regularity $q \approx 0.7$ in District 3 in St. Louis and since tables are only computed for $q = 0.6$ and $q = 0.8$, we display figures only for $q = 0.6$. (In practice, one would either compute the formula separately for $q = 0.7$ or extrapolate between the two tables: $q = 0.6$ and $q = 0.8$.) The remaining parameters take on the following values.

γ = 0.00, 0.01, 0.02, 0.03

σ = 0.03, 0.05, 0.07, 0.10

r = 0.125, 0.250, 0.500

The "box" is put around that set of values that is considered most typical for the Phase I FLAIR System in St. Louis (District 3), given the preceding discussions. The results are displayed in Table 5-7. Note that the values behave as we expect: p increases smoothly with increasing random error σ, increasing systematic error γ, and with decreasing turn probability r.

We can now compare the figures for p in Table 5-7 with the empirical values for "mean losses per car per day" in the first

Table 5-7

Illustrative Values of Vehicle Loss Probability*

γ \ σ	0.03	0.05	0.07	0.10
0.00	0.00	0.01212	0.03808	0.09174
0.01	0.02460	0.04177	0.06490	0.11069
0.02	0.10244	0.11469	0.12996	0.15982
0.03	0.19436	0.19998	0.20768	0.22358

r fixed at r=0.125
q=0.60

γ \ σ	0.03	0.05	0.07	0.10
0.00	0.00	0.00218	0.01118	0.03855
0.01	0.00211	0.00774	0.01850	0.04535
0.02	0.01737	0.02702	0.03970	0.06462
0.03	0.05069	0.06013	0.07207	0.09353

r fixed at r=0.250
q=0.60

γ \ σ	0.03	0.05	0.07	0.10
0.00	0.00	0.00015	0.00173	0.01063
0.01	0.00003	0.00056	0.00281	0.01229
0.02	0.00064	0.00246	0.00637	0.01728
0.03	0.00370	0.00731	0.01303	0.02551

r fixed at r=0.500
q=0.60

* Each entry in the table is the probability that the vehicle will become lost on a randomly executed turn, given the particular model parameters specified.

DEFINITIONS

r = turn probability   σ = incremental variance

q = street regularity   γ = systematic error

part of this chapter. We reason as follows: since the average block length is 330 feet, there are 5,280/330=15 blocks/mile. Records from the District 3 files indicate that the typical car drives about 50 miles during an eight-hour tour of duty. This corresponds to 50 x 16 = 800 blocks per eight-hour tour. Since r = 0.125 is too small and r = 0.50 is too large to reflect realistic probabilities of turning at a random intersection, we focus on the plausible (lower bound) value of r = 0.25. Thus, if the vehicle turns, roughly, once every four blocks, it must turn an average of 800/4 = 200 times per eight-hour tour. This corresponds to 600 turns in 24 hours. Now, if the average car becomes "lost" 11 times a day, <u>and if all losses occur in normal tracking</u>, then the <u>empirical value</u> for p, the loss of probability, must be approximately

$$p \approx \frac{11}{600} \approx 0.018.$$

We can consider this an upper bound for p (as experienced in Phase I) because (as discussed earlier) not all losses occur in normal tracking. A lower bound for p is not possible to specify, but to obtain the "safe" target objective of two losses per car per day, one would require

$$p \leq \frac{2}{600} \approx 0.00333,$$

the inequality stemming from the fact that certain losses will always arise from open-loop tracking, magnetic anomalies, etc.

Examining the middle table of loss probabilities (Table 5-7) corresponding to r = 0.25, we see that p ≈ 0.020 implies rather

modest requirements on systematic and random error. A value of $\gamma = 0.02$ (a two percent systematic error) with small random error ($\sigma = 0.03$) yields $p = 0.01737$, which would mean about 10.4 losses per car per day (assuming all losses occurring in normal tracking). Or, a small systematic error ($\gamma = 0.01$) with a larger random error ($\sigma = 0.07$) yields $p = 0.01850$, meaning about 11.0 losses per car per day. As this parametric example indicates, it is useful to be aware that one can trade off systematic against random error to achieve the desired system performance (as measured by p, mean time between losses, or mean number of losses per car per day).

Now, to achieve the target level of no more than two losses per car per day, rather stringent requirements are placed on both systematic and random error. From the table (Table 5-7) we see that the objective is achieved with $\gamma = 0.01$ (a one percent systematic error) and $\sigma = 0.03$ (a small random error) or with $\gamma = 0.00$ (virtually no systematic error) and $\sigma = 0.05$ (a value for the random error more in line with our preliminary analyses). Both sets of values yield about 1.3 losses per car per day, thus allowing a very small margin of only 0.7 loss per car per day due to other factors (such as open-loop tracking, magnetic anomalies, etc.) If such stringent conditions are impossible to maintain, perhaps it is more reasonable to assume a 1.0% systematic error ($\gamma = 0.01$) and $\sigma = 0.05$; then $p \approx 0.0074$ and the number of losses per day would be about 4.6 per car (plus any due to factors not in the model).

While our empirical estimates for many of the model parameters are still very preliminary, the above parametric analysis suggests that great attention must be directed during Phase II toward reducing systematic and random errors to the smallest values possible (within budgetary constraints). Virtually any systematic error exceeding the one percent level or random error exceeding $\sigma = 0.05$, will cause unacceptable[21] deterioration in system performance. This implies that the Phase II computer-tracking algorithm should account for such things as tire wear and, especially if rayon belted tires are used, changes in circumference due to changes in speed; this latter requirement entails real-time speed monitoring and odometer correction. In addition, increased attention should be directed at position uncertainties caused by modeling (and mapping) streets as connected straight-line segments. This topic will be a key concern in the Phase II evaluation.

8. Other Error Producing Factors. As discussed earlier, additions to the basic model (all developed in Appendix A) focus on position estimation errors due to quantization in time, angle, and distance. Early Phase I experience with time quantization forced a doubling of the vehicle polling rate from once every two seconds to once each second.

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[21] Here "unacceptable" is used to mean more than four or five losses per day during regular tracking.

The unit of distance quantization, which was 25 feet during Phase I, causes a constant addition to the variance of the position estimation. This constant term was not included in the analysis in the preceding section but, if significant (for a larger value of the quantization interval), could easily be added to Equation (10) in Appendix A, and the formula recomputed. Partially to reduce this constant addition to the variance and partially to accurately monitor vehicle speed, the unit of distance during Phase II is one-quarter that during Phase I, being reduced to approximately six feet. This is accomplished by adding two bits to the digital odometer reading.

The unit of angular quantization during Phase I was $360^{0}/2^{5} = 11.25^{0}$ (corresponding to five bits of transmitted information). As shown in Appendix A, streets diverging at angles of this magnitude or less could greatly increase error probability when vehicles traverse them. One example in St. Louis was the Jefferson Avenue exit of Interstate Highway 44, which repeatedly caused lost vehicles. During Phase II the unit of angular quantization will be reduced to one-quarter of the previous value, becoming $360^{0}/2^{7} \approx 2.8^{0}$. This too requires the addition of two bits, increasing the number of angular bits to seven. During Phase II this level of angular quantization will be "in the noise" associated with the heading sensor itself and should no longer be a primary source of error.

Given the factor of four increases in the precision of the distance and angle data during Phase II, it is likely that the only

remaining potentially serious quantization variable is time, with an update rate expected to be once per 1.215 seconds. There is no straightforward way to increase this rate without a corresponding decrease in number of cars per channel. Whether this update rate will be a problem will be a question for the Phase II evaluation.

After constructing the model, four additional sources of error, each increasing the rate of lost vehicles per day, have been identified:

a. Open-loop tracking. As discussed in Chapter IX, when the vehicle is traversing a parking lot or other surface recognized by the computer--but not mapped in the center-line fashion--then the tracking algorithm switches to open-loop mode. This entails updating the vehicle's position simply by integrating the vehicle's distance and angle over time. Too great a travel distance in the open-loop mode automatically triggered a *V* in the Phase I algorithm, most probably because the open-loop integrated distance was prone to error from the large angle and distance quantization intervals. Even if the automatic flag was not raised, the likelihood of a *V* shortly after resuming on-the-street driving was significantly higher than usual due to the increased positional uncertainty occurring when the vehicle is recognized to reenter the street.

In a small number of tests conducted by PSE, it was found that open-loop driving (primarily in parking lots and around buildings)

caused a *V* or *W* to appear about one-half of the time (that is, in one-half of the open-loop areas driven through). This value is quite speculative due to small sample size and, whatever the Phase I value, it is almost certain to be reduced during Phase II because of the finer grain angle and distance quantization intervals.

It is very difficult to model open-loop tracking in a way which would predict the increase in the frequency of lost cars. For one thing, each driver has a different pattern for the number and type of open-loop areas driven through per day. For another, each area is unique, most likely having its own characteristic probability of loss. Still, an attempt (perhaps being primarily empirical) will be made in the Phase II evaluation to more accurately determine the lost car frequency associated with open-loop driving.

b. Missed radio transmissions. On occasion, in weak signal areas or due simply to random noise, the radio receiver at Headquarters does not receive a vehicle's data during one or more (successive) polling intervals. Modeling of this phenomenon would require a communications system model of the (moving) transmitter (in the car), the noise of the transmission medium (influenced by the terrain--natural and man-made--of the city in question), and the receiver at Headquarters. Such a model is beyond the scope of the present evaluation. As discussed in Chapter IX, the probability that a single transmission will be missed was found

empirically in Phase I to be about 0.029. The probability of missing two successive transmissions was 0.003. Thus, the mean time between single misses was 0.57 minutes, and between double misses was 5.5 minutes.

Each miss, especially a multiple miss, increases the likelihood of losing the vehicle. The model developed during Phase II will incorporate this phenomenon, taking primarily an empirical approach.

c. Magnetic anomalies. Also as discussed in Chapters II and IX, magnetically active areas (such as the flood wall and Vandeventer viaduct) increase the probability of a *W* almost to one when the vehicle traverses such areas. Again this is difficult to model abstractly due to the very particular nature of each such anomaly and to the driving patterns of each officer (which are constrained in this case by his beat assignment). To the extent possible, the presence of such anomalies will be included empirically in the Phase II model.

d. Proneness to subvertability. Given that the probability of becoming "lost" is much greater if one drives through magnetically active regions, poor signal regions (resulting in lost transmissions), or open-loop regions, the system is prone to subversion (of its intended use) by officers not sympathetic to its purpose. This issue is discussed at greater length in Chapters X and XII. A special evaluation focus will be directed

at this (potential) problem during Phase II, but no model will be constructed that explicitly includes system subvertability.

C. Concluding Remarks

As seen from this chapter, the FLAIR Phase I performance of about 11 losses per car per day fell far short of the two losses per day, considered a "safe" level by some of the evaluators. Given all of the quantifiable and non-quantifiable sources for error, each contributing to loss frequency, it is doubtful if the computer-tracking and dead-reckoning technology will ever achieve a level of only two losses per car per day (at least in the City of St. Louis). Given our current knowledge of the sources of error and the improvements anticipated for Phase II, we should expect that a more realistic target would be four or five losses per car per day.

Whether this is acceptable depends on the requirements of the potential user agency. At the very least, it is necessary to recognize that such levels of vehicle loss frequency imply about 2,500 initializations per day in a city having a fleet of 500 tracked vehicles. This represents a measurable increase in dispatcher workload and a noticable addition to the tasks of a motorized patrol unit. Experience during a special three-week test of the FLAIR System described in Chapter VII indicates[22]

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[22] In fact, the workload of initializations per car per day was even higher during the test, at an 11.5 average. However, even under these adverse circumstances the System seemed to perform relatively smoothly. The key, though, was a selected set of capable, motivated dispatchers.

that such a workload could be tolerated, but it requires highly motivated dispatchers and patrolmen[23] who are sympathetic to the goals of the system and a minimum of patrolmen who would deliberately maneuver their vehicles so as to subvert the system. Given these conditions--which are most often associated with the more professional police departments--a frequency of five losses (or less) per car per day should not severely impair the effectiveness of system operation.

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[23] Also see Chapters VI and X.

CHAPTER VI

RESPONSE TIME

A. Introduction and Overview: *Alternative Methods of Response Time Reduction; Chapter Overview.* B. Description of the St. Louis Police Emergency Response System: *The Telephone Switchboard; Complaint Evaluation; Alternative Responses by Complaint Evaluators; Complaint Evaluation Processing Times; Dispatching; Definition of Dispatching Processing Times.* C. Analysis of Telephone Complaint Processing. D. Analysis of FLAIR-Related Response Time: *Summary of Earlier Modeling Work; A Limitation of the FLAIR Distance Metric; Data Sources for Response Time Analysis; District 3 Response Patterns; Use of the Simulation Model; Examination of District 3 Versus City-Wide Patterns; Factors Impacting Response Times; Summary of Findings.*

Reader's Guide to Chapter VI: This chapter is devoted to an analysis of the impact of FLAIR on response time. Since this question has received a great deal of attention, the chapter includes a large volume of specific information. (For the reader looking for a quick overview, a summary of the findings concerning response time is provided in Chapter XI.) The chapter begins with an introduction and overview. A detailed description of the St. Louis MPD emergency response system is then provided, followed by an analysis of telephone complaint processing. The remainder of the chapter is devoted to a review of FLAIR-related response time. This section includes both empirical results and an analysis of the potential impact of AVM derived through the simulation model developed for this project.

CHAPTER VI: RESPONSE TIME

A. Introduction and Overview

Reduction in response time is often heard as the primary argument in favor of AVM systems. Thus, a major focus of the Phase I evaluation was directed toward the response time question, and a summary of response time findings is presented in this (and the next) chapter.

1. Alternative methods of response time reduction. Response time is considered to be the total time between a citizen's attempt to contact the police and arrival of police service at the scene. In this light, response time is comprised of several distinct components, each identified with a particular process or activity within the police emergency response system. Response time reduction can usually be achieved by a combination of several policy changes, each affecting a particular component of the system. This section of the chapter will now briefly review some of the alternative methods for response time reduction.

Even prior to official contact with the police, there are reporting delays between the time the need for police assistance is apparent and the time the police are contacted. In certain medical emergencies involving serious chest pains (perhaps signifying the onset of a myocardial infarction), the median delay from onset of the symptoms until the victim or a relative contacts an emergency medical system has been found to be three

hours.[1] Likewise in crime reporting, often several hours elapse between commission of the crime and police notification. In such situations, a reduction of response time by 30 seconds, a minute or even two minutes seems superfluous.[2] Various steps are now being taken in U.S. cities to reduce reporting delays that can be attributed to lack of access to a communication system. These include free dialing over 911, open police call boxes[3], and personal "wristwatch" alert devices.[4] However, implementation of technology

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[1]T.P. Hackett, and N.H. Cassem, "Factors Contributing to Delay in Responding to the Signs and Symptoms of Acute Myocardial Infarction," American Journal of Cardiology, Vol. 24, p. 651, 1969.

[2]The importance of the time involved in reporting an incident is currently receiving extensive examination in a study conducted under contract for the Kansas City, Missiouri, Police Department under a grant from LEAA's National Institute of Law Enforcement and Criminal Justice. For example, in an article reporting on some of the preliminary results concerning robbery response time, it was found that of three response time components which they defined (occurrence through detection [t_0 to t_1 in Figure 6-1]; reporting the incident [t_1 to t_3]; and response arrival at the scene [t_3 to t_9]), the most important element was reporting the incident. (See Deborah K. Bertram and Alexander Vargo, "Response Time Analysis Study: Preliminary Findings on Robbery in Kansas City," Police Chief, May, 1976, Volume XLIII, Number 5.) Obviously, these results will have an important influence on evaluating the impact of an innovation such as AVM and will receive careful review as they become available during the Phase II evaluation. (The study is entitled "Response Time Analysis Study," William Bieck, Principal Analyst, Grant No. 73-NI-99-0047-G.)

[3]This policy was tried in St. Louis a few years ago, but it was terminated due to a high vandalism rate. Staff at the St. Louis Commission on Crime and Law Enforcement have stated that there is little chance that it would ever be tried again.

[4]For example, efforts are underway concerning the establishment of a prototype Citizen Alarm System, see "Summary and Concept Definition for an Improved Citizen Alarm System, Volume I: Technical Summary," August, 1974, R.C. Rountree, The Aerospace Corporation, prepared for the National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration.

should not be expected to reduce those reporting delays that are attributable to public attitudes about reporting crimes, medical emergencies, or other emergency situations.

Once initial contact has been attempted within the police emergency response system, delay reduction methods include adding extra telephone operators to reduce queuing delays[5] and implementing 911 (to reduce look-up and dialing time, to pre-sort emergency calls from routine business without going through a manual switchboard--as exists in St. Louis). Operator service time can be reduced by providing automatic address look-up, verification, and conversion to a police district, beat, and reporting area--a task performed rapidly by most CAD (Computer-Assisted Dispatch) systems. In St. Louis, a manual electronic system is used for writing dispatch tickets, and this creates a slight delay in that the caller's information is usually first recorded onto a slip of paper, then (after call termination and necessary look-ups) rewritten on the electrowriter. The possibility of a "blocked" electrowriter (due to another complaint operator simultaneously writing to the same dispatcher) also creates the possibility of minor additional delay.

There are also numerous sources of possible delay at the dispatcher's position:

- Delay while previous calls for service are dispatched.

[5] R.C. Larson, "Improving New York City's 911," in Analysis of Public Systems, A.W. Drake, R.L. Keeney, P.M. Morse, Eds., MIT Press, Cambridge, Massachusetts, 1972.

- Delay while other dispatcher activities take place (recording disposition, relaying messages, clerical tasks, FLAIR initializations, etc.).

- Delay due to non-work activities.

- Delay while waiting for cars to become available, which will be of greater magnitude for an "area car" (or "beat car") method of dispatching than for the "closest car" method.

On average, the sum of these delays is usually greater than all other processing delays combined, so that automating or otherwise improving the dispatch function represents one of the areas of greatest potential in terms of cost-effective response time reduction.

Following dispatch delays, travel time reduction can be accomplished by selecting the closest available car (using an AVM system or polling the cars--usually infeasible due to congested radio frequencies) and/or by increasing the number of available cars. Hiring additional personnel is not the only way to increase the number of available cars; others include allocating resources more effectively and reducing service times (which is often infeasible).

Summarizing, there are many policy alternatives available for reducing response time, including:

<u>Reporting Delays</u>
open police callboxes
dial tone first (free dialing of emergency numbers)
citizen alarm system

Processing Delays

- increased operator (and evaluator) manpower
- 911
- computerized, prioritized dispatch ticket transmission
- CAD

Travel Time Delays

- AVM systems (refer to Chapter II)
- improved resource allocation
- service time reductions
- hiring extra personnel

The purpose of this very cursory tour of alternative response time reduction methods has been to provide a system perspective for considering the role of AVM, or CAD, or 911 or any technological innovation for reducing delays. In assessing each possible response time reduction, police administrations should be cognizant of the total response time they are affecting and thus the percentage of reductions they can achieve. For instance, measurements in St. Louis indicate that it takes an average of around 10.5 minutes from the time a call first rings at the MPD until a unit arrives at the scene of an incident. An administrator seeking to reduce average response time, say by 25 seconds, should ask the following question: "What is the value of a 25-second reduction in travel time when one realizes that such a reduction represents only 4% of the total response time?" There is also a related question: "Are there any other modifications to the response system that would produce larger effects, or even similar effects at lower cost?" Each city should, after determining the priority of response time

reduction, consider the relative effectiveness versus cost of each of the alternatives available. (Several suggestions along these lines are given later in this chapter and in Chapter XII.)

2. Chapter overview. Our primary purpose in this chapter is to analyze the St. Louis police emergency response system, particularly with respect to the delay reductions achieved because of Phase I FLAIR implementation. Thus, our first task is to describe the St. Louis police emergency response system in sufficient detail to convey the complexities of operation that bear on FLAIR evaluation. Stemming from this, we present our analysis of processing delays incurred prior to the dispatching operator; this is the non-FLAIR-related part of response time, representing a constant addition to a total response time, with or without FLAIR.

We then focus on FLAIR-related response time. To provide a context and intuition for that analysis, a brief review of earlier relevant modeling work is presented. In addition, a limitation of the FLAIR distance metric is discussed. Then, a detailed empirical analysis of FLAIR-related response time (i.e., delay at the dispatcher's position and travel time) is presented, augmented where necessary by simulation modeling analysis.

Crudely summarizing a detailed analysis, we find that the net effect of FLAIR on response time during routine Phase I operations was not negative; however, the evidence supporting a positive effect is not strong. This is due to myriad factors, not the least of which is related to the unique characteristics of a

Phase I prototype installation. Perhaps more important than equipment malfunctions, though, is the importance of the dispatcher on the operation of the system. In some cases dispatchers during the routine Phase I operations did not take full advantage of the system's potential--for example, not always identifying and dispatching the FLAIR-designated closest car. This fact, coupled with the rather inconclusive empirical analysis reported here, gives rise to the need for a carefully controlled test period during which optimal conditions for FLAIR operation would be maintained. The results of such a test are reported in Chapter VII. Even in the special test, though, only modest reductions in response time were experienced.

B. Description of the St. Louis Police Emergency Response System

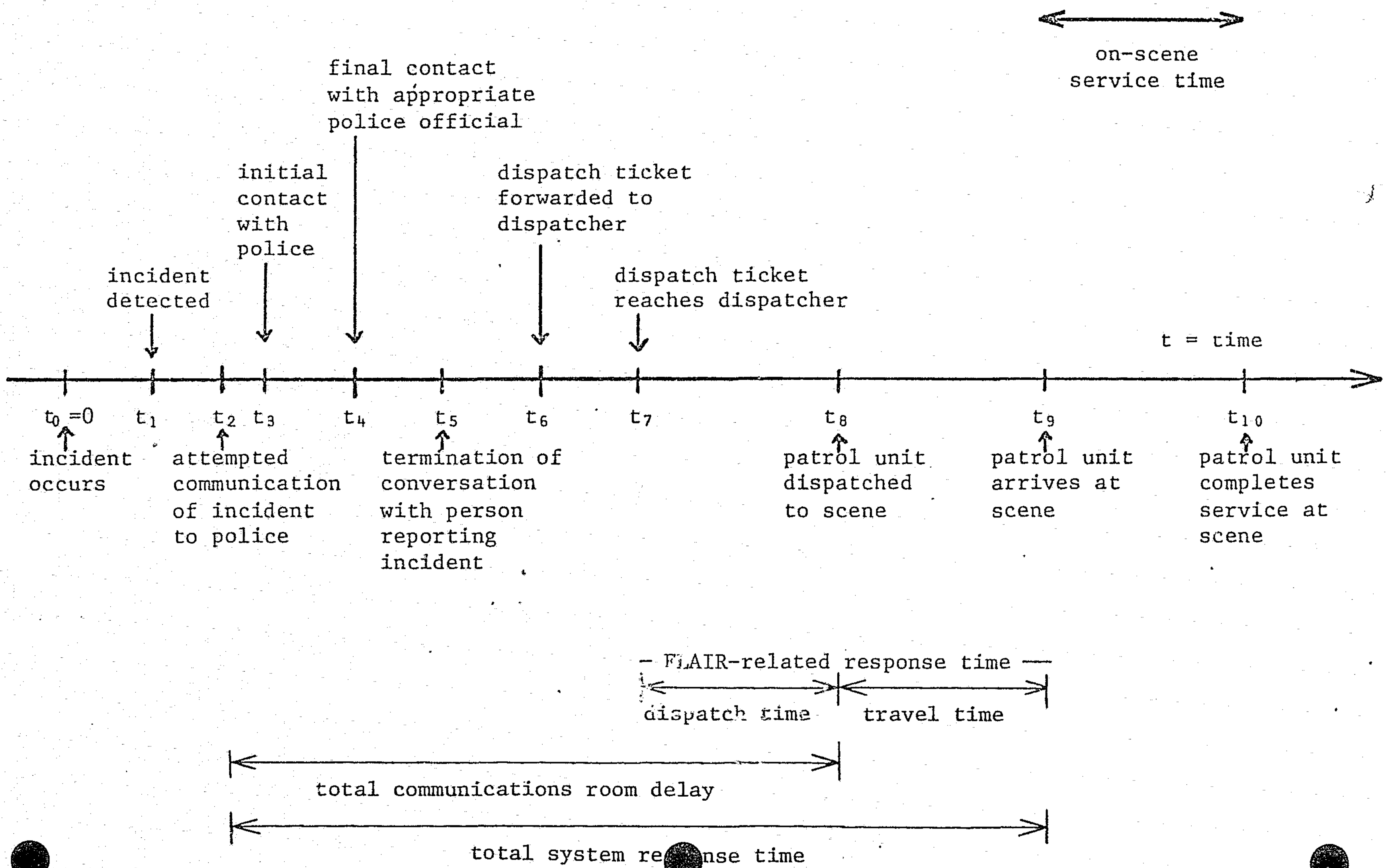
The overwhelming majority of requests for police assistance reach the Metropolitan Police Department in St. Louis via the telephone system. When a call is first answered at the police switchboard, a sequence of processing stages is activated which will eventually direct the complaint to the proper resolution. Of vital concern is the sum of the processing delays encountered by complaints which require on-the-scene police services since such instances often present the potential for personal injury or property loss. To assess the full impact of an innovation such as FLAIR on the elapsed time between a complainant's report and police arrival, it is imperative to consider not only those response system segments directly or indirectly affected by the implementation of FLAIR (FLAIR-related response), but also those links which will remain essentially unaltered in the new operating environment. Our description of the St. Louis police emergency response system includes both types of response delays.

The general structure of a police response system was outlined in Chapter I and is reproduced here as Figure 6-1. Recall that an incident is assumed to occur at time $t=0$ and at specific times thereafter (t_1, t_2, ...) other distinct events occur. In particular, initial (telephone) contact is made with the police at time t_2, the dispatcher receives the relevant information at time t_7, and the dispatched patrol vehicle arrives at the scene at time t_9. The first major delay interval t_7-t_2, representing pre-dispatcher delays, is the non-FLAIR-related part of response

Figure 6-1

Typical Time Sequence of Events in Police Emergency Response System

(Not Drawn to Scale in Time)



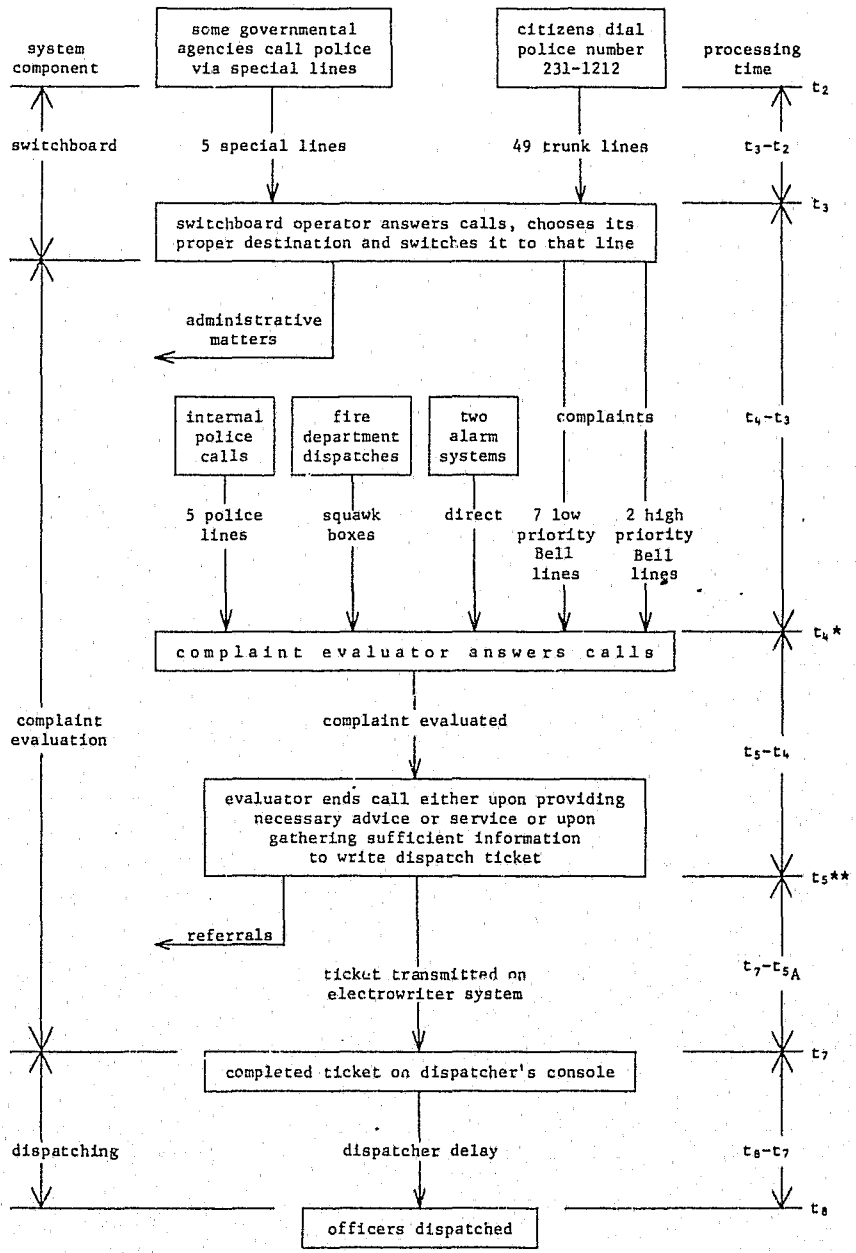
time; the second major delay interval, t_9-t_7 (representing dispatching delay and travel time), is the FLAIR-related part of response time.

Figure 6-2 is a more detailed presentation of the St. Louis system for times t_2 through t_8 (from initial police contact to dispatch of a patrol unit). The corresponding interval, t_8-t_2, it the total communications room delay. Particular aspects of Figure 6-2 will be highlighted throughout this section.

1. The telephone switchboard. All citizen's calls requiring police attention in St. Louis are directed to the switchboard at Headquarters on the single number, 231-1212, which is fed by 49 trunk lines. We have let t_2 be the time at which a complainant first hears a ring after dialing. It is important to emphasize that everything from administrative matters to the most urgent of emergencies funnel through the same number. (Some governmental agencies (transit, etc.) can call the police switchboard via five special lines other than 231-1212, but these are unavailable to private citizens.) Four civilian operators normally attend the switchboard and serve as the first filter to route calls according to their characteristics. The interval extending from the first ring heard in the caller's phone (t_2) until an operator answers (t_3) has been labelled t_3-t_2 and represents the first delay in complaint processing and will be referred to as switchboard answering time. Should a call seem to possess potential for the dispatch of officers, the operator switches it to an area known as complaint evaluation via one of two types of telephone lines--

Figure 6-2

Telephone Complaint Processing in St. Louis MPD
(not to scale in time)



* either t_{4L} (low priority) or t_{4H} (high priority)

** either t_{5A} (dispatch required) or t_{5B} (no dispatch required)

low priority (seven lines) or high priority (two lines). High-priority lines (or "hotlines" as they are called) are to be answered in complaint evaluation even before low-priority lines which may have been awaiting attention for some time. Since the two priorities are routed differently it is necessary to identify two answering points in complaint evaluation: (1) t_{4H} for high priority calls, and (2) t_{4L} for low priority calls. We will refer to the intervals $(t_{4H} - t_2)$ and $(t_{4L} - t_2)$ as high- and low-priority complaint evaluation answering times, respectively.

2. Complaint evaluation. Complaint evaluators serve to further sort and direct requests for service to various agents, not all of whom are within the police department. In some cases they dispose of incidents themselves by either providing the appropriate official service or informing the complainant that no official recourse is available. Since the business of an evaluator is basically to determine what is and is not within police jurisdiction, all but a few evaluators are active or retired sworn personnel. Although the evaluation room can accommodate eight evaluators simultaneously, the average number on duty will vary between three and five for offpeak and peak periods respectively.

The nine Bell system lines from the switchboard are not the complaint evaluators' only sources for telephone activity. In addition, five police lines have direct access to the evaluators from internal police areas such as district stations and street boxes. Theoretically, only internal police business such as

administrative dispatches should arrive on these lines, but a citizen caller often dials the station number. It is therefore impossible to know until answering whether calls in the internal line are items of internal police business or a citizen's complaint[6].

3. Alternative responses by complaint evaluators. Complaint evaluator's have two basic responses to complaints or incidents: either they decide that an officer dispatch is warranted and relay the necessary information to the dispatcher, or they conclude otherwise and terminate the call or refer it elsewhere[7]. The conversation termination point, t_5, must therefore then be split into two parts--t_{5A} and t_{5B} which apply respectively to calls which will receive tickets (t_{5A}) and those which will not (t_{5B}). ($t_{5A} - t_4$) and ($t_{5B} - t_4$) will be referred to as conversation times irrespective of call priority.

If the evaluator writes a dispatch ticket, it is done at this point on an "electrowriter". This machine consists of an ordinary ballpoint pen used to write on a mechanical linkage which converts the evaluator's handwriting motions to electrical

[6]Additional inputs exist at complaint evaluation though they are relatively minor in comparison to telephone volume. Since police are required to respond to fires, fire department dispatches are communicated directly to complaint evaluation via squawk boxes. Two alarm systems also sound there. One, which responds to emergencies in several public and private buildings, flashes the incident location directly on its panel, while the other, a sophisticated burglar detection system, displays a digital code indexing the alarm's location in a card file.

[7]As an example of a call that may not justify dispatching officers, some evaluators who are currently in uniform can take stolen property reports over the telephone relieving street personnel of that workload.

representations. The transmission of these signals to similar devices in front of the dispatchers allows the simultaneous transcription of ticket information to the dispatcher as the evaluator copies it from his conversation with the complainant. Emergency tickets can be emphasized by the evaluator activating a buzzer at the dispatcher's electrowriter immediately before or after the transmission. Usually this purpose is served by asking another evaluator to walk into the dispatching area and shout the information. Tickets are routed by the electrowriter to one of the six dispatchers by pressing a selecting button (although there are nine districts, Districts 4 and 5, 1 and 2, and 6 and 8 are paired for dispatching purposes). Should a chosen line be in use and therefore unavailable, a busy signal is activated, and a warning sounds if writing is attempted. Blocked lines are sometimes circumvented by writing to the nearest available dispatcher who in turn hands the ticket to its proper destination.

4. Complaint evaluation processing times. Several processing times for telephone complaints are evident in complaint evaluation and are explicitly collected here for subsequent use[8]:

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[8]It may be recalled from Chapter I that t_6 in the general police response system (dispatch ticket forwarded to dispatcher) requires reinterpretation in St. Louis. We reiterate the sequence: at t_{5A} the complaint evaluator terminates a conversation leading to a dispatch ticket; at t_6 he obtains the electrowriter line to the appropriate district and begins to write the ticket; at t_7 the completed ticket is on the dispatcher's console. Complaint evaluators note t_7 on their tickets by visual reference to one of two clocks in their room which are synchronized at best to within one minute of each other.

(continued on next page)

1. $(t_3 - t_2)$ — Switchboard answering time. The interval from the first ring heard in the complainant's phone until a switchboard operator answers.

2. $(t_{4H} - t_2)$ or $(t_{4L} - t_2)$ — High or low priority complaint evaluation answering times. The interval from the first ring in the caller's phone until he reaches a complaint evaluator for either high or low priority incidents [includes $(t_3 - t_2)$].

3. $(t_{5A} - t_4)$ or $(t_{5B} - t_4)$ — Conversation times. Durations of conversations either leading or not leading to dispatch tickets irrespective of priority.

4. $(t_7 - t_{5A})$ — Ticket writing time. The interval from conversation termination to ticket completion irrespective of priority.

5. Dispatching. If a citizen's complaint passes through the screening processes at the switchboard in complaint evaluation, it will arrive in the form of a written ticket at the appropriate dispatching console. Figure 6-3 depicts the various inputs and activities which define the dispatching area. Dispatchers are primarily civilians but a few uniformed personnel serve in that role also. However, an appreciable proportion of the civilians are actually police cadets who are awaiting entry to the police academy. In the near future, cadets will be unavailable for

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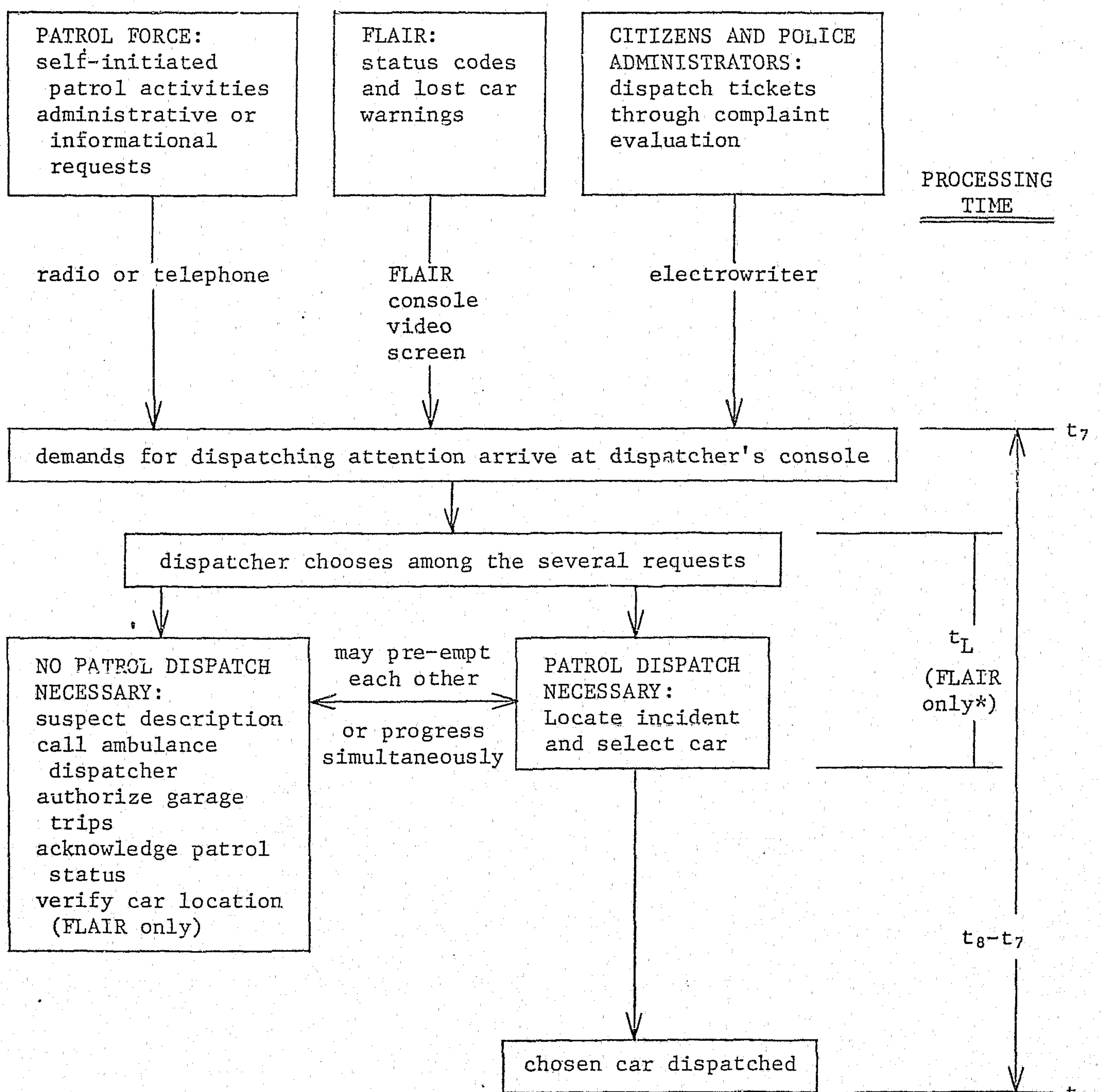
(Practice varies as to when t_7 is actually recorded during ticket writing, but observations indicate that on the majority of tickets it is the last item to be entered.) Dispatchers can, of course, read partial ticket entries prior to t_7, due to the electrowriter system, but it is apparent that they only infrequently dispatch officers until all ticket information is available. Experimentally, the point t_6, when an electrowriter line is first obtained, was a most elusive datum. Therefore it has been dropped from the quantitative analysis. However, the interval $(t_7 - t_{5A})$, from conversation termination to ticket completion, was noted and will be called the ticket writing time.

Figure 6-3

Inputs and Activities in Dispatching

(not to scale in time)



* car selection with FLAIR follows immediately on incident location

dispatching and replacements will be sought.

Tickets arriving in dispatching from complaint evaluation are hardly the sole inputs with which dispatchers deal. Since they serve as general clearing points for most radio communication within their respective areas, dispatchers themselves generate an appreciable stack of dispatch tickets relating to self-initiated patrol functions, assignments of assisting officers, administrative requests from field command personnel, etc. In addition, dispatchers serve as the main link between the patrol officers in their areas (via radio or telephone) and other city emergency services (via telephone) such as ambulances.

Several stages are involved in converting the request on a dispatch ticket from complaint evaluation into police assistance at the incident. Unfortunately for technical analysis, these contributing processes are not sharply separable and occasionally border on an "art form" rather than a "science". If there is a backlog of dispatching activity, newly arriving service requests must wait in a queue. In other instances a dispatcher may be free to handle a ticket immediately upon arrival, but find no officers available due to excessive levels of patrol activity.

Once the dispatcher turns to a ticket, two of the most readily identifiable processes which then follow are incident location and car selection. For non-FLAIR dispatching, the incident is located by memory among the more experienced dispatchers, and by scanning a map among those less experienced. However, to use the closest car FLAIR capability, the incident must be located by scanning an

electronic map with a cursor movable with a joy stick. Car selection in non-FLAIR circumstances entails consulting an overhead status board to identify available cars and meshing this with incident location and intradistrict command boundaries to arrive at the proper choice. Closest car operation under FLAIR automatically displays the four "closest"[9] in-service cars in order and irrespective of command, as the cursor is positioned, thus obviating much of the selection stage of non-FLAIR dispatching. (On occasion a travel barrier, expressway, etc., may cause the dispatcher to override the FLAIR selection for dispatch.) Although in either dispatching mode it is clear that car selection is strongly influenced by incident location, the selection is automatically determined immediately after location in ideal closest car FLAIR dispatching, while selection is somewhat judgmental and often simultaneous with location in non-FLAIR dispatching.

The point at which officers are actually dispatched, t_8, is recorded on the ticket by the dispatcher using a punch clock at his console. The interval from completed ticket arrival to officer dispatch, $t_8 - t_7$, is the dispatcher delay and it is this interval (as recorded on the dispatch ticket) which is used to measure dispatch time. Since there are six clocks in dispatching (one for each console) and two in complaint evaluation with little synchronization effort between the rooms in evidence, uncertain biases may appear in estimates of dispatcher delay calculated by

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[9] Here "closest" is defined by the FLAIR distance metric: see Section D.2 of this chapter.

using data from dispatch tickets.

Distinctions between FLAIR and non-FLAIR operations arise in the acknowledgment of patrol status by the dispatcher. In the former case, voice communication is usually unnecessary since each officer should display his status on the FLAIR console via digital codes he transmits from his patrol car panel, but such communications are entirely vocal in non-FLAIR dispatching. A significant duty borne by FLAIR dispatchers but not at all by their non-FLAIR counterparts is the verification of patrol car location upon visual warning, a *V* or a *W*, from FLAIR that it may have "lost" the car in its tracking efforts. In this case, the dispatcher must ask the officer to identify an intersection at which he can stop and hold while the dispatcher locates him on the FLAIR map. This search is automatic, requiring only the entry of the car identification number and pushing a button. Should the car be accurately displayed, no further action is necessary. However, if error greater than a specified policy minimum is evident, the dispatcher must move the cursor to the car's true position and instruct FLAIR (with a few key strokes at the terminal) to reposition the car at that spot.

6. Definition of dispatching processing times. In light of the above outline, three activities in dispatching which delay police response can be defined:

1. d_L — Location delay. The interval required to find the geographical location of the incident in the city. Although d_L is applicable to both FLAIR and non-

FLAIR dispatching, measurements are presented only for FLAIR due to the difficulty of observing the location process in non-FLAIR operations. Note that the starting point for d_L is not necessarily the instant at which the dispatcher receives the ticket (t_7 as defined earlier) since patrol assignment may not be made immediately.

2. $D_d = (t_8 - t_7)$ Dispatcher delay. The delay from ticket receipt in dispatching until a vehicle is dispatched. Dispatcher delay is applicable to both FLAIR and non-FLAIR dispatching.

3. d_V Verification delay. The inverval extending from a dispatcher's request to an officer for car location until verification is complete. Applicable only to FLAIR.

For the delays d_L and d_V, measurements will be presented which were obtained during the summer of 1975. These served as preliminary results in preparation for later data from the special three-week test which was undertaken in the fall of 1975. (See Chapter VII.)

C. Analysis of Telephone Complaint Processing

We are now ready to analyze the non-FLAIR-related components of delay in the police emergency response system. By estimating the mean (and variance) of delay in the "front-end" of the system, we will be able to compute the system-wide percentage response time reduction attributable to FLAIR.

To accomplish the analysis, several inter-related limited surveys were conducted. In the first, with the concurrence of the St. Louis MPD, an on-the-scene evaluator placed and timed 100 low-priority test calls over the course of about one month (June 23 to July 24, 1975). Dialed over 231-1212, these calls, which reported fictitious low-priority incidents to the switchboard operators[10], were distributed over hours of the day and days of the week according to levels of directed incidents and assists in St. Louis in 1974. Such intermittant calling did not perturb the workload experienced over 231-1212, which typically receives slightly less than 5,000 calls per day, about 25% of which are referred to complaint evaluation. The second survey consisted of real-time observations in the complaint evaluation room first during 23 half-hour periods distributed over June 25 to July 24, 1975, and second during 14 one-hour blocks during July 12 to July 21, 1975[11]; this allowed estimation of parameters related to

[10]Complaint evaluators were told of the test as soon as they came on the line, and the test was terminated.

[11] No observations occurred during early morning hours or weekend evenings and only limited observations occurred at certain other low workload periods.

call evaluation processing.

A summary of the results of these surveys is given in Table 6-1. The first entry in the table, $(t_3 - t_2)$, represents the switchboard answering time. This constitutes the delay from the first ring heard in the phone until an operator answers the call. The mean delay was five seconds. Fully 90% of all 82 observed values were answered in less than 10 seconds and 67% in less than five seconds. At no time was a buzy signal received when dialing 231-1212. Thus, initial telephone answering is about as prompt as one might expect even in an operating system.

The second row in the table spans the time from the first ring heard on the phone (by the complainant) until the call is answered by an evaluator, assuming low-priority calls. In a sample of 100 calls, the mean time until first contact with an evaluator was 30 seconds, with a standard deviation of 22 seconds. 43% of the calls reached call evaluation in less than 20 seconds, 64% in less than 30 seconds, and 85% in less than 45 seconds; the minimum and maximum were 11 and 121 seconds, respectively. Remembering that a portion of this delay is incurred by the citizen describing the trouble to the switchboard operator and that through practice this was minimized by the on-the-scene caller, these standards are likely to be slightly shorter than those experienced by the general public. On two of the calls exceeding 100 seconds, considerable delay resulted from no lines being available into the complainant evaluation room, but these were the only instances of overload encountered.

The third row in Table 6-1 reports the same delay as above

Table 6-1

Summary of Processing Times from Complainant's

Placing Call until Dispatcher Receives Ticket

(FLAIR Independent)

Processing Time	Symbolic Representation	Begins/Ends	Sample Size	Average (in seconds)	Standard Deviation	Minimum	Maximum
Switchboard Answering Time	$t_3 - t_2$	Complainant Calls/ Operator Answers (all priorities)	82	5 sec. (.08 min.)	5 sec. (.08 min.)	2 sec. (.03 min)	36 sec. (.60 min.)
Time until Answering by Evaluator (low priority)	$t_{4L} - t_2$	Complainant Calls/ Evaluator Answers (low priority)	100	30 (.5)	22 (.37)	11 (.18)	121 (2.02)
Time until Answering by Evaluator (high priority)	$t_{4H} - t_2$	Complainant Calls/ Evaluator Answers (high priority)	*	21 to 26 (.35 – .43)	14 (.23)	–	–
Evaluator Telephone Conversation Time (ticket to be written)	$t_{5A} - t_4$	Evaluator Answers/Call Terminated (all priorities receiving dispatch ticket)	152	43 (.72)	26 (.43)	10 (.17)	137 (2.28)
Ticket Writing Time	$t_7 - t_{5A}$	Call Terminated/ Completed Dispatch Ticket on Dispatcher's Desk (all priorities)	152	46 (.77)	31 (.52)	11 (.18)	156 (2.6)

* Estimate based on sum of contributing components.

Table 6-1

(continued)

Summary of Processing Times from Complainant's Placing Call until Dispatcher Receives Ticket

(FLAIR Independent)

(continued)

Processing Time	Symbolic Representation	Begins/Ends	Sample Size	Average (in seconds)	Standard Deviation	Minimum	Maximum
Total Evaluator Service Time (per call)	$t_7 - t_4$	Evaluator Answers/ Completed Dispatch Ticket on Dispatcher's Desk (all priorities)	194	88 sec. (1.47 min.)	41 sec. (.68 min.)	26 sec. (.43 min.)	230 sec. (3.83 min.)
Evaluator Telephone Conversation Time (<u>no ticket to be written</u>)	$t_{5B} - t_4$	Evaluator Answers/Call Completed (all priorities <u>not receiving</u> dispatch ticket	62	81 (1.35)	74 (1.23)	12 (.20)	342 (5.70)
Total Non-FLAIR-related Response Time (low priority)	$t_7 - t_2$	Complainant Calls/ Completed Dispatch Ticket on Dispatcher's Desk (<u>low priority</u>)	*	118 (1.97)	47** (.78)	-	-
Total Non-FLAIR-related Response Time (high priority)	$t_7 - t_2$	Complainant Calls/ Completed Dispatch Ticket on Dispatcher's Desk (high priority)	*	109 to 114 (1.82 to 1.90)	43*** (.72)	-	-

* Estimated by summing components.

** Assuming $t_{4L} - t_2$ and $t_7 - t_4$ are uncorrelated.

*** Approximate. Assuming $t_{4H} - t_2$ and $t_7 - t_4$ are uncorrelated.

(calling-to-evaluator answering delay) for <u>high-priority</u> calls $(t_{4H} - t_2)$. Since it was impractical to place high-priority test calls, an estimate of this delay was approximated by observing the time it took complaint evaluators to answer actual high-priority calls once they had passed through the switchboard. We designate this interval as $t_{4H} - t_3'$, where t_3' is the point at which high-priority calls leave the switchboard. (Data on $t_{4H} - t_3'$ are not recorded in Table 6-1.) Sixty-one percent of the 107 recorded $(t_{4H} - t_3')$ values were less than ten seconds, and 80% were less than 20 seconds; the minimum was one second and the maximum was 78 seconds. The overall average for $(t_{4H} - t_3')$ was 11 seconds and the standard deviation was 13 seconds. By adding switchboard answering time $(t_3 - t_2)$ and allowing five to ten seconds for complainant-operator conversations, one can arrive at an approximation of the high-priority complaint evaluation time $(t_{4H} - t_2)$. Estimates from the above data indicate that it requires on the average 21 to 26 seconds for someone with an emergency to dial the phone and reach an evaluator. This is 70% to 87% of the analagous average delay for low-priority calls.[12]

Of a total of 1,523 random Bell line calls counted in the evaluation room, 113 were hotline calls. This indicates that on the average, 7.4% of all incoming citizen's calls were hotlines and thus high-priority.

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[12] Assuming independence among switchboard answering times, operator-complainant conversation times, and the intermediate interval $(t_{4H} - t_3')$, yields an estimate of 14 seconds for the standard deviation of the high-priority complaint evaluation answering time as compared to 22 seconds in the low-priority case.

The fourth row in Table 6-1 contains data on evaluated on-phone conversation time for those calls resulting in a dispatch ticket. Since priority classification for calls could not be reliably noted, these results apply unconditionally to calls of both priorities. Of the 152 clocked conversations that resulted in dispatch tickets, 34% ended in less than 30 seconds, 72% in less than 50 seconds and 93% in less than 90 seconds; the briefest such conversation lasted ten seconds, and the lengthiest required 137 seconds. These data yielded a mean conversation time of 43 seconds with a standard deviation of 26 seconds.

The ticket writing time, $(t_7 - t_{5A})$, was noted for each of the 152 calls in which $(t_{5A} - t_4)$ was recorded. As shown in the fifth row of Table 6-1, the mean ticket writing time was 46 seconds, with a standard deviation of 31 seconds, a minimum of 11 seconds and a maximum of 156 seconds; 29% of the resulting tickets were written in less than 30 seconds and 80% required less than 60 seconds to complete.

An additional 42 ticketed calls were observed in which the intermediate point, t_{5A}, was not recorded. Combining these figures with those previously enumerated, a total of 194 ticketed calls were observed giving an average value for $(t_7 - t_4)$ of 88 seconds with a standard deviation of 41 seconds. This is the total complaint processing time in evaluation after a call destined to receive a ticket has been answered. Cumulative discriptions for the total complaint processing time in evaluation indicate that 26% of the observed ticketed complaints were completely processed

in less than 60 seconds, 63% in less than 90 seconds, and 81% in less than 120 seconds. It should be re-emphasized that these data for conversation and ticket writing time apply to both low- and high-priority calls.

Calls not warranting a dispatch ticket provided a small sample size of 62 from which an estimate of their average conversation time is 81 seconds with a standard deviation of 74 seconds, minimum of 12 seconds, and maximum of 342 seconds. By comparing the number of calls receiving tickets to the total number of calls observed, an estimate is obtained that 76% of calls arriving at evaluation receive tickets[13].

By summing the averages of all the components of complaint handling up to dispatching (complaint evaluation answering time plus conversation time plus ticket writing time), one arrives at an average time between a complainant's dialing the police and his information reaching a dispatcher ($t_7 - t_2$) of 118 seconds (1.97 minutes) for low-priority incidents and 109 to 114 seconds (1.82 to 1.90 minutes) for high-priority incidents. Assuming independence between answering times and the evaluation-ticketing times, the standard deviation of this delay is 47 seconds (.78 minutes) for low-priority incidents and about 43 seconds (.72 minutes) for high-priority incidents. It is most important to remain mindful

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[13] The conditions of the test require that this be qualified as an upwardly biased estimate. That is, longer lasting non-ticketed calls tended to be passed over in favor of shorter ticketed calls to make more effective use of limited testing time.

of the fact that this delay, $(t_7 - t_2)$, will remain unaffected by FLAIR implementation; i.e., it is not FLAIR dependent.

One can conclude that a citizen's complaint will encounter approximately two minutes of FLAIR-independent delay in processing before reaching a dispatcher. Anticipating the analyses of the following sections, one can assign estimates to dispatching delay of about 3.5 minutes and to travel time of about 5 minutes to arrive at an overall emergency response delay of about 10.5 minutes, of which travel time constitutes approximately 48% and dispatcher delay about 33%. Therefore, percentage changes in dispatcher delay and travel time resulting from FLAIR deployment must be multiplied by .48 and .33 respectively and added together to estimate the percentage change in total system response time. For example, a 20% reduction in travel time and 5% increase in dispatcher delay translate to about a 7% reduction in overall response delay. Placing travel time reduction in a global perspective is vital to the final evaluation of FLAIR as an effective technology.

In addition, in analyzing response time in St. Louis it is appropriate to note other areas where improvements might be achieved. The St. Louis Metropolitan Police Department utilizes a single number (231-1212) for both emergency and administrative calls. However, this necessitates that the emergency caller describe the incident twice to police operators, once to the first switchboard operator and then to the complaint evaluator. While the answering delay (averaging 10 seconds) for the first switchboard

is about as small as one might hope for in an operating system, the caller experiences an average of about 30 seconds from completion of dialing until initial conversation with a complaint evaluator--the person who will record the details of the incident and direct the information to a dispatcher. Limited evidence suggests that a fraction of callers may have to wait considerably longer than 30 seconds, due to queuing delays caused by all complaint evaluators being simultaneously busy. Such delays at this point are viewed as very undesirable since the caller may be in a critical situation not allowing 30 seconds or more of hold time. <u>It is the opinion of the evaluators that at least 20 seconds of this 30-second delay could be eliminated by instituting two separate police numbers--one for emergencies and one for all other (mostly administrative) calls</u>. Additional look-up and dialing time could be eliminated by making the emergency number the now popular three-digit number--911. Delays over the emergency number could be kept uniformly low throughout the day by scheduling complaint evaluators according to some prespecified performance criterion, utilizing statistics on call rates, conversation times, and the theory of queues. It is worth noting that the St. Louis MPD is considering the possibility of a 911 system. While it is difficult to estimate the cost of such a change, it is unlikely that the cost would equal that of a CAD or AVM system.

Once the caller is in contact with the complaint evaluator, another 90 seconds (approximately) is required (on average) before

the information about the call is before the dispatcher. Somewhat controllable factors which contribute to this delay are 1) writing the information twice--once on a miscellaneous slip of paper and then on the electrowriter; 2) address look-up and conversion; and 3) blockage of electrowriter--if another complaint evaluator is simultaneously writing to the same dispatcher. Of the 90 seconds of delay, approximately one-half is on-phone conversation time and half is "ticket writing" time. It is the opinion of the evaluators that the majority (at least 25 seconds) of the ticket writing time could be eliminated with the installation of an easy-to-use CAD system. Such a system would eliminate the need to record information twice and to look up a fraction of addresses for conversion to police area coding. It would also detect incorrect addresses, multiple reports of the same incident, and it would have a number of other features. A CAD system could possibly increase mean telephone conversation time, with nearly the total complaint evaluator time per call (estimated to be about 90-25=65 seconds) spent on the telephone.

Costs of CAD systems depend markedly on city size and system capabilities, but a reasonable planning figure for a city the size of St. Louis would be about $800,000 (for design, purchase and installation). There would be a recurring annual cost probably in excess of $100,000.

The identification of pre-FLAIR delays and ways to reduce them is not meant to imply that we recommend a separate emergency number or a CAD system. That decision rests with administrators

of the MPD in St. Louis and most likely will hinge on an evaluation of the relative costs and benefits involved, together with budget constraints. Certainly the possibility of CAD would require much more evaluation before a move in that direction could be undertaken. If the St. Louis MPD is interested in response time, though, other aspects of the response time system besides AVM could receive consideration.

D. Analysis of FLAIR-Related Response Time

Dispatching procedures and patrol car response are affected by FLAIR, and the associated response time component (dispatch delay and response time) constitute the FLAIR-related part of response time. Evaluation of the impact of FLAIR on both components is complicated by the multitude of factors that come into play, not the least of which is the general attitude of the police personnel involved.

For dispatch delay, it is not clear *a priori* whether the dispatch procedures associated with the FLAIR System would cause a net increase or decrease in time required to assign a unit to a particular call. It is not obvious that the new tasks of locating the cursor and checking the closest car list would take longer or shorter than determining the approximate location of a call, checking the car availability list, and then dispatching a vehicle as was done before FLAIR.

The second category, travel time, has more definite expectations associated with it. From the beginning, travel time reductions realized through the ability to consistently dispatch the closest vehicle to an incident, have been cited as a primary goal of an AVM system. The first objective listed in a 1972 MPD Narrative Work Program (requesting funding for FLAIR) was the reduction of "response time of the patrol units to crime and service requests in order to increase the probability of apprehension." A similar emphasis on the importance of travel time was made in the Phase I Evaluation report issued by the MPD on March 21, 1975.

Also, a majority of command rank personnel interviewed in September, 1975 perceived travel time reductions as the most significant benefit expected from the AVM system.[14]

Before launching directly into an empirical analysis of the St. Louis situation, it is helpful to gain some insight into the types and magnitudes of travel time reductions anticipated with AVM. The next section will briefly summarize the key results of several researchers who have modeled mathematically the police patrol force operating with AVM dispatching. Section 2 will then discuss a limitation of the FLAIR distance metric, and Sections 3 through 8 will report the results of the Phase I response time system.

1. Summary of earlier modeling work. The first major modeling work in this area performed by Bellmore as part of the work of the Science and Technology Task Force of the President's Commission on Law Enforcement and Administration of Justice[15]. Bellmore specified a probability p that any particular unit would be busy and thus unavailable to respond to a call for service; higher levels for p indicate a patrol force with higher workloads. Units were determined to be available or busy independently of the

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[14] Also see Chapters I and X.

[15] M. Bellmore, "Automatic Car Locators", pp. 149-151 of Appendix E ("Electronics Equipment Associated withthe Police Car") in President's Commission of Law Enforcement and Administration of Justice, Task Force Report, Science and Technology, U.S. Government Printing Office, Washington, D.C., 1967.

status of others. A square simulated region contained a given number of square, evenly spaced patrol beats. Position estimation resolution of the AVM system was specified by a "beat fraction" 1/r, where r might be 2, 3, 5, 10 or any positive integer. For a given r each beat was partitioned into r^2 square sub-beats, thereby allowing a model for AVM accuracy. The AVM system would specify the sub-beat of the patrolling unit with certainty, but the location of the unit within the sub-beat was assumed random (and uniform). Acting as if each available unit were at the center of the sub-beat specified by the AVM system, the dispatcher (in the computer model) would always dispatch that available unit estimated to be the closest to the incident. Bellmore's analysis focused on travel time savings achievable with AVM as a function of workload p and resolution r. The conclusion of the study was that nearly no additional savings in average travel time were available for systems more accurate than one-fifth of a beat side, and two-fifths of a beat side appeared to be acceptable.

A second effort, by Bales[16], used most of Bellmore's ideas but with a resolution model that was found to be more realistic for most radio-trilateration AVM systems. This modelled the position estimation error according to a circularly symmetric Bell-shaped

[16] R.A. Bales, "A Police Car Simulation Model: Conventional Versus AVM Dispatching", in Proceedings of the 1970 Carnahan Conference on Electronic Crime Countermeasures, University of Kentucky and Institute of Electrical and Electronic Engineers, pp. 1-23 (April 16-18, 1970).

probability curve,[17] where the peak of the curve was located at the response unit's location. His results were not dissimilar to those of Bellmore.

The third effort was done by Larson[18], who used a model for AVM resolution similar to the one Bales used, but who incorporated AVM dispatching into a rather general simulation model of police dispatching and patrol deployment. The model allowed prioritized dispatching, overlapping sectors, preemption (or interruption) of busy units to send them to high-priority calls, and a number of other realistic properties of actual police operation. Among other things, Larson's AVM analysis focused on the following questions:[19]

1. What is the probability of dispatching other than the closest car with present manual dispatching systems?

2. How do increased workloads affect the potential benefits of AVM systems?

3. What is the anticipated reduction in travel time that can be obtained with AVM information?

4. Does closest-unit dispatching <u>degrade</u> system performance in any way?

5. What effect does the size of the command have on the value of car location information?

6. How will AVM systems function with overlapping beats?

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[17] Technically, this was a circularly symmetric Gaussian or Normal probability density function.

[18] R. C. Larson, <u>Urban Police Patrol Analysis</u>, the MIT Press, Cambridge, Massachusetts, 1972, Chapters 6, 7.

[19] R. C. Larson, <u>Urban Police Patrol Analysis</u>, p. 205.

We summarize Larson's answers to these questions as follows:[20]

1,2. The probability of dispatching other than the closest unit with present manual dispatching systems depends on beat geometries, workload factors, and on type of position estimation used. For low workloads, this dispatch error probability ranges from 1/6 (= 0.167) for straight-line beats to about 0.30 for arrays of square beats.

As workload increases above minimal levels, this probability may increase for a while, but it eventually starts to decrease (for workloads greater than 30 percent) and it goes to zero as workload approaches 100 percent. Thus, location information is most valuable for low and moderate workload situations and least valuable for heavy workload situations.

2,3. The reduction in area-wide average travel time that can be obtained with car location information depends on the same factors cited above for dispatch error probability, with typical reductions averaging between 10 and 20 percent. For low workloads, a perfect resolution AVM system would reduce mean travel times by about 12 percent in straight-line beats and about 15 percent in arrays of square beats. Mean travel time reduction varies with workload in a way very similar to that of dispatch error probability, perhaps increasing until workload reaches 20 to 30 percent, then gradually decreasing to zero. The lack of benefits from AVM at heavy workloads is understandable since the dispatch choices available to the dispatcher are quite limited, and perhaps simply the unit's beat location will be sufficient to specify the closest available unit.

4. If increased out-of-beat responses are accepted as undesirable, then closest-unit dispatching degrades system performance in that it results in greater amounts of interbeat dispatching. Patrol administrators such as V. A. Leonard[21]

[20] Ibid., pp. 238-240.

[21] V. A. Leonard, Police Patrol Organization (Springfield, Illinois: Charles C. Thomas, Publisher, 1970), p. 19.

and O. W. Wilson[22] have argued for maximum involvement of an officer in his own beat. At very low workloads, assuming closest unit dispatching, the fraction of dispatches that are interbeat dispatches is 0.167 for straightling beats and about 0.30 for arrays of square beats, As the percentage of time worked on calls for service increases, the fraction of dispatches that are interbeat increases, remaining greater than the workload percentage for all but the highest workloads.

5. Generally speaking, unit location information is more valuable in larger commands that allow more dispatch alternatives than smaller commands.

6. If a flexible patrol plan is implemented in which conventional beats are eliminated and each unit patrols one larger area, independently of other units, and if perfect resolution unit location information were used to dispatch the closest available unit, then the travel time characteristics of this overlapping beat system are nearly identical to those of a manual dispatch system with conventional beats.

While Larson's analyses were performed with idealized linear and square beats, each of his general conclusions applies to the more complicated District 3 in St. Louis, and the combination of factors that come into play make it very difficult to detect empirically a 10 or 15 percent reduction in mean travel time, comparing say one year to the next. For instance, the analysis suggests that a simultaneous shift to AVM and overlapping beats should leave mean travel time unchanged. (Such a change was instituted for a short period in District 3). So, the effects of AVM on mean travel time are tied in a very complicated way to patrol deployment policies, and one needs a mathematical model

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[22] O. W. Wilson, Police Administration, 2nd Ed. (New York: McGraw-Hill Book Co., 1963), p. 252.

to "normalize" the effects of variations in deployment policies, workloads, and number of units fielded. This is the key reason for our use of a reprogrammed and improved version of the Larson simulation model later in this section.

2. A limitation of the FLAIR distance metric. The FLAIR system design is directed primarily at accurately tracking and displaying the estimated positions of FLAIR-equipped vehicles. The underlying philosophy of the display is that the dispatcher can take into account numerous factors other than simply relative positions of units and the incident in order to arrive at an "appropriate" dispatch decision. These factors include one-man vs. two-man cars, the location of the "stack" car, one-way streets, expressways, etc.

Still, on a corner of the FLAIR console is a rank-ordered list of the four "closest" available units to the incident (actually to the locator of the cursor on the map). This rank-ordered list has some serious limitations that (1) for dedicated dispatchers will increase dispatching decision-making time above zero; (2) will often result in nonoptimal dispatches if the first entry in the list is used indiscriminately, and (3) will limit the accuracy of dispatcher recommendations in a CAD/AVM system, if the same procedure were used in such a merged system.

As long as the dispatcher understands the limitations of the system and carefully reviews the map prior to each dispatch, such a rank ordered list should cause little problem. However, we discuss this topic here because of its relevance to dispatch

delay (the rank-ordering method used should increase dispatch delay) and to travel time (which could be degraded if the FLAIR-recommended cars were always dispatched). Unlike the discussions of Chapter V, which focused on estimated vehicle location errors and vehicle losses, system error in this case is not tied to locations, but rather to the linking of locations to travel times. It is necessary to link incident and patrol unit locations to travel times in order to make reasonable dispatch recommendations to the dispatcher.

The FLAIR rank-ordered list of dispatch preference is generated by using the "right-angle" distance metric. If an incident is located at point (x_1, y_1) and a vehicle is located at (x_2, y_2), then the right-angle travel distance to the incident is

$$\left|x_1 - x_2\right| + \left|y_1 - y_2\right| .$$

Vehicles are rank-ordered by this distance.[23]

There are several complications that limit the usefulness of this approximation in actual practice. The first deals with the general directions of street travel in various parts of the

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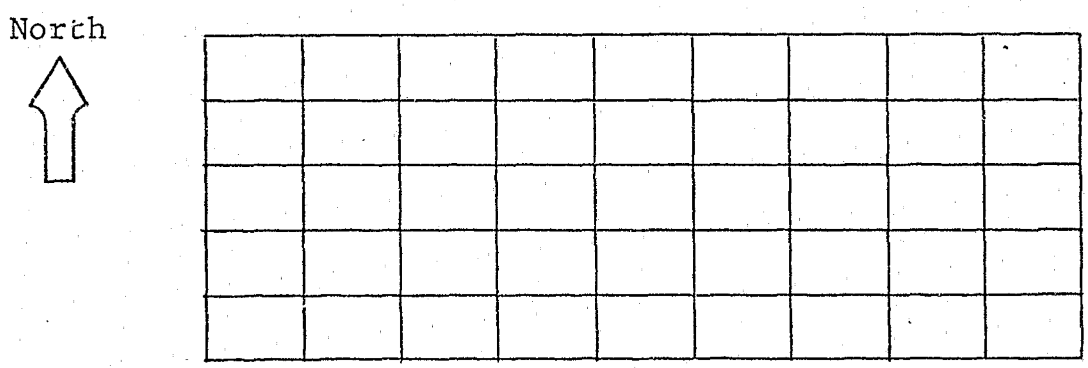
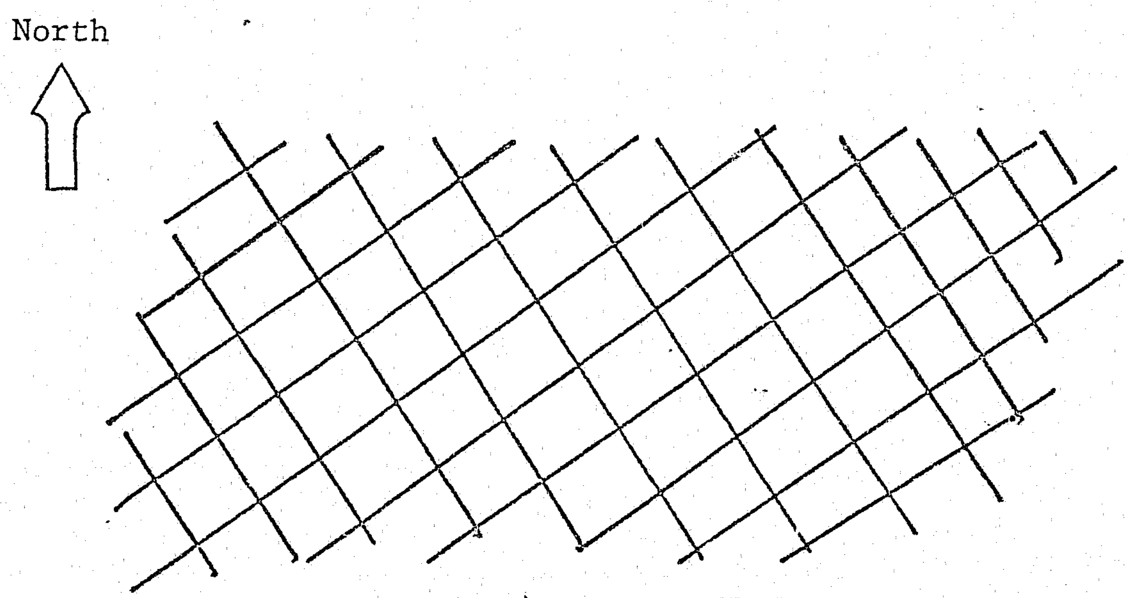
[23] If the right-angle distance metric correctly describes response paths, then it is not necessary to incorporate speed (in the denominator) in order to accomplish the rank-ordering. Even if speed is a monotone increasing function of distance (increasing at a rate less than distance squared), one always would have the spatially closest vehicle being the closest one in time also.

city. In most of District 3 most of the street patterns look like this:

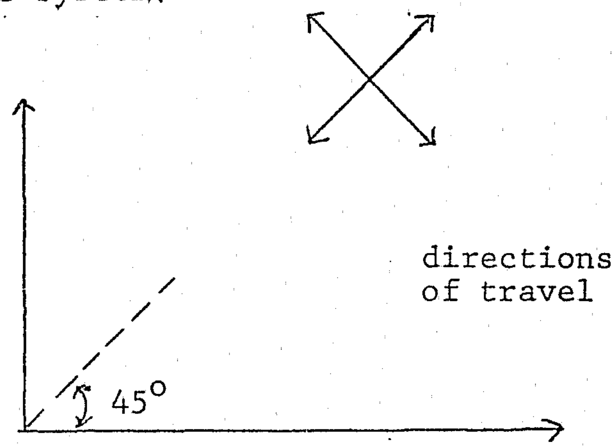


But the street patterns in the Fairground Park area look like this:



If the x-y coordinate system is not rotated to account for these street rotations, and it is not in the FLAIR system (Phase I version), then serious errors in distance estimation could occur. For example, suppose the street grid is rotated at 45° to the

directions of the x-y coordinate system:



Then, the FLAIR software would estimate a travel distance of

$$(d_{FLAIR}) = \left| x_1 - x_2 \right| + \left| y_1 - y_2 \right| ,$$

whereas the actual distance can be shown to be

$$d = \sqrt{2}\ \text{MAX} \{ \left| x_1 - x_2 \right| , \left| y_1 - y_2 \right| \}.$$

Typical errors that can occur because of this lack of rotation are given in Table 6-2. (For convenience, the patrol car location of Table 6-1 are also displayed in Figure 6-4.

Note, for instance, that the <u>first preferred</u> FLAIR car (car II) is actually tied with two other cars for third (in closeness to the scene). The car actually closest (car V) is tied for third according to FLAIR software. Somewhat astoundingly, FLAIR's second preferred car (car VIII) is actually <u>eighth</u> in distance from the incident.

The travel time consequences of these travel distance estimation errors can be considerable. Entries in the last column

Table 6-2

Two Different Distance Calculations: Based on Rotated and Non-Rotated Coordinate Systems

Patrol Car Number	Incident Location	Patrol Car Location	d_{FLAIR} (estimated travel distance in miles)	d (actual travel distance in miles)	FLAIR Rank Order (in terms of closeness)	Actual Rank Order (in terms of closeness)	Travel Time Difference in Minutes (at 20 mph) Using Estimated and True Distances*
I	(0, 0)	(1, 1)	2	$\sqrt{2}$ = 1.41	1	tie for (3, 4, 5)	1.77
II	(0, 0)	(0, 1)	1	$\sqrt{2}$ = 1.41	1	tie for (3, 4, 5)	-1.23
III	(0, 0)	(1.2, 1)	2.2	1.70	tie for (7, 8)	7	1.50
IV	(0, 0)	(0.5, 1)	1.5	2 = 1.41	tie for (3, 4)	tie for (3, 4, 5)	0.27
V	(0, 0)	(0.75, 0.75)	1.5	1.06	tie for (3, 4)	1	1.32
VI	(0, 0)	(1.1, 1.1)	2.2	1.56	tie for (7, 8)	6	1.92
VII	(0, 0)	(.8, .9)	1.7	1.27	5	2	1.29
VIII	(0, 0)	(0, 1.25)	1.25	1.77	2	8	-1.56

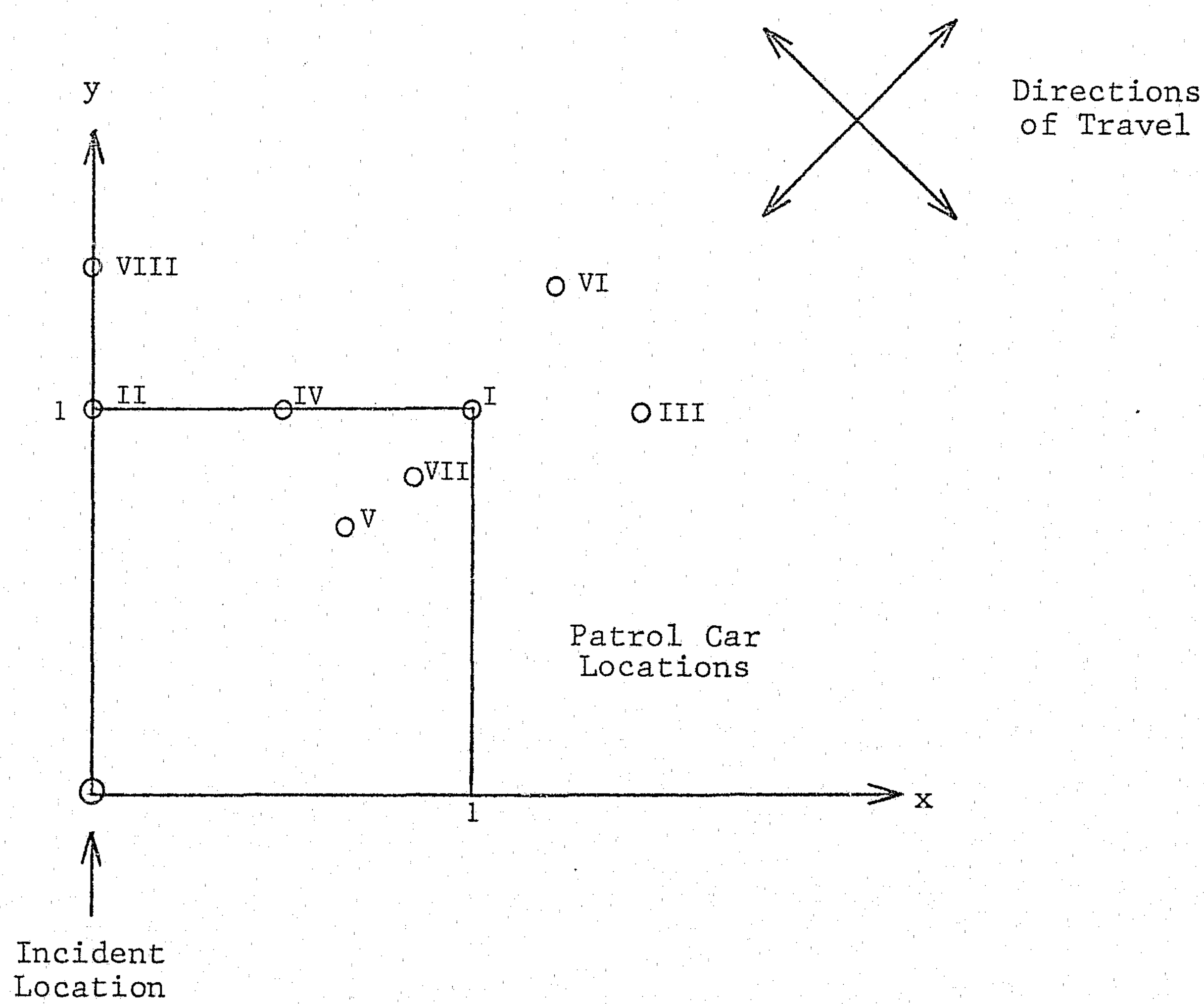
* Entries in this column are calculated as follows: $3(d_{FLAIR} - d)$. (minutes)

The factor of 3 arises because 20 mph = (1/3)mile/minute.

A positive entry here indicates that FLAIR overestimates the true travel time (by the amount shown); a negative entry indicates underestimation.

Figure 6-4

Set of Eight Possible Patrol Car Locations



of Table 6-2 contain the difference in the travel time estimates of FLAIR and the true travel time, assuming a fixed response speed of 20 mph. For this example, all but one of these differences exceed one minute in magnitude and four (50 percent) are 1.50 minutes or more in magnitude. This is considerable when one realizes that the typical travel time reduction of a perfectly working AVM system is on the order of 10-to-15 percent (as predicted by simulation models), which means 1.0 to 1.5 minutes for a system whose pre-AVM mean travel time was 6.0 minutes. Thus, any travel time reduction due to AVM information could be washed away by errors of comparable magnitude in the distance estimation procedure. (Since most of District 3 is generally on a north-south grid, this is less of a problem in District 3 than it will on much of the rest of the city.)

One not unreasonable fix for this problem would involve utilizing a different coordinate system rotation for each different part (probably district) of the city. Since angles of streets do not usually change significantly within a district such a fix would greatly alleviate this problem (although it would create new, but solvable, complications in estimating interdistrict travel times).

The next complication that is not dealt with by FLAIR is barriers to travel such as expressways, railroad tracks, rivers, cemetaries, parks, etc. Thus, the FLAIR vehicle selection algorithm may place a vehicle at the top of the dispatch preference list since it is only two blocks from the incident but with an

expressway intervening, thereby making travel time excessively long. The FLAIR second-preferred vehicle, say six blocks from the incident, may actually be much closer in a travel time sense. In such cases, to avoid obviously bad dispatch decisions, the dispatcher is to use his detailed knowledge of the city to override the FLAIR-recommended first unit.[24]

A third and similar complication not treated by FLAIR is one-way streets. Here too the presence of one-way streets may make the vehicle listed first according to the right-angle distance metric actually second, third, or lower in real travel time to the scene. As argued in Chapter 3 of Larson's book[25], the presence of one-way streets can sometimes increase the minimal travel distance to the scene by six block lengths.

Certainly the combination of random street rotations, barriers, and one-way streets can make the rank-ordered closest cars as computed from the right-angle distance metric very much different from the actual rank-ordered list (as measured by actual travel time). As long as the dispatcher is carefully briefed on this limitation and realizes that a careful scrutiny of the map prior to each dispatch is required, use of the right-angle distance metric should cause little problem. However,

[24] Those who are interested in the increased travel time due to barriers, should see Chapter 3 of R.C. Larson, Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972.

[25] Ibid.

since AVM systems are likely to become integrated with CAD (Computer-Aided Dispatch) systems, this problem should be solved prior to a CAD-AVM marriage.[26]

The limitations of the FLAIR car rank-ordering procedure are indicative of a number of factors, each of which can affect travel time and sometimes dispatch delay by up 10 percent or more. Other factors are manning levels (an increase or decrease of one car can affect average travel time by a few percent and dispatch delay by more than a few percent), work loads (which are impossible to control from year to year), personnel attitudes, number of non-FLAIR cars fielded, geometrical sector designs, etc. Thus, even if "true" FLAIR-related response time is reduced by X percent (where X could range up to say, 25%), it might be difficult to detect such a drop empirically.

Armed with this precaution, we are now ready to examine the empirical results.

3. Data sources for response time analysis. The response time data were provided by the Evaluation Unit of the St. Louis Commission on Crime and Law Enforcement from data belonging to the MPD and stored on magnetic tape at the Regional Justice Information Service (REJIS) in St. Louis. For a specified time

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[26] One solution that is obvious--but costly in terms of storage requirements--would be to store a point-to-point travel time matrix within the computer. Then, if the patrol vehicle is at location i and there is an incident at location j, the estimated travel time is equal to the $(i,j)^{th}$ element, say T_{ij}, of the matrix.

period (usually one month), the output presents statistics on six response categories and for 33 different call types. The response system times contained on these tapes are: dispatch delay, travel time, and on-scene service time. As indicated earlier, the sum of the first two times, which is also calculated directly on the tapes, is the time elapsed between dispatcher receipt of call to the time a unit arrives on the scene. Because "time of arrival" is not always reported by the responding officer, values for dispatch delay are calculated using a larger number of observations than either travel time or FLAIR-related response time. The three statistics reported in the output are the number of incidents used (sample size), the average time, and the standard deviation, all calculated for each incident type on a district and city-wide basis.

In the recorded dispatch delays, slight errors may be present in the data due to the fact that the clocks used by complaint evaluators (for the time the dispatcher receives the dispatch ticket) and the clock used by the dispatcher for subsequent times (dispatch time, arrival time, service completion time) are not perfectly synchronized. While these should be random errors, any particular value for the error would tend to persist for some time. Thus recorded average dispatch delays could be in error (for a particular district) by the value of the random error for a particular month. From our observations, this monthly error value could be as large as 30 seconds. Since only one

clock is used subsequently, no such random biasing occurs for travel times or on-scene service timing. Moreover, the average values should not be biased in any way due to the practice of rounding times, say to the nearest minute. Such translation practices do, however, increase the variance slightly;[27] so the standard deviations reported here would tend to be slight over-estimates of the true values.

Due to the importance of the dispatch delay and the imprecision of the measuring instrument, additional fine-grained on-the-scene analyses were conducted of the FLAIR dispatcher's activities. The details of these procedures are discussed below.

4. District 3 Response Patterns. In order to gauge any changes that might have occurred during the Phase I implementation, data on response times were analyzed on a monthly basis for January through November of both 1974 (pre-FLAIR) and 1975 (during FLAIR). The month of December was not used because the system actually became operational on December 16, 1974, which made comparison with December, 1975 difficult. Monthly comparisons were used in an effort to reduce any seasonal effects on workload, demand pattern, travel time, and manpower. Using values obtained for dispatch delay, travel time, and FLAIR related response time over all incident types, statistical t-tests were performed to

[27] R. C. Larson, Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972, pp. 120-123.

test for a significant difference between 1974 and 1975 averages. A standard t-test assuming equal standard deviations was used for those comparisons where the sample standard deviations were within ten percent of each other. Otherwise, an approximate method developed by Welch was used.[28] Only results that obtained at least a .90 level of significance are reported as significant.

a. Dispatch Delay Times. Dispatch delay time is the time elapsed between when the call is received by the dispatcher and the time the call is assigned to a field unit. The time includes not only time required for the dispatcher to process a call, but also any queuing delays the call may have experienced because a proper unit was not available.

Average dispatcher delays encountered during the Phase I implementation presented a mixed pattern when compared to 1974 data. For five of the first six months of the year, 1974 dispatch times were significantly shorter than their 1975 counterparts. Beginning in July and continuing through August to the special three-week test period in September, dispatch delay times were significantly shorter during 1975. In October and November, too, the 1975 averages were slightly lower than in 1974, but the differences were not large enough to be significant in a statistical sense. These findings are summarized in Table 6-3, which also reports a net decrease of 1.4% from the 1974 11-month average to the 1975 11-month average.

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[28] Statistical Package Extended, CSS, Inc., Norwalk, Connecticut, April 1974.

Table 6-3

Monthly Comparison of Dispatch Delay Times for the First Eleven Months of 1974 and 1975

Month	1974 (pre-FLAIR)	1975 (during FLAIR)	% Change	Significance of Change
January	3.22	3.46	+7.5%	.900
February	3.02	3.46	+14.6%	.990
March	3.25	3.21	-1.2%	N.S.*
April	2.65	2.93	+10.6%	.975
May	2.54	3.66	+44.1%	.999
June	3.70	4.38	+18.4%	.999
July	5.22	3.62	-30.7%	.999
August	4.60	4.06	-11.7%	.999
September	4.74	3.81	-19.6%	.999
October	3.46	3.43	-0.9%	N.S.
November	3.97	3.77	-5.0%	N.S.
Average	3.67	3.62	-1.4%	

*N.S. = Not Significant.

The early apparent increases in time required to dispatch a vehicle were not unexpected. The new process of locating a cursor precisely at the location of an incident required a more detailed knowledge of the district than was previously needed to dispatch a car. Combine this with vehicle initializations and a new digital communication capability, and one has a situation that required the learning of a new set of dispatcher skills. It was anticipated that this learning process would produce slightly longer dispatch times until the dispatchers became familiar with the system. Indications from the data are that the dispatchers became acclimated to the system sometime during the summer when dispatch delays improved.

b. Detailed Dispatching Analysis. In an attempt to gain a better understanding of the dispatch delay results, detailed observations of the FLAIR dispatching process were carried out during the summer of 1975. A total of 26 one-hour observation periods provided data on several fine-grained dispatcher procedures. Since observations were conducted at a remote FLAIR console monitor, although dispatchers were generally aware that they were being studied, they were most likely unaware of the observer's presence at specific times. The focus was on discretionary dispatches, which meant those assignments for which the dispatcher could choose any available qualified car. An example of a non-discretionary dispatch would be an administrative request that a specific car report to a district station. Also excluded from consideration were

dispatches to cruisers which had never had FLAIR equipment. For the last 17 observation periods, the number of dispatches given to cars from the closest car column was also noted without regard to position in the column. However, the substantial majority of such dispatches was given to the first ("closest") car. (A further breakdown according to position in the closest car column can be found in the three-week test results, Chapter VII.)

For a variety of reasons including a fleet changeover, there was a low level of street implementation for FLAIR during the summer months. Thus, indications of cursor and closest car utilization given here will serve as worst case comparisons for those data.

Of the 331 recorded discretionary dispatches, the cursor was used to locate the incident in 114 cases, or only 35% of this total. (This proportion ranged from 13 to 57%.) In 45 of the 236 dispatches for which the assigned car was noted, that car came from the closest car column. This indicates only a 19% usage level for the closest car dispatching with a variation between 6% and 32%, over individual observation periods (dispatchers). Although the already mentioned low level of FLAIR street implementation during these observations was clearly a factor in promoting such infrequent average cursor and closest car utilization, it may be reasonably inferred from the wide variation about the mean of individual dispatchers that the particular individual who sits at the dispatching station has much to do with the impact of FLAIR.

For this reason, it was believed necessary to exercise some discrimination in choosing dispatchers to work with FLAIR during the three-week test period so as to insure the fairest possible experimental atmosphere. Accordingly, those dispatchers who had demonstrated previous willingness to work with and use FLAIR rather than to ignore it were assigned to the Third District console for the three-week test. Further details of dispatcher selection and briefing are in Chapter VII.

For 84 of the 114 instances of cursor utilization of the mean location delay (d_L) was 14 seconds with a standard deviation of 8 seconds. Practically every cursor movement was accomplished on <u>the most detailed map scale</u> (<u>16x</u>). Since lost car warnings sent by FLAIR to the dispatcher can assume one of two forms, a V or W, information gathered on verification delay (d_V) should be separated into four categories: instances where reinitialization is required and those where it is not, for both warning types. V's are the most prevalent warning type and 87 observations of V's where reinitialization was necessary yield an estimated mean for verification delay of 17 seconds (standard deviation = nine seconds). For 25 V's where reinitialization was unnecessary, this delay averaged 12 seconds (standard deviation = seven seconds). A mean of 21 seconds for verification delay (standard deviation = ten seconds) was found for processing 19 W's requiring reinitialization, and no W's occurred for which reinitialization was not needed. This is reasonable in light of the fact that cars flagged with W's tend to be in serious

tracking trouble. Overall then, it can be said that a dispatcher would require on the average from 12 to 21 seconds between asking a flagged car for its location and legitimately clearing the flag from the status column, the value depending on the exact nature of the tracking warning. Such time need not be exclusively devoted to this task, however, since other duties can be initiated while waiting for the car to stop for verification. Accordingly, time consumed in FLAIR "housekeeping" activities cannot be interpreted as purely additive terms in the overall emergency response time calculation. A table of all results from these detailed observations are provided in Table 6-4.

These analyses made it clear that FLAIR was not being used in the way that it was intended during the middle part of 1975. Dispatchers' utilization of the cursor was low, incidence of non-FLAIR equipped vehicles was high, interest in FLAIR was comparitively low, and use of the closest car columns (even with cursor use) was low. These factors combine to reduce the FLAIR-related significance of the monthly response time data reported in this sector, and they motivated the special three-week test discussed in Chapter VII. Still, with the appropriate caveats in mind, it is useful to analyze the monthly data to compare to the results expected from simulated analysis. The discussion here - while the data are primarily inconclusive - presents a framework for the analysis to be conducted during the Phase II city-wide implementation.

Table 6-4

Summary of Cursor and Closest Car Utilization Data and Measurements of Cursor Location Delay and Verification Delay

Utilization levels

Test condition	Sample size	Occurrence of test condition	Utilization (range)
Use of cursor to locate incident	331 discretionary dispatches	114 discretionary dispatches	35% (13 to 57%)
Assignment of first car in closest car column	236	45	19% (6 to 32%)

Cursor location delay, d_L, and verification delay, d_V

Processing time	Sample size	Average	Standard deviation	Minimum	Maximum
Cursor location delay, d_L	84	14 sec.	8 sec.	2 sec.	56 sec.
Versification delay, d_V *V*'s with reinitialization	87	17 sec.	9 sec.	4 sec.	58 sec.
Verification delay, d_V *V*'s with no reinitialization	25	12 sec.	7 sec.	3 sec.	27 sec.
Verification delay, d_V *W*'s with reinitialization	19	21 sec.	10 sec.	6 sec.	52 sec.
Verification delay, d_V *W*'s with no reinitialization	0	-	-	-	-

c. Travel Times. Travel time is the time elapsed between when the dispatcher assigns a unit and the instant the unit arrives at the scene. It is in this response category that AVM in general, and FLAIR in particular, was expected to have the largest impact. Table 6-5 shows that in nine of the eleven months tested, travel time in District 3 was significantly shorter in 1975 than 1974.[29] The averages of the other two months maintained this trend, but the drops were not large enough to be significant. The largest percentage decrease came during the special system test in September when there was a 15.1% drop in travel time. This represented an average of 50 seconds saved in travel time to the scene of an incident. The percent drop in the 11-month averages was 8.0%, down almost 26 seconds from the 1974 figure of 5.35 minutes. The introduction of FLAIR coincided with major decreases in travel time. (An interpretation as to just what these numbers might represent should wait until later in the chapter when District 3 reductions are normalized based on city-wide analysis.)

d. FLAIR Related Response Time. This measure combines the two response categories that the AVM system directly impacts: "dispatch delay" and "travel time." Results for four of the first

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[29] During the period December 16, 1974 - February 5, 1975, the traditional best concept was eliminated and best cars were allowed to "float" over larger parts of District 3. Such an overlapping beat plan would tend to increase travel times slightly (over the case of nonoverlapping beats). Thus, the January figures should be interpreted with this in mind.

Table 6-5

Monthly Comparison of Travel Times for the First Eleven Months of 1974 and 1975

Month	1974 (pre-FLAIR)	1975 (during FLAIR)	% Change	Significance of change
January	5.44	5.30	-2.6%	N.S.*
February	5.16	4.97	-3.7%	.950
March	5.29	4.89	-7.6%	.995
April	5.18	4.79	-7.5%	.999
May	5.31	4.90	-7.7%	.999
June	5.32	4.83	-9.2%	.999
July	5.46	4.78	-12.5%	.999
August	5.59	4.84	-13.4%	.999
September	5.58	4.74	-15.1%	.999
October	5.31	5.18	-2.4%	N.S.
November	5.18	4.90	-5.4%	.950
Average	5.35	4.92	-8.0%	

*N.S. = Not Significant.

five months of the year show that increases incurred in dispatch delay were larger than the corresponding travel time reductions and caused a net increase in FLAIR related response time. This began to turn around in June, and by July the 1975 figures began to demonstrate definite improvement. The monthly data, along with the results of the statistical tests, are presented in Table 6-6. One can see that the 1975 11-month average was 6.2% (32.4 seconds) less than the 1974 average of 8.76 minutes.

e. Comparison by Incident Types. Outputs provided by the Crime Commission tabulated response statistics for 33 incident types. Four of these (auto patrol duties, communications, administrative call, and other) were not used because they represented, for the most part, incidents not generated by the public or assigned by the dispatcher. The remaining 29 incident types are listed in Table 6-7 and range from the seven Part I index crimes to disturbance, traffic violations, and "additional information" calls. Data for the first five months[30] of 1975 were compared with 1974 figures and the difference was tested for statistical significance using the same t-test described earlier. For this analysis, the response categories of dispatch delay, travel time, and on-scene service time were tested. The latter was used because early expectations were that the street personnel would service incidents more quickly because they were being "watched" by the dispatcher.

[30] For an examination of response times for specific incident types later in Phase I, see Chapter VII on the special three-week test conducted in September.

Table 6-6

Monthly Comparison of FLAIR-related Response times for the First Eleven Months of 1974 and 1975

Month	1974 (pre-FLAIR)	1975 (during FLAIR)	% Change	Significance of change
January	8.49	6.60	+1.3%	N.S.*
February	7.76	8.23	+6.1%	.990
March	8.26	7.82	+5.3%	.975
April	7.61	7.41	-2.6%	N.S.
May	7.70	8.33	+8.2%	.999
June	8.74	8.64	-1.1%	N.S.
July	10.02	7.79	-22.2%	.999
August	9.97	8.56	-14.1%	.999
September	10.22	8.48	-17.0%	.999
October	8.47	8.41	-0.7%	N.S.
November	9.13	8.19	-10.3%	.999
Average	8.76	8.22	-6.2%	

*N.S. = Not Significant.

Table 6-7

Call Types Included in Analysis

Homicide	Injury
Rape	Fire
Robbery	Accident
Assault	Animal Case
Burglary	Sick Case
Larceny	Death
Auto Theft	Assist
Destruction of Property	Miscellaneous Hazard
Fraud	Call for Police
Sex Offense	Suspicious
Flourishing	Lost Article
Person Down	Missing Person
Disturbance	Additional Information
Traffic Violation	Arrest
Alarm Sounding	

Significant differences appeared in a wide range of incident types. Of the 435 pairs tested,[31] 80 (18.4%) represented differences that were significant at the .90 level or greater. Forty-one of the significant differences corresponded to average FLAIR-related response times being shorter <u>in 1974 than 1975</u> (pre-FLAIR). Thirty of the 41 yielded statistically significant shorter dispatch delay times before FLAIR on incident types ranging from high priority calls like "flourishing" a weapon and "alarm sounding" to lesser priority calls like "animal case." However, the incidence of shorter 1974 dispatch delays decreases as time passes, corresponding to dispatchers' learning the operation of FLAIR. Only 12 significant differences appeared in on-scene service times, seven of which were for reductions in 1975. This is definitely not enough of a difference to confirm a significant overall reduction in on-scene service time as a result of the AVM system. In contrast, all indications do point to the continuing trend of reduced travel times. Twenty-one of the 27 significant travel time differences were due to shorter 1975 values. Major decreases were experienced in the areas of "disturbance" and "assist" calls.

f. <u>Analysis of Sector Changes</u>. The interpretation of response time changes is complicated by a redesign of sector configurations that took effect on December 16, 1974 (the date FLAIR became operational). Up until that point, the Third District

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[31] 3 response categories x 29 incident types x 5 months=435 tests.

fielded 14 beat cars, two cruisers, a stack car, and auxilliary watch cars as available. The beats were aggregated into four precincts, each precinct comprising four or five contiguous sectors (beats) and being the responsibility of a sergeant. The stack car handled calls on a district-wide basis, many of which were calls that could be queued (or "stacked"). Auxilliary watch cars were fielded so that they overlapped two shifts. They were deployed at the discretion of the district commander. The two cruisers divided the district, each cruiser responsible for two precincts. The cruisers were vans that are used for transporting people as well as for responding to assigned radio calls. This deployment plan is presented in Figure 6-5.

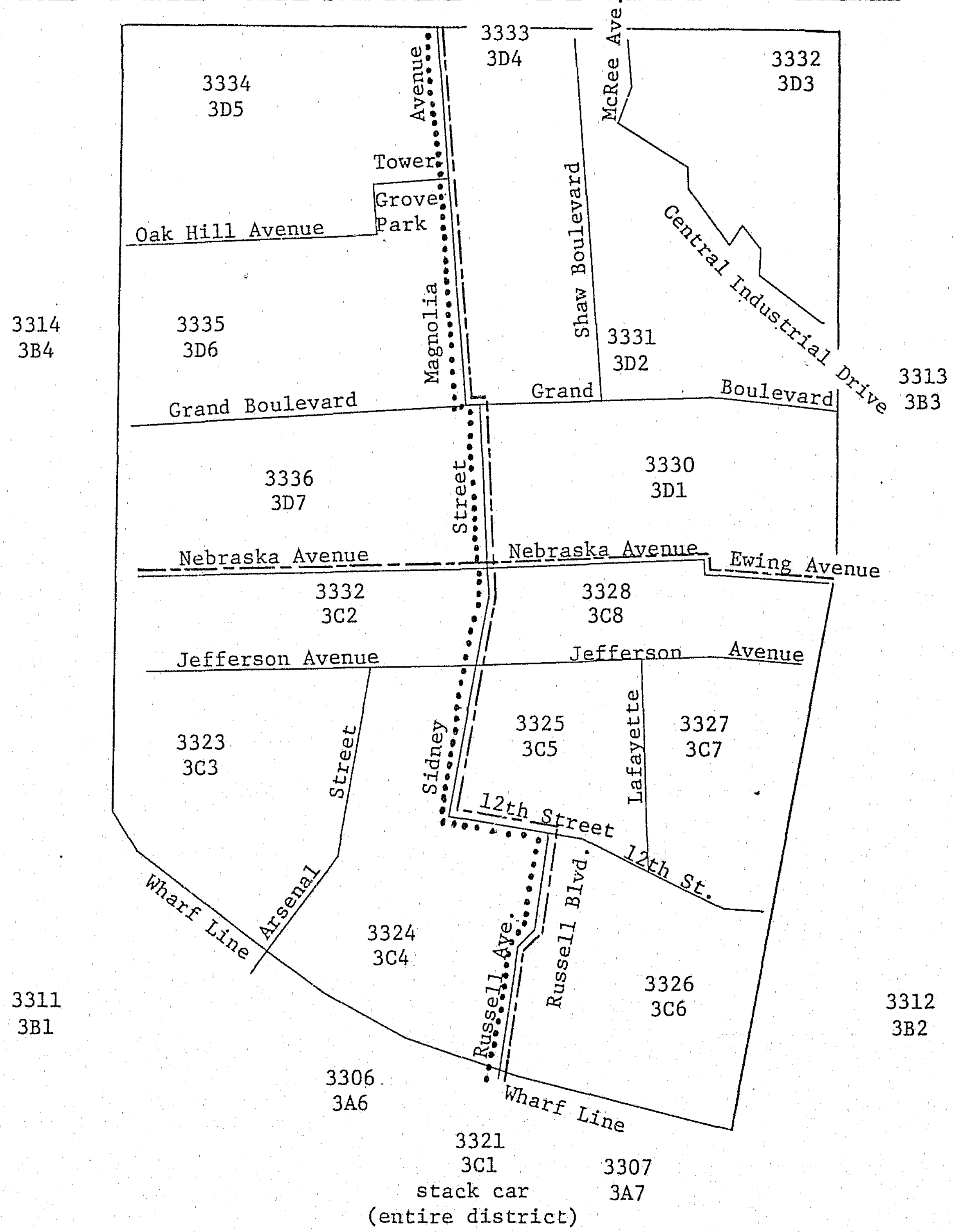
On December 16, 1974, a new plan went into effect. In this plan, the Third District fields 15 beat cars, two cruisers, and the stack car. Auxilliary watch cars were reduced to allow manpower for the additional beat car.

One significant aspect of the new configuration was the assignment of one vehicle to the whole riverfront area. In a memo proposing the change, the District 3 captain explained to his Commander that this would allow concentrated patrol in the industrial area paralleling the river. The assigned car was to remain within the area except for emergencies. Other beat cars were discouraged from entering the area. As an additional benefit, this plan reduced from three to one the number of beat cars assigned to patrol along the troublesome flood wall which was the cause of severe magnetic anomalies (affecting adversely the in-car

Figure 6-5

Pre-12/16/74 Sector Configuration

Showing Deployment of Beat Cars, Sergeant Cars and Cruisers



Key:

3306, 3307 - Cruisers

3311, 3312, 3313, 3314 - Sergeant Cars

All Others - Beat Cars

Third District

FLAIR heading sensor). This new plan still maintained a four precinct organization with cruisers and stack car. A map of the new scheme is given as Figure 6-6.

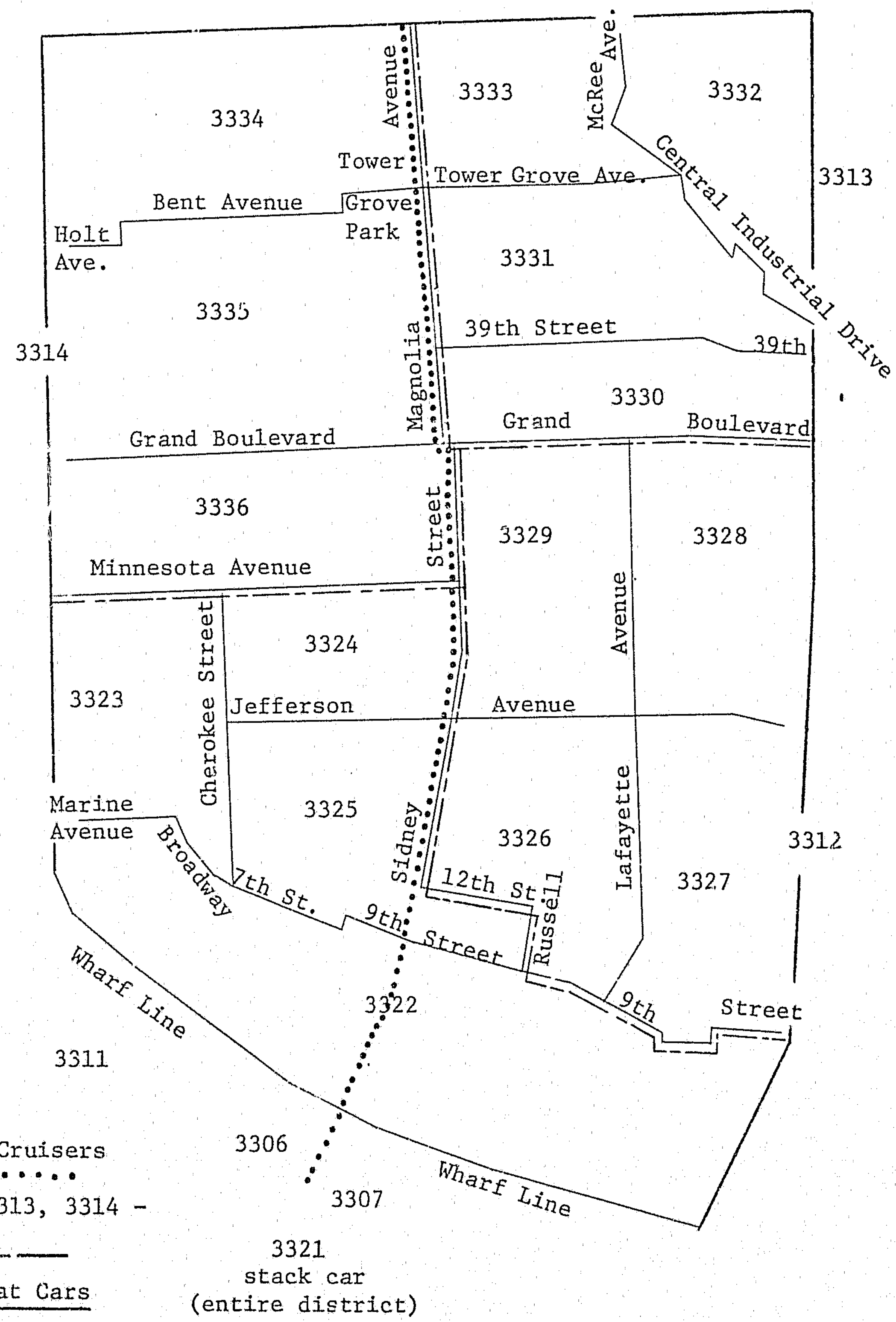
5. Use of the Simulation Model. In anticipation of this change and realizing that the new design will have to be tested to see if it would - because of the spatial redeployment of personnel - cause any changes in travel time, a simulation model was designed which included AVM dispatching. The design and development of the simulation model will be treated in depth in Chapter VIII, but an explanation of data inputs developed will be discussed here. Briefly, the model requires information on the distribution of field personnel, calls, and service times along with a description of the dispatch process. The centroid and area of each Pauly block (reporting area) in the Third District was determined from a map and coded. Geographic distribution of calls was obtained from tape outputs for December, 1974 and May, 1975.

a. The Dispatch Strategy. The development of a precise dispatch strategy for pre-FLAIR dispatching was very important. The dispatch strategy under the AVM system was easy to model, just select the closest available car. The original strategy was much less obvious. A short, eight-question survey was developed and verbally administered to eight Third District dispatchers during July, 1975. Each question gave the location of a fictional incident along with a list of cars unavailable for dispatch. The

Figure 6-6

Post-12/16/74 Sector Configuration

Showing Deployment of Beat Cars, Sergeant Cars and Cruisers



Key:

3306, 3307 - Cruisers
•••••••••••••••

3311, 3312, 3313, 3314 -
Sergeant Cars
— — — — — —

All Others - Beat Cars

Third District

objective was to force a choice between two available units and test to what degree the selection of an assigned non-beat car is affected by the location of the incident. For instance, if the same non-beat car is always dispatched independent of incident location within the beat, then the pre-programmed strict center of mass (SCM) option would be used.[32] If the decision on what unit to send was based on incident location, then a modified center of mass (MCM) strategy would be used. The latter strategy, which is entirely feasible without an AVM system, increases the chance of dispatching the closest available unit; it typically reduces mean travel time by 5-to-10% compared to SCM dispatching.[33]

Table 6-8 lists the incident locations, the beat they are in, and the list of busy units used for the survey. The last two columns list the units that are statistically[34] closest and second closest (according to detailed average travel time calculations) and the number (in parentheses) of dispatchers that selected the unit. For the first five locations, the statistically second closest car

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[32] For a complete description of standard dispatch strategies, see R.C. Larson, "Computer Program for Calculating the Performance of Urban Emergency Service Systems: User's Manual (Batch Processing) Program Version 75-001 (Batch)," TR-14-75, Operations Research Center, MIT, Cambridge, Massachusetts, March 1975.

[33] R.C. Larson, Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972, pp. 90-91, 97-99.

[34] "Statistically closest unit" means the dispatcher realizes that a unit could be patrolling anywhere in his beat, but that, on the average, the unit is closer than any other beat cars available for dispatch. Larson (Ibid., p. 87) has shown that for uniform patrol patterns this average position corresponds to the center of mass of the beat.

Table 6-8

Tabulation of Results from Survey Administered to Eight Third District Dispatcher to Determine Effective pre-FLAIR Dispatch Strategies

Location of call	Beat and precinct call located in	Busy units	choices: statistically closest unit # of responses	choices: statistically 2nd closest unit # of responses	Type of choice forced
1. Lousiana & Magnolia	Beat 36 Precinct 34	36,23,24, 25,30,31	Unit 29 Precinct 32 1	Unit 35 Precinct 34 7	Unit from same
2. Lousiana & Potomac	Beat 36 Precinct 34	36,23,23, 25,30,31	Unit 29 Precinct 32 0	Unit 35 Precinct 34 8	precinct as call
3. Armand & California	Beat 29 Precinct 32	29,25,26, 36	Unit 24 Precinct 31 0	Unit 28 Precinct 32 8	versus a statistically
4. Nebraska & Russell	Beat 29 Precinct 32	29,25,26, 36	Unit 24 Precinct 31 0	Unit 28 Precinct 32 8	closer unit from
5. Wyoming & Oregon	Beat 24 Precinct 31	24,25,26, 29	Unit 36 Precinct 34 0	Unit 23 Precinct 31 8	another precinct.
6. Dolman & Park	Beat 27 Precinct 32	27,29	Unit 26 Precinct 32 8	Unit 28 Precinct 32 0	Two units from the same precinct that
7. Missouri & Park	Beat 27 Precinct 32	27,29	Unit 26 Precinct 32 4	Unit 28 Precinct 32 4	generated the call.
8. Nebraska & Russell	Beat 29 Precinct 32	29,22,24, 25,26,27, 28,39,35, 36	Unit 31 Precinct 33 3	Unit 23 Precinct 31 5	Two units from outside the precinct.

was almost unanimously chosen over the statistically closest car. This is because, in each case, the statistically second closest car was from the same precinct that generated the call. This additional level of aggregation between the beat and district levels meant that a very complex dispatch strategy had to be specified that gave preference to available units of the same precinct over other beat cars, even if they are closer.

When a dispatcher is faced with a choice between two units from the same precinct that generated the call, the selection of what unit to send is sensitive to the location of the call in the beat. For example, location six in Table 6-8 forces a choice between units 26 and 28, both of which are in the same precinct as beat 27, where the hypothetical call is located. Unit 26 is statistically much closer and was selected by all of the dispatchers. In contrast, location seven forces a choice between the same two units, but this time the difference in the statistical distance between the units and the incident is small, and the eight dispatchers responded by assigning unit 26 four times and unit 28 four times. When interviewed, the four dispatchers that assigned unit 28 stated they did so because they thought it would be the closer of the two. This implies that when an intra-precinct choice is forced, a unit is preferred by a dispatcher if he thinks the unit is closer to the call, which conforms to the assumptions of the MCM dispatch strategy. Therefore, whenever the simulation is faced with an intra-precinct choice, it will respond by dispatching according to the MCM policy.

What happens when the dispatcher is faced with a choice between two units, both of which are from precincts other than the precinct generating the call? Location eight in Table 6-8 presents this type of choice. Unit 31 is statistically closer than unit 23, but the difference is small. Three of the dispatchers said they would assign unit 31 in this situation, and the remaining five favored unit 23. When asked to state why they selected one unit over the other, each of the dispatchers stated that he sent the unit that he thought was closest to the call. Since the dispatchers actually intended to send the closest available unit (even though their perception of closest may be incorrect), the simulation will use the MCM strategy to assign cars when it is faced with a choice between two or more units that are from outside the precinct generating the call.

To summarize, the pre-FLAIR dispatch strategy is modeled as follows:

- If the unit assigned to a particular beat is available when a call arrives from that beat, then that unit will be assigned the call.
- If the unit assigned to a particular beat is busy when a call arrives from that beat, and if one or more units assigned to the same precinct are available, then the statistically closest available precinct unit to the call will be assigned to handle it, independent of whether or not a unit from another precinct is statistically closer.
- If the unit assigned to a particular beat is busy when a call arrives from that beat, and if all other units assigned to that precinct are also busy, then the call will be assigned to the statistically closest available unit in the district.

- If all units are busy when a call arrives, then the call will be held in queue to be assigned when a unit becomes available. If more than one call is in the queue when a unit becomes available, then the oldest, most urgent call is assigned to that unit.

b. Simulation Data. The simulated calls were divided into four priorities. MPD computer output indicated that workloads for assigned calls, assigned assists, and patrol-initiated activities were divided in a ratio of 5:1:3, respectively, at an average workload of about 20%. An examination of output of the number and service times of emergency and in-progress call types led to the approximation that 8% of all assigned incidents were emergencies[35] and took, on the average, about 18 minutes to handle. The low average service time is evidently due to the high percentage of false alarms. These calls are designated as priority for the program and given an average response speed of 16 miles per hour. The average of 16 recognizes that responding units may achieve peak speeds higher than 16 miles per hour, but it also takes into account time when a unit is accelerating, decelerating, or cornering. Even though this estimate may not be exactly the speed encountered, it is used consistently throughout the runs and should allow for comparisons between simulation runs.[36] The remaining assigned calls, assigned assists, and

[35] This is consistent with the measured 7.4% of "hotline" calls discussed earlier in Section C of this chapter.

[36] The travel time metric is the right-angle metric. For short distance responses, the practice of using a fixed speed (rather than a reduced speed) may underestimate true travel times (since there is a "fixed time" associated with each response) and thus overstate the probable travel time reduction available with AVM.

patrol-initiated activities are designated as priority two, three, and four, respectively. Historical data yielded average service times of 36.8 minutes for assigned calls, 22 minutes for assigned assists, and 22 minutes for patrol-initiated activities. The first three call priorities were dispatched on a first-come first-served basis, while the opportunities for patrol-initiated activities were lost unless they occurred at the same time an available unit was within the immediate area.

c. Simulation Results. Sixteen simulation runs were made for the Third District. Each run consisted of approximately 1000 simulated calls for service plus self-initiated incidents and represented a different combination of sector configuration, dispatch strategy, and workload.[37] An average workload level of X means that, on the average, patrol units in the district are busy servicing calls and/or performing patrol initiated activities X percent of the time. Average district-wide workload levels of .1, .2, .4, and .6 were used to determine what effects, if any call for service volumes might have on the anticipated travel time reductions resulting from closest car dispatch. All other factors, including response speeds, spatial distribution of calls, and service times remained constant through all of the simulation runs.

Results from the simulation runs indicate that the change in sector configuration should have little effect on district-wide

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[37] 2 sector configurations x 2 dispatch strategies x 4 workload levels = 16

CONTINUED

3 OF 10

average travel time, while, at the same time, a change in dispatch strategy from pre-AVM to AVM should produce significant travel time reductions. When comparing the pre 12/16/74 sector design with the post 12/16/74 design one finds only minor travel time differences while controlling for the dispatch policy and workload. (See Table 6-9.) When comparing the two designs using the pre-AVM dispatch policy, one sees for comparable workload levels very small travel time differences between the two designs. The differences in means average less than ten seconds and are so small that the points on the corresponding distributions could be drawn from the same travel time distribution (significance level of .995).[38] One finds the same type of relationship when using the AVM closest car dispatch capability on both sector designs. In this case, the average differences at comparable workload levels is only 8.1 seconds, and, once again, the points could be drawn from the same travel time distribution.

The "closeness" of the travel time distributions is further demonstrated by a plot of workload versus travel time for each of the four combinations of sector configuration and dispatch policy (Figure 6-7). Once again, it can be seen how closely the two pre-AVM dispatch curves and the two AVM dispatch curves match. The insensitivity of travel time to the change in sector configurations means that no correction for the sector designs is

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[38] Results obtained from using a chi squared goodness of fit test assuming that the pre 12/16/74 configuration was the expected distribution.

Table 6-9

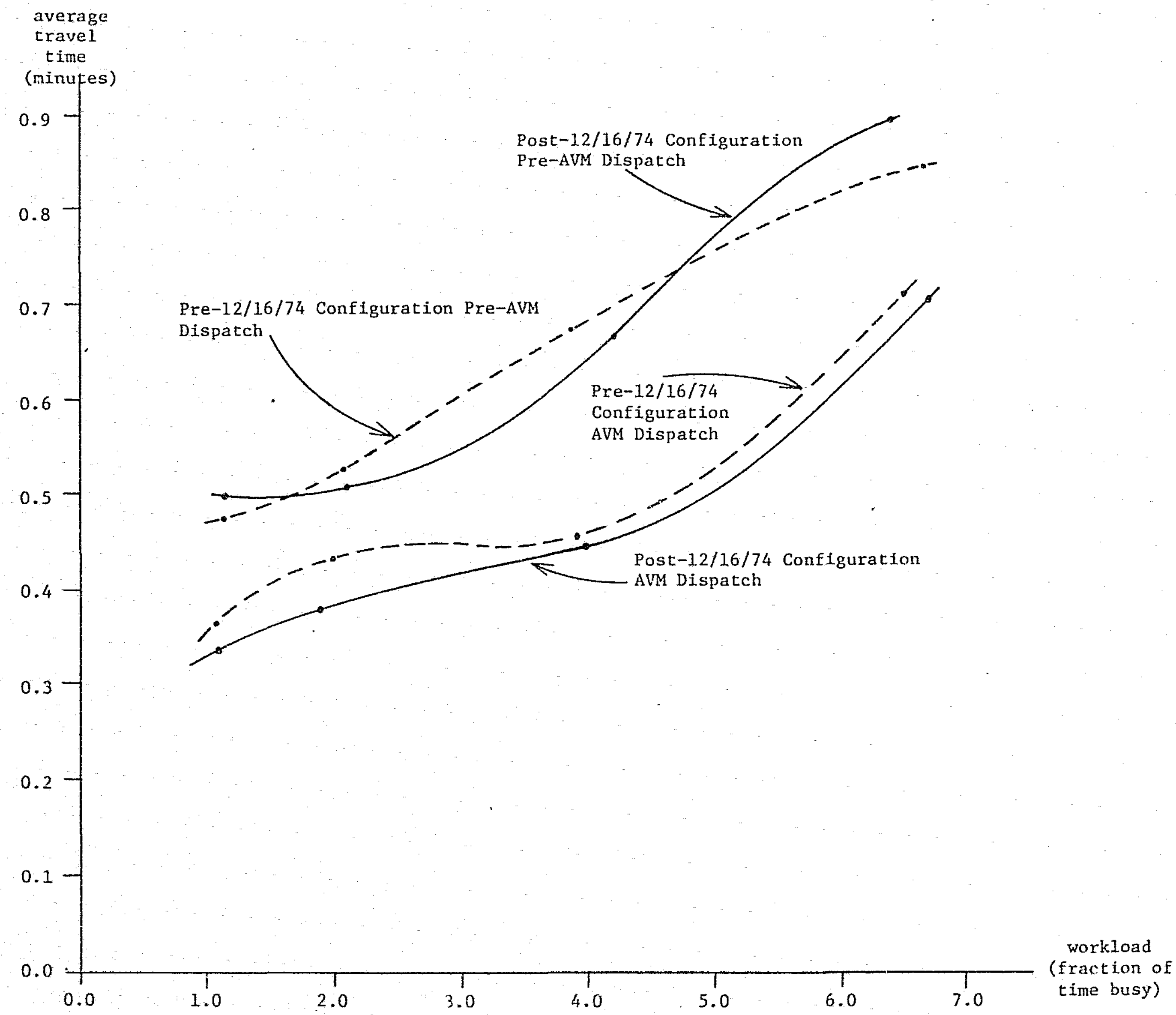
Tabluation of Results of 16 Simulation Runs Presenting Simulated Workload, Travel Time, Maximum Travel Imbalance (Between Beat Areas), Patrol Frequency (Passings per hour), and per cent of non-Closest Car Dispatches

Configuation & Approximate Workload (fraction of time busy)	Pre-AVM Dispatch Policy: Simulated workload	Pre-AVM: Average travel time (minutes)	Pre-AVM: Maximum travel time imbalance	Pre-AVM: Patrol frequency (passing/hr)	Pre-AVM: % non-closest car dispatch	AVM Dispatch Policy: Simulated workload	AVM: Average travel time	AVM: Maximum travel time imbalance	AVM: Patrol frequency	AVM: % non-closest car dispatch	AVM: % average reduction in travel time
Pre 12/16/74											
.1	.115	4.87	1.22	.535	16.6	.118	3.71	1.44	.533	0.0	23.8
.2	.209	5.32	.86	.478	26.9	.202	3.98	.92	.483	0.0	25.2
.4	.416	6.78	.82	.353	35.4	.389	4.54	.76	.379	0.0	33.0
.6	.662	8.50	.52	.204	33.9	.652	7.16	.45	.221	0.0	15.8
Post 12/16/74											
.1	.116	4.99	2.60	.535	15.5	.115	3.44	2.07	.535	0.0	31.1
.2	.213	5.26	2.05	.476	24.9	.193	3.79	1.37	.488	0.0	27.9
.4	.417	6.71	1.06	.353	36.4	.395	4.57	.87	.366	0.0	31.9
.6	.620	8.89	.94	.230	39.1	.666	7.11	.80	.202	0.0	20.0

Figure 6-7

Travel Time versus Workload Level for Four Combinations of Sector Configuration and Dispatch Strategy

(values obtained from Simulation Model)



needed when evaluating changes in 1974 and 1975 response time data.

Comparison of pre-AVM to AVM simulated travel times suggest that if the FLAIR system is operating as an accurate AVM system and if it is properly used by dispatchers, then one can expect significant reductions in travel time. Results from Table 6-9 suggest that this reduction should average approximately 25% over all of the workload levels simulated. It should be emphasized, however, that a large function of this anticipated reduction in travel time is attributable to the relatively inefficient precinct-oriented dispatch strategy used prior to introduction of the AVM system. While the simulation is running, it assigns units on the basis of the dispatch strategy input into the model. In the case of District 3 prior to the FLAIR system, the strategy was the complex one described earlier which preferred precinct cars to closer vehicles not in the same precinct.

The earlier modeling analysis reported in Section D.1. of this chapter, as well as indepedent analyses of the District 3 data base by Franck,[39] indicate that the average travel time reduction achievable by AVM compared to a more conventional non-precinct-oriented dispatch strategy is approximately 11 to 15%, not 25%, for the relevant range of workloads. Thus, the potential benefits

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[39] Franck, Evelyn, Implementing Closest Vehicle Dispatching Strategy on the Hypercube Model, unpublished Masters Thesis, Operations Research Center, Massachusetts Institute of Technology, February, 1976.

of AVM depend critically on the system to which it is compared.

Each time the simulation assigns a vehicle using a non-AVM strategy it also keeps track as to whether this was the closest available car. At the completion of the run, the program outputs a summary statistic reporting the fraction of all dispatches that sent other than the closest vehicle. The results, also displayed in Table 6-9, indicate that the pre-AVM precinct-oriented strategy sent other than the closest car up to 39% of the time, depending on the workload and sector configuration. (The AVM strategy, by definition, always sends the closest car, hence the result of 0% non-closest car dispatches.) The average workload level for District 3 on calls for service and patrol initiated activities is approximately 1.6 hours per eight-hour shift, or 0.20. At that average workload using the pre-AVM dispatch policy, one would expect that approximately one out of every four dispatches historically sent other than the closest available District 3 car. A properly operating AVM system, by allowing dispatch of that closest available unit, would reduce overall average travel time.

A close examination of the percent of non closest car dispatches also tends to confirm expectations that an AVM system produces the most dispatching benefits over non-AVM policies for workloads in the range of 0.4 to 0.8. This makes sense because during the times of low workload there are many units to choose from, and the additional travel time incurred by selecting the second closest unit is not very large. At the other extreme,

when all units are busy and calls are queued, the calls get assigned to the first vehicle to clear and no mistake can be made. It is somewhere in between these extremes that the percent of non-closest car dispatches is at its highest and an AVM system would provide the greatest benefit.

After establishing that the changes in sector design have essentially no effect on district-wide average travel times, it is interesting to examine whether the sector changes affect the equity of service distribution within the district. The simulation model calculates the average travel time to calls within each beat area. From this data it is possible to obtain a measure of the relative inequality of travel times to different sections of the Third District. By taking the difference between the largest and smallest average beat travel times and dividing that value by the average region-wide travel time, one obtains a measure of the relative maximum travel time inequality. The value of this indicator is also presented in Table 6-9 for each simulation run, and one finds that the magnitude of the imbalance generally tends to decrease as the workload increases. This makes sense because as the district gets busier, cars begin answering calls from all parts of the district and sectors receive fairly equal treatment. It is also important to note that the post-12/16/74 sector plan has consistently larger travel time imbalances than the earlier design. The larger values are due primarily to the 3322 sector created along the waterfront. In every simulation run using the newer configuration, this sector had, by far, larger average

travel times than other beats in the district. The fact that district-wide average travel times remained unchanged meant that other areas experienced slightly shorter travel times while this beat experienced the increase.

How does the change in sector configurations or dispatch strategy affect patrol operations? With one major exception, one would expect that they should have little effect and the simulation confirms this. The model generates three key indicators: the number of patrol passings per hour; the number of patrol-initiated activities; and the degree of inter-beat dispatching. The first measure uses an estimate of the number of street miles in each Pauly block (reporting area), the amount of free time, and an average patrol speed to obtain the number of times a unit would pass a random point per hour. The results of this measure are recorded in Table 6-9 as the patrol frequency. The number of passings per hour decreases as workload increases because cars have less time to patrol as calls for service increase. As expected, all four combinations of sector design and dispatch strategy behave similarly when compared at equivalent workload levels.

This is also true of the second measure, the number of patrol-initiated activities. The model allows the user to generate "opportunities" for patrol-initiated activities, but these opportunities are only taken advantage of if they occur at the same location and time a unit is available and on patrol. If this condition is not met, the opportunity passes and is not serviced. At each of the four workload levels, the number of patrol-initiated activities serviced was fairly constant over all combinations of dispatch strategy and sector design.

However, the third measure is the fraction of dispatches which are cross beat (or inter beat) dispatches. As indicated in point four of Section D.1. of this chapter, closest-unit dispatching degrades system performance since it results in greater amounts of cross beat dispatching. In non-AVM dispatching systems, the fraction of dispatches that are interbeat is usually about equal to the average workload (that is, fraction of time not available for dispatch, say 20%) of the patrol force. With AVM, this fraction is increased, usually markedly for low-to-moderate workload systems. District 3 in St. Louis is no exception. At workloads of 0.1, 0.2, 0.4, and 0.6, and using the pre 12/16/74 sector configuration, the fractions of cross beat dispatches for the pre-AVM dispatching strategy were simulated to be 17.9, 30.9, 53.6, 73.4 percent, respectively. With AVM dispatching, these fractions are increased to 54.3, 56.3, 64.2, and 76.8 percent, respectively.[40] Such increases should be of particular concern to police departments that desire to maintain (to the extent feasible) the one-man, one-beat concept. For other departments that desire wider overlapping areas of patrol responsibility, this operational consequence of AVM dispatching should cause little or no problem.

Summarizing, the computer simulation results have indicated the following:

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[40] Due to limited use of the closest car concept during Phase I, these increases could not be confirmed empirically from the dispatch tapes, even though a special program was written to print out data of the type, "fraction of dispatches sending car into Pauly area." These data will be scrutinized during Phase II, however.

- Travel time should not be affected by the change in sector configurations.
- Travel time has the potential to be affected by a change in dispatch policy from pre-AVM to the AVM closest car strategy.
- Due to a precinct (sub-district) strategy, the original pre-AVM dispatch policy was not very efficient in assigning the statistically closest vehicle to a particular call.
- Although district-wide travel time is not affected by the change in sector configuration, the new design tends to be more inequitable in its distribution of travel times to different beats in the district.
- Changes in sector designs or dispatch policy should not appreciably affect patrol frequencies or the number of patrol initiated activities in the Third District. However, a change to AVM dispatching should increase the number of cross-beat dispatches.

6. Examination of District 3 versus City-Wide Patterns.

Monthly response time averages for District 3 during 1975 showed a pattern of slight reductions in dispatch delay and FLAIR related dispatch time accompanied by apparent major reductions in average travel time from the 1974 data. Due to a lack of long-term data it is difficult to determine to what degree 1974 represented a "normal" year or whether the variations in 1975 were due to forces other than the FLAIR system. Such limitations will be removed to some extent during Phase II since we will have data for 1974, 1975, and 1976 for comparisons. In a further effort to control for factors other than the AVM system, a decision was made to compare the District 3 changes to changes experienced by the rest

of the city during the same time period. Once again, the comparisons will center about the response time categories of dispatch delay, travel time, and their sum, which is the FLAIR-related response time.

a. Dispatch Delay Times. Early in 1975 the Third District experienced dispatch delays higher than in comparable months of 1974. This trend reversed itself in July and the 1975 11-month average actually showed a net decrease from the 1974 average. One explanation for the pattern of higher and then lower dispatch delays was the learning curve involved in utilizing the new FLAIR closest car dispatch procedure. The results suggested that once the procedure was mastered, reductions in dispatch delay could be expected. Comparisons with data from the rest of the city indicate that the conclusions might not be so straightforward. Table 6-10 restates the District 3 data and also presents average dispatch delays for the city excluding District 3. The fact that early 1975 dispatch delays for the rest of the city actually decreased while the District 3 averages increased means that the "cost" of the learning process was actually much higher than indicated in just the District 3 comparisons. For example, the 7.4% increase experienced in District 3 combined with the 27.9% decrease in January dispatch delay for the rest of the city, suggests that the actual learning process might have represented a "cost" of as much as 35% over what might have occurred in District 3. Data for the period of July to November of 1975 actually represented months in which the District 3 reductions were not as great

Table 6-10

Tabulation of Average Dispatch Delays Encountered in District 3 and the Rest of the City for 1974 and 1975

(Entries in boxes correspond to months of intensive on-scene evaluation, including stop-watch monitoring, interviewing and special testing.)

	District 3			City-Wide Less District 3		
	1974	1975	% Change	1974	1975	% Change
	Average Dispatch Delays (in minutes)			Average Dispatch Delays (in minutes)		
JAN	3.22	3.46	+7.4	2.44	1.76	-27.9
FEB	3.02	3.46	+14.6	2.20	1.81	-17.7
MAR	3.25	3.21	-1.2	2.29	1.80	-21.4
APR	2.65	2.93	+10.6	2.19	2.05	-6.4
MAY	2.54	3.66	+44.1	2.12	3.56	+67.9
JUN	3.70	4.38	+18.4	2.93	2.84	-3.1
JUL	5.22	3.62	-30.6	3.41	2.74	-19.6
AUG	4.60	4.06	-11.7	3.85	2.92	-24.2
SEP	4.74	3.81	-19.6	3.52	3.02	-14.2
OCT	3.46	3.43	-0.9	3.03	2.78	-8.2
NOV	3.97	3.77	-5.0	2.75	2.79	+1.4
AVG.	3.67	3.62	-1.4	2.79	2.55	-8.6

as the comparable city-wide changes. Therefore, what appeared to happen during Phase I of the ARAC Project was that District 3 dispatchers encountered fairly high learning "costs" in adjusting to the new system (sometimes as much as 35% of the dispatch delay), but once the system was learned, dispatch delays returned to a level comparable to the rest of the city. There are no indications in these data that, once mastered, the FLAIR closest car dispatch procedures will cause the MPD any additional dispatch delays than encountered with previous procedures. A good dispatcher can dispatch cars just as quickly under either system. The difference in dispatchers is more likely to be encountered in the ability to maintain system tracking standards (by proper initializations) and by the ability to properly use the closest car information presented by the system.

In Tables 6-10, 6-11 and 6-12, the entries in boxes (July, August, and September, 1975) correspond to months of intensive on-scene evaluation, including stop-watch monitoring, interviewing, and special testing. It is noteworthy that significant response time drops occurred - both city-wide and in District 3 - during these months.

b. Travel Time. During the first 11 months of 1975 the Third District experienced a reduction in average travel time of 8.0% from the 1974 11-month average. Further, each month had an average travel time lower than its corresponding month in 1974. This implies a fairly significant trend towards lower travel times during the time FLAIR was operating in the Third District. The

Table 6-11

Tabulation of Average Travel Times Encountered in District 3 and the Rest of the City for 1974 and 1975

(Entries in boxes correspond to months of intensive on-scene evaluation, including stop-watch monitoring, interviewing and special testing.)

	District 3			City-Wide Less District 3		
	1974	1975	% Change	1974	1975	% Change
	Average Travel Times (in minutes)			Average Travel Times (in minutes)		
JAN	5.44	5.30	-2.57	5.55	4.83	-12.97
FEB	5.16	4.97	-3.68	4.86	4.62	-4.94
MAR	5.29	4.89	-7.56	4.82	4.60	-4.56
APR	5.18	4.79	-7.53	4.76	4.59	-3.57
MAY	5.37	4.90	-8.75	4.90	4.69	-4.29
JUN	5.32	4.83	-9.21	4.89	4.67	-4.50
JUL	5.46	4.78	-12.45	5.05	4.73	-6.34
AUG	5.59	4.84	-13.42	5.29	4.62	-12.67
SEP	5.58	4.74	-15.05	5.22	4.71	-9.77
OCT	5.31	5.18	-2.45	5.02	4.60	-8.37
NOV	5.18	4.90	-5.41	4.97	4.80	-3.42
AVG.	5.35	4.92	-8.00	5.03	4.68	-7.0

Table 6-12

Tabulation of Average FLAIR-Related Response Times Encountered in District 3 and the Rest of the City in 1974 and 1975

(Entries in boxes correspond to months of intensive on-scene evaluation, including stop-watch monitoring, interviewing and special testing.)

	District 3			City-Wide Less District 3		
	1974	1975	% Change	1974	1975	% Change
	Average Response Times (in minutes)			Average Response Times (in minutes)		
JAN	8.49	8.60	+1.3	7.42	6.13	-17.4
FEB	7.76	8.23	+6.1	6.58	6.12	-7.0
MAR	8.26	7.82	-5.4	6.75	6.07	-10.1
APR	7.61	7.41	-2.6	6.68	6.28	-6.0
MAY	7.70	8.33	+8.2	6.64	7.72	+16.3
JUN	8.74	8.64	-1.1	7.33	7.13	-2.7
JUL	10.02	7.79	-22.3	7.86	7.00	-10.9
AUG	9.97	8.56	-14.1	8.72	7.24	-17.0
SEP	10.22	8.48	-17.0	8.22	7.34	-10.7
OCT	8.47	8.41	-0.7	7.57	7.06	-6.7
NOV	9.13	8.19	-10.3	7.32	7.25	-1.0
AVG.	8.76	8.22	-6.2	7.37	6.85	-7.1

behavior of the rest of the city complicates the analysis, however. Table 6-11 shows that the remainder of the city also had monthly average travel times that were lower for every month of 1975 than 1974. For nine of the 11 months, District 3 had larger reductions than the city, but the city-wide differences were usually of the same magnitude. The relative similarity of the reductions is evident when one compares the 8.0% 11-month average reduction for District 3 and the 7.0% decrease for the rest of the city. The AVM system had possibly reduced travel time, but the size of the reduction - when normalized for city-wide reductions - appears to be not as large as the 1974-1975 District 3 comparisons suggested or the simulation model predicted for a properly operating AVM system.

c. <u>FLAIR Related Response Time</u>. FLAIR related response time is the time elapsed between the time the dispatcher receives a call to dispatch and the time the unit arrives at the location of the call. For District 3 the net change was mixed for the first six months and then significant reductions appeared as the net decreases in both dispatch delay and travel time combined to produce fairly large decreases in the FLAIR related response time. The rest of the city had fairly uniform reductions for both dispatch and travel times to produce net reductions in ten of the 11 months studied (Table 6-12). The decrease in the 11-month city-wide average was 7.1% as compared to a 6.2% reduction in District 3. The possible impression that the AVM system is actually hindering operations is probably incorrect, however.

One must remember that the dispatchers were still learning the system during the first six months of 1975. Once this obstacle was passed, District 3 averages went down significantly so that the average change was a 13.3% reduction for the last five months of the sample period. This is compared to a 9.6% decrease for the rest of the city, or the same five-month period. FLAIR may help, but the exact magnitude of the change may be fairly small and difficult to isolate due to several intervening factors.

7. Factors Impacting Response Times. Several types of factors can affect the average response times experienced by a police department in general and St. Louis in particular. Four general categories of intervening elements will be discussed in this section. They are (in order): random fluctuations, non-FLAIR effects, direct effects of FLAIR, and the effects of a major intervention in operations.

a. Random Fluctuations. Response times to a particular call can be influenced by many factors, including traffic, number of turns and stop signs, weather, and so on. The presence of these factors is apparently random and uneffected by police policy. They can combine in such complex ways that they produce unpredictable fluctuations in travel or dispatch that cannot be controlled for in an experiment. These fluctuations could cause either increases or decreases in average response times. A common way of approaching this problem is to look at a long historical pattern of data and use it to smooth out the random

fluctuations. This was not possible during Phase I because only 1974 data was available. Therefore, suspiciously high values (such as the July and September, 1974 District 3 dispatch delays of 5.22 and 4.74 minutes, respectively) have to be considered without knowing their true significance. This problem will be somewhat alleviated by the end of the Phase II evaluation when 3-4 years of response time data will be available (1974, 1975, 1976, and part of 1977).

b. Non-FLAIR Effects. This category includes some factors that the department can affect and others that it cannot really control. An example of the first is the number and quality of personnel fielded. For instance, the Third District always fields a full contingent of beat cars every afternoon watch. Some cars, like 3327 and the stack car, are almost always two-man cars, and other beat cars have two men assigned to them when the work schedule permits. The district also tries to field auxilliary cars whenever it can to boost manpower during the busier periods of the day. Since these cars are optional, their number is dependent upon the number of men assigned to the district. A large number of "loans" or temporary reassignments can mean that no auxilliary cars are fielded at all, and the total number of vehicles on the street drops.

Another example of how the department can affect the quality of personnel fielded is the special three-week test described in the next chapter. In this case, the best dispatchers were consistently

assigned to the Third District console and apparently were responsible for an improvement in the operation of the AVM system during the September test.

One of the most important factors that the MPD cannot control is the demand for service pattern from the community. The rate and geographic pattern of demand can affect dispatch delays by generating a queue of calls waiting for assignment and travel times by causing a large fraction of inter-beat dispatches. It is probably a major change in this factor that caused lower dispatch and travel times on a city-wide basis during Phase I. Data prepared for release in the 1975 MPD Annual Report show that the number of calls for service in 1975 was 815,589, down 92,772 (10.2%) from the 1974 value of 908,361.[41] In comparison, the number of total dispatches in the Third District decreased during the eight-month period of January to August, 1975, down 12% from the dispatches reported the year before, approximately the same magnitude of response time reductions experienced by the city. This means a good portion of the 8.0% Third District travel time reductions and the 7.0% city-wide reductions might be attributed to the decreasing call rates.

c. Direct effects of FLAIR. Given the limited implementation in Phase I, FLAIR can directly affect only response times in the Third District. However, given the highly visible

[41] Workload information is taken from the annual reports of the St. Louis MPD.

presence of Boeing engineers and evaluation personnel and given the fact that dispatchers serve districts other than District 3 (rotating through assignments on the FLAIR console), it is not unreasonable to suspect that an increased attentiveness to response time contributed to a "spill-over" effect, yielding response time reductions in other districts. This effect, if present, will not be a problem in the city-wide implementation in Phase II.

A properly operating FLAIR system is designed to track vehicles accurately and to recommend them for dispatch on the basis of their proximity to the location of a call for service. If both aspects of the system are functioning correctly, the computer simulation model predicts average travel time reductions on the order of 25%. Any deviations from ideal system performance would cause the reductions to be somewhat smaller, and, unfortunately, some deviations did present themselves during Phase I. A combination of early tracking problems and dispatcher inattention to correcting mis-tracked vehicles meant that, at times, the system was tracking far below its potential level. This, combined with some question as to the adequacy of the algorithm that determines the closest car to an incident (Section D.2 of this chapter), suggests that actual travel reductions to be realized from the Phase I implementation are much less than the 25% estimate.

By no means can system malfunctions be singled out as the sole factor responsible for smaller Phase I response reductions than projected. Operational factors also play a major role. As touched upon in Chapter V, dispatcher operation of the system was,

for a time, not consistent with proper FLAIR procedures on handling vehicle initializations. Other types of error can directly effect travel time through the quality of dispatches made. For instance, the order of vehicles in the closest car list is sensitive to the placement accuracy of the cursor. An obvious example of this occurs when a dispatcher completely misses the location of a call. In this case, other than the closest car will most likely be sent, incurring additional travel time due to improper operation. Therefore, it is most likely a combination of system and operational problems that reduce the potential effects FLAIR might have on travel time.

Results during Phase I suggest that the concern over increased dispatch delays due to learning of the FLAIR system should be only temporary. This is because the dispatchers soon master the new system and dispatch delays drop to a value comparable to the pre-AVM times. Presumably, each dispatcher should have to master the system only once and this will not become a recurring problem.

One final FLAIR related problem is the presence of non-FLAIR-equipped vehicles in the district when most other units have the AVM equipment. As the dispatcher becomes acclimated to the AVM system recommending units for dispatch, he or she soon forgets the non-FLAIR-equipped beat car, and the district is essentially operating with one less vehicle. A reduction in the effective number of vehicles answering calls for service means that the average travel time per call will increase. This type

of situation was observed frequently during Phase I and, undoubtedly, acted to lessen the magnitude of travel time reductions that would have occurred had all vehicles been FLAIR-equipped.

d. Effects of Major Intervention in Operations. Within the police emergency response system, the dispatch center is the major decision-making unit. The speed of assigning calls and the quality of dispatch decisions will greatly affect response time. The St. Louis Metropolitan Police Department has a system that is typical of pre-CAD response systems in U.S. police departments. It was in partial recognition of this lack of use of available technology that the FLAIR System is being implemented there. Also, during the process of the implementation it became evident that the MPD had problems in the area of dispatcher competence and motivation. Many dispatchers did not know the streets or addresses in the districts they were working. Many were not motivated to use the FLAIR console as it was intended.[42] Such problems did not apply to all personnel, but certainly to a sizeable fraction. The center suddenly came under careful scrutiny during Phase I, not only by MPD and Boeing personnel, but by evaluation staff as well, no minor part of the scrutiny being the on-the-scene response studies presented earlier in this chapter and two attitudinal surveys reported in Chapter X. It may only be a coincidence that July, 1975, the first month to show major

[42] See Section D.4.b of this chapter.

dispatch time reductions, was the same month that evaluation personnel were sitting with dispatchers and complaint clerks collecting data on system operation and performance. (See entries in "boxes" in Tables 6-10, 6-11, and 6-12.) It is very likely that the novelty of being part of an experiment (FLAIR), the pressures of being monitored on performance, and increased command presence played a role in affecting dispatch operations city-wide. This would not only cause lower dispatch times, but better quality dispatches leading to lower travel times.

The total impact on response times is probably a combination of all four factors: random fluctuations, non-FLAIR effects, direct effects of the FLAIR System, and the effects of a major intervention in operations. Each one could act to increase or decrease response times through mechanisms that might or might not be controlled by the MPD. Also, both hardware and behavioral problems can act to reduce the potential beneficial effects of the FLAIR System. It is this complex series of interactions that has precluded marked response time reductions in Phase I. The most we can confidently say now is that there is a reasonable indication that the new Phase II system, if accompanied by trained and motivated police personnel, will most likely reduce the time required to get a police car to the scene of an incident. If the next installation can perform without the hardware and behavioral problems encountered by its predecessor, it appears to have a chance of living up to expectations for response time reductions.

8. <u>Summary of Findings</u>. From the analysis conducted comparing city-wide data to changes experienced by the Third District, one can make the following general observations:

- The rest of the city experienced larger reductions in dispatch delay than did District 3. The disparity between city-wide and District 3 reductions lessened as the dispatchers learned the new system.
- District 3 experienced larger travel time reductions than did the rest of the city during 1975.
- The rest of the city experienced slightly larger reductions in FLAIR-related response times than did District 3.

In any case, due to the large number of intervening factors (all discussed in this chapter), the magnitude of changes observed was not large enough to establish a pattern of response time reductions attributable to the Phase I AVM system.

Many issues of a general nature were discussed in this chapter and they should provide a framework for approaching the city-wide Phase II evaluation. However, at this time, about all that can be said of the monthly response time data for Phase I is that the results pertaining to FLAIR are inconclusive. The general downward trend of District 3 dispatch delays over the course of Phase I plus the marked drop in FLAIR-related response times during the three-month period of intensive on-site evaluation suggest strongly that achieving the promised response time reductions depends on cooperation and enthusiasm of dispatchers and patrol personnel, perhaps even more than on a correctly functioning hardware system. In an attempt to structure such an

environment during Phase I - thus providing optimal circumstances for FLAIR performance - a special three-week test was conducted during September, 1975. This is the subject of the next chapter.

SCOPE

CHAPTER VII: THE THREE-WEEK SPECIAL TEST

A. Background. B. Preparations for Test: *Dispatcher Preparations; FLAIR Radio Repair Preparations.* C. Test Indicators: *Travel Time; Proportion of Dispatches Involving FLAIR Use; Amount of Time to Locate Cursor in Dispatching; Increase in Total Dispatcher Workload Due to FLAIR.* D. Test Monitoring Indicators: *Number of Initializations of Lost Cars; Use of the System by Patrolmen; Elements of Hardware Maintenance.* E. Test Results: *Travel Time; Proportion of Dispatches Involving FLAIR; Amount of Time to Locate Cursor in Dispatching; Amount of Time in Initializations; Initialization Rates; Effect of FLAIR on Dispatcher Workload; Dispatch Times; Response Time; Hardware Maintenance; Personnel Attitudes During Test.* F. Conclusions.

Reader's Guide to Chapter VII: This chapter describes in detail the design and results of a three-week special test of the FLAIR System under favorable operational conditions, and documents the way in which the system was used by St. Louis dispatchers. Essential findings include: travel time was reduced, but not substantially; proper operation of the system does not require an increase in dispatch time; overall response times in the test district are not appreciably lower than those in the city as a whole; dispatchers perceive an increase in workload with the FLAIR System; trained and motivated dispatchers are essential to the successful use of the system; the digital code system is an important improvement; and spare vehicles are essential.

CHAPTER VII: THE THREE-WEEK SPECIAL TEST

A. Background

As we have discussed in previous chapters, certain operational and accuracy difficulties developed during the Phase I implementation of the FLAIR System. In addition, the travel time results which were reported in Chapter VI based on comparisons of standard monthly data between 1974 and 1975 were generally inconclusive. In order to examine the operations and influence of the Phase I FLAIR System under a more favorable set of circumstances, a special test was designed and conducted in District 3. The test was needed to study the operation of the system under two important conditions: 1) proper use by dispatchers and 2) full coverage of the entire district by FLAIR-equipped vehicles. During the test, which operated for the period of one shift[1], from September 15 to October 5, 1975, these two conditions were carefully monitored to assure meaningful results. Information about man-machine interaction and the effect of FLAIR and closest car dispatching on vehicle travel times are presented as the principal results of this test of the FLAIR System. The results of the test show how well the System can perform if used correctly--through

[1]As explained in greater detail in Chapter VI, the St. Louis MPD has three watch periods during a 24-hour day. There are three platoons in each District, with each platoon serving one of the three watches. Every three weeks the three platoons rotate watches. The three-week period between rotations is known as a <u>shift</u>.

proper dispatcher procedures and full FLAIR deployment--and what effort it takes on the part of dispatchers to use the System as it was designed.

In monitoring the first condition, proper FLAIR use by dispatchers, the following quantities were computed at intervals throughout the test: the proportion of calls for which the dispatcher used FLAIR location information, the amount of time it took to use FLAIR to find the closest car, and the amount of time consumed in other FLAIR-related activities.

The second condition, full FLAIR vehicle deployment, was also important. Cars in District 3 had not always been FLAIR-equipped, most often because of mechanical or repair problems. Prior to the test, it was likely at any time that two or three patrol cars (of a total of 25) might be in operation without FLAIR. To dispatch these cars, pre-FLAIR (position "guesstimation") methods had to be used. The dispatchers, understandably, found it difficult to interweave the FLAIR closest car dispatching method with the pre-FLAIR area car dispatching method. One communications sergeant remarked that "Dispatching with a non-FLAIR car out there is like playing cards with a deck that has one card missing." On occasion, in an attempt to make the two methods compatible, the locations of the non-FLAIR cars were requested by the dispatcher. Such problems served as an excuse for some dispatchers not to place the cursor at the incident location and not to use the closest car feature. Even if the closest car feature had always been used for FLAIR cars, system performance (in terms of response time

reduction) would have been degraded due to the presence of the non-FLAIR cars.

For the FLAIR System to list the four closest[2] cars (rank-ordered), the dispatcher must move the cursor (an electronic cross on the Display) by means of the cursor control (on the Display) to the location of the incident. Observations of dispatchers made by PSE, Boeing, and MPD personnel prior to the test indicated that only 30% (approximately) of the dispatchers placed the cursor correctly to dispatch the closest car most of the time; another 30% rarely placed the cursor at the incident location, thus dispatching cars in the same manner as they had been doing before FLAIR and not deriving benefit from the closest car concept; and the remaining 40% sometimes placed the cursor and sometimes not--depending on the type of activity and the location of the incident. It was estimated that prior to the test the dispatchers placed the cursor less than 50% of the time.

Placement of the cursor by the dispatcher consumes a certain amount of time, which varies from dispatcher to dispatcher because of differences in their knowledge of the streets in the district and differences in their ability to use the cursor on lower magnification map scales. The time a dispatcher takes to locate the scene of an incident with the cursor could add to the overall response

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[2]FLAIR measures "closeness" in terms of the right-angle distance metric, which can result in inaccuracies due to random street rotations, barriers to travel, expressways, one-way streets, etc. See Chapter VI, Section D.

time, thus reducing the net effect of any savings accrued in travel time.[3]

In addition to selecting the closest car, the dispatcher must perform two other duties: 1) respond to digitally-coded FLAIR messages similar to "ten" codes sent from patrol cars, and 2) initialize the locations of vehicles which the System has "lost." These two tasks are necessary to maintain the dispatcher's knowledge of the status and location of his units. Even though they are not tied to an individual dispatch, these tasks are a vital portion of the dispatcher's job. Thus, the effect of these tasks on a dispatcher's workload and performance is important.

B. Preparations for the Test

In order to obtain results which would more accurately describe the performance and effects of the FLAIR System as it was ultimately intended to be used, dispatching conditions were upgraded and radio repair conditions were maintained at a high level. During the test, only the best trained and most experienced FLAIR dispatchers were assigned to the FLAIR-equipped District 3 dispatcher's position. The manpower and technical expertise of the radio repair crew were augmented by the presence of a Boeing technician, who helped in maintaining a very high level of availability in the FLAIR mobile installations.

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[3]If a computer-aided dispatching (CAD) system were used in conjunction with FLAIR, this manual operation would be made unnecessary, thereby reducing overall response time. It would also virtually eliminate any chance of error due to incorrect positioning of the cursor.

1. Dispatcher preparations. Those dispatchers who were judged to be the best at dispatching with the FLAIR System under the pre-test conditions were selected by the Department to serve during the test. These dispatchers, along with their supervisors, MPD command personnel, Boeing representatives and PSE representatives, attended a meeting prior to the test. The dispatchers were informed of the nature of the test, that they were selected because of their competence and cooperation in the use of FLAIR, and that the purpose of the test was to determine whether use of the closest car concept resulted in improved travel times. It was explained that this would not be a test of the skill of the dispatchers as individuals. A number of questions concerning MPD policies on dispatching procedures and the use of FLAIR were brought up for clarification; these are highlighted in Table 7-1. In addition, some of the techniques for using FLAIR were discussed to ensure that all dispatchers were aware of the most preferred methods. Cited as good dispatching techniques were: keeping the status column cleared, using lower magnification map scales to decrease cursor motion time, and using an approximation of the location incident site[4] rather than spending time finding the exact location.

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[4]As argued elsewhere in this report (Chapter VI, Section D), mathematical analysis shows that most of the possible travel time reduction is achieved by an AVM system having 1/4 beat-length resolution. Similarly, when dispatching according to the position of the incident, and assuming a highly accurate AVM system, the estimated position of the incident can be in error by 1/3 to 1/4 of a beat length without causing marked increases in travel time. This statement obviously must be qualified for those incidents near barriers, expressways, etc.

Table 7-1

Clarification of MPD Policies Prior to Three-Week Test Concerning Dispatching Procedures and the Use of FLAIR

- Officers will be instructed that dispatchers will select the closest car and that men on the street will not disagree on which car is closest.
- Cars are asked to send a code 74 (request for voice contact) before establishing voice contact with the dispatcher.
- When a sergeant is unavailable for supervisory or assist assignments from the dispatcher, he is to change his status to "not available for service."
- Cars are transmitting digital codes which remove them from those available for service (e.g., 27 (occupied car check), 72 (arriving at scene), and 76 and 77 (leaving for scene, low and high priority)), and then failing to clear this transmission after the dispatcher has acknowledged it, resulting in congestion in the vehicle status column of the FLAIR display. Dispatchers are to remind the men when they fail to properly clear these codes.
- Certain digital messages, including 58 (radio repair), 61 (auto trouble), and 67 (gas) do not change the in-service status of the vehicle, sometimes resulting in unavailable cars showing in the closest car column. Vehicles sending these codes are to send an additional code to notify FLAIR that they are unavailable for service.
- Officers should wait for acknowledgment of code 27 (car check) and then send in the car's registration number.
- At the beginning of the test period, each man in each car will be furnished with a miniature (portable) radio so that he can be contacted while away from his vehicle.

2. <u>FLAIR radio repair preparations</u>. During the summer of 1975, the Third District replaced its old patrol cars with new Nova compact models. This involved transferring both FLAIR and voice communication equipment in all 25 District 3 cars, which required testing and calibration. This consumed a considerable amount of manpower and may have had an effect on the reliability of the FLAIR units in the patrol cars. During their manufacture, the new cars had been moved and transported by electromagnets so problems were encountered with residual magnetism requiring degaussing of the trunk area. Since it affected the heading sensor, this magnetism resulted in an abnormally high number of initializations, particularly during the three weeks immediately prior to the test.

Because the scheduled starting date of the test had been pushed back several times and could be delayed no longer, considerable pressure was placed on radio repair personnel to prepare the cars. The necessary preparation was performed admirably in the limited time available. For the duration of the test, Boeing sent a technician to St. Louis to provide help and further training for the MPD FLAIR repair people. Vehicle reliability was backed up by the use of three FLAIR-equipped garage "extras" when regular FLAIR cars were undergoing repair or maintenance.

C. Test Indicators

The experimental indicators focus on the elements of the response system affected by FLAIR: travel time, the percentage of time FLAIR

information is used, cursor location time, and changes in the total dispatcher workload.

1. Travel time. Travel time results are obtained from MPD computer printouts summarizing performance by district, normally on a monthly basis. The month of September, 1975 was separated into two halves; of which the 15th through the 31st was totally occupied by the test period. Data from the first five days of October, also a part of the test period, were obtained later, but the sample size for most kinds of incidents was too small to provide for statistically significant results. In order to control for normal seasonal variations, the months of September, 1974 and October, 1975 were compared with the test period. Comparisons were not made with the first half of September, 1975 because of the abnormal strains placed on the system by the turnover of the vehicle fleet. As a necessary control factor, the magnitude and statistical significance of the differences in city-wide response times for the same time periods were compared to results obtained in the District 3 test sample.[5]

2. Proportion of dispatches involving FLAIR use. Use of the closest car concept, which has obvious implications for the travel

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[5]Given the intense interest in the test, other individuals connected with the test analyzed the travel time results shortly after the test. (An internal MPD summary of results was prepared for the Chief on December 9, 1975.) While this analysis yielded travel time reductions during the test similar to those reported later in this Chapter, it failed to normalize the results by comparison with other city-wide data.

time results, is measured directly by the fraction of dispatches involving FLAIR. While there is no precise comparison sample for this indicator[6], we do know that the degree to which FLAIR was used varied considerably from dispatcher to dispatcher before the test. During the test all of the selected dispatchers were reasonably similar in their use of FLAIR, enabling the on-site observer to make intermittent random samples of the use of the FLAIR System in dispatching cars to a sample of 262 incidents. Observations were made by looking over the dispatcher's shoulder and by asking questions when they were necessary or appropriate.

3. Amount of time to locate cursor in dispatching. The amount of time it takes the dispatcher to locate the scene of an incident on the FLAIR display with the cursor, thereby obtaining closest car information, has a direct influence on total response time. The cursor has a fixed maximum speed, which is the same for all map scales. Thus, by using a less magnified map scale, the dispatcher can cover greater distances with the cursor in less time. Since the lower magnifications have correspondingly less detailed location information, they call for increased dispatcher knowledge of the district. As with other dispatcher-oriented performance measures, there is little accurate prior information available for this indicator.

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[6]Mr. Gilbert Larson of PSE, after numerous observations and discussions with Boeing and MPD personnel, estimated that dispatchers used FLAIR for less than 50% of all dispatches during the second quarter of 1975.

Observations of the amount of time consumed in locating the cursor and the map scale strategy used were made both next to the dispatcher and at the auxiliary FLAIR display which is located in another room. Elapsed time was calculated to the nearest second from the digital clock on the FLAIR screen. Observations were occasionally hampered by the dispatcher's habit of "playing" with the cursor, aimlessly or purposefully moving the cursor across the screen in activities unrelated to the dispatching of patrol cars.

Results are broken down in terms of the average cursor motion time for each map scale strategy and the relative frequency of the various map scale strategies.

4. Increase in total dispatcher workload due to FLAIR. Although not directly related to response time, one of the results of the three-week special test was an assessment of the gross increase in the amount of work done by the dispatchers which can be attributed to FLAIR. The increases result from time to locate the cursor and time to initialize lost vehicles. Information concerning net increases was not obtained because there was no existing comparison data available for non-FLAIR dispatching; no figures for change in dispatcher workload could be compiled. For instance, workload decreases might result from the digital communications feature of FLAIR. Observations of workload increases during the test (particularly the number of initializations required per car per day) substantiate the findings previously developed in Chapter V.

D. Test Monitoring Indicators

Certain monitoring indicators were measured during the test to assure compliance with designed test procedures. The three major indicators involve the number of initializations of lost cars, the use of the system by patrolmen, and the elements of hardware maintenance for both the mobile and fixed positions in the system.

1. Number of initializations of lost cars. The number of initializations is important since it serves as a somewhat "noisy" indicator of the quality of location information available to the dispatcher. In addition, this measure also contributes to a test indicator--increased dispatcher workload--since initializations require dispatcher time. While a low number of initializations might be equally likely to indicate good tracking by the System or poor data upkeep by the dispatcher, an abnormally high number of initializations does imply the existence of problems. As an element of dispatcher workload, the number of initializations may also contribute to response time through increased dispatch time (causing queuing) as the dispatcher becomes busier. Knowledge of this measure helps to clarify earlier results on initializations (Chapter V), in which accurate data about the number of FLAIR-equipped vehicles on the road each day was not kept and the dispatchers engaged in the practice of "bulk clearing."

2. <u>Use of the system by patrolmen</u>. The cooperation of patrolmen in the use of the System helps make the dispatcher's job easier and increases System accuracy. The number of code 22's (self-initializations) sent, as discussed previously in Chapter V, is an important indicator for this reason. Use of the emergency button on the FLAIR transmitter is an indicator of the confidence that patrolmen have in the System's ability to let the dispatcher know where they are with great accuracy.

3. <u>Elements of hardware maintenance</u>. Failures of either the mobile or headquarters portion of the FLAIR System will result in problems for the dispatcher. In the test, the duration rather than the nature of the failure is the indicator of importance. For information on reliability and the nature of repairs, the reader is referred to Chapter IX.

Maintenance of the FLAIR equipment at headquarters is of primary importance because such failures leave the dispatchers totally without the benefits of FLAIR information, and closest car dispatching is rendered impossible.

Maintenance of equipment in the FLAIR vehicles is also of central importance for two reasons: first, a poorly maintained FLAIR vehicle unit will give poor location information, and second, the use of non-FLAIR vehicles during repair of FLAIR vehicles requires "mixed" dispatching procedures, as discussed previously. The need for garage extras for repair trade-ins is apparent if a full fleet is to be continuously fielded. Three extras were available for a fleet of 20 cars during the special test.

E. Test Results

The results of the three-week special test are the best information currently available about the performance of FLAIR under operational conditions. Travel time implications of FLAIR, unfortunately, remain inconclusive. There was an apparent increase in the fraction of dispatches involving FLAIR information, and a very close adherence to the concept of closest car dispatching. More reliable estimates than previously available were developed for cursor location time and increases in dispatcher workload.

1. Travel time. 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 Table 7-2, for 29 categories of incidents plus an overall total. Overall, District 3 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). This total, plus seven categories showed statistically significant[7] decreases in District 3, including: larceny, flourishing a weapon, destruction of property, disturbance, alarm sounding, fire, and assisting

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[7]Significance judged at the 90% level for a modified T-test as used in the SPX statistical package.

Table 7-2

Travel Time Changes

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

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Homicide	NA	NA	NA	NA
Rape	NA	NA	1.01	23
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
Fraud	NA	NA	0.90	17
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

(continued on next page)

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

NA Data not available because number of samples was too small for MPD data tabulation program.

Table 7-2
(continued)

Travel Time Changes

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

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
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
Lost Article	NA	NA	3.38	53
Missing Person	NA	NA	3.07*	44
Additional Information	1.59	24	0.50	8
Arrest	NA	NA	5.30	25
TOTAL	0.84*	15	0.57*	11

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

NA Data not available because number of samples was too small for MPD data tabulation program.

an officer. Each of these, except perhaps larceny, usually implies a high-priority (rapid response) call for service. While the District 3 figures may be impressive, it is noteworthy that <u>city-wide average travel time also decreased in a statistically significant way during the same period</u>. The drop was from 5.18 minutes (September, 1974) to 4.72 minutes (test period), or a drop of 11 percent (34 seconds). Moreover, by category, city-wide figures show statistically significant reductions in all of the statistically significant District 3 categories except fire calls, <u>plus nine others</u>, for a total of 15 categories; the additional categories are assault, burglary, auto theft, person down, traffic violation, injury, miscellaneous hazard, call for police, and missing persons. Neither the test district nor the city as a whole showed any significant increases. Given these results, it is difficult to attribute more than 4% of the 15% reduction (corresponding to 14 seconds) to the presence of FLAIR.

Similar comparisons were made between the September test period and the following FLAIR-equipped month, October, 1975, to determine the effect of the test conditions[8] (Table 7-3). Overall, travel time in District 3 was significantly lower (8.5% or 0.44 minutes) during the test period in District 3. In September

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[8]We recognize that due to the three-week scheduling of the test, which coincided with one shift period, the first five days of the October sample are contaminated by the experimental procedures. However, this contamination is minimized due to the deterioration of the availability of FLAIR-equipped cars, which resulted in a more standard level of about one non-FLAIR car fielded during each of these five days. (See Section D.9.b. of this chapter.)

Table 7-3

Travel Time Changes

(Travel time of October, 1975 minus travel time of September, 1975 test period (in minutes))

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Homicide	NA	NA	NA	NA
Rape	NA	NA	0.52	13
Robbery	-0.39	-33	-1.09	-37
Assault	0.61	16	0.41*	12
Burglary	-0.09	2	0.04	1
Larceny	0.60*	11	0.21	4
Auto Theft	0.87	14	-0.41	-7
Destruction of Property	1.24*	20	0.47	8
Fraud	3.00	46	0.77	15
Sex Offense	0.97	22	0.27	6
Flourishing	-0.90	-38	0.18	6
Person Down	0.98*	20	0.72*	15
Disturbance	0.26*	6	0.13*	3
Traffic Violation	2.50	21	0.59	8
Alarm Sounding	0.42*	10	0.05	1
Injury	-0.11	-3	-0.22	-6
Fire	0.35	9	0.15	4
Accident	-0.44	-9	0.01	0
Animal Case	-0.23	-3	-0.02	0
Sick Case	0.61	14	-0.13	-3
Death	-1.89	-49	-0.86	-15

(continued on next page)

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

NA Data not available because number of samples was too small for MPD data tabulation program.

Table 7-3
(continued)

Travel Time Changes

(Travel time of October, 1975 minus travel time of September, 1975 test period (in minutes))

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Assist	0.29	6	-0.20*	-4
Miscellaneous Hazard	0.50	7	0.04	1
Call for Police	0.66	23	0.48*	18
Suspicious	0.77*	14	-0.38	-8
Lost Article	NA	NA	2.00	40
Missing Person	NA	NA	2.38	38
Additional Information	0.80*	14	0.21	4
Arrest	NA	NA	14.72	48
TOTAL	0.44*	8	0	--

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

NA Data not available because number of samples was too small for MPD data tabulation program.

the average travel time was 4.74 minutes and in October it was 5.18 minutes. By category, District 3 travel times were significantly lower for the following: larceny; destruction of property; person down, disturbance; alarm sounding[9]; suspicious persons and cars; and additional information. City-wide average travel time was unchanged, but between the September test and October, four categories were significantly lower city-wide during the test: assault, person down, disturbance, and call for police; one category, assisting an officer, was significantly higher during the test. Because the test period highlighted the careful control of dispatcher use of the system, this comparative result emphasizes the importance of good dispatching in the achievement of travel time reductions in FLAIR. A further discussion of travel time trends during FLAIR-equipped months is found in Chapter VI. (For example, for the first 11 months of 1975, District 3 travel times decreased 8.0% as compared to 1974. Over the same period, city-wide travel times decreased 7.0%.)

2. Proportion of dispatches involving FLAIR. During the test, FLAIR was used in 69.5% of 262 observed dispatches, and including obvious dispatch choices, the closest car was selected for dispatching 85.9% of the time (Table 7-4). Since 6.9% of dispatches were non-urgent calls normally assigned to the stack

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[9]The previous four categories also showed decreases from September, 1974 to the test for the test district.

Table 7-4

Proportion of Dispatches Involving FLAIR

	%	Sample Size
DISPATCHES MADE ACCORDING TO POLICY	92.8%	243
Closest Car (Subtotal)	85.9	225
FLAIR Dispatching	69.5	182
Closest Car in Column	39.3	103
Other Than Closest Car*	30.3	79
Sergeant	22.5	59
2 Needed	5.3	14
1 Needed	3.1	8
Travel Barrier	2.3	6
Obvious Dispatches	16.4	43
One Car Available	13.4	35
Two Cars Available	3.1	8
Stack Car	6.9	18
NOT DISPATCHED ACCORDING TO POLICY*	7.3	19
No Cars Available	3.1	8
Sector Car	2.3	6
Non-FLAIR Unit	2.3	6
On Way to Station	0.7	2
Two Calls at Once	0.4	1
Skipped Due to V	0.4	1
Eyeball, Incorrect	0.4	1
TOTAL	100.0%	262

* Items under this entry add to more than the entry itself because more than one item may apply to each incident.

car, the fraction of dispatches which adhered to the experimental guidelines was very high at 92.8%. As outlined below, even the remaining 7.3% of dispatches cannot be faulted for improper dispatch procedure.

In 30.2% of the total of all dispatches, FLAIR information was used to select a car other than the top car in the closest car column of the FLAIR display. Such discretionary dispatch selections were made either from the remaining cars in the closest car column or from the map display in order to allow for departmental policy considerations or technical limitations. In 22.5% of all dispatches at least one[10] car in the column was passed over for dispatch purposes because it was a sergeant's car. This tended to happen more frequently as the District's workload increased; as one might expect intuitively, due to the departmental policy of saving sergeant's cars for non-routine calls. In 5.3% of all cases, a one-man car was passed over because a two-man car was needed. (Two one-man cars, however, were never skipped over in favor of a two-man car.) In 4.6% of all cases, there were cars in the closest car column which were out of service but had not sent a digital code to alert FLAIR that they were unavialable. In 3.1% of all dispatches, a two-man

[10] Figures in the subcategories of this paragraph add to more than 30.2% of all dispatches because there was sometimes more than one reason for a particular discretionary dispatch.

car was skipped over because a one-man car was sufficient and the dispatcher wanted to save the two-man car for higher priority assignments. Finally, 2.3% of all cases involved cars which were not closest, due to travel barriers or street configurations. (An extreme example of this is given in Figure 7-1.)

In a separate category of 16.4% of all dispatches, the closest car was obvious to the dispatcher without the use of FLAIR information. For 3.1% of all dispatches, it was obvious to the dispatcher which one of two available cars was closest to the scene. The remaining dispatches in this category were dispatches from a queue of waiting calls; in such cases the closest car (to the closest or highest priority waiting incident) is obvious since it is the only car available.[11]

In addition to closest car dispatches, 6.9% of all dispatches were assigned to the district's stack car. These are lower-priority calls which come from all regions of the District and are assigned without regard to location. Both before and during the test, it was Department policy to assign as many such calls as possible to this one car, which would be kept concinuously busy.

Including stack car assignments, 92.8% of all dispatches observed during the test adhered to Departmental policies set out

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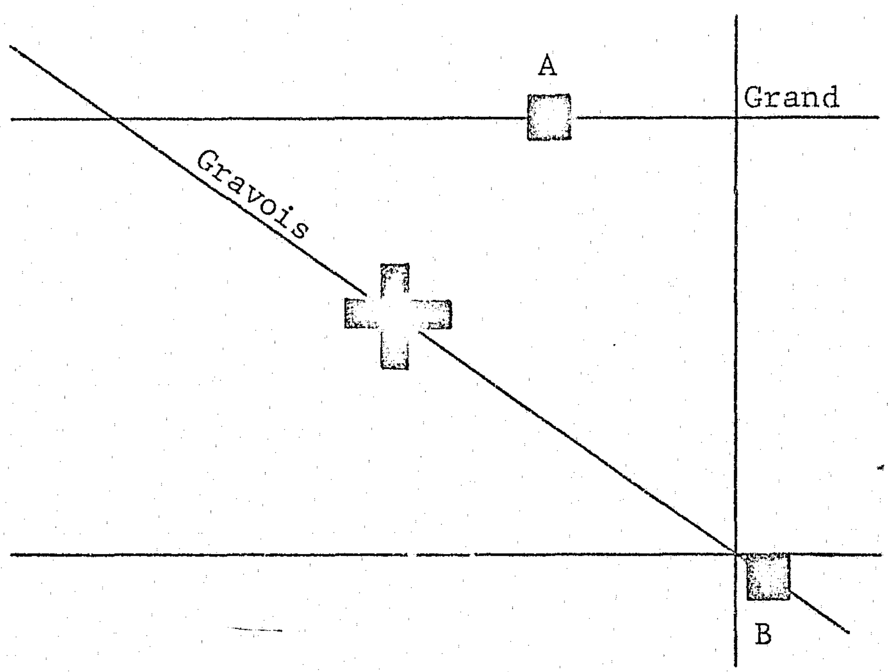
[11] In the Third District, it was estimated from observation during the test that perhaps two to up to five hours of each 24-hour day were peak-load periods during which no cars would be available for immediate dispatch.

Figure 7-1

Street Configuration Error



One dispatch involved a situation where the FLAIR distance metric (based on "Manhattan" distances) selected the incorrect car, in the travel time or travel distance sense. The configuration of this case is displayed above, where FLAIR selected car A when B was closest. The dispatcher commented that this situation doesn't happen too often, because the cars aren't usually that close together. "But," he commented, "it doesn't help the system's credibility any." This may become more of a problem in other districts. (See Chapter VI, Section D, on street patterns, barriers, and the FLAIR distance metric.)

for the test. In addition, no major problems were created in the dispatch process by the shift to a closest car dispatching policy. Of 262 dispatches recorded in this set of observations, only 19 were made in apparent contradiction to the policy of closest car dispatching, and even in some of these cases justifications seemed to exist for the dispatch choice made.

The greatest single source of non-closest car dispatches was assignments to cars which were still on assignment to a call and had not called clear, which accounted for eight of the 19 improper dispatches.[12] One of the major reasons for this practice was to encourage some officers, whom dispatchers felt to be taking too long in servicing an incident, to clear the scene and take on more work. This should not be faulted as poor dispatching technique, under the circumstances.

The pre-FLAIR sector car concept was a consideration in six of the 19 improper dispatches. Four of these sector car dispatches occurred at relief time, when all cars were still very near the station and bunched closely together. Further, all of the calls were of a lower priority nature. While it is doubtful that the "sector car" dispatches had any adverse effect on travel time results, they represent improper dispatches under written MPD policies (when strictly interpreted).

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[12] Since it is the purpose of the stack car to handle calls in this manner, such assignments, when given to the stack car, are not included here.

Non-FLAIR units (cruisers and footmen) also accounted for six dispatches. These dispatches were generally made at a time when very few cars were available and to calls of at least moderately high priority. Even under these conditions, dispatchers deliberately tried to save their cruisers from assignments in anticipation of other needs. As long as non-FLAIR units are deployed through the dispatcher, though, they will continue to draw assignments.

The low-priority assignments were given to cars on their way to the district station. One call was given out by eyeballing the location on the FLAIR console; but the car chosen was the fourth or fifth closest to the scene. One (non-stack) car was given two unrelated assignments simultaneously. One closest car was skipped because it had a *V* displayed in the status column. All of these incidents represent improper dispatching technique under written MPD policies.

Of all non-closest car dispatches, no individual reason accounted for more than 3.1% of all dispatches; and even this problem (assigning incidents to cars which had not yet been cleared) was shown to be a special circumstance. There was no identifiable tendency for the dispatchers chosen for the test to prefer "old style" dispatching to the closest car method. All in all, the dispatching procedures followed during the test followed the spirit of the test guidelines to the maximum extent that could be expected.

3. Amount of time to locate cursor in dispatching. The amount of time consumed in locating the scene of an incident with the FLAIR cursor in order to select the closest car is a potentially important component of dispatch delay and, therefore, response delay. For 149 observations made during the three-week test, the average time to place the cursor in dispatching was 13.5 seconds. When the 18 observations requiring more than 20 seconds are removed, the average time to place the cursor drops to 9.0 seconds. Unfortunately, there are no prior data on the amount of time it would take the specially chosen test-period dispatchers to select proper units under the traditional sector car style of dispatching.

As some of the dispatchers pointed out during the preliminary meetings, the cursor can be moved faster on the less detailed map scales. Thus, when compared to the highly magnified 16x scale, the cursor covers four times as much area in a fixed amount of time on the 4x scale. During the test, observations were made of such time-saving uses of the map scales. The most widely used strategy was to stay on the 16x scale, occurring in 64% of 69[13] observations of dispatcher usage of map scales. It required an average of 15.0 seconds to locate an incident, using an average of

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[13] Since cursor motion times are an important factor in determining the impact of FLAIR on response time, it received greater attention during the three-week test and as such a greater number of observations were made of cursor motion times as compared to map scales.

4.0 adjacent map changes. The next most commonly used strategy was to use the 4x map first and the 16x map for fine tuning. This accounted for 17% of the dispatches, averaging 15.3 seconds over 4.4 maps. This strategy took longer, partially because it was used to cover greater distances. Next came the 1x to 16x strategy, 7% of the dispatches, averaging 5.8 seconds per dispatch. Eight other strategies accounted for the remaining dispatches, averaging 18.9 seconds each.

It was originally expected that use of the 4x-16x strategy would result in a reduced amount of time to place the cursor. This did not happen, partially because this strategy was the one normally used to cover long distances, therefore taking a longer period of time, and partially because switching from the 16x map to the 4x map, moving the cursor on the 4x map, then shifting back to the 16x map and moving the cursor again is not substantially faster than just moving the cursor all the way across three adjacent 16x maps. Real dispatch time reductions from the continuous 16x map strategy (obtained by using the 4x map or the 1x map) require considerable knowledge of the streets. The lower magnification maps have considerably less detail, and require much more thought. There are few street names on the 4x map and none on the 1x map. No dispatcher was able to use either of these strategies on a regular basis.

4. <u>Amount of time in initializations</u>. Initialization of FLAIR vehicles is an important factor for two reasons: the accuracy of

the system, and therefore its usefulness, depends upon timely initializations; and the initialization process has been cited as a source of increased dispatcher workload. Although the overall initialization process does not lend itself well to "time-motion" studies of dispatcher activity per se, it can be broken down into a number of separate steps, as shown in Figure 7-2 and noted below:

- A *V* or *W* appears in the status column.
- Delay until the decision that a car with a *V* or *W* needs to be initialized.
- Requesting the vehicle's location.
- Vehicle response.
- Vehicle arrival at suitable location.
- Moving the cursor to the location.
- Initializing the vehicle.

While an "ideal" dispatcher should keep his status column clear at almost all times, only a few of the dispatchers are very concerned about this. A backlog of other tasks may cause a buildup of status checks, cars showing *V*'s or *W*'s may not be available for service because of assignment to an incident[14], or the dispatcher may choose to let the status checks remain while he converses with other dispatchers. Obviously, the relative impact of each reason varies from dispatcher to dispatcher, but

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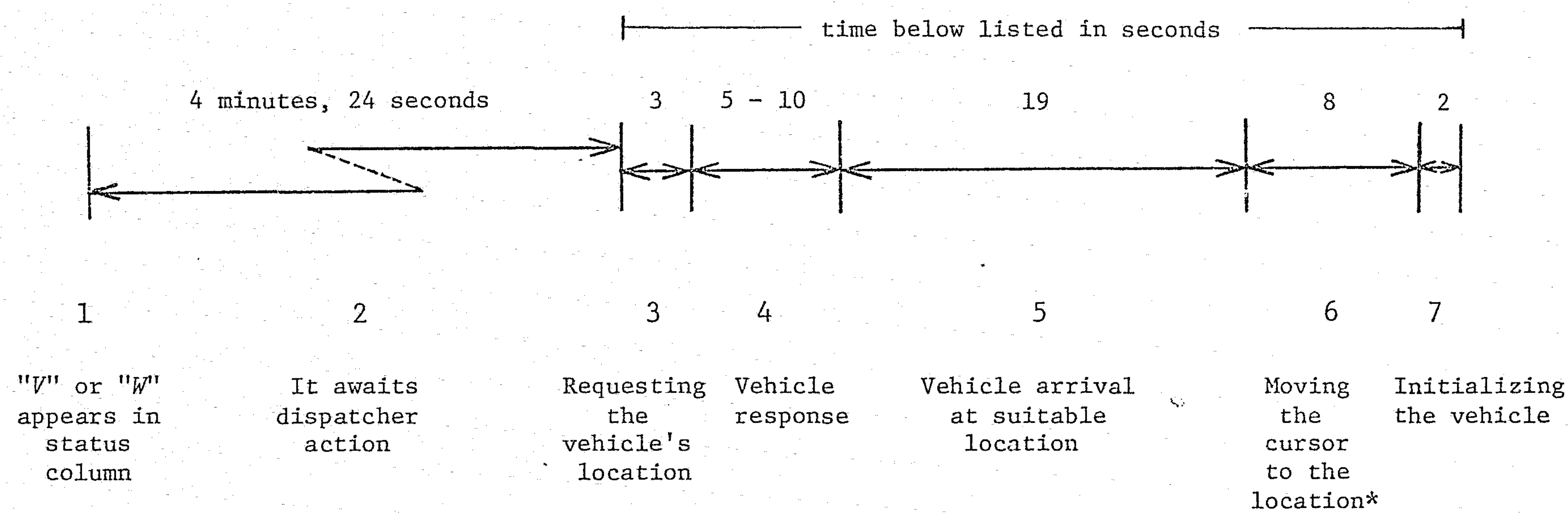
[14] When the officer has left the car, it is impossible to verify location.

Figure 7-2

The Initialization Process: Discrete Steps and Associated Average Times



* Sometimes overlaps (at least partially) with Step 5.

generally the greatest source for uncleared *V*'s and *W*'s is the cars which are out of service, followed by the backlog effect of other tasks. Also, it seems that a cleared status board is watched more carefully--the first *V* or *W* is likely to be checked immediately while additions to a standing list are more likely to be ignored. In a small[15] sample of 45 *V*'s or *W*'s observed during the test period, a mean time from appearance to clearing of four minutes 24 seconds was observed. The variance was extremely high because there were many times when a *V* would await action for the entire amount of time it took an officer who had left his vehicle to complete service on a complaint. (Not including 11 times of five minutes or more, the average wait before clearing a *V* was 68.8 seconds.) While delay in the decision to initialize does affect the quality of the information the dispatcher gets, it is only delay and does not result in an addition to the dispatcher's task. From discussions with dispatchers, the largest effect is probably an increase in the perceived amount of work to be done, due to the queuing of tasks. Dispatchers look forward to periods of inactivity; the queued tasks, such as initializing cars, take away their rest periods.

Requesting location information is a task with a less than 100% success rate: either the car responds with its correct

[15] Considering the variation in the data.

location or it does not. If not, the request must be repeated. Interruptions from other cars are fewer if the "FLAIR check" is requested during another conversation (for example, giving a disposition while clearing an incident) with the car to be located. Requesting a location check is a simple subtask requiring two to four seconds of dedicated dispatcher time.

Vehicle response is almost always immediate; few officers wait until they have arrived at a suitable intersection; most often they simply name the next convenient intersection and then proceed there. This takes five to ten seconds of dedicated dispatcher time.

After the vehicle has selected the intersection for initialization, the dispatcher must wait for a period of time for the vehicle to travel there. This subtask, too, is of highly variable duration, because cars are often in traffic or on their way to an intersection some distance away. The wait averaged 19.2 seconds for the 11 observations made. This time may or may not be used for other tasks by the dispatcher. The longer the wait becomes, the more likely the dispatcher is to take on other tasks. The best dispatchers will immediately proceed to other tasks after the vehicle responds, watching the screen to see when the car comes to a stop.

Moving the cursor to the appropriate location is generally a very short part of the initialization task. Most often, it is done while waiting for the car to arrive at the intersection.

(Thus, cars that choose an intersection ahead of them do not have to stop as long as those that say exactly where they are when asked.) Because cars are rarely far from the location selected, this task generally takes only about five seconds. It is difficult to develop an accurate indicator for this time because it is of such short duration, because dispatchers often use the waiting period to make unnecessary motions with the cursor, and because of occasional mistakes where the intersection located is incorrect and the cursor must be moved to a nearby intersection (again, about five seconds). Moving the cursor during initialization is a semi-dedicated task; during this time the dispatcher will talk with the car being initialized, but will not perform any other tasks. A sample of 11 of these cursor motion times yielded a mean of 8.4 seconds. Because these times are so difficult to measure, there are obvious reservations about the use of this number. The 8.4 seconds includes a considerable amount of unnecessary cursor motion. The sample divided fairly evenly between a two-to-seven second group and a 12-to-18 second group. The former group may be more indicative of the true time to locate the cursor.

After the car has stopped, and the cursor has been properly located, initialization is accomplished by simply pressing the INTLZ button, which takes a second or two.

In a sample of 32 incidents, the mean time required for the steps of initialization from asking the vehicle for its location to initialization of the vehicle was 22.9 seconds. Remember that

this time includes the vehicle-arrival waiting period, which does not require any dispatcher attention and during which other activities may take place. One of these activities is the motion of the cursor, which is why the waiting period plus the time to locate the cursor is larger than the total time required for initializations.

5. Initialization rates. During the test, the overall initialization rate per car per day was 11.4. This compares with an average of 11.0, obtained over a period of eight months (January 6 to August 25) and reported in Chapter V. Most dispatchers took an interest in making sure that their *V*'s and *W*'s on display were kept to a minimum. Several dispatchers commented that the number of *V*'s and *W*'s during the test was a great improvement over conditions immediately previous to this test,[16] and that the current level of *V*'s and *W*'s (an 11.4 average per car per day) did not represent an unacceptable burden when a full complement of FLAIR-equipped cars made FLAIR a useful tool for dispatching.

6. Effect of FLAIR on dispatcher workload. The total increase in the dispatcher's workload due to FLAIR can be expressed as the fraction of the dispatcher time absorbed by initializations and placement of the cursor at incident locations. (Note that this method accentuates the negative impact on workload since it ignores any possible reduction in dispatcher workload due to FLAIR.)

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[16] Recall the difficulty encountered when switching to a new fleet of vehicles (See Section B.2 of this chapter).

The time spent initializing cars can be approximated by multiplying the mean time to complete an initialization (22.9 seconds) by the mean number of initializations per dispatcher per hour during the test, 9.4, to obtain the result of 3 minutes and 35 seconds per dispatcher hour (6.0% of dispatcher time) expended on initialization. This includes the period of time spent waiting for cars to arrive at intersections, which can be used for other activities, but does not include time spent checking the positions of vehicles which turned out to be accurately located. (Compare this with a result of 5.8% obtained in Chapter V, Section A.)

The time spent placing the cursor at the incident site can be approximated by the mean time required for cursor location (13.8 seconds) times the mean number of incidents per hour (8.73 during the September portion of the test) to obtain the result of exactly two minutes per dispatcher hour (3.33% of dispatcher time).

Thus the total gross increase in dispatcher workload due to FLAIR is equal to 3 minutes and 35 seconds plus 2 minutes, or a total of 5 minutes and 35 seconds per dispatcher hour or 9.3% of the dispatcher's time.[17] In addition to this actual increase, the presence of queued tasks on the status board helps to contribute to dispatcher perceptions of an additional increase in workload.

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[17] (Time consumed by initialization) x (number of initializations per unit time) + (time consumed by incident location) x (number of incidents per unit time) = (22.9 seconds) x (9.4 per hour) + (13.8 seconds) x (8.73 per hour) = 5 minutes 35 seconds per dispatch hour = 9.31% of total dispatcher time.

To determine the net effect of FLAIR on dispatcher workload, some way to judge time saved due to FLAIR is needed. Because PSE was not observing non-FLAIR dispatching during the test, no reliable comparison figures are available. Sources of FLAIR time savings include: reduced time receiving digital codes and possible reduced time in determining the car to dispatch.[18]

In addition to task queuing, the use of the FLAIR System allows tasks to be subdivided further than under non-FLAIR dispatching. Deciding where an incident is and deciding who to send are two different tasks which are no longer performed simultaneously. Initializations, as discussed previously, can be broken down into six separate subtasks. The visual digital code system allows dispatchers to queue tasks requiring interaction with officers on a selective basis according to priority and probably duration. This may aid in packing such tasks into a smaller amount of time by reducing dead time between tasks. It can also allow for increased "break" time at the console for dispatchers, some of whom occasionally allow lower-priority tasks to build up for a while before acting on them. While this is not the optimal way to deal with such tasks, it may help to relieve tension produced by a workload which is perceived to be higher.

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[18] This time may be reduced or increased with FLAIR, depending upon the care of nonFLAIR dispatchers in making dispatch decisions.

7. Dispatch times. Changes in the dispatch times reported by the MPD were analyzed in the same fashion as were travel times. Here dispatch time, as measured by the St. Louis Police Department, is defined to be the time that the ticket waits at the dispatcher's desk. Test period figures for 29 crime types were compared with those obtained in September, 1974 and October, 1975. The first set of comparisons contrasts FLAIR with non-FLAIR dispatching, the second set shows the effect of the additional care needed to dispatch the way FLAIR was intended to be used.

During the special test, dispatch times were lower than they were in the September, 1974 comparison sample by 0.93 minutes (20%) in the test district and by 0.59 minutes (16%) in the city as a whole. Dispatch time decreased from 4.74 minutes to 3.81 in the test district and from 3.78 minutes to 3.19 city-wide. The categories in District 3 and 13 city-wide showed statistically significant reductions, as shown by the asterisks in Table 7-5. Thus, dispatchers using FLAIR the way it was inteneded to be used did not experience an increase in average dispatch time, and dispatch times actually decreased more in District 3 than they did city-wide. (Regarding this reduction, it is important to recall that the dispatchers in District 3 during the test were specially selected and included a number of the best in the Department.)

Table 7-6 shows the comparison of dispatch times for the test period versus the month following the test, October, 1975. Dispatch times were 11% higher (0.38 minutes) during the test period in District 3 and 9% higher (0.27 minutes) during the test in the city as a whole. Six categories in District 3 and seven

Table 7-5

Dispatch Time Changes

(Time from Receipt of Dispatch Ticket Until Dispatch of Patrol Unit)

(Dispatch time of September, 1974 minus dispatch time of September, 1975 test period (in minutes))

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Homicide	NA	NA	NA	NA
Rape	NA	NA	-0.11	-6
Robbery	0.74*	41	0.31	17
Assault	1.39*	53	0.66*	30
Burglary	0.46	14	0.44	13
Larceny	1.90*	38	0.57*	14
Auto Theft	1.22	26	0.64*	17
Destruction of Property	1.20	23	0.27	7
Fraud	0.50	33	0.96	26
Sex Offense	0.28	13	0.88*	32
Flourishing	0.69*	34	0.94*	43
Person Down	-0.55	-19	0.06	3
Disturbance	0.62*	19	0.66*	20
Traffic Violation	-1.13	-9	0.75	8
Alarm Sounding	0.68*	24	0.62*	24
Injury	-0.28	-11	0.14	5
Fire	0.66*	25	0.29*	13
Accident	1.04*	32	0.61*	21
Animal Case	1.56	31	0.07	2
Sick Case	-0.15	-6	0.51*	19
Death	0.15	5	-0.34	-10

(continued on next page)

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

NA Data not available because number of samples was too small for MPD data tabulation program.

Table 7-5
(continued)

Dispatch Time Changes

(Time from Receipt of Dispatch Ticket Until Dispatch of Patrol Unit)

(Dispatch time of September, 1974 minus dispatch time of September, 1975 test period (in minutes))

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Assist	1.88	85	-15.79	-675
Miscellaneous Hazard	-0.71	-9	-0.95*	-12
Call for Police	1.10*	59	0.06	3
Suspicious	2.85	35	1.23*	21
Lost Article	NA	NA	-0.17	-4
Missing Person	NA	NA	NA	NA
Additional Information	1.57	26	0.66	11
Arrest	NA	NA	NA	NA
TOTAL	0.93*	20	0.59*	16

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

NA Data not available because number of samples was too small for MPD data tabulation program.

Table 7-6

Dispatch Time Changes

(Time from Receipt of Dispatch Ticket Until Dispatch of Patrol Unit)

(Dispatch time of October, 1975 minus dispatch time of September, 1975 test period (in minutes))

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Homicide	NA	NA	NA	NA
Rape	NA	NA	-0.17	-9
Robbery	-0.32*	-44	-0.29	-23
Assault	0.23	16	0.23	13
Burglary	-0.45	-19	-0.42*	-17
Larceny	-0.47	-18	-0.50*	-17
Auto Theft	-0.44	-14	0.13	3
Destruction of Property	0.06	1	0.13	3
Fraud	0.83	45	-0.41	-18
Sex Offense	0.13	7	0.04	2
Flourishing	-0.27	-25	0.16	11
Person Down	-2.24	-187	-0.58*	-35
Disturbance	-0.57*	-27	-0.29*	-12
Traffic Violation	-0.80	-6	-0.03	0
Alarm Sounding	-0.56*	-35	0	--
Injury	-1.38*	-94	-0.57	-28
Fire	-0.24*	-16	-0.15	-9
Accident	-0.04	-2	-0.23*	-11
Animal Case	0.36	-9	-0.73	-20
Sick Case	-0.40	-17	0.89	30
Death	0.73	20	0.03	1

(continued on next page)

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

NA Data not available because number of samples was too small for MPD data tabulation program.

Table 7-6
(continued)

Dispatch Time Changes

(Time from Receipt of Dispatch Ticket Until Dispatch of Patrol Unit)

(Dispatch time of October, 1975 minus dispatch time of September, 1975 test period (in minutes))

	District 3		City-Wide	
	(minutes)	(%)	(minutes)	(%)
Assist	3.00	90	-16.53	-1,033
Miscellaneous Hazard	-1.38*	-19	-1.17*	-23
Call for Police	0.11	12	-0.58	-48
Suspicious	1.02	16	-0.09	-2
Lost Article	NA	NA	0.00	--
Missing Person	NA	NA	NA	NA
Additional Information	0.17	4	-0.96	-23
Arrest	NA	NA	NA	NA
TOTAL	-0.38*	-11	-0.27*	-9

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

NA Data not available because number of samples was too small for MPD data tabulation program.

in the city as a whole showed longer dispatch times during the test period than during October, 1975. Although dispatch time was higher during the test, dispatchers in the test district did not have to sacrifice any substantial amount of dispatch time as compared to city-wide in order to perform the extra duties necessary to use FLAIR as it was intended to be used.

8. Response time. The change in the total response times can be obtained by adding together the time it takes to receive and process a complaint prior to the dispatcher's desk ("pre-dispatch delay"), dispatch time, and travel time. As shown in Table 7-7 percentage reductions in response time due to FLAIR are diluted when total response time is considered, due to the additive constant of 1.97 minutes which is assumed for telephone answering and complaint writing time (See Chapter 5, Section B). The results show that the test district performed three to four percent better than the city as a whole in both comparison samples. Considering that part of this performance may be attributable to the specially selected dispatchers, we may conclude that the combination of FLAIR with clearly delineated dispatch directives and highly motivated dispatchers reduced average system-wide response time by about three to four percent (when corrected for changes in city-wide response times).

The importance one can place on an exact percentage reduction is limited for at least two reasons. First, as is well known, police workloads fluctuate rather widely from day to day and from month to month, depending on such things as hours of sunshine or rain, temperature, etc. Thus, the few sample points that are

Table 7-7

Response Times

(Sum of dispatch time, travel time and pre-dispatch delay (in minutes))

(September, 1974) MINUS (Test Period)

	District 3			City-Wide		
	Time (Sept., 1974)	Reduction During Test	% Reduction	Time (Sept., 1974)	Reduction During Test	% Reduction
Pre-Dispatch Delay*	1.97	--	--	1.97	--	--
Dispatch Time	4.65	.93	20	3.69	.59	16
Travel Time	5.60	.84	15	5.18	.57	11
Total Response Time	12.22	1.77	14	10.84	1.16	11

(October, 1975) MINUS (Test Period)

	District 3			City-Wide		
	Time (Oct., 1975)	Reduction During Test	% Reduction	Time (Oct., 1975)	Reduction During Test	% Reduction
Pre-Dispatch Delay*	1.97	--	--	1.97	--	--
Dispatch Time	3.45	-.38	-11	3.00	-.27	-9
Travel Time	5.50	.44	8	4.72	0	--
Total Response Time	10.92	.06	1	9.69	-.27	-3

* This 1.97 minutes is attributed to telephone answering and complaint writing delay. It is assumed to be a constant term in all comparisons.

represented here include a variablility due to such factors, and thus greatly affect the degree of statistical confidence one can place on differences in response times. In addition, we are looking at a comparison of response time rates between only two years, 1974 and 1975. This tends to increase the possibility of random variations since we do not have longer term patterns of response time rates over, say, a four or five-year period. (Data from Phase II for 1976 and 1977 should help alleviate this difficulty.)

All of the dispatching is done from the same communications room in headquarters. The emphasis on dispatching during the test, including special dispatcher selection, could hardly be ignored by the other dispatchers. In fact, it is not improbable that there might have been a sort of competitiveness among dispatchers. These observations lead one to conclude that the drop in response time obtainable by more stringent dispatch directives can be significant, perhaps even greater than that which can be attributed to FLAIR alone. To be fair to the FLAIR System, however, it is doubtful if all of this competitiveness--to the degree that it existed--could have been brought about without the AVM system. Thus, we speculate that the new technology may have increased the perceived level of professionalism of the dispatchers, thereby causing the drop in response times both in District 3 and city-wide. This argument suggests that the three to four percent reduction in response time attributable to FLAIR may be a conservative estimate (since absolute--uncorrected--response times dropped in District 3 by 14 percent, compared to

the corresponding pre-FLAIR month). It is clear that the technology and the user create a complex man-machine interface, and the net operational improvements measured are due probably more to personnel attitudes and perceptions than to the specifics of the hardware (assuming a certain acceptable level of performance of the hardware).

9. Hardware maintenance. If FLAIR information is not available to the dispatcher, closest car dispatching is a practical impossibility. If the system at headquarters is inoperative, it is obvious that the dispatcher receives no FLAIR-generated information. And it can be seen that after a certain portion of the patrol cars are non-FLAIR, the dispatcher's task will become sufficiently complex as to make FLAIR dispatching impractical.

a. Headquarters system down time. During the three-week test, the FLAIR System was down four times: twice for dispatcher training (3-5 a.m. on Friday, September 18 and 4-5 a.m. on Wednesday, October 1); once for base station testing at intermittent periods between 2 and 6 a.m. on Wednesday, October 1; and once for adjustments to the cursor at the dispatcher's console from 9:31 to 11:01 a.m. on Friday, October 3.

System down time was 0.89% of total operation time during the three-week test. Two-thirds of this down time was attributed to dispatcher training; the remaining one-third is extraordinary maintenance which is only needed every few months.

b. Vehicle down time. For purposes of this test, a full complement of FLAIR-equipped patrol vehicles had to be maintained, so that dispatchers could rely on FLAIR alone for their information needs. As reflected in a log maintained at the dispatcher console by one watch commander, only twice during the September test period did a car spend an entire watch in the field without a functioning FLAIR unit. One of these occasions was on the night shift, after the regular car for the area in question had been involved in a major accident. The other occurred on the second day of the test.

Starting October 1, this high level of FLAIR availability diminished by almost one car per day when the garage extras normally maintained for exchange during FLAIR and other repairs were unavailable due mainly to mechanical problems. Of five Third District FLAIR cars at LaClede Garage in a sample on October 2, only one was there for a FLAIR-related problem, and it had been fixed after a 45-minute repair. The other four suffered mechanical difficulties.[19] The unavailability of FLAIR-equipped garage extras means that cars with no FLAIR equipment are sent out on patrol until the FLAIR vehicle is fixed (even if the repairs have nothing to do with the FLAIR equipment).[20]

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[19] One accident, one transmission out, and two cars in for preventive maintenance, according to radio room personnel.

[20] The finely tuned calibration of the heading sensor and time slot phasing precluded rapid exchangeability of FLAIR equipment among cars.

The portion of vehicle down time which resulted in the use of non-FLAIR vehicles as regular patrol units on the street was 1.60% during the three-week test period, including the October portion of the test. This level is equivalent to about 23 minutes per day for the system. It is important to note that this definition of system reliability is not the same as vehicle reliability. The 1.60% figure overstates vehicle reliability; this low value is due principally to the three garage extras used during the test. Also, in the data collection, the reporting of non-FLAIR vehicles was not 100% complete, and time spent by a vehicle on the way to the repair shop or waiting at the shop is not recorded. But even if the 1.60% figure was actually twice what was reported here, it would still be reasonably small and probably represents an acceptable level of percent time without a full fielded complement of FLAIR-equipped vehicles.

c. FLAIR vehicle maintenance. During the three-week special test, 94 FLAIR repair incidents were recorded among 23 FLAIR vehicles,[21] of which 20 were usually on the road. This is 7.7 days between repairs for an "average car." These repairs were only those made to FLAIR equipment, and did not include automobile repairs. For the 17 cars experiencing more than one repair, the inter-repair intervals are displayed in Figure 7-3. The nine repairs which occurred on the same day as

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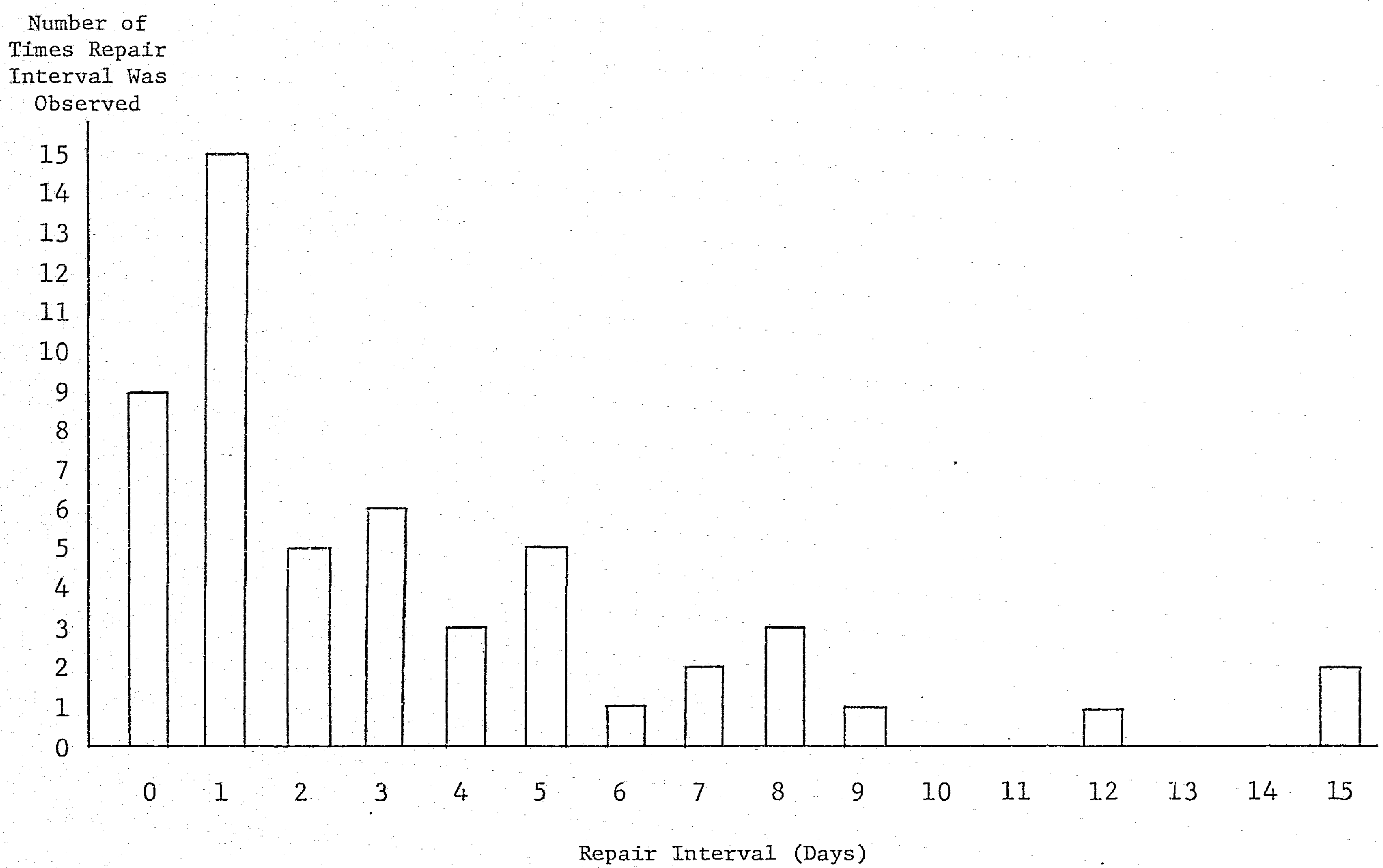
[21] As discussed earlier, three were kept as garage extras to be given out when regular FLAIR vehicles are brought in for repair.

Figure 7-3

Repair Intervals during Three-Week Test



(Six cars experienced less than two repairs and thus are not represented in this distribution.)

the first repair, plus the 15 repairs occuring one day after a repair (the modal point of the distribution) suggest that the first "fix" often does not completely solve the encountered problem. Additional detail on the types of repairs performed can be found in Chapter IX.

10. Personnel attitudes during test. Cooperation from the patrol force is a necessary prerequisite for proper operation of FLAIR as a dispatching tool. All indicators of patrol officer cooperation indicate that it was at a level at least equal to the best prior performance of the system for most of the duration of the test period. One indicator of the degree of cooperation obtained is the total number of digital codes sent and the number of self-initializations (22's) sent by the officers in the field. The number of 22 codes averaged 131 per day, which is 52% more than the 86 per day sent during the preceding 21-day period[22] and 31% more than the eight-month average of 99.5 per day from January 6 to September 14, 1975.

Use of the FLAIR System in emergencies gives a measure of officer confidence in the system. Only a small number of emergencies were observed, including a foot pursuit, sent in over a miniature radio, and an officer sustaining minor injuries in a car accident sent in as a code 55 (emergency need to talk to dispatcher). In addition, a legitimate code 33 emergency

[22] These figures may not be entirely comparable due to differences in the number of FLAIR-equipped cars on the road during the prior 21-day period.

(pursuit of vehicle) was sent during the test period.[23]

There were no formal surveys of police officer or dispatcher opinions conducted during the test, but a number of personnel mentioned to the observer during the test that their opinion of the system was greatly improved. Two factors had a strong influence on officer satisfaction with the system: (1) an increased air presence of dispatchers with whom the field personnel were comfortable, and (2) the introduction of the miniature radios. These factors seemed to have a greater influence on general morale and job satisfaction than on specific views towards AVM.

Informal field interviews conducted shortly after the test in the Third District showed that the dispatcher, as well as the actual system operation, can play a major role in acceptance by patrol officers. (A further discussion of this is found in Chapter X.) Individual dispatchers vary widely in their knowledge of the District and their performance and courtesy over the air. Knowledge of the District is a quality street personnel recognize and appreciate in a dispatcher. Radio discourtesy, be it by specific words or simply by inflection, can reduce the cooperation that field personnel show to the dispatcher. Maintaining a good dispatcher-beat officer relationship is

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[23] Other "emergency" messages sent include four tests, three accidental broadcasts, three cases where the emergency button was pushed ostensibly in order to clear a jammed digital code transmitter panel, two additional code 33's (high-speed chase) sent where the officer said he did not send the code (from the car which had legitimately sent a 33 two and one-half hours earlier), and three emergency messages of an unknown nature.

important because the dispatcher's requests for "FLAIR checks" and "send me a 76" (out of service), are the closest contacts that the street officers have with the FLAIR System. One would expect the policemen to look more kindly upon the FLAIR System when the "better" dispatchers were working. Presumably, this is what happened during the test period. It emphasizes the importance of the position of the dispatcher in the acceptance of FLAIR by the MPD.

As an unforeseen side effect, the test period appeared to reduce tensions between dispatchers and street personnel. Prior to the test a primary source of friction was that not all beat cars were FLAIR-equipped. Often when a dispatcher would receive a call for dispatch, he or she would locate the cursor near the location of the incident and dispatch the nearest FLAIR car without too much concern for the presence of non-FLAIR equipped units. However, the officer in a non-FLAIR equipped unit, if he was near the incident, would sometimes respond with "dispatcher, this is my beat, I will handle." Such situations represented a challenge to dispatcher authority and to beat integrity and many times resulted in tension over the radio. There were some dispatchers who followed FLAIR-related procedures quite strictly and almost ignored a non-equipped vehicle until it was the last one left in service. Several times when a busy FLAIR-equipped car was sent to the garage for preventive maintenance, the officers would return to the field in a non-equipped garage extra and not receive

any further directed assignments. Other FLAIR-equipped cars would be assigned to calls within his beat. This type of situation decreased significantly during the test period and the result was a better relationship between dispatchers and street personnel. It further highlights the necessity of having a full contingent of FLAIR-equipped garage extras available when the system goes citywide.

F. Conclusions

Here we attempt to summarize the key conclusions derived from the three-week test.

1. Travel time was reduced, but not substantially. Travel times were down 15% (0.84 minutes) in the test district as compared to the twelve-month earlier (pre-FLAIR) levels, but city-wide travel times were down 11% (0.57 minutes). The importance of the test conditions was emphasized by the fact that test period travel times were lower than those in the following month, which did have the benefits of FLAIR, even normalizing for city-wide travel time (which was unchanged). Regarding the effect of FLAIR on average travel times, we must view these results as inconclusive. Certainly there is no indication that FLAIR increases travel time; but the empirical evidence that it decreases it is not very strong. Dispatcher attitudes, perceptions and motivations may have played a key role in measured travel time reductions--both in District 3 and city-wide.

2. Proper operation of the system does not require a significant increase in dispatch time. Compared to pre-FLAIR dispatch times, the Third District shows an even greater reduction in dispatch times during the test than does the city as a whole. In addition to random error, much of this may be due to the selection of special dispatchers. Dispatch times from the month following the test suggest that FLAIR dispatch times change in approximately the same proportion as city-wide dispatch times.

3. Overall response times in the test district are not appreciably lower than those in the city as a whole. Because neither travel times nor dispatch times showed major shifts, overall response time performance cannot be said to have significantly improved, dropping by only about three or four percent (when normalized for city-wide performance). Apparent improvements are even less important, in percentage terms, when fixed elements of response time before dispatch time are included in the total response time. If one accepts that dispatchers may have been competing for response time reductions, however, normalizing the 15% reduction in District 3 by the 11% city-wide reduction may under-estimate the effects of FLAIR.

4. Dispatchers perceive an increase in workload with the FLAIR System. The System is estimated to create 5.6 minutes of work per hour--due to initializations and cursor positioning by dispatchers--that would not occur without FLAIR. Still, the

entire perceived increase may not be real, since some of the system contributes to decreased workload: for example, the digital codes. But because dispatchers are constantly aware of the location check that may be queued in the status column, they anticipate periods of inactivity less often then they would without FLAIR.

5. Trained and motivated dispatchers are essential to the successful use of the System. The AVM system, with effective and motivated dispatchers, can increase the logic and attention associated with the dispatching process. The ability to dispatch the closest car, with such a sophisticated technology, not only improves dispatch decisions directly, but it appears to increase the perceived level of professionalization of dispatchers. Also, the way the dispatchers use AVM as an aid to their activities is a major factor in the way officers in the field regard the AVM system, thereby affecting field performance through such activities as voluntary self-initializations.

6. The digital code system is an important improvement. From on-site observation we have seen that the digital codes help to lighten the dispatcher's workload and increase his control of the radio channel. In communicating mobile to base, the digital code system allows instant access (preemption) of the dispatches, where before a delay would have been incurred to obtain channel access. Such improvement in the way mobile

to base communications are established have important implications for officer safety and overall communication effectiveness.

7. Spare vehicles are essential. System performance and user attitudes are very adversely affected by the presence of non-FLAIR vehicles in the field. It is important to establish the appropriate number of spare FLAIR-equipped vehicles in order to achieve some acceptable level of system performance (e.g., a full complement of FLAIR-equipped vehicles at least 98.0% of the time). Determination of the required number of spares could be accomplished by the use of simple reliability theory, assuming accurate statistics are recorded allowing estimation of mean time until breakdown and mean time until repair.

CHAPTER VIII

THE AVM SIMULATION MODEL

A. Application. B. Comparison with Previous Simulation and Analytical Models. C. General Description. D. Capabilities and Features. E. Simulation Output. F. Sample Illustration.

Reader's Guide to Chapter VIII: This Chapter will give the reader a general description of the simulation model which was developed as a part of this evaluation project, and is therefore in the public domain and available to other users. Although the model was utilized to simulate the specific dispatching of patrol units in St. Louis (as described in Chapter VI), it was also designed to serve as a general model of emergency service systems. The Chapter provides a detailed description (which is as non-technical as possible) of the purposes and operations of the model. For the reader interested in greater explanation, Appendix C was written as a user's manual and includes complete documentation and examples of all simulation output. Since Chapter VIII is intended only to describe the model, it contains no "results" pertaining to the specific evaluation of the St. Louis AVM System.

CHAPTER VIII: THE AVM SIMULATION MODEL

A. Application

As we have indicated in previous chapters, one of the goals of this project was to develop an approach to the evaluation of AVM systems. One important part of this was the development of a simulation model of an urban emergency services system. While this model was especially tailored to the St. Louis Metropolitan Police Department and the FLAIR AVM system, it was also designed to be a general model of any such emergency service system.

As discussed in Chapter VI, this model was used to simulate the dispatching of patrol units in St. Louis both with and without the capabilities of a vehicle location system. Actual data were obtained from the MPD to provide accurate modelling of the dispatcher's strategy for selecting and assigning particular patrol units. Also obtained was the spatial distribution of calls for service, the service time distribution, and other related data. From the model we were able to predict travel times and compare the results of travel times without AVM information, workloads of individual units, and similar operational data.

In designing the model, every attempt was made to keep the programs perfectly general and easily transferable to other cities, departments and uses. The simulation is also well

suited to a variety of uses in planning and research within a department. For example, the model provides a means to study the allocation of the department's resources by applying changes in patrol force strength, dispatching procedures, patrol operations procedures, etc.; the model can measure in quantitative terms those parameters that are indicative of the quality of the overall patrol operation. The model allows comparative experiments with different allocation strategies providing a measure of the relative costs and benefits, to assist in making decisions on actual allocation policies and procedures. The simulation is also ideally suited for use in sector and district boundary design and for investigating the prioritizing of calls, different queue disciplines, and general changes in patrol assignment policies.

B. Comparison with Previous Simulation and Analytical Models

This simulation model is an outgrowth of earlier simulation and modelling performed by Richard Larson and James Williamson. The initial development of the model itself was performed by Richard Larson as his Ph.D. dissertaion at MIT.[1] At that time Larson developed the first working form of the simulation as programmed in the MAD language at MIT. This model served as a

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[1]R. C. Larson, Models for the Allocation of Urban Police Patrol Forces, Technical Report No. 44, Operations Research Center, MIT, 1969.

a research tool, but it was not user-oriented and lacked the general capability to be applied to an actual police department.

During 1970 and 1971 Larson and Williamson reprogrammed this model into the PL/I language in a special form tailored to the Boston Police Department. The first phase of this work (ending in August, 1971) developed a working model. The second phase, ending in September, 1972, transformed this model into a user-oriented, working form that provided inter-active communication with the user via a CRT terminal. However, at this stage the model still was tailored to the specific application of the Boston Police Department and lacked any capability to handle general geographic or department organizational structures. From 1973 through 1975 Larson developed an analytical model of an urban emergency service system. This model, which he termed the Hypercube, was implemented in the PL/I language, well documented, and placed in the public domain.[2]

The simulation model developed as part of this grant was intended to incorporate the power and flexibility of a true simulation model using many of Larson's early algorithms, coupled with the generalized formats, easy transferability, and ease of use of the more recent hypercube work. To this end, whenever possible the identical formats and operating procedures used with the

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[2]R. C. Larson, Computer Program for Calculating the Performance of Emergency Service Systems: User's Manual (Batch Processing) Program Version 75-001 (Batch), Technical Report No. TR-14-75, "Innovative Resource Planning in Urban Public Safety Systems," Operations Research Center, MIT, Cambridge, Massachusetts, 1975.

hypercube have been incorporated into the simulation model. In fact, a user could execute a run of the simulation by submitting a hypercube data deck with only one minor change. This change would involve one number of the first data card which indicates a simulation run rather than a hypercube run. This provision was added so that a user could actually combine the hypercube and simulation models into one package and then select which is to be executed by changing this one variable. In practice, the user would most likely want to add numerous other options which invoke many of the advanced capabilities of the simulation such as prioritizing of calls, self-initiated incidents, etc.

The output results of the simulation are also totally compatible with those of the hypercube. All hypercube formats are produced by the simulation (of course, using simulated results rather than calculated anlytical results as in the hypercube). In addition, several output summaries are generated to display simulation-specific data. These formats as well as changes in the input data deck are detailed in Appendix C.

The compatibility between the hypercube and the simulation extends from philosophy to input data formats and through the user's documentation. In fact, the Simulation User's Manual (see Appendix C) assumes that the user is familiar with and has access to the Hypercube User's Manual (previously footnoted).

C. General Description

Although to understand and use the simulation model does not

require detailed knowledge of its internal operations, insights into its basic operation might prove helpful. The basic elements in this or any simulation are various mathematical techniques concerned with probabilistic behavior. Although probability theory can become quite complicated, the basic principle is that most types of physical actions or occurrences can be described mathematically in terms that describe the relative likelihood of observing a specific outcome. These mathematical descriptions are then combined into a complete programming system. When this simulation is run, it will step through the entire process of assigning cars to preventive patrol, assigning cars to a call, placing and retrieving calls from a queue, traveling to a call, servicing the call, etc. in a manner similar to real life but at a much faster rate. While this is going on, the program automatically keeps track of many different factors and variables, the statistics of which serve as a means of evaluating the simulation run. These statistics are measures of the simulation's values of service times, number of incidents, delay times, etc. that one would measure if observing the patrol system in the real world. Of course before a simulation can be trusted it must be verified that it actually does accurately model the patrol force. Only through years of study and development at MIT has this simulation model been perfected to the point where it can be a useful tool for the study of patrol operations.

The simulation model works in the following way. "Incidents" are generated throughout the city, randomly in time and place.

Each incident has an associated priority number, the lower number designating the more important incidents. As each incident becomes known, an attempt is made to assign or dispatch a police unit to the scene of the incident. In certain cases this assignment cannot be performed because the congestion level of the force is too high; then, the incident joins a queue of incidents awaiting dispatch. The queue is depleted as cars become available.

Important measures of operational effectiveness are tabulated by the model. These include travel times, queue length, time spent in queue, workoads of individual units, fraction of dispatches which were intersector, fraction of dispatches which were non-optimum (that is, dispatched to a car not closest among the available cars), service times, etc.

1. Event-paced model. The simulation is an event-paced model. That is, once a certain set of operations associated with one event is completed, the program determines the next event which occurs, and updates a simulation clock by adding to the present time, the time until the next event. The program then proceeds with the set of operations associated with that event. Once the clock reaches the maximum time (specified by the user) the simulation is terminated and summary statistics are tabulated and printed. One complete "run" of the simulation entails inputting data, executing the program for an equivalent time, T_{max}, and printing summary statistics.

There are two major classes of events: report of an incident and a patrol unit completing service of an incident. When the report of an incident occurs, a dispatch algorithm is executed. This algorithm is quite flexible and allows the dispatcher to follow a wide variety of different policies which can include the use of a perfect resolution vehicle location system. Given a particular dispatch policy, the dispatcher must determine which patrol units are eligible and available to dispatch to the scene, and from this list, select the best one. Two considerations are important in determining eligibility: the priority levels of the activity on which the unit is currently engaged and of the reported incident, and the estimated travel time between the unit and the incident. In addition, the user of the simulation can assign an equivalent priority level to preventive patrol for each patrol unit. This flexibility allows the user to guarantee a certain level of preventive patrol coverage.

Upon completing service of an incident, the patrol unit may return to preventive patrol or be immediately reassigned from its current position to the scene of a waiting unserviced incident. Or it may be reassigned immediately after resuming preventive patrol in its own sector. This flexibility allows the user to model either the case where a unit routinely calls in to see if another call is waiting upon completion of one call, or the case where a unit routinely returns to its home sector before notifying the dispatcher.

D. Capabilities and Features

As mentioned previously, the simulation model uses much the same input data as does the hypercube model. For this reason, the simulation model has all of the capability of the hypercube to handle general geographical and organizational structure of a department. The simulation also uses the same method of developing a matrix of "dispatch preferences" which details a priority order of assigning available units to a call. The user has a great deal of leeway in allowing the simulation to make assumptions about this order to make minor or major changes in the assumed order. The actual methods of using the generalized geography as well as the dispatch preference matrix are well documented in the Hypercube User's Manual.

In addition to the above mentioned features which are common to the hypercube, the simulation contains a number of advanced features which are not part of the basic hypercube data base. These include prioritizing of calls, enhanced dispatcher strategies, additional queue disciplines, the ability to model different types of units, preemption assignments, and the modelling of self-initiated incidents. Each of these will be described briefly.

1. Prioritizing of calls. The simulation contains the ability to model any number of priorities of calls. Although there is no theoretical maximum to the number of types of calls, normally a user would use only the number for which there is a

discernable difference of action on the part of the department (normally three to five). For the use of this model in the evaluation of the Boeing FLAIR system, four priorities were used. The first (highest) corresponded to very high priority calls such as "in progress" calls, the second corresponded to "normal" calls which required a response by the Department, the third corresponded to "assigned assist" calls such as back-up cars for disturbances. The fourth priority was reserved for those calls which were "self initiated" (see 6.4.4). The user has complete control over specifying the response of the department to each priority of call. He may assume that such items as queue method, speed of response, service time, etc. are equal for all prorities, or he may specify each individual value of each parameter.

2. Enhanced dispatcher strategies. In addition to the dispatcher strategies which are modelled by the hypercube (strict center-of-mass, modified center-of-mass, expected strict center-of-mass, and expected modified center-of-mass), the simulation provides several other features which allow very accurate modelling of other dispatcher strategies. These include the abilitity to model the use of a perfect resolution vehicle location system. This feature was used in the evaluation of the Boeing FLAIR system.

An additional feature of the dispatching algorithm of the simulation is its method of performing two reassignment

interrogations. A reassignment interrogation refers to the process of attempting to reassign a unit completing service on a previous call to a new call waiting in queue. The first interrogation assumes that the unit is still at the location of the previous incident. This models the policy of calling in "clear" from the scene. The second interrogation assumes that the unit has returned to preventive patrol in its home sector before calling in. The user has control over these two interrogations and can specify that either one method or the other be used exclusively, or by using a special "distance matrix," can specify a combination of the two methods for each priority of call.

Another enhanced dispatcher strategy allows the user to specify a maximum estimated travel time for each priority of call. This can be used in a number of ways, including serving as a ceiling to prevent a unit from travelling across town to service a minor incident, to preventing very low priority calls from being serviced by anything other than a unit which happens to be in the immediate area. This option can be used very effectively with other options which can restrict the service of a call to only the "sector car" or even to only a unit which happens to be in the same specific geographical "atom"[3] as the incident.

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[3]An atom is a subarea within a sector (beat), typically no more than a few city blocks in size. It is the smallest geographical unit for aggregating statistics.

3. Queue disciplines. The only two queue disciplines modelled by the hypercube are first-come, first-served and what is essentially a no-queue option (which could mean either discarding of calls or referring them to a neighboring jurisdiction). The simulation allows both of these (specified by priority, if desired) as well as others. An additional discipline is closest-car, closest-call. This discipline specifies that a unit will be assigned to a call which is closest (i.e., minimum estimated travel time) of all calls in queue of that priority. An additional powerful tool is the inclusion of a weighting factor in the queue discipline. This weighting factor allows the user to model many different queue disciplines which are a combination of the first-come first-served, closest-car closest-call, and no queue options. In addition the user has the ability to specify each of these by priority of call. Thus, the user could design a discipline so that calls of highest prority are immediately dispatched to the first available unit, medium priority calls are dispatched to a unit when a unit is reassigned which is "reasonably" close, and lowest priority calls are discarded and not queued. The specification of the queue discipline (as well as all options in the simulation) is structured such that the user may use the basic simulation by specifying no option (allowing the simulation to use 'default assumptions'), or a very detailed discipline combining several options and the weighting factors, or any combination in

between. In all cases, a detailed knowledge of all possible features and their combinations is not necessary for effective use of the simulation.

4. Self-initiated incidents. The simulation model has an option which allows a user to model the servicing of self-initiated incidents. These are incidents which are discovered by a patrolling unit. They are characterized by being located at the home sector of a unit and will require no travel time to reach the incident. Self-initiated incidents are generated totally separate from 'normal' incidents with a call rate specified separately, and a separate dedicated priority. This feature is used in conjunction with other options specifying a no-queue and same atom restriction for that priority of call.

5. Different types of units. The use of a combination of various options allows the user to effectively model many different types of patrol units. The user can specify that a particular unit may service calls only at a certain level of priority. The combination of this option with the ability to assign a unit to any arbitrary geographical area allows the user to model units such as ambulance/wagons, district-wide units, patrol sergeants, etc.

6. Preemption assignments. The simulation has an option which allows the modelling of preemption assignments. This refers to assigning a high-priority call to a unit already

servicing a relatively low-priority call. Of course this assumes a situation where the unit servicing a call is in radio contact with the dispatcher. The lower priority call which was preempted is placed in a queue and will await an available unit to complete servicing of the call.

E. Simulation Output

The output of the simulation consists of three portions: output of the control parameters before the start of the simulation; output generated during the execution of the simulation; and output calculated and printed after the conclusion of the simulation. This output is summarized below.

1. Output of control parameters and calculated travel times.

a. Title and summary information. The user should find this section to be self-explanatory.

b. Inter-atom travel times. This output consists of a table of values which gives the calculated travel times from each geographical atom to each other atom. This is a large, detailed table which obviously will not change unless either the geography or response speed is changed. For these reasons the user will most likely select that this matrix be printed only when such a change is made, and then retain this page of output for use in analyzing subsequent runs.

c. Unit-to-atom travel times. This matrix gives the calculated travel times for each unit to reach each atom.

d. Cost of dispatching matrix, unit to atom. This matrix gives the unit-to-atom travel time matrix, as estimated by the dispatcher (or dispatching algorithm) and as otherwise modified by the particular dispatching strategies in force for that run. Thus, the minimum cost for a particular atom would indicate the unit which would be given first preference for dispatching to that call.

e. Spatial allocation when available. This table essentially indicates the preventive patrol areas for each unit. Because the user has complete freedom to specify the patrolling structure, it is very possible for an individual atom (corresponding to a small geographical area such as a reporting area) to be included in the sector for a particular unit without actually receiving any preventive patrol coverage. The structure of atoms assigned to each unit as well as the fraction of time spent patrolling that atom are indicated in this table.

f. Call-for-service distribution by atom. This output merely displays to the user the distribution of calls for service as specified in the input data.

g. Street miles per atom. This output also displays to the user information specified on input cards.

g. Summary of simulation control parameters. This table displays a list of ten key simulation control parameters and their values. These parameters are those which are unique

to the simulation (i.e., not common with the hypercube) and specify such things as total simulation time, T_{max}, maximum travel time restrictions, call preemption policy, and various parameters which are specified as a function of priority.

2. Output generated during execution.

a. Status dump. When this option is selected by the user, a table showing the status of each response unit and its location is printed each T hours. The value of T is specified by the user, and may assume any value from 0 (indicating no status dump) to the equivalent maximum simulation time. When this option is in effect, a table is printed at time zero indicating the initial preventive patrol position of each unit. In addition, a final status dump is given at the end of the simulation even if the total simulation time is not a multiple of T.

b. Trace. When this option is selected, a complete record of each event of the simulation is printed.

3. Output calculated and printed after conclusion of the simulation. The reader should find the following summary of calculated output to be self-explanatory except possibly for the terms: "non-optimum dispatch" and "no-queue option." A non-optimum dispatch is focused strictly on a travel time criterion and is defined to be a call which was dispatched to a response unit which was not closest to the incident in question (i.e., not

CONTINUED

4 OF 10

lowest travel time). Such a dispatch occurs because the travel time as estimated by the dispatcher is not the actual travel time (for all dispatching policies except one utilizing a perfect resolution vehicle location system). The simulation automatically calculates the number of such dispatches as well as the extra travel time due to the non-optimum dispatch. It should be pointed out that the user of the model who dictates overrides of the travel time dispatch criterion (using the "FRONT" card or the "BACK" card or even the "MIDDLE" card -- see hypercube users manual) may not consider all of the non-closest car dispatches to be in error. Then he should read "non-optimum" as "non-closest available car."

The no-queue option refers to the queue discipline which dictates that a call for service which cannot be serviced because all units were busy should not be placed in queue but rather should be discarded. This procedure might correspond to either actually not servicing the call or the situation where the call is referred to another jurisdiction for servicing. This option is selectable by priority so it is often used in conjunction with the simulation of self-initiated incidents. In this case, if an incident is generated and no unit is in the same geographical atom as the incident, that call should not be queued but rather should be discarded.

A summary of output calculated and printed after conclusion of the simulation follows:

a. Output summary

- Percentage of dispatches which were non-optimum
- Mean extra travel time due to non-optimum dispatches
- Mean number of calls in queue when call arrives by priority
- Mean length of time in queue by priority
- Percentage of calls preempted by priority
- Mean travel time to all calls by priority

b. Performance measure specific to each patrol unit

- Unit name and number
- Fraction and percent of mean for workload
- Fraction and percent of mean for out of district dispatches
- Average travel time

c. Performance measures that are specific to each district

- District name and number
- Fraction and percent of mean for workload
- Fraction and percent of mean for inter-district dispatches
- Mean travel times into district

d. Performance measures that are specific to each geographic atom

- Atom number
- Workload
- Travel time into each atom
- Fraction of calls each unit to each atom

e. <u>Workload of each unit by priority</u>

f. <u>Simulation-specific output</u>

- Non-optimum dispatches
- Number of calls not serviced due to no-queue option
- Mean number of calls in queue when call arrives
- Mean length of time in queue
- Percentage of calls preempted
- Mean travel time to all calls by priority

F. Sample Illustration

Although a complete description and samples of the simulation output are given in Appendix C (Simulation User's Manual), a brief hypothetical run of the simulation will be described here in an attempt to illustrate how the simulation might be interpreted based on trace and status dump output.

Let us assume, for the purposes of this example, that we have a small system comprised of three response units and seven geographical atoms. This is the precise geography used as an illustrative example in the Hypercube User's Manual.

At the start of the simulation the input data deck would be "read" by the simulation and the first eight items of output (as described above) would be printed (if the user had so specified). After this beginning printout the actual simulation would begin. If the user has specified that a simulation trace be printed,

and that a status dump be printed every 30 minutes, the output might appears as follows:

Initial Preventive Patrol Assignments

Unit	Atom	Status
1	3	Prev. Pat.
2	7	Prev. Pat.
3	5	Prev. Pat.

This first status dump indicates the initial preventive patrol positions. Each unit is randomly placed in a location within its preventive patrol area (normally considered that unit's sector). This placing is done in proportion to the amount of coverage that unit provides for that atom as specified in the input data deck. Although the unit in real life would be constantly patrolling throughout its sector, the simulation assumes that the unit remains in this initial location until assigned to an incident. (A little analysis should convince the reader that this is not a limitation of the model.) As soon as a call for services arrives, the following trace item would be generated:

```
TIME:  17.248
CALL - ATOM NO. 6 PRIORITY = 2
ASSIGN UNIT NO. = 2
TRAVEL TIME = 3.409
TIME AT SCENE = 37.213
TOTAL SERVICE TIME  = 40.622
```

This block of output indicates that a call of priority 2 located in atom 6 arrived in an elapsed time of 17.248 minutes. The elapsed time (17.248) was selected by sampling a negative

exponential distribution function with mean a function of the user-specified call-for-service rate. Because in this example the dispatcher is using a strict center-of-mass dispatching discipline, he selects unit 2 (the sector car for that atom). The travel time indicated (3.409) is not that used by the dispatcher to estimate the travel time to the incident, but rather is the actual calculated travel time based on the known position of the unit. As explained in the Hypercube User's Manual, this distance, from atom 7 (location of unit 2) to atom 6 (location of incident) is 30.0 100-ft units, or 3,000 feet. The actual travel time is equal to the travel distance divided by the effective travel speed, which in this case equals

$$\frac{3{,}000 \text{ ft.}}{5{,}280 \text{ ft./mi.}} \div 10 \text{ mph} = .0568 \text{ hr.} = 3.409 \text{ min.}$$

The time at scene is calculated by sampling an exponential distribution with mean specified by the user. The total service time is the sum of the travel time and on scene time. If no additional activity took place within the first 30 minutes, the first status dump would appear as follows:

STATUS DUMP - TIME = 30.000

Unit	Atom	Status
1	3	PREV. PAT.
2	6	CALL - PRIOR 2
3	5	PREV. PAT.

QUEUE OF WAITING CALLS:

** NO WAITING CALLS **

The next item on the trace would be another call for service:

```
TIME:  48.812
CALL - ATOM NO. 4  PRIORITY = 1
ASSIGN UNIT NO. 3
TRAVEL TIME = 1.136
TIME AT SCENE = 51.627
TOTAL SERVICE TIME = 52.763
```

This output indicates that a call of priority 1 (the highest priority) arrived at an elapsed time of 48.812 minutes. Again using the strict center-of-mass dispatching strategy the dispatcher would determine that unit 2 was the first preferred unit. However, unit 2 was busy on the previous call so that the dispatcher would assign this incident to the second preferred unit, which is unit 3. The true known position of unit 3 (on preventive patrol is atom 5 as indicated by the last status dump) would yield a calculated travel time of 1.136 minutes. This combined with the relatively long on the scene service time (which might reflect a high mean value for high priority incidents) would yield a total service time of 52.763 minutes.

The next item on the trace would be the completion of service by unit 2 of the first incident. This would appear as follows:

```
TIME:  57.870
ASSIGN TO PREVENTIVE PATROL
UNIT = 2  ATOM NO. = 4
```

This indicates that unit 2 completed service on the first car at an elapsed time of 57.870 minutes. (17.248 {time of original assignment} + 40.622 {total service time of first incident}). Had there been a queue of waiting calls at this point the

reassignment algorithm would have been executed to see if a reassignment to a waiting call should be made.

Assuming no other incident appears in the next 2.25 minutes, the next status dump would appear as:

STATUS DUMP - TIME = 60.000

Unit	Atom	Status
1	3	PREV. PAT.
2	4	PREV. PAT.
3	4	CALL - PRIOR 1

QUEUE OF WAITING CALLS:
** NO WAITING CALLS **

If the user has specified a total simulation time of 60 minutes, the actual simulation would end at this time and the simulation output would be printed. Here again, the quantity and type of output is user specified.

Although the sample just given is a trivial one, it does indicate just one of the many types of simulation output. Complete documentation and examples of all simulation output is given in Appendix C (Simulation User's Manual).

EVALUATION OF AN IMPLEMENTED AVM SYSTEM: PHASE I

prepared for the

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(Chapters IX-XII and Appendices A-D)

SCOPE

CHAPTER IX: TECHNOLOGICAL EVALUATION

A. Introduction. B. System Operation and Description: *Location Technique; Information Transfer; Operational Problems; Tracking Process; Initialization; Self-Initializing.* C. System Test: *Visual Inspection; Accuracy Tests; Digital Communication.* D. FLAIR Computer Hardware and Software: *General Description; Computer Hardware; Computer Software; Computer Maintenance; Overall System Accuracy; Computer-Generated Reports; Computer Maps; Expansion Capability.* E. Repair Characteristics of the FLAIR System: *Headquarters/Base Station; Mobile Equipment; Repair Crew Workloads; Spare Car Requirements; Expectations for Phase II.*

Reader's Guide to Chapter IX: This chapter provides a technological evaluation of the AVM system and therefore includes an overall description of the performance and operation of FLAIR. A major emphasis is on accuracy and the cause of error. Also included is a description of the FLAIR System and the tracking process, a review of the contribution of digital communications in system effectiveness, and an outline of improvements expected in Phase II. System reliability is reviewed both for base station equipment (mostly computer-related) and mobile equipment. By necessity, much of the material in this chapter is technical and to obtain a full understanding, some technical background would be desirable.

CHAPTER IX: TECHNOLOGICAL EVALUATION

A. Introduction

The Boeing FLAIR*AVM System is considered a major development in a new technological field. Its purpose is to provide to the law enforcement community a tool to make police dispatching and command and control operations more effective. The system locates, identifies and shows the status of each car in a fleet on a color TV-type screen. It also provides:

- Display maps having three different scales, the most magnified (16x) being about one square mile on which most street names are identified.
- Identification of each vehicle by number, class of service (the car symbol is square for patrol cars, triangle for detective cars, bow-tie for sergeants' cars, etc.) and one versus two-man cars (two dots associated with the car symbol indicate a two-man car).
- Priority status of each vehicle. A vehicle available for assignment will show its symbol with steady brightness, a car with a low-priority assignment will blink at a slow rate, and one with a high-priority assignment will blink at a faster rate.
- Updates of location and status information at one-second intervals.
- Car location displayed on streets and other drivable surfaces (this is accomplished by the computer which "holds" each car on a street through a map-matching process).
- Instant location of any car in the fleet, by keying in the car numbers and locate button on the display console. The car will be displayed with a bold square surrounding its symbol, and the car will be continuously tracked as long as required. As the car approaches the edge of the displayed map, a new map will be automatically selected.
- Automatic selection of the four closest cars to an incident site, displayed in the order of their

*FLAIR is a trademark of the Boeing Company.

proximity. The incident site must first be located by having the dispatcher move a cursor (a white cross on the display screen) using the cursor control, to the site (or this operation could be automatic if the AVM system is operated in conjunction with a CAD [Computer-Aided Dispatching] system having a geographical file).

- Instant identification and location of a car that has activated the EMERGENCY alarm. An audible alarm is sounded at the display console, and the symbol representing the car that activated the alarm blinks at a rapid rate.

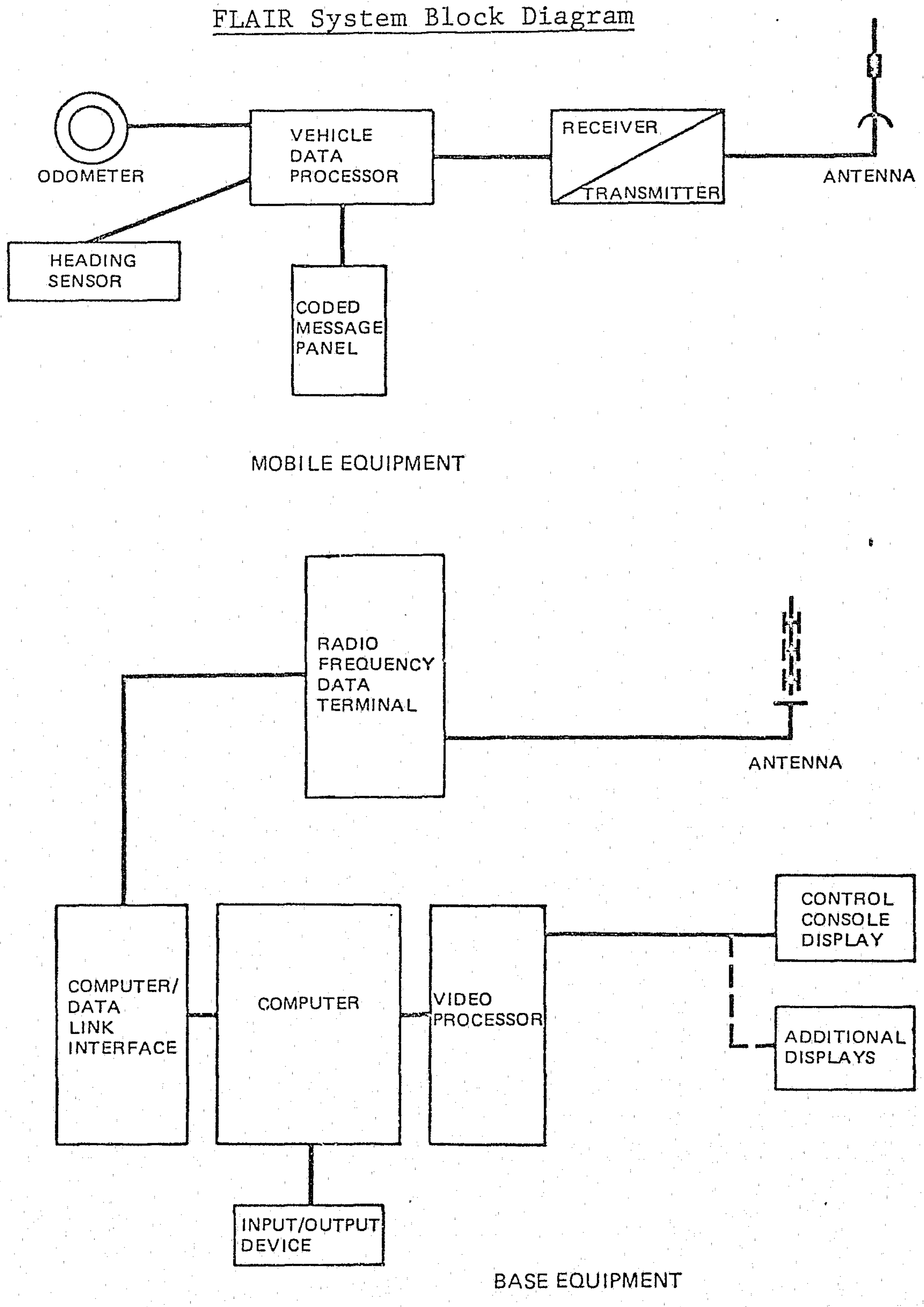
The above represents real-time information, much of which has not heretofore been available to the dispatch or command and control functions. It would be expected that such a system could provide many benefits, if the people using it were properly trained, if its operation was reasonably simple, and if its performance and reliability were such as to create confidence from the users. It is the purpose of this chapter to review system operation during the trial (Phase I) period, particularly with regard to performance and reliability. Section B describes the operation of the system in detail and Section C outlines the results of a number of system tests which were conducted. Section D discusses the computer hardware and software for the FLAIR System and Section E reports on the repair characteristics of the System.

B. System Operation and Description

1. Location technique. The location technique for the FLAIR AVM System is based on the dead-reckoning principle where--if the starting position is known--frequent data from the vehicle of distance (odometer) and direction (heading sensor) readings

Figure 9-1

FLAIR System Block Diagram



Source: "Fleet Location and Information Reporting: The FLAIR System," Document D246-2004-2, The Boeing Company, August, 1975.

will make possible the continuous updating of the vehicle position. Two additional features are provided that tend to reduce the effect of accumulated errors considered common to normal dead-reckoning systems, and the incidence of lost cars (see Chapter V).

- As a vehicle travels along a street its course is kept precisely on the street by the computer through a process called map-matching, and
- When a vehicle turns a corner, the computer will locate the car at that (nearest) corner even though its indicated position may not be precisely at the corner.

With these two features, FLAIR is more appropriately described as a computer-tracked dead-reckoning system or a hybrid system.

In addition to providing vehicle location information, the system also provides for vehicle identification and status. By using an assigned time slot in the one-second update period, each vehicle is identified by the computer software; incorporated in a time-division multiplex system, each time slot has a number which is readily translated to the patrol car number by the computer, which is displayed next to the car symbol on the display screen. Vehicle status information is also transferred to Headquarters via the same radio time-slot and permits up to 99 messages, selected by keying into the numerical 10-digit coded message panel.

As seen in the system block diagram, Figure 9-1, the <u>mobile unit</u> contains an odometer, providing distance information; a

magnetic heading sensor, providing heading direction; a coded message panel, generating status information; a vehicle data processor that serves to interface data from these three sources to the radio transmittor; and the radio transmittor-receiver.

2. Information transfer. The time-slot time division multiplex system[1] is used as the method of transferring digital information from each mobile unit to the headquarters base station. Each mobile unit is assigned a time-slot number, from 1 to 200.[2] With the help of synchronization signals from base to mobile, transmitted once each second, and crystal controlled timing circuits in the vehicle data processing unit, each vehicle in turn transmits its time slot data.

The phase I digital format is shown in Figure 9-2. At the beginning of each update period, the base transmitter transmits a synchronizing signal consisting of five cycles of a 1000 Hz signal. The mobile receiver identifies the signal by its frequency and by counting the cycles, and unless such a signal is identified, the mobile transmitter will not transmit data during the "next" time-slot (to avoid non-synchronous interference). Guard bands are provided before and after the synchronizing signal. This allows time for the base station receiver to recover

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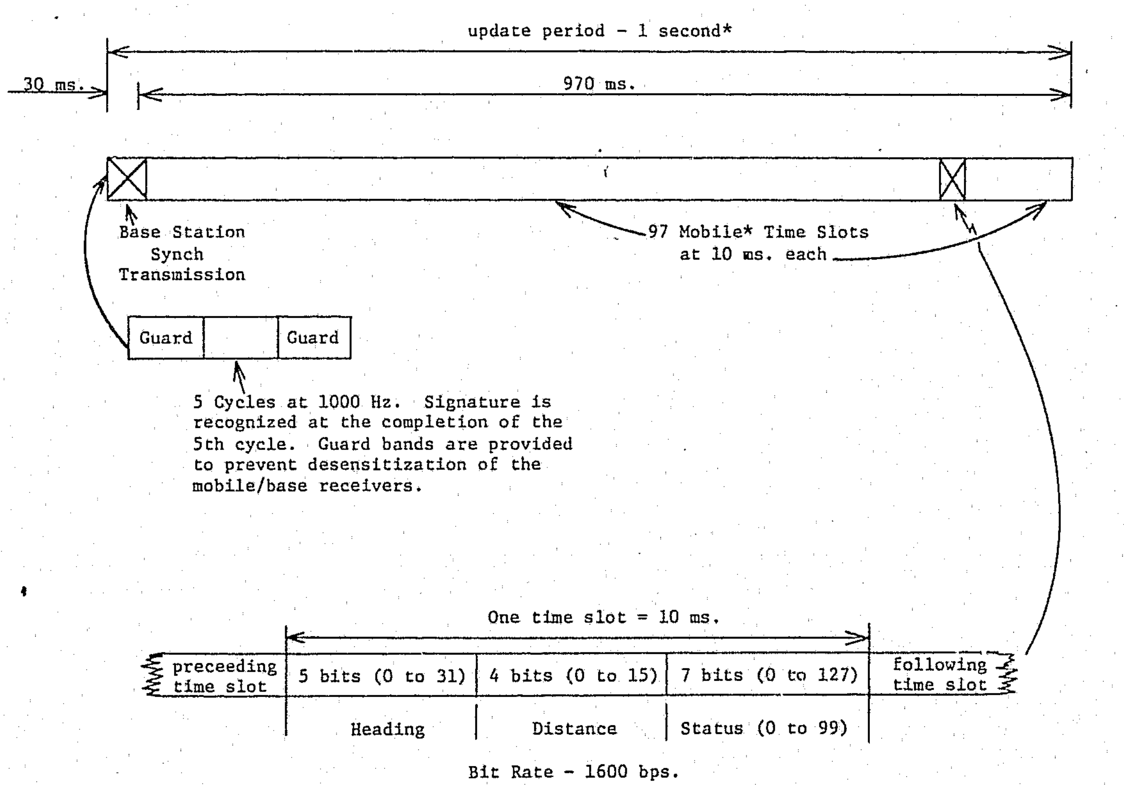
[1]See Chapter II for other methods.

[2]200 is the FCC required capacity. Phase I capacity was reduced to 97 for improved accuracy. See paragraph 3a.

Figure 9-2

Information Transfer
Modulation Format
Phase I FLAIR



* The original Phase I FLAIk System had 2-second update period and about 195 time slots. Change to 1-second update and 97 time slots was made to improve accuracy and the incidence of lost cars. FCC requires a minimum of 200 cars, which FLAIR will have in Phase II.

full sensitivity before receiving time slot #1 data; and the "before" guard band allows time for the receiver in time slot #97 to fully recover before receiving the base station synchronizing signal.

Each time-slot contains five bits for heading information, four bits for distance and seven bits for status for a total of 16 bits. At a bit rate of 1600BPS, the slot time is 10 ms. The heading information, with five bits, can be resolved to one part in 32. For the 360° azimuth, the resolution then is 1/32 X 360 = 11.25° or ± 5.62°).

The distance, with four bits, can measure up to 16 units, the unit of measure in Phase I is 25 feet; therefore, the total distance measured before recycle is 16 X 25 = 400 feet. In other words, if a car were travelling at 60 MPH, successive distance measurements (in feet) with 1 second update period would be 88, 176, 264, 352, 40 (440-400), 128, etc. The need for a 400-foot distance base is to avoid ambiguity in cases of a missed signal; if four successive signals were missed (a very rare event) and if the car were travelling at 68 MPH (also rare) the distance measurement would be 400 feet, or, to the computer, the car would be standing still.

The status, with seven bits, is capable of 128 status codes but for the convenience of a two-digit read-out, is used only to 99.

3. Operational problems. A number of problems were encountered in the use of the above system during Phase I as follows:

a. Phase I update rate. The Phase I update rate was originally set at two-second intervals but because of accuracy problems and an excessive rate of lost cars during tests early in Phase I, the update period was reduced to one second. This reduced the number of time slots to 97. Phase II will meet the FCC 200 car-requirement by increasing the bit rate to 4800 BPS.[3]

b. Heading resolution. The heading resolution of 11.25^0 was found too coarse to identify streets that branched off at small angles (such as some expressway exits); likewise, distance resolution of 25 feet was found too coarse, which, together with poor heading resolutions, contributed to inaccuracies and excessive lost cars.[4] Phase II will increase the heading resolutions from 11.25^0 to 2.8^0 (from five to seven bits) and the distance resolution from 25 feet to six feet (from four to six bits).

---

[3]To meet the 200-car FCC requirement, to retain the update rate at approximately one second, and to correct other deficiencies that were identified in Phase I, the Phase II digital format for location and status data and other requirements will be completely changed. The new information transfer system is expected to have innovations, some being near the state-of-the-art. For example, the high bit rate of 4800 bps will be transmitted over a UHF channel where FCC requires, for voice transmission, high attenuation of modulation frequencies above 3000 Hz in the transmitter voice amplifier to control side band splatter in the r-f output. It is assumed, the same standards of side band splatter will be required for digital modulation. The higher bit rate could also adversely affect the signal-to-noise performance. In other regards, the new Phase II format appears well-designed for correcting problems encountered in Phase I.

[4]See Chapter V for more in-depth analysis.

c. <u>Time slots</u>. The time slots are stacked end-to-end without guard bands between, causing potential loss of accuracy due to adjacent time slot interaction. Interactions can be caused by slight variations in timing due to noise in synchronizing signal; variations in crystal timing circuits (a crystal accuracy of .05% can cause an error 0.5 ms in a one-second period); phasing tolerance in adjusting the mobile slot to the base station slot, and error due to signal travel time--where, for example, a car 20 miles from the base station will respond about 1/3 of a bit length late compared to a car near the base station (a bit is .625 ms long). During Phase I, the 25 cars were distributed in every other time slot most of the time. For Phase II, a new digital type synchronous signal at a higher bit rate will provide more precise timing, better methods are being developed for phasing the mobile slot to the base station, and guard bands are being provided between each time slot.

4. <u>Tracking process</u>. To understand the vehicle location process and some of its related problems, some detail as to how the system operates, is necessary. For normal conditions, where the car is travelling via a street that is in the computer memory and the car has been properly located on the computer map (initialized), then, as the car travels, its location will be updated each update period (one second) by the transmission of its heading and incremental distance. Its location may be represented by a series of vectors, each having a direction of the heading sensor and a length equal to the distance travelled in each one-second

period. Vector direction comes from the magnetic compass heading sensor, and since this is not a precise device (generating a noisy signal) and is influenced by magnetic anomalies, minor deviations in direction can be expected. Such variations are corrected by the computer that, in a map matching process, keeps the car on the known street. The distance measure (vector length) may not be representative of actual distance travelled, because of the course resolution, measuring distance in increments of 25 feet. If the car is tracked at 10 mph (not uncommon) it travels less that 15 feet in one second, so it may show incremental distance as zero; this does not represent an error as a unit of measure (25 feet) will be shown as soon as that distance has been accumulated. Continuing travel at 15 feet per second, at the end of 10 seconds the car will have travelled 150 feet during 10 update periods, where four of the update periods show zero distance and six one-unit each. Thus the vector path of the vehicle will be uneven by these considerations.

Errors can be caused by missed signals and/or signals with bad data. A missed signal is one where the signal strength is so weak that there are no recoverable data. This can be the result of insufficient synchronizing signal to the car receiver, which automatically prevents transmission of the mobile data (to avoid non-synchronous interference) or the transmitted signal from the car cannot be received at the base station.

Missed signals are weak signals and are caused by poor transmission path, such as when a car travels where a hill is between it and the base station antenna. Other causes can be tunnels, underpasses, heavy foliage on trees, etc. In general, for a transmission path to be good, line-of-sight conditions are

required; i.e., the mobile antenna must be "seen" by the base station antenna (at UHF frequencies including the 900 Mhz band). To cover a reasonable area, such as the city of St. Louis, it is necessary to mount the base station antenna on a tower, its height determined by the distance to be covered and the extent of hills and other obstructions within the covered area. An alternative to an excessively high base station antenna may be satellite receivers and even satellite transmitters. In most localities, it would be normal to expect some conditions that would cause weak signals.

Bad data occurs when the received data of heading, distance or status is incorrect. The cause of bad data can simply be noise in the received signal or the transmission of incorrect information. In digital transmissions a common method to detect bad data would be by the use of parity bits; this method, however, requires additional "bit space" in the transmission format and would require trade offs such as transmitting fewer bits of other information, fewer vehicles per channel, slower update data, etc. The FLAIR System employs a computer logic test of received data as a check on its validity. For example, if a car had been traveling a uniform distance of one to two units per update period, and suddenly seven units appeared, then the computer would reject the entire time-slot data--because it would be impossible to accelerate that fast. Likewise, if a car suddenly showed data representing an impossible change in heading, or a status number above 99, the data would be rejected. However, such computer logic checks are not fool-proof. If, for example, the distance in the above example incorrectly read four, it would have been accepted,

and caused an error.

To illustrate errors that can result from poor signals or bad data, suppose the tracked car made a turn into a cross street at the same time two consecutive missed signals (or bad data) occurred. If the car had been traveling at one to two units per second, by the time the computer got the next signal it would show distance of four to five units (100 - 125 feet) presumably along the original street and with heading indicating a turn to a cross street. This could put the car at an alley, where the computer could select the wrong street. A single missed or rejected bad data signal will probably not cause an error that will not be corrected, but two or more consecutive missed signals will increase the probability of error and lost cars.

If a car travels down a street in the closed-loop mode and then makes a turn, the computer will put the car in an open-loop mode until it can identify the street turned into, at which time it will be placed back into closed-loop mode. If on the other hand, the car turns into a shopping center, parking lot, etc., the car remains in the open-loop mode until the computer can identify it again on a street. While in the parking lot, shopping center, etc., the car operates solely on dead-reckoning, without computer assist, depending on correct position by incremental distance and heading data for each update period. It is likely that the car will make more turns per distance travelled in such an environment than with normal driving on a street. The probabilities of distance errors due to the course resolution (25 feet per unit) and of direction errors due to course angular

resolution are much greater than when driving on a street.

In Phase II the greater resolution for heading (2.8^0 compared to 11.25^0) and distance (6 feet compared to 25 feet) are expected to greatly improve accuracy and lost car performance.

5. Initialization. When a car can no longer be tracked by the computer, because, for example, it was placed on an incorrect street due to errors--the computer will list the car number followed by a *V* in the status column on the display console. This action tells the dispatcher that the car location must be verified. This means the dispatcher must contact the car by voice radio (FLAIR does not provide digital communication base to mobile) and instruct the driver to stop at the next convenient intersection and identify it. After the intersection is identified, the dispatcher places a cursor (a white cross on the display screen) at that location. If the car symbol is also at the correct location, the dispatcher enters the car number into the display keyboard and presses the "clear" button which removes the car number from the status column; if the car is not at the correct location, the dispatcher presses the "initialization" button which causes the car symbol to be moved to the cursor location, and removes it from the status column.

Before the computer displays the car number with a *V* in the status column, it will attempt to match the car's current route with streets having a similar pattern in the computer map. This is sometimes successful. Also, if a car goes into a shopping center, parking lot, etc., that the computer recognizes, and when

the car travels 1800 feet in such an open loop environment, a *V* will appear indicating the likelihood of excessive accumulated errors.

Another type of location uncertainty is identified by a *W* following the car number in the display status column. A *W* is displayed when a car turns off of a street into an area not recognized by the computer (such as an industrial complex) and travels a total of 600 feet--indicating a probability of excessive error. Also a *W* will be displayed when a car is in an area known to have a magnetic anomaly (two such areas exist in District 3, St. Louis). When a car leaves such an area, it must be initialized. Also during Phase I a *W* was caused by a car leaving the patrolled area (District 3 in St. Louis); when the Phase II System is implemented throughout the entire city a *W* will appear when cars leave the city (one block beyond the city).

It is important that the dispatchers clear a displayed *W* or *V* through a verification initialization procedure on a timely basis, in order to keep the confidence level of correct positioning high. It is likely that such verification/initialization may be delayed somewhat during the dispatcher's peak load period; also such procedures cannot be undertaken with cars that are on call or servicing an incident. The objective, however, is to keep the status column clear.

6. Self-initialization. To improve system performance and to decrease the dispatcher load for verifying "lost" cars, a self-initialization procedure is provided. The location immediately in front of the district 3 station is a self-initialization point, where, if the officers enter the appropriate code into the coded message panel (22 for district 3) and press the transmit button, the computer will automatically locate the car at that location without dispatcher assistance. This is a voluntary procedure, and the police officers must be encouraged to do this each time they visit the district station. During Phase II, it is planned to locate such self-initialization points at each district station (9 total) and perhpas at some other appropriate sites.

7. Other options. Additional options, to further improve system performance, will be made available, perhaps during the Phase II implementation. One is automatic initialization which may be activated by a signpost having a radio transmitter continuously transmitting its identification. When a patrol car enters the field of such a signpost, its radio will receive the signal and automatically transmit this data at the next update cycle, causing the computer to locate the car at that site. Another option is a second odometer mounted on the right front wheel which is expected to reduce or eliminate the effect of magnetic anomalies. If, for example, a car passes a d-c feeder to a subway system, the magnetic heading sensor will be affected--indicating that the car has turned; the second odometer output will be matched

with the one on the left fron wheel, and if the speed of both match, the car has not turned, causing the effect o. ᵗhe magnetic anomaly to be ignored.[5]

C. System Tests

A number of tests were conducted on the implemented Phase I trial system to determine system performance and the suitability of the system to police department needs. A visual inspection was made of the major items of the system, with emphasis on subsystems in the vehicle, for the purpose of assessing their suitability for the intended application as well as serviceability. Other tests include accuracy under normal closed loop and open loop conditions, signal field strength tests covering the entire city area, random and systematic tests to show the effects of driving conditions and environment, lane switching, tire inflation, tire wear, speed, etc. These tests and the evaluation of the results follow.

1. Visual inspection and component description.

a. Mobile equipment. The FLAIR components located in the vehicle (see block diagram, Figure 9-1) include:

- an odometer for measuring distance
- a compass for indicating direction heading

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[5]This checking, if done at Headquarters, could only be performed with small distance quantization intervals, not the larger Phase I interval of 25 feet.

- a coded message panel which houses a keyboard and controls for transmission of digital coded messages

- a vehicle data processor which processes the inputs from these three components and generates a time base with the appropriate time slot for presentation to the transmitter/receiver

- the two-way communication-type transmitter/ receiver

- a roof (or deck) mounted antenna

The odometer is a small rugged coil assembly mounted in close proximity to the cooling fins of the left front wheel disk brake. As each cooling fin passes the coil core an inductance change results which is processed as a modulated wave, thus producing one "count" for each fin. The standard unit of measure is approximately 25 feet which consists of several wheel turns and a large number of counts. The odometer is calibrated by accumulating the "counts" over a fixed distance and entering that number into the computer software. The system can accommodate different make cars having different numbers of fins per wheel rotation. It may be necessary to turn the fins down in a lathe in order to provide close tolerance with the coil assembly.

The odometer appears well built, the connecting cable is sealed for moisture and a sleeve protects the cable from abrasion. An apparent reliability problem could occur during cold winter weather where snow accumulates in the area of the coil assembly which then could form ice between the coil assembly and the disk brake when the vehicle is standing as for a lunch break. When the car starts again problems could occur. In fact, one failure

that could have been attributed to this occurred on such a cold day during Phase I.

The compass heading unit is a solid state unit completely encapsulated in epoxy; it measures approximately two inches square by approximately 3/4 inch thick, and has a cable with several leads emerging from it. It is mounted in the back area of the car trunk, away from items that might be movable (the spare tire was left out of the Ford cars, but not the newer Nova cars). Ordinary and reasonable trunk loading does not appear to disturb the readings. Car trunks are notorious for achieving peaks in temperature (hot and cold) but the coils in the compass are temperature-compensated so there is no apparent mass calibration problem when temperature extremes are encountered.

Compass calibration is a difficult task and is the most recurrent maintenance problem (see Section E of this chapter). The car must be oriented in the true North, South, East and West positions, calibration screws adjusted in each location and readjusted in repeat locations untill all directions are within defined tolerances. During Phase I, compass calibration was achieved by driving the car in the calibration area so as to line up with road markings representing the appropriate directions; in Phase II, the car will be driven onto a rotatable and non-magnetic fixture--making the task much easier.

The coded message unit is a small unit having a 10-button keyboard, a transmit and clear button, a two-digit display panel and an EMERGENCY button. It is mounted convenient to the driver so that he can readily key in a two-digit code (01 to 99). The

principal problem with the unit involved accidents where coffee or "coke" were spilled on the unit, causing the liquid to leak through the keyboard into the inside thus making a general mess. Also, there is evidence of the EMERGENCY alarm button being accidently bumped, setting off false alarms. Design and mounting methods are being altered for Phase II to alleviate these problems.

The Vehicle Data Processor receives inputs from the odometer, heading unit and coded message unit, processes this data to the appropriate binary bit format, the output of which is then supplied to the AVM transmitter. The AVM receiver provides a synchronous timing signal to the Vehicle Data Processor which initiates a crystal controlled time base for generating a predetermined time slot. The module containing these timing circuits has eight miniature switches for conveniently selecting the assigned time slot (FLAIR number). Not so convenient is a time delay adjustment which fine-tunes the mobile time slot to that of the base station receiver. During Phase I, adjusting this delay involved technicians at the base station and at the mobile unit (garage) with a telephone line between them. This will be changed in Phase II.

The four modules in the processing unit were responsible for about half of the total FLAIR repairs, and the distance multiplexer module was the one most frequently repaired (see section on FLAIR maintenance later in this chapter). This relatively high repair rate was due in part to manufacturing processing methods and to changes added to the modules as the result of tests performed in Phase I. Phase II reliability is expected to be much better.

The FLAIR Transceiver is an RCA series 700UHF unit, modified

by Boeing. The transmitter has 25 watts output power and a receiver quieting sensitivity of better than .5 microvolts. Transmitter frequency drift is rated at 0.0002%. The Boeing modifications include:

- new transmitter/receiver audioamplifiers
- two Army/Navy type multi-pin connectors replacing RCA's
- double shielded coaxial antenna cable

Potential problem areas resulting from such modifications:

- changes of the transmitter circuits could nullify the FCC-type acceptance of the equipment
- changes performed by Boeing could nullify the RCA warranty.

The modified RCA radio performed well and required reasonably few repairs or frequency adjustments during a four-month observation period. It is noted that the mobile transmitter operates for only 10 ms per second for a duty cycle of 1%.

b. Headquarters Base Equipment. Referring to Figure 9-1, a G.E. transmitter/receiver is used, where the transmitter power is 70 watts, the antenna is a DB Product #610 having 11 db gain, and the antenna is located on a 280-foot tower which is on top of the 80-foot high Police Headquarters building in downtown St. Louis. The transmitter sends the synchronizing signal to all FLAIR mobile units. This signal is 5 cycles at 1000 Hz[6] modulation once each second, for a low duty cycle of 0.5%. The one-base transmitter

[6] Synchronizing signal is being changed to a pulse format in Phase II.

with one channel is intended to serve all FLAIR-equipped vehicles in the St. Louis MPD, regardless of how many base receive channels are required to service the fleet (200 cars per channel).

Time slot data transmissions from each of the vehicles in the fleet are received at the Headquarters base station. The receiver output is fed to the computer/data link interface where the data from each time slot is sorted out for the computer.

For Phase I, there was no hot standby base station transmitter or receiver specifically for FLAIR, but the equipment is similar to those used for the six voice communication channels for which there is a standby. For Phase II, a standby transmitter/receiver will be provided for FLAIR. Two technicians are assigned to the base station to provide coverage during the more active part of the day. During Phase I operation, no failure of the transmitter/receiver base station equipment was observed except on July 30 when lightning struck the tower and caused rather extensive damage to the transmitter/receiver and other equipment. The downtime for this failure was 48 hours.

c. Headquarters processing of the location and status data is performed by a Varian 73 computer, interface equipment and computer peripherals. The principal tasks are to update location and status of each vehicle in the fleet at one-second intervals. In addition, the computer "holds" each vehicle to a street through a map-matching process; corrects vehicle location--if necessary--when a corner is turned; searches the computer map for a route corresponding to that of the vehicle if the vehicle should become "lost," and relocates the vehicle if the locating search is successful

relocates vehicle (if necessary) when a patrol officer performs a self-initialization routine; checks digital data for accuracy through a series of logic tests, and accumulates operational data for daily reports and more.

Because the computer and software programs constitute the heart of the FLAIR System, its operation is detailed in a following section of this chapter.

d. The Dispatcher Display Terminal is the interface between the FLAIR System and the primary police user--the dispatcher. To be effective, the display must convey information to the dispatcher (and the command staff) that enables improved performance which in turn justifies the system investment and operating cost. To understand better the functions of the display, a brief description will be given.

Referring to Figure 9-3, the map is displayed in one of three magnifications, X1, X4 and X16. The most magnified represents about one square mile and shows all the streets and most of the street names. The less magnified scales show proportionally fewer streets and names. The fish-like outline on the upper left corner is metropolitan St. Louis and the white square on the city outline is the map area being displayed.

On the left and below the map outline is a listing of car numbers together with their message code. Cars requiring location verification are also shown in this area (with a *V* or *W* after the car number). For normal status messages, they will appear sequentially in the order of arrival, with the last one at the bottom. If a high priority call comes in--such as 3321 33E (high

Figure 9-3

FLAIR Display Terminal

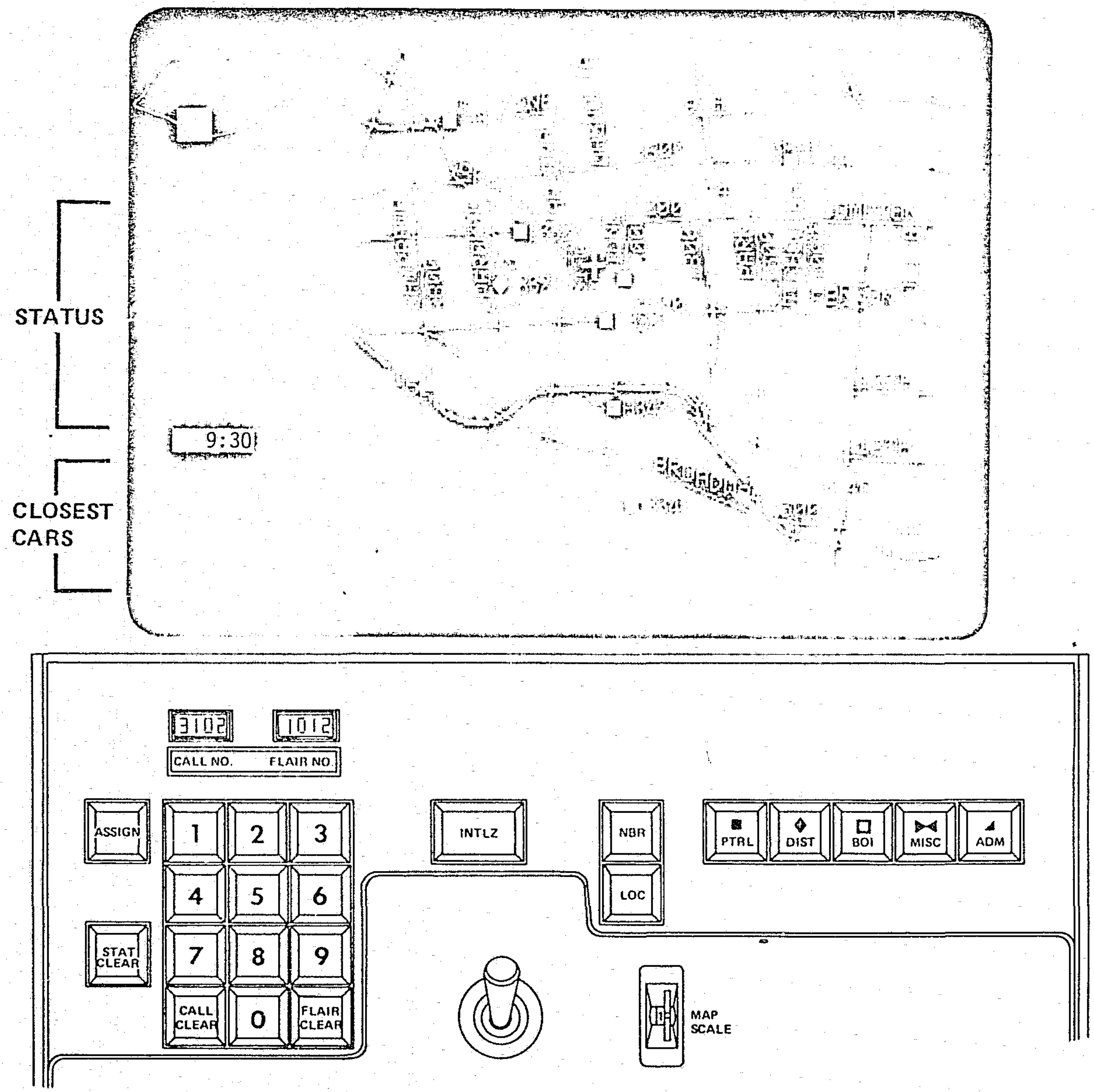

Figure 9-4

Status Codes

METROPOLITAN POLICE DEPARTMENT – CITY OF ST. LOUIS
DIGITAL CODES – RADIO DISPOSITION CODES

*"E" (7260) EMERGENCY – OFFICER IN NEED OF AID
7207 Send Cruising Patrol
7210 Send Ambulance, Routine
7211 Send Ambulance, Urgent
7221 Report Your Location
7226 Unoccupied Car Check
7227 Occupied Car Check
7228 Pedestrian Check
7229 Building Check
7230 Going On Information Channel
7231 Going Off Information Channel
7233 High Speed Chase - Criminal
7235 Personal Relief
7240 Meals
7241 One Man Car
7242 Two Man Car
7244 Auto Accident With Injury
7254 Female Prisoner in Car
**7255 Emergency Need to Talk to Disp.
7257 Laclede Garage
7258 Radio Repair
7259 Wash Rack
7261 Auto Trouble
7264 Prisoner Processing
7267 Gasoline
7268 Out-Of-Service
7272 Arrived at Scene
7273 In Service
**7274 Voice Contact With Dispatcher
7276 Leaving for Scene - Low Priority
7277 Leaving for Scene - High Priority

MPD Form 300-6 (R-4)

UNFOUNDED
7280 No bona fide incident, but have name of witness.
7281 No victim or witness can be found.
7282 No such address.
7283 Disposition previously submitted on same incident; or disposition to be submitted by a different car. (Indicate reason and radio call letters of car that will give disposition.)

PEACE DISTURBANCE AND COMPLAINT
7284 Perpetrator gone on arrival, no arrest or summons, no prosecution or injury, no City Counselor's Referral Card issued.
7285 Peace restored - no arrest or summons, no prosecution or injury, no City Counselor's Referral Card issued.

FIRE
7286 Fire - no persons are injured or require medical attention, no explosion or arson expected.
7287 False alarm of fire, no arrest, suspect unknown.

PROWLER
7288 No description of suspect and/or pertinent information.

MISCELLANEOUS HAZARD
7289 Other agency notified, no persons are injured or require medical attention, public health or safety not impaired.

MISCELLANEOUS INCIDENT
7290 Sick Case – Not police personnel, no poison case, death not apparent, no suspicious circumstances.
7291 Accidental Injury – Accidental injury on private property and/or from another jurisdiction, not police personnel, death not apparent, no suspicious circumstances.
7292 Suspicious: Person/Auto/Occupant of Auto – Person - can account for his presence. Auto - not stolen or wanted.
7293 Call for Police – no police service necessary.
7294 Alarm Sounding – activated alarm. Burglar Alarm - no entrance attempt evident. Holdup Alarm - alarm set off accidentally.
7295 Non-criminal incident, no written report required, no other code provided.

*To be used only for an officer in need of aid. Officers shall not use code 60 "Emergency" - only depress the Emergency Button to summon aid. Code 60 causes same action as emergency.

**To be used for emergency contact with the dispatcher other than above.

***To be used for voice contact with dispatcher (e.g. additional information - reclassified coded incidents - returning to service requiring verbal disposition and C.N.)

Codes are listed in 7200 series to conform to computer requirements. HOWEVER, OFFICERS AND DISPATCHERS SHALL USE ONLY THE LAST 2 NUMBERS OF THE CODES IN TRANSMISSIONS.

On codes 30, 31, 41, 42, 76, 77 transmitted, wait 5 seconds before clearing. All others must be acknowledged by dispatcher.

speed chase--see Figure 9-4 for a listing of digital codes)--it commands an override and goes to the top of the list. If more messages are received than spaces available, an overflow is indicated. Most status calls have to be aknowledged by the dispatcher at which time the car number and clear button are entered--which clears the message from the screen. Some messages perform an automatic function such as code 42 which signifies a two-man car, which places two dots by the car number (e.g., see car 3333 in Figure 9-3).

The numbers displayed below the digital clock are the numbers selected by the computer to be the closest to an incident site, the closest being first on the list. In Figure 9-3, the cursor (a white cross located between Compton and Jefferson near Arsenal) is placed by the dispatcher (using the cursor control) at the incident site and the car numbers will automatically appear. It is good practice for the dispatcher to select visually the closest cars, with the aid of the closest car list, in order to account for one-way streets and barriers that might alter the choice. (The computer algorithm does not take into consideration these factors.) Also, computation of the closest car is made on an X plus Y basis where X is north-south streets and Y is east-west. This method is satisfactory when all streets in a city are uniformly layed out in this manner, but if a car is located on a street that angles across the normal street direction (such as Gravois Ave), or if the car is in an area where the rectangular street pattern is rotated to be other than in the north-south and east-west directions (such as the

Fairground Park-O'Fallon Park areas), then dispatcher verification of the closest cars is again required. (See Chapter VI, Section D2 for a discussion of the extent of such errors.) Car selection by the dispatcher will also be influenced by the car symbol (e.g., a solid square is a patrol car) and one versus two-man cars. A car on assignment will code in a 76 or 77 for low and high priority respectively which will automatically make the car symbol blink at a slow versus faster rate. Cars showing steady brightness are available for call.

The dispatcher display is a modified commercial color TV receiver. The color is used to emphasize various display functions; for example, the maps, status identification and closest car are blue, car symbols and car numbers are yellow, the cursor cross is white, and the St. Louis map is purple. During Phase I, the display operated reliably, the principal problem being a drift in cursor location on several occasions. Most dispatchers reacted favorably toward the display, but some volunteered that the blue color was hard on their eyes and difficult to see. Some would like to have a brightness control for adjusting to individual tastes (which appears to be a good idea). The buttons for coding in car numbers and other operations are located on the vertical display panel, requiring the dispatcher to reach across the screen and several inches above table top, which is inconvenient and tiring. The new Phase II arrangement will have these operating buttons and controls located on a subpanel placed on the table top for easier operation.

2. Accuracy tests. Accuracy is the most important performance

characteristic of an AVM system. Accuracy of most AVM systems can be defined by the mean or average error of the indicated location compared to actual; or the accuracy might be stated as that error producing a 95% confidence level, indicating that 95% of the errors are within this limit. For dead-reckoning and computer-aided dead-reckoning systems (FLAIR), an additional measurement is necessary to defince accuracy--the frequency of lost cars or the mean time between lost cars. The lost-car aspect of the accuracy tests is covered in Chapter V including (1) emperical test results and (2) a computer model for estimating the mean time bewteen losses. Also detailed are the variables that contribute to the problem of lost cars. In this chapter tests will be described that determine location accuracy.

a. Location accuracy test. During a one-month period[7] the District 3 dispatchers stopped each car (an average of about 18 were fielded each day) twice a day to check the actual position compared with the display indicated position. The dispatchers were instructed as follows:

- Cars were to be stopped during non-premium time so as to cause minimum interference with normal police duties
- Only cars on patrol and available for call were to be stopped

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[7] Tests were conducted from February 10, 1975 to March 9, 1975.

- Only cars not displaying a *V* or *W*[8] were to be stopped
- Cars were to be randomly selected
- Recording of errors to be as follows:

Range	if display error is	error recorded in log is	average error is
1	0 to 1/8"	0"	45 feet[9]
2	1/8 to 1/4"	1/8"	135 feet
3	1/4 to 1/2"	1/4"	270 feet
4	1/2 to 1"	1/2"	540 feet
5	1" to 2"	1"	1080 feet

A summary of the measurements is shown in Table 9-1 and a curve showing error distribution and % confidence level is shown in Figure 9-5.

Interpreting the test results, 80% of the measurements show cars between 0 and 90 feet from the true location, which indicates the effectiveness of the map matching and corner correcting features of the FLAIR System. However, the 95% confidence level is a rather poor 625 feet and the average error is 137 feet or 101 feet (upper and lower bounds respectively) which shows the significant negative

[8]A *V* is displayed by a car number in the status column on the display when the computer suspects the cars may be lost. A *W* is displayed when the car leaves District 3, is in the vicinity of a known magnetic anomaly, or has travelled an excessive distance in an off-street area knot in the computer's memory.

[9]1/8" on the 16 x map scale is approximately 90 feet.

Figure 9-5

Error Distribution

Accuracy Tests - 2/10 to 3/9/75

(total number of samples - 713)

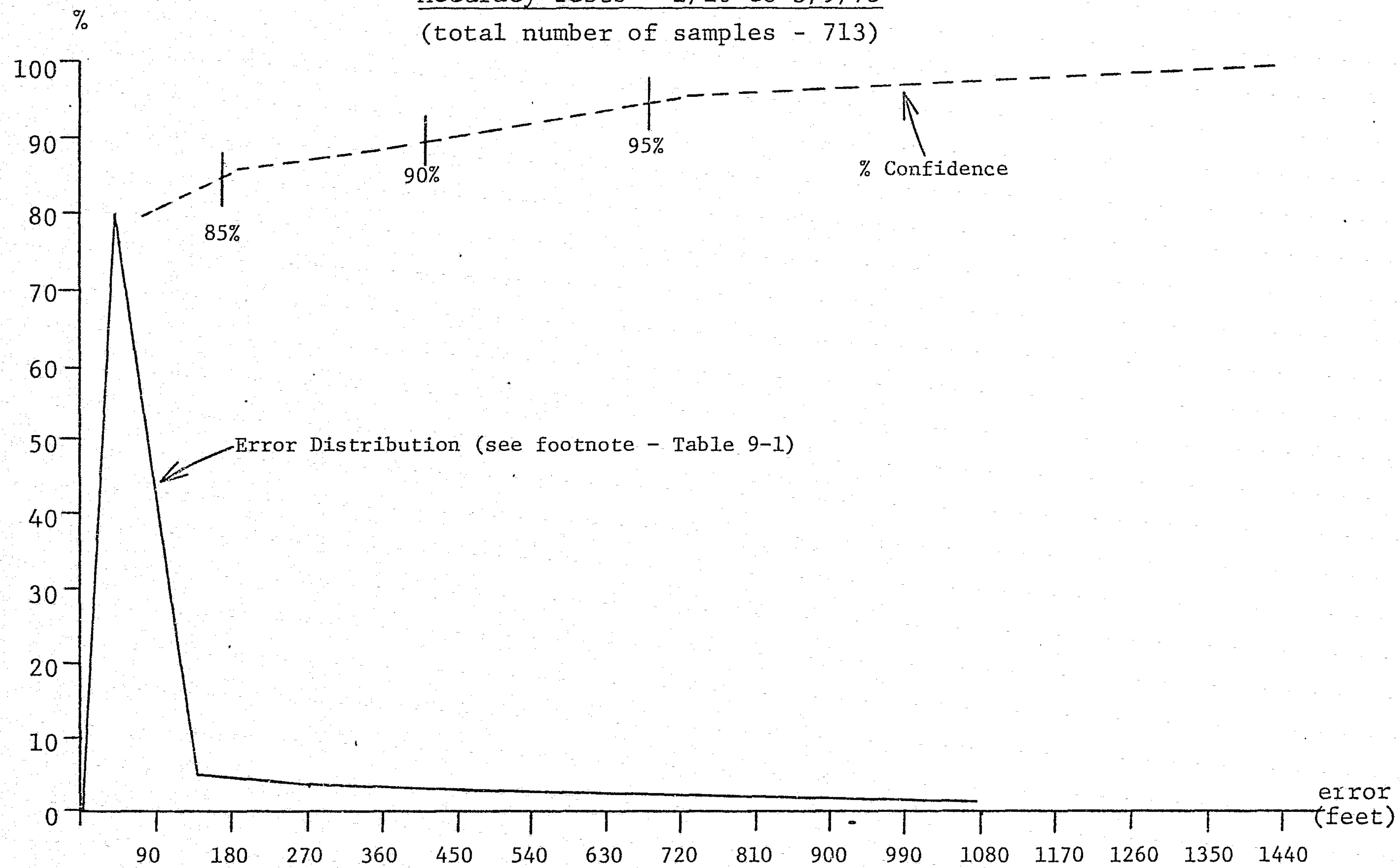

Table 9-1

Accuracy Tests - 2/10 to 3/9/75

Error Distribution

	Error Range	Average Error	Number of Readings	Accumulated % of total	Total Error
1.	0 to 90 feet	45 feet	569	80	25,605*
2.	90 to 180	135	39	85	5,265
3.	180 to 360	270	24	89	6,480
4.	360 to 720	540	50	96	27,000
5.	720 to 1440	1080	31	100	33,480
	TOTALS		713		97,830

Average error (upper bound)	137 feet
" " (lower bound)*	101 feet

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*In the above table, error distribution in all measurement ranges is assumed to be uniform. Such distribution can be considered reasonable for ranges 2 through 5, but range 1, containing 80% of the measurements, should have a probability distribution favoring zero feet error. The "lower bound" average error assumes the error in range 1 to be zero.

contribution of a relatively few cars that apparently escaped the hold of the map-matching computer and were in the process of getting lost or found.

b. Off-street tracking. When a car leaves the street to enter a shopping center, parking lot, industrial area, etc., its location mode changes from closed loop (computer assisted) to open loop (dead-reckoning). The open loop mode should be sufficiently accurate so that when the vehicle again enters the street, the computer will probably locate it without initialization. Tests were made in nine off-street areas in District 3. It was not known which of these areas were recognized by the computer. Results were as follows.

Area 1 - Truck terminal - Residence[10] = 7.1 min. No flag after leaving area. Tracking well.

Area 2 - School lot - Residence = 7.1 min. *W* appears 1.2 min. after leaving area. Initialized to Salena and Utah. Error = 625 ft.

Area 3 - School lot - Residence = 2.0 min. No flag after leaving. Tracking well.

Area 4 - Shopping Center - Residence = 11.2 min. After leaving area, tracking is ragged with frequent self corrections and *V* appears 3.9 min. later. Initialized to Phillips and Oak Hill. Error = 1165 ft.

Area 5 - Store parking lot - Residence = 4.8 min. No flag.

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[10] Residence is the time interval spent in the off-street areas.

Tracking well.

Area 6 - Store parking lot - Residence = 5.2 min. No flag. Tracking well.

Area 7 - Industrial Zone - Residence = 6.5 min. *W* appears .6 minutes after leaving area. No initialization required--display and true position identical. Restart at District 3 station.

Area 8 - Open area - Residence = 5.9 min. *W* appears after 4.3 minutes of residence. Unable to initialize.[11]

Area 9 - Industrial Zone - Residence = 8.2 min. Area 9 entered 7.8 minutes after leaving Area 8. *W* which occurred in Area 8 is initialized at Sprint and Choteau after leaving Area 9. Error = 930 ft.

Since the *W* could not be initialized after Area 8, areas 8 and 9 are considered as one for the purposes of analysis. With this in mind, it can be seen that initialization flags appeared for 4 of the 8 off-street areas; 3 of these were *W*'s and one was a *V*. Three of the 4 flags actually required initialization, the one not needing such action was the *W* from area 7, and the average error was 907 feet. *W*'s tended to appear shortly after exiting from an off-street section while the one *V* observed was reported only after extended attempts by the system to place the vehicle on the appropriate

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[11] Upon leaving area 8 located at Lafayette, west of Vandeventer, the car proceeded to area 9 across the Vandeventer viaduct which has a known magnetic anomaly and cars cannot be initialized until they leave that area.

street. Since effort was made to cover test areas in a manner similar to patrol patterns, one can expand these results to predict that regular police vehicles entering off-street areas have about a 50% chance of being flagged for initialization. Due to the small sample size, more tests of this sort are planned for Phase II in order to pin down this number more precisely. Based on this information, though, it seems that error from this cause is likely to be large, frequent initializations will be necessary, and even if they are not, dispatcher workload is still increased by having to verify locations with the driver.

c. Random and systematic tests. Tests were made to determine what variables might influence the accuracy of the odometer mounted on the left front wheel of a FLAIR-tracked car. Two types of tests were conducted to determine 1) random variations in measured distance as caused by driving methods and road conditions, or tire pressure, and 2) systematic (or persistent) measurement variations as might be caused by tire wear and speed. The results of these tests were used in a computer model for determining mean time between losses (see Chapter V, B).

Random test results. (See Table 9-2.) Tests run on Arsenal Street allow little driving choice as it is a two-lane road, one lane in each direction. Also, it is straight, providing little chance for variation due to curves, lane switching, etc. Variation in indicated distance was slight, showing 0% (all runs the same) to 0.07% (4 feet per mile). The greatest variation occurred on the Broadway run (3 lanes in each direction) with .18% (10 feet per mile)

Table 9-2

Random Tests

Test location		Distance miles	Maximum variation* feet	% variation	Notes
Arsenal	- east	3.0	0	0	single lane
	- west	3.0	10.5	.07	each direction
Broadway	- south	2.8	21	.14	3 lanes
	- north	2.8	26.4	.18	each direction
exagerated lane switching	- south	2.8	37	.25	
	- north	2.8	42	.28	
Grand	- south	2.6	16	.12	2 lanes
	- north	2.6	26	.19	each direction
Gravois	- south-west	2.5	16	.12	2 lanes
	- north-east	2.5	16	.12	each direction
Tire pressure					
30 pounds pressure					
Arsenal	- east	3.0	10	insignificant	
	- west	3.0	5	insignificant	
20 pounds pressure					
Arsenal	- east	3.0	10	insignificant	
	- west	3.0	0	insignificant	
30 pounds compared to 20 pounds					
Arsenal	- east	3.0	10	insignificant	
	- west	3.0	5	insignificant	

*To determine effects of driving habits and road conditions on indicated travel, test car was driven between fixed landmarks, 3 times in each direction, using a fifth wheel (accurate to 0.001 mile). Maximum variation in the indicated mileage of the 3 runs is shown.

for normal driving and .28% (15 feet per mile) under conditions of exaggerated lane switching.

The effect of indicated travel variation due to tire pressure was measured in the Arsenal test run, because of its demonstrated consistancy. Variations in indicated distance with tires inflated to 30 or 20 pounds per square inch pressure were insignificant. Tire pressure, if within reasonable limits, appears not to cause errors.

Systematic tests results. (See Table 9-3.) Variation in measured distance because of tire wear is substantial, being 2% or 106 feet per mile for rayon belted tires and 1.2% or 63 feet per mile for steel radials. Measured distance increased with tire wear (the wheel required more rotations due to reduced diameter of worn tires, to cover the same distance). Speed variation using rayon belted tires was also very significant, causing about 2% change in measured distance when traveling at 60 MPH compared to 30 MPH. Under these conditions, the tires get larger in diameter with speed due to centrifugal force and heat (measured distance was less than actual at higher speeds). At 70 MPH, the error in measured distance was 2.7% or 143 feet per mile! Steel radials[12] performed much better having a variation of only .3% at about 60 MPH.

d. Interpretation of test results. Variation in indicated distance as determined in the foregoing tests is only

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[12] The rayon belted tires tested were Uniroyal Dynacor firstrak belted, H78-15; the steel radials were Uniroyal, HR-78-15. The reader is cautioned that other brands of tires may not perform in the manner described above. In fact, without further testing, variation in different tires from the same manufacturer is not known.

Table 9-3

Systematic Tests

Indicated travel distance, old versus new tires*

	Rayon Belted		Steel Radial	
Tire type	Tread depth	FLAIR counts per mile**	Tread depth	FLAIR counts per mile**
New tires	13/32"	212.05	12/32"	213.58
Old tires	5/32"	216.27	3/32"	216.20
% change in indicated mileage	2% (106 ft/mile)		1.2% (63 ft/mile)	

Old tires, with smaller wheel diameter, will show more indicated travel distance than new tires.

Indicated travel distance versus speed***

		Rayon Belted		Steel Radial	
Speed, mph	Direction	FLAIR counts per mile**	% change	FLAIR counts per mile**	% change
30	east	214.36	ref.		
30	west	214.66	ref.		
35-40	east	213.32	.5	213.85	ref.
40-45	west	212.21	1.15		
47-50	east	211.95	1.4	213.85	0
48-55	west	210.92	1.8	213.62	.1
53-60	east	210.39	1.9	213.40	.21
53-65	west	209.98	2.2	213.25	.28
62-70	east	208.72	2.7		
64-75	west	208.94	2.7		

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*Test made in Arsenal Street, between Seventh Avenue and Maury Avenue District 3. Speed was under 30 mph.

**Distance travelled was between fixed points. From a standing start cars accelerated to indicated speed and then came to a quick stop. FLAIR counts per mile were determined from total FLAIR odometer reading (from computer print out) divided by distance travelled (from 5th wheel).

***Test made on Interstate Highway 44 between Mississippi and Kings highway.

serious if significant location errors result and perhaps more importantly, if such variation causes an increased rate of lost cars. To establish a frame of reference, the various activities that patrol cars normally engage in are reviewed. Most patrol cars are assigned to a beat (sector) where the beat dimension may be only a few blocks (densely populated areas) to over a mile (Kansas City). While on a beat, the patrol activity requires reasonably frequent turns, when the computer will correct for minor accumulated errors as a turn is made to a recognized street. When on call, the patrol car can respond anywhere within a district and is more apt to take a direct route with fewer turns. District dimensions may be several miles in each direction (District 3, St. Louis is approximately three miles square). After city-wide implementation, some cross district dispatching is anticipated for longer distance. Other FLAIR-equipped cars, such as Command cars, special service cars, detective cars, etc., may respond anywhere within the city and are even more likely to take direct routes with longer distance between turns.

The longer a FLAIR-equipped car travels without making a turn, the greater the probability of an accumulated odometer error that will cause the computer to place it on the wrong street, causing the car to (ultimately) get lost. Typical rectangular blocks in St. Louis have short dimensions of approximately 300 feet, and those with alleys, 150 feet (from street to alley). An area of confusion exists if the car is located about midway between drivable surfaces that a car may turn, which would be 150 feet for streets

without alleys, or 75 feet for those with alleys. So a measure of the seriousness of an error-producing cause can be expressed as the miles driven before it has an accumulated error that would cause the car to be located in the area of uncertainty (150 or 75 feet). A tabulation of these results follows.

error type	% variation	error feet/miles	miles driven for accumulated error of 75 feet	150 feet
Random				
3 lane road (e.g., Broad-way)	.25	13	5.8	11.6
2-lane (Grand)	.15	8	9.4	18.8
Systematic				
worn tires (rayon belted)	2.00	106	.7	1.2
(steel radials)	1.20	63	1.2	2.4
speed - 60 mph (rayon bleted)	2.00	106	.7	1.4
(steel radials)	.25	13	5.8	11.6

Under normal driving conditions, a car may experience errors from all the above causes, simultaneously. At the same time, errors can be contributed because of the course distance and heading resolution, driving in off-street areas, missed signals and bad data. The evaluation of all these effects, and others, requires application of such data to the computer model on mean time between

losses, as covered in Chapter V-B.[13]

Referring to the above tabulation, errors caused only by random effects would probably not be serious while the car remains in the sector or district. Serious error could result under conditions requiring travel city wide. For worn tires and speed, however, errors can be very serious even while in a sector. Recommendations are:

- Automatic computer correction for error due to tire wear or alternatively, schedule frequent odometer calibrations such as every 5000 miles.
- Automatic computer correction for error due to speed (this is expected to be included in Phase II). Correction factors of each tire type must be developed. Use of steel radials appears desirable.

e. Signal field strength. Missed signals and bad data can be a major source of error. To determine the reliability of signal strength, tests were made within the St. Louis city limits in anticipation of Phase II, and beyond the city to determine ultimate range and safety factor. The routes travelled were expressways, selected to reasonably cover the entire city and 20 miles beyond. See Figure 9-6.

A FLAIR-equipped police car was used as the source of signals. Signals were received at Police Headquarters base station, were processed through the data processor and mini-computer and the data was recorded on a printer.

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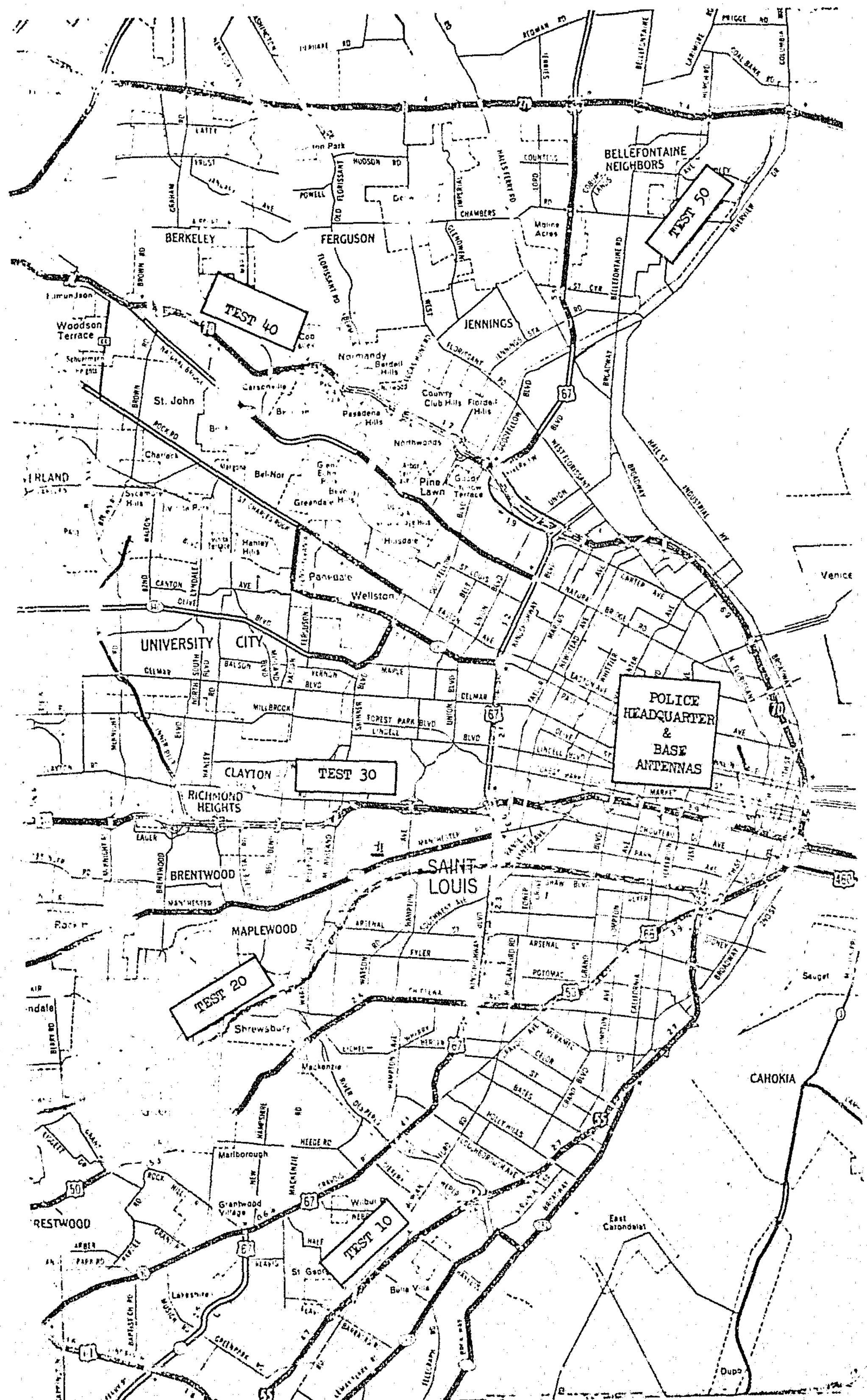
[13] The effect of missed signals and bad data are not included in the present model.

Figure 9-6

Field Strength Test Route



Data was transmitted from mobile to base every second. Each transmission provided heading direction (5 bits), distance (4 bits), and status digits (7 bits). If no transmission was received, an NT was printed after the data printout--indicating the mobile either had not received a synchronizing signal which would prevent a mobile transmission, or that the mobile signal received at the base was of insufficient strength to be distinguished from noise. If the received mobile signal was adequate in signal strength but of questionable accuracy, a BD (for bad data) was printed after the data printout. The BD determination was made by the mini-computer through a series of logic tests, such as--if the indicated distance travelled was unrealistic compared to prior distance information; or the status digits were beyond the range of the system (0 to 99), and so forth.

To determine test vehicle location, a status code was assigned to each test run. For example, code 10 was selected for route 55 (south), code 20 for route 44 (southwest), and so forth. Each test was started near police headquarters base station and the basic status code (i.e., 10) was used during travel to the city limits. Travel beyond the city limits reflected an increase in 1 digit for each 2 miles (i.e., 11 was from city limits to 2 miles beyond, 12 was from 2 miles to 4 miles, etc). Tests were conducted 20 miles beyond city limits (where practical) after which the vehicle returned on the same route before starting the next run, thus enabling verification of data.

<u>Interpretation of signal field strength test results</u>. An occasional missed transmission (NT) or bad data (BD) will likely

have little if any affect on performance of the FLAIR System. The distance data, which records from 0 to 15 (the unit of measurement being approximately 25 feet) will show the correct travel distance during the next transmission, and the heading direction is not likely to change sufficiently to cause error during the omission of a single one-second update. However, if two or more successive data transmissions are omitted, the probability of error increases. For this reason, occasions of two or more successive missed transmissions were recorded in the data summary. Accumulated errors from missed transmissions or bad data will increase the frequency of "lost" cars with the resultant need to initialize them.

Test results are summarized in Table 9-4. Of a total of over 5,000 test points, only 16 (.31%) represented two consecutive missed transmissions.[14] However, nine of the 16 were in a region 1½ miles within the city limits on Route 44. Figure 9-7 is a computer printout of the received data in this region, with the test car in the outbound direction. The inbound data showed similar results. Otherwise the test shows adequate signal strength on all the routes followed, which should be indicative of signal conditions throughout the city except for isolated local conditions. Signal conditions beyond the city limits were generally favorable for two to four miles in all directions. Beyond four miles, signal reliability deteriorated fast.

Additional signal strength tests were conducted on residential streets in the region 1½ miles within the city on Route 44 where weak signals were noted during the city-wide tests. The route followed is

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[14] A test point is a data printout of direction, distance, and station code, occurring at one-second intervals. There were 16 occasions where two consecutive misses occurred.

Table 9-4

Field Strength Survey, City of St. Louis

Summary of total city

		% of tests
Number of tests within the city	5137	
Number of missed transmissions	121	2.35
Bad data transmissions	30	.58
Total missed and bad data	151	2.94
Number of 2 successive missed transmissions	16	.31

Note: 46 of the 121 missed transmissions, and 9 of the 16 times 2 successive transmissions were missed occurred 1½ miles within the city limits on test route 20 (Rt.44).

System specifications

Base station (location, Clark Avenue at 12th - downtown)

- Transmitter power, 70 watts to the antenna (synch signal only)
- Receiver sensitivity, .5uv for 20 db quieting
- Antenna, DB Products #610, 11db gain
- Antenna height, 280 foot tower on top of 80 foot P. D. building

Mobile (RCA radio, Series 700, UHF)

- Transmitter power, 25 watts
- Receiver sensitivity, .5uv for 20 db quieting
- Antenna, omnidirectional, 3 db gain
- Frequency stability, .0002% (-20°C to +60°C)

Figure 9-7

Signal Strength Test
(computer printout)*

West on Interstate 44 to City Limits and 2 Miles beyond

23 4 20	23 7 20	23 11 20	23 15 20	24 2 20
25 6 20	22 9 20	22 13 20	22 1 20	22 4 20
22 8 20	22 11 20	22 15 20	22 2 20	22 6 20
9 15 92 NT	22 13 20	21 1 20	22 4 20	21 8 20
21 11 20	21 15 20	21 2 20	21 6 20	21 9 20
21 13 20	21 1 20	21 4 20	21 8 20	21 11 20
21 15 20	21 3 20	21 6 20	21 10 20	21 13 20
21 1 20	21 5 20	21 8 20	5 2 108 NT	21 0 20
21 3 20	21 7 20	21 11 20	21 14 20	21 2 20
21 5 20	20 9 20	20 12 20	20 0 20	20 3 20
20 7 20	19 11 118 NT	20 14 20	19 2 20	20 5 20
19 9 20	19 12 20	18 0 20	18 4 20	18 7 20
18 11 20	18 14 20	29 3 80 NT	29 4 74 NT	8 13 86 NT
17 13 20	13 11 14 NT	6 11 81 NT	17 8 20	17 11 20
17 15 20	17 2 20	18 6 20	18 10 20	22 3 23 NT
19 1 20	18 4 20	19 8 20	19 11 20	8 14 94 NT
19 2 20	10 15 90 NT	10 5 45 NT	20 13 20	20 1 20
4 1 32 NT	4 5 73 NT	27 1 50 NT	20 4 42 NT	19 3 20
19 7 20	19 10 20	19 1 107 NT	19 2 20	21 13 16 NT
20 9 20	19 13 20	29 7 71 NT	20 4 20	20 7 20
20 11 20	20 14 20	19 2 20	19 5 20	19 8 20
2 4 78 NT	19 15 20	19 2 20	19 6 20	19 9 20
15 12 72 NT	19 15 20	19 3 20	19 6 20	9 0 77 NT
12 11 39 NT	20 0 20	18 13 73 NT	20 6 20	16 8 84 NT
21 13 20	21 0 20	21 3 20	21 7 20	28 2 13 NT
22 13 20	20 7 89 NT	21 4 20	26 10 102 NT	21 11 36 NT

CITY LIMITS

20 14 21	20 1 21	20 4 21	20 7 21	19 10 21
19 14 21	19 1 21	19 4 21	19 7 21	19 10 21
19 13 21	19 0 21	20 4 21	20 7 21	22 10 21
17 13 21	20 1 21	22 4 21	18 7 21	21 11 21
21 14 21	22 1 21	22 5 21	22 8 21	10 13 43 NT
22 15 21	23 2 21	16 6 81 NT	23 9 21	23 13 21
23 0 21	24 4 21	24 7 21	24 11 21	24 14 21
24 2 21	24 5 21	24 6 105 BD	4 4 11 NT	23 0 21
23 3 21 BD	23 7 21	23 10 21	23 14 21	22 1 21
22 5 21	22 8 21	22 11 21	22 15 21	21 2 21
20 6 21	20 9 21	21 13 21	21 0 21	21 4 21
21 7 21	21 11 21	21 14 21	22 2 21	20 5 21
19 9 21	20 12 21	20 0 21	4 11 77 NT	20 7 21
19 11 21	19 14 21	19 2 21	10 1 47 NT	19 9 21
19 13 21	19 1 21	19 4 21	19 8 21	9 7 5 NT
20 15 21	19 3 21	19 6 21	19 10 21	19 13 21
19 1 21	20 5 21	19 8 21	18 12 21	19 15 21
19 3 21	20 7 21	19 10 21	19 14 21	19 1 21
20 5 21	21 9 21	21 12 21	21 0 21	21 4 21
21 7 21	4 8 55 NT	21 14 21	26 4 42 NT	21 6 21
21 9 21	22 13 21	22 1 21	22 4 21	22 8 21
22 12 21	22 0 21	22 3 21	22 7 21	22 10 21

2 MILES OUT

22 3 22	22 7 22	22 11 22	22 15 22	22 2 22
22 6 22	22 10 22	22 14 22	22 2 22	22 5 22
22 9 22	22 13 22	21 1 22	21 4 22	21 8 22
21 12 22	21 0 22	21 3 22	21 7 22	21 11 22
21 15 22	22 3 22	21 6 22	22 10 22	21 14 22
21 2 22	21 5 22	21 9 22	20 13 22	20 1 22
20 4 22	20 8 22	20 12 22	26 14 42 NT	21 3 22
20 7 22	20 10 22	21 14 22	21 2 22	21 5 22
23 9 22	23 13 22	23 1 22	23 4 22	23 12 22
23 12 22	23 0 22	23 3 22	23 7 22	23 11 22
23 15 22	23 3 22	23 7 22	10 5 75 NT	22 15 22
22 3 22	20 14 89	22 11 22	22 15 22	22 3 22
22 11 105 BD	22 11 22	22 15 22	22 2 22	22 6 22
21 5 56 NT	21 14 22	22 2 22	22 5 22	22 9 22

* This is an actual copy of the computer printout. Each update signal consists of a series of three numbers such as 16 11 0 where 16 is the heading (16 x 11.25°) and 0 is the status. Number sequence is from left to right across then step to the next line.

shown in Figure 9-8, and the frequency of two consecutive missed signals is plotted on Figure 9-9. Location codes in Figure 9-9 are shown on the route map, Figure 9-8. This test shows that signals may not be adequate for reliable performance. On several streets the incidence of two consecutive missed signals were more than 5% of total transmission, and on Jamieson Avenue between Chippewa and Arsenal Streets (and adjacent areas) missed signals were over 10%. See computer printout sample, Figure 9-10, for more details. This poor reception area is in the shadow of a hill located just east of the Jamieson Avenue/Longfellow school area. For reliable service to this area, a satellite receiver may be required.

3. Digital communications. Normally, police departments use voice communications between the dispatcher and the patrol force. As the level of police activity has increased over the years, the demands on the communication system have become more severe. These include:

- Congestion of the voice channels during peak periods, due to scarcity of radio channels.
- Inability of the mobile operator to reach the dispatcher on a timely basis during peak periods, because of congestion. This reduces his effectiveness.
- Eavesdropping on the police frequencies due to recent availability and popularity of police frequency monitor radios. Such capability to listen to police dispatching might create a nuisance from the curious public, and an advantage to those engaged in crime.

Most AVM systems employ digital modulation consisting of a number of bits (0 or 1) to transmit location data in binary code.

Figure 9-8

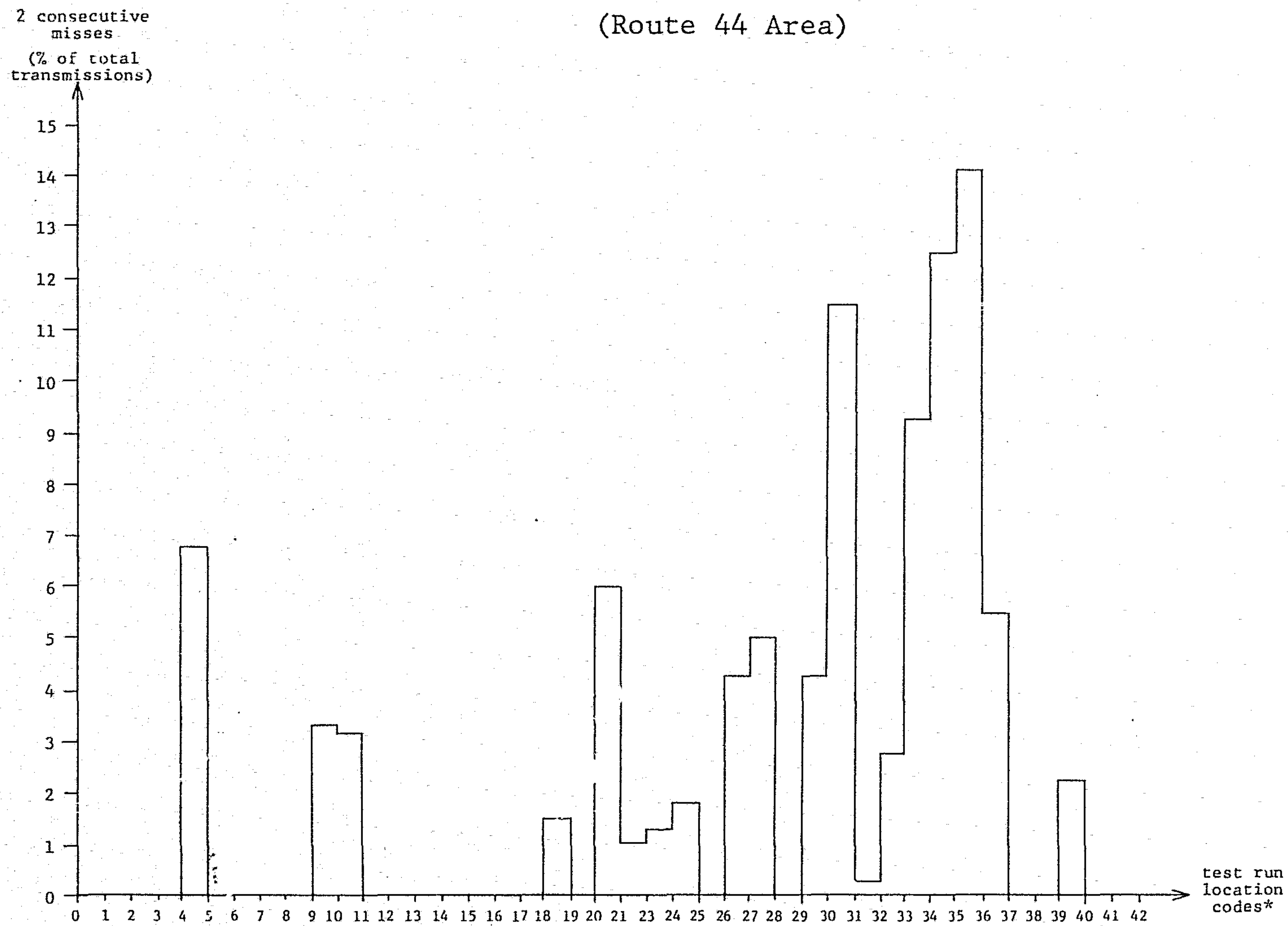
Field Strength Test Route

(Route 44 Area)

Figure 9-9

Two Consecutive Missed Signals

(Route 44 Area)



* Refer to map (Figure 9-8) for street identification.

Figure 9-10

Signal Strength Test
(computer printout)*

Residential Streets in Route 44 Area

25	8	0		25	9	0		10	13	118	NT	25	12	0		25	13	0		
25	14	0		25	0	0		25	1	64	NT	25	2	0		25	4	0		
25	5	0		25	7	0		14	7	29	NT	25	10	0	NT	6	3	127	BD	
25	13	0		21	7	94	NT	25	0	0		25	2	0		25	3	0		
25	5	0	NT	4	13	18	NT	5	3	37	NT	25	9	0		25	10	0		
25	11	0		25	11	0		15	9	90	NT	25	11	0		25	11	0		
25	11	0		25	11	0		25	11	0		29	8	67	NT	25	11	0		
24	11	0	BD	25	11	0		25	11	0		4	7	91	BD	25	11	0		
25	11	0		31	15	97		13	4	127	BD	25	11	0		25	11	0		
25	11	0		25	11	0		25	11	0		25	11	0	NT	25	12	0		
25	12	0		25	12	0		25	12	0		1	5	39	NT	25	14	0		
24	15	0	NT	24	0	0		24	1	0	NT	24	2	0		24	4	0		
24	5	0	NT	24	6	0		24	7	0		24	9	0		24	10	0		
24	11	0		24	13	0		21	13	91	NT	25	0	0		24	1	0		
24	3	0		24	4	0		24	6	0		24	7	0		24	8	0	NT	
24	10	0		24	11	0	NT	25	12	0		25	13	0		25	14	0		
25	15	0		25	6	20	NT	25	0	0		25	0	0		25	0	0		
18	1	93	NT	25	0	0		25	0	0		25	0	0		5	7	46	NT	
24	0	0		5	4	121	NT	25	1	0		25	2	0		25	2	0		
24	3	0		25	4	0	NT	25	5	0		25	6	0		25	7	0		
25	8	0		25	9	0		25	11	0		25	12	0		25	13	0		
26	14	0		9	13	66	NT	26	0	0	BD	23	1	0		20	1	0		
20	2	0		5	5	25	NT	20	4	64		20	5	0		10	9	43	NT	
20	8	0	NT	20	9	0		20	10	0		20	11	0		20	12	0		
21	13	0	NT	21	15	0		21	0	0		22	1	0		22	2	0		
22	3	0	NT	20	4	0		21	5	0		4	15	45	NT	2	7	43	NT	
22	7	0		22	7	33		22	7	33	NT	22	7	33	NT	22	7	33	NT	
22	7	33	NT	22	7	33	NT	22	7	89	NT	22	7	81	NT	22	7	96	NT	
15	9	59	NT	22	7	34	NT	22	7	34	NT	22	7	34	NT	22	7	34		
22	7	34		22	7	34		13	9	28	NT	22	7	34		22	7	34		Location 34
22	7	34		22	7	34	NT	22	7	34	NT	22	7	34		11	12	101	NT	
22	7	34		22	7	0		7	9	12	NT	23	8	0		24	8	0		
25	9	0	NT	25	9	0		25	10	0		24	10	0		23	10	0	NT	
22	11	0		21	11	0	BD	4	5	110	NT	20	12	0		19	12	0		
19	12	0		19	12	0		3	12	0		3	12	0	NT	3	12	0		
5	12	120	NT	4	13	0		5	13	0		5	13	0		6	13	0		
26	10	122	NT	6	14	0		7	14	0		7	14	0		23	14	0		
22	14	0	NT	21	14	0		21	15	0		20	15	0	NT	27	9	37	NT	
19	1	0		28	3	4		12	3	19	BD	22	14	13	NT	19	4	0		
19	5	103	NT	19	6	0	NT	19	7	0		5	7	5	NT	19	9	0		
10	4	95	NT	19	11	0		18	12	0		18	13	0		18	14	0		
17	15	0		17	15	0		16	0	0	BD	16	0	0		16	1	0		
16	1	0		16	2	0		16	2	0		15	2	0	NT	15	3	0		
15	4	0	NT	10	7	45	NT	13	14	10	NT	16	7	0		16	8	0		
16	9	0		16	10	80	NT	16	12	0		18	6	25	NT	16	14	0		
16	15	0		16	0	0		15	1	0		15	2	0		16	3	0		
16	4	0		17	5	0		18	6	0		20	6	0		23	7	120	NT	
25	7	0		25	7	0		25	7	0		25	7	0		24	7	0	BD	
25	7	0		25	7	0		25	7	0		25	7	0		25	7	0		
25	7	0		25	7	0		25	7	0		25	7	0		25	7	0		
29	5	94	NT	26	7	0	NT	25	7	0	NT	25	7	0	NT	9	8	127	NT	
25	7	0	NT	25	7	35	NT	25	7	35	NT	25	7	35	NT	25	7	35	NT	Location 35
11	3	35	NT	25	7	35	NT	25	7	35		25	7	35		25	7	35		
25	7	35	BD	25	7	35		25	7	35	NT	25	12	60	NT	8	10	94	NT	
4	10	44	NT	5	6	83	NT	24	7	91	NT	25	7	35	NT	25	7	35	NT	
25	7	0		25	7	0	NT	26	7	0		27	8	0		30	8	0		
0	9	0		0	10	0		0	11	0		0	12	0		0	13	0		
1	14	0		1	15	0		0	0	0		1	2	0	NT	26	8	39	NT	
1	4	0		1	5	0		1	6	0		1	8	0		1	9	0		
11	6	115	NT	1	11	0	NT	1	13	0		1	14	0		1	15	0	NT	
12	13	37	NT	18	10	59	NT	1	4	0		0	5	0		0	6	0		
31	8	0		14	11	44	NT	6	8	86	NT	28	13	0		10	11	12	NT	
31	0	0		31	1	0		1	3	32	NT	11	10	82	NT	1	6	0		
1	8	0		0	9	0		10	11	23	NT	31	12	0		31	14	0		
30	15	0		31	1	0		29	2	0		29	4	0		28	5	0		

* This is an actual copy of the computer printout. Each update signal consists of a series of three numbers such as 16 11 0 where 16 is the heading (16 x 11.25°), 11 is the distance (11 x 25 feet) and 0 is the status. Number sequence is from left to right across then step to next line.

It is relatively simple and inexpensive to add digital communication to this system, for transmitting messages as "canned codes". The FLAIR System transmits 99 prearranged codes from mobile to base, but does not have a base-to-mobile capability (some AVM systems have two-way capabilities). The possible advantages to such a digital communication system include:

- The mobile operators can reach the dispatchers on a timely basis, during the next update period, even when the voice channel is congested. Digital codes are transmitted on the AVM radio channel.

- Use of coded messages saves "voice transmission" time, and is expected to reduce voice congestion on police voice channels.

- Digital communication is secure, as it takes more elaborate equipment to decode it, which is not available to the consumer, and not easily available to the professional criminal. Also, if necessary, codes can be changed. Two-way digital messages would further increase security.

During Phase I, the St. Louis Metropolitan Police Department monitored cumulative transmission and receive time at the base station, before and during the FLAIR Phase I implementation. This monitoring was done in District 3 (trial district for FLAIR) and in District 5 (control district). The purpose of the test was to determine the effect of digital communications on voice channel airtime. Results of the MDP-conducted test are shown in Table 9-5 and Figures 9-11 through 9-14.

Table 9-3 shows a 2% decrease in occupancy time compared to the control district. This change is not considered significant, and indicates instead about the same use of the voice channel.

Table 9-5

Radio Air Time Occupancy Study*

3rd District

	Before FLAIR	With FLAIR	+ -
Total channel occupancy time	362.4** hrs	351.1	-11.3
Daily average occupancy time	7.9 hrs	7.6	- .3
Daily average occupancy time percent	33%	32%	- 1%

5th District

	1973-74	1974-75	+ -
Total channel occupancy time	234.2 hrs	245.7	+11.5
Daily average occupancy time	5.1 hrs	5.3	+ .2
Daily average occupancy time percent	21%	22%	+ 1%

Air occupancy time shows 1% decrease with FLAIR

Air occupancy time shows 1% increase in control district

Minus 2% difference with FLAIR

Study period - 46 days - December 17 to January 31, inclusive.

*Test performed by the St. Louis MPD.

**.1 of 1 hour = 6 minutes.

Figure 9-11

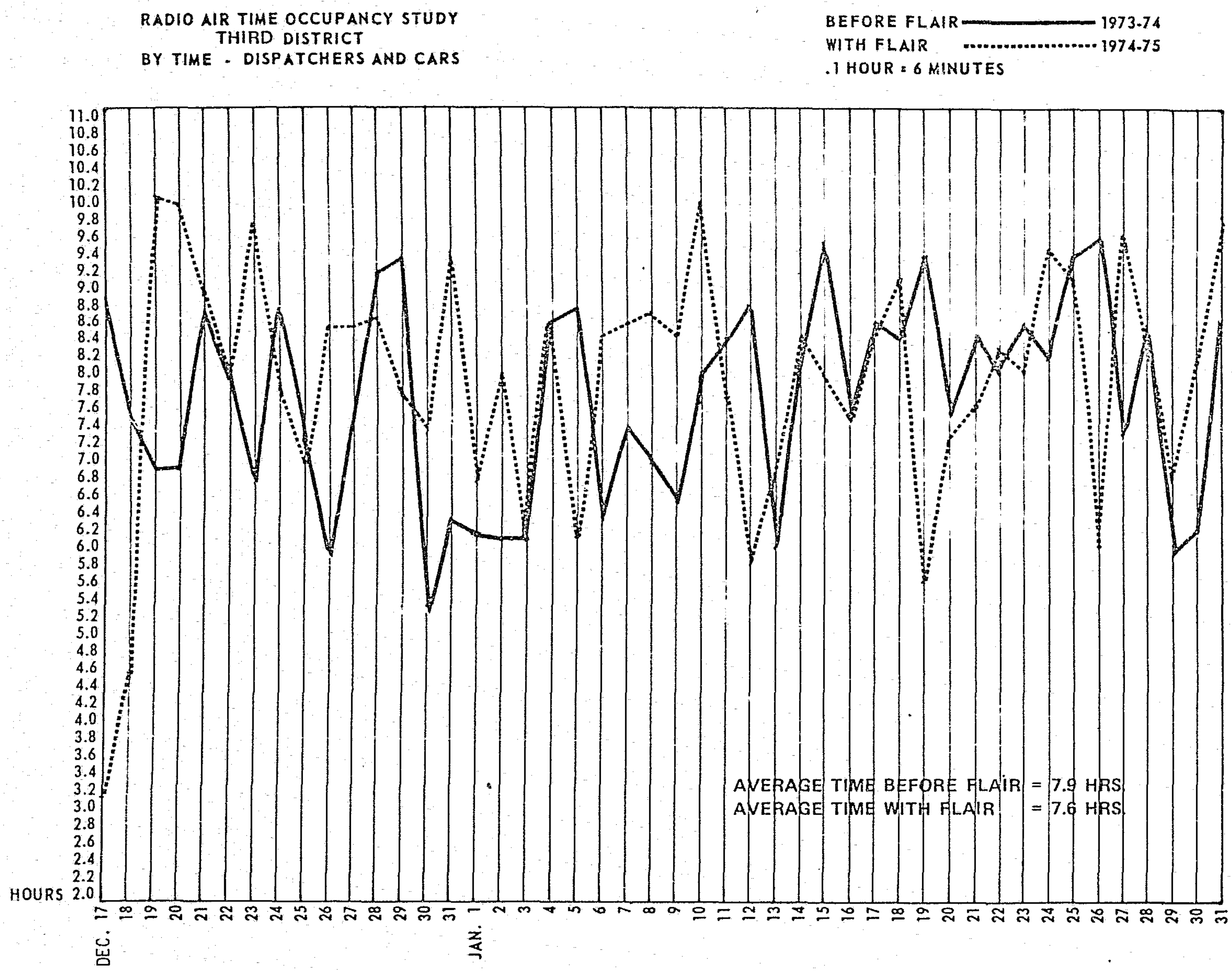
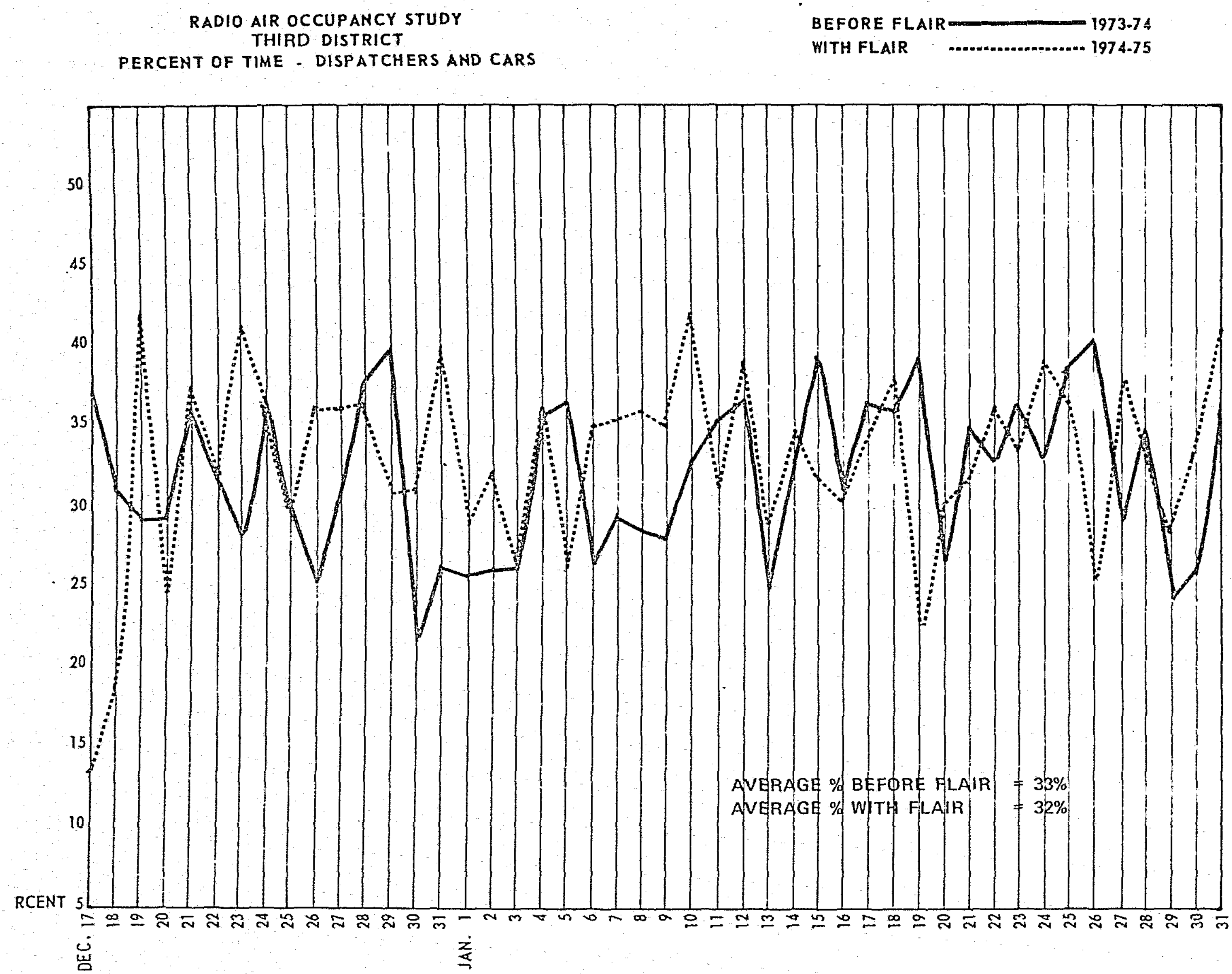

RADIO AIR TIME OCCUPANCY STUDY
THIRD DISTRICT
BY TIME - DISPATCHERS AND CARS
BEFORE FLAIR 1973-74
WITH FLAIR 1974-75
.1 HOUR = 6 MINUTES
HOURS
AVERAGE TIME BEFORE FLAIR = 7.9 HRS.
AVERAGE TIME WITH FLAIR = 7.6 HRS.
DEC.
JAN.

Figure 9-12


RADIO AIR OCCUPANCY STUDY
THIRD DISTRICT
PERCENT OF TIME - DISPATCHERS AND CARS
BEFORE FLAIR 1973-74
WITH FLAIR 1974-75
50
45
40
35
30
25
20
15
10
RCENT 5
DEC. 17
18
19
20
21
22
23
24
25
26
27
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29
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31
JAN. 1
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AVERAGE % BEFORE FLAIR = 33%
AVERAGE % WITH FLAIR = 32%

Figure 9-13

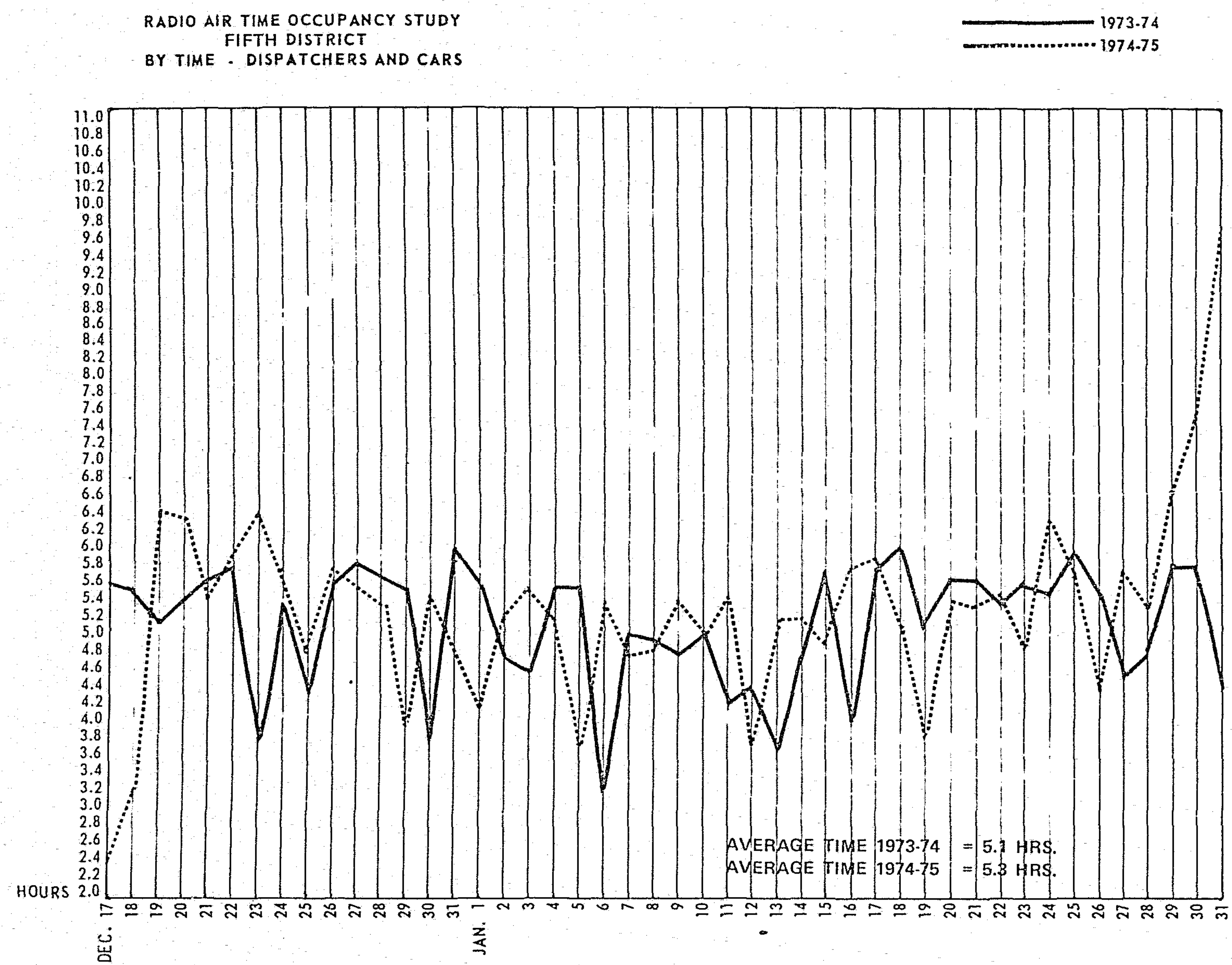
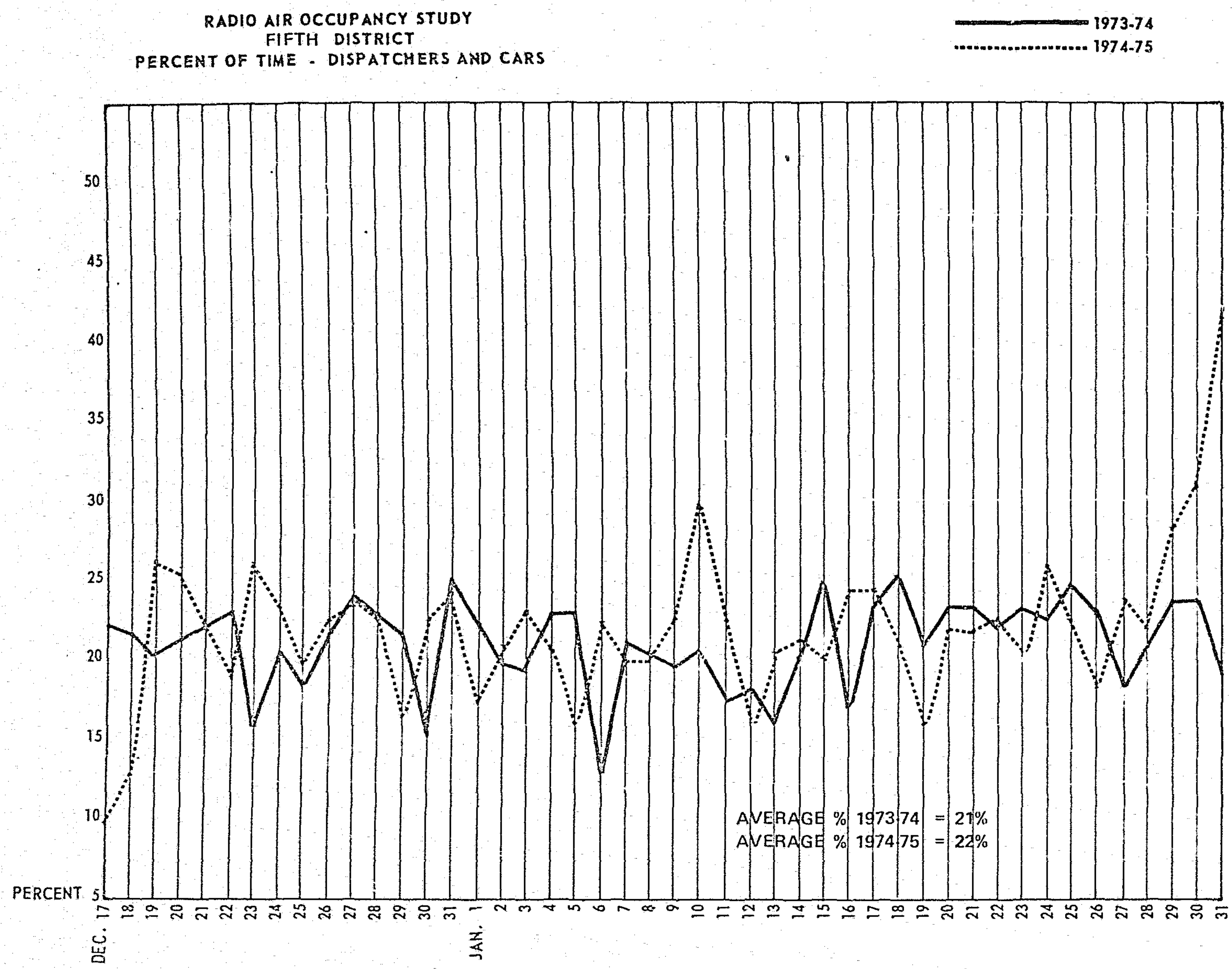

RADIO AIR TIME OCCUPANCY STUDY
FIFTH DISTRICT
BY TIME - DISPATCHERS AND CARS
1973-74
1974-75
HOURS
AVERAGE TIME 1973-74 = 5.1 HRS.
AVERAGE TIME 1974-75 = 5.3 HRS.
DEC. 17
JAN. 1

Figure 9-14


RADIO AIR OCCUPANCY STUDY
FIFTH DISTRICT
PERCENT OF TIME - DISPATCHERS AND CARS
1973-74
1974-75
50
45
40
35
30
25
20
15
10
PERCENT 5
AVERAGE % 1973-74 = 21%
AVERAGE % 1974-75 = 22%
DEC. 17
18
19
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21
22
23
24
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30
31
JAN. 1
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However, the patrol officers used the digital communications in considerable volume, between 2,000 and 2,500 codes per day (over 100 codes per car per day). Almost all codes required voice acknowledgement from the dispatcher, and some codes specifically requested voice communication with the dispatcher. Further, with FLAIR some additional voice channel time is required to verify/ initialize car location, which would be offsetting time that might otherwise be saved. Even though occupancy time on the voice channel did not decrease significantly, the addition of 2,000 coded messages per day indicates a significant expansion in the overall capacity of the communications system. The net result therefore means better communication and improved effectiveness. Nearly all patrolmen and dispatchers favored digital codes--in fact many seemed to regard this as one of the most important features of the FLAIR System.

D. FLAIR Computer Hardware and Software Systems Evaluation

The computer hardware/software processing capabilities of FLAIR provide the dispatcher with a number of important features that contribute to their knowledge and information. The computer software performs among other things the function of 1) updating the vehicle's position on the display terminal, 2) locating the vehicles on streets and other driveable surfaces, 3) correcting vehicle position when a corner is turned, 4) selecting the vehicles closest to an incident site, 5) preparing many operational daily reports, and more. It is considered the "heart" of the FLAIR System.

Evaluation of the FLAIR System must include an evaluation of the computer and software system. The computer hardware, being standard commercial equipment can be evaluated in terms of memory capacity, speed of operation, reliability and similar factors. The key to system performance, however, is the software. This is more difficult to evaluate because by its very nature it is "hidden" from view and is not open and subject to analysis as is the hardware. Also, like most independently generated software programs, the FLAIR software is considered proprietary. Available information about the software was therefore limited and the consequence has been that this part of the evaluation effort has been difficult and somewhat limited in scope.

1. General description. A block diagram of the FLAIR System is shown in Figure 9-15. This illustrates the relationship of the computer to the other system components. Figure 9-16 shows more detail of the computer system.[15] The following paragraphs extracted for a Boeing brochure, "The FLAIR System," August 1975 serve as a description of the basic functions and capabilities of the FLAIR computer system.

> The computer system includes memory and dedicated processing capability for tracking mobile units and operating the displays. The video processor provides the link to transfer digital data and control signals between the computer system and

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[15] Presentation prepared by Boeing for PSE entitled "FLAIR System Review for Public Systems Evaluation, Inc.", October 28, 1975.

Figure 9-15

FLAIR SYSTEM

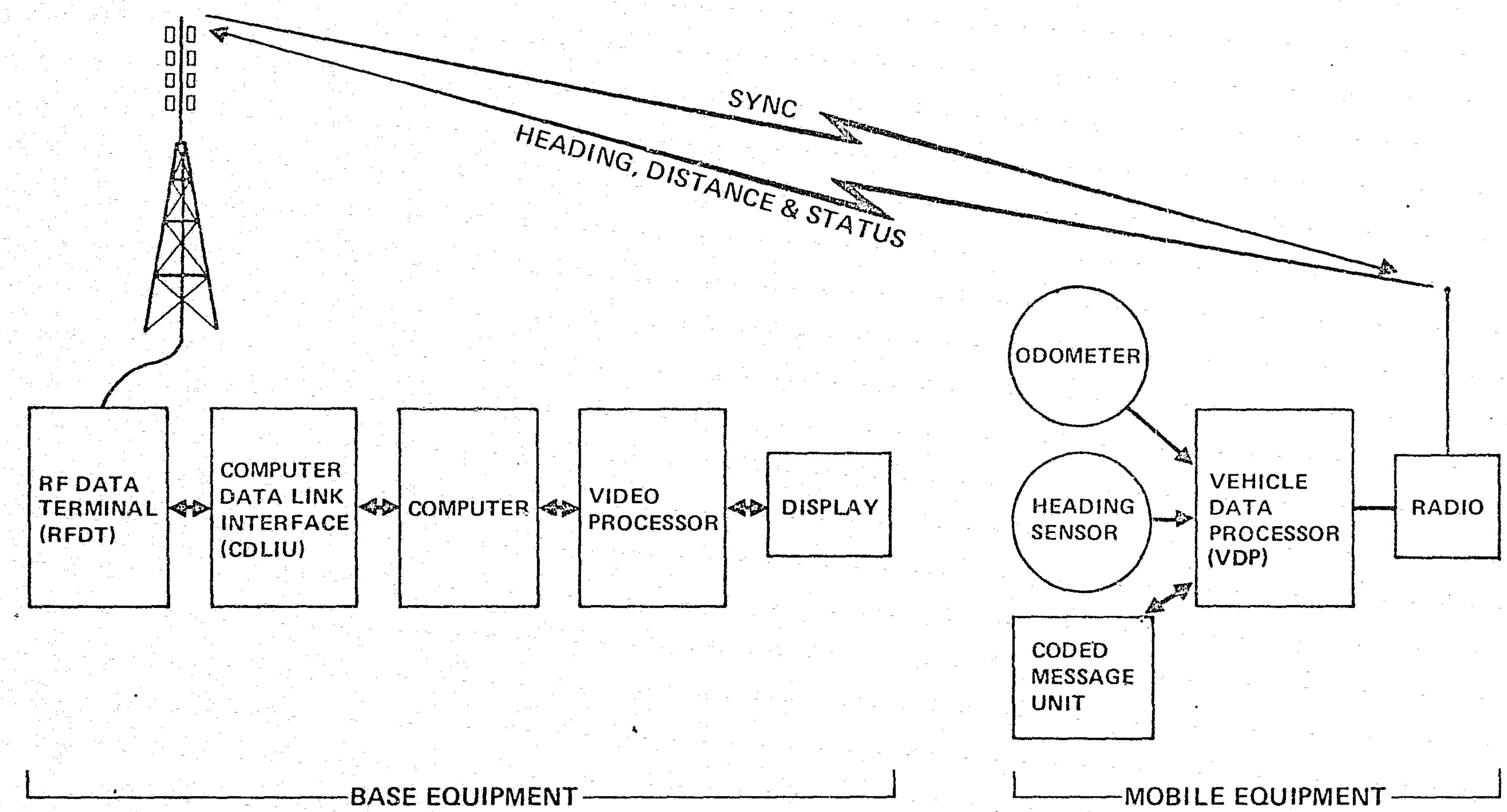
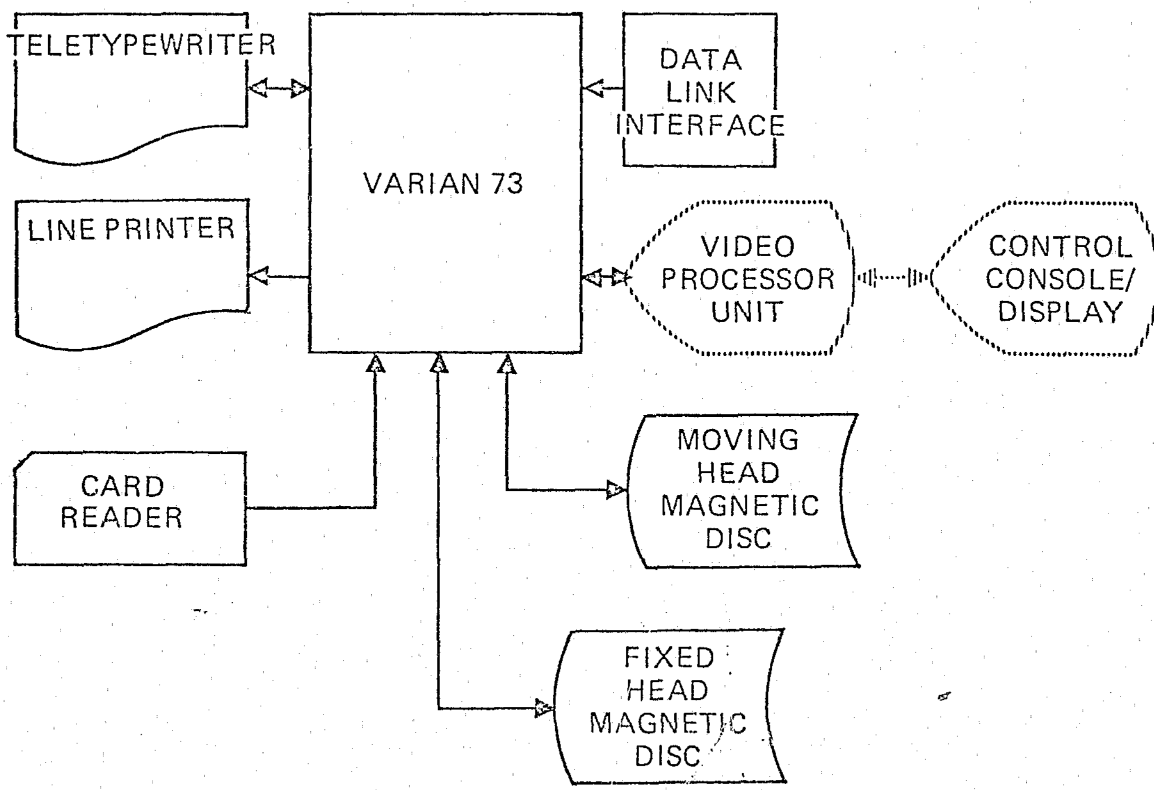


Figure 9-16

FLAIR Computer System



the control console/display. The computer provides the control, analysis, input/output, and other computational capabilities required to track vehicles, decode status information and present the resulting data to the dispatcher on the control console/display. A fixed head magnetic disc is used for vehicle tracking and a moving head magnetic disc supplies storage for system and program files, scratch areas and display maps. The teletypewriter, card reader, and line printer provide the programmer interface to the computer.

The computer, a Varian Model 73, is a system-oriented general purpose mini-computer. It is designed for maximum performance in instrumentation, data acquisition and communications systems. The computer system is modular and the configuration can be modified to suit particular police department's requirements.

The FLAIR software system (for Phase II) is based on the Varian Omnitask Real-Time Executive (Vortex II) operating system. The operating system controls, schedules, and monitors task in a real-time multi-programming environment. The operating system also provides for background operations such as compilation, assembly, debugging, or execution of tasks not associated with the real-time functions of the system.

2. Computer Hardware. Both the Phase I system and the proposed Phase II system have been analyzed. Several key problems have been identified in the Phase I computer hardware system. A number of them have been alleviated in the proposed Phase II system and where this is the case, it will be discussed. The problem areas are:

a. Inability of the Police Department to operate the computer system. This problem will be eliminated in Phase II when police personnel are trained to operate the system and operating manuals, which were lacking in Phase I, are published.

b. Lack of any type of backup in the system if any componen

failed to operate. This is solved with the dual-computer system proposed in Phase II.

c. Lack of readily-accessible hardware diagnostics. Hardware diagnostics are specially written software pr rams or routines which aid service personnel in diagnosing har re problems. For example, if there is a problem in the co ter memory, a memory diagnostic could be run in the compute ich would locate the bad bit(s) or word(s) in the memory by ning "worst case" bit patterns throughout the memory module uestion. Well written and tested diagnostics can be a very power and effective tool in aiding service personnel in the locati of hardware problems. An additional use of such diagnostic their use in "preventive maintenance". This type of maintenanc normally refers to a weekly period where the machine is onnected from its normal function and cleaned and adjusted. Hard diagnostics are normally run at this time to locate inte tent and marginal conditions which later might appear as hard lures if left undiagnosed and repaired.

In reviewing the service and maintenance experience h the Phase I system, with one exception, it appears that t hard-ware diagnostics were capable of aiding a trained service erson in locating the source of a hardware problem. The one ex ption appears to be in the Varian supplied disc diagnostic. Ap rently this diagnostic only checks a few limited tracks on the di , checking little besides a crude ability to assess the disc. Large ortions

of the disc were not exercised with this diagnostic. Boeing had indicated that this problem will be alleviated with Phase II. The major problem with hardware diagnostics is their lack of ready accessibility. All of the hardware diagnostics on the Phase I system were contained on reels of paper tape which can be extremely slow in correcting problems. Boeing has indicated that all diagnostics will be on some form of high speed input medium, either cards or magnetic tapes, in Phase II.

d. <u>Lengthy time for system restart</u>. Evaluators witnessed a "cold start" of the FLAIR computer on March 24, 1975. This procedure took more than 15 minutes just to bring the computer up. This time did not include that required for the dispatcher to initialize all units and to achieve a smooth running dispatching situation with FLAIR.

e. <u>Lack of an automatic power fail-safe system</u>. The Phase I computer system lacked any type of power fail-safe protection. This relatively inexpensive hardware option provides a computer system with a capability to sort and protect the operating program status when a power failure occurs. When power returns the system can automatically return to an operational status. It should be noted that such a capability is included in the Phase II configuration.

A digital computer is susceptible to information loss during even brief momentary power fluctuations. This is because all internal high speed registers, both arithmetic and control, are

volatile and require a constant power source to retain their contents. A power fail-safe unit is a fast acting combination of hardware and software which upon sensing a drop in voltage will automatically start execution of a special routine to restore the contents of all pertinent registers and status and will resume execution precisely where it left off when the voltage dropped.

The value of such a system in any given situation with FLAIR of course depends on the length of time the power is out. The following periods of power outage will be discussed: momentary, less than two minutes, less than the time remaining in the tour, and long-term.

Momentary. A momentary drop in voltage, even for a fraction of a second, will normally stop the execution of a computer program. A power fail-safe unit would protect the viability of the FLAIR software system and would cause the system to regain complete execution with no change except for the momentary stoppage of execution.

Less than two minutes. A power outage of longer duration than a few seconds will cause problems with the FLAIR System. This is because all vehicles which are moving at a reasonable rate of speed will most likely have travelled sufficient distance that the location algorithm would be unable to "find" them when execution is restored. However, if the length of power outage is not too long, perhaps 30 seconds to two minutes, a sufficient number of units will have not moved or will have travelled slowly enough that the algorithm will still know their position and the entire force will not have to be initialized.

Less than the time remaining in the tour. If the length of time of the power outage is longer than a few minutes, clearly all units will have to be initialized. However, there is another type of status information which is still usable if the power returns before the end of the current tour. This is the status indicating the makeup and allocation of the current patrol force. This will list the correspondence between FLAIR numbers and patrol car numbers, etc.

Long-term. Any long-term power outage, in fact anything beyond the end of the current tour, will require complete restart of the system. In this case the power fail-safe unit will be of little use to the FLAIR System.

f. Dedication of the FLAIR System to one computer vendor. With the exception of "one ten-step Fortran I/O routine" the entire Phase I system was coded in assembly language for the Varian 73 computer. Assembly language programs are by definition dedicated to one computer and in general are not transferrable to another system (except to a limited extent within one "family" of computers like the IBM system 360 or 370 families). For this reason it is clear that the success of the FLAIR System, as currently implemented, is predicated on the success and future of the Varian Computer Company. Although Varian appears to be a very solid, well-run company, the rapid rise and fall of computer companies is well known. (Many companies with large investments in computer hardware built by General Electric, RCA, and Xerox are suffering under current conditions even though their systems are supposedly now supported

by other computer companies.)

The Varian computer Model 73 is a powerful and fast mini-computer ideally suited for a real-time application such as FLAIR. However, it would appear advisable that Boeing develop a FLAIR System also capable of using a second source computer. Boeing has indicated that a large percentage of the software for Phase II will be coded in a higher level language, presumably Fortran. Although this should ease the problem of transferrability, switching from one computer to another invariably results in a complete rewrite of the software.

g. Service arrangements. The Phase I system appears to have a good record in terms of Mean Time Between Failure (MTBF) considering that it is a 24-hour a day, real-time system in a prototype situation. However, as discussed below, the Mean Time to Repair (MTTR) seems abnormally high. The reasons for this are several:

Service capability. Evaluators witnessed several periods of computer down time, and the procedures carried out by the Varian personnel assigned to do the repair. These personnel seemed poorly equipped to diagnose and solve the difficulties with which they were confronted. The running of a disc diagnostic program was witnessed which indeed did recognize the problem and came to a program "halt". However, the personnel were unable to locate the documentation for the diagnostic to be able to interpret the result. On another occasion it was clear that they were unable to replace a part in the system when the replacement part was received. This

level of capability is perhaps satisfactory when repairing a computer system in a research lab or small business, but certainly is unsatisfactory for a real-time, 24-hour a day system upon which a large police department is basing the control of its patrol force.

Maintenance arrangement with the hardware vendor. During the Phase I contract, the MPD did not enter into a service agreement with the hardware vendor, Varian, but rather decided to pay for service on an "as-needed" basis. For Phase II, if a service contract were negotiated, terms could include the availability of skilled help and spare parts to minimize MTTR and systems down time. Entering into a service agreement with Varian or other qualified service sources would seem to be a prudent decision for the Phase II system, at least until more experience is gained. Eventually the MPD could acquire in-house capability, proper test equipment for performing the diagnoses, and spare parts. It is recognized that service contracts are fairly expensive, but at this stage of system implementation, it removes one major responsibility from the MPD at a time when other problems in a new system are likely to develop, needing their full attention.

3. Computer software. The evaluation of the computer software is logically broken down into two parts: the part authored by Varian and the part authored by Boeing.

a. Varian-authored software. The Phase I FLAIR System used a minimum amount of Varian-authored software so very little evaluation could be performed on that portion. The questionable quality of certain Varian-authored hardware diagnostics has been

previously discussed.

The proposed Phase II software system, however, will have a heavy reliance on Varian-authored software. The entire FLAIR System will be based on the Varian Omnitask Real Time Executive (Vortex II) operating system. This operating system will control, schedule, and monitor tasks in a real-time multiprogramming environment. In addition, the operating system will allow simultaneous background operations such as compilation of programs, printing of summary reports, or running programs which facilitate making changes in either the display or tracking map.

The basic functions of the Vortex II operating system are:

- Real time foreground operation
- Dynamic memory allocation
- Real time I/O processing
- Interrupt processing
- Priority task scheduling
- Individual task protection
- Automatic background scheduling

In addition, the system provides a Fortran IV compiler, and system assembler and necessary utility routines.

The Vortex II operating system is definitely at or near the state of the art for a real-time mini-computer operating system. Its choice as the operating system for the Phase II system is logical.

The reliability and maintainability of this operating system is difficult to assess. It sould be noted that Varian software is well respected in the industry and should, by itself, cause no

difficulty. A potential problem would be with the application software which is designed to function with the operating system. However, there is no way that this portion of the software could be evaluated at this time.

b. Boeing-authored software. As we pointed out earlier, there will be a complete rewrite of the FLAIR software system for use with the Phase II. From Phase I we learned of a number of problems, principally those involved with maintainability, ease of use, speed of recovery or start-up after a failure, etc. Boeing has indicated that these problems have been or will be resolved within the Phase II software.

4. Computer systems maintenance. Some problems with maintenance and repair efficiency have been mentioned in the preceding section. Additional analysis of Phase I operations is provided in Section E of this chapter. In summary, the past performance indicates the system was down for computer-related failures an average of 3.4% of the time the first 11 months of 1975; during the last five month period (July through November 1975), downtime was at a much reduced rate of .3%--excluding a major incident caused by lightning. The mean time between failure (MTBF) for the eleven month period was 38.9 days, and the mean time to repair (MTTR) was 1.32 days--for computer related failures. Boeing states the Phase II system availability considering all causes of down time, should be 0.994 (.6% down time).[16]

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[16] "The FLAIR System", August 1975, Boeing publication.

The proposed Phase II system with a back-up computer system should provide greatly improved performance. It should be pointed out, however, that the proposed Phase II system is probably more than twice as complicated as the relatively simple Phase I computer system so there is still concern about the overall computer system reliability and maintainability. There are several reasons for this:

- Although the Mean Time Between Failures (MTBF) for the Phase I computer system is not bad, the Mean Time to Repair (MTTR) is far too long.
- The more complicated Phase II computer system consists of two computers, each with 65k (thousand words) of memory. This compares to the Phase I system with 32k of memory. Thus total memory will be four times as large as in Phase I.
- From the present Phase I configuration of one single platter disc, the Phase II system will have two single platter, fixed head discs, and two removable "IBM-2316 type" disc pack drives. The present system has the highly reliable, mil-spec Model 35 teletype. The Phase II system will have two (one for backup) Model 33 teletypes. The Model 33 is generally considered somewhat less reliable than the Model 35.
- An additional complicating factor is that the software system for Phase II is far more complicated than that used during Phase I. The Phase I system was essentially a low-level, paper-tape based system, while the proposed Phase II system is the highly sophisticated Varian Omnitask Real-Time Executive (Vortex II) operating system. This system, which is authored entirely by Varian, is an extremely complicated multi-programming system with simultaneous foreground/background operation. This system in itself is, like all software, not "fool proof" and may be subject to its own maintainability problems.
- The Boeing software system for Phase II is evidently a total rewrite and revamping of the Phase I system. This has implications of a

debugging period and unknown longer range maintenance considerations.

- The proposed backup system should improve the Mean Time to Repair of the overall system (not necessarily of the individual computer system). However, it should be noted that any computer problem will require a minimum of 30 minutes to recognize and to switch in the backup system. This does not include time to initialize the entire fleet and to once again get into smooth full operation.

5. Overall system accuracy. Although many components of the FLAIR System contribute to determining the overall system accuracy, two extremely important factors are the quality of the algorithms and the actual implementation of the algorithms in the software. The location algorithm appears to be closely tied with the design of its software implementation. Because of proprietary considerations, little is known about the actual algorithm, although some information about its implementation is available, and this may shed some light on the algorithm itself.

The basic core of the implementation of the algorithm consists of two routines. The highest order routine converts the digital data from the vehicle into an (x, y) ordered pair to update the current (x, y) location of the vehicle and vector (r, θ) form for the street searches.

No attempt is made in this routine to correlate the (x, y) location with a location in the city. Approximately 90% of the actual execution time of the software is spent in this routine. For this reason, Boeing has expended a great deal of effort in

its optimization.

There is a set of criteria which determines when this routine is left and a lower level routine is executed to attempt to locate a vehicle on the city tracking map. These criteria have not been documented. However, one criterion appears to be the following: when the algorithm is confident that it has correctly determined the location of a vehicle, it "looks" down the road on the tracking map and determines the next node or corner where the vehicle may turn. It records the (x, y) location of this node and until the vehicle reaches this node it will not attempt to "correct" the location of that vehicle. Of course, another criterion such as a sustained change in direction (sustained eliminates variations due to lane changes) may force execution of the map location algorithm.

Obviously, there is much more to the location algorithm than these two main routines. Also, little is known about any attempts at error detection, error correction, unbiasing (such as that from the problem of tire wear discussed elsewhere in this report), data smoothing, and possible deliberate skewing of streets to correct for magnetic anomalies.

Little can be concluded at this time about the overall quality of the algorithm and its role in the overall system accuracy. It appears that in many instances in the Phase I system, the software has been patched to attempt to resolve problems which are totally removed from the computer. Of course, this use of software to compensate for hardware problems is a very legitimate use

of software. However, it is important to define when such action has been taken. A situation might develop either in the maintenance of mobile or base stations or in making changes to the map where such information would be useful to the Department.

6. Reports generated by the FLAIR System. The FLAIR System will, by its very nature, have a large data base which could be the source for a large number of reports. While no formal reports were generated under the Phase I system for use by the Department, some daily reports concerning initialization and accuracy data were made available. Boeing has defined a number of reports which will be generated by the Phase II system. These reports are summarized as follows:

Two types of reports are possible--those produced automatically and those which are produced on request. Those which are produced automatically are produced every 24 hours. The Department has the option of producing a report based on the previous 24-hour calendar day, or the 24 hours immediately prior to the time the report is printed. These automatic reports are:

a. Daily summary report/Part I. This report lists the console assignments (list of which dispatcher consoles handle which districts), a list of emergency transmissions (listing time of day, call number, and (x, y) location), and a list of each self-initialization code with the quality of initialization and the average distance moved as a correction.

b. Daily activity report (daily summary report/Part III).

This summary report gives the activity by district for the previous 24-hour period. The following data elements are tabulated: number of digital codes, two special code tabulations (user specified), display event counts (such things as number of initializations, clear status, assign units, cursor map changes by console, locate car, change map scale by console), number of cars in system, average mileage per car, self initializations, list of cars with mileage more than 150 percent of average, and those less than 50% of average.

c. Daily report car performance (daily summary report/ Part IV). This chart gives a summary of operational data which reflect the quality of data transmissions from the mobile units. The chart includes a summary of rejected data per car, update distance per mile per car (a measure of the distance corrected when a vehicle turns and the computer thus has a known position), initializations per car, and a list of the 20 worst performing cars in the four categories: data rejected by base station, data rejected by program, update distance per mile, and initialization per mile, and finally, a list of cars appearing in all categories, and a list of those appearing in three of the four categories. This report--available each morning--provides valuable assistance in determining cars having potential FLAIR problems. Based on this information they can be directed to the maintenance station for calibration and/or repair.

The following two reports can be generated at will by typing a command at the console teletype:

1. Hourly activity report (daily summary report/Part II). This chart is identical to the daily activity report described above except that this consists of 24 pages of data, one for each hour in the 24-hour period.

2. Systems analysis report. This chart will contain a summary analysis of rejected data (presumably data rejected either because of detected errors or missed signals, or data rejected by the software algorithm), open loop and street search analysis, verification request analysis, display interrupt summary, maintenance program ·activity central processing unit/workload, and restart analysis.

It appears that a good set of basic reports has been designed. However, good reports are not enough. The Department must now begin to consider the management use to which these reports will be put. It must be decided who will receive copies of each report, and how often, and how corrective measures or administrative actions will be implemented based on the reports. An additional advantage of the Department starting now to organize these procedures is that omissions in the reports might be noted in time to request changes or additions. The Department may very well find that one difficulty with the reports as planned is a surplus of information. For example, the Daily Activity Report contains some information which is very useful in evaluating the operational effectiveness of FLAIR. One of these is the tabulation of average mileage per car, and list of cars with mileage of more than 150% of average, and list of those less than 50% of average. However, the mileage

figures are included on the same summary report page with such items as display event counts (number of clear status, etc.), number of digital codes sent, etc. A one-page summary of street miles per vehicle, perhaps coupled with similar type operational data may be a more powerful tool than burying the same information in the middle of a report which includes a wide vairety of unrelated data.

It is therefore important for the Department to consider what it wants in the way of reports from the FLAIR System. A special report could be structured for the officer responsible for vehicle maintenance (this would most likely be the Daily Report Car Performance). An additional report could be designed for the officer charged with overall responsibility of the operation of the patrol force. This report could list the various street mileage figures, and lists of emergency transmissions, self-initializations, etc. A report for the officer in charge of the dispatching function could include display event counts (number of initializations, clear status, assign units, cursor map changes, etc.), console assignments (list of which dispatcher consoles are assigned to which districts), number of digital codes, etc. A report designed for the director of base station maintenance could provide much of the information included in the present Systems Analysis Report.

Such an organization of reports by function rather than the present grouping might prove more useful to the Department. The final decision must clearly rest with the MPD; now is the time, though, to be addressing this issue.

This brings us to the apparent inflexibility of the planned reporting system. While it is best for the Department to decide now what reports it will like in the Phase II system, in reality only with the time and experience of using the implemented system will the Department really know what its report needs are. This raises the question of responsibility for generating the software that makes the reports, or even to modify them. It appears that Boeing feels such responsibility should be theirs, presumably to assure proper software implementation. From the customer's (St. Louis MPD) point of view, this policy delays implementation of such reports, programs or changes, and adds cost. Consideration should be given to a Boeing trained MPD specialist who can handle such routines.

8. Computer maps. The FLAIR System contains two distinct maps. The first is the tracking map used in the location algorithm. This map consists of a set of directed line segments which is generated by an automatic digitizer. A high quality map of the city is mounted on the digitizer table and each street segment is manually approximated with straight line segments of approximately the same total length as the original line. The digitized output of these line segments is converted to the set of directed line segments required by the algorithm. The process approximates lines with stair-step functions where necessary.

The display map is that map used by the dispatcher for console display purposes. It is created from the tracking map, with the addition of street names. The display map is stored in a pictoral

character form.

A key question involved with the maps is how will their maintenance and support be handled? The planned system allows the user to make map changes but the processing of the software changes, again, is Boeing's responsibility. The first of two methods proposed will have the user provide marked-up maps. Boeing will digitize the necessary changes and prepare the data on punch cards. The user will use these cards to modify the necessary system and map disk utilizing either the "background" of the main FLAIR computer or the "background" of the backup computer. Another method of changing the maps is to have the user provide marked-up maps and Boeing would then deliver a completely modified system disk. Both methods add delay and cost to the customer.

Phase II will incorporate the disignation of one-way streets, street widths, and parking lot information as integral parts of its new tracking algorithm. Changes in these three items within a city are a fairly common occurrence. The inefficiency and cost to the customer to rely on someone else to make even these minor changes is undesirable. A Boeing trained MPD specialist should be considered for doing such tasks.

9. Expansion capability.

a. Vehicle system capability. The constraints the computer may have on system capacity are not known. Boeing's Phase II proposal to St. Louis covered a 200 car and a 400 car system, both apparently using the same computer system. It is assumed therefore that the presently designed 200 car Phase II system can be expanded

to 400 cars with the existing computer. How much further can it be expanded before an additional or higher capacity computer is needed? Does expansion involve other major expenditures other than that interface equipment that relates directly to the number of vehicles (time slots).

b. Compatibility with other technologies. A new technological system such as AVM is one of several innovative additions that can effect the efficiency and performance of a law enforcement operation. Computer Aided Dispatching (CAD) is another such new system, and like AVM, relates to the dispatcher by providing additional and faster information. AVM and CAD systems should be designed to work together, because to a large degree, each provides the other with complimentary and some overlapping information. Computer Aided Dispatching provides benefits principally related to computer stored information such as:

- a geographic file of each address with its (x, y) coordinates. From this, the authenticity of the address is verified and the distance from patrol cars to incident locations can be computed to enable the use of the closest car concept.
- a record of relevant occurances at particular addresses or areas--to forewarn officers of potential problems.

Contrasted to CAD, AVM provides benefits principally related to dynamic, real-time events. This includes actual car location, identification and status. CAD combined with AVM provides the benefits of each system and more. For example, CAD can locate the incident site for AVM, saving the time it now takes the

dispatcher to place the cursor at the site, which averages 9 seconds with well-trained and highly motivated dispatchers. This saving in time should reflect directly in response time saved. AVM and CAD systems should be designed for mutual compatibility; they should be interfaced so that one can be installed after the other without requiring expensive modification. In a similar manner, other innovative systems should be considered in the long range planning--with the eye toward making the system design mutually compatible. Such additional systems include:

- 2-way alpha-numeric digital communications
- 911 systems
- ANI (automatic number identification)[17]
- MIS (Management Information System)
- Vehicle Maintenance Records System

E. Repair Characteristics of FLAIR Equipped Vehicles

Because the value of an AVM system lies in its ability to provide accurate and timely information on the location and status of department vehicles, it is especially important to examine the frequency, nature, and seriousness of the various malfunctions the system may experience. The most serious of FLAIR-related failures are those which occur at the base station, particularly in the computer system. Such failures reduce the dispatcher's vehicle location information all the way to the pre-AVM level. Additional

[17] Verifies telephone number of complainant.

problems can develop in the hardware of an individual vehicle which will result in the disappearance of that vehicle from the display or in an unnecessarily large number of initializations. The repair characteristics of individual components are important to the personnel responsible for system maintenance, and the total repair characteristics of the system are important to the system users.

1. FLAIR repair at headquarters/base station. Since the FLAIR base station equipment became operational on December 16, 1974, nine substantial failures have been recorded, as displayed in Table 9-6. An additional number of minor software failures have occurred, perhaps four or five, as estimated by the MPD Officer in charge in which the system was quickly restored by department personnel. No records of these minor failures are available.

Considering only the equipment failures shown in Table 9-6, they amount to a total of 330 hours, 37 minutes in the period between the initial system activation on December 16, 1974 and December 1, 1975. Not including lightning damage, hopefully a rare event, this would indicate a mean time to repair (MTTR) of 1.32 days and a mean time between failures (MTBF) of 38.9 days, or 12.4 days of down time per year.

The great majority of the lost time was accrued in the first seven months of this period; in the last five months (excluding lightning damage losses of 48:12), down time was at a rate of 0.97 days per year, which represents a considerable improvement.

Table 9-6

Base Station Failures*

Device	Time of Failure	Time Restored	Duration of Failure (hours : minutes)	Reason
Computer	11:08 pm, 2-28-75	7:32 pm, 3-1-75	48:00	Hardware voltage
Computer	3:15 pm, 3-23-75	3:15 pm, 3-24-75	26:00	Hardware voltage & adjustment
Computer	9:00 am, 6-12-75	4:58 pm, 6-18-75	152:00	Unable to search disk**
Data interface	4:50 pm, 6-25-75	3:30 pm, 6-27-75	46:40	Bad IC's in data output module
Computer	8:40 am, 7-2-75	10:40 am, 7-2-75	1:00	Unknown
Entire base system	2:35 pm, 2-30-75	2:47 pm, 8-1-75	48.12	Lightning damage
Teletype***	1:00 pm, 3-14-75	5:00 pm, 8-14-75	4:00	Minor mechanical
Display console	11:30 am, 7-8-75	1:15 pm, 7-8-75	1:45	Power supply
Display console	Unknown 10-25-75	Unknown 10-25-75	3:00	Defective wiring
		Total	330:37	

*Starting date: December 16, 1974; ending date: December 1, 1975

**Mr. Matthis (Boeing) describes the problem as a loss of disk alignment and further states that this will eventually require replacement of the disk.

***This failure may not necessarily imply loss of system use.

However, the largest of the early failures, a disk alignment problem, has been noted as one which is particularly likely to recur and may eventually require the replacement of the disk. Otherwise, no definite patterns of repair requirements identifying particular system components have emerged.

As indicated in the previous section, under Phase II of the FLAIR project, considerable alterations to the software are being made which may affect reliability. The base station hardware will be augmented to include a backup computer (with manual switchover), which should result in reduced system downtime caused by the base station computer failures. No backup units will be provided for the data link unit, or any of the six display consoles.

2. FLAIR repair in the vehicle. The Department has recorded 303 FLAIR vehicle repairs on 211 occasions between July 3 and October 5 of 1975, which are distributed as shown in Table 9-7. During this period the MPD was solely responsible for repairs except during the special test (September 13 to October 5), at which time a Boeing technician arrived in order to augment the maintenance staff. For the entire fleet of 26 FLAIR vehicles, MTBF was 0.30 days, which amounts to 3.4 FLAIR repairs per day. The observed mean time between FLAIR repairs averaged 7.7 days per car.

a. Patterns. Table 9-8 shows the distribution of the number of FLAIR repairs broken down by the FLAIR car involved, the component repaired, and the percentage of repair incidents involving a particular component. Also in Table 9-8 the distribution of

Table 9-7

FLAIR Repairs: 7/2/75 to 10/3/75
(Excluding Installation-Type Adjustments)

Components	Function	Total Repairs	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56
			Vehicle FLAIR Number																									
CPA	Digital code panel	33	-	2	2	1	-	1	-	-	2	1	6	5	-	1	1	-	2	1	5	1	-	1	-	1	-	-
VDP	Vehicle data processor	14	1	-	-	-	-	-	-	-	-	2	3	-	-	-	-	-	-	1	1	1	-	-	2	2	1	-
IA1	Clock sync	13	-	1	-	-	3	-	1	-	-	1	1	1	-	-	-	-	-	-	-	1	-	-	-	2	2	-
IA2	Time gate	25	-	2	-	1	3	1	1	-	-	1	1	1	-	-	1	1	1	-	1	4	1	-	-	3	2	-
IA3	Distance multiplexer	39	1	-	5	2	3	-	4	-	-	-	1	1	3	1	-	1	6	1	4	2	1	2	-	1	-	-
IA4	Heading processor	12	-	-	1	-	-	-	1	-	-	1	5	-	-	-	-	-	1	-	1	-	-	-	1	1	-	-
RCA	FLAIR radio	11	-	-	-	-	-	1	-	-	-	2	2	-	-	1	-	-	1	1	-	-	-	2	-	-	1	-
ODOM	Odometer	10	-	1	-	-	-	3	-	-	-	-	-	-	1	-	-	-	1	-	-	1	-	-	-	-	2	1
4AF	Four Amp fuse	15	-	-	-	-	-	-	3	-	-	1	1	-	1	-	-	-	1	-	1	1	1	-	-	2	3	-
PS	Power supply (from battery)	17	-	-	-	-	1	-	2	-	1	1	1	1	-	-	1	-	-	1	2	1	1	-	1	1	1	1
Component repair subtotal		189	2	6	8	4	10	6	12	0	3	10	21	9	5	3	3	2	13	5	15	12	4	5	4	13	12	2
Adjustments																												
Heading		75	3	2	5	2	3	2	3	1	1	6	8	4	2	2	2	1	3	3	4	3	1	2	2	5	4	1
Frequency		6	-	-	2	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Delay		13	1	1	2	-	-	-	1	-	-	-	1	-	1	-	-	-	-	1	1	-	-	1	-	-	3	-
Voltage regulator		3	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-
Adjustment subtotal		97	4	3	10	2	3	2	4	2	1	7	10	4	3	2	2	1	4	4	5	3	1	3	3	5	8	1
Miscellaneous																												
No problem located		15	3	1	-	-	-	-	-	-	1	1	-	1	1	-	-	-	3	-	-	1	-	-	-	2	1	-
Antenna lines		2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Miscellaneous subtotal		17	3	1	1	0	0	0	0	0	1	1	0	1	1	0	0	0	3	0	0	1	0	0	0	2	2	0
Total number of repair activities		303	9	10	19	6	13	8	16	2	5	18	31	14	9	5	5	3	20	9	20	16	5	8	7	20	22	3
Number of repair events		211	8	8	13	3	7	7	11	1	6	11	17	11	6	5	4	2	15	4	12	14	5	6	4	14	13	4

Table 9-8

Component Repairs

Component	July 3 to Sept. 13, 1975		Sept. 13 to Oct. 3, 1975 Special test		Total repairs	
	N	%	N	%	N	%
CPA	22	13	11	9	33	11
VDP	7	4	7	5	14	5
JAI	3	2	10	8	13	4
IA2	11	6	14	11	25	8
IA3	27	16	12	9	39	13
IA4	2	1	10	8	12	4
RCA	6	3	5	4	11	4
ODOM	7	4	3	2	10	3
4AF	11	6	4	3	15	5
PS	13	7	4	3	17	6
Subtotal	109	62	80	62	189	63
Adjustment						
Heading	34	20	41	32	75	25
Frequency	6	3	-	-	6	2
Delay	13	7	-	-	13	5
Voltage RFG	3	2	-	-	3	1
Subtotal	56	32	41	32	97	33
Miscellaneous						
No problem	7	4	8	6	15	5
Antenna	2	1	-	-	2	1
Subtotal	9	5	8	6	17	6
TOTAL	174	99	129	100	303	102

component repairs performed by the Department during the summer (7/3/75 to 9/18/75) is compared with the distribution of repairs performed with the assistance of a Boeing technician during the special test period. Some discernable patterns emerged as follows:

- The most recurrent repair problem was not a component failure, but a calibration failure of the heading (direction) sensor, requiring appropriate adjustment. During the summer period, this accounted for 20% of the total maintenance faults, and during the special test 32% for a composite total of 25%. The distribution of this problem was quite uniform among the 26 FLAIR equipped cars, where every car was calibrated at least once and only 2 cars were calibrated more than 5 times (one 6 and one 8). The average number of heading calibrations per car were 2.9 for a 3-month period or nearly once a month per car. If this rate should continue in Phase II, there would be nearly 200 calibrations per month and if each could be done in 15 minutes, 50 hours of a technician's time per month. Reasons for this poor performance should be investigated and corrections made.

- The coded message panel was also a large contribution to service problems. Eleven percent of all repairs were on this unit; the problem is believed to be caused by spilling coffee and other refreshments on the panel, which drip through the digital keyboard into the switches and other components. Boeing is modifying the design and mounting arrangement for Phase II for the purpose of overcoming this problem.

- The most trouble-free unit was the odometer (three percent of the total) and the modified RCA two-way radio(four percent of the total). Significant also was that only six frequency adjustments (two percent of total repairs) were made on the RCA radio during the three month period.

- For the 26 FLAIR equipped cars, there were 303 total repair activities for an average of 11.6 per car; seven cars had five or

less repairs and four had 20 or more (one had 31).

b. Maintenance and repair operations. During Phase I, the St. Louis MPD hired and trained two technicians for servicing the FLAIR equipment. The training was mostly on-the-job type with the Boeing technicians serving as instructors. Boeing technicians were on site performing the servicing and training duties until July 1, 1975--at which time the responsibilities were taken over by the MPD--except for the three week special test period when a Boeing technician was again assigned to help. Efficient service routines were hindered by:

- The lack of a suitable maintenance and repair manual. Very sketchy diagrams, parts list and servicing techniques were available due to the trial nature of Phase I. A proper manual will be available for Phase II.

- Difficulty in diagnosing trouble areas and defective components. In part, this was due to the technicians' unfamiliarity with the equipment including the lack of a history of faults and probable corrections. Also, this type of (digital) equipment requires special test instruments to diagnose quickly the trouble. Boeing will provide a specially designed "Fleet Monitor and Mobile Tester" in Phase II.

- The calibration site for the heading sensor was in a parking lot across the street from the repair facility and contained markings on the surface for heading directions (requiring the driver to position the car accurately in the marked directions). This area was sometimes occupied (illegally) by other parked cars, the surface markings were sometimes covered with snow and ice and the weather (rain and cold) made the adjustment process fairly miserable. For Phase II, Boeing is providing a rotatable non-magnetic platform upon which the car can be placed. Headings can be easily and quickly calibrated by rotating the platform--which

should greatly simplify this task. It is not known if a roof shelter will be provided.

- Adjustment of the time-slot delay requiring technicians at the base stations and at the repair facility with a telephone line between the two. Boeing has indicated a method has been developed permitting this adjustment to be made at the repair facility and without help at the base station.

- A suitable stock of spare parts and modules was not available. This should be alleviated in Phase II.

c. Unresolved issues. The St. Louis repair facility has been accustomed to the repair of communication equipment by replacing defective components; Boeing indicates agreement with this procedure on FLAIR equipment at the mother-board level, but has suggested complete replacement (on an exchange basis) of plug-in modules. The Boeing suggestion has merit in that it permits repair more rapidly (assuming that the test provided in the equipment permits isolation of defective modules faster than the component or adjustment at fault); and it places the responsibility for the test and suitable performance levels with the manufacturer (facilitated perhaps by test equipment used in production). The MPD method has merit because a replaced component (or adjustment) is less costly; inventory investment (components versus module assemblies) is substantially less; and at times an operable module might be inadvertently exchanged, an unnecessary expense. Perhaps a logical compromise would be for the MPD to replace modules where repair time is most important (base station equipment), and develop a program to eventually optimize component replacement in preference to module replacement in mobile equipment.

3. Repair crew workloads and vehicle availability. The mean time between failure (MTBF) and the mean time to repair (MTTR) can be used to estimate the number of technicians required at the repair facility. These factors (and others) also determine the number of spare FLAIR equipped patrol cars required to field a patrol force fully FLAIR equipped.

a. Number of technicians required. During Phase I, repair activity may be stated as follows:

Total repairs (July 3 to Oct. 3, 1975)	303
Mean time to repair (228 @ $1.05[18] hrs)	239.4 hours
Mean time to calibrate heading unit (75 @ .25[19] hrs)	18.8 hours
Total repair time (13 weeks)	258.2 hours
Repair time per week	20 hours
Repair time per car (26) per week	.77 hours

For Phase II, number of cars are 200, then

Repair time per week (.77 x 200)	154 hours
Number of 40-hour periods	3.85
Estimated technician utilization rate	50%[20]
Estimated total number of technicians required (Phase II)	8

If the MTBF and MTTR remain the same in Phase II implementation

[18] Boeing report, "Pilot Program Final Report", dated May 9, 1975.

[19] Estimated by Boeing field representative.

[20] Arrivals of defective equipment are not uniformly spaced, resembling more a totally random (Poisson) process. Some idle time must be anticipated, resulting in defective cars not always being in backlog, otherwise queuing delays until repair would be excessively long. Also, technicians spend time on non-repair matters such as locating parts, preparing reports/records, coffee breaks and other interruptions. It is assumed that 50% of his time is actually spent repairing FLAIR equipment.

CONTINUED

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as experienced in Phase I, the above data suggest a total of eight technicians would be required for maintenance of the FLAIR equipment in the vehicles. However, it is expected that Phase II equipment will be more reliable and the technician efficiency will improve due to better instrumentation and additional experience. If the reliability is improved by 2:1 and the efficiency by 25% the technician requirements for the FLAIR mobile equipment will be three. However, recognizing that FLAIR malfunctions could occur any day in the week, and any time of the day, it could be argued that a technician capable of repairing FLAIR should be on duty at all times. If such a policy were followed the number of technicians required would increase from three to five, including 4.2 forty-hour periods and allowing for holidays, vacations, etc. This manning arrangement would minimize the number of FLAIR-equipped spare patrol cars required for replacing those being serviced.

An alternate and perhaps preferred manning arrangement would be to have two technicians scheduled each of the seven days, with one on day time shift, from 7 am to 4 pm, and the other from perhaps 1 pm to 10 pm. This arrangement provides a three hour overlap which is believed necessary for communicating status of repairs in process and for diagnosing difficult problems. It is expected that the computer prepared Daily Summary Report on car (FLAIR) performance will be run early each morning (e.g. 7 am) and will designate most of the cars needing service attention. If this proves true the day/evening arrangement as proposed here would be the best time to service the cars. The backlog of defective cars

accumulating during the night, which would require spare cars, may not be excessive. This alternative manning arrangement would then require three technicians plus one to fill in for holidays, vacations, etc., for a total of four.

b. Spare car requirement. Again, referring to Phase I, repair activity may be stated as follows:

Total repairs (13 weeks)	303
Average repairs per day (91 days)	3.33
Average repairs per day per car (26 cars)	0.13

For Phase II, the number of cars is 200, then:

Total spare cars per day (.13 x 200)	26 cars
Total spare cars with 2:1 improvement in reliability	13 cars

Assuming a four hour turn-around time for repairs, then:

For a full 3-shift schedule, number of spare cars required are $\frac{13}{6}$ =	2.2 or 3 cars
For two overlap shifts, number of spare cars required are $\frac{13}{3}$ =	4.4 or 5 cars

The above estimation of spare car requirements is for FLAIR service only. Spare cars to replace patrol cars being serviced for communication equipment problems and for mechanical maintenance or repair are additional to that required for FLAIR. During Phase I, records on the frequency and duration of such non-FLAIR service could not be obtained, but the St. Louis MPD should estimate the additional needs so that an adequate quantity of FLAIR-equipped spare cars will be avialable. The special three week test demonstrated the importance of having a full complement of FLAIR cars in the field, for a smooth functioning dispatching process.

The above calculations are based on averages and other assumptions. If the probability of uneven timing between repair events and unequal duration of repairs is to be considered, then the number of FLAIR-equipped spare cars required will increase, or conversely, the number of non-FLAIR cars in the system will increase. It is expected that experience will finally determine the number of spares required; also, with additional data on non-FLAIR repairs, PSE will construct a mathematical model that can be used for more accurately estimating these requirements, during Phase II evaluation.

4. Expectations for Phase II. It is anticipated that reliability of Phase II equipment will be substantially better than Phase I, due to improvements in methods and process. Time to repair and quality of repair should be improved due to new test facilities, including a Heading Alignment Fixture, an Odometer Calibration Kit and a Fleet Monitor and Mobile Tester. Base station down time should be greatly reduced by the standby computer. Identifying cars in need of FLAIR repair should be greatly facilitated by the daily computer report showing those cars that are most likely to have defects. Areas of continued concern are:

- The high rate of heading sensor calibrations.
- Institution of periodic scheduled maintenance checks for such purposes as odometer calibration (tire wear), heading sensor calibration, radio frequency checks, etc.
- The performance and reliability of the new digital processing format (see Chapter IX) providing 200 cars per channel and the effect of more fully loaded channels.

In summary, high reliability and timely maintenance are vital

to the long term success of the system. Any slackening.in these areas can result in gradual decrease in accuracy of the system, increase in the frequency of lost cars, loss of confidence in the system and even lack of use of the system.

SCOPE

CHAPTER X: ATTITUDINAL ANALYSIS AND ORGANIZATIONAL IMPACT

A. Introduction. B. Evaluation Design: *Survey Design; Survey Administration.* C. Results of the "Before" Surveys in the Third and Fifth Districts: *General Description of Officers and Their Attitudes toward Police Work; General Attitudes toward FLAIR; What Factors Influence Attitudes toward FLAIR; Influence of FLAIR on Police Activities.* D. Results of the Surveys Conducted after the Implementation of FLAIR: *Analysis of the Second Third District Survey; Analysis of the Second Fifth District Survey.* E. Dispatcher Survey: *General Attitudes toward FLAIR; Influence of FLAIR on Dispatcher and Police Activities; Dispatcher Confidence in FLAIR and Their Evaluation of Benefits versus Costs.* F. Summary Analysis of the Survey Results: *General Attitudes toward FLAIR; Influence of FLAIR on Police Activities; Influence of FLAIR on Police Patrol; Effects of the Special Three-Week Test on Third District Officers.* G. Implications of the Attitudinal Analysis for the Phase II Implementation: *The Link between Operations and Attitudes; Involvement and Training of Police Personnel; The Interface between Technological and Human Factors; Involvement of Top Police Supervisors; Long-Term Commitment and Continuity of Personnel over Time.*

Reader's Guide to Chapter X: This chapter provides an analysis of some of the attitudinal and organizational implications of implementing an AVM system in St. Louis. The results of surveys of field and dispatcher personnel conducted both "before" and "after" the implementation of the Phase I system will be discussed. In addition, the implications of this attitudinal analysis for the Phase II implementation will be reviewed, and recommendations for the future will be discussed. Since many readers may be interested in the details of the survey results, a large number of tables are included in this Chapter, particularly in Sections C, D and E. However, if the reader is primarily interested in a more rapid overview, we would suggest that they read Sections A and B which provide an introduction and outline of the evaluation design, skim Sections C, D and E, which provide a detailed review of the "before" and "after" surveys, and then read Sections F and G which summarize some of the highlights of the surveys and outline the implications and recommendations for Phase II.

CHAPTER X: ATTITUDINAL ANALYSIS AND ORGANIZATIONAL IMPACT

A. Introduction

The implementation of new technology in law enforcement--such as establishing an automatic vehicle monitoring (AVM) or computer-aided dispatch (CAD) system--is a complex process. It means more than simply introducing technological change. Such innovations also have important behavioral and organizational impacts. For example, if the FLAIR*System is functioning from a technical perspectvie, the dispatcher (and potentially the police supervisor) will know the status and location of all police units at all times. Implemented successfully on a city-wide basis, the system could have a real impact on the management and control of police resources and the relationship between command staff and the police officers "in the street". In turn, the way police officers perceive such impacts will have an important influence on their attitude and support toward FLAIR, and the actual long term success or failure of the system. In fact, survey and case study research on the use and implementation of new technology by the police has demonstrated that some of the most important factors influencing implementation are behavioral and interpersonal.

In 1971 and 1974 Colton conducted surveys sponsored by the International City Management Association on the use and impact of computers by the police. One of the conclusions of the two surveys was that "the primary problems faced by the police in

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* FLAIR is a trademark of the Boeing Company.

using the computer are not technical, but behavioral and people oriented".[1] In both 1971 and 1974 the greatest difficulties which were identified had to do with human factors including scheduling and setting priorities, training police personnel to use the system, and patrol officer and management acceptance. Further, in a recent study by the Rand Corporation on modeling efforts in the criminal justice field, a study was made to determine what factors contributed to the failure of models to achieve the level of use for policy decisions which had originally been intended. It was found that the primary problems rested not with the attributes of the models themselves, but with the characteristics of the user agencies and in the interactions between model builders and user agencies.[2]

Realizing the impact of behavioral and human dimensions, one of the three basic components of the evaluation of an implemented AVM system was to examine the attitudinal and behavioral aspects of the new technology in St. Louis. Special surveys of both officers and dispatchers were designed and conducted before and after the Phase I experiment both in District 3, and in a control district, District 5. The purpose of this evaluation was twofold:

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[1]See Kent W. Colton, "Computers and the Police: Police Departments and the New Information Technology", Urban Data Service, November, 1974, International City Management Association.

[2]See J. Chaiken, T. Crabill, L. Holliday, D. Jaquette, M. Lawlis, E. Quade, Criminal Justice Models: An Overview, Rand Corporation, October, 1975, Rand Report #R-1859-DOJ, Santa Monica, California, particularly Chapter 7.

- to look closely at the attitudes and feelings of the members of the St. Louis Police Department toward the system and to examine any changes in feelings they may have experienced as a result of implementing FLAIR

- to begin to examine what implications, if any, the new AVM System might have on the patrol operations and/or organization of the M.P.D.

Since only Phase I of the FLAIR System was implemented during this evaluation and the implementation occurred only in District 3, little impact can be expected so far concerning the organization and operation of the police department. The primary focus of this chapter will therefore be to examine the attitudes of the personnel in the St. Louis M.P.D. and how those attitudes evolved with the implementation of the Phase I System. After an explanation of the evaluation design, the next three sections of the chapter will report on:

- the results of the surveys that were conducted in the Third and Fifth Districts prior to FLAIR

- the results of the surveys made after the FLAIR implementation

- the results of the dispatcher surveys.

Besides asking about the general attitudes of the patrol officers toward the new system, the surveys also raised questions about the influence of FLAIR on police operations. Realizing that conclusions in this area are still by necessity tentative, enough has been learned to begin to point out potential impacts for the future and to highlight those areas which should receive special attention during the implementation and evaluation of Phase II.

The last two sections of this chapter will therefore address these topics as they present a summary analysis of the survey results and outline conclusions regarding the Phase II implementation of FLAIR.

B. Evaluation Design

At the outset of the project the attitudinal and behavioral analysis was designed to be carried out in three parts. First, a survey was conducted "before" the implementation of the FLAIR System in order to obtain the initial attitudes, perceptions and expectations of the sworn personnel in both the experimental district, District 3, and the control district, District 5. Second, interviews were conducted "after" the system had been in operation for approximately four months. At this time the officers in Districts 3 and 5 were once again surveyed in an attempt to guage any changes in attitudes or perceptions about FLAIR or police work in general. Third, the final portion of the research will be conducted after the Phase II System is implemented city-wide. A sampling of all officers in the St. Louis M.P.D. will be surveyed regarding their attitudes and reactions toward the system. This survey will not only provide overall evaluation data, but it will provide further comparison with the previous data from the Third and Fifth Districts.

Right from the outset, the objective of the evaluation was to obtain a broad sample of police opinion while at the same time to probe specific responses in greater depth. To do this a two-part survey methodology was developed. The primary source of information was from written surveys which were administered to

the majority of the members of the Third and Fifth Districts. As a secondary source of data, oral interviews were conducted on a selective basis (only in the Third District) to fill in gaps from the written answers and to help the evaluators to probe the reasons behind the simple "yes" or "no" type responses to the written survey.

1. Survey Design. The survey was designed to guage three types of information:

- basic demographic information concerning police personnel
- general feelings toward FLAIR and police work
- information concerning expectations toward FLAIR and its impact on police activity.

The demographic factors that were of most interest were years as a policeman, education, and whether or not the officer was currently taking any courses for credit. In order to obtain the general attitude toward FLAIR questions were included concerning whether or not officers thought it was a "good idea" or whether it would justify the costs. Among the questions concerning the expectations toward FLAIR and its impact on police activity were inquiries about the effects of FLAIR on particular patrol fuctions, the quality of police work, and departmental discipline.

During the "before" survey it appeared desirable to word the surveys differently for sergeants and patrol officers in both the Third and the Fifth Districts. As a consequence four surveys were designed and they are included as Surveys 1-4 in Appendix D. In the second set of "after" surveys it was decided that the distinction between patrolmen

and sergeants was unnecessary, and identical surveys were used for both ranks, although different surveys were designed for Districts 3 and 5. (See Surveys 5 and 6 in Appendix D.)

The specific survey instrument was developed in consultation with the St. Louis M.P.D. and Boeing. An initial draft was prepared by PSE personnel and then circulated for comment and modification.[3] Based on this review, a modified instrument was administered on a "pre-test" basis for patrolmen and sergeants in District 3. After each completed survey, they were asked for comments concerning the wording and content of the form. A final version was then formulated and approved by the M.P.D.

2. Survey Administration. The surveys were administered to the Third District officers who reported for duty during the time periods of August 1 - August 4, 1974 and March 31 - April 4, 1975. Surveys in the Fifth District were conducted August 5 - August 9, 1974 and June 18 - June 22, 1975. Table 10-1 indicates the number of men that were surveyed in each District during each time period. An interviewer was present at each shift at least three times over each of the five days. The Watch Commander provided the interviewer with a duty roster listing every officer (and his radio call number) on duty. As officers became available on the street they were recalled to the station to fill out the survey

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[3]PSE also received the special consultation of Dr. Jack Fowler, Director of the Survey Research Program of the University of Massachusetts and the Joint Center for Urban Studies of M.I.T. and Harvard.

Table 10-1

Third District Surveys

	Approximate number of field personnel assigned to the Third District*	Number of officers surveyed	Percent surveyed
"Before" survey, August 1 - August 5, 1974	215	166	77%
"After" survey, March 31 - April 4, 1975	205	119	58%

Fifth District Surveys

	Approximate number of field personnel assigned to the Fifth District*	Number of officers surveyed	Percent surveyed
"Before" survey, August 5 - August 9, 1974	120	74	62%
"After" survey, June 18 - June 22, 1975	120	64	53%

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*Including sergeants.

on department time. Space was provided in the station for the surveys to be filled out away from the main stream of traffic. If more than two officers reported to complete the questionnaire, they were separated into different rooms. An interviewer was present to answer any questions regarding the procedure for filling out the surveys. Upon completion, each officer was instructed to place his survey into a blank envelope, seal it, and then place it in a box. This procedure was necessary to assure officers that their responses would remain anonymous and that only outside evaluators would see the completed forms. Police personnel are often suspicious and it was feared that without such methods personnel would not give honest and candid answers.[4]

After the "before" surveys were complete, individual oral interviews were conducted selectively in the Third District with a place chosen for the oral interview away from the general flow of traffic. Waiting until after the written surveys had been administered allowed the evaluators to examine responses and direct the oral interviews into more interesting and meaningful areas. In conjunction with the "before" surveys officers to be interviewed orally were selected somewhat randomly from the platoon rosters and interviews were conducted in a fairly formal manner. About 5% of the men in the Third District received oral interviews. During the second round of "after" surveys, though, oral interviews

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[4]At one point, it was contemplated that officers would be given a number so as to allow for comparisons of the "before" and "after" survey results. However, the fear that this would inhibit candid responses lead the researchers to discard this proposal.

were conducted by PSE personnel on a more informal basis while "riding patrol" with the men in the Third District. Essentially no oral interviews were conducted in the Fifth District.

C. Results of the "Before" Surveys in the Third and Fifth Districts

This section will examine the results of the first "before" surveys which were conducted in the Third and Fifth Districts prior to the implementation of the FLAIR System. It will report on the demographic description of the officers in both districts, their attitude toward police work in general and FLAIR in particular, and their specific expectations concerning the impact of the new system.

1. <u>General discription of officers and their general attitudes toward police work</u>. Only slight differences emerged in the composition of the two police districts. Even though the breakdown of surveyed officers by rank is almost identical--89.8% patrolmen in District 3 as compared with 89.2% patrolmen in District 5--District 5 has, on the average, a slightly less experienced patrol force. Table 10-2 is a cumulative distribution of the number of years as a policeman. The average officer in District 3 has almost eight months more experience than the average District 5 officer. This is apparent in the large percentage of first and second year officers in District 5 as compared to District 3.

The average District 3 officer also appears to be slightly more educated than his District 5 counterpart (Table 10-3). This may be only temporary, though, because the slightly younger

Table 10-2

Cumulative Distribution
of Years as a Policeman
for District 3 and District 5

Years as a Policeman	District 3 %	District 3 cumulative %	District 5 %	District 5 cumulative %
1	5.5	5.5	12.2	12.2
2	16.4	21.8	20.3	32.4
3	11.5	33.3	5.4	37.8
4	12.7	46.1	18.9	56.8
5	11.5	57.6	5.4	62.2
6	7.9	65.5	2.7	64.9
7	4.2	69.7	5.4	70.3
8	4.8	74.5	1.4	71.6
9	3.0	77.6	8.1	79.7
10	1.8	79.4	1.4	81.1
11	1.8	81.2	1.4	82.4
12	.6	81.8	5.4	87.8
13	1.2	83.0	1.4	89.2
14	.6	83.6	0.0	89.2
15	1.8	85.5	1.4	90.5
16 - 20	6.0	91.5	2.8	93.2
21 - 25	3.6	95.2	2.7	95.9
25+ years	4.8	100.0	4.1	100.0
	Mean = 7.6 years		Mean = 6.9 years	

Table 10-3

Education Levels

Highest education level attained	District 3 (% of responses)	District 5 (% of responses)
high school or equivalent	29.3	32.4
some college	60.4	58.1
bachelors degree	8.5	9.5
some graduate work	1.8	0.0
taking classes	24.8	33.8

District 5 officers have yet to complete their educational plans. Over one-third of the District 5 patrolmen are still attending classes while slightly less than one-quarter of the District 3 officers reported that they were still in school.

One of the first questions asked in both the Third and Fifth Districts was "how satisfying do you find your profession as a policeman?" As the information in Table 10-4 indicates, the officers in District 3 were far more likely than those in District 5 to find their work very satifsying. Almost two-thirds in District 3 stated they were very satisfied compared to only slightly over one-half in District 5. Only 3% of the District 3 policemen were "not very" satisfied as compared to an 8.1% negative response in District 5.

Table 10-4

Job Satisfaction

Current satisfaction with job as a policeman	District 3 (% of responses)	District 5 (% of responses)
very satisfying	66.9	52.7
fairly satisfying	30.1	39.2
not very satisfying	3.0	8.1

Although the general attitude towards police work is probably unrelated to FLAIR initially, it is possible that job satisfaction will contribute to the willingness of officers to accept an innovation such as FLAIR. For example when asked to speculate on how FLAIR would effect the way they felt about their job in the future, District 3 officers were again more positive than their District 5 counterparts. Table 10-5 shows that the balance of the policemen in both districts felt that FLAIR would not change the satisfaction police work gave them. However, one-third of the District 5 officers thought the anticipated implementation of FLAIR would lessen the satisfaction they received from being a policeman, while only 21.5% of the District 3 officers responded likewise[5].

[5]A statistical test was carried out to see if there was any statistically significant relationship between current job satisfaction and projected satisfaction under the FLAIR System. The test proved to be negative, however.

Table 10-5

Projected Job Satisfaction

Projected impact of FLAIR on job satisfaction	District 3 (% of responses)	District 5 (% of responses)
more satisfying	19.6	4.2
same	58.9	62.5
less satisfying	21.5	33.3

2. General attitudes toward FLAIR. Even though the selected demographic factors were similar for Districts 3 and 5, the general attitudes of the personnel toward police work and FLAIR were very different. The factors contributing to these differences will be discussed in greater depth later. However, it is important to note that prior to the time of the survey, 89% of the officers in the Third District had attended a FLAIR orientation session conducted by Boeing. The District 5 officers were not given the same opportunity. Although the differences in attitude between District 3 and District 5 officers cannot necessarily be attributed solely to the FLAIR seminar, the training session did seem to have an important influence in preparing officers for the introduction of the new system.

When asked whether or not they thought FLAIR was a "good idea", District 3 officers responded favorably by almost a two-to-one margin while District 5 personnel responded negatively in an almost reverse ratio. (See Table 10-6.) This question is significant

for several reasons. First, it highlights a major difference in response between the two districts (to be discussed in the next section). More importantly, it indicates the generally positive attitude towards FLAIR which many of the officers in the Third District had at the beginning of the experiment. This initial attitude will serve as a baseline for later comparison.

Table 10-6

Do you think FLAIR is a good idea?	District 3 (% of responses)	District 5 (% of responses)
yes	64.4	36.4
no	35.6	63.6

Peer pressure is an important factor in influencing police attitudes, and questions concerning this influence further demonstrate the differences in initial feelings between the two Districts. (See Table 10-7.) When asked to anticipate the responses of their fellow officers,the reaction in District 3 was essentially split with three out of ten feeling officers would be for it, and three out of ten feeling most would be against it. District 5 officers were considerably more negative with only one out of ten feeling that most officers would be for it, and four out of ten feeling most would be against it. The importance of peer pressure is even more strikingly demonstrated when responses as to whether officers think FLAIR is a good idea are compared with expectations as to how an officer feels his or her peers will feel toward the system. Of the three out of ten officers in District 3

who felt that most of their fellow officers would be for FLAIR, every single one also felt that FLAIR was a good idea. (Table 10-9.)

Table 10-7

How do you think most patrolmen will feel about FLAIR?	District 3 (% of responses)	District 5 (% of responses)
most will be for it	29.9	12.9
about 50-50	40.2	47.1
most will be against it	29.9	40.1

FLAIR's effect on an officer's ability to do his job was also viewed differently in each district (see Table 10-8). The majority (51.4%) of the District 5 officers expected no difference with FLAIR. However, this view was held by only 39% of the District 3 officers. The largest segment (40.9%) of the District 3 officers anticipated that FLAIR would actually help them perform as policemen. This is about double the percentage of officers in District 5 who expected that FLAIR would have a positive influence on their ability to do their job.

Table 10-8

How do you think FLAIR will affect you ability to do your job?	District 3 (% of responses)	District 5 (% of responses)
help	40.9	20.8
no difference	39.0	51.4
hinder	20.1	27.8

Table 10-9

Cross Tabulation Between Personal Attitudes toward FLAIR and Expected Attitudes of Other Officers *

District 3

Indication as to how most patrolmen will feel about FLAIR	Attitude toward FLAIR: Good idea	Attitude toward FLAIR: Not a good idea
Most will be for it	49	0
About half-and-half	40	23
Most will be against it	14	33

District 5

Indication as to how most patrolmen will feel about FLAIR	Attitude toward FLAIR: Good idea	Attitude toward FLAIR: Not a good idea
Most will be for it	7	2
About half-and-half	15	14
Most will be against it	2	25

* This table is a listing of actual responses rather than a cross tabulation of percentages.

3. <u>What factors influence attitudes towards FLAIR</u>. One of the most interesting questions raised by the results of the survey is what factors seem to influence the differences in the attitude of the officers towards FLAIR. This question is important both in terms of differences <u>between</u> District 3 and District 5 and <u>within</u> the two districts themselves.

What accounts for the variations <u>between</u> Districts 3 and 5? First, it was mentioned earlier that the officers in District 3 had received a special orientation session from Boeing concerning the purposes and operations of the FLAIR system. District 5 officers had received no such briefing and as such they were uninformed concerning many aspects of FLAIR. Rumors and misunderstandings can spread quickly if they go unchecked, and appropriate communication and training is therefore essential in the introduction of any new innovation. However, probably more than simply one training session contributed to the more positive attitude toward the FLAIR System on the part of the District 3 patrolmen. There is an important psychology in being chosen for an experiment. The people in District 3 had been told that they were special and that they were going to be the first in the M.P.D. to participate in the introduction of a new system, a system which could bring national prominence to the St. Louis police force. Although, according to the oral interviews this "limelight" caused a few of the officers to react in an extremely negative fashion (in fact, one man was transferred from the District because of his strong negative attitude), it seems that the majority felt that this was a positive

factor, and they were willing to give FLAIR a chance.

The next question is what factors seemed to influence attitudes toward FLAIR within the two Districts? Although the primary purpose of the survey was to obtain documentation of police officer perceptions of the FLAIR System, at the beginning of the survey, a few simple hypotheses were proposed concerning what things would influence officer reaction toward the system. Each of these will be discussed below:

- the initial source of information about FLAIR will effect acceptance of the system
- the better informed an officer feels about the system, the more likely he is to accept the system
- "acceptance" of FLAIR will correlate positively with job satisfaction
- the longer a police officer has been on the force, the less likely he will be to favor a change such as the FLAIR System
- a higher level of education will correspond to an increased tendency to favor the FLAIR System.

a. Initial source of information. It is interesting to examine the first source of information concerning the FLAIR System and whether or not this source influenced attitudes toward the AVM system. Table 10-10 indicates that in both districts the most common source was other patrolmen, and Districts 3 and 5 are quite similar in terms of the percentage of personnel who first heard about FLAIR from patrolmen or sergeants. The significant differences then lie in the fraction of officers citing command officers, Patrolman's Association, and the media as their initial information

Table 10-10

Source of initial information on FLAIR	District 3 (% of responses)	District 5 (% of responses)
patrolman	25.6	28.8
sergeant	8.5	9.6
command officer	18.9	27.4
Boeing representative	11.0	*
Patrolman's Association	7.9	11.0
newspaper, TV, or radio	22.6	16.4
other	5.5	6.9

Table 10-11

Cross-tabulation of Source of Initial Information vs. Whether or Not FLAIR is a Good Idea

	District 3 (% of responses)		District 5 (% of responses)	
Source of information	Good idea	Not a good idea	Good idea	Not a good idea
patrolman	21.4	6.7	6.6	24.6
sergeant	5.4	3.4	4.9	3.3
command officer	11.4	7.4	13.1	18.0
Boeing representative	8.7	3.4	*	*
Patrolman's Association	3.4	4.7	1.6	11.5
newspaper	15.4	8.7	9.8	6.6
	65.7	34.3	36.0	64.0

*Boeing personnel had not made a presentation to District 5 officers.

source. (While conducting the surveys in the Fifth District it became clear that the large fraction of District 5 responses referring to a command officer as a source was attributed to the fact that District 5 had a very active lieutenant who was personnaly interested in the FLAIR System and undertook to explain it to the officers under his command.)

Does the initial source of information affect the views concerning FLAIR? An examination of Table 10-11[6], a cross-tabulation of the initial source of information with whether or not the respondent thought FLAIR was a good idea, suggests that it does. In District 3, where all officers favored FLAIR by a two-to-one margin, those officers citing other policemen as their initial source of contact with FLAIR favored the system by better than three-to-one. In District 5, where FLAIR was in disfavor by two-to-one, the officers citing other officers as first contact disfavored FLAIR by almost four-to-one. In each case, what appears to be operating is a strong peer pressure which reinforces itself as time passes. This further demonstrates the importance of peer pressure in police attitudes.

A second source, which seemed to affect opinion is the Patrolman's Association. The Patrolman's Association was the only source which correlated with an unfavorable view of FLAIR in both District 3

[6]In Table 10-11 and subsequent cross-tabulations, it is possible that columns and rows of the tables will not necessarily sum to the same percentabe responses presented in the frequency listings. This is due to the fact that responses are not used in the cross-tabluations unless they answer both questions.

5. In District 5, respondents citing the Patrolman's Association as their initial source of information voted against FLAIR by over seven to one[7].

b. Level of information about the new system. How well informed the officers felt about different aspects of the FLAIR project also influenced their perceptions of whether they thought it was a good idea. Officers were asked to respond on how well informed they felt about the goals of the FLAIR System, how they would operate it, and how the supervisors would use it. Table 10-12 summarizes the results for Districts 3 and 5 and the differences between the two are predictable. As a result of the orientation by Boeing, District 3 officers felt (and were) much more informed about the system. However, even after the orientation, District 3 officers were still unclear as to how their supervisors might use the system. This is probably because Boeing personnel were primarily responsible for the presentation, and understandably, concentrated on explaining why the police force needed FLAIR and on teaching the use of the system. It was neither Boeing's place nor intention to explain how supervisory personnel would use it. Also, at the time that the surveys were being administered the M.P.D. staff had not clearly identified the procedures and policy concerning the supervisory aspects of FLAIR.

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[7] It is interesting to note that the Patrolman's Association in St. Louis was using information to discredit FLAIR which it received from the Patrolman's Association in Wichita, Kansas, where Boeing first tested the AVM system.

Table 10-12

Tabulation of how Informed Officers Felt about Three Aspects of FLAIR System

How well informed they felt:	District 3 (% of responses)	District 5 (% of responses)
about goals		
very well	41.2	13.0
fairly well	48.5	50.7
not very well	10.3	36.2
about the operations of the system		
very well	33.9	11.6
fairly well	60.0	42.0
not very well	6.1	46.4
about how supervisors would use it		
very well	20.1	16.2
fairly well	40.9	10.1
not very well	39.0	64.7

If one assumes that an AVM system is beneficial, it is reasonable to expect that the more informed a person feels about the system the more likely that person is to favor it. This type of behavior is exhibited by cross-tabulating how well informed the officers felt about operating the system with whether or not they thought FLAIR was a good idea (Table 10-13). Even though Districts 3 and 5 responded very differently to the "good idea" question, officers in both districts were more likely to favor FLAIR when

they felt very informed about its operation. This same behavior was demonstrated for questions on familiarity with the system goals and supervisor use of FLAIR.

Table 10-13

Cross-tabulation of how Well Informed about Operation of System by whether or not it is a Good Idea

How well informed about the operations of the system	District 3 (% of responses) Good idea	District 3 (% of responses) Not a good idea	District 5 (% of responses) Good idea	District 5 (% of responses) Not a good idea
very informed	25.8	9.5	7.9	4.8
fairly informed	35.8	23.3	14.3	23.8
not very informed	2.5	3.1	14.3	34.9
	$x^2 = 4.093$	df = 2	$x^2 = 3.093$	df = 2
	significance ≃ .85		not significant	

c. Other factors influencing attitudes: job satisfaction, length of police service, level of education. Although the first two hypotheses--the initial source of information and how well informed the officers felt--both seemed to have a positive correlation on whether or not patrolmen thought FLAIR was a "good idea," it is interesting to note that the other three factors--job satisfaction, length of time on the force and level of education--all seem to have little influence on attitude. Table 10-14 indicates that although whether an officer is satisfied with his work seems to have some influence on his attitude toward FLAIR (for example, those in District 5 who are very satisfied are less negative towards the system than other officers), overall the correlation, particularly for District 3, has a low level of statistical significance--clearly less than what was postulated before the survey.

Table 10-14

Cross-tabulation of Job Satisfaction by whether or not FLAIR is a Good Idea

	District 3 (% of responses)		District 5 (% of responses)	
Job satisfaction	Good idea	Not a good idea	Good idea	Not a good idea
Very satisfying	43.2	23.1	22.4	28.4
Fairly satisfying	20.6	10.0	11.9	28.4
Not very satisfying	0.6	2.5	1.5	7.4
	64.4	35.0	35.8	64.2
	x^2=.069 df=1* not significant		x^2=2.065 df=1* significance≈.85	

Time on the force also seems to have little impact on attitude. In fact it is interesting to note that those who have been on the force the longest seem to have the most positive attitude towards FLAIR in both Districts 3 and 5. (See Table 10-15.) (This may be explained by the fact that the sergeants were generally positive towards the system and had also been on the force the longest period of time.) Also, although those with some college or a bachelors degree in Destrict 3 seem to be more favorable towards FLAIR than those with only a high school education, the correlations in either Districts 3 or 5 are not statistically significant. (See Table 10-16.)

Table 10-15

Correlation Between Years on the Force and Attitude toward FLAIR

Years on the force	District 3 (% of responses) Good idea	Not a good idea	District 5 (% of responses) Good idea	Not a good idea
1 year	3.1	2.5	4.4	5.9
2 years	10.7	5.7	7.4	14.7
3-5 years	23.3	12.6	11.8	20.6
6-10 years	12.0	9.4	2.9	16.2
11+ years	15.7	5.0	8.8	7.3
	64.8	35.2	35.3	64.7
	x^2=3.265 df=4 not significant		x^2=4.260 df=4 not significant	

Table 10-16

Correlation Between Level of Education and Attitude toward FLAIR

Level of education	District 3 (% of responses) Good idea	Not a good idea	District 5 (% of responses) Good idea	Not a good idea
High school or equivalent	17.1	12.7	11.9	16.4
Some college	39.2	21.5	20.9	40.3
Bachelors degree	7.6	1.9	3.0	7.5
	63.9	36.1	35.8	64.2
	x^2=2.549 df=2 not significant		x^2=.536 df=2 not significant	

4. Influence of FLAIR on police activities. Four topics will be discussed concerning the influence of FLAIR on police activity: (1) the importance and effect on various aspects of police performance, (2) the influence on police patrol, (3) disciplinary concerns, and (4) benefits compared to costs.

a. The importance and effect on police operations. In an effort to ascertain which police related goals the officers saw as important and how they anticipated the FLAIR System would affect these goals, the officers were asked in two different questions to rate first the importance and second the expected influences of FLAIR on six aspects of police operations: dispatching the nearest officer, officer safety, availability of non-patrol vehicles for emergency calls, preventing crime, keeping track of the patrol force, and radio congestion. An opportunity was provided to suggest others, but no significant factors were identified.

The responses from both Districts 3 and 5 to the first question concerning importance are summarized in Table 10-17. Understandably, over 78% of the officers in both districts thought officer safety was very important, and this factor was clearly the number one feature of FLAIR as far as the men were concerned. Only one other factor, dispatching the nearest officer, was guaged to be very important by over a majority of officers in both districts. A third factor, radio congestion was cited as very important by 52.8% of the District 3 officers compared to 44.3% of the Fifth District personnel. (However, radio congestion was still the third highest factor mentioned by officers in both the Third and

Table 10-17

Perceived Importance of Six Aspects of Policework

	District 3 (% of responses)	District 5 (% of responses)
Dispatching nearest officer		
very important	65.1	62.2
fairly important	26.5	29.7
not important	8.4	8.1
Officer safety		
very important	78.7	78.4
fairly important	15.2	10.8
not important	6.1	10.8
Availability of non-patrol officers for high priority calls		
very important	48.2	40.3
fairly important	31.7	44.4
not important	20.1	15.3
Preventing crime		
very important	32.7	35.6
fairly important	32.7	34.2
not important	34.5	30.1
Keeping track of the patrol force		
very important	33.7	26.0
fairly important	34.4	32.9
not important	31.9	41.1
Reducing radio congestion		
very important	52.8	44.3
fairly important	36.0	35.7
not important	11.2	20.0

Fifth Districts.) Preventing crime and keeping track of the patrol force held the lowest ratings in both districts.

What kind of impact is FLAIR expected to have on these six aspects of police work? Table 10-18 summarizes responses to the second question: "How will the FLAIR System affect performance?" Interestingly, keeping track of the patrol force is perceived as being the area where FLAIR will have the greatest impact on performance in both Districts 3 and 5.

About 78% of the patrol officers in District 3 expected safety to improve, but only 54.8% of the force in District 5 felt the same. (The training seminar in District 3 had stressed officer safety.) Reduced radio congestion and dispatching the nearest officer are other areas where FLAIR is expected by officers in both Districts 3 and 5 to improve performance. Once again few officers in either District think that FLAIR will have a major influence on preventing crime.

b. Influence of FLAIR on police patrol. In a further effort to examine the impact of FLAIR on patrol activities, officers were also asked to rate how they felt FLAIR would alter four patrol tasks: the time spent on preventive patrol, flexibility to follow individual hunches, coordinated operations with fellow officers, and quickness to respond to emergency calls. (See Table 10-19.) Both districts responded similarly. Once again, "quickness of response" (which is closely related to the idea of dispatching the nearest officer) received a high rating by both Districts. At the outset of the FLAIR experiment, response time was clearly

Table 10-18

How will the FLAIR System affect Performance?

	District 3 (% of responses)	District 5 (% of responses)
Dispatching nearest officer		
improve	75.3	73.6
no effect	23.5	22.2
worsen	1.2	4.2
Officer safety		
improve	77.9	54.8
no effect	19.6	38.4
worsen	2.5	6.8
Availability of non-patrol officers for high priority calls		
improve	56.3	46.5
no effect	37.6	49.3
worsen	6.1	4.2
Preventing crime		
improve	31.1	20.5
no effect	64.6	72.6
worsen	4.3	6.8
Keeping track of the patrol force		
improve	80.6	76.7
no effect	13.9	20.5
worsen	5.5	2.7
Reducing radio congestion		
improve	74.7	68.7
no effect	22.2	22.4
worsen	3.2	9.0

Table 10-19

Anticipated Influence of FLAIR on Four Aspects of Patrol

	District 3 (% of responses)	District 5 (% of responses)
Preventive patrol time		
increase	22.7	26.0
stay the same	70.6	65.8
decrease	6.7	8.2
Flexibility to follow hunches		
increase	13.7	2.7
stay the same	35.4	39.7
decrease	50.9	57.5
Coordinated operations with fellow officers		
increase	24.5	18.3
stay the same	37.4	46.5
decrease	38.0	35.2
Quickness of response		
increase	63.4	62.5
stay the same	34.8	31.9
decrease	1.8	5.6

Table 10-20

How Do You Think FLAIR Will Affect Discipline in the Department?

Effect on discipline	District 3 (% of responses)	District 5 (% of responses)
make it fairer	10.3	2.7
make no difference	31.5	27.4
make it less fair	58.2	69.9

perceived to be one of the most significant impacts of the FLAIR System, by both the officers in the street and those sponsoring the innovation. Both districts also responded similarly to the preventive patrol questions, in this case expecting essentially no change. However, no clear trend emerged between the districts as to the projected effect on coordinated operations between patrol units.

It is interesting to note that the officers in each District expected a decrease in flexibility to follow individual hunches. Based on the oral interviews it seems that this response is due to two concerns. First, the officers expect that FLAIR will be used to keep them strictly on their beat, not allowing them to follow up investigations into other areas within their district. Second, they fear FLAIR will be used to keep them constantly moving and not allow them to remain stationary while in service.

c. Disciplinary concerns. One of the primary concerns and issues surrounding the FLAIR System is the influence it might have on headquarters being able to observe the actions of patrol officers in a "big brother" fashion and the disciplinary abuse that might result. When asked how FLAIR would affect different apsects of their job, officers in both districts agreed that there would be no effect on either their relationship with their patrol supervisor or the public in general. However, as far as FLAIR's effect on departmental discipline, officers in both districts agreed that the impact would be negative, although there were some

differences on the degree of the influence. Table 10-20 predicts that the majority of the officers in both districts thought FLAIR would make discipline less fair. (District 5 officers were stronger in this feeling with almost a full 70% of the policemen anticipating a less fair process.) Only 10.3% and 2.7% of the District 3 and District 5 officers, respectively, thought the process would become fairer with the addition of FLAIR.

Throughout the first survey and subsequent oral interviews it became apparent that the fear of the M.P.D. using FLAIR as a "big brother" to "control" the street personnel was a primary concern to the personnel, particularly when FLAIR was first introduced. Discipline is administered at two levels in the department. The first is at the district level, primarily through powers exercised by the field supervisors and district commander. The second level is from department headquarters. This very often takes the form of punishments or "bad inspections" made as a result of actions of the Office of Inspections. It is this office that the street personnel fear the most. They are afraid that lieutenants from the Inspectors Office will sit at the FLAIR console and issue complaints. Although the M.P.D. command staff states that this is not their intent, the department has yet to issue any statements forbidding such actions on the part of the Inspectors, and a certain amount of fear of abuse still exists. (Although the level of this concern has dropped due to reasons that will be discussed later.)

A look at potential problem areas for FLAIR (Table 10-21)

once again brings out the primary cause of officer fears. 65.1% of the Third District officers and 56.8% of the Fifth District officers cited disciplinary abuse as a potential problem[8]. The untested hardware ranked second in each district followed by lack of support from the street officers. It is not surprising that twice the fractions of District 5 officers as compared to District 3 officers expected street support problems, mainly because a much larger fraction of the District 5 officers disliked the FLAIR System.

Table 10-21

Tabulation of Possible Problem Areas

Possible problem areas	District 3* (% of responses)	District 5* (% of responses)
equipment problems	44.0	43.2
lack of street support	15.1	28.4
disciplinary abuses	65.1	56.8
difficulty in operating	7.8	16.2
other	1.8	6.6

d. Benefits compared to costs. Finally, the officers were aksed whether or not the anticipated FLAIR program benefits were worth the costs. According to sworn personnel the answer is

[8]Note that the columns total more than 100% because each officer was allowed to select more than one response.

no, benefits are not worth the cost. (See Table 10-22.) Only 38.3% and 26.1% of the Third and Fifth District personnel, respectively, thought the system would justify its $3 million-plus costs. Even though the idea is an interesting one to many officers, albeit vulnerable to disciplinary problems, it was not seen as being worth the investment necessary to bring it to St. Louis.

Table 10-22

Do the Benefits of FLAIR Justy the Cost?

Is FLAIR worth the cost?	District 3 (% of responses)	District 5 (% of responses)
yes	38.3	26.1
no	61.7	73.9

D. Results of the Surveys Conducted after the Implementation of FLAIR

As we discussed in Chapter III, an operational FLAIR System was scheduled to be installed in District 3 in August 1974. (The "before" surveys were therefore conducted during the first week in August.) However, the initial implementation of the system was delayed until September, with the operating Phase I System being turned over to the St. Louis Police Department in December, 1974. In order to wait until after the Phase I system had been in operation for some time, the second round of surveys were not conducted until April 7, approximately four months after the system was installed on a fairly operational basis.

As the report has already outlined, a number of difficulties were experienced and recognized during the Phase I experiment (for example problems concerning system accuracy and the high number of lost cars), and a number of modifications are planned when Phase II is implemented. It was expected that such difficulties would have an impact on the reactions of the men in the street, and that this would be reflected in their responses to the "after" surveys. If modifications in Phase II equipment resolve some of the problems identified during Phase I, then attitudes may change accordingly, although such changes may involve a certain time lag. This section of the chapter will report the result that have been obtained to date, and then the implications of these results for the Phase II implementation of the FLAIR System will be discussed in the final sections of the chapter.

1. <u>Analysis of the second District 3 survey</u>. During the first week of April,1975, a second survey concerning the FLAIR System was administered to the St. Louis Metropolitan Police Department personnel stationed in the Third District. The purpose of the survey was to gauge any changes in officer attitudes and perceptions that might have taken place during the first phase of the project. When officers were first surveyed in August,1974, the results indicated a general acceptance of the FLAIR System (two-thirds of those surveyed thought FLAIR was a good idea) although some expressed reservations about the possible use of the system as a disciplinary tool. After using the FLAIR System for approximately four months, the officers changed their views

significantly. The performance of the system did not meet all of their earlier expectations.

A total of 174 surveys were completed in the first survey in 1974 and 119 of the officers were surveyed again in 1975. (See Table 10-1.) The following three sections will examine the general attitudes toward police work and FLAIR, the factors that seem to contribute to changes in feelings, and the influence of FLAIR on police activities. Unless otherwise stated, all frequencies will be expressed as percentages of total responses.

a. General attitudes towards FLAIR and police work. 89.8% of the survey respondents in 1974 were patrolmen and 92.4% were patrolmen in 1975, (meaning fewer sergeants were interviewed the second time). The average number of years of experience of those surveyed dropped from 7.6 to 6.6 years. This drop was partially due to the lower fraction of sergeants interviewed. Table 10-23 shows that the percent of officers with at least some college increased from 60.4% in 1974 to 72.0% in 1975. Also, the fraction of officers taking courses nearly doubled to a 1975 value of 42.4%. This increase is primarily due to the fact that the first survey was taken before the beginning of the regular school year. In the eight months between surveys, job satisfaction dropped slightly in the Third District (Table 10-24). In 1975, 60.5% of the officers stated that they were very satisfied with their jobs, a modest drop from the 66.9% level indicated in the previous survey.

Table 10-23

Highest Level of Education Completed for 1974 and 1975 Respondents*
(District 3)

	1974	1975
High School	29.3	18.7
Some college	60.4	72.0
Bachelors degree	8.5	6.8
Some graduate credits	1.8	2.5
Currently taking courses	24.8	42.4

Table 10-24

Officer Satisfaction with Job for August, 1974 and April, 1975*
(District 3)

	1974	1975
Very satisfying	66.9	60.5
Fairly satisfying	30.1	35.3
Not very satisfying	3.0	4.2

* Numbers expressed as a percent of responses.

General attitudes towards FLAIR changed significantly during the four-month period that the officers used the system. This is highlighted by the results of Table 10-25. Before using the system, 64.4% of the District 3 officers thought FLAIR was a "good idea" for Phase I, while in 1975 only 39.8% of the officers thought it was a "good idea". This is a net shift of 24.6% of the sworn personnel and is a major change in attitude which will be discussed in the next section.

Table 10-25

Responses to the Question Asking whether of not the Officer thought FLAIR was a "Good Idea"*
(District 3)

	1974	1975
A good idea	64.4	39.8
Not a good idea	35.6	60.2

* Numbers expressed as a percent of responses.

Feelings regarding the FLAIR System's ability to aid the officer in doing his job also changed substantially during Phase I. In 1974, 41% of the Third District officers thought that FLAIR would help them do a better job. This dropped to 22% in April, 1975, with the number who felt it would make no difference rising from 39% to 60%. (Table 10-26.) Attitudes in this area therefore shifted from initial feelings which were somewhat optimistic and supportive to apparent indifference.

Table 10-26

Perceived Affects on the Officer's Ability to do the Job*

(District 3)

	1974	1975
Help	40.9	21.8
Make no difference	39.0	59.7
Make it harder	20.1	18.5

* Numbers expressed as a percent of responses.

Responses on how well informed the officers felt about the goals of the program or how the supervisors would use the system, changed little over the eight-month period. However, as a result of working with the system during Phase I, the officers did report that they felt better informed on how they were to operate the equipment (Table 10-27). As also reported in Table 10-28 the officers now find the FLAIR-coded message unit easy to use.

Table 10-27

How Well Informed did Officers Feel on how to Operate the FLAIR System*

(District 3)

	1974	1975
Very informed	33.9	47.1
Fairly informed	60.0	47.9
Not very informed	6.1	5.0

* Numbers expressed as a percent of responses.

Table 10-28

Tabulation of Results on Ease of Using Coded Message Unit *

(District 3)

Very easy	79.0
Fairly easy	18.5
Difficult	2.5

* Numbers expressed as a percent of responses.

Even though a smaller fraction of officers favored the AVM system in 1975 than in 1974, it is important to note that both surveys showed a generally positive correlation between how well informed an officer felt about system operation and whether or not he thought FLAIR was a good idea. (Table 10-29.) Even though most officers in the second survey were negative towards FLAIR, the category of officers who felt "very well" informed about operating the FLAIR System were actually more likely to think FLAIR was a good idea in 1975.

Table 10-29

Cross-tabulation of "Good Idea" Versus how well Informed on Operation of System *
(District 3)

	Response to whether or not the FLAIR System was a "good idea"			
	1974		1975	
Response concerning how well informed officers felt**	Good idea	Not good idea	Good idea	Not good idea
Very	25.8	9.5	24.4	22.7
Fairly	35.8	23.3	14.3	32.8
Not very	2.5	3.1	0.8	4.2
	x^2=4.0933 df=2* sign ≃ .85		x^2=5.7992 df=2 sign ≃ .90	

* Numbers expressed as a percent of responses.

** Chi-squared calculations were performed on the actual responses rather than the reported percentages.

b. <u>What factors seem to contribute to the change in attitude toward FLAIR?</u> Since the attitudes of the patrol officers seemed to change so dramatically, it is important to ask what factors influenced this switch. In the second survey, officers were asked whether or not the FLAIR System lived up to their initial expectations. The results, presented in Table 10-30, indicate that almost 40% of the officers found the Phase I implementation of FLAIR to be less then expected. About half felt that FLAIR had been about what they expected, and only 10% thought that FLAIR had exceeded their initial expectations. Correlating this survey result with the interviews conducted while "riding police patrol" following the second survey, it seems that a number of officers felt that the system had been "oversold". At this point, though, it is difficult to attribute this disappointment to the system itself or to problems of implementation. A combination of factors is probably involved.

Table 10-30

How well did FLAIR match initial expectations?*
(District 3)

Better than expected	10.1
About what epxected	51.3
Less than expected	38.6

* Numbers expressed as a percent of responses.

When asked to name the main probelm that FLAIR had encountered, 78% felt that equipment problems were most significant. This is up from only 34% in August, 1974. (See Table 10-36.) The report has already discussed in earlier chapters (see for example

Chapters V, VII and IX) how a number of problems were encountered due to the high number of lost cars which in turn lead to a number of inquiries by dispatchers during early 1975 as to vehicle locations. Because of both system testing and tracking problems, dispatchers were frequently required to ask a unit for his "21" (location). Often when the location given was different from that displayed on the TV console, the dispatcher would state this over the radio, therefore publicizing the problem. Also, several times when a dispatcher would repeat what he saw to be a unit's location for an occupied vehicle check, the officer would come on the air and correct the location. Officers were therefore very aware of accuracy problems and this helped to contribute to a lack of confidence in the system. Seven out of ten of the officers felt that FLAIR could not locate them in an emergency at least "most of the time". (Table 10-31.) Only 3.4% feel that they can depend on the system "almost all the time".

Table 10-31

Officer Responses to Question Asking Perception of Fraction of Time the FLAIR System would Accurately Locate Them in an Emergency *

Almost all of the time	3.4
Most of the time	25.2
Some of the time	46.2
Not much of the time	25.2

* Numbers expressed as a percent of responses.

Contributing to this feeling was the following incident (which occured two weeks before the second survey) where an officer needed help but the system failed to display his proper location:

> At 4.24 a.m. on March 16, Unit 3328, a Third District officer was fired upon. He hit the emergency button and was answered by a query from the dispatcher asking if he were in need of aid. When he finally acknowledged that he was (his windshield was shot out and his face cut by flying glass), the dispatcher put out his location as given on the FLAIR console. However, responding units could not find the car. After this was reported to the dispatcher, the officer was raised once again (he might have passed out), and gave a location approximately 3 to 4 blocks away from where the colsole had him. An examination of the previous two hours' printout showed that the dispatcher had been clearing the board without reinitializing vehicles. During 2 - 3 a.m., only one vehicle was reinitialized. No vehicles were initialized between 3 - 5 a.m.

This type of dispatcher inattention to the proper operation of the system contributed heavily to the lack of officer confidence, and also points out the heavy reliance of the FLAIR System on effective operation by the dispatchers. Since the capabilities of the dispatchers who worked with FLAIR were mixed, this uneven quality contributed to the problems experienced during the implementation of the AVM system.

A further problem in implementing FLAIR was the fact that at most times during the experiment all District 3 cars were not equipped with FLAIR units. This meant the dispatchers were working both with cars that were displayed on the video screen and those that were not. This complicated the dispatchers' job and

seemed to contribute to the declining feelings of the officers towards the system.

However, although attitudes toward FLAIR dropped significantly, it is important to qualify this change in feelings. FLAIR is a new system and as such many of the problems and advantages of the system are still untested. Under such circumstances it is likely that attitudes toward such a new innovation will be volatile, particularly where the system is still being perfected. This is not to say that the shift is not significant or that it should not receive careful attention during the Phase II implementation. In fact, once first impressions are formed they may be hard to change. Rather it means that if the operational performance of the system improves, attitudes could possibly rebound--although a time lag would probably be involved. In fact, there is some evidence that attitudes may have risen to some extent during the special three week test in September, 1974, and this will be discussed in greater detail in Section F.4 of this chapter.

c. Influence of FLAIR on police activities. As outlined in Section C, four topics will be discussed concerning police activities: 1) perceived importance and effect on police performance, 2) influence on police patrol, 3) disciplinary concerns, and 4) benefits and costs.

(1) Importance and effect on police performance. In 1975, officers were again asked to rate how important six aspects

of police work were to the department in implementing FLAIR (Table 10-32). Five of the six aspects experienced a decrease in perceived importance. The three most important changes came in the areas of dispatching the nearest car, officer safety, and reducing radio congestion.

The biggest drop came in the area of dispatching the nearest car. Whereas in 1974, 65% of the men had felt that this was "very important", the percentage dropped by more than half in 1975 to 30%. In fact, 32% indicated that they did not feel that dispatching the nearest officer was an important aspect of FLAIR. To some extent this drop may be attributed to a change in patrol procedure. For a three-month period prior to March 15, 1975, officers were allowed to patrol over their whole precinct as opposed to just their own sector. (A precinct is an area of three to four sectors under the direct control of one field supervisor.) Based on oral interviews it seems that the officers enjoyed the new freedom and at least some felt that this made the closest car concept more functional. They also cited the advantages for the new system for both better officer back-ups and concentrated patrol in problem areas. When this system was changed some officers saw the order to return to their sectors as not only a loss of freedom, but also as an abandomnent by the department of the closest car dispatching strategy. This same feeling was reflected in answers which the officers gave to another question on response time. In 1974, 75.4% of the officers anticipated a reduction in response time from dispatching

Table 10-32

Perceived importance in District Three of
Six Aspects of Police Operations in Implementation of FLAIR *
(District 3)

	1974	1975
Dispatching nearest officer		
very important	65.1	30.5
fairly important	26.5	37.3
not important	8.4	32.2
Officer safety		
very important	78.7	53.4
fairly important	15.2	21.2
not important	6.1	25.4
Availability of non-patrol officers for high priority calls		
very important	48.2	23.5
fairly important	31.7	27.0
not important	20.1	49.5
Preventing crime		
very important	32.7	17.8
fairly important	32.7	21.2
not important	34.5	61.0
Keeping track of patrol force		
very important	33.7	30.5
fairly important	34.4	30.5
not important	31.9	39.0
Reducing radio congestion		
very important	52.8	40.7
fairly important	36.0	39.8
not important	11.2	19.5

* Numbers expressed as a percent of responses.

the nearest available car. By April, 1975, only 42.4% of the respondents anticipated such a drop.

Even though officer safety was still found to be the most important of the six goals in 1975 by a wide margin (Table 10-32), its absolute importance also dropped significantly from the first survey. In 1975, the officers thought that officer safety was not as important to the Department in implementing FLAIR as it was perceived to be in August, 1974. In fact, when asked about the perceived effect FLAIR might have on police operations, officers felt that the presence of FLAIR had "no effect" on officer safety (Table 10-33). A surprising 10.1% felt that it actually worsened the situation. (Their argument is that officers may build up a false confidence in the accuracy of the system and therfore hit the emergency button and "bail out" thinking that help is on the way, when FLAIR has actually misplaced them.)

Predictably, officer confidence in the accuracy of FLAIR and perceptions of its effect on officer safety are positively correlated (Table 10-34). Those officers who thought FLAIR would accurately locate them "almost all" or "most" of the time were much more likely to think FLAIR improved officer safety than those officers who thought FLAIR was accurate "some" or "not much" of the time.

Table 10-33

Perceived Effects on Six Aspects of Police Operations *
(District 3)

	1974	1975
Dispatching nearest officer		
improve	75.3	42.4
no effect	23.5	45.8
worsen	1.2	11.8
Officer safety		
improve	77.9	31.9
no effect	19.6	58.0
worsen	2.5	10.1
Availability of non-patrol officers for high priority calls		
improve	56.4	10.2
no effect	37.6	76.3
worsen	6.1	13.5
Preventing crime		
improve	31.1	7.6
no effect	64.6	78.8
worsen	4.3	13.6
Keeping track of the patrol force		
improve	80.6	68.9
no effect	13.9	23.5
worsen	5.5	7.6
Reducing radio congestion		
improve	74.7	58.5
no effect	22.2	25.4
worsen	3.2	16.1

* Numbers expressed as a percent of responses.

Table 10-34

Cross-tabulation of Confidence versus Perceived Effects on Officer Safety*
(District 5)

	Improve	No effect	Worsen	Total
Almost all of the time and Most of the time	16.0	11.0	1.7	27.7
Some of the time	13.5	28.6	4.2	46.3
Not much of the time	2.5	18.5	4.2	25.2

$x^2 = 16.33$ df = 3

sign ≃ .99

* Numbers expressed as a percent of responses.

Although reduction in radio congestion dropped in importance along with the rest of the factors, it received the second highest rating for importance in 1975 (Table 10-32), and regarding effect on police operations in 1975 it was one of two factors where a majority of officers thought FLAIR would act to improve the situation (Table 10-33). (In oral interviews it was found that the reasons officers checked the "no effect" or "worsen" categories was that they felt that any time saved by the digital communication capability was lost because of the large number of location checks and initialization performed for the system.)

(2) Influence of FLAIR on police patrol. In 1974 personnel were asked to state what effects, if any, FLAIR had on the amount of preventive patrol time, flexibility to play individual hunches, coordination with fellow officers, and quickness of response time. In 1975 the same questions were asked and an

additional inquiry was raised concerning impact on police pursuits. (See Table 10-35.) Over three-quarters of the officers felt that the amount of preventive patrol time had remained unaffected by the presence of FLAIR[9]. 14.2% of the officers stated that FLAIR had decreased preventive patrol. (This might, to some degree, be tied with their resentment of being returned to their beats rather than being allowed to cruise the whole precinct.) Further, based on their answers to the question concerning their flexibility to "play hunches", many officers see FLAIR as a barrier to striking out on their own. In 1974 and 1975 about half felt that their flexibility would decrease with FLAIR. (This is also a result of being assigned to what they see as small and confining boundaries.) Finally, it seems that officers have come to view FLAIR as having little effect on coordinated operations with other officers.

(3) Disciplinary concerns. Responses differed greatly between 1974 and 1975 on what officers saw as the potential problem areas for FLAIR. (See Table 10-36.) As a result of the large number of tracking problems, as well as several computer failures, 78.2% felt that euqipment problems significantly troubled the FLAIR implementation. This is up 34% from August, 1974. One other very interesting change related to the impact of FLAIR on police work was the percent of officers that were concerned about possible disciplinary abuses. In 1974, 65.1% of the officers expected disciplinary abuses to be the biggest problem FLAIR would

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[9] During the Phase II evaluation a more detailed examination of preventive patrol time will be conducted.

Table 10-35

Tabulation of Perceived Effects of FLAIR upon Five Aspects of Police Patrol *
(District 5)

	1974	1975
Preventive patrol time		
increase	22.7	8.8
stay the same	70.6	77.0
decrease	6.7	14.2
Flexibility to play individual hunches		
increase	13.7	2.6
stay the same	35.4	48.7
decrease	50.9	48.7
Coordinated operations with fellow officers		
increase	24.5	8.0
stay the same	37.4	62.8
decrease	38.0	29.2
Quickness of response to emergency calls		
increase	63.4	31.9
stay the same	34.8	62.8
decrease	1.8	5.3
Pursuits		
increase	NA	27.3
stay the same	NA	59.1
decrease	NA	13.6

* Numbers expressed as a percent of responses.

Table 10-36

Perceived Problem Areas for Implementation of FLAIR
(District 5)

	1974*	1975*
Equipment and computer	44.0	78.2
Lack of street support	15.1	21.0
Disciplinary abuses	65.1	27.7
Communications problems	--	24.4

*Percentages sum to greater than 100% because officers were allowed to select more than one.

face. After working with the system, these fears were lessened to the point that only 27.7% saw potential disciplinary abuses as a major problem for FLAIR in 1975. This same change in attitude is evidenced in Table 10-37 as well. Whereas in 1974 58% felt FLAIR would make disciplinary practices "less fair", in 1975 only 26% felt this way, while two-thirds (68%) felt that FLAIR would make no difference in the department's disciplinary process. The officers are beginning to see FLAIR as no real threat to the departmental disciplinary process, although rumors still persist of lieutenants from the Inspector's office being seen sitting behind the FLAIR console. Many officers have stated that they are not as worried about FLAIR's disciplinary potential because of the inaccuracy of the system.

Table 10-37

Perceived Effects of FLAIR on Departmental Disciplinary Process *

(District 3)

	1974	1975
Fairer	10.3	6.0
No difference	31.5	68.4
Less fair	58.2	25.6

* Numbers expressed as a percent of reponses.

(4) Benefits as compared to costs. Overall, are the benefits of FLAIR worth the costs? In 1974 the officers felt they weren't. It should be no surprise to find that even a smaller percentage of the officers now feel that FLAIR is worth the investment. (See Table 10-38.) Only 14.3% feel that they system is cost beneficial. Of these the predominant opinion which was expressed in personal interviews was that if FLAIR saved one policeman's life it would be worth the money.

Table 10-38

Do the Benefits of FLAIR Justify the Cost?*
(District 3)

	1974	1975
Yes	38.3	14.3
No	61.7	85.7

* Numbers expressed as a percent of responses.

2. Analysis of the second Fifth District survey. During the week of June 16, 1975, officers reporting for duty in the Fifth District were asked to complete a second FLAIR survey. The purpose of the survey was to gauge any changes in officer attitudes and perceptions that might have taken place during the first phase

of the Project. Officers were initially surveyed in August, 1974, and the results at that time as reported in Section C of this Chapter indicated a general dislike of the FLAIR System with a special concern shown in the areas of disciplinary abuse and officer initiative. Almost a year later the views of the men were generally similar to those expressed during the first survey, and it seems that the Phase I implementation of FLAIR in the Third District had relatively little influence on the attitudes of the Fifth District officers.

a. General attitudes towards FLAIR and police work. The composition of officers surveyed differed only slightly by rank from 1974 to 1975. In 1974, 89.2% of the responses were patrolmen as compared to 90.6% in 1975. The average number of years as a policeman was 9.7 years, virtually unchanged from the 9.8 years reported for 1974. The average education level had increased slightly since August of 1974. This was apparently due to the high fraction (37.5%) of the officers taking courses at the time of the second survey. (See Table 10-39.)

Table 10-39
(District 5)

Highest education level attained	(%) 1974	(%) 1975
high school or equivalent	32.4	20.3
some college	58.1	65.6
bachelors degree	9.5	6.2
some graduate work	0.0	7.8
	100.0	100.0
taking courses	33.8	37.5

The 1975 survey respondents showed a slight increase in job satisfaction from 1974 values. (See Table 10-40.) When asked what effects FLAIR would have on projected job satisfaction, the officers gave responses somewhat more polarized than in the previous survey. Table 10-41 shows that in 1974, 62.5% of the officers thought the presence of FLAIR would have no effect on job satisfaction. This decreased in 1975 to a value of 48.3%. The remaining 14% split fairly evenly between "more satisfying" and "less satisfying".

Table 10-40

Current Satisfaction with Job as a Policeman
(District 5)

	1974 (%)	1975 (%)
Very satisfying	52.7	64.1
Fairly satisfying	39.2	32.8
Not very satisfying	8.1	3.1

Table 10-41

Projected Satisfaction with Job as a Policeman as a Result of FLAIR
(District 5)

	1974 (%)	1975 (%)
More satisfying	4.2	11.7
Same	62.5	48.3
Less satisfying	33.3	40.0

Responses to general questions on whether or not FLAIR was a good idea and perceptions as to how FLAIR would affect an officer's ability to do his job remained fairly static from 1974 to 1975, although some very modest improvements in attitudes occurred. Officers still thought FLAIR was not a good idea by a margin of three to two (Table 10-42), a slight improvement from 1974. They also anticipated that FLAIR would provide little help to the officer, although the fraction of officers expecting that FLAIR would actually hinder operations dropped slightly from 27.8% to 22.6% (See Table 10-43.)

Table 10-42

Do You Think FLAIR is a Good Idea?
(District 5)

	1974 (%)	1975 (%)
Yes	36.4	40.0
No	63.6	60.0

Table 10-43

How do You Think FLAIR will Affect Your Ability to do Your Job?
(District 5)

	1974 (%)	1975 (%)
Help	20.8	19.3
No difference	51.4	58.1
Hinder	27.8	22.6

One interesting change did take place in the Fifth District. Even though there was no formal FLAIR instruction in the Fifth

District, the percentage of officers who felt very informed on the operation of the system increased from 11.6% in 1974 to 29.0% of the personnel in 1975 (Table 10-44). In fact, whereas in 1974 there had been little correlation in District 3 between attitude and how well informed officers felt, the 1975 responses established a significant positive relationship between perceived ability to operate the system and whether or not FLAIR was seen as a good idea (Table 10-45). Importantly, those officers who felt very informed on how they would operate the system were also more likely to think that FLAIR was a good idea.

b. Influence of FLAIR on police activities. This section will examine survey results related to the potential influence of FLAIR on police activities. Overall, the responses show that attitudes and perceptions changed little over the ten-month period after the initial survey.

(1) Importance and effect on police performance. The officers were once again asked to rate the importance of six facets of police work as they apply to the implementation of the FLAIR System (Table 10-46). The aspects of dispatching the nearest officer, officer safety, reduction of radio congestion and keeping track of the patrol force received essentially identical responses in 1974 and 1975, with officer safety clearly being the most important. Whereas the Third District officers had indicated a significant reduction in the importance

Table 10-44

How Well Informed Are You on How to Operate the System?
(District 5)

	(%) 1974	(%) 1975
Very Informed	11.6	29.0
Fairly Informed	42.0	29.0
Not Very Informed	46.4	42.0

Table 10-45

Cross-Tabulation of How Well Informed About Operation of System by Whether or Not it is a Good Idea
(District 5)

How well informed do you feel about FLAIR?	1974 Good Idea	1974 Not a Good Idea	1975 Good Idea	1975 Not a Good Idea
Very Informed	7.9%	4.8%	20.4%	13.0%
Fairly Informed	14.3	23.8	5.6	24.0
Not Very Informed	14.3	34.9	13.0	24.0
TOTALS	36.5%	63.5%	39.0%	61.0%
	$\chi^2 = 3.093$	df = 2	$\chi^2 = 6.58$	df = 2
	Not Significant		significance = .95	

Table 10-46

Perceived Importance of
Six Aspects of Police Work
(District 5)

	1974 (%)	1975 (%)
Dispatching Nearest Officer		
Very Important	62.2	63.5
Fairly Important	29.7	25.4
Not Important	8.1	11.1
Officer Safety		
Very Important	78.4	80.6
Fairly Important	10.8	8.1
Not Important	10.8	11.3
Availability of Non-Patrol Officer		
Very Important	40.3	46.0
Fairly Important	44.4	31.8
Not Important	15.3	22.2
Preventing Crime		
Very Important	35.6	28.6
Fairly Important	34.2	28.6
Not Important	30.2	42.8
Keeping Track of Patrol Force		
Very Important	26.0	29.0
Fairly Important	32.9	25.8
Not Important	41.1	45.2
Radio Congestion		
Very Important	44.3	44.5
Fairly Important	35.7	33.3
Not Important	20.0	22.2

of officer safety and dispatching the nearest officer, in District 5 officer safety remained every bit as high and was the most important aspect followed by dispatching the nearest officer. Regarding the importance of determining the availability of non-patrol officers for dispatch to emergency call, the percent of responses of "fairly important" dropped 12% with the difference being split fairly evenly between "very important" and "not important." Preventing crime was the only aspect that incurred a major drop in perceived importance. The percent of officers citing "not important" increased from 30% to 43%.

The officers were asked to anticipate the effects that the FLAIR System would have on the same six components of police work (Table 10-47). Although the responses were generally similar to those reported in 1974, a few interesting differences appeared, particularly when the observations in the Third District are compared with those in the Fifth. In 1974, 55% of the officers in District 5 had indicated that officer safety would improve as a result of FLAIR, and in 1975 the percent increased to 69%. This increase is especially interesting when compared to the dramatic drop in perceived improvement which was reflected in the Third District (from 77.9% thinking that it would improve performance in 1974 to only 31.9% in 1975). The drop in expectations that the District 3 officers had experienced towards the "officer safety" aspects of the FLAIR System had not been communicated to the police in District 5. District 5 experienced some drop in the perceived effect of FLAIR on dispatching the nearest officer (from 74% who felt FLAIR would improve the

Table 10-47

Perceived Effects on Six Aspects of Police Operations (District 5)

	1974	1975
Dispatching Nearest Officer	(%)	(%)
Improve	73.6	65.1
No Effect	22.2	34.9
Worsen	4.2	0.0
Officer Safety		
Improve	54.8	69.8
No Effect	38.4	27.0
Worsen	6.8	3.2
Availability of Non-Patrol Officer		
Improve	46.5	50.8
No Effect	49.3	41.0
Worsen	4.2	8.2
Preventing Crime		
Improve	20.5	22.2
No Effect	72.6	69.9
Worsen	6.8	7.9
Keeping Track of Patrol Force		
Improve	76.7	77.4
No Effect	20.5	12.9
Worsen	2.7	9.7
Radio Congestion		
Improve	68.7	60.3
No Effect	22.4	34.9
Worsen	9.0	4.8

situation, to 65%). However, this is only a modest drop when compared to District 3 where the percent who felt that dispatching the nearest officer would improve fell from 75% to 43%.

(2) Influence of FLAIR on police patrol. Personnel were asked to state what effects, if any, FLAIR would have on the amount of preventive patrol time, flexibility to follow individual hunches, coordinated operations with fellow officers, and quickness of response time (Table 10-48). Results in 1975 were basically the same as those in 1974. In 1974, 65.8% of the officers anticipated that FLAIR would have no effect on the amount of preventive patrol time. This figure increased to 71.4% in 1975. In 1975, 62% of the officers felt the presence of FLAIR would decrease the flexibility to play individual hunches, up from 58% in 1974. The 1975 distribution of answers on anticipated effects on coordinated operations with fellow officers was generally similar to that given in 1974.

(3) Disciplinary concerns. In both 1974 and 1975 disciplinary abuse ranks as the largest potential problem area perceived by the men in the Fifth District, followed closely by equipment and computer problems (Table 10-49).[10] There was a 5.5% drop in concern for disciplinary abuse between 1974 and 1975 (from 58.6% in 1974 to 53.1% in 1975), but this was significantly less than the 37.4%

[10] The number indicating equipment and computer problems rose from 43% to 48%, but this is significantly smaller than the rise from 44% to 78% in the Third District. Again, it seems that the concerns in the Third District were not necessarily being expressed to other police districts.

Table 10-48

Tabulation of Anticipated Effects of FLAIR on Four Aspects of Police Patrol

(District 5)

	1974 (%)	1975 (%)
Preventive Patrol Time		
Increase	26.0	15.9
Stay the Same	65.8	71.4
Decrease	8.2	12.7
Flexibility to Play Individual Hunches		
Increase	2.7	9.5
Stay the Same	39.7	28.6
Decrease	57.5	61.9
Coordinated Operations with Fellow Officers		
Increase	18.3	19.4
Stay the Same	46.5	41.9
Decrease	35.2	38.7
Quickness of Response		
Increase	62.5	61.3
Stay the Same	31.9	38.7
Decrease	5.6	0.0

drop which occurred in District 3. In 1975, 61.7% of the Fifth District officers thought that the presence of FLAIR would make the departmental disciplinary process less fair (Table 10-50). This figure is down slightly from 69.9% in 1974. In 1975, 8.3% felt that FLAIR would actually make the process more fair.

(4) Benefits compared to cost. Finally, officers were asked again to state whether they felt the benefits of FLAIR justified the costs. An overwhelming majority (83.9%) stated that

they did not (Table 10-51). This is up 10% from the 73.9% the previous year.

Table 10-49

Tabulation of Possible Problem Areas*
(District 5)

	1974 (%)	1975 (%)
Equipment and Computer	43.2	48.4
Lack of Street Support	28.4	28.1
Disciplinary Abuses	56.8	53.1
Difficulty in Operating	16.2	12.5
Communications	NA	12.5

* Totals sum to more than 100% because each officer was allowed to cite more than one answer.

Table 10-50

How Do You Think FLAIR Will Affect Discipline in the Department?
(District 5)

	1974 (%)	1975 (%)
Make it Fairer	2.7	8.3
Make no Difference	27.4	30.0
Make it Less Fair	69.9	61.7

Table 10-51

Do the Benefits of FLAIR Justify the Cost?
(District 5)

	1974 (%)	1975 (%)
Yes	26.1	16.1
No	73.9	83.9

E. Dispatcher Survey

During January and July of 1975, MPD personnel working as dispatchers were surveyed on their attitudes toward FLAIR and its perceived affect on the Department. A total of 32 dispatchers were surveyed in January and 45 in July. In each sample about 50% of those surveyed stated that they had received training on the FLAIR System. Sixty-two percent of the personnel had actually worked the System by 1975, up 13.8% from the earlier survey. General results point to a decline in attitudes toward the Phase I system, but more specific responses fail to pinpoint the apparent cause of this decline. Even with the decline, the results remain, for the most part, positive.

1. General attitudes toward FLAIR. Table 10-52 shows that expressed job satisfaction declined during the time between surveys, but still remained quite high.[11] Not one respondent in either sample checked "not satisfactory." Those stating that they found their job "very satisfying" decreased from 81.2% to 59.1%.

Concerning whether or not the dispatchers thought FLAIR was a good idea, 76.7% felt that it was in the first survey and in the second survey the percent dropped to 58.5% (Table 10-53). However, it is interesting to note that the dispatchers remained much more positive on the System than did the District 3 officers. Finally, as might be expected, dispatchers felt slightly more informed about the System in July than they did in January (Table 10-54).

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[11] Later in this section a case will be made that the attitudes expressed on the formal written surveys may show the dispatchers to be more positive toward the system than is actually the case.

Table 10-52

Tabulation of Current Job Satisfaction of Dispatch Personnel

	January (%)	July (%)
Very Satisfied	81.2	59.1
Fairly Satisfied	18.8	40.9
Not Satisfied	0.0	0.0

Table 10-53

Tabulation of Responses on Whether Dispatchers Thought FLAIR Was a Good Idea

	January (%)	July (%)
Yes	76.7	58.5
No	23.3	41.5

Table 10-54

Tabulation of How Well Informed Dispatchers Felt About the Operation of the FLAIR System

	January (%)	July (%)
Very Informed	39.3	39.5
Fairly Informed	32.1	44.2
Not Very Informed	28.6	16.3

2. Influence of FLAIR on dispatcher and police activities. It became obvious early in Phase I that the FLAIR System would require some additional effort on the part of MPD dispatchers. The digital communications capability meant that the radio frequency would be less busy but that more transactions could occur at the same time. Codes that might have been delayed or not given earlier (such as arrival at the scene) due to a busy channel are now transmitted and queued on the console to be acknowledged by the dispatcher. Also, the additional requirements of locating the cursor to determine the closest cars and initializing lost vehicles are both new tasks the dispatchers must learn to perform. As discussed in Chapters VI and VII, the dispatchers have not only apparently learned these tasks, but appear able to dispatch cars as fast as before the FLAIR System was implemented. What, then, is their impression of how prepared they are to operate the System, and of how FLAIR has affected their ability to perform their job?

Table 10-55 demonstrates a fairly polarized set of responses to how FLAIR affects a dispatcher's ability to do his job. In the first survey, 40% of the dispatchers thought that FLAIR would make no difference in their ability to perform as a dispatcher for the MPD. In the second survey the figure dropped to 22.7%. The fraction of people that perceived FLAIR as a hindrance rose from 23.3% to 38.6%. What this means is that roughly two-fifths of the dispatch personnel think FLAIR helps them, two-fifths think FLAIR hinders them, and the remaining one-fifth perceive no difference.

Table 10-55

Tabulation of the Degree to Which FLAIR Would Help Them Do Their Job

	January (%)	July (%)
Help	36.7	38.6
Make No Difference	40.0	22.7
Hinder	23.3	38.6

The dispatchers were also asked to rate seven aspects of police operations on two scales, just as police officers in Districts 3 and 5 had been asked to do. The first was their perception of how important each aspect was to the Department in implementing the FLAIR System, and the second measured their impression of how FLAIR and the project actually affected these seven areas. Table 10-56 lists the results of the question asking about importance. Changes occurring between the two surveys in January and July were, for the most part, minor. The largest positive changes occurred in reducing radio congestion and the availability of non-patrol officers to respond to emergency calls. As discussed in Chapters VII and IX, the digital communications aspects of the System have provided worthwhile benefits to dispatchers and patrolmen, and these benefits are reflected in a positive rating by the dispatchers. Preventing crime and keeping track of the patrol force dropped in importance, with most of the changes consisting of transitions from "very important" to "fairly important." Perceptions on dispatch delay remained the same.

Table 10-56

Perceived Importance of Seven Aspects of Police Operations

	January, 1975 (%)	July, 1975 (%)
Dispatching Nearest Car		
Very Important	74.2	74.4
Fairly Important	22.6	20.9
Not Important	3.2	4.7
Reduce Dispatch Delay		
Very Important	54.8	56.1
Fairly Important	25.8	31.7
Not Important	19.4	12.2
Officer Safety		
Very Important	93.5	86.0
Fairly Important	6.5	7.0
Not Important	0.0	7.0
Availability of Non-Patrol Officers for Dispatch		
Very Important	40.0	42.9
Fairly Important	30.0	45.2
Not Important	30.0	11.9
Preventing Crime		
Very Important	48.3	29.3
Fairly Important	17.2	34.1
Not Important	34.5	36.6
Keeping Track of Patrol Force		
Very Important	48.4	33.3
Fairly Important	22.6	38.1
Not Important	29.0	28.6
Reducing Radio Congestion		
Very Important	46.7	61.0
Fairly Important	63.3	29.3
Not Important	10.0	9.7

In reviewing how dispatchers felt FLAIR had affected police operations, the surveys show a pattern of perceived improvements that generally match earlier expectations (Table 10-57). A large majority of responses indicated a feeling that FLAIR improved police operations in the areas of dispatching the nearest officer, reducing radio congestion, officer safety, and keeping track of the patrol force. These perceptions are in line with the changes anticipated by dispatchers in the first survey. However, 71% of the dispatchers expected that FLAIR would have no effect on preventing crime when first surveyed in January, and almost 83% saw no effect by July. In the remaining categories, reducing dispatch time and the availability of non-patrol officers to respond to an emergency, the anticipated and perceived effects are fairly split, distributed between answers of "improve" and "no effect," with but a small fraction of the respondents citing "worsen" in each case.

8. Dispatcher confidence in FLAIR and their evaluation of benefits versus costs. Up to this point the dispatchers exhibited a fairly positive attitude towards the system in general, albeit slightly less positive than before they had the opportunity to use it. A majority of the personnel thought it was a good idea and job satisfaction apparently remained high during Phase I. However, it is important for the reader to remember the accuracy problems which developed during Phase I in order to understand why 38.6% of those surveyed in July of 1975 stated that they had no confidence in the system (Table 10-58). In January, this percent

Table 10-57

Perceived Effect of FLAIR on Seven Aspects of Police Operations

	January, 1975 (%)	July, 1975 (%)
Dispatching Nearest Officer		
Improved	77.4	79.5
No Effect	19.4	13.6
Worsen	3.2	6.8
Reduce Dispatch Delay		
Improved	41.9	41.9
No Effect	32.3	37.2
Worsen	25.8	20.9
Officer Safety		
Improved	76.7	70.5
No Effect	10.0	25.0
Worsen	13.3	4.5
Availability of Non-Patrol Officers for Dispatch		
Improved	36.7	42.5
No Effect	53.3	47.5
Worsen	10.0	10.0
Preventing Crime		
Improved	16.1	14.6
No Effect	71.0	82.9
Worsen	12.9	2.4
Keeping Track of Patrol Force		
Improved	74.2	65.1
No Effect	19.4	23.3
Worsen	6.4	11.6
Reducing Radio Congestion		
Improved	70.0	74.4
No Effect	23.3	16.3
Worsen	6.7	9.3

Table 10-58

Tabulation of Dispatcher Confidence in Accuracy of FLAIR System

	January, 1975 (%)	July, 1975 (%)
Much Confidence	36.7	38.6
Some Confidence	40.0	22.7
No Confidence	23.3	38.6

had been only 23.3% with no confidence in the accuracy of FLAIR, so the level of confidence obviously dropped during the Phase I experiment. Even with the decrease in the level of confidence, though, in July, 1975 61.3% of the dispatchers still had at least "some confidence" or "much confidence" in the System.

Problems in system accuracy are probably the cause for much of this confidence drop. However, one other factor is worth mentioning. The dispatchers were asked whether or not the system benefits justified the costs. In the first survey in January, half of those interviewed indicated that they did. Interestingly, this was the first time that any group of people surveyed had responded somewhat positively (at least neutral) to this question. However, when asked again in July, the perception of benefits had dropped and only 34.1% of the dispatchers thought that FLAIR actually justified the investment. Apparently, the benefits incurred and recognized by the dispatchers during Phase I were less than what they initially expected and as a consequence their overall rating dropped (Table 10-59).

Table 10-59

Tabulation of Whether Dispatchers Feel Benefits of FLAIR Justify the Cost

	January, 1975 (%)	July, 1975 (%)
Yes	50.0	34.1
No	50.0	65.9

During the course of the Phase I experiment, a number of different PSE evaluators spent time in the dispatch room observing operations and discussing FLAIR. As a result of these observations, evaluators found the results of the written surveys to be much more positive than the impressions gained while talking with the personnel. In person, dispatchers were much more critical of not only the idea of AVM, in general, but also of the operational behavior of the Phase I system in particular. They disliked the fact that the tasks needed to maintain system accuracy (such as correcting *V*'s and *W*'s) used time that they would otherwise have free under the old system. They were also sensitive to the increased tensions between dispatchers and field officers due to constant initializations. There was, however, a core of dispatchers that enjoyed operating the system and used it to advantage when assigning cars. These dispatchers were the ones utilized during the special three-week test in September. (The attitudinal influences of the special test will be discussed in the next section of this chapter.)

F. Summary Analysis of the Survey Results

Results presented in the previous sections describe the changes in attitudes and perceptions that took place during Phase I in both the experimental and control districts. In the experimental Third District, attitudes towards the AVM system started at a relatively positive level and dropped significantly over the first four months of the implementation. This contrasts with the relatively low but stable opinion exhibited by the Fifth District police officers. It is interesting to note that the general attitudes towards FLAIR in the two districts converged. However, the two districts still continue to hold quite different views about the specific behavior and benefits of the system. This latter observation seems particularly reasonable since the Fifth District officers have not worked with an operating system.

In order to compare the survey results found before and after the implementation of FLAIR this section of the chapter will focus on three topics: 1) the general attitudes toward FLAIR and police work; 2) the influence of FLAIR on police activities; and 3) the effects of the special three-week test on the District 3 officers.

1. <u>General attitudes toward FLAIR</u>. Results presented from the first round of surveys indicated that the officers in the Third and Fifth Districts felt quite different about the potential benefits of an AVM system. However, views on whether FLAIR was a good idea and what effects it might have on ability to do police tasks became almost identical after Phase I (see Table 10-60).

Table 10-60

1975 "After" Comparisons Between the Third and Fifth District*

Do you think FLAIR is a Good Idea?

District 3		District 5
39.8	Yes	40.0
60.2	No	60.0

How Has FLAIR Affected Your Ability to Do Your Job

District 3		District 5
21.8	Help	19.3
59.7	No Effect	58.1
18.5	Hinder	22.6

* Numbers expressed as a percent of responses.

This convergence is accounted for by the major shift in attitudes of the District 3 officers with 64.4% thinking FLAIR was a good idea before using the system, and only 39.8% still feeling that way after the Phase I implementation. The important question to ask is what accounted for the shift in attitudes in District 3?

Most importantly, this shift shows a crucial link between attitudes and operational performance. As indicated in Chapters V and IX, the Phase I system experienced a number of accuracy and reliability problems. Officers were required to initialize their cars on an average of eleven times per car per day. This was an irritant and in addition resulted in decreasing confidence in the system. Due to these operational difficulties many of the initial expectations of the system were not met, and unfulfilled expectations led to the disillusionment of some officers and a drop in positive feelings towards the system. Further, the effective operation of FLAIR relies heavily on well motivated and trained dispatchers. The capability of the dispatchers who worked with FLAIR were of mixed quality, though, and this unevenness contributed to the shift in attitude.

Attitudes are volatile and such a trend may be reversible in the future if the Phase II system functions smoothly. Significant technical modifications are scheduled for Phase II and if these changes alter the operational behavior of the system and result in improved performance and accuracy, feelings towards FLAIR may change again. (In fact, some indications of such a shift were

found during the special three-week test, and these will be discussed in greater detail later in this section.) Still, once a negative attitude is established, intitial impressions are difficult to overcome.

At a minimum the major shift in attitudes which occurred during the Phase I implementation point to the significance of behavioral factors in establishing and maintaining an AVM system over the long term. The effective operation of FLAIR requires a certain amount of officer cooperation (such as remembering to initiate "22" code self-initializations or aiding the dispatcher when an reinitialization is required). And, in fact, there are a number of subtle ways the police may work to actually subvert the system such as intentionally traveling to an area where magnetic anomalies exist or sending a "22" code from a place other than directly in front of the District station. Experience in implementing other technologies has demonstrated the potential impact of such subversion. For example, in Oakland, California a voluntary "digimap" vehicle location system was implemented on a trial basis. The system failed for a number of reasons, many of them having to do with technical problems. However, behavioral factors also contributed to the system's demise. The system required that officers indicate their location by pressing on a "digimap" placed on the dashboard of the car. However the "digimap" was installed in a spot which required that their clipboard be removed, and this removal was

not well received. When technical problems brought a temporary shutdown in the use of the system, the "digimaps" were used as a clipboard, eventually resulting in a number of maps being broken.[12]

A second important factor contributing to attitudes is training and communication. The initial training seminar in District 3 seemed instrumental in influencing initial positive attitudes as compared to District 5. Even after the attitudes of the officers in District 3 dropped, a strong correlation was found to exist between those officers who still felt FLAIR was a good idea and those who felt well-informed about the system. Being well-informed, though, means more than just an initial training seminar. It required attention to the whole process of communication concerning a new system including response to questions that arise, establishing appropriate channels for feedback, system education, etc.

A third factor which seemed important in influencing attitudes was the initial source of information concering FLAIR. This factor is closely tied to peer pressure and officer attitudes seem to be reinforcing. For example, before the system was introduced in District 3, those officers citing other policemen as their initial source of contact with FLAIR favored the system by better than three to one, well above the overall two-to-one favorable response for the Third District. In District 5, where FLAIR was in disfavor initially by a two-to-one factor, just the reverse was true. The officers who cited other policemen as their first contact disfavored the new

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[12] Scott Herbert, "Communications and Dispatching Technology in Oakland Police Department," Chapter 7 of a Final Report to be submitted to the National Science Foundation on the Innovative Resources Planning Project carried out at M.I.T. and sponsored by NSF-Rann (National Science Foundation Grant Number G038004).

system by almost four to one. In each District it appears that there is a peer pressure which helps to reinforce the prevailing attitude. Related to this, the Patrolmen's Association in St. Louis has generally opposed the introduction of FLAIR, and the Patrolmen's Association was the only initial source of information which correlated with an unfavorable view of FLAIR in both Districts 3 and 5.

Finally, it is interesting to note that at the outset of Phase I it was felt that job satisfaction, length of police service, and level of education would influence attitudes toward the system. However, it was found that all three of these factors seemed to have little influence on attitudes.

2. Influence of FLAIR on police activities. Important shifts occurred during the Phase I test period regarding the perceived influence of FLAIR on police activities. First, although officer safety remained as the top area of importance to officers, its overall rating of importance dropped significantly after implementation (see Table 10-61). Whereas eight out of every ten of the officers surveyed in both Districts 3 and 5 before implementation felt that officer safety was a very important goal in the FLAIR System, after implementation only five out of every ten of the officers in District 3 maintained such feelings. (Attitudes in District 5 towards officer safety remained the same.) Operational difficulties obviously influenced the confidence of District 3 officers in whether the system would locate them in times of stress.

Table 10-61

Perceived Importance of Six Aspects of Policework

District 3 1974	District 3 1975		District 5 1974	District 5 1975
		Dispatching Nearest Officer		
65.1%	30.5%	Very important	62.2%	63.5%
26.5	37.3	Fairly important	29.7	25.4
8.4	32.2	Not important	8.1	11.1
		Officer Safety		
78.7%	53.4%	Very important	78.4%	80.6%
15.2	21.2	Fairly important	10.8	8.1
6.1	25.4	Not important	10.8	11.3
		Availability of Non-Patrol Officers for High Priority Calls		
48.2%	23.5%	Very important	40.3%	46.0%
31.7	27.0	Fairly important	44.4	31.8
20.1	49.5	Not important	15.3	22.2
		Preventing Crime		
32.7%	17.8%	Very important	35.6%	28.6%
32.7	21.2	Fairly important	34.2	28.6
34.5	61.0	Not important	30.2	42.8
		Keeping Track of Patrol Force		
33.7%	30.5%	Very important	26.0%	29.0%
34.4	30.5	Fairly important	32.9	25.8
31.9	39.0	Not important	41.1	45.2

Table 10-61

Perceived Importance of Six Aspects of Policework
(continued)

District 3			District 5	
1974	1975	Reducing Radio Congestion	1974	1975
52.8%	40.7%	Very important	44.3%	44.5%
36.0	39.8	Fairly important	35.7	33.3
11.2	19.5	Not important.	22.0	22.2

Second, the perceived importance of FLAIR in dispatching the nearest officer also dropped significantly in District 3--again showing the influence of operational results on attitudes whereas 75% of District 3 officers had indicated in 1974 that AVM would improve performance with respect to dispatching the nearest officer, in 1975 only 42% held that opinion (see Table 10-62). Once again attitudes in District 5 remained fairly constant.

Third, concern over disciplinary abuses dropped significantly in District 3 after the Phase I implementation. In 1974, 65 % of the officers expected disciplinary abuses to be the major problem, in 1975 only 28 % saw such abuses as a major problem for FLAIR (Table 10-63). Much of this must be attributed to operational problems since a number of officers felt that the system could not track them accurately. However, the latent fear that remains in the M.P.D. on this matter is demonstrated by the fact that even after implementation in District 3, disciplinary abuses still remain as the primary concern in District 5.

Fourth, although perceptions regarding whether or not AVM would reduce radio congestion also dropped, this aspect by District 3 officers as one of the most important factors of the system. In 1975, 80 % of the officers in District 3 indicated that reducing radio congestion was either very important or fairly important (Table 10-61). As indicated earlier, this same positive feeling was shared by the dispatchers.

Table 10-62

How Will the FLAIR System Affect Performance?

District 3 1974	District 3 1975		District 5 1974	District 5 1975
		Dispatching Nearest Officer		
75.3%	42.4%	Improve	73.6%	65.1%
23.5	45.8	No effect	22.2	34.9
1.2	11.8	Worsen	4.2	0.0
		Officer Safety		
77.9%	31.9%	Improve	54.8%	69.8%
19.6	58.0	No effect	38.4	27.0
2.5	10.1	Worsen	6.8	3.2
		Availability of Non-Patrol Officers for High Priority Calls		
56.3%	10.2%	Improve	46.5%	50.8%
37.6	76.3	No effect	49.3	41.0
6.1	13.5	Worsen	4.2	8.2
		Preventing Crime		
31.1%	7.6%	Improve	20.5%	22.2%
64.6%	78.8	No effect	72.6	69.9
4.3	13.6	Worsen	6.8	7.9
		Keeping Track of Patrol Force		
80.6%	68.9%	Improve	76.7%	77.4%
13.9	23.5	No effect	20.5	12.9
5.5	7.6	Worsen	2.7	9.7
		Reducing Radio Congestion		
74.7%	58.5%	Improve	68.7%	60.3%
22.2	25.4	No effect	22.4	34.9
3.2	16.1	Worsen	9.0	4.8

Table 10-63

Tabulation of Possible FLAIR Problem Areas

District 3			District 5	
1974	1975	Possible Problem Areas	1974	1975
44.0%	78.2%	Equipment Problems	43.2%	48.4%
15.1	21.0	Lack of Street Support	28.4	28.1
65.1	27.7	Disciplinary Abuses	56.8	53.1
7.8	16.8	Difficulty in Operating	16.2	12.5
N.A.	24.4	Communications Problems	N.A.	12.5

Perceived Effects of FLAIR On Departmental Disciplinary Process

District 3			District 5	
1974	1975		1974	1975
10.3%	6.0%	Fairer	2.7%	8.3%
31.5	68.4	No Difference	27.4	30.0
58.2	25.6	Less FAir	69.9	61.7

Finally, it is worth noting that the general attitudes towards FLAIR and its impact on police activities remained relatively constant in District 5. What is even more notable is that the perceptions of District 5 officers are strikingly close to those held by District 3 officers prior to the implementation of Phase I, i.e., high rating of officer safety, importance of dispatching the nearest officer, etc. (see Table 10-61). This again demonstrates how the use of the AVM system had a major influence on attitudes. More importantly, though, it illustrates how the officers in District 5--and perhaps the rest of the city--still have fairly high expectations concerning certain aspects of the FLAIR system, but lingering fears concerning the potential for disciplinary abuse. Such attitudes provide the environment for the implementation of the Phase II system.

3. Influence of FLAIR on police patrol. Further research is needed in order to evaluate the impact of FLAIR on police patrol. The potential has been identified for the use of the system as a tool for better command and control of patrol operations. For example, in February of 1975, an incident was reported where FLAIR was instrumental in a high speed chase. Following is a brief synopsis of the event:[13]

> "At 1:10 a.m. on 2/3/75, a Third District Officer observed a tractor trailer which was wanted for leaving the scene of an accident. As the officer attempted to stop the vehicle, the driver accelerated and attempted to elude the patrol vehicle. At that time the dispatcher was advised of the pursuit.

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[13]Reported in "Report of the Director of the ARAC Project," St. Louis Police Department, Phase I, March 21, 1975.

> The dispatcher was able to track the pursuing police vehicle which, while following the wanted tractor trailer, drove a circuitous route through the Third District. During the pursuit, various police cars were dispatched to intercept the wanted vehicle.
>
> At one of the road blocks the police car was rammed and demolished by the tractor trailer, but fortunately, the officer was not seriously injured. The wanted vehicle stopped and two occupants were arrested by other officers who arrived at the scene. It was then learned that the vehicle was stolen a short time prior.
>
> As a direct result of FLAIR and dispatcher action, the tractor trailer, valued at $75,000, was recovered and charges are pending against the two arrested persons.

Although this incident reflects the potential for AVM to assist in pursuits, this same potential was not reflected in the survey results. After using the system during Phase I only, 27% of the officers felt that FLAIR would increase capability during pursuits, while 59% felt that capability would remain the same and 14% actually felt that it would be reduced (Table 10-64).

Ambiguous results also occurred regarding the impact of FLAIR on other aspects of police patrol. In earlier Chapters of this report we have indicated that one important possible benefit of AVM might be to improve the management of police resources. Part of this improvement may come from more effectively supervising preventive patrol and other aspects of patrol activity. However, responses to the surveys indicate that officers feel that FLAIR will have (or has had) little impact on police preventive patrol (Table 10-64). On the other hand, officers do feel that

Table 10-64

Perceived Effects of FLAIR on Five Aspects of Police Patrol

District 3 1974	District 3 1975		District 5 1974	District 5 1975
		Preventive Patrol Time		
22.7%	8.8%	Increase	26.0%	15.9%
70.6	77.0	Stay the same	65.8	71.4
6.7	14.2	Decrease	8.2	12.7
		Flexibility to Play Individual Hunches		
13.7%	2.6%	Increase	2.7%	9.5%
35.4	48.7	Stay the same	39.7	28.6
50.9	48.7	Decrease	57.5	61.9
		Coordinated Operations with Fellow Officers		
24.5%	8.0%	Increase	18.3%	19.4%
37.4	62.8	Stay the same	46.5	41.9
38.0	29.2	Decrease	35.2	38.7
		Quickness of Response to Emergency Calls		
63.4%	31.9%	Increase	62.5%	61.3%
34.8	62.8	Stay the same	31.9	38.7
1.8	5.3	Decrease	5.6	0.0
		Pursuits		
N.A.	27.3%	Increase	N.A.	57.1%
N.A.	59.1	Stay the same	N.A.	36.6
N.A.	13.6	Decrease	N.A.	6.3

the AVM system will improve the ability of the department to keep track of where police are located, and in turn, according to survey results, this may diminish their flexibility and force their continued movement on patrol. Such comments point to the need for more detailed research in this area in order to discover the influence, if any, that FLAIR may have on police patrol. This topic will therefore receive additional attention in Phase II.

4. <u>Effects of the special three-week test on Third District officers</u>. Although specific surveys were not conducted during the three-week test period, an effort was made to ascertain whether any shifts in attitude toward FLAIR occurred as a result of having a better performing, operational AVM system. Following the three-week test a special evaluator was sent to the Third District to conduct oral interviews while riding patrol with the District 3 officers. The evaluator remained in the District for almost a week, and although no "hard" data are available, a number of impressions were formed.

Although it was not clear whether or not officers' attitudes had changed towards FLAIR as a whole, several factors had occurred during the three-week test which had a positive effect upon officer satisfaction with the AVM system and with their job. First, special dispatchers were selected for the test. As a consequence the field personnel "liked" the dispatchers that were on the job during the test period, and the relationship between

dispatchers and the field improved significantly. Second, long-promised miniature radios were provided for all of the men in the District. Third, all field cars in operation for at least the first two weeks of the test were FLAIR cars. Whereas in the past, non-FLAIR cars had tended to be "neglected" by the dispatcher because he or she did not know the location of the car, now all cars could be "seen" by the dispatcher and the dispatcher could treat them all equally.

All three of these factors seemed to have a positive influence on the officers in the Third District. Although if asked specifically about FLAIR a number of police officers would still have responded it was "not a good idea," they had noticed that there were differences in the operation of the system, and they approved of the modifications.[14]

It had become apparent through field interviews and written surveys conducted in the Third District that the dispatcher, along with the actual operation of the system, could play a major role in acceptance by the patrol officers. Individual dispatchers can vary widely as to their knowledge of the district and their courtesy over the air. Knowledge of the district is a quality "street personnel" recognize and appreciate in a dispatcher. Any sign of radio discourtesy, be it by words or inflection, will almost immediately turn personnel against a dispatcher. Maintaining a good dispatcher-beat officer relationship is important to FLAIR since it is the dispatcher with his "FLAIR checks" and

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[14] For example, the evaluator felt that of the three changes, the miniature radios actually did more to increase job satisfaction and general morale than to change any views towards AVM. However, such a change in morale inadvertently improved attitudes toward FLAIR.

"send me a 76" (out of service--low priority), that personifies the FLAIR system to the patrol officer. One would, therefore, expect the policemen to look more kindly upon the FLAIR system when the "better" dispatchers were working. This seems to be exactly what happened during the test period. It further points to the conclusion that the position of the dispatcher in the St. Louis Metropolitan Police Department should be upgraded to attract, on the average, people of the same caliber as those working during the test period.

As an unforseen side effect, the test period appeared to reduce tensions between dispatchers and police personnel. As discussed in Chapters V and VII, prior to the test a primary source of friction revolved about the fact that not all beat cars were FLAIR-equipped. Often, when a dispatcher would receive a call for dispatch, he or she would locate the cursor near the location of the incident and dispatch the nearest FLAIR car with little concern for the presence of non-FLAIR equipped units. If it fell near the area assigned to a non-equipped beat car, the officer would often get on the air and say something like "dispatcher, that is my beat, I will handle." This type of situation represented a challenge to both dispatcher authority and beat integrity and the result was tension between the dispatcher and patrol. Several times, while riding patrol, evaluators noted situations where a busy FLAIR-equipped beat car would be sent to the garage for preventive maintenance,

return to the field in a non-equipped garage extra, and not receive a directed assignment even though other equipped beat cars would be assigned to calls within the beat. This type of situation decreased significantly during the special test period and points to the necessity of having a full contingent of FLAIR equipped garage extras available when the system goes city-wide.

G. Implications of the Attitudinal Analysis for the Phase II Implementation

A number of successes have been achieved to date regarding the implementation of "routine" technological innovations in police departments such as establishing a real-time computer information system to provide rapid retrieval of information for the officer in the street. However, when efforts to implement go beyond routine systems to more non-routine innovations, such as transferring modeling or operations research type technologies or implementing an AVM or CAD system, the process has proven to be far more complex and the success to date has been limited.[15] Further, research experience has demonstrated that the success of implementing and transferring new technology has

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[15]For a complete discussion of this topic and a distinction between routine and non-routine applications see Kent Colton, "Computers and the Police: Police Departments and the New Information Technology," Urban Data Service, November, 1974, ICMA.

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varied widely from agency to agency.[16] A number of these factors relate to behavioral and attitudinal influences. For example, in work by Colton, six elements were identified which influenced success:[17]

1. Involvement and quality of leadership at the top.
2. Involvement of other police personnel (and ability to bridge the gap between EDP and police).
3. Basic approach and establishment of priorities.
4. Caliber of computer systems and technical staff.
5. Emphasis placed on human-computer interaction.
6. Continuity in personnel and purpose over the years.

After analyzing these influences and relating them to the other findings of this research, five elements can be identified which seem especially important in St. Louis. Included within these

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[16] In research by Kent Colton nine police deparments who were using the computer extensively or planning to do so in the immediate future were visited. In those departments an evaluation was made as to the overall acceptance of the computer, the attitude and understanding of the police, the range of applications involved, the level and use of performance, and both past and present problems encountered. Although overlaps obviously occurred, departments were found to split into at least three basic groups. Two police departments were unmistakably successful, four were performing adequately but it was really still too early to tell what the eventual outcome would be, and three groups were definitely having major difficulties. (See Colton, "Use of Computers by Police: Patterns of Success and Failure," Urban Data Service Report. ICMA April, 1972.) Further, in a study by the Rand Corporation, 39 cases of efforts to implement modeling in the criminal justice area were examined looking at all parts of the criminal justice system. This study also found that success varied widely among these various efforts.

[17] See Colton, K., Urban Data Service, November, 1974, as cited in footnote 16 above.

five factors are specific recommendations concerning the Phase II implementation of FLAIR.[18]

1. <u>The link between operations and attitudes</u>.

Accuracy and reliability are essentialif the new system is to be accepted and made to work over the long run. In order to avoid the rapid decline in attitudes experienced in District 3 during Phase I, the Phase II system should be tested under realistic operational field conditions before it is implemented city-wide--preferably in District 3 because of the previous experience and familiarity with the system in that District. Even though the system receives such a test, it should be realized that unexpected problems may still arise when the system is implemented city-wide (such as map errors, magnetic anomalies, questions resulting from inter-district dispatching, etc.) Such difficulties should be anticipated as a part of implementing a new technological innovation, and in fact, it is better to prepare people in advance for such occurrences.

2. <u>Involvement and training of police personnel</u>.

There is a paramount need for effective training and communication concerning FLAIR. However, this means more than just an initial training seminar. As we pointed out earlier, feeling informed about the system was one of the most important factors influencing attitudes toward AVM. An "on-going" dialogue is therefore necessary to answer questions and to explain problems that may arise. Boeing has already designed an impressive training program for Phase II. We recommend that

[18]These recommendations are also repeated in Chapter XI.

this be supplemented by monthly or bimonthly visits by St. Louis and/or Boeing personnel to the "roll calls" at the beginning of each shift in order to answer questions and to discuss the problems of the Phase II implementation.

On the other hand, care should be taken not to "oversell" the system. The evidence indicates that initial expectations were too high in District 3. In introducing the Phase II system it is important to discuss the problems of Phase I in order to establish a realistic but positive set of expectations.

3. The interface between technological and human factors.

One of the most significant elements in determining success or failure in implementing 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. The role of the dispatcher must receive priority attention in the Phase II implementation. A major turnover in dispatchers has been projected for 1976 due to a discontinuance of the cadet program. Capable people must be placed in the new jobs and this may require an upgrading of the dispatcher's job description, qualifications and salary. In addition, procedures for dispatcher-car interactions should be clearly specified, and special training might be provided. For example, dispatchers seldom receive specific training on how to handle such "rare events" as responding to an officer-in-trouble call, handling pursuits, or handling civil distubances.

One approach to rectify this might be training exercises or field experiences whereby dispatchers would be able to simulate these kinds of occurrences.

4. Involvement of top police supervisors.

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 I results have demonstrated that the response time benefits of the system are below initial expectations. Other potential benefits such as the opportunity for improved command and control or better management of resources must therefore be examined to determine the degree to which the benefits may justify the costs. In order to test these areas, though, the deep involvement of the St. Louis command staff is required. For example, as pointed out in Chapter IX of the final report a new set of computer prepared operational reports has been designed for the Phase II FLAIR System. If these reports are to be worthwhile, they should be modified and perfected by the St. Louis command staff so as to provide the best information possible from a management perspective. Further, to truly test the benefits of the system, it may be appropriate 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.

5. Long-term commitment and continuity of personnel over time.

In a recent study by the Rand Corporation it was found that efforts to implement operations research modeling projects in criminal justice agencies are often promoted by a single or small group of advocates.[19] Although such advocates play an important role in spreading innovation, their presence also leaves the innovation vulnerable if a shift in personnel occurs and the advocate leaves the agency or is transferred. In order to assure success of the FLAIR System in St. Louis, a long-term commitment based on a broad base of support is required. To broaden involvement and develop support for technological innovation, some police departments have established a management users committee of top level command officers to help monitor and oversee change. The St. Louis M.P.D. might consider establishing such a committee.

In summary, it must be said that FLAIR 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.

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[19] See. J. Chaiken, et. al., Criminal Justice Models: An Overview, Chapter VII, October, 1975, Rand Corporation, Rand Report #R-1859-DOJ, Santa Monica, California.

CHAPTER XI: SUMMARY AND CONCLUSIONS

A. Operations Analysis: *Response Time Evaluation; Effects on Dispatching Due to FLAIR; Effects on Travel Time Due to FLAIR; Special Three-Week Test.* B. Technological Evaluation: *System Performance; System Accuracy; Location Accuracy Test Results; Mean Time Between Losses; System Reliability.* C. Analysis of Attitudinal and Organizational Impact: *Summary of Findings; Implications for the Phase II System; System Objectives and Cost Considerations; Response Times; Emergency Alarm; Digital Communications; Other System Objectives; Cost and Other Considerations.*

Reader's Guide to Chapter XI: This chapter provides both a summary and the conclusions concerning the Phase I implementation of the FLAIR System in St. Louis. Results are reported concerning the operations evaluation, the technological evaluation, and the attitudinal evaluation. For the reader who turns to this chapter first but is interested in greater detail, references are provided as to where specific topics are discussed in the remainder of the report.

CHAPTER XI: SUMMARY AND CONCLUSIONS

Automatic Vehicle Monitoring (AVM) systems are potential tools for law enforcement agencies, as first indicated by the President's Commission on Law Enforcement and Administration of Justice in 1967. Studies at that time suggested that such systems might achieve cost-effective reductions in response time. Some hypothesized that AVM would improve apprehension rates and thus serve as a deterrent to crime. Within recent years the potential market for AVM--both within the public and private sectors--has been recognized and a number of prospective manufacturers have devoted substantial resources to develop systems. However, the installation of the FLAIR System[1] by the St. Louis Metropolitan Police Department is the first full-scale implementation of an AVM system by a major urban police department. Recognizing the potential and importance of this new technology, the National Institute of Law Enforcement and Criminal Justice of the Law Enforcement Assistance Administration (LEAA) authorized, at the request of the St. Louis Metropolitan Police Department, an evaluation of this implementation, to be conducted by Public Systems Evaluation, Inc. under LEAA Grant No. 75NI-99-0014. This report is an evaluation summary of the Phase I implementation in District 3 of the St. Louis Metropolitan Police Department.

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[1]FLAIR is a registered trademark of the Boeing Company, signifying Fleet Location And Information Reporting.

FLAIR is a computer-assisted dead-reckoning system. This type of system requires that the car's initial position be known, after which frequent "updating" of distance and direction data supplied by the vehicle will make it possible to track its position. Additionally, the FLAIR computer usually keeps the cars' positions on a street (through a map-matching process), and corrects for accumulated distance errors when the vehicle turns into another street. All of this information is presented to the dispatcher on a computer-derived map displayed on a television type screen, utilizing various colors, magnification scales, and a dispatcher-controlled cursor for indicating locations of incidents and vehicles. Occasionally, accumulated errors can develop which may eventually cause the car to become "lost." When the computer recognizes a car may be lost, a *V* (or *W*) is displayed with the car number in the status column of the display. This signals the dispatcher to verify the car's location, and if incorrect, to reinitialize to the proper location. The system utilizes mobile-to-base station "canned" messages to be transmitted to the dispatcher without using the voice channel. The system has other features which are referred to in this chapter and have been discussed in detail in this report.

The methodology used in this evaluation was based on a three-part analysis of <u>operations, technology and attitudes</u>. (For an overview of the evaluation approach, see Figure 11-1.) A summary of the results in each of these three areas will be provided in the following sections of this chapter. The final section

Figure 11-1

EVALUATION PLAN

AVM System Implemented
in St. Louis
Phase I

ESTABLISH SYSTEM OBJECTIVES

1. Reduction in response time
2. Officer safety, emergency alarm
3. Decrease voice-band congestion by digital communication
4. Cost effective justification

OPFRATIONS ANALYSIS

Response time

- Dispatch time
- Travel time
  - empirical results
  - simulated results

Special test

Computer models

- Simulation model
- Mean time between lost cars model

TECHNOLOGICAL ANALYSIS

Performance

- Accuracy
  - location
  - lost cars
  - target objectives
- Radio-channel capacity
- Computer software package

Reliability

- Headquarters equipment
- Mobile equipment

ATTITUDINAL ANALYSIS

Surveys

- Patrol officers
- Dispatchers
- Command staff

Findings

- Change in attitudes
- Causes for change
- Effect of special test on attitudes

Recommendations for Phase II

will discuss system objectives and cost considerations. This three-part evaluation also provides the building blocks for a general methodology for evaluating AVM systems and other technological innovations. For example, specific products have been developed, such as computer simulation models and survey design instruments, which can be applied in assessing potential benefits of AVM in other cities.

It should be remembered that this chapter summarizes an evaluation of an experiment in progress. The implications are two-fold: first, the Phase I system was an "experimental model" which will receive extensive revision in Phase II when the system is implemented city-wide; and second, Phase I involved only District 3 and many of the benefits of operating an AVM system depend on having the system available on a city-wide basis.

A. Operations Analysis

Reduction in response time is often heard as one of the primary arguments in favor of an AVM system. Thus, a major focus of the Phase I operational evaluation was directed toward response time. To properly relate the effects of response time due to AVM, it was necessary to examine the entire police response system, both those aspects which were influenced directly by the FLAIR System and those which were not.

1. Response time evaluation. Response time is considered to be the total time between a citizen's attempt to contact the police

and the arrival of police service at the scene. Response time is comprised of several distinct components, each of which is described in detail in Chapter VI. For the purposes of this summary, four aspects of the St. Louis police response system are worth describing:

- Reporting the incident to the police. This includes the time to detect the incident and to make contact with the police.
- Complaint evaluation processing. In St. Louis a citizen's call goes from the central operator to a complaint evaluator who either forwards the incident to the dispatcher so that an officer can be sent to the incident or handles the call in some other manner.
- Dispatch time. This is the time required from when the dispatcher receives notification of an incident from the complaint evaluator to when a car is dispatched.
- Travel time. This is the time from when the police unit is dispatched to its arrival at the scene of the incident.

Dispatch time and travel time are both directly influenced by the FLAIR System and at times in our evaluation have been referred to as FLAIR-related response time. Although some expressed concern that the proper operation of the FLAIR System--placing the cursor at the scene of the incident, initializing, etc.--might result in an increase in dispatcher workload and dispatch time, such an increase did not occur. However, reductions in travel time were modest, particularly when considering the impact of FLAIR on the overall response system. Observations were also made regarding other aspects

of the overall response time system. (The approximate mean magnitudes of the key components of response time (for District 3) are shown in Figure 11-3.)

2. Effects on dispatching due to FLAIR.

a. Dispatch time-empirical results. Proper operation of the system did not require a significant increase in dispatch time. Mean dispatch time during 1975 (January-November) was 3.62 minutes in District 3, down 1.4% from 1974. The comparable figures city-wide (less District 3) were 2.55 minutes, down 8.6% from 1974.[2] (See Table 11-1.) The 1975 District 3 dispatch times were consistently greater than 1974 times during the first half of the year, but starting in July they dropped noticeably below the 1974 figures. The initial rise can be attributed to the time required for the dispatchers to learn the use of the new system. Once the system was mastered, though, dispatch times for District 3 dropped significantly, in fact at a rate faster than the overall city-wide average. Other factors which influenced the city-wide and District 3 reduction in dispatch time included a drop in call for service workload--a 12% decrease in District 3 and a 10% reduction city-wide, and perhaps the dispatchers' awareness of the increased attention being given to this matter as exemplified by the presence of on-scene evaluators.

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[2]Dispatch time in District 3 has consistently been longer than the rest of the city. Probable reasons include the heavy workload in District 3 and the resulting queuing of dispatchers during peak periods.

Figure 11-2

OPERATIONS ANALYSIS

Police Emergency Response System: Response Time

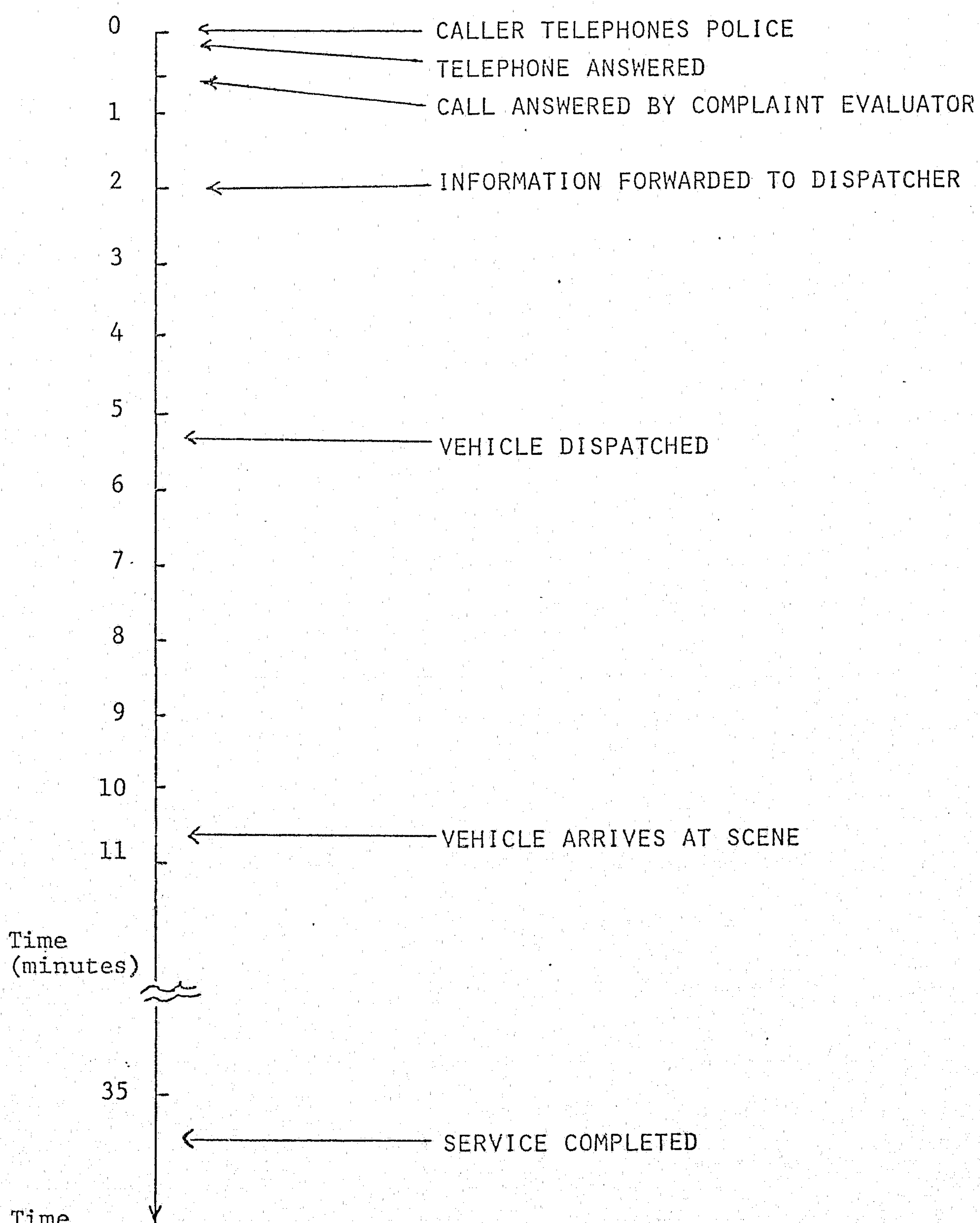

Table 11-1

Tabulation of Average Dispatch Delays Encountered in District 3 and the Rest of the City for 1974 and 1975

(Entries in boxes correspond to months of intensive on-scene evaluation, including stop-watch monitoring, interviewing, and special testing.)

	District 3			City-Wide Less District 3		
	1974	1975	% Change	1974	1975	% Change
	Average Dispatch Delays (in minutes)			Average Dispatch Delays (in minutes)		
JAN	3.22	3.46	+7.4	2.44	1.76	-27.9
FEB	3.02	3.46	+14.6	2.20	1.81	-17.7
MAR	3.25	3.21	-1.2	2.29	1.80	-21.4
APR	2.65	2.93	+10.6	2.19	2.05	-6.4
MAY	2.54	3.66	+44.1	2.12	3.56	+67.9
JUN	3.70	4.38	+18.4	2.93	2.84	-3.1
JUL	5.22	3.62	-30.6	3.41	2.74	-19.6
AUG	4.60	4.06	-11.7	3.85	2.92	-24.2
SEP	4.74	3.81	-19.6	3.52	3.02	-14.2
OCT	3.46	3.34	-0.9	3.03	2.78	-8.2
NOV	3.97	3.77	-5.0	2.75	2.79	+1.4
AVG	3.67	3.62	-1.4	2.79	2.55	-8.6

b. Dispatcher workload. While mean dispatcher times increased for District 3 during the first several months of FLAIR, the decrease in dispatch times over the remaining months indicates that the effects of increase in workload is at least balanced by other factors. FLAIR is estimated to create 5.6 minutes of additional work per hour for the dispatcher--due to initializations and cursor positioning on dispatches--that would not occur without FLAIR. However, some of the time that would have been spent in on-the-air conversations is eliminated by the car-to-dispatcher digital codes. Whether or not dispatcher workload is in fact increased, dispatchers do perceive an increase. This appears to arise from dispatchers being constantly aware of a location check (*V* or *W*) that may be queried in the status column, thereby yielding anticipated periods of inactivity less often than they would without FLAIR.

3. Effects on travel time due to FLAIR.

a. Travel time-empirical results. Mean travel time decreased an average of 8.0% during 1975 (January-November) compared to the analogous pre-FLAIR period in 1974. However, mean city-wide travel time decreased 7.0% during this period. These average travel times were 4.9 minutes and 4.7 minutes for District 3 and city-wide respectively. (See Table 11-2.) Due to under-utilization of FLAIR during much of 1975, it is difficult to draw strong conclusions from these data. During a specially monitored three-week test, mean travel time in District 3 was down 15% (0.89 minutes) in

Table 11-2

Tabulation of Average Travel Times Encountered in District 3 and the Rest of the City for 1974 and 1975

(Entries in boxes correspond to months of intensive on-scene evaluation, including stop-watch monitoring, interviewing and special testing.)

	District 3			City-Wide Less District 3		
	1974	1975	% Change	1974	1975	% Change
	Average Dispatch Delays (in minutes)			Average Dispatch Delays (in minutes)		
JAN	5.44	5.30	-2.57	5.55	4.83	-12.97
FEB	5.16	4.97	-3.68	4.86	4.62	-4.94
MAR	5.29	4.89	-7.56	4.82	4.60	-4.56
APR	5.18	4.79	-7.53	4.76	4.59	-3.57
MAY	5.37	4.90	-8.75	4.90	4.69	-4.29
JUN	5.32	4.83	-9.21	4.89	4.67	-4.50
JUL	5.46	4.78	-12.45	5.05	4.73	-6.34
AUG	5.59	4.48	-13.42	5.29	4.62	-12.67
SEP	5.58	4.74	-15.05	5.22	4.71	-9.77
OCT	5.31	5.18	-2.45	5.02	4.60	-8.37
NOV	5.18	4.97	-5.41	4.97	4.80	-3.42
AVG	5.35	4.92	-8.00	5.03	4.68	-7.00

the test district as compared to the 12-month earlier (pre-FLAIR) levels, but city-wide mean travel times were down 11%, suggesting a net 4% decrease due to FLAIR. Some of these reductions could have arisen from decreased call-for-service workloads in 1975. Regarding the effect of FLAIR on average travel times, we must view the results of Phase I as inconclusive. Certainly there is no indication that FLAIR increases travel time; but the empirical evidence that it decreases is not very strong. Dispatchers' attitudes, perceptions and motivations may have played a key role in measured travel time reduction--both in District 3 and city-wide.[3]

b. Travel time - simulated results. Employing a PSE-developed simulation model of police patrol and dispatching, mean travel time was estimated to be reduced by up to 25% by switching from pre-FLAIR dispatching procedures to closest car dispatching. This figure applied to both pre-FLAIR and FLAIR sector configurations in District 3. 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)

[3]As discussed in Chapter 6 travel time is only one small part of the overall response time system. Studies which are currently underway in Kansas City, Missouri will focus on the time involved in the overall response time system, particularly the time to report an incident. These results will have an important influence in evaluating the impact of an innovation such as AVM and therefore will receive careful review during the Phase II evaluation. For a preliminary discussion of the study see Deborah K. Bertram, and Alexander Vargo, "Response Time Analysis Study: Preliminary Findings on Robbery in Kansas City," Police Chief, May 1976, Volume XLIII, Number 5. (The study is entitled "The Response Time Analysis Study," William Birch, principal analyst, and it is funded by LEAA's National Institute of Law Enforcement and Criminal Justice, Grant 73-NI-99-0047-

precinct-oriented dispatch strategy used prior to FLAIR. Other modeling analyses indicate that about the most travel time reduction that can be expected from FLAIR is roughly 11 to 15%, not 25%, 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.

c. Limitation of AVM dispatch information. After the dispatcher locates the cursor at an incident site, the computer selects the 4 closest cars and displays the car numbers over the CRT Screen in the order of distance from the incident sites. The computer determines the distance by adding the X dimension (East-West) to the Y dimension (North-South), which gives correct answers when the blocks are laid out in this manner. However, in areas where the axis is rotated to other than North-South and East-West, or where diagonal streets exist, errors result from this method of computation, which--from examples constructed--can exceed 1 minute in estimated travel time. Also, the computer listing of closest cars does not take into consideration barriers (such as expressways, canals, etc.) or one-way streets. It is therefore necessary that the dispatcher verify the closest car by observing its location on the visual display.

d. Overall response system considerations. As shown in Figure 3, mean system response time in District 3 is roughly 2 minutes (reporting the incident and complaint evaluation) + 3.5 minutes (dispatch time) + 5.0 minutes (travel time) = 10.5 minutes. So a 30 second reduction in mean travel time corresponds to about a 5% reduction in overall mean response time. Even if the simulated 25% reduction in mean FLAIR travel time is found to apply

during Phase II, this would correspond to 1.25 minutes or 75 seconds, about a 12% reduction in overall mean response time. Recalling that about half of the simulated 25% reduction is due to precinct-oriented dispatching, only about 37.5 seconds of the travel time reduction could reasonably be attributed to FLAIR, corresponding to 6% of the total system response time. One of the conclusions from this is that if the St. Louis M.P.D. is interested in response time improvements they should also concentrate on other aspects of the police response system which are not directly related to FLAIR.

e. Telephone answering delay. An estimated 20 seconds of the 30 seconds of delay experienced by an emergency caller reporting an incident to the police might be eliminated by implementing two public police telephone numbers in St. Louis--one for emergencies and one for other calls (mostly administrative). Additional early delay reduction could be achieved by making the emergency number the now popular three-digit number--911. (Such a change to a 911 system is now being considered by the St. Louis M.P.D.)

f. Complaint evaluation processing. Of the roughly 90 seconds required for the complaint evaluator to record the caller's information and direct it to a dispatcher, about half or more is spent after the telephone conversation. Probably 25 seconds could be eliminated by procedures and/or systems which remove the practice of recording identical information twice and manually looking up a

fraction of addresses. One possibility which requires further evaluation is a CAD (Computer-Aided Dispatch) system.[4]

g. Cross-beat dispatches. Closest-unit dispatching influences patrol performance since it results in a greater amount of cross-beat and cross-district dispatching. In non-AVM dispatching systems, the fraction of dispatchers that are interbeat is usually about equal to the average workload (that is, fraction of time not available for dispatch, say 20%) of the patrol force. With AVM, this fraction is increased, usually markedly for low-to-moderate workload systems. Using the simulation model, this behavior was found to be true for District 3. Such increases in cross-beat dispatches should be of particular concern to police departments that desire to maintain (to the extent feasible) the one-man, one-beat concept. For other departments that desire wider overlapping areas of patrol responsibility, this operational consequence of AVM dispatching should cause little or no problem.

4. Special three-week test. A number of operational and accuracy difficulties developed during the Phase I implementation of the FLAIR System in District 3. The accuracy difficulties will be discussed in the next section which describes the technological evaluation of the system. In addition, on-scene evaluation suggested that the dispatchers were not using the FLAIR System as it was intended to be used during much of Phase I. In one

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[4]As discussed in Chapter XII, there are other arguments favoring the compatible merger of AVM with CAD systems.

sample, the cursor was used in only about 35% of discretionary dispatches and information from the closest car column influenced the dispatch for only 19% of dispatches. Wide variability of these figures by dispatcher indicates that certain dispatchers were well-motivated and used the system as intended; others bordered on virtually ignoring the system. Part of the problem was created by an overall decreased interest in FLAIR due to a lack of a fully FLAIR-equipped fleet of vehicles in District 3 during Phase I.

In order to examine the operations and influence of the Phase I system under a more favorable set of circumstances, a special test was designed and conducted in District 3 from September 15 to October 5, 1975. The test was needed to study the operation of the system under two important conditions: 1) proper use by dispatchers (a special set of dispatchers were selected to work with the FLAIR System during the test), and 2) full coverage of the entire district by FLAIR-equipped cars (extra cars were kept in the garage as spares to be substituted if any of the District 3 vehicles required repair or maintenance). The complete results of the special test are described in Chapter VII. A few of the relevant conclusions, though, are summarized here.

a. The operations of the system improved significantly. During the test substantial improvement was experienced in the proper use of the system. Dispatchers utilized the components of the system to dispatch the closest car, and patrol officers seemed more satisfied with overall operations. Although no specific surveys were conducted, on-site evaluators (after talking to patrol officers

and riding patrol in police vehicles) reported an increase in confidence in the system. As reported earlier, travel time was reduced during the three-week test, but not substantially (when normalized for city-wide reductions). Once again the special test confirmed that if the system is operated properly, there should be no increase in dispatch time.

b. Trained and motivated dispatchers are essential to the successful use of the system. With effective and motivated dispatchers an AVM system can increase the logic and attention associated with the dispatching process. The ability to dispatch the closest car with such a sophisticated technology not only improves dispatch decisions directly, but it appears to increase the perceived level of professionalism of dispatchers. Also, the way the dispatchers use AVM as an aid to their activities is a major factor in the way officers in the field regard the AVM system, thereby affecting field performance through such activities as voluntary self-initializations.

c. Spare vehicles and maintenance personnel are essential. System performance and user attitudes are very adversely affected by the presence of non-FLAIR vehicles in order to achieve some acceptable level of system performance (e.g., a full complement of FLAIR-equipped vehicles at least 98% of the time). Determination of the required number of spares could be accomplished by the use of simple reliability theory, assuming accurate statistics are recorded allowing estimation of mean time until breakdown and mean time for repair.

5. Use of models in other cities. The simulation model (described in Chapter VIII) allows a police planner to simulate the dispatch and patrol operations of his city--operating in a rather complex mode which could replicate in close detail the operations of most cities. The simulation can be run for both AVM and non-AVM dispatching, thereby facilitating the pre-implementation evaluation of AVM in other cities.

The "mean-time-between-losses" model (discussed in Chapter V) outlines and describes the process in a five-step procedure. This model is particularly useful in projecting the relative importance of error sources that cause location error and "lost" cars. It may not be directly applicable to other cities because city-specific programs can be included in the computer software.

These two models--both in the public domain--along with other aspects of our Phase I evaluation, represent the beginning of a transferrable AVM evaluation-methodology--usable in other cities.

B. Technological Evaluation

This section highlights Phase I FLAIR technical performance, with emphasis on identified problems, Phase II corrective actions, and other implications where applicable. Also included is a summary of the system reliability during Phase I, service problems and concerns for Phase II.

1. System performance. Considering the complexity of the new technology, the system performed well and functioned as intended

The color display terminal shows the selected map of a part of the city with police vehicles traveling in streets and with each vehicle identified by number and by class. The display of vehicle status (available for call, on call, etc.), digital code messages, and the four closest cars to an incident site were readily discerned. Operation of the display terminal was reasonably simple, and most of the better dispatchers integrated the FLAIR-supplied information into the dispatching process.

The principal hardware operating problem during Phase I was accuracy, particularly as it related to the frequency of lost cars. Another major system problem was radio-channel capacity wherein the assigned channel (UHF frequency) accommodated only 97 cars compared to 200 required by the FCC. These two problems were largely responsible for two major design changes for Phase II:

- An entirely new radio transmission format which provides for the increased number (200) of cars per channel, better distance and angular resolution, more precise synchronizing signals, satellite stations and other improvements.

- An entirely new software package that increases computer capacity, includes changes to improve open and closed-looped tracking[5] and provides more information on street widths and off-street areas for improved accuracy.

The effect of these changes will be evaluated during the Phase II study.

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[5] Open-loop tracking occurs when the vehicle is not known to be driving on a street and non-corrected dead reckoning information is used to update its position. Closed-loop tracking, representing the more usual form of tracking, constrains the estimated vehicle position to streets.

2. System Accuracy. In Chapters II and V suggested performance levels for AVM systems operating in an urban police environment were developed. These accuracy levels were based on system objectives including operating in a dense urban environment and/or using the system as a tool for command and control operation and locating an officer in trouble. Suggested performance levels are:

- For location accuracy the indicated position should be within 220 feet of true position 95% of the time with an outside limit of 400 feet suggested.
- For frequency of lost cars, a level substantially less than the 11 per car per 24-hour day as experienced in Phase I. An acceptable level has not been established. Factors influencing this limit are discussed later in this report.

3. Location Accuracy Test Results. Phase I tests showed 95% of the measurements to be within 625 feet[6] an average error of 137 feet (upper bound) to 101 feet (lower bound) depending upon error distribution assumptions, and 80% of the cars within 90 feet of their true location. The computer assistance in keeping cars located in streets through a map-matching technique and correcting for accumulated distance errors when a corner is turned is responsible for the exceptional performance for 80% of the samples of the cars taken; however, too many of the cars escaped the computer hold causing the relatively poor 95% confidence level and the large number of lost cars. Phase II changes should result in substantial improvement.

a. Location errors with known corrections. A number

[6]This measurement is frequently referred to as the 95% confidence level.

of error sources have been identified and Phase II corrections applied as follows:

- Angular and distance resolution was too course, being 11.25° (± 5.6°) and 24 feet respectively. Phase II will be 2.8° (±1.4°) and 6 feet.

- Tires increased in diameter with speed causing errors at 60 mph (compared to 30 mph) of 2% (or 106 feet per mile) for a rayon belted tire and 0.25% (or 13 feet per mile) for a steel radial tire. Phase II will incorporate "velocity" correction in the computer algorithm to correct errors from this source.

- Tires decreased in diameter due to wear, measuring 2% (106 feet per mile) for rayon belted and 1.2% (63 feet per mile) for steel radial. Phase II corrections would include frequent odometer calibrations (perhaps every 5,000 miles). A preferred method would be to have a "wear" correction added to the computer algorithm although this is not now planned.

b. <u>Location errors without known corrections</u>.

- Errors are caused by random effects such as driving methods, road conditions, lane switching, inside versus outside lane travel at curves and corners, etc. Measurements show this to cause errors of from 0.1% (five feet per mile) to 0.28% (15 feet per mile).

- Errors can be caused by missed signals or bad data. In a test throughout the city involving a total of over 5,000 time-slot transmissions, 2.35% of the signals were missed (weak), 0.58% were bad data and 0.31% were one of two consecutive missed signals. Overall, this is considered good performce except that one area within the city was in the shadow of a hill. Weak signals in the area around Jamieson between Chippewa and Arsenal caused two or more consecutive missed transmissions 10% or more of the time, which could result in unsatisfactory performance. This will be verified during Phase II.

- Tests in off-street areas (parking lots, shopping centers, etc.) under open-loop conditions caused a *V* and *W* to appear from four out of eight areas visited, and required three initializations. This indicated poor performance, but the results require further verification because of the small sample size. A more thorough study of this problem is planned for Phase II.

- Two areas having magnetic anomalies were located (by Boeing) in District 3; one is the area around the flood wall near the river, and the other at the Vandeventer viaduct. These areas are recognized by the computer, which will flag a FLAIR-equipped car entering the area with a *W* requiring initialization after the car leaves the area. The extent of magnetic anomalies in other areas of the city is not known. If too many develop, the frequent initializations required from this cause can contribute to lack of confidence in the system. Boeing has developed an option using a second odometer whose output can be compared with the first to detect and over-ride errors caused by magnetic anomalies. This is yet to be proven, however.

c. Other error sources. Map errors resulting in incorrect distances between any two points, or errors caused by the process of digitizing the map for computer storage into directed line segments could potentially be as much of a problem as those caused by equipment. The magnitude of such errors is not known, since errors of this type were corrected by the contractor in the Phase I implementation. Phase II will offer a better opportunity for this study, and map accuracy tests are planned.

A number of error sources have been described in the foregoing, some appearing to be of minor consequences. The cumulative effect of even small errors causes loss of location accuracy and increases

the frequency of lost cars. While considerable improvement is expected from Phase II corrections, additional testing of error sources is expected to continue during Phase II evaluation.

4. Mean time between losses. When a vehicle becomes lost, the computer can no longer track it, and the dispatcher is required to correctly locate the vehicle by the process known as initialization. The following reviews test results, causes and allowable levels.

a. Test results. During Phase I (including a specially conducted three-week test), the FLAIR System experienced an average of about 11 initializations per car per day or about 2.2 hours between losses of a FLAIR vehicle. While it is too early to make a final conclusion regarding the maximum allowable number of initializations per car per day-- consistent with acceptable system performance--the figure of 11 per day is too great to instill the necessary confidence and enthusiasm for FLAIR in dispatchers and patrol officers. Given the results of a PSE-developed model which examines "mean time between losses," results in the range of four per car per day may be a more reasonable objective for Phase II, but only tests will demonstrate whether this will maintain the confidence and enthusiasm required.

b. Mean time between losses - causes. Errors that cause loss in location accuracy also cause an increase in the number of lost cars. A modeling analysis, coupled with empirical

tests, indicated that the following factors all contribute to smaller values of the mean time between losses (or equivalently, increased values of the number of initializations per car per day):

- Random error - due to tire slippage, irregular driving patterns, speed variations (if viewed as incorrectable), and mapping errors.
- Systematic error - due to temperature, tire wear, and speed (if viewed as correctable).
- Quantization in time, distance and angle. (The addition of two bits for both the distance and the angular information should essentially remove any error effects due to distance and angle quantization in Phase II.)
- Missed signals - if the headquarters receiver misses two or more consecutive signals, serious errors can occur if a turn has occurred during that time. Three or more consecutive missed signals is more serious due to the fact that the digital odometer may recycle, suggesting a much lower travel speed than actual speed. In Phase II, more historical data will be retained in the computer and the algorithm will be modified to reduce the probability of error from these causes.
- Open-loop tracking - due to crude quantization intervals in Phase I, open-loop driving was a primary cause of lost vehicles. This problem should be reduced in Phase II.
- Susceptibility to subversion - the system is open to acts on the part of patrol officers and/or dispatchers aimed deliberately at reducing system effectiveness. These include deliberate driving near magnetic anomalies, reporting incorrect locations, etc. This will be a major concern of the Phase II evaluation.

c. Allowable random and systematic errors. The model developed to predict the mean time between losses, while using admittedly tentative parameter estimates, suggests that every

effort should be made during Phase II to reduce systematic and random errors to the maximum extent possible. Otherwise it will be very difficult to obtain a mean time between losses greater than, say, six hours. The inclusion of real-time speed monitoring in Phase II (made allowable by a finer distance quantization interval) plus the apparent universal use of steel belted radial tires (to reduce tire circumference changes due to speed) are steps in the direction of reducing systematic error. A certain amount of random error will remain--the exact amount to be determined--due to the center-line street mapping technique. The model suggests that reasonably tight tolerances on systematic and random error could reduce to between one and two per day the number of losses (per car) due solely to these types of errors. Of course, additional losses can still occur due to missed signals, open-loop tracking, and system vulnerability.

5. System Reliability. Failures in the base station cause the entire system to be down. During Phase I the mean time between failure (MTBF) was 38.9 days, the mean time to repair (MTTR) was 1.32 days--resulting in a total down time per year of 12 days. Most of these failures were computer-related. Phase II will have a standby computer, which should greatly improve this performance. However, the transfer from one computer to the other is a manual operation requiring perhaps half an hour to accomplish-- and this does not include the time required to reinitialize all the cars in the fleet that have moved during this period and those that

have not been self-initialized.

For the FLAIR mobile equipment, the mean time between failure was 7.7 days per car (or for a 26 car fleet, 0.3 days). The mean time to rapair is estimated by Boeing at 1.05 hours. (This repair time does not include delays at the repair shop due to backlog of cars requiring servicing.) The most recurrent repair problem was recalibration of the magnetic heading sensor, accounting for 25% of all service problems. Any corrective actions planned for alleviating this problem in Phase II are not known.

The number of repair incidents in Phase I is considered high, but perhaps not unreasonable f a trial system. Reliability was adversely affected by fixes that were applied as problems were uncovered and some non-production construction methods. Also Phase I service operations were hampered by a lack of service information, test equipment, and spare parts. It is expected that reliability of the Phase II production equipment will improve by a factor of perhaps 2 to 1.

The number of technicians required to service the 200 cars for FLAIR failures during Phase II is estimated at four or five, depending upon the shift arrangement adopted. It is anticipated that the service facilities will be manned seven days a week. The number of spare FLAIR-equipped cars required to replace those undergoing repair for FLAIR causes is estimated at three to five cars, again depending on the shift arrangement adopted. The total number of FLAIR-equipped spare cars must be sufficient to replace those being serviced for non-FLAIR causes also, such as for

communication equipment and for mechanical reasons. Proper provisioning of FLAIR-equipped spare cars is considered important for maintaining a nearly 100% FLAIR presence in the field, because non-FLAIR cars are likely not to be dispatched. Servicing efficiency in Phase II will be enhanced by new service equipment supplied by Boeing, proper service manuals, adequate spare parts, more technical experience and better construction methods.

6. Phase II concerns. Many changes and improvements are scheduled for Phase II that are expected to improve performance and reliability. However, areas of concern remain as follows:

- The software is all new, is more sophisticated and has four times the memory and eight times the number of cars to track. Some debugging should be expected.
- It is not known if the M.P.D. will enter into a computer service contract with the supplier or other vendor, or provide other arrangements. A service contract is strongly recommended, at least until a performance history has been established.
- The radio transmission digital format is entirely new, employing some state-of-the art design techniques and it will be operating with much greater loading of the time slots. Effects on performance and reliability must be determined.
- Signal strengths are weak in the area around Jamieson Street between Chippewa and Arsenal. To correct this, a satellite receiver may be necessary. Such a unit is yet to be tried in the FLAIR system. Also, other areas of weak signal may be discovered during the city-wide implementation.

C. Analysis of Attitudinal and Organizational Impact

The implementation of an AVM system implies more than routine

introduction of a new technology; such an innovation also has important behavioral and organizational consequences. In Chapter X we pointed out that a number of successes have been achieved to date regarding the implementation of "routine" technological innovations in police departments such as establishing real-time computer information systems to provide rapid retrieval of information for the officer in the street. However, when efforts to implement go beyond routine systems to more non-routine innovations, such as transferring modeling or operations research type technologies or implementing an AVM or CAD system, the process has proven to be far more complex and the success to date has been limited.[7] One of the reasons that such efforts have faltered has been a failure to take into consideration the importance of behavioral and human factors. Several studies have demonstrated that it is often not technical difficulties which limit long-run implementation, but behavioral and people-oriented factors.[8] Attitudinal and organizational implications therefore comprise one of the primary components of our evaluation.

A number of attitudinal surveys of dispatchers and patrol officers in District 3 and District 5 (the control District) were

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[7]This is discussed in Chapter X, Section F. Also for example see Colton, "Computers and the Police: Police Departments and the New Information Technology," Urban Data Service, November 1974, ICMA.

[8]See Colton, op. cit.; also see J. Chaiken, J. Crabill, L. Holliday, D. Jaquett, M. Lawless, E. Quade, Criminal Justice Models: An Overview, Rand Corporation, October 1975, Rand Report #R-1859-DOJ, Santa Monica, California.

conducted, both before and after the implementation of the system. We will first summarize the results of these surveys, and then outline what they mean for the Phase II implementation of FLAIR.[9]

1. Summary of findings. The details of our findings in this area are described in Chapter X. Some of the highlights are as follows:

General attitudes toward FLAIR shifted significantly during the Phase I test period. Before using the system, 64.4% of the District 3 officers thought FLAIR was a "good idea." After the Phase I implementation only 39.8% still thought FLAIR was a "good idea." A number of factors contributed to this change in attitude:

- Most important, there is a crucial link between attitudes and operational performance. Problems with the accuracy and reliability of the system seem to be the primary cause for the drop in attitudes.
- Due to operational problems many of the initial expectations of the system were not met. Such unfulfilled expectations led to the disillusionment of some officers and a drop in positive feelings toward the system.
- The effective operation of FLAIR relies heavily on well motivated and trained dispatchers. Since the capabilities of the dispatchers who worked with FLAIR were mixed, this uneven quality contributed to the shift in attitudes.
- Attitudes are volatile and the negative trend may be reversible if the Phase II System functions smoothly. In fact, during the special three-week test conducted in September and October, 1975, the careful selection of dispatchers, the availability of a full fleet of FLAIR-equipped cars, and personal

[9]Copies of the actual survey instruments are provided in Appendix D.

two-way radios all seemed to have a positive influence on the officers in the Third District. Still, once a negative attitude is established, initial impressions are difficult to overcome.

a. <u>Other behavioral factors have an important influence on attitudes</u>. Two other factors were found to be especially important in influencing attitudes toward FLAIR: first, level of information about the system; and second, initial source of information.

- The initial training seminar in District 3 seemed instrumental in influencing positive attitudes as compared to District 5. Even after the attitudes of the officers in District 3 dropped, a strong correlation was found to exist between those officers who still felt FLAIR was a good idea and those who felt well-informed about the system.
- Regarding the initial source of information, the opinions of other officers seemed particularly important in influencing and reinforcing feelings toward the new system.

b. <u>Important shifts occurred during Phase I test period regarding the perceived influence of FLAIR on police activities</u>.

- First, although officer safety remained as the top area of importance to officers, its overall rating of importance dropped significantly after implementation. Whereas eight out of every ten of the officers surveyed in both Districts 3 and 5 before implementation felt that officer safety was a very important goal in the FLAIR System, after implementation only five out of ten of the officers in District 3 maintained such feelings. Operational difficulties obviously influenced the confidence of the officers in whether the system would locate them in times of stress.
- Second, the perceived importance of FLAIR in dispatching the nearest officer also dropped significantly in District 3--again showing the influence of operational results on attitudes.

- Third, the benefits of the digital communication capability of FLAIR were perceived by both police officers and dispatchers to be one of the most important aspects of the new system.

- Fourth, concern over disciplinary abuses dropped significantly in District 3 after the Phase I implementation. (In 1974, 65.1% of the officers expected disciplinary abuses to be the major problem, in 1975 only 27.7% saw such abuses as a major problem for FLAIR.) Much of this must be attributed to the operational problems since a number of officers felt that the system could not track them adequately. However, the latent fear that remains in the M.P.D. on this matter is demonstrated by the fact that even after implementation in District 3, disciplinary abuses still remain as the primary concern in District 5.

c. Further research is required during Phase II in order to evaluate the impact of FLAIR on police operations. Responses to surveys indicate that officers feel that FLAIR will have (or has had) little impact on police preventive patrol. However, officers do feel that the AVM system will improve the ability of the department to keep track of where police are located, and in turn, according to survey results, this may diminish their flexibility and force their continued movement on patrol. Such comments regarding potential impact on police operations are at this stage primarily speculative based only on initial officer perceptions. This area will receive additional attention in Phase II.

2. Implications for the Phase II System. In Chapter X a number of factors are outlined which contribute to the successful

implementation of new technological innovations. After analyzing these influences and relating them to the St. Louis situation, five elements can be identified which seem especially important to the Phase II implementation.

a. The link between operations and attitudes. Accuracy and reliability are essential if the new system is to be accepted and made to work over the long run. In order to avoid the rapid decline in attitudes experienced in District 3 during Phase I, the Phase II system should be tested under realistic operational field conditions before it is implemented city-wide--preferably in District 3 because of the previous experience and familiarity with the system in that District. Even though the system receives such a test, it should be realized that problems may still arise when the system is implemented city-wide (such as map errors, magnetic anomalies, questions resulting from inter-district dispatching, etc.). Such difficulties should be anticipated as a part of implementing a new technological innovation, and in fact, it is better to prepare people in advance for such occurrences.

b. Involvement and training of police personnel. There is a paramount need for effective training and communication concerning FLAIR. However, this means more than just an initial training seminar. As we pointed out earlier, feeling informed about the system was one of the most important factors influencing attitudes toward AVM. An "on-going" dialogue is therefore necessary to answer questions and to explain problems that may

arise. Boeing has already designed an impressive training program for Phase II. We recommend that the training be supplemented by monthly or bimonthly visits by St. Louis and/or Boeing personnel to the "roll calls" at the beginning of each shift in order to answer questions and to discuss the problems of the Phase II implementation.

On the other hand, care should be taken not to "oversell" the system. The evidence indicates that initial expectations were too high in District 3. In introducing the Phase II system it is important to discuss the problems of Phase I in order to establish a realistic but positive set of expectations.

c. The interface between technological and human factors. One of the most significant elements in determining success or failure in implementing 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. The role of the dispatcher must receive priority attention in the Phase II implementation. A major turnover in dispatchers has been projected for 1976 due to a discontinuance of the cadet program. Capable people must be placed in the new jobs and this may require an upgrading of the dispatcher's job description, qualifications and salary. In addition, procedures for dispatcher-car interactions should be clearly specified, and special training might be provided. For example, dispatchers now do not receive specific training on how to handle such "rare events" as responding to an officer-in-trouble call, handling pursuits, or

handling civil disturbances. One approach to rectify this might be training exercises or field experiences whereby dispatchers would be able to simulate these kinds of occurrences.

d. Involvement of top police supervisors. 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 I results have demonstrated that the response time benefits of the system are below initial expectations. Other potential benefits such as the opportunity for improved command and control or better management of resources must therefore be examined to determine the degree to which the benefits may justify the costs. In order to test these areas, though, the deep involvement of the St. Louis command staff is required. For example, as pointed out in Chapter IX of the final report a new set of computer prepared operational reports has been designed for the Phase II FLAIR System. If these reports are to be worthwhile, they should be modified and perfected by the St. Louis command staff so as to provide the best information possible from a management perspective. Further, to truly test the benefits of the system, it may be appropriate 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.

e. Long-term commitment and continuity of personnel over time. In a recent study by the Rand Corporation it was found that efforts to implement operations research modeling projects in criminal justice agencies are often promoted by a single or small group of advocates.[10] Although such advocates play an important role in spreading innovation, their presence also leaves the innovation vulnerable if a shift in personnel occurs and the advocate leaves the agency or is transferred. In order to assure success of the FLAIR System in St. Louis, a long-term commitment based on a broad base of support is required. To broaden involvement and develop support for technological innovation, many police departments have established a management users committee of top level command officers to help monitor and oversee change. The St. Louis M.P.D. might consider establishing such a committee.

3. System objectives and cost considerations. One of the most important questions in evaluating an AVM system such as FLAIR is determining whether the objectives of the system have been met and whether the benefits justify the cost. It is impossible to reach a final conclusion on this issue based solely on the results of the Phase I system. In Chapter I though, we outlined the potential benefits of AVM systems and it is worthwhile at this point to discuss our initial conclusions in each of these areas. (See Figure 11-3).

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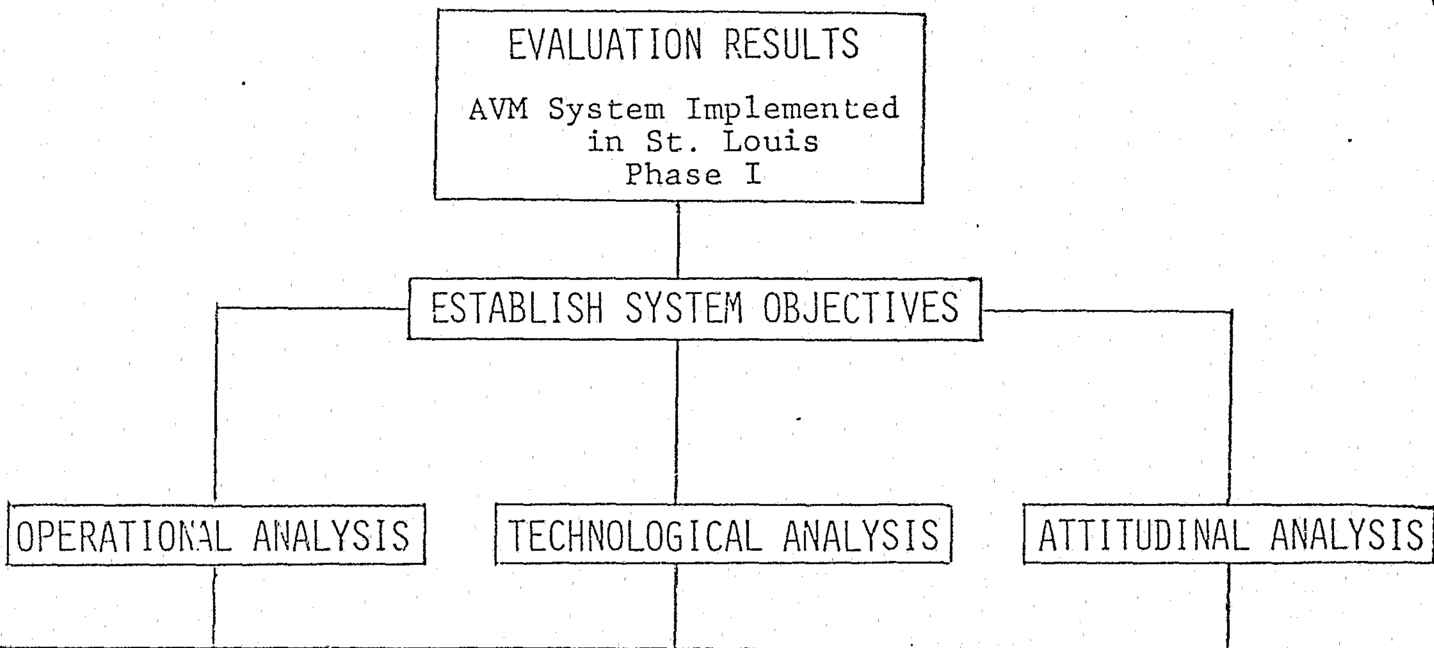
[10] See J. Chaiken, et. al., Criminal Justice Models: An Overview, Chapter VII, October 1975, Rand Corporation, Rand Report #R-1859-DOJ, Santa Monica, California.

Figure 11-3



MEETING SYSTEM OBJECTIVES

1. Response time - only modest reduction; results inconclusive.

2. Officer safety - results inconclusive because of equipment/accuracy problems and small sample size.

3. Digital communications - level of voice-band congestion was not materially changed. However, system experienced high usage; permitted instant mobile to base communication; provided flexibility in dispatcher operations.

4. Cost-effectiveness - system cost ≅ $2,000/year/car or 2% of total cost for one-man car. Cost justification not yet established.

5. New objectives identified for Phase II evaluation -
   Command and control operations.
   Improved management of resources.

a. Response Times. As reviewed earlier in this chapter, the system objective of greatest interest is the reduction in response time resulting from automatic selection and subsequent dispatching of the closest car(s). Phase I tests do not support the expected substantial reduction. Although we will continue to examine this question closely in Phase II, current findings lack evidence to suggest that savings in travel time due solely to AVM will significantly improve police operations or reduce cost.

b. Emergency alarm. Another original objective, and the one most important to patrol officers, is the emergency feature, whereby an officer in trouble can obtain assistance quickly. When the emergency alarm is activated, the dispatcher is alerted visually and audibly; and the location of the vehicle sounding the alarm is known immediately from the display. In addition, the computer-selected closest cars are identified for quick dispatch. Achievement of this objective has not been established during Phase I, largely for the following reasons:

- The high rate of lost cars and system location errors has decreased the confidence of patrol officers as to the dispatcher's ability to locate him accurately and consistently. There appears to be a preference of at least some officers to announce their situation and location over the voice radio.

- The emergency alarm has been improperly used by some officers (e.g., activating the alarm to test whether or not the system is operating) and has been accidently activated at times causing a "false alarm" condition that tends to decrease the urgency in responding to a real alarm.

- The number of real alarms has been small, making a proper evaluation difficult due to small sample size.

Improvements in the Phase II system and equipment (to increase accuracy); additional training of the officers and better emergency knob design (to reduce apparent false alarms); and city-wide implementation (to increase the number of incidents) should establish improved conditions for evaluation during Phase II.

c. Digital communications. Digital communications gives an additional communication means to the patrol officer, which for FLAIR provides transmission from mobile to Headquarters of 99 "canned" messages. One of the original objectives was to decrease voice-band congestion by using this new medium. Tests made by the M.P.D. during Phase I show essentially no change in voice-band occupancy levels. However, other benefits become apparent including:

- High usage of digital communication by the patrol officers involving over 2,000 messages per day or over 100 per day per car. This amounts to an expansion in the capacity of the communications system compared to what could be accommodated by existing voice channels.

- The patrol officer can communicate a change in status instantly to the dispatcher whereas with voice radio only, he would normally wait for clear channel status which could involve considerable delay, or he may not bother to communicate.

- The dispatcher can organize work tasks better, permitting some digital inquiries to accumulate before acknowledging if other matters have higher priority. Voice radio does not have this flexibility.

- Digital messages are relatively secure and cannot be intercepted by the commonly available "police" monitor radio.

The above benefits should make police operations more effective and increase confidence of the patrol force. Both police officers and dispatchers felt that digital communication provided some of the most important benefits of the system.

d. Other system objectives. During the Phase I evaluation, other system objectives were identified which will be evaluated in greater detail during Phase II. These include:

(1) Command and control operation. The dispatcher display locates, identifies and shows status of all patrol cars in the fleet. In case of a major incident such as a bank robbery, chase, bombing, riot, etc., the dispatcher knows the location of each type of car available for service in the vicinity of the incident, and can strategically deploy them to seal off an area, intercept a chase, etc. The capability was illustrated in a chase that started in District 3 and progressed out of the FLAIR-equipped area.[11] While the chase was in District 3, the dispatchers ordered patrol cars by voice radio in a clear and controlled manner to locations for possible interception; after the chase left District 3, the effectiveness of the dispatcher was greatly reduced because most of the radio time was spent asking for the location of the various cars involved.

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[11]This chase occurred in October, 1975.

Phase II, being city-wide, will provide more opportunities to evaluate the command and control benefits of the system. To take full advantage of this we recommend that dispatchers receive special instruction concerning dispatching strategies, and that organizational experiments be conducted such as having an officer experienced in the field of deployment assigned to help oversee the dispatching function for such major incidents, particularly incidents which cross district boundaries. In addition, should the St. Louis M.P.D. be considering alternative patrol strategies[12] for command and control modifications, the existence of FLAIR provides the department with an important tool for evaluation since it tracks the actual location of all police cars.

(2) Improved management of police resources. With implementation of FLAIR in District 3, it was our impression that fewer patrol cars volunteered for unnecessary back-up assignments and fewer patrol cars appeared to congregate for prolonged visits than what seemed to have been the practice. Conversely, the FLAIR-equipped cars appeared to be attentive to their assigned duties, whether on assignment or on patrol. This can be observed by viewing the display, and of course the patrol officers are aware of the display. This may result in negative consequences as well, though. For example, the attitudinal surveys of patrol officers indicated that FLAIR had limited their flexibility and

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[12]For an illustration of such experimentation of patrol strategies, see "The Kansas City Preventive-patrol Experiment, a Technical Report", by George L. Kelling, Tony Pate, Duane Diechman and Charles E. Brown, published by the Police Foundation, Washington, D. C., 1974.

their ability to follow up on hunches. If such limits in flexibility result in a reduction of time wasted, good. On the other hand, if officers feel overly restricted in carrying out their law enforcement work this may have a negative impact. Properly used, AVM may be useful in improving the efficiency and effectiveness of the patrol force, but this still must be tested.

During Phase II, an attempt will be made to develop measures indicating the extent of such improvement. These may include a measure of miles driven per day on preventive patrol as opposed to responding to calls, the number of self-initiated activities, time spent at the District Station, and others. If it can be shown that the force is more effective because of FLAIR, this could be a cost-effective benefit. An improvement of say 10% should be compared to the amount of additional manpower that would be required to achieve the same 10% improvement. However, we recognize that a conclusive evaluation based only on quantitative measures may be difficult, and that subjective measures may also be necessary.

4. Cost and other considerations. The total cost of implementing the Phase II FLAIR System is estimated at $2,700,000.[13] However, these expenses must be placed in the context of overall police operations. In Chapter II an illustration is given of the probable Phase II annual costs of FLAIR. From this example, the total system cost is equal to $9,500 per car (capital invest-

[13] This amount includes both Phase I and II.

ment), or for a 10-year life the annual depreciation will be $950 per car per year. The operating/service costs exceed this amount, estimated at about $1,000 per car per year. The total of amortized investment cost and operation/maintenance costs over a ten-year period then approaches $2,000 per car per year.

The cost of a one-man patrol car is in the vicinity of $100,000 per year. The total FLAIR cost at $2,000 per year then represents 2% of the total cost for a one-man car, or 1% of the total cost for a two-man car Compared to the one-man car, if it can be shown that FLAIR (or any other AVM system) will increase the efficiency and effectiveness of the force by X% (because of better management of the forces), then FLAIR will provide an X:2 return on the investment. If X is equal to 10%, for example, this would produce an impressive 5:1 return on investment.

We also realize that more than just monetary factors must be considered when evaluating the advantages and disadvantages of AVM. For example, it is important to examine the implications that AVM might have on police policy and approach. To the extent that AVM stresses rapid response to call for service and dispatching the closest car it may limit or conflict with an alternative approach to policing--the "one-man, one beat" approach which gives a patrol officer responsibility for a particular area (such as with team policing). It may be impossible then, to do a definitive review of costs and benefits that will be applicable to all police departments. The costs and benefits for each city will be different depending on their goals and priorities. However, at the present

time, there are a number of unknowns and even myths concerning the application of AVM technology. Phase I has already been important in answering many of these unknowns, and it is anticipated that the Phase II evaluation will prove extremely useful in providing significant insights into the remaining issues.

SCOPE

CHAPTER XII: RECOMMENDATIONS FOR OTHER CITIES

A. Analysis of Location Situation: *Review of Police Emergency Response System; Use of Simulation Model or Comparable Tool.* B. Critical Factors of Concern: *Operational Factors; Technological Factors; Attitudinal Factors.* C. Long-Term Commitment to AVM.

Reader's Guide to Chapter XII: Much of this report has been devoted to the evaluation of an AVM system implemented in the St. Louis Metropolitan Police Department. The St. Louis experience, though, provides an important background for others in the field of law enforcement who are interested in the potential of installing an AVM system. This chapter provides a set of recommendations for other cities and outlines a process by which they should analyze their situation. The critical factors involved in such a pre-implementation study will also be outlined.

CHAPTER XII: RECOMMENDATIONS FOR OTHER CITIES

While Chapter XI focused on St. Louis-specific conclusions of the Phase I evaluation, this final chapter attempts to build from the St. Louis experience to date to present in summary form a set of recommendations for potential AVM consumers in the field of law enforcement. Recognizing the "in-progress" nature of the St. Louis evaluation, these recommendations should be viewed as tentative; they may be modified as a result of the Phase II evaluation.

Given the diversity of potential applications of AVM in police operations and given that each city is likely to apply its own unique value weight to each application, it is important that each city analyze its own situation with respect to AVM. A focus of this chapter is the process by which such an analysis can occur. This ranges from the activity of goal setting, to data collection, to mathematical modeling, to the setting of performance specifications, etc. After outlining the process of analyzing the local situation, critical factors of concern--all dervied from our St. Louis experience and related work in the field of law enforcement--are discussed within the three-pronged evaluation framework: operations, technology and attitudes. The chapter concludes with a discussion of long term commitment to AVM and related technologies.

A. Analysis of Local Situation

Each city that is likely to consider the purchase of an AVM system is unique in some way. Each can be described in aggregate terms such as the area of the city, its street mileage, its population density, its annual volume of police calls for service, its total number of sworn personnel, its total number of radio-dispatched vehicles, etc. Other qualitites of the city are likely to affect the technical performance of certain types of AVM systems; these include the density and configuration of skyscrapers, the statistical properties of the street layout (including average block length and barriers to travel), the number of patrol vehicles per square mile in various parts of the city, magnetic anomalies, the "hilliness" of the region, etc. Still other qualities of the city's police department itself are apt to affect the operational effectiveness of an AVM system. These include attitudinal and professional factors associated with the personnel. Such factors stem from a department's history of professionalism and willingness to try innovations. They are related to such measures as the percent of personnel with some college education, the percent of civilians in the department, the median age of personnel, the salary level, etc. They are also related to such intangibles as the attitudes of the chief and his associates and the department's ties to city hall (and the extent to which the department is a part of the city's political structure). The operational effectiveness of an AVM system also depends on the department's dispatch and

resource allocation policies. For instance, a department without sufficient patrol manpower to handle the current volume of calls for service is not likely to experience significant reductions in travel time from an AVM system.

Because of these concerns, each city's situation with respect to AVM is unique. The operational benefits and the technical performance of an AVM system in each city will depend to some extent on conditions in that city. So, before purchasing an AVM system, administrators in a city should carefully analyze their own situation in an attempt to assess the likely benefits and costs of an AVM system. This will require discussions with command staff, data collection and certain elementary types of analysis. The city might benefit greatly from impartial assistance from the outside in performing such an analysis.

The first step in discussing the possibility of an AVM system with command staff is the listing of probable benefits of the system. Such a list might include the following:

- Reduced response time
- Increased officer safety
- Improved command and control operation
- Increased control over dispatching
- Improved management of resources in the field
- Improved crisis management ability and real-time direction of criminal pursuit
- Better police patrol operations using such indicators as more miles driven on preventive patrol
- Improved morale due to a higher perceived level of professionalization

- Ability to recreate and to study situations in the field (via videotape or similar medium)
- Improved public image

Next to such a list should be created a list of possible disadvantages of an AVM system, perhaps including:

- Increased cross-beat dispatching (thus bringing a loss of "beat identity")
- Possible increased dispatcher workload
- Possible negative response of patrolman's union (representing officers who might resent their position being monitored)
- Increased annual costs (due to maintenance and upkeep of the system and amortized purchase cost)
- Negative consequences stemming from possible abuse of the system

If, as a result of preliminary meetings, the possible advantages seem attractive (even given the possible disadvantages), then some more formal steps of analysis should be undertaken.

1. Review of police emergency response system. The first formal step, which might require outside assistance, is a review of the police emergency response system and the collection of data describing this system. First, a block diagram (similar to Figure 6-2 in Chapter VI, Section A) depicting each of the key steps in the emergency response system would be generated. Then the parameters of the system would be defined. These would include both controllable parameters, such as the number of telephone complaint clerks (call evaluators), number of dispatchers,

and number of radio-dispatching patrol units (all by time of day) and uncontrollable parameters, such as rate of calls for service (by type and time of day); service times of complaint clerks, dispatchers, and patrol units; miscellaneous processing delays; response speeds; and the description of the patrol resource allocation policy. If a city is interested in reducing response time AVM is only one of many potential changes that could be made.

The sample size for these data need not be huge, perhaps totalling a period of four weeks of operations (preferably one week from each season of the year). The data should be processed to compute summary statistics such as mean, median, mode and variance.

2. Use of simulation model or comparable tool. The next step is to review the police emergency response system with respect to possible improvements that could be instituted--both in terms of the extent of improvement and cost. In the area of reducing response time, the following are potential improvements:

- Institution of a 911 system
- Implementation of an ACD (Automatic Call Distribution) system
- Implementing a CAD (Computer Aided Dispatching) system
- Rescheduling of complaint clerks
- Rescheduling of dispatchers
- Rescheduling of patrolmen
- Modification of the dispatching procedures

(perhaps by priority of call)

- Implementing an AVM system with specified accuracy characteristics
- Addition of one or more radio channels

Many of these changes bear on the other entries in the list of benefits (in addition to response time reduction). Additional changes that are not directly related to response time include:

- Improved training of complaint clerks and dispatchers
- Enhanced public education in the use of the police emergency number
- Institution of specialty units in the field (e.g., for family crisis intervention, emergency medical services, etc.)

Many of these alternatives for improvement will have to be treated subjectively, that is, without recourse to detailed statistical or modeling analysis. Others require more formal treatment, such as predicting the response time savings accruing from an AVM system. This analysis can be carried out in a fairly inexpensive manner by using a patrol force simulation model, such as the one applied in Chapter VI and described in Chapter VIII (and detailed in Appendix C). For instance, the Chapter VIII simulation model when applied to District 3 in St. Louis indicated that almost half of the predicted 25% reduction in mean travel time was due to the M.P.D.'s precinct-oriented dispatch policy; when compared to a more standard non-precinct-oriented policy, AVM was predicted by the simulation model to reduce mean travel time by 10 to 15%.

The simulation used in this study is in the public domain and will therefore be made available for use in other cities. For illustrative use of the simulation in the AVM setting, we refer the reader to Chapter VI (Section D.5).

Other formal tools that could be applied at this stage include the "mean time between losses" model (Chapter V and Appendix A) should a computer-tracked dead-reckoning system such as FLAIR be considered as a candidate AVM system. Also, simple "back of the envelope" models are useful in the analysis.[1]

While the analyses we are suggesting need not be as detailed as those described elsewhere in this report, the point of the analysis is to lay out all the major alternatives for improving performance of the police emergency response system and to indicate that installation of an AVM system is just one of those alternatives. Its ranking competitively with other alternatives will depend on subjective and objective analyses of costs and benefits of the system in comparison to each of the other alternatives.

B. Critical Factors of Concern

Once the initial analyses have been performed, if AVM is then being seriously considered as a potential means for improving police services, then there are several key factors with which

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[1]R.C. Larson, Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972.

potential consumers should concern themselves. It is recommended that each of these factors--detailed below--be critically discussed and reviewed prior to signing any contract for an AVM system. For convenience, the factors can be grouped into the three categories underlying the St. Louis evaluation: operational, technological and attitudinal.

1. Operational factors.

a. Accuracy. Any AVM system should have one or more meaningful measure(s) of accuracy. In the FLAIR System the three main measures were the mean time between losses of a FLAIR vehicle, the location error (in feet) representing 95% confidence[2], and the mean error (in feet). AVM systems, other than computer-tracked dead-reckoning types (e.g. FLAIR) use only the location error measures to define accuracy since vehicles do not become "lost" in the other types of systems. However, other systems may have their own unique measures; for instance, the manufacturer of a fixed post sensor system might quote the mean time between passings of a sensor.

Whatever the choice, the contract for delivery of the system should contain a clause guaranteeing a level of performance as indicated by the relevant measure(s) of accuracy; and the test procedure for verifying that performance should be agreed upon.

The level of accuracy required will be determined by the

[2]Vehicles are correctly located within that distance 95 percent of the time.

needs analysis discussed above. A very dense city with narrow streets, small blocks and limited long-range visibility will in all likelihood require a more accurate system than in a more "sparse" city. A city that selects an AVM system for command and control operations and officer safety as well as response time reduction will most likely require a more accurate system than one whose only purpose is travel time reduction (e.g. having a location error within 220 feet, 95% of the time).

The value of the accuracy parameters may also have a direct bearing on other components of the emergency response system. For instance, a FLAIR-type system with mean time between losses of a vehicle of 6 hours would require 2,000 dispatcher initializations per day in a fleet having 500 vehicles. If each initialization consumed 15 seconds of time then the additional workload for dispatchers per day would be significant: 30,000 seconds, or 500 minutes, or 8 1/3 hours. (This is the summed extra workload for all dispatchers.) An increase of mean time between losses (per vehicle) to 12 hours would reduce the extra dispatcher workload to 4 1/6 hours; however, a system not having a binding value of this performance measure might yield an unsatisfactory mean time between losses of two hours per vehicle. This would result in an extra workload at the dispatchers' positions of 25 hours per day.

It is important that any police department contemplating an AVM system be aware of the various accuracy definitions of alternative AVM systems and the implications of each on its

operations.

b. Need for response time reduction. AVM systems are typically "justified" on the basis of their response time reduction benefits. One purpose of the needs analysis discussed above was to determine representative values of response time for each of the components of the police emergency response system. Only then can one determine if the reduction in travel time (typically 10 to 15 percent) derived from an AVM system justifies the cost of the system; and one must remember that the AVM system might increase the response time of some other component of the system (e.g., at the dispatcher's position, due to increased workload).

In addressing the issue of response time reduction, the potential consumer should consider the following:

- Little is known about the relationship between response time and apprehension probability[3]. Response time as a key performance measure is a surrogate measure, albeit not an unreasonable one.

- The potential average travel time reductions possible from an AVM system vary according to patrol workload (on calls for service and other matters). The average reduction typically starts at some positive value (say 10% improvement) at zero workload, builds to a maximum (say 15% improvement)

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[3]The best two studies are by Isaacs in an Appendix to the Science and Technology Task Force Report of the President's Crime Commission (a study done in Los Angeles) and by Clawson and Chang in Seattle (to appear in a special issue of Management Science on Criminal Justice, A. Blumstein and R. Larson, co-guest editors). Also, an extensive study on response time is currently underway in Kansas City. This is discussed in footnotes in Chapters VI and XI. See Deborah K. Bertram and Alexander Vargo, "Response Time Analysis Study: Preliminary Findings on Robbery in Kansas City," Police Chief, May, 1976, Volume XLIII, Number 5.

at about 20 to 30 percent workload, and then gradually drops to 0% improvement as workload approaches 100%. (For a discussion of this see Chapter VI, Section D.1.)

- In addition to addressing the average travel time reduction of an AVM system, one should look at the distribution of travel time reductions. Typically, the majority of dispatch decisions are unaffected by AVM information. However, those dispatch decisions that are changed due to AVM may result in a travel time reduction of 25 percent, 50 percent, or more. Such distributional effects also vary by location within the city.
- In an urban environment, travel time, as a component of total system response time, rarely exceeds about 40 percent of total system response time. Thus, a 10 percent reduction in travel time is not likely to decrease total systems response time by more than about 4 percent.

Even if total system response time is found to be unaffected by an AVM system, there may be other important reasons for implementing the system. These have been discussed elsewhere in this report and in the first section of this chapter.

c. Tie to CAD. The Science and Technology Task Force of the President's Crime Commission, when discussing AVM systems, viewed them primarily as a key component of a CAD (Computer Aided Dispatch) system. In the late 1960's most police emergency response systems were founded on a technology that had not changed appreciably since the 1930's. CAD systems were technically feasible, building from recent developments

in on-line computer time-sharing systems. And the capital investment in a CAD system, which would still be under $1,000,000 for most cities, almost always represents a smaller incremental investment than a high accuracy AVM system (implemeted city-wide). Finally, certain call processing improvements can be accomplished solely with a CAD, without the assistance of automatic vehicle location.

Implementing an AVM system before a CAD system results in less than optimal performance of the AVM system. Such activities as manual cursor positioning for incident placement could be performed virtually instantly by a CAD computer, but they represent increased workload to a dispatcher in a manual system. Also, dispatching personnel trained in the ways of a computer within a CAD context are likely to be less resistant to the notion of AVM information, which would appear to them to be a natural add-on to the CAD system.

For these reasons, potential consumers of AVM systems should think carefully about the advisability of AVM without CAD and about the time phasing of CAD and AVM installation. It is not difficult to write into the specifications of a CAD system features that would make it compatible (with minimal switchover costs) with an AVM system. While it is conceivable to design AVM systems that "stand alone" and yet are likely to be compatible with some yet-to-be-designed CAD system, it is more difficult to do so and likely to be more costly to switch over. A CAD system "waiting for an AVM hookup" is likely to yield beneficial improvements in operations (as they have since 1968, when

New York City's SPRINT system was installed), whereas an AVM system awaiting a CAD connection is likely to yield less than the full advantage of AVM information.

d. Need for more knowledge of patrol activities. Prior to the installation of an AVM system, serious attention has to be focused on the patrol force to discover just how its members spend their time. A good illustration of a detailed analysis of patrol activities is contained in the technical write-up of the Kansas City Preventive Patrol Experiment[4], combining police "noncommitted time" and time spent on activities known to the dispatcher.

A main reason for such a study is to discover the fraction of time that a unit's position is mobile and therefore unknown to the dispatcher. The higher this fraction of time, the greater the benefits of an AVM system; the lower, the less benefits. Just as a fire chief would have limited use for an AVM system (since he is almost always aware of the location of his fire aparatus), a police chief suffering from an overabundance of calls for service would have limited use for an AVM system. This is because a system saturated with calls for service has the great majority of its units positioned at scenes of calls for service (i.e., at known locations); and, most dispatches

[4]"The Kansas City Preventive Patrol Experiment, A Technical Report", by George L. Kelling, Tony Pate, Duane Dieckman, and Charles E. Brown, published by the Police Foundation, Washington, D.C., 1974 (537 pp. plus appendices). Also see their "Summary Report" (60 pp.).

occur in a back-to-back manner from a queue of waiting calls, assigning a unit at a known location to an incident at a known location. In such a system, the need for AVM information would be minimal; most likely, other changes should occur first in the police emergency response system (perhaps an increase of manpower in the field or a stricter call screening policy).

A patrol force with adequate manning to handle its call-for-service volume is more likely to incur benefits from an AVM system. But even in these cases the exact magnitude of the benefits may be surprisingly city-dependent. For instance, the Kansas City Report indicated that fully one-half of police noncommitted time was at stationary locations rather than mobile locations. This could mean an availability to the dispatcher significantly smaller than that suggested by call-for-service workload, or it could suggest that one could know the exact location of about one-half the noncommitted fleet without an AVM system, simply by instituting a call-in procedure whenever a unit stops at a fixed location.[5]

In addition to the recommended "before component of patrol time analysis, one should continue the analysis after the

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[5]As part of the Phase I St. Louis evaluation, an attempt was made to include in the analysis police committed time not associated with calls for service. This was done by generating "patrol initiated activities" in the simulation model of District 3. Even with this capability, however, predicted travel time reductions were greater than those measured, perhaps indicating additional committed time not incorporated in the model. Since the amount of committed time has such a direct bearing on the utility of an AVM system, it will be a focus of the Phase II evaluation.

implementation of AVM. In addition to all the "before" questions, one can now examine patterns of patrol (as to which is more effective against certain types of crime), space-time dependence of crime (say armed robbery) and patrol units, etc.

2. Technological factors.

a. Maintenance and technological obsolescence. AVM systems are based on the latest state-of-the-art technology, usually employing digital communications, solid state circuits, and computationally fast minicomputers. None of these systems has experienced a multi-year test in the operationally severe environment of a police department. Thus, as was evident in our Phase I evaluation, it is likely that maintenance problems will arise that were unanticipated prior to implementation. Even if they don't, the type of anticipated maintenance--on digital communications equipment, on small solid state circuits, on minicomputers--represents a major advance in technological sophistication for the maintenance personnel of a police department, who until recently have been accustomed to older technology, much of it essentially unchanged in several decades.

Both scheduled and unscheduled maintenance on these systems will undoubtedly be required and a police department contemplating the purchase of a system employing such technology should carefully plan out their maintenance policy ahead of time. It is likely that some maintenance tasks will have to be subcontracted to outside specialist firms--say for the minicomputer.

Other tasks may be assumed by the department's regular maintenance personnel, provided adequate plans are laid out for their training, the upgrading of their test and repair equipment, and backup services should they run into difficulty.

An estimate of the annual cost of maintenance should be included in the early deliberations, prior to a department committing itself to a particular system. Costs of maintenance contracts for minicomputers can be significant. Typically this cost is 1% per month of the original purchase price. For a redundant system (with two computers) and with peripheral equipment valued at $200,000, the annual cost would be $24,000. Costs of upgraded in-house maintenance can also be high, considering the associated new equipment, space and perhaps additional personnel. A department contemplating an AVM system might consider including the cost of maintenance equipment, training, and perhaps even all first-year maintenance as part of the purchase contract.

Because of the state-of-the-art technology used in AVM systems, the technology is changing rapidly on a year-to-year basis. New system concepts are known to be under development (e.g., passive sign post systems) and systems now undergoing trial implementation in major cities (e.g., FLAIR in St. Louis, Hazeltime pulse trilateration in Dallas) are likely to involve further refinement. This means that 1) installed systems are likely to become technologically obsolete perhaps as soon as five years and almost certainly within ten years--and 2) the passage of time is

likely to result in less expensive systems. Thus a department contemplating the purchase of an AVM system is confronted with an "action-timing" problem--namely when to purchase, considering factors such as price, technological obsolescence, tests in operating police departments, etc. Evaluation results of currently implemented AVM systems--such as those in St. Louis and Dallas--plus AVM consumer "handbooks"[6] should help a department confronting such a decision.

b. Accountability of hardware vendor. The supplier of the AVM system should be required to deliver a system which performs according to prestated specifications. These should be spelled out in detail in the contract. These specifications could be stated in terms of target levels for the key performance measures of the system.

As an illustration, a set of system performance measures (for a computer-tracked dead-reckoning system) may look something like this:[7]

(1) Accuracy

- Mean time between losses of a vehicle driving routinely should be no less than 6 hours.

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[6]For instance, see G. R. Hansen and W. G. LeFlaug, "Application of Automatic Vehicle Location in Law Enforcement--an introductory planning guide", Jet Propulsion Laboratiry Doc.#JPL 5040-17, Pasadena, Cal. 91103, 1976.

[7]The numerical values used here are illustrative and are not meant to imply a recommended set of standards for every city.

- Mean location estimation error of a properly tracked vehicle should not exceed 75 feet.

- There should be no driveable places within the city at which the system does not function.

- The system should be able to track in "open loop" mode (off mapped streets) for five minutes, accumulating an error of no more than 200 feet 95% of the time (assuming speeds and turns usually associated with a patrolling vehicle).

(2) Maintenance and Repair.

- Mean time between failures of in-car AVM equipment should exceed 60 days (per car).

- Mean time to repair the in-car AVM equipment should be less than three man-hours.

- Mean time between failures of the primary tracking minicomputer should exceed 60 days.

- Percent of time system totally operational shall exceed 99.8 percent.

(3) System capacity.

- The system will be capable of tracking 400 vehicles under normal operating procedures.

- The system will be capable of tracking 400 vehicles, with up to 100 executing a turn in the same polling interval.

(4) System adaptability.

- The system manual will provide a detailed description of how to link up the software to a compatible CAD system (with prespecified file formats, for instance geographical files).

• The system manual will spell out in detail how likely changes in the city's street layout are to be incorporated into the system.

The above performance measures, target values, and related specifications were illustrative only. An actual contract might contain more (or fewer) specifications and, undoubtedly, their numerical values would be different and city-specific. However, without such a list of specifications the consumer has no assurance of "what he is getting". The time necessary to detail these requirements is minimal in comparison to the time (and cost) involved should the system not perform according to the consumer's expectations.

c. Costs. Certainly cost is a major consideration when contemplating an AVM system. It appears that the cost estimates of the Science and Technology Task Force of the President's Crime Commission, which were in the range of $500 to $1,000 per vehicle, were quite optimistic for a high accuracy vehicle monitoring system. While exact cost estimates are difficult to quote due to the lack of production line quantities, it appears that the cost per car of the FLAIR System (including apportioned costs of the central facility--with computer and displays) exceeds $7,000. Few systems appear to be available that would cost less than, say, $2,500 per vehicle, and the less expensive systems tend to offer less accuracy and fewer features than the FLAIR System.

While these purchase costs may appear high, one must consider

on the other hand that city police departments are typically labor intensive and under capitalized. As discussed in Chapter I, it is not unusual for 90 percent or more of a police budget to be consumed directly by salaries, fringe benefits, and pensions. The annual cost of a round-the-clock two-person patrol unit now ranges between $150,000 and $400,000 in most cities, the latter high figure deriving from ever-more-generous pension plans. So, the apparently high purchase costs of an AVM system are likely to be small in comparison with personnel costs.

In addition to purchase costs, which can be amortized over the likely lifetime of the system, there are yearly operating costs. These are due primarily to maintenance and repair, any special staff that has to be hired, space (occupied by the system), electrical power (consumed by the system), and the percent of time of regular personnel devoted to the operation of the system. These costs may be offset by any cost savings due to a reduction in the regular patrol force made possible by travel time savings or other beneficial aspects of the AVM system.

Any city contemplating an AVM system should as accurately as possible lay out the main components of costs, both one-time and recurring. In doing this, the one-time costs should be amortized over the lifetime of the system, which for planning purposes, will probably be about ten years.

3. <u>Attitudinal factors</u>.

a. <u>Morale, attitudes, education</u>. Given a system that is technologically sound, in projecting the degree of implementation success, it is difficult to identify a concern more important than the attitude of police personnel toward the AVM system. A highly positive attitude would greatly increase the chances that the system will function for the purposes intended. A highly negative attitude will almost certainly result in the effective failure of the system. Virtually all systems are subvertible in some way and a negative attitude could lead to acts effectively terminating useful system operation. Strong negative attitudes could also yield a tough union bargaining position at the next round of contract negotations.

<u>There appear to be two key ingredients in influencing positive police attitudes toward an AVM system</u>. The first is the requirement of a properly working system. Police have little tolerance with an obviously faulty system that is being marketed to them as a potential life saver. Like many members of the general population, many police officers recall past events by their deviation from the norm, not their adherence to it. Thus, obvious failures of an AVM system (during the early implementation phase)--even if only few in number--could be sufficient to turn an originally positive attitude into a largely negative one. Especially if they start to question the reliability of the system during a potential life or death situation, confidence will be eroded and attitudes will turn downward. Perhaps rightly

so, police have little tolerance in using their city as a laboratory for "ironing out the bugs" of a newly devised system. Thus, to the maximum extent possible, an implemented system should be thoroughly tested (hopefully under realistic field conditions) prior to transferral of the system to police personnel. This may require installation within the city and simulated police driving for an amount of time prior to transferral.

The second key ingredient is education and communication regarding the new system. Patrol officers, dispatchers and supervisors must be thoroughly briefed on the purposes of the system. This includes officer safety, assisting in criminal pursuits, reduced response time, and all the other objectives cited earlier. The issue of position monitoring by supervisors should be discussed and the department's policies in this area presented candidly. The step-by-step detailed operation of the system should be presented, along with possible operational problems or limitations. A lack of comprehensive educational programs and communication on such topics could result first in confusion and misuse of the equipment and second in frustration and increasing skepticism regarding the utility of the system.

b. <u>Subvertibility of the system</u>. By system subvertability, we mean the susceptibility of the system to deliberate acts aimed at decreasing system effectiveness. In computer-tracked dead-reckoning systems such acts could be performed by the patrol officer--reporting an incorrect address at the time of "loss correction" (or initialization) or self initializing at

an incorrect site--or they may be the work of vandals or criminals deliberately planning to make the AVM system inoperative.

While well-trained and highly motivated patrolmen are not likely to engage deliberately in acts aimed at foiling the system, virtually any patrol force contains a spectrum of officers, each with different attitudes toward technological innovations such as AVM systems. A dispatcher-triggered alarm system that was implemented several years ago in Boston was quickly destroyed since the in-car units became inexplicably inoperable. A completely volunatry vehicle location system implemented on a trial basis in Oakland, California failed due to technical problems and, in part, its voluntary position reporting feature.[8] We are led to believe that system subvertibility is tied directly to the extent of "voluntariness" of the system--the less frequently the officers must report or correct their location, the more technically successful the system is likely to be.

With FLAIR-type systems, even if mean time between failures is shown in a test to be, say, 8 hours, this value pertains to average (typical) driving patterns of a patrolling vehicle. As long as there are parts of the city in which the system does not function (e.g., due to magnetic anomalies), their subvertibility and "voluntariness" are increased. However, vehicles that frequently try to become "lost" can be spotted on FLAIR print-outs,

[8]Scott Hebert, "Communications and Dispatching Technology in the Oakland Police Department," Chpater 7 of a Final Report to be submitted to the National Science Foundation on the Innovative Resources Planning Project carried out at M.I.T. and sponsored by NSF-RANN (National Science Foundation Grant Number GO38004).

and if investigation indicates no faultiness in the vehicle's hardware, appropriate discussions can be held with the officers involved.

The second type of subvertibility is due to work of vandals or serious criminals. Regarding vandals, one must question the security of systems having spatially distributed components (such as proximity sensing systems). How secure are callboxes at intersections or magnets or coils in the roadway? How secure are transmitters? These questions are far from academic since several cities have recently experienced severe tampering with their police callbox systems.

The serious criminal poses perhaps the greatest problem with regard to system subvertibility. In any AVM system one must raise the issue of jamming of the frequency (or frequencies) used between mobile and base station. At present there does not appear to be a reasonably inexpensive way to counter such a tactic; as a minimum precaution, the identities of these frequencies should not be publicized. Any in-field hardware that is susceptible to vandalism is also a target for the serious criminal. While it is impossible to design a foolproof system, these issues should be kept in mind when considering alternative systems to install.

c. Response of patrolman's union. In many cities in the U.S. within the last 10 to 20 years, the unions or fraternal organizations (de facto unions) representing patrolmen in labor matters have gained considerable power. Their influence has

extended beyond such standard labor negotiation issues as wages, pensions, dues check off, and rules on overtime, and into certain operational management areas previously thought to be management prerogative. These include work rules (scheduling of tours of duty, assignment to precincts, assignment to special details, one-person vs. two-person cars) and methods of operation (e.g., response of two vehicles to certain types of incidents).

With proper attention given to the patrolman's perspective, it is possible that the union could be an integrative force in explaining the benefits (to the patrolman) of an AVM system. From his perspective, the likely benefits are officer safety, assistance in criminal pursuits, increased coordination in crisis situations, and improved morale due to a higher perceived level of professionalization. Travel time reduction may play a positive role here too, although many patrolmen think that near-by officers will "volunteer" for high-priority calls, thereby greatly reducing the projected travel time reduction benefits of an AVM system.

As illustrated in our St. Louis officer surveys, the major initial concern of patrolmen regarding AVM systems was the unwarranted monitoring of their positions by supervisors (or worse yet, bureaus of "internal affairs") and the possible reprimands that may result. They argue, correctly in many instances, that one cannot determine the activity of a patrol officer by merely monitoring his position. A vehicle stopped for two hours may be performing an important stakeout function. On the other

hand, the officer may be taking an unauthorized rest break. AVM systems are likely to reduce fraternizing among patrolmen in the field--a habit that many patrolmen will argue serves a necessary communication function (including exchange of crime-related information). In District 3 in St. Louis there are indications that fraternizing within the station house increased markedly after implementation of FLAIR.

There are other activities, too, both good and bad, that will tend to be curtailed as a result of AVM. The patrolmen's union can be relied upon to represent the patrolman's interests in these matters. In a city in which police labor and management continually clash, AVM may be virtually infeasible due to union hostility. In a city with "collusive"[9] bargaining relations between labor and management, it is likely that compromise understandings can be reached. In a city having traditionally good labor-management relations, implementation of AVM should be no problem, provided again that the patrolman's perspective is considered.

We cannot overemphasize the need to consider "labor's" response to such technological innovations as AVM systems. An otherwise excellent system can be made unworkable by failure in the labor-management area.

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[9]Margaret Levi, Conflict and Collusion: Police Collective Bargaining, IRP Technical Report No. TR-07-74, September, 1974 (237 pp.), Innovative Resource Planning, Massachusetts Institute of Technology, Cambridge, Massachusetts.

C. Long-term Commitment to AVM

Installation of an AVM system in police operations could be, in many ways, parallel to the installation of automibles (to motorize patrolman in the 1910's) and the two-way radio (to enchance communication cababilities in the 1930's). Thus, a switch to AVM (like CAD and several other new high technology systems) is not likely to represent a temporary mode of operation, but rather one that can and will affect in a permanent way the very essence of policing in any department that employs it. So, cost and other more immediate considerations aside, the long-term consequences of an AVM system should be discussed and projected by departmental personnel. Recurring cost and personnel obligations in order to keep the system functioning and up-to-date should be outlined, and financial commitments from the city should be obtained, if needed.

With our current state of relative ignorance with respect to the actual in-the-field effects of an AVM system, it may be several years (requiring monitoring and evaluation of the first several AVM installations--such as that in St. Louis as well as experience in Dallas, etc.) before a department can, with some confidence, project the effect of an AVM system on its own operation. Thus, in learning to project the long-term consequences of an AVM system, it is essential that we follow the scientific method to the extent possible, thereby allowing learning from the early implementations through the process of observation, hypothesis generation, and testing with careful attention to operational, technological and attitudinal concerns.

Appendix A

OPERATIONAL MODEL FOR PREDICTING TIME BETWEEN LOSSES OF A FLAIR-TRACKED VEHICLE

TABLE OF SYMBOLS

Symbol	Definition
t_Q	Time between updating estimated position of vehicle (sampling interval or unit of quantized time)
d	True vehicular travel distance measured on the odometer (from last update)
$D(d)$	Estimated position of vehicle on center-line maps, given that the vehicle has measured d miles of distance from the last update (zero-check)
$x(d)$	Random displacement of estimated vehicle position from its true position, as computed on center-line maps, after the vehicle has measured d miles of travel from the last update.
σ^2	Variance of the random displacement per unit of distance travelled
γ	Mean systematic displacement per unit of distance travelled
P_f	Probability that a lost vehicle can be successfully found
b	Length of the shortest possible city block
q	Probability of incurring an intersection after travelling a distance b
$\bar{\ell}$	Mean distance between intersections
r	Probability that the vehicle turns at any given intersection
p_ℓ	Probability of loss of a vehicle on a randomly selected turn
$\bar{D}_L$	Mean distance travelled between losses
$\bar{T}_L$	Mean time between losses
N	Number of bits transmitted containing angular (heading) information
α_Q	Quantized heading angle
α	Actual heading angle
a_i	The i^{th} divergence angle from an intersection
p_{α_Q}	Probability of loss of a vehicle at an intersection due to angular quantization

Table of Symbols

(continued)

d_Q	Unit of quantized distance
W	Window of positional uncertainty due to time quantization

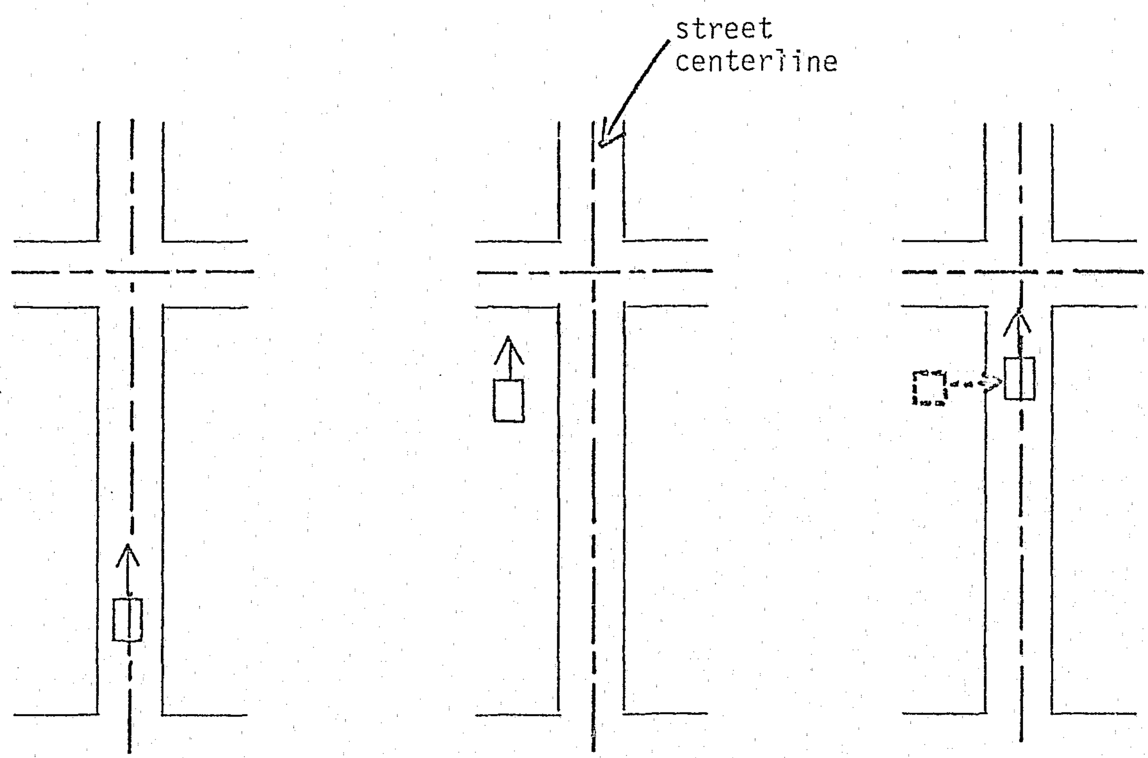
I. Introduction

In AVM systems such as FLAIR, an important characteristic of operational performance is some measure of the system error. Until recently this has usually been measured in feet or meters and stated in such forms as the "mean error is 100 feet," or "at least 95 percent of all position estimations are within 50 meters of the true position."

Computer-tracked vehicle location systems such as FLAIR pose new problems, however, in analyzing, modelling, and interpreting system errors. These systems use an in-car odometer and compass to provide a crude form of inertial guidance; the somewhat noisy information from the odometer and compass are transmitted periodically (every second in FLAIR) to a central receiver where it is processed. by a computer algorithm whose purpose is to update the estimated position of the vehicle. The update is performed with the aid of a detailed street map which is a collection of connected straight-line segments (representing street center lines) and "available" to the algorithm. In regular tracking, whenever the estimated position is infeasible, say off the street (perhaps in the center of an apartment complex), the computer "corrects" the estimated location back to the most likely center-line street position. This correction feature is depicted in Figure 1.

Figure A-1

Self-Correction Feature of FLAIR



a. estimated vehicle position at time $t = t_1$.

b. estimated vehicle position at time $t = t_1 + t_Q$, uncorrected

(t_Q = time between updates)

c. estimated vehicle position at time $t = t_1 + t_Q$, corrected

II. Odometer Error: A One-Dimensional Error

To examine the error characteristics of this system, suppose for a moment that the vehicle always travels on a single road, never turning at intersections. Then position estimation error accumulates only in one dimension, that is along the direction of travel on the roadway. The accumulated error would be due to a collection of random phenomena that cause the odometer to yield inaccurate readings--bumps in the road; deviations from strict straight-line travel (e.g., lane switching); pebbles, rocks, sand and other conditions that cause the tires to skip, and--if viewed as uncorrectable--travel speed (which alters tire circumference). As argued in Chapter 5, random error can also arise along curved roads due to inaccuracies in the straight-line segment street map. In addition, there may be other phenomena that result in inaccurate odometer readings--but these may be systematic in some sense and, if detectable, correctable to some degree; examples include outside temperature (which alters in a predictable way the tire circumference), tire pressure, tire wear, and--if viewed as correctable--travel speed.

To summarize, the one-dimensional odometer error may be broken down into a strictly random component and a "systematic" (but perhaps still unknown) component.

II.1 Modelling the Random Error

In physical situations not unlike the current one researchers have found the Weiner process* to be an excellent model for the random component of the error. Historically, this stochastic process was first used to model the motion of a particle immersed in a liquid or gas, exhibiting

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*See, for example, Emmanuel Parzen, Stochastic Processes, Holden-day, San Francisco, 1962, pp. 8, 26-29, 40, 67-68.

countless irregular motions. The central idea is that the particle is immersed in a field that offers continual bombardments of infinitesimal magnitude that cause the particle to become displaced from center. These bombardments show no preference for any particular direction (forwards or backwards in the case of one-dimensional displacement), so the net effect of the bombardments may be to move the particle in any of the possible directions (forwards or backwards in a two-dimensional case). This idea still applies in situations in which the particle is persistently moving in one direction, say due to wind currents or electrical currents (in the case of electrons in semiconductors). Then the random error is measured as random deviation from that position which would be obtained if the particle were governed only by the persistent movement.

In the vehicle location setting we must establish a frame of reference for the persistent movement and a measure of error from the anticipated position. We will measure the persistent movement by the true mileage d that the vehicle itself has measured since the last zero check (i.e., the last time the estimated and true position were known to coincide.) This measured mileage is accumulated over straight and winding roads, with and without lane switching, with and without slippage, etc. Associated with the traversed path of the vehicle is a sequence of connected straight-line segments representing street centerlines in the computer map. Suppose we measure a distance d along these connected segments, starting with the position of the last zero check. That process will yield a point on one of the segments representing the estimated position of the vehicle. The true position of

the vehicle is presumably at some other (not-too-distant) point, most probably on the same segment. The location estimation error is the (center-line) distance between these two points. This method for determining location estimation error naturally incorporates errors due to both driving behavior and mapping procedures.

Invoking the Central Limit Theorem from probability theory, one assumes that the position of the particle (vehicle) about its anticipated position has a Gaussian or Normal distribution. This distribution is found in many applications of probability where the net effect of some process or activity is the sum of many small processes or activities. Moreover, we assume with the Weiner process model that the random perturbations in vehicle positioning occurring during one time interval or distance interval are independent of the perturbations occurring during another non-overlapping time or distance interval. For instance, we assume that the random error incurred while traversing one block is independent of the random error incurred while traversing the previous, the next, or any other block(s).

Finally, we would expect that as a vehicle (particle) travels further (i.e., exposed to more random perturbations), the accuracy of the position estimate deteriorates. This is exactly what happens with the Weiner process model--the variance of the distribution about the mean grows linearly in time (or distance).

To formalize our discussion to this point, we model the random component of the odometer error as follows:

Let $X(d)$ = the random displacement of the estimated vehicle position, as computed on center-line maps, after the vehicle has measured d miles of travel from the starting position (or last update)

$D(d)$ = estimated position of vehicle on center-line maps, given the vehicle has measured d miles of travel from its starting position

$= d = X(d)$.

By definition $X(0) = 0$. Now the Weiner process model requires that $X(d)$ have a Gaussian distribution with zero mean and variance that grows linearly with d. If

$f_X(x|d)$ = probability density function of $X(d)$,

then

$$f_X(x|d) = \frac{1}{\sqrt{2\pi\sigma^2 d}} e^{-x^2/2\sigma^2 d} \qquad -\infty < x < +\infty \tag{1}$$

where

σ^2 = a parameter indicating the intensity of the infinitesimal perturbations.

Here σ^2 can be considered to be the variance of the random displacement per unit of distance travelled. As one verifies from Eq. (1), the mean or expected value of the random displacement is zero, i.e.

$$E[X(d)] = 0 \tag{2}$$

and the variance $(\sigma^2_{X(d)})$ grows linearly with distance, i.e.,

$$\sigma^2_{X(d)} \equiv E[X(d) - E[X(d])^2] = \sigma^2 d. \tag{3}$$

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* Ignoring truncation errors, for the moment. (See Section IV.)

Thus the probability law of the Weiner process is specified by Eq. (1), which reveals the importance of the parameter σ^2. This parameter must be empirically measured in most applications, although occasionally a theory can be constructed that predicts σ^2 in terms of more fundamental quantities. For instance, in the case of the Weiner process model for Brownian motion, where σ^2 is the mean squared displacement of the particle per unit time, Einstein in 1905 showed that

$$\sigma^2 = \frac{4RT}{Nf},$$

where R is the universal gas constant, N the Avogadro number, T the absolute temperature, and f the friction coefficient of the surrounding medium. Unfortunately, we know of no similar relationship for odometer displacements, thereby revealing the need for empirical measurement.

Numerical Example

To illustrate an example of the use of the Weiner process model, suppose that we repeatedly drive a vehicle over a 10,000-foot test course and measure the map displacement error at the end of each 10,000-foot test drive. The Weiner process model predicts that the histogram of such errors would resemble a bell-shaped (normal or Gaussian) curve, symmetrically positioned about its mean of zero. Suppose as a result of the test runs we calculate the standard deviation of the error to be 50 feet. Then, the histogram would resemble the Gaussian curve depicted in Figure 2. From these data we can obtain an estimate

of σ^2, which is the mean square error displacement per unit distance (foot). We set the standard deviation of the Weiner process model equal to the measured value, thereby obtaining

$$\begin{aligned}\sqrt{\sigma^2 d} &= 50 \\ \sigma^2(10{,}000) &= 2{,}500 \\ \sigma^2 &= 0.25 \\ \sigma &= 0.50.\end{aligned}$$

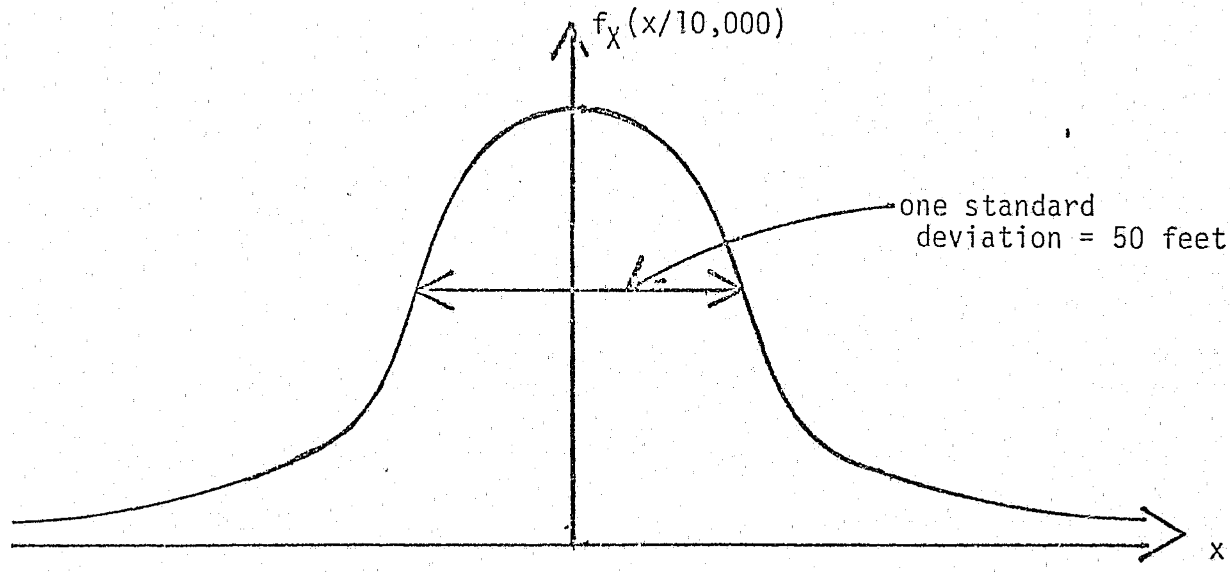
Table 1 presents a summary of the probabilities computed from the Gaussian probability law. Each entry in Table 1 gives a probability that a Gaussian random variable is within y standard deviations of its mean. For instance, using our example, the probability that the estimated position is correct to within ±25 feet (corresponding to one half of a standard deviation on either side of the mean) is 0.383, assuming $\sigma^2 = 0.25$. The probability that the estimated position is within ±50 feet (corresponding to one standard deviation on either side of the mean) is 0.6826. Note from Table 1 that it is quite likely (probability = 0.9974) that the estimated position is correct to within ±150 feet (three standard deviations).

If the vehicle travels 100,000 feet (about 19 miles) the standard deviation now becomes $\sqrt{.25(100{,}000)} = 158.1$ feet. Then, for instance, the likelihood that the estimated position is correct to ±158.1 feet (one standard deviation) is 0.6826.

At the other extreme, if the vehicle travels 100 feet, the standard deviation is $\sqrt{.25(100)} = 5$ feet. It will be for longer distances (on

Figure A-2

Distribution of Odometer Error,
Given the Vehicle Has Travelled 10,000 Feet
(without Systematic Error)



$$\text{one standard deviation} = 50 \text{ feet} = \sqrt{\sigma^2 d}$$

$$\sigma^2(10,000) = 2500$$

$$\sigma^2 = 0.25$$

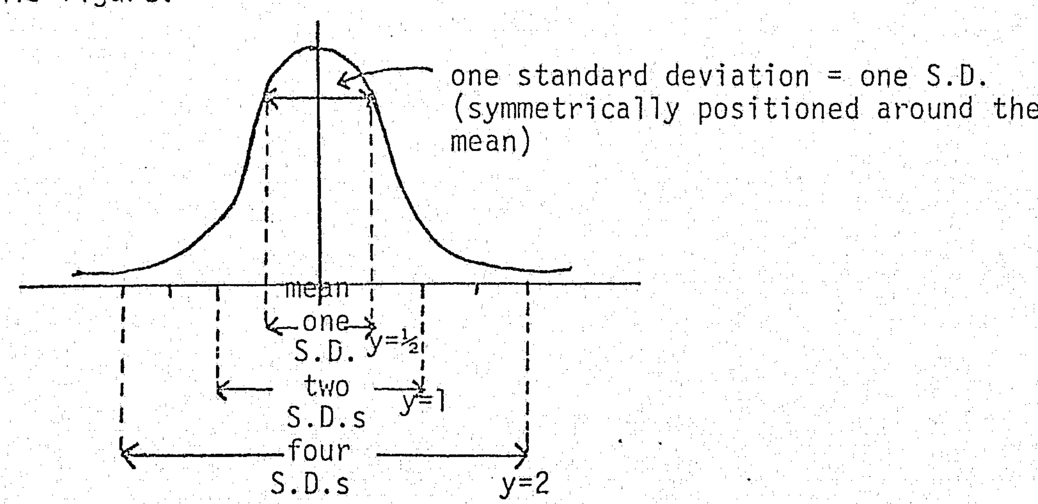
$$\sigma \simeq 0.50$$

Table 1

Probability that a Gaussian Random Variable Is within (+)y Standard Deviations of Its Mean*

y	Probability	y	Probability
0.00	0.00	1.60	0.8904
0.10	0.0796	1.70	0.9108
0.20	0.1586	1.80	0.9282
0.30	0.2358	1.90	0.9426
0.40	0.3108	2.00	0.9544
0.50	0.383	2.10	0.9642
0.60	0.4514	2.20	0.9722
0.70	0.516	2.30	0.9786
0.80	0.5762	2.40	0.9836
0.90	0.6318	2.50	0.9876
1.00	0.6826	2.60	0.9906
1.10	0.7286	2.70	0.9930
1.20	0.7698	2.80	0.9948
1.30	0.8064	2.90	0.9962
1.40	0.8384	3.00	0.9974
1.50	0.8664		

*"Within y standard deviations" means ± y standard deviations, as shown in this figure:



the order of one block length or more) that we will find most use for the Weiner process model.

2. Modelling the Systematic Error

The Weiner process model accounts for the zero-mean truly random error in the odometer. However, in applications one is likely to find large systematic errors that, if undetected and uncorrected, could dominate the random errors. The systematic errors could be due to outside temperature, tire pressure and wear, travel speed, etc.

We can model the systematic error of a vehicle operating under fixed conditions (i.e., constant temperature, speed, tire wear and pressure, etc.) by adding a bias term to the Weiner process probability law. With the bias, the expected value of the odometer displacement is no longer zero, but is given by

$$E[X(d)] = \gamma d, \qquad (4)$$

where γ is the mean systematic displacement per unit of distance travelled. Allowing for the bias, we still assume the same variance, i.e.,

$$\sigma^2_{X(d)} = \sigma^2 d, \qquad (5)$$

so that the probability law of the odometer displacement becomes

$$f_X(x|d) = \frac{1}{\sqrt{2\pi\sigma^2 d}} e^{-(x-\gamma d)^2/2\sigma^2 d} \quad -\infty < x < +\infty. \qquad (6)$$

The important point with this realistic modification to the model is that γ is usually a random variable, that is, its value is unknown

prior to testing and monitoring the odometer performance of each vehicle. Determining the value of γ for a particular vehicle corresponds to "calibrating" the odometer.* If a numerically large value of γ is left undetected and uncorrected (at least within the vehicle-tracking computer software), then the systematic error could "swamp" the random errors.

Numerical Example

Continuing with the numbers of our first example, suppose again that we repeatedly drive a vehicle over a 10,000-foot test course and measure the odometer error (displacement) at the end of each 10,000-foot test drive. Again, we assume that $\sigma^2 = 0.25$. But now we also assume a systematic error corresponding to $\gamma = 0.004$. Thus

$$E[X(d)] = 0.004d.$$

This means, for instance, that if the vehicle is driven 10,000 feet, the expected value (average value) of the odometer displacement is $E[X(10{,}000)] = 0.004(10{,}000) = 40$ feet. The Gaussian curve now indicating the distribution of odometer displacement is shifted to the right of zero by 40 feet, as indicated in Figure 3. Now the probability that the odometer reading is correct to ±50 feet is considerably reduced over that found earlier. The "±50 feet" converts to the region extending from 90 feet to the left of the mean to 10 feet to the right of the mean. This corresponds to 1.8 standard deviations to the left and 0.2 standard deviations to the right. We can obtain the appropriate probability estimate from Table 1.

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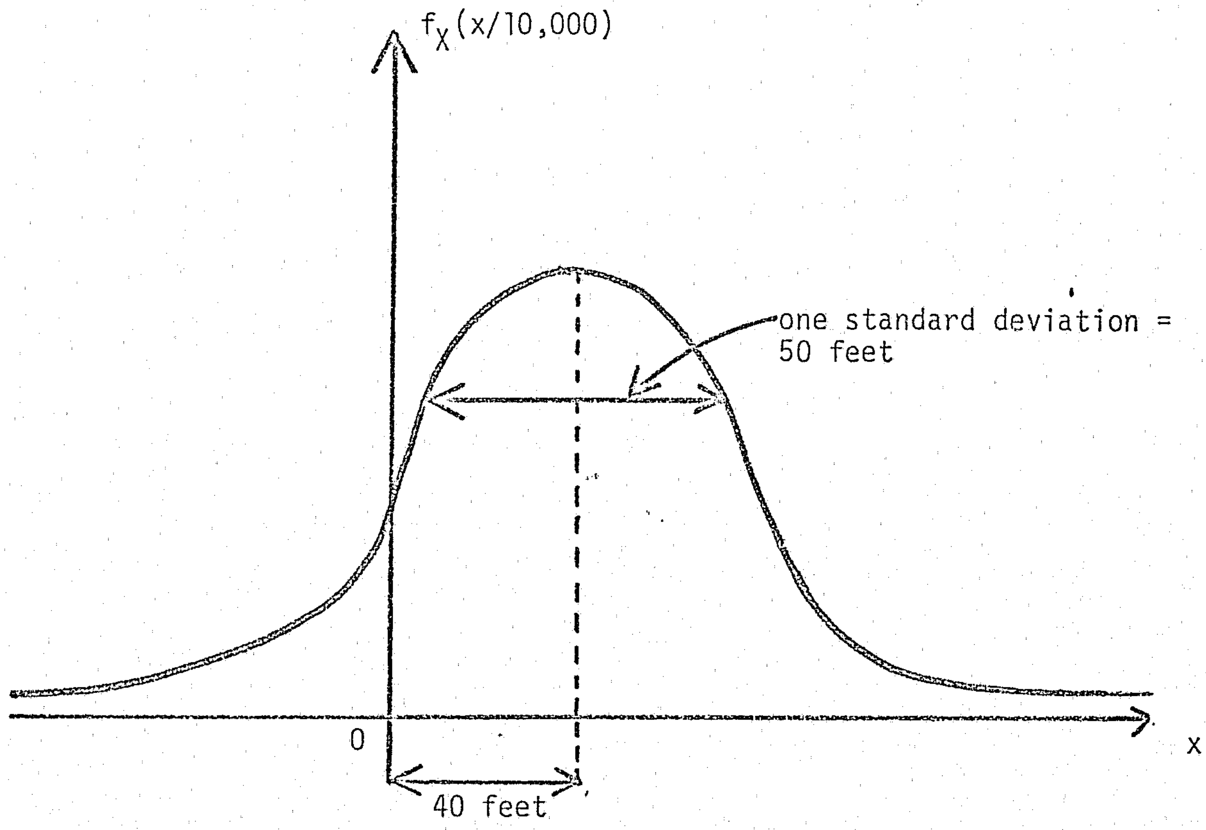
*If the biasing effects of vehicular speed are viewed as correctable, then it may also be a function of time, varying in a systematic way with the speed of the monitored vehicle.

Figure A-3

Distribution of Position Estimation Error,
Given the Vehicle Has Travelled 10,000 Feet
(with Systematic Error)



one standard deviation = 50 feet = $\sqrt{\sigma^2 d}$

σ^2 = 0.25

γ = 0.004

which indicates that the probability of being within ($\pm$) 1.8 standard deviation is 0.9282, and dividing by 2 (yielding 0.4641) since we are only concerned with the side of the distribution to the left of the mean. A similar computation for the area to the right of the mean yields a probability equal to 0.1586/2 = .0793. Adding the two probabilities we discover that the probability that the odometer reading is correct to $\pm$50 feet is 0.4641 + 0.0793 = 0.5434 reduced from 0.6826 in the case of no systematic error (a reduction of 20.8 percent in this measure of accuracy).

Now consider the case in which the vehicle travels 100,000 feet. Here again the standard deviation is $\sqrt{.25(100,000)}$ = 158.1 feet. However, the bias in E[X(100,000)] = 100,000(0.004) = 400 feet. In this case, the likelihood that the odometer reading is correct to ±158.1 feet ($\pm$ one standard deviation) is approximately equal to the probability that the displacement falls in an interval to the left of the mean, starting at 3.5 standard deviations from the mean and ending at 1.5 standard deviations from the mean. This probability is approximately $0.5 - \frac{0.8664}{2} \approx$ 0.0668, a reduction from 0.6826 in the case of no systematic error (a 90 percent reduction in this measure of accuracy).

Thus we see the importance of the systematic error term. A vehicle with even a small amount of systematic error can incur large position estimation errors as the driving distance from the last zero-check increases.

III. TIME BETWEEN LOSSES OF A VEHICLE

The Weiner process model applied to odometer readings in a computer-tracked vehicle monitoring system is a one-dimensional model; that is, it does not incorporate vehicles turning at intersections. However, it is this vehicular action which on the one hand allows very accurate position estimates to be sustained over long periods of time (even with σ^2 moderately large) and on the other hand gives rise to a unique type of position estimation error--the vehicle being "lost."

We are now ready to model the more realistic situation in which the vehicle occasionally makes turns at intersections. The situation of a turn is illustrated in Figure 4. Here the vehicle approaches the intersection from the south. The heading sensor (from the in-car compass) correctly gives a reading of "north." However, the estimated position of the vehicle on the street is two or three car-lengths north of the actual vehicle location. A time t_Q later (corresponding to the sampling interval) a new odometer reading is received and the direction of travel is now east. If the compass direction had not changed from north to east, the computer tracking algorithm would have placed the vehicle back on the north-south street center-line at a latitude projected from the new odometer reading. However, since the compass direction has changed, the algorithm "assumes" that the vehicle has turned at the nearest possible intersection and correctly places the vehicle on the appropriate east-west street (headed east) at a point very close to its actual

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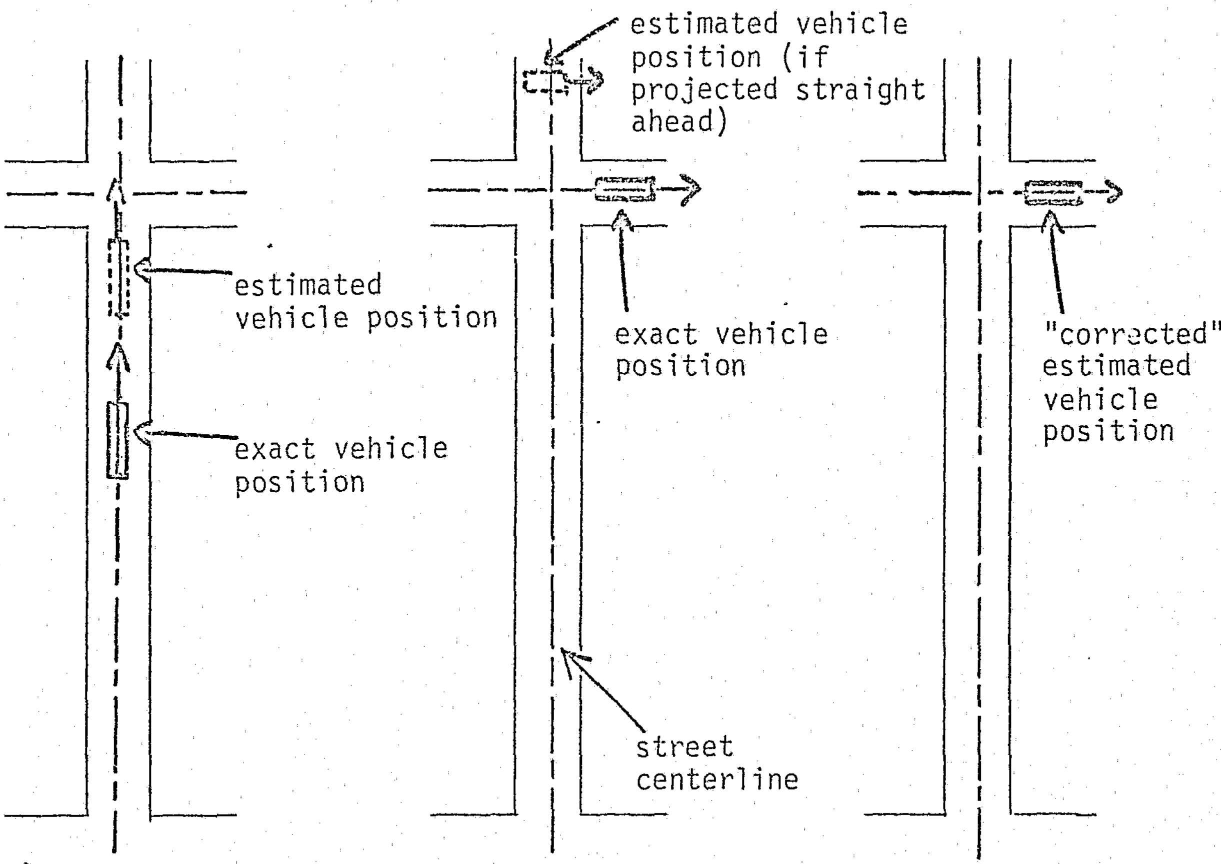
Figure A-4

Self-Correction Feature of FLAIR Vehicle Turning



a. estimated vehicle position at time $t = t_1$

b. estimated vehicle position at time $t = t_1 + t_Q$, uncorrected (t_Q = time between updates)

c. estimated vehicle position at time $t = t_1 + t_Q$, corrected

position.* The important point to notice here is that virtually all** of the accumulated odometer error since the last zero-check is eliminated if the tracking algorithm correctly detects and interprets the vehicle's turn. Thus, each successfully monitored turn corresponds to an odometer zero-check. If all turns are monitored correctly, the system distance error does not build up indefinitely, but rather reaches some small average value as suggested by the Weiner process model (with or without systematic errors).

The major system accuracy problems occurs, however, when a turn is not detected or, if detected, not interpreted properly. This can occur in several ways, one of which is depicted in Figure 5. Here, the vehicle is headed north on a north-south street, but the estimated vehicle position is about two-thirds of a block length ahead (north) of the vehicle. When the vehicle turns east on street 2, the estimated position is now closer to the street immediately north of the vehicle, approximately only one-third of a block length from street 3, but two-thirds of a block length from street 2. Since the compass direction has suddenly changed from north to east, the tracking algorithm correctly detects that a turn has occurred. However, the estimated position of the unit is "corrected" to street 3, rather than street 2, resulting in the vehicle being "lost." This is the key error event in the system and one which we will attempt to model.

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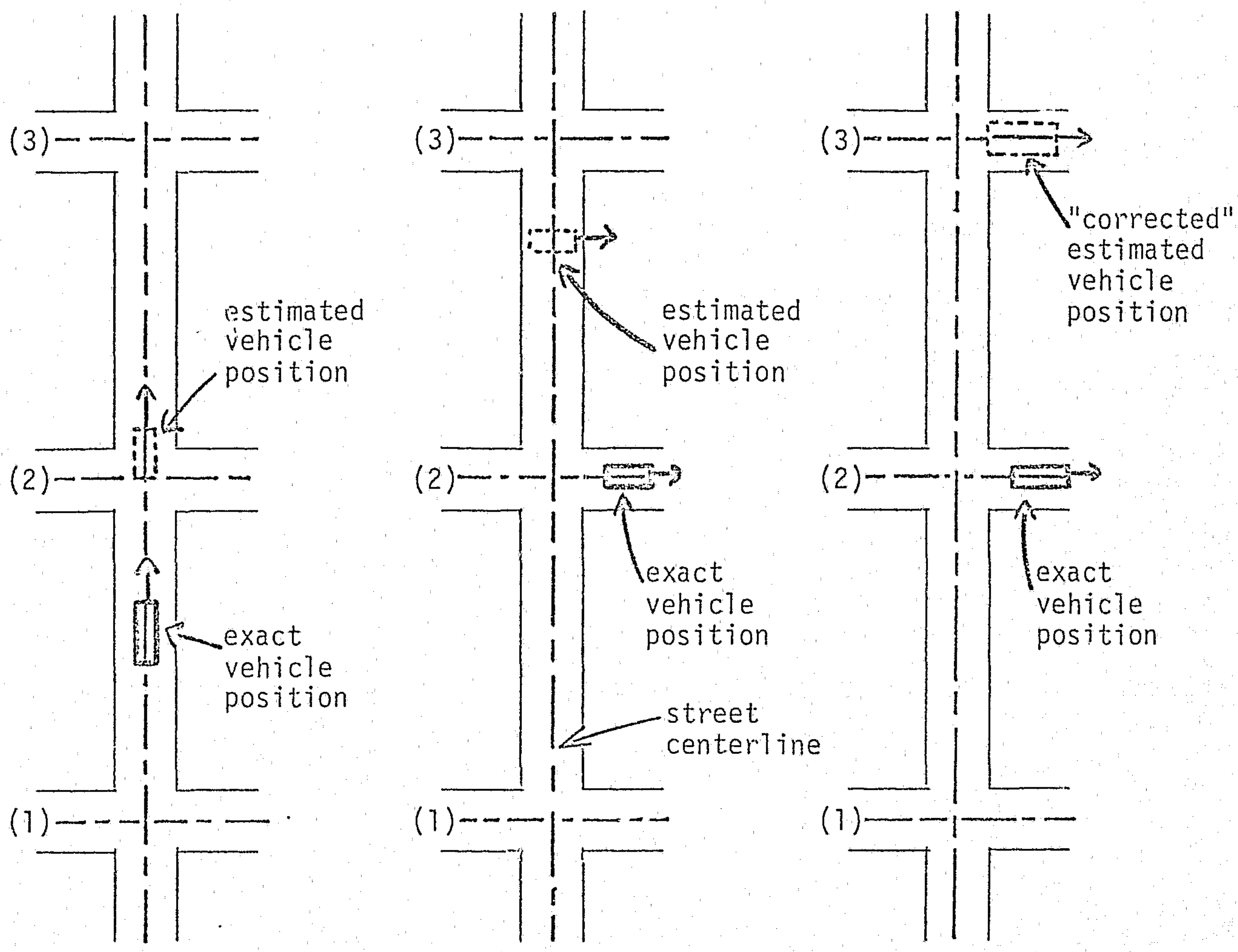
* See detailed discussion in Section IV.3.

** Again, see Section IV.3 which discusses a (usually) small amount of error that remains after the turn.

Figure A-5

Loss of Vehicle: A Vehicle Turn Incorrectly Interpreted



a. estimated vehicle position at time $t = t_1$

b. estimated vehicle position at time $t = t_1 + t_Q$, uncorrected (t_Q = time between updates)

c. estimated vehicle position at time $t = t_1 + t_Q$, "corrected;" vehicle now "lost."

While the event causing loss of the vehicle is shown in Figure A-5, the computer tracking algorithm may not detect the loss until sometime later (due to apparently infeasible turns executed by the vehicle). Assuming that the time from incorrectly interpreting a turn until detection of loss is very small (say, minutes) compared to the mean time between incorrectly interpreted turns (say, hours), we ignore the small intervening time span in the model; thus we say that a vehicle is lost as soon as the incorrectly interpreted turn occurs.

It is worth noting that sophisticated tracking algorithms can sometimes correct for a vehicle that is determined to be lost, that is, they can "find" a lost vehicle. We will not be concerned with the details of such finding procedures, but we will characterize the success of such an algorithm by a probability

p_f = probability that a lost vehicle can be successfully found.

Current computer software can usually find about 50 percent of lost vehicles, resulting in $p_f \approx 0.50$.

We now procede to the model formulation. We want to predict the mean and the variance (or more generally the probability law) of the time or distance between losses (for simplicity we will initially use distance rather than time). For the moment we will assume $p_f = 0$, thereby ignoring corrections after losses (we can easily incorporate a nonzero p_f after we have developed the model). We assume that each time a vehicle makes a turn and is correctly tracked, the accumulated odometer error goes to zero and this event is a renewal event. If the vehicle turns and is not tracked correctly, then the vehicle is lost; this is the event of interest.

We wish to incorporate in the model the following features:

1. Both systematic and random errors as discussed above.
2. The spacings between streets.
3. Some measure of the regularity or irregularity of the street pattern.
4. The frequency with which the tracked car makes turns at intersections.

To model both features 2 and 3, we assume that adjacent intersections are located kb units apart where

b = length of the shortest possible city block,

k = an integer random variable whose probability mass function is geometric.

Thus the probability law for k can be written

$$p\{k = v\} = (1 - q)^{v-1} q \qquad v = 1, 2, 3, \ldots \qquad (7)$$

There are several ways of interpreting this obviously simplified model of street positionings. In one interpretation, each time the tracked vehicle travels a distance b from the last intersection there is a probability q that it will incur another intersection; regardless of "success" or "failure" at finding an intersection at that point, the probability of incurring an intersection at a distance 2b from the original intersection is also q. In general, each time the vehicle travels b units of distance there is a probability q that an intersection will exist there.

Examining some limiting cases of the model, suppose q = 1. This corresponds to a situation in which the streets are designed in a regular square grid pattern, each (actual) block being exactly b units in length. This might be an accurate depiction of the streets in

Wichita, Phoenix, Tuscon and several other midwestern and far-western cities, where b typically is about 500 feet. At the other extreme, suppose $q = \varepsilon$, where ε is very small but positive. This would correspond to an almost totally random positioning of streets, with adjacent intersections positioned as in a Poisson process with mean "inter-arrival time" (mean distance between intersections) equal to b/ε. Here the parameter b (by itself) has little meaning, since in applications we would probably specify the ratio b/ε (which would correspond to the empirically measured mean distance between intersections), we would note the Poisson process nature of the street spacings, and we would set b and ε (keeping b/ε constant) sufficiently small so as to achieve the required accuracy in the model.

Having examined extreme values of q, we see that intermediate values correspond to intermediate degrees of regularity or irregularity in the street pattern, with higher values indicating greater regularity.

In actual applications, how do we determine numerical values for b and q? From the model we can compute that the mean distance between adjacent intersections is b/q and the variance is $b^2(\frac{1-q}{q^2})$. We can also compute empirical values for these quantities from a map of the city being modeled. Suppose the empirically calculated mean distance between intersections is $\bar{\ell}$ and the variance is σ_ℓ^2. Then set

$$\bar{\ell} = b/q \qquad \text{(a)}$$

and

$$\sigma_\ell^2 = b^2\left(\frac{1-q}{q^2}\right). \qquad \text{(b)} \qquad (8)$$

Manipulating these equations, we get

$$q = 1 - \frac{\sigma_\ell^2}{\bar{\ell}^2} \qquad \text{(a)}$$

$$b = \bar{\ell}\left(1 - \frac{\sigma_\ell^2}{\bar{\ell}^2}\right). \qquad \text{(b)} \qquad (9)$$

Note that in order for q to remain nonnegative, we must have $\sigma_\ell \leq \bar{\ell}$. This is just as we expect since the most random distribution of streets that we can model is the Poisson process distribution, and this corresponds to $\sigma_\ell = \bar{\ell}$. It is important to note that the parameter b now becomes the <u>unit of distance</u> in our model.

Feature 4 of the model, the frequency with which the vehicle makes turns, can be modelled simply by defining

r $\equiv$ probability that the vehicle turns at any given intersection.

We assume that the turning decision is made independently at each intersection and thus that turns occur as a Bernoulli process with parameter r.

We are now ready to compute the unconditional probability of "loss" of a vehicle on a randomly selected turn. Call this quantity p. Clearly,

$$p = \sum_{i=1}^{\infty} \text{Prob\{vehicle makes next turn i units of distance from last turn\}Prob\{loss}|\text{i\}}.$$

If a vehicle is almost at a distance d = i from the last turn, the probability of turning at i is simply equal to q r, the probability that a street intersection exists at d = i multiplied by the probability of turning, given that an intersection exists. Thus the probability that

the vehicle makes its next turn exactly i units of distance from the last turn is a geometrically distributed random variable with parameter qr , and we can write

$$p = \sum_{i=1}^{\infty} qr(1 - qr)^{i-1} \text{Prob}\{\text{loss}|i\}.$$

Our next task is to express Prob{loss|i} in terms of previously defined parameters. We assume that a vehicle is lost if it is estimated to be closer to an intersection other than the one at which it is actually turning. Figure 6 depicts "forward loss" of a vehicle, that is a situation in which the vehicle is estimated to be closer to an intersection "in front of the vehicle" than the one at which it is turning. In Figure 6 the vehicle turns at $d = i$, the next intersection ahead of the vehicle is located at $d = i + j$. If the estimated position of the vehicle is to the right of the halfway point between the two intersections $(\frac{2i + j}{2})$, then the vehicle has incurred <u>forward loss</u>. <u>Backward loss</u> occurs in a directly analogous fashion with the nearest intersection "behind" the vehicle at $d = i$. Utilizing the Weiner process model, the probability of incurring forward loss in this case is

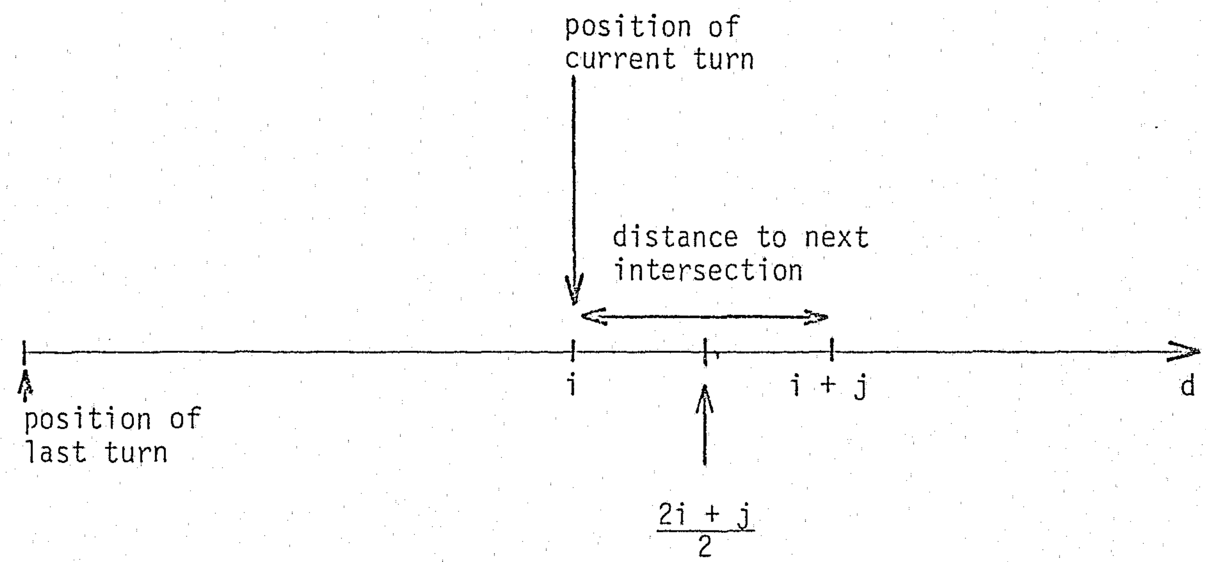
$$\int_{j/2}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i} dy.$$

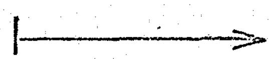
The analogous probability of backward loss is

$$\int_{-i}^{-j/2} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i} dy.$$

Figure A-6

Forward Loss of a Vehicle





vehicle must be estimated to be to the right of $d = \frac{2i + j}{2}$ for "loss" to occur

In most cases of practical interest, in which σ^2 and γ are sufficiently small to yield a small p, we can approximate p by changing -i (the lower limit on the last integral) to $-\infty$. Thus we approximate

Prob{loss x = i and next intersection j units in distance} $\approx$

$$\int_{j/2}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i}\, dy + \int_{-\infty}^{-j/2} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i}\, dy =$$

$$= 1 - \int_{-j/2}^{j/2} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i}\, dy.$$

Now, the probability that the next intersection is j units in distance is $q(1 - q)^{j-1}$, j = 1, 2, ... Thus

$$\text{Prob}\{\text{loss}|x = i\} \quad \sum_{j=1}^{\infty} q(1 - q)^{j-1} [1 - \int_{-j/2}^{j/2} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i}\, dy].$$

Finally, the quantity of interest, p (the unconditional probability of loss on a randomly selected turn of the vehicle) is given by

$$p = \sum_{i=1}^{\infty} qr(1 - qr)^{i-1} \sum_{j=1}^{\infty} q(1 - q)^{j-1} [1 - \int_{-j/2}^{j/2} \frac{1}{\sqrt{2\pi\sigma^2 i}} e^{-(y-\gamma i)^2/2\sigma^2 i}\, dy] \quad (10)$$

Illustrative values of this probability have been tabulated with the assistance of a computer. (See Table 1.)

Since losses occur as in a Bernoulli process, the mean number of turns executed between losses is 1/p. The mean number of intersections

Table 2

Illustrative Values of Vehicle Loss Probability (p)

STREET PATTERN IRREGULARITY FIXED AT Θ= 0.2

GAMMA = SYSTEMATIC BIAS PER UNIT DISTANCE
SIGMA = STANDARD DEVIATIØN ØF RANDØM BIAS PER UNIT DISTANCE
r = PRØBABILITY THAT VEHICLE TURNS AT RANDØM INTERSECTIØN

GAMMA	SIGMA	r	p
0.00	0.01	0.500	0.00000
0.00	0.01	0.250	0.00000
0.00	0.01	0.125	0.00000
0.00	0.02	0.500	0.00000
0.00	0.02	0.250	0.00000
0.00	0.02	0.125	0.00000
0.00	0.03	0.500	0.00000
0.00	0.03	0.250	0.00000
0.00	0.03	0.125	0.00000
0.00	0.05	0.500	0.00216
0.00	0.05	0.250	0.00862
0.00	0.05	0.125	0.02331
0.00	0.07	0.500	0.00819
0.00	0.07	0.250	0.02267
0.00	0.07	0.125	0.04835
0.00	0.10	0.500	0.02311
0.00	0.10	0.250	0.04933
0.00	0.10	0.125	0.08882
0.00	0.20	0.500	0.08973
0.00	0.20	0.250	0.14379
0.00	0.20	0.125	0.21206
0.01	0.01	0.500	0.00000
0.01	0.01	0.250	0.00000
0.01	0.01	0.125	0.00000
0.01	0.02	0.500	0.00000
0.01	0.02	0.250	0.00000
0.01	0.02	0.125	0.00000
0.01	0.03	0.500	0.00345
0.01	0.03	0.250	0.02271
0.01	0.03	0.125	0.07882
0.01	0.05	0.500	0.00765
0.01	0.05	0.250	0.03089
0.01	0.05	0.125	0.08679
0.01	0.07	0.500	0.01406
0.01	0.07	0.250	0.04180
0.01	0.07	0.125	0.09871
0.01	0.10	0.500	0.02807
0.01	0.10	0.250	0.06341
0.01	0.10	0.125	0.12387
0.01	0.20	0.500	0.09211
0.01	0.20	0.250	0.14962
0.01	0.20	0.125	0.22519

GAMMA	SIGMA	r	p
0.02	0.01	0.500	0.00000
0.02	0.01	0.250	0.00000
0.02	0.01	0.125	0.00000
0.02	0.02	0.500	0.00000
0.02	0.02	0.250	0.00000
0.02	0.02	0.125	0.00000
0.02	0.03	0.500	0.01924
0.02	0.03	0.250	0.07582
0.02	0.03	0.125	0.18761
0.02	0.05	0.500	0.02402
0.02	0.05	0.250	0.08020
0.02	0.05	0.125	0.18896
0.02	0.07	0.500	0.03010
0.02	0.07	0.250	0.08623
0.02	0.07	0.125	0.19151
0.02	0.10	0.500	0.04186
0.02	0.10	0.250	0.09908
0.02	0.10	0.125	0.19955
0.02	0.20	0.500	0.09907
0.02	0.20	0.250	0.16612
0.02	0.20	0.125	0.26018
0.03	0.01	0.500	0.00000
0.03	0.01	0.250	0.00000
0.03	0.01	0.125	0.00000
0.03	0.02	0.500	0.04328
0.03	0.02	0.250	0.13275
0.03	0.02	0.125	0.27923
0.03	0.03	0.500	0.04450
0.03	0.03	0.250	0.13332
0.03	0.03	0.125	0.27904
0.03	0.05	0.500	0.04811
0.03	0.05	0.250	0.13519
0.03	0.05	0.125	0.27858
0.03	0.07	0.500	0.05289
0.03	0.07	0.250	0.13801
0.03	0.07	0.125	0.27823
0.03	0.10	0.500	0.06198
0.03	0.10	0.250	0.14452
0.03	0.10	0.125	0.27899
0.03	0.20	0.500	0.11011
0.03	0.20	0.250	0.19084
0.03	0.20	0.125	0.30747

Table 2

(page 2 of 5)

Illustrative Values of Vehicle Loss Probability (p)

STREET PATTERN IRREGULARITY FIXED AT Q= 0.4

GAMMA = SYSTEMATIC BIAS PER UNIT DISTANCE
SIGMA = STANDARD DEVIATION OF RANDOM BIAS PER UNIT DISTANCE
r = PROBABILITY THAT VEHICLE TURNS AT RANDOM INTERSECTION

GAMMA	SIGMA	r	p
0.00	0.01	0.500	0.00000
0.00	0.01	0.250	0.00000
0.00	0.01	0.125	0.00000
0.00	0.02	0.500	0.00000
0.00	0.02	0.250	0.00000
0.00	0.02	0.125	0.00000
0.00	0.03	0.500	0.00000
0.00	0.03	0.250	0.00000
0.00	0.03	0.125	0.00000
0.00	0.05	0.500	0.00056
0.00	0.05	0.250	0.00431
0.00	0.05	0.125	0.01710
0.00	0.07	0.500	0.00381
0.00	0.07	0.250	0.01626
0.00	0.07	0.125	0.04436
0.00	0.10	0.500	0.01622
0.00	0.10	0.250	0.04523
0.00	0.10	0.125	0.09413
0.00	0.20	0.500	0.09510
0.00	0.20	0.250	0.16538
0.00	0.20	0.125	0.25224
0.01	0.01	0.500	0.00000
0.01	0.01	0.250	0.00000
0.01	0.01	0.125	0.00000
0.01	0.02	0.500	0.00000
0.01	0.02	0.250	0.00000
0.01	0.02	0.125	0.00000
0.01	0.03	0.500	0.00033
0.01	0.03	0.250	0.00686
0.01	0.03	0.125	0.04428
0.01	0.05	0.500	0.00202
0.01	0.05	0.250	0.01515
0.01	0.05	0.125	0.05946
0.01	0.07	0.500	0.00627
0.01	0.07	0.250	0.02761
0.01	0.07	0.125	0.07938
0.01	0.10	0.500	0.01899
0.01	0.10	0.250	0.05442
0.01	0.10	0.125	0.11815
0.01	0.20	0.500	0.09665
0.01	0.20	0.250	0.16909
0.01	0.20	0.125	0.26016

GAMMA	SIGMA	r	p
0.02	0.01	0.500	0.00000
0.02	0.01	0.250	0.00000
0.02	0.01	0.125	0.00000
0.02	0.02	0.500	0.00000
0.02	0.02	0.250	0.00000
0.02	0.02	0.125	0.00000
0.02	0.03	0.500	0.00379
0.02	0.03	0.250	0.03772
0.02	0.03	0.125	0.14071
0.02	0.05	0.500	0.00780
0.02	0.05	0.250	0.04676
0.02	0.05	0.125	0.14746
0.02	0.07	0.500	0.01384
0.02	0.07	0.250	0.05804
0.02	0.07	0.125	0.15672
0.02	0.10	0.500	0.02706
0.02	0.10	0.250	0.07961
0.02	0.10	0.125	0.17707
0.02	0.20	0.500	0.10122
0.02	0.20	0.250	0.17988
0.02	0.20	0.125	0.28239
0.03	0.01	0.500	0.00000
0.03	0.01	0.250	0.00000
0.03	0.01	0.125	0.00000
0.03	0.02	0.500	0.01252
0.03	0.02	0.250	0.08308
0.03	0.02	0.125	0.23479
0.03	0.03	0.500	0.01431
0.03	0.03	0.250	0.08523
0.03	0.03	0.125	0.23533
0.03	0.05	0.500	0.01960
0.03	0.05	0.250	0.09156
0.03	0.05	0.125	0.23717
0.03	0.07	0.500	0.02662
0.03	0.07	0.250	0.09983
0.03	0.07	0.125	0.24017
0.03	0.10	0.500	0.03983
0.03	0.10	0.250	0.11539
0.03	0.10	0.125	0.24805
0.03	0.20	0.500	0.10866
0.03	0.20	0.250	0.19682
0.03	0.20	0.125	0.31513

Table 2

(page 3 of 5)

Illustrative Values of Vehicle Loss Probability (p)

STREET PATTERN IRREGULARITY FIXED AT Q= 0.6

GAMMA = SYSTEMATIC BIAS PER UNIT DISTANCE
SIGMA = STANDARD DEVIATIØN ØF RANDØM BIAS PER UNIT DISTANCE
r = PRØBABILITY THAT VEHICLE TURNS AT RANDØM INTERSECTIØN

GAMMA	SIGMA	r	p
0.00	0.01	0.500	0.00000
0.00	0.01	0.250	0.00000
0.00	0.01	0.125	0.00000
0.00	0.02	0.500	0.00000
0.00	0.02	0.250	0.00000
0.00	0.02	0.125	0.00000
0.00	0.03	0.500	0.00000
0.00	0.03	0.250	0.00000
0.00	0.03	0.125	0.00000
0.00	0.05	0.500	0.00015
0.00	0.05	0.250	0.00218
0.00	0.05	0.125	0.01212
0.00	0.07	0.500	0.00173
0.00	0.07	0.250	0.01118
0.00	0.07	0.125	0.03808
0.00	0.10	0.500	0.01063
0.00	0.10	0.250	0.03855
0.00	0.10	0.125	0.09174
0.00	0.20	0.500	0.09174
0.00	0.20	0.250	0.17332
0.00	0.20	0.125	0.27325
0.01	0.01	0.500	0.00000
0.01	0.01	0.250	0.00000
0.01	0.01	0.125	0.00000
0.01	0.02	0.500	0.00000
0.01	0.02	0.250	0.00000
0.01	0.02	0.125	0.00000
0.01	0.03	0.500	3.41E-05
0.01	0.03	0.250	0.00211
0.01	0.03	0.125	0.02460
0.01	0.05	0.500	0.00056
0.01	0.05	0.250	0.00774
0.01	0.05	0.125	0.04177
0.01	0.07	0.500	0.00281
0.01	0.07	0.250	0.01850
0.01	0.07	0.125	0.06490
0.01	0.10	0.500	0.01229
0.01	0.10	0.250	0.04535
0.01	0.10	0.125	0.11069
0.01	0.20	0.500	0.09293
0.01	0.20	0.250	0.17617
0.01	0.20	0.125	0.27911

GAMMA	SIGMA	r	p
0.02	0.01	0.500	0.00000
0.02	0.01	0.250	0.00000
0.02	0.01	0.125	0.00000
0.02	0.02	0.500	0.00000
0.02	0.02	0.250	0.00000
0.02	0.02	0.125	0.00000
0.02	0.03	0.500	0.00064
0.02	0.03	0.250	0.01737
0.02	0.03	0.125	0.10244
0.02	0.05	0.500	0.00246
0.02	0.05	0.250	0.02702
0.02	0.05	0.125	0.11469
0.02	0.07	0.500	0.00637
0.02	0.07	0.250	0.03970
0.02	0.07	0.125	0.12996
0.02	0.10	0.500	0.01728
0.02	0.10	0.250	0.06462
0.02	0.10	0.125	0.15982
0.02	0.20	0.500	0.09645
0.02	0.20	0.250	0.18455
0.02	0.20	0.125	0.29589
0.03	0.01	0.500	0.00000
0.03	0.01	0.250	0.00000
0.03	0.01	0.125	0.00000
0.03	0.02	0.500	0.00266
0.03	0.02	0.250	0.04739
0.03	0.02	0.125	0.19251
0.03	0.03	0.500	0.00370
0.03	0.03	0.250	0.05069
0.03	0.03	0.125	0.19436
0.03	0.05	0.500	0.00731
0.03	0.05	0.250	0.06013
0.03	0.05	0.125	0.19998
0.03	0.07	0.500	0.01303
0.03	0.07	0.250	0.07207
0.03	0.07	0.125	0.20768
0.03	0.10	0.500	0.02551
0.03	0.10	0.250	0.09353
0.03	0.10	0.125	0.22358
0.03	0.20	0.500	0.10222
0.03	0.20	0.250	0.19794
0.03	0.20	0.125	0.32149

Table 2

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Illustrative Values of Vehicle Loss Probability (p)

STREET PATTERN IRREGULARITY FIXED AT Q= 0.8

GAMMA = SYSTEMATIC BIAS PER UNIT DISTANCE
SIGMA = STANDARD DEVIATIØN ØF RANDØM BIAS PER UNIT DISTANCE
r = PRØBABILITY THAT VEHICLE TURNS AT RANDØM INTERSECTIØN

GAMMA	SIGMA	r	p
0.00	0.01	0.500	0.00000
0.00	0.01	0.250	0.00000
0.00	0.01	0.125	0.00000
0.00	0.02	0.500	0.00000
0.00	0.02	0.250	0.00000
0.00	0.02	0.125	0.00000
0.00	0.03	0.500	0.00000
0.00	0.03	0.250	0.00000
0.00	0.03	0.125	0.00000
0.00	0.05	0.500	4.26E-05
0.00	0.05	0.250	0.00113
0.00	0.05	0.125	0.00858
0.00	0.07	0.500	0.00076
0.00	0.07	0.250	0.00760
0.00	0.07	0.125	0.03202
0.00	0.10	0.500	0.00667
0.00	0.10	0.250	0.03198
0.00	0.10	0.125	0.08674
0.00	0.20	0.500	0.08486
0.00	0.20	0.250	0.17532
0.00	0.20	0.125	0.28593
0.01	0.01	0.500	0.00000
0.01	0.01	0.250	0.00000
0.01	0.01	0.125	0.00000
0.01	0.02	0.500	0.00000
0.01	0.02	0.250	0.00000
0.01	0.02	0.125	0.00000
0.01	0.03	0.500	3.51E-06
0.01	0.03	0.250	0.00066
0.01	0.03	0.125	0.01362
0.01	0.05	0.500	0.00016
0.01	0.05	0.250	0.00404
0.01	0.05	0.125	0.02970
0.01	0.07	0.500	0.00124
0.01	0.07	0.250	0.01244
0.01	0.07	0.125	0.05332
0.01	0.10	0.500	0.00768
0.01	0.10	0.250	0.03722
0.01	0.10	0.125	0.10259
0.01	0.20	0.500	0.08582
0.01	0.20	0.250	0.17769
0.01	0.20	0.125	0.29067

GAMMA	SIGMA	r	p
0.02	0.01	0.500	0.00000
0.02	0.01	0.250	0.00000
0.02	0.01	0.125	0.00000
0.02	0.02	0.500	0.00000
0.02	0.02	0.250	0.00000
0.02	0.02	0.125	0.00000
0.02	0.03	0.500	9.32E-05
0.02	0.03	0.250	0.00756
0.02	0.03	0.125	0.07259
0.02	0.05	0.500	0.00074
0.02	0.05	0.250	0.01545
0.02	0.05	0.125	0.08877
0.02	0.07	0.500	0.00285
0.02	0.07	0.250	0.02721
0.02	0.07	0.125	0.10836
0.02	0.10	0.500	0.01074
0.02	0.10	0.250	0.05239
0.02	0.10	0.125	0.14502
0.02	0.20	0.500	0.08868
0.02	0.20	0.250	0.18471
0.02	0.20	0.125	0.30440
0.03	0.01	0.500	0.00000
0.03	0.01	0.250	0.00000
0.03	0.01	0.125	0.00000
0.03	0.02	0.500	0.00042
0.03	0.02	0.250	0.02475
0.03	0.02	0.125	0.15378
0.03	0.03	0.500	0.00079
0.03	0.03	0.250	0.02822
0.03	0.03	0.125	0.15716
0.03	0.05	0.500	0.00250
0.03	0.05	0.250	0.03839
0.03	0.05	0.125	0.16696
0.03	0.07	0.500	0.00611
0.03	0.07	0.250	0.05164
0.03	0.07	0.125	0.17947
0.03	0.10	0.500	0.01593
0.03	0.10	0.250	0.07597
0.03	0.10	0.125	0.20281
0.03	0.20	0.500	0.09340
0.03	0.20	0.250	0.19603
0.03	0.20	0.125	0.32576

Table 2

(page 5 of 5)

Illustrative Values of Vehicle Loss Probability (p)

STREET PATTERN IRREGULARITY FIXED AT Q= 1

GAMMA = SYSTEMATIC BIAS PER UNIT DISTANCE
SIGMA = STANDARD DEVIATION OF RANDOM BIAS PER UNIT DISTANCE
r = PROBABILITY THAT VEHICLE TURNS AT RANDOM INTERSECTION

GAMMA	SIGMA	r	p
0.00	0.01	0.500	0.00000
0.00	0.01	0.250	0.00000
0.00	0.01	0.125	0.00000
0.00	0.02	0.500	0.00000
0.00	0.02	0.250	0.00000
0.00	0.02	0.125	0.00000
0.00	0.03	0.500	0.00000
0.00	0.03	0.250	0.00000
0.00	0.03	0.125	0.00000
0.00	0.05	0.500	1.11E-05
0.00	0.05	0.250	0.00059
0.00	0.05	0.125	0.00609
0.00	0.07	0.500	0.00032
0.00	0.07	0.250	0.00514
0.00	0.07	0.125	0.02668
0.00	0.10	0.500	0.00400
0.00	0.10	0.250	0.02611
0.00	0.10	0.125	0.08075
0.00	0.20	0.500	0.07618
0.00	0.20	0.250	0.17397
0.00	0.20	0.125	0.29393
0.01	0.01	0.500	0.00000
0.01	0.01	0.250	0.00000
0.01	0.01	0.125	0.00000
0.01	0.02	0.500	0.00000
0.01	0.02	0.250	0.00000
0.01	0.02	0.125	0.00000
0.01	0.03	0.500	3.30E-07
0.01	0.03	0.250	0.00021
0.01	0.03	0.125	0.00755
0.01	0.05	0.500	4.10E-05
0.01	0.05	0.250	0.00213
0.01	0.05	0.125	0.02127
0.01	0.07	0.500	0.00052
0.01	0.07	0.250	0.00837
0.01	0.07	0.125	0.04388
0.01	0.10	0.500	0.00459
0.01	0.10	0.250	0.03022
0.01	0.10	0.125	0.09441
0.01	0.20	0.500	0.07697
0.01	0.20	0.250	0.17604
0.01	0.20	0.125	0.29797

GAMMA	SIGMA	r	p
0.02	0.01	0.500	0.00000
0.02	0.01	0.250	0.00000
0.02	0.01	0.125	0.00000
0.02	0.02	0.500	0.00000
0.02	0.02	0.250	0.00000
0.02	0.02	0.125	0.00000
0.02	0.03	0.500	1.16E-05
0.02	0.03	0.250	0.00316
0.02	0.03	0.125	0.05026
0.02	0.05	0.500	0.00021
0.02	0.05	0.250	0.00875
0.02	0.05	0.125	0.06836
0.02	0.07	0.500	0.00121
0.02	0.07	0.250	0.01860
0.02	0.07	0.125	0.09052
0.02	0.10	0.500	0.00640
0.02	0.10	0.250	0.04227
0.02	0.10	0.125	0.13179
0.02	0.20	0.500	0.07935
0.02	0.20	0.250	0.18217
0.02	0.20	0.125	0.30975
0.03	0.01	0.500	0.00000
0.03	0.01	0.250	0.00000
0.03	0.01	0.125	0.00000
0.03	0.02	0.500	4.92E-05
0.03	0.02	0.250	0.01191
0.03	0.02	0.125	0.11964
0.03	0.03	0.500	0.00014
0.03	0.03	0.250	0.01481
0.03	0.03	0.125	0.12444
0.03	0.05	0.500	0.00077
0.03	0.05	0.250	0.02388
0.03	0.05	0.125	0.13802
0.03	0.07	0.500	0.00269
0.03	0.07	0.250	0.03663
0.03	0.07	0.125	0.15478
0.03	0.10	0.500	0.00955
0.03	0.10	0.250	0.06152
0.03	0.10	0.125	0.18449
0.03	0.20	0.500	0.08328
0.03	0.20	0.250	0.19212
0.03	0.20	0.125	0.32831

traversed between turns is 1/r. Reinserting b as the minimal spacing between intersections, the mean distance between adjacent intersections is $\frac{b}{q}$. Combining these results, the mean distance travelled between losses is

$$\boxed{\bar{D}_L = \frac{b}{q}\frac{1}{r}\frac{1}{p}} \qquad (11)$$

If the vehicle travels at an average speed of s mph (accounting for stops at calls for service, meal breaks, intersections, etc.), then the mean time between losses is

$$\boxed{\bar{T}_L = \frac{b}{sqrp}} \qquad (12)$$

Let us now apply this equation to some hypothetical data to test its implications. Suppose our problem can be modelled with the following parameter values:

$\bar{d}_\ell$ = 528 feet = 0.1 mile

σ_ℓ = (1/2) $\bar{d}$

s = 10 mph

r = (1/3) (probability of a turn at a random intersection)

That is, the mean spacing between adjacent intersections is 528 feet, or one-tenth of a mile. The standard deviation of this spacing is

one-half of the mean. These two facts imply, using Equations 9 (a) and 9 (b), that

$$q = 3/4$$

$$b = 396 \text{ feet} = 0.075 \text{ mi.}$$

Substituting into Equation (12) for $\overline{T}_L$, we have

$$\overline{T}_L = \frac{0.075 \text{ mi.}}{(10 \text{ mi/hr}) \frac{3}{4} \frac{1}{3} p} = \frac{0.03}{p}.$$

A popular system design objective calls for a mean time between losses not to be less than 12 hours. Thus,

$$\overline{T}_L \geq 12 \text{ hours.}$$

This implies a rather stringent requirement for the loss probability per turn, p, in the sense that

$$\frac{0.03}{p} \geq 12$$

or

$$p \leq \frac{0.03}{12} = 0.0025.$$

To put this in stronger terms, this means that the computer tracking software must correctly detect and interpret 99.75 percent of all turns made by the vehicle. This requirement would become even more stringent if we (1) increased the average travel speed above 10 mph; (2) decreased the

mean spacings between intersections; (3) increased the probability of turning* above 1/3; (4) increased the variability (standard deviation) of the spacing between intersections above one-half of the mean.

IV. QUANTIZATION ERROR

The discussion to this point has assumed continuous tracking of the vehicle in time and space. In practice the time and space tracking are quantized, where the time quantization interval corresponds to the inverse of the polling rate per vehicle and the spatial quantization occurs both in the odometer (distance) and the heading sensor (angle). This section will discuss the ways in which these three types of quantizations increase the error probability predicted in Equation (10).

1. Angular Quantization

The heading sensor information is transmitted to the tracking computer as an N-digit binary number. This allows only 2^N different angular readings to be transmitted. It is customary to position uniformly the different quantized readings between 0 and 2π (radians), starting at 0. If we call α_Q the quantized angle, then α_Q can take on the values $0, 2\pi/2^N, 2\cdot 2\pi/2^N, \ldots, (2^N - 1)\cdot 2\pi/2^N$. Then, if the actual reading of the heading sensor is α, the value α_Q is transmitted, where α_Q is the quantized angle nearest α. In this way the set of possible

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* Increasing the probability of turning naturally decreases p, since less distance is traversed between zero checks.

heading angles ranging from 0 to 2π is partitioned into quantization intervals $(-\pi/2^N, \pi/2^N)$, $(\pi/2^N, 3\pi/2^N)$, $(3\pi/2^N, 5\pi/2^N)$,...,
$((2^{N+1} - 3)\pi/2^N, (2^{N+1} - 1)\pi/2^N)$.

As an example, if N = 3, (bits), the angular information might be arranged as follows:

α_Q	Quantization Interval	Possible Binary Code
0	$(-\pi/8, \pi/8)$	000
$\pi/4$	$(\pi/8, 3\pi/8)$	001
$\pi/2$	$(3\pi/8, 5\pi/8)$	010
$3\pi/4$	$(5\pi/8, 7\pi/8)$	011
π	$(7\pi/8, 9\pi/8)$	100
$5\pi/4$	$(9\pi/8, 11\pi/8)$	101
$3\pi/2$	$(11\pi/8, 13\pi/8)$	110
$7\pi/4$	$(13\pi/8, 15\pi/8)$	111

This situation is depicted in Figure 7. Naturally, the greater the number of bits N, the greater is the accuracy of the transmitted information.

There appear to be two types of key errors that can occur due to angular quantization. The first is a consistent error that occurs while tracking a vehicle along a street whose actual angle is α but which is quantized as α_Q. This is illustrated in Figure 8(a), where a vehicle is travelling in a straight line at angle α (say $\alpha = 7\pi/16$)

Figure A-7

An Example of Angular Quantization, N = 3 bits

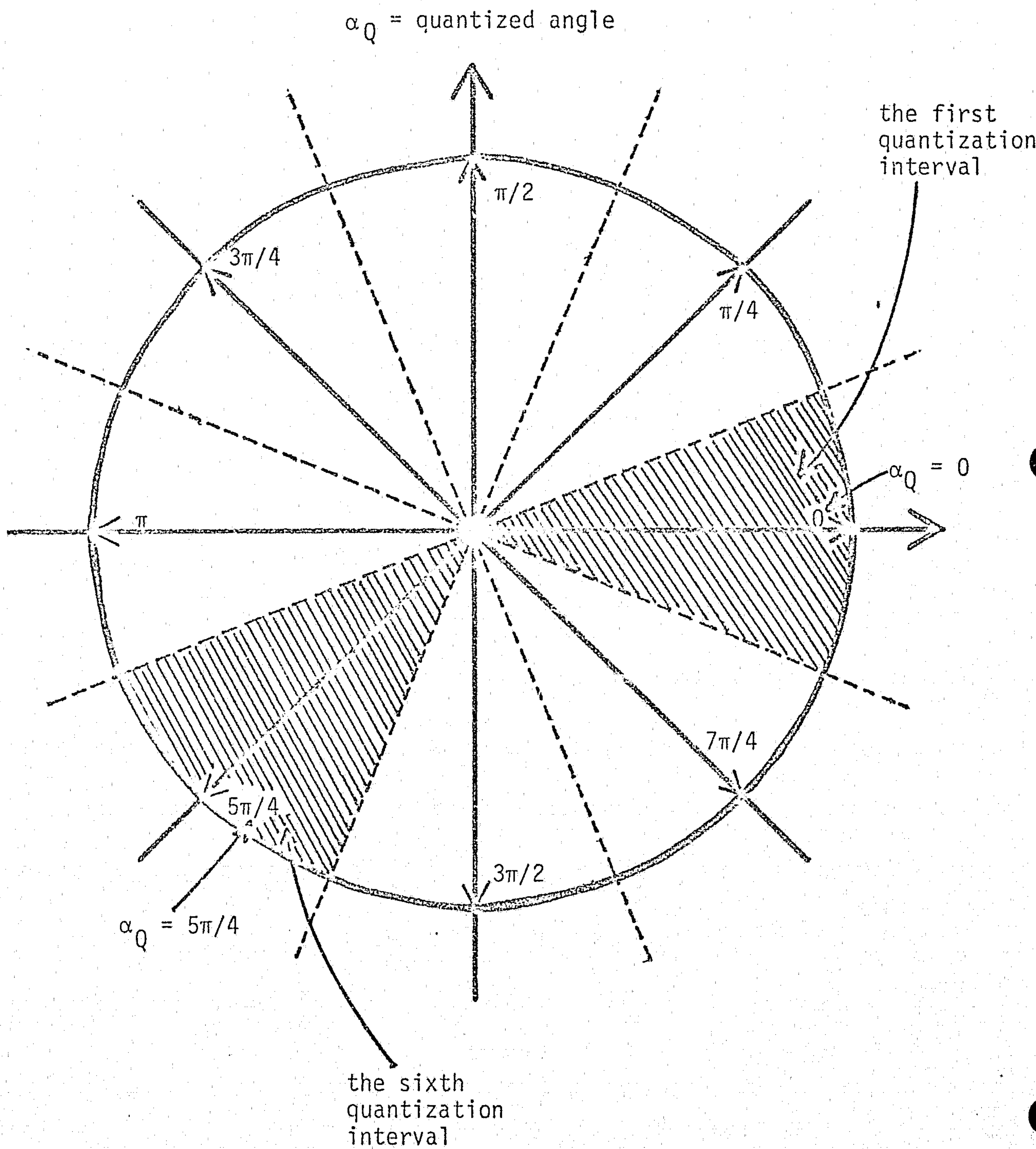
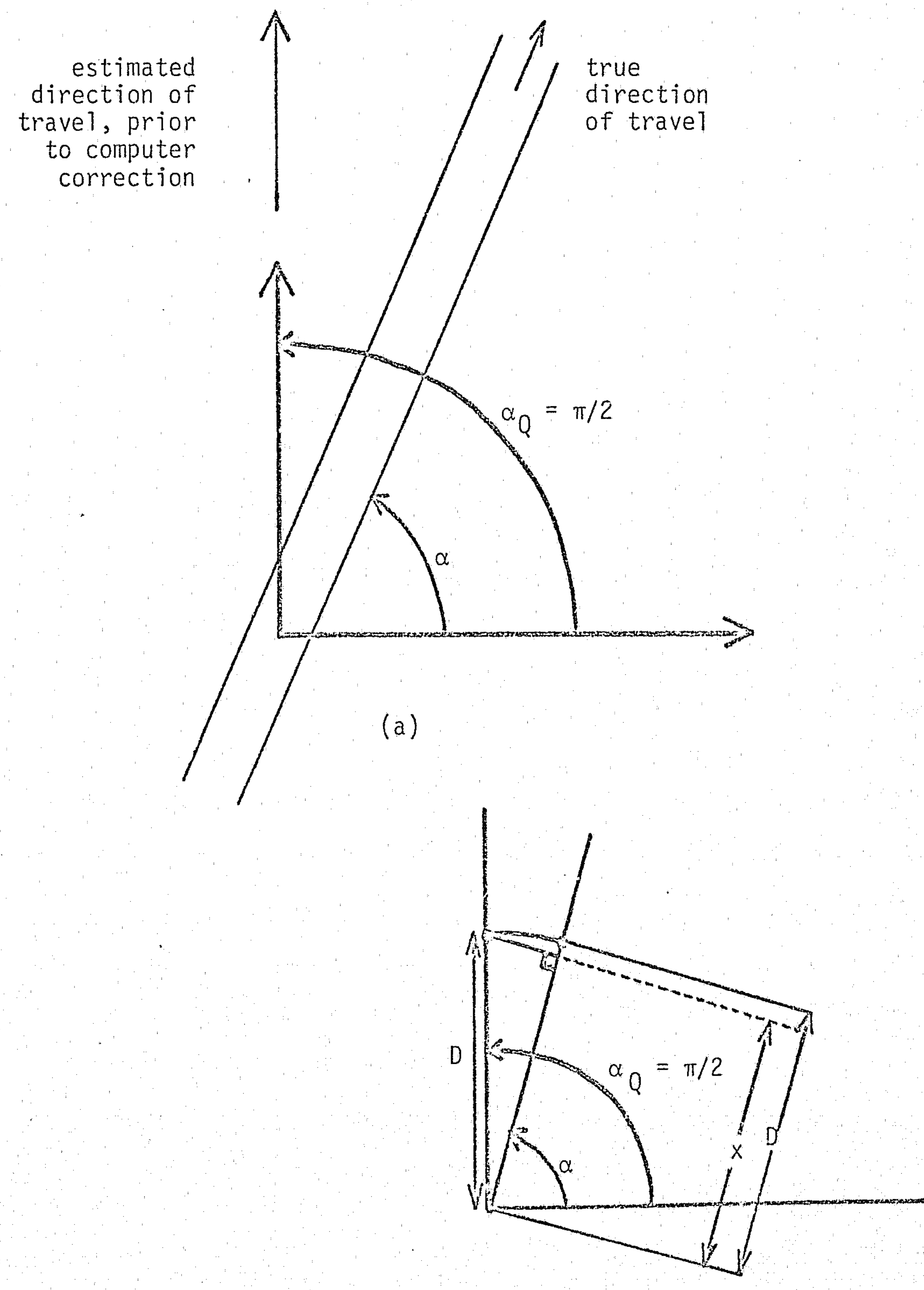


Figure A-8

Example of Consistent Tracking Error Due to Angular Quantization



(b)

but the quantized angle is α_Q(= $\pi/2$), yielding an angular error due to quantization of $|\alpha - \alpha_Q|$.

Developing this example, suppose the vehicle travels a distance D, then a "naive" tracking algorithm which did not take account of angular quantization might "correct" the position of the tracked vehicle back on the street at the point on the street closest to the current estimated (uncorrected) location of the vehicle. But this would yield a travelled distance on the actual street of only $x = D \cos |\alpha - \alpha_Q| \leq D$. (See Figure 8(b).) A distance estimation error would then be caused by the angular quantization; its magnitude would be $D - D\cos|\alpha - \alpha_Q| = D(1 - \cos|\alpha - \alpha_Q|)$. Obviously, the tracking algorithm need not be naive since the true angle of the street α is known and is maintained in the computer map. Thus, the correct procedure here is for the tracking algorithm to move the vehicle forward of its position as determined by a perpendicular to the street by an amount $D(1 - \cos|\alpha - \alpha_Q|)$; or, more simply, to move the vehicle along the street by a total amount D, not $D \cos|\alpha - \alpha_Q|$.

Since this type of consistent error can be easily corrected, we shall no longer concern ourselves with it. However, seeing the limited usefulness of the quantized angular information in tracking a vehicle along straight lines, it becomes apparent that the major purpose of angular information is to detect vehicular turns, when the vehicle changes streets on which it is travelling. So a question of concern is "How does angular quantization affect the ability of the tracking algorithm to detect vehicular turns?"

To answer this question, we need to introduce the notion of the divergence angle of street intersections. In Figure 9, we show two examples, a simple four-way perpendicular intersection and a complicated five-way intersection. Consider the simple example first. Imagine a vehicle entering the intersection from any one of the possible four directions. Upon exiting from the intersection, the tracking algorithm must determine if the vehicle has turned, that is if its angular direction has changed by $\pi/2$ or $-\pi/2$ radians (or by π, if u-turns are permitted). This it can readily do as long as there are at least four quantization intervals, corresponding to at least $N = 2$ bits. Now assume that the vehicle is entering the five-way intersection from any one of the incoming streets. Allowing u-turns, the computer tracking algorithm must determine which of the possible angles (α_1, α_2, α_3, α_4, or α_5) describes the motion of the exiting vehicle. Clearly if each of the actual angles α_i falls in a different quantization interval, then the direction of travel can be determined without error. This will be guaranteed to occur if the angles between all adjacent exiting streets, called divergence angles, are greater than the size of the quantization interval $2\pi/2^N$. Mathematically, the divergence angles in the example of Figure 9(b) are:

$$|\alpha_2 - \alpha_1| = a_1$$

$$|\alpha_3 - \alpha_2| = a_2$$

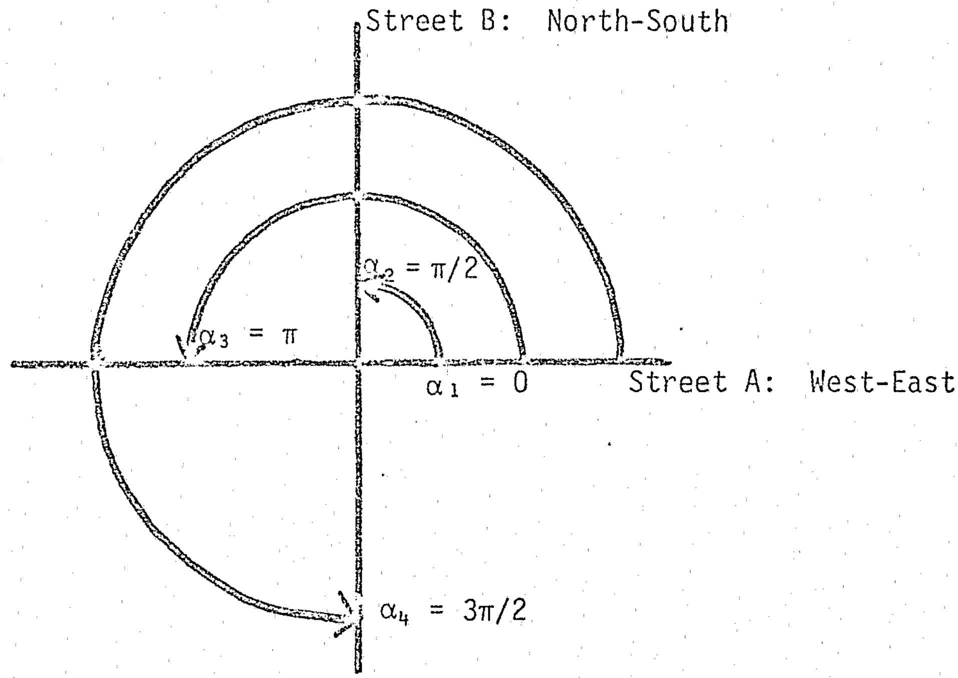
$$|\alpha_4 - \alpha_3| = a_3$$

$$|\alpha_5 - \alpha_4| = a_4$$

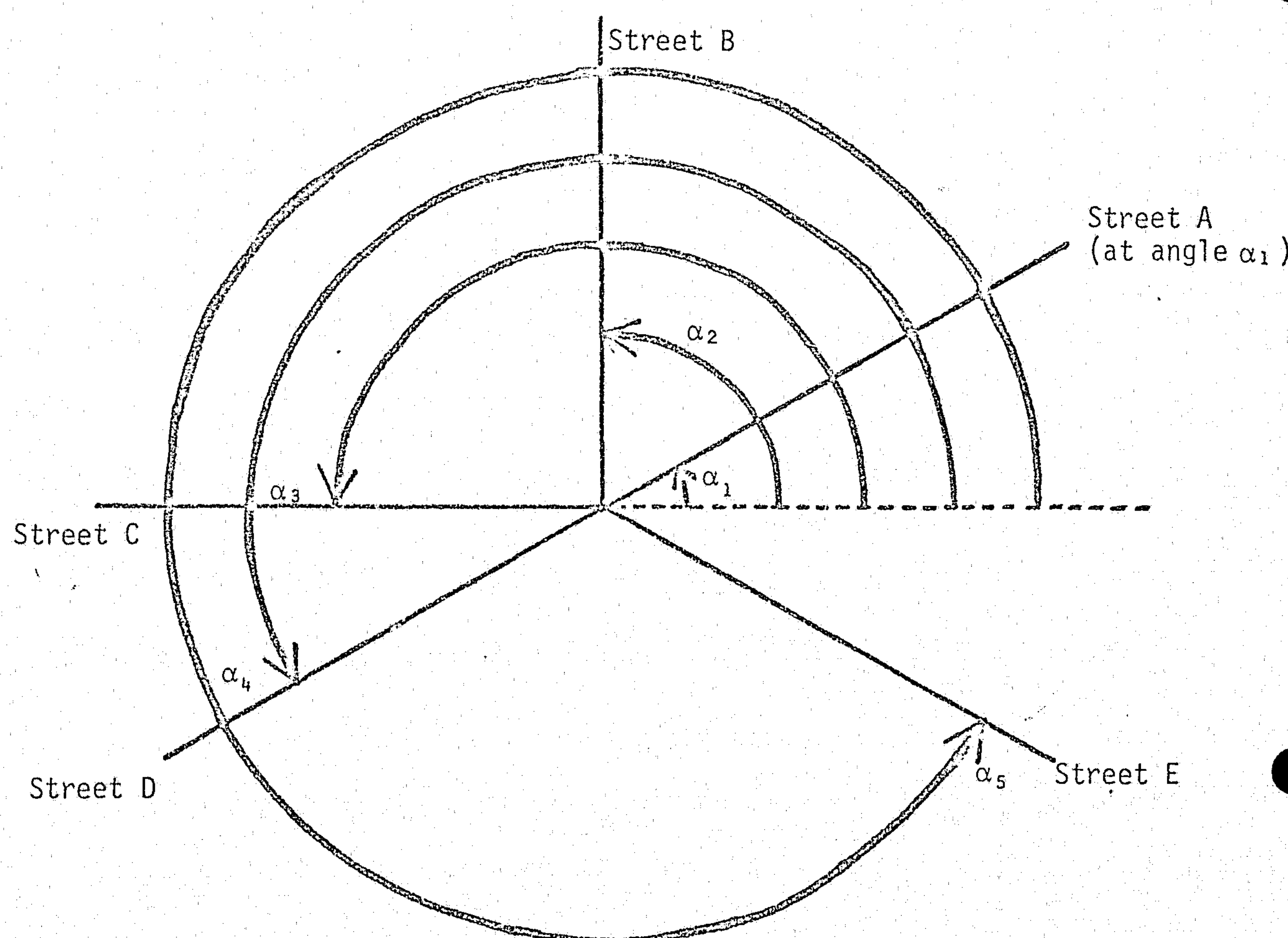
$$|\alpha_1 + 2\pi - \alpha_5| = a_5$$

Figure A-9

Street Angles at Intersections



(a) Simple Four-Way Perpendicular Intersection



(b) Complicated Five-Way Intersection

Thus, if $MIN\{a_i\} > 2\pi/2^N$, then the tracking algorithm can determine the street of exit from the intersection without error.

If, on the other hand, there are two adjacent streets whose divergence angle is less than $2\pi/2^N$, then they may or may not be in the same quantization interval. For the N = 3 example, where the quantization interval has size $\pi/4$ radians, consider two adjacent streets with angles $3\pi/16$ and $5\pi/16$. Here the divergence angle $a = 5\pi/16 - 3\pi/16 = \pi/8 < \pi/4$. Yet, the first street falls in the quantization interval with $\alpha_Q = 0$ and the second falls in the one with $\alpha_Q = \pi/4$. So, in this case, no error will occur when distinguishing between the first and second streets as exiting streets. However, suppose two other adjacent streets were directed at angles $\pi - \pi/16$ and $\pi + \pi/16$; then we still have a divergence angle $a = \pi/8 < \pi/4$, but the two streets both fall in the same quantization interval with angle $\alpha_Q = \pi$. In such a case in which two streets are contained within the same quantization interval, then the tracking algorithm must "guess" the correct street, and it would be reasonable to assume that the conditional probability of error would be 1/2.* (We will ignore the unlikely cases in which three or more streets are in the same quantization interval.)

To complete our discussion of angular quantization, we seek to find a way to compute

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* By utilizing statistics on turning probabilities and frequency of street usage, this conditional error probability presumably could be reduced below 1/2. However, we will ignore such sophistication.

P_{Q_A} ≡ probability of loss of a vehicle at an intersection due to angular quantization.

One way to compute P_{Q_A} would be to examine each intersection in the city and determine by inspection which intersections have diverging streets falling within the same quantization interval. If there are found to be 10,000 pairs of diverging streets in the city and 13 of them had angles falling within the same quantization interval, then we would estimate

$$P_{Q_A} \approx \frac{1}{2}\,\frac{13}{10{,}000} = 0.00065.$$

Of course this estimation procedure could be refined by incorporating data on street usage and (if available) turning probabilities. However, in the absence of such information, this simple calculation is not an unreasonable way to proceed.

A second method, particularly appropriate for very large cities, would be to estimate the probability distribution of the divergence angles by sampling a representative subset of them. Suppose

$F_a(x)$ = Fraction of divergence angles less than or equal to x.

Then, for a randomly selected divergence angle,

$$F_a(x) = \text{Prob}\{a \leq x\}.$$

In this context it is natural to call

$$f_a(x) = \frac{d}{dx} F_a(x)$$

the probability density function of divergence angles. The final concept we need here is that of the probability of loss of the vehicle due to angular quantization, given the value of a,

$$P_{Q_A}(x) \equiv \text{Prob}\{\text{vehicular loss due to angular quantization} | a = x\}.$$

In the earlier exhaustive way of computing P_{Q_A}, this probability was always either 0 or 1/2. Now, given that we are only sampling the divergence angles, we will assume that the absolute angle of rotation of the streets at a random intersection is uniformly distributed between 0 and 2π. That is, at intersection j, the i^{th} street leaving the intersection is situated at an angle $\alpha_{ij} + \theta_j$ for all i, and θ_j is uniformly distributed between 0 and 2π. (Note that such a random rotation leaves unchanged the divergence angles such as $a_{1j} = |\alpha_{2j} + \theta_j - (\alpha_{1j} + \theta_j)| = |\alpha_{2j} - \alpha_{2j}|$.) In such a case, P_{Q_A} can take on values between 0 and 1/2. In fact, it is easy to see that

$$P_{Q_A}(x) = \begin{cases} \frac{1}{2} - \frac{1/2}{(2\pi/2^N)} x & 0 \le x \le 2\pi/2^N \\ 0 & \text{otherwise.} \end{cases} \tag{13}$$

That is, the conditional probability of error drops linearly from 1/2 to 0 as the divergence angle increases to the length of the quantization interval $2\pi/2^N$; once above that value, the conditional error probability remains at zero. For the N = 3 case, we gave two examples in which the divergence angle was $a = \pi/8$, one yielding an error

probability of 0 and the other 1/2. In this new setting in which the absolute street rotations are considered random, we would have

$$P_{Q_A}(\pi/8) = \frac{1}{2} - [\frac{1/2}{2\pi/2^3}]\frac{\pi}{8}$$

$$= \frac{1}{2} - \frac{1}{4} = \frac{1}{4}.$$

Thus, streets whose divergence angles are one-half of the length of the quantization interval have a 50-50 chance of falling within the same quantization interval; given that they do, the conditional error probability is 1/2. The unconditional error probability is therefore $\frac{1}{2}\cdot\frac{1}{2} = \frac{1}{4}$, so our result checks with intuition.

Finally, utilizing each of the above concepts, the unconditional probability of vehicular loss at an intersection due to angular quantization is

$$P_{Q_A} = \int_{x=0}^{2\pi/2^N} \frac{1}{2}[1 - \frac{1}{(2\pi/2^N)} x] f_a(x)dx \quad (14).$$

This formula provides a relatively easy way for a city whose angular characteristics are summarized in $f_a(x)$ to compute vehicular loss probability (due to angular quantization) as a function of the number of bits given for angular information N.

2. Distance Quantization

In a manner paralleling angular information, distance information is also transmitted digitally, therefore necessitating a distance quantization interval d_Q. Thus, in a moving vehicle, if the odometer

reading has just changed (by adding 1 bit to the previous reading) then the next odometer change will occur after the vehicle has travelled a distance equal to d_Q. Clearly if d_Q is of the same order of magnitude as block lengths then this type of quantization could severely increase the loss probability. However, typically d_Q is 25 feet or less (at least one order of magnitude less than a typical block length).

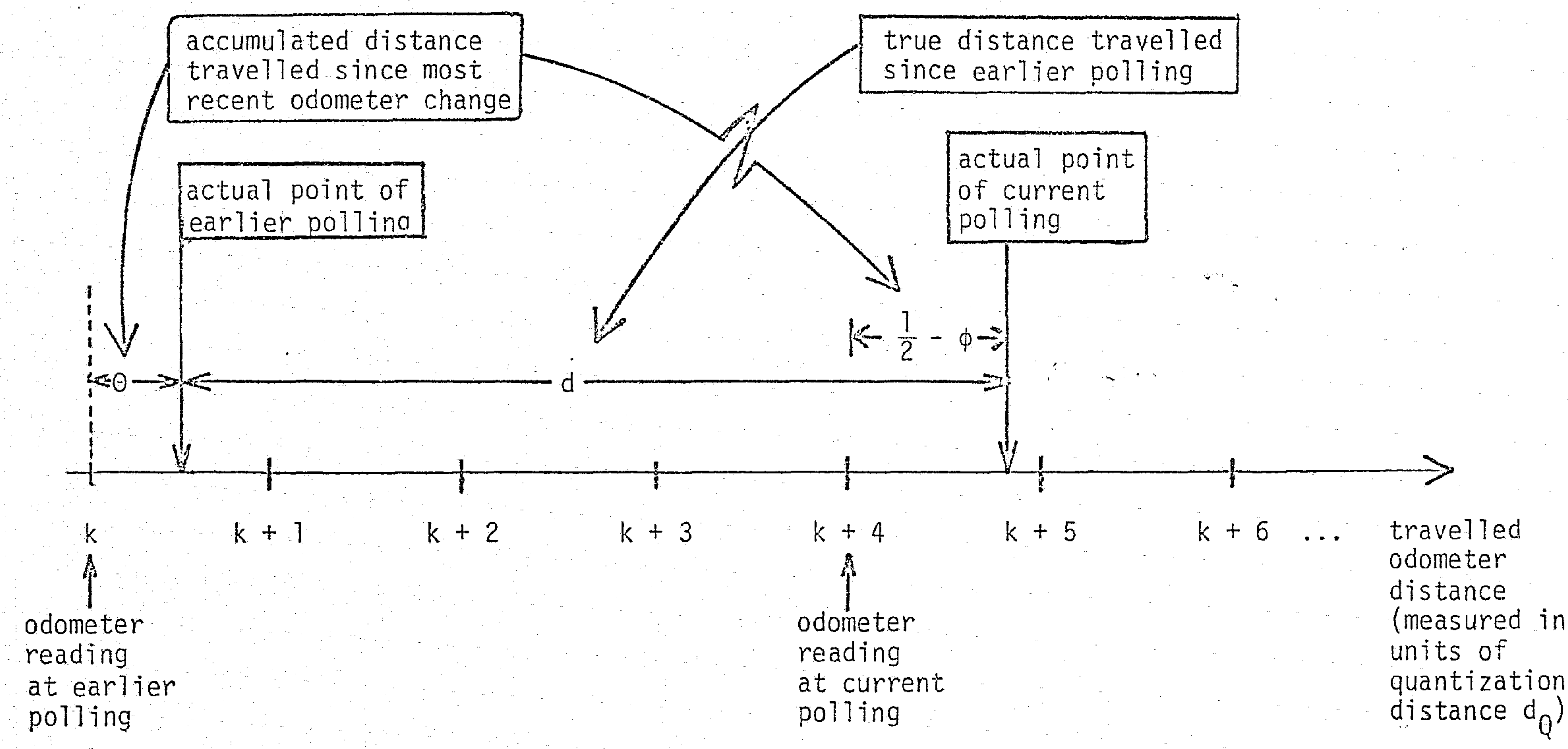
The overall effect of distance quantization can be understood by examining Figure 10. We focus on the current and an earlier polling of the vehicle. At the earlier polling the odometer reading is some (arbitrary) integer k. But at the actual point of polling the vehicle had travelled θ units (where distance is measured in units of quantization distance d_Q) since the odometer reading changed to k. (Obviously, $0 \leq \theta < 1$.) The uncertainty in the value of θ increases our uncertainty regarding the position of the vehicle. The vehicle then travels an exact odometer distance equal to d, at which point the current polling takes place. The odometer reading must be an integer, so we round down to the integer which represents the current odometer reading. The amount by which we round down is $\frac{1}{2} - \phi$, where $-\frac{1}{2} \leq \phi < \frac{1}{2}$. As we will see, this rounding off procedure also causes uncertainty in our estimate of the vehicle's location. Summarizing, the odometer reading of the vehicle between any two arbitrary* pollings is given by

$$\hat{d} = d + \theta + \phi - \frac{1}{2}.$$

*Assuming that the vehicle is moving, to avoid degenerate cases.

Figure A-10

Key Variables in Distance Quantization



The following assumptions regarding the two random variables θ and ϕ and the variable d seem reasonable:

1. θ is uniformly distributed between 0 and 1.
2. ϕ is uniformly distributed between $-\frac{1}{2}$ and $+\frac{1}{2}$.
3. θ is independent of the subsequent value of d.

Clearly, ϕ is dependent on $d + \theta - \frac{1}{2}$ since ϕ is determined by the non-integer part of the latter quantity.

The polling procedures are obviously unbiased since

$$E[\hat{d}] = d + E[\theta] + E[\phi] - 1/2$$
$$= d + 1/2 + 0 - 1/2 = d.$$

Thus d is an unbiased estimator of the measured odometer distance D.

Following the argument of Section II.1, the updated map center-line distance between any two pollings, given that the odometer has measured d units of travel, is

$$D(d) = \hat{d} + X(d)$$
$$= d + \theta + \phi - 1/2 + X(d),$$

where X(d) is the Gaussian error term of Section II.1.

Assuming $\sigma = 0$ (for convenience of presentation),

$$E[D(d)] = d,$$

as expected. However, we wish to compute the variance of D(d) to determine the manner in which the polling procedure adds to position estimation uncertainty at intersections at which the vehicle may turn. This variance is:

$$\sigma^2_{D(d)} = E[(d + \theta + \phi - 1/2 + X(d) - E[D(d)])^2$$

After some straightforward manipulation we obtain

$$\sigma^2_{D(d)} = \sigma^2_{X(d)} + \sigma^2_{\theta} + \sigma^2_{\phi} + 2E[\phi(X(d) + \theta - 1/2)].$$

As one can see, the uncertainty of vehicular position is increased over that due solely to random odometer error ($\sigma^2_{X(d)}$) by (1) the unknown odometer distance travelled since the most recent odometer change at the last polling (σ^2_{θ}), (2) the integer round-off procedure (σ^2_{ϕ}) and (3) the dependence of ϕ on the other variables.

Here, assuming d is at least a block length (which should be several units of distance--measured in terms of d_Q), we can assume that (approximately) ϕ is independent of $X(d) + \theta - 1/2$, thus reducing the above equation to

$$\sigma^2_{D(d)} \approx \sigma^2_{X(d)} + \sigma^2_{\theta} + \sigma^2_{\phi}.$$

Since $\sigma^2_{\theta} = \sigma^2_{\phi} \doteq 1/12,$

$$\sigma^2_{D(d)} = \sigma^2_{X(d)} + 1/6.$$

Since this derivation has been carried out in units of d_Q, if we switch back to feet (or some other absolute standard of distance) we obtain

$$\sigma^2_{D(d)} = \sigma^2_{X(d)} + d_Q^2 /6 \tag{16}$$

In practice we can use this result in a very simple and straightforward way. We invoke the facts that X(d) is a Gaussian random variable and that D(d) is the sum of random variables. Since usually $\sigma^2_{X(d)} > d_Q^2/6$, the Central Limit Theorem should apply quickly here, indicating that D(d) can be treated as a Gaussian random variable, having mean 0 and variance $\sigma^2_{X(d)} + d_Q^2/6 = d\sigma^2 + d_Q^2/6$.

Thus, applying this result to the two pollings associated with two successive turns, the increase in the vehicle loss probability at a random turn due to distance quantization could be estimated by adding $d_Q^2/6$ to the Weiner process variance ($\sigma^2 i$) in Equation (10).

To obtain an intuition for the numbers involved, suppose a turn occurs after 10,000 feet and suppose the Weiner process variance is $\sigma^2(10,000) = 2,500$ (as in the example in Section II.1.). Suppose further that the quantization interval is $d_Q = 25$ feet. Then $d_Q^2/6 = 625/6 \approx 104$. Thus the total variance of the estimated distance travelled is

$$\sigma^2_{\hat{D}}(1,000) = 2,500 + 104.$$

As can be seen even with this simple example, reasonably small values for the distance quantization interval d_Q should result in little degradation in system performance (as measured by vehicle loss probability). Note, however, that a larger quantization interval of $d_Q = 100$ feet would result in a significant increase of the total variance (from 2500 to 4166).

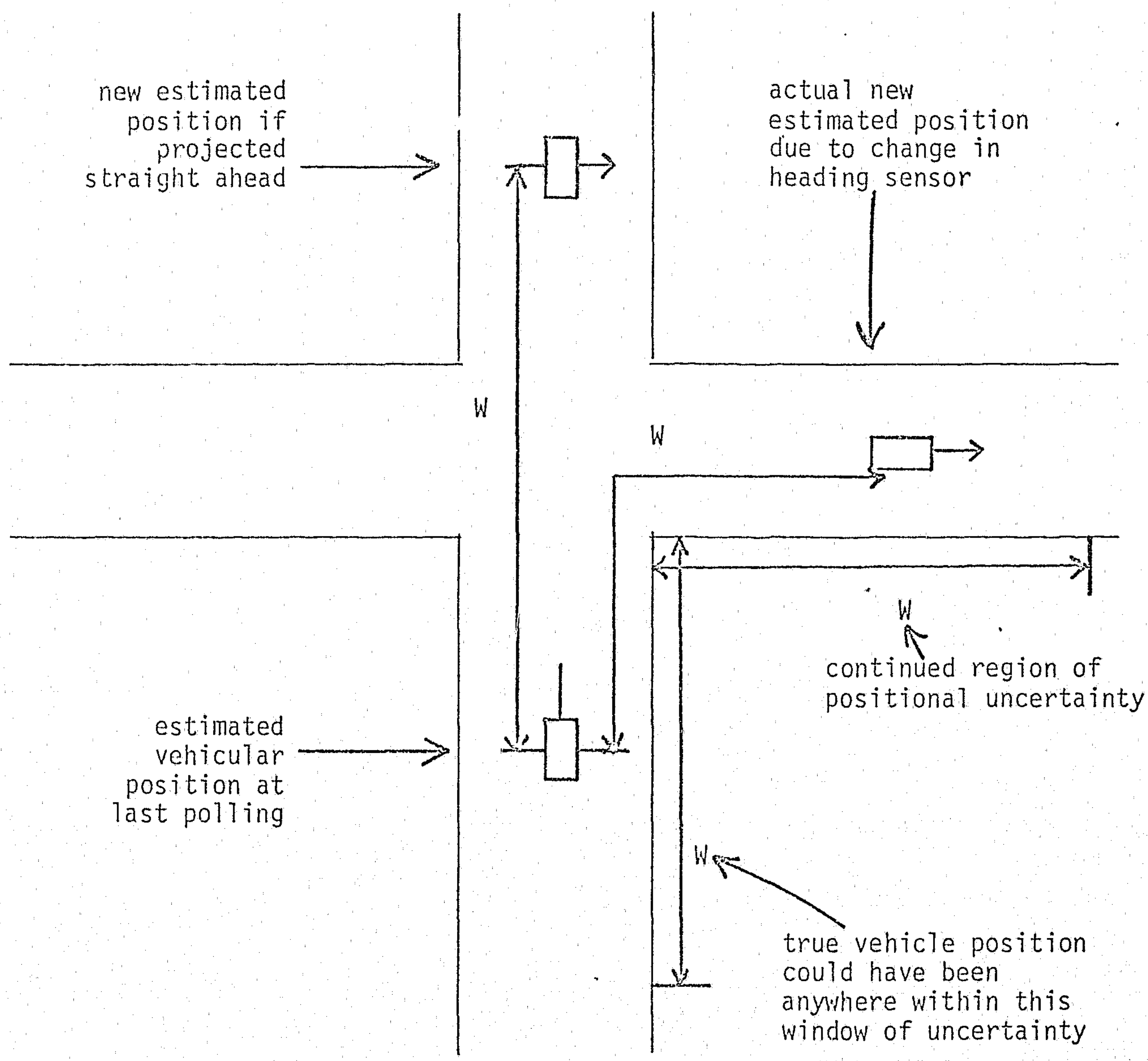
3. Time Quantization

Like angular and distance quantization, time quantization too causes additional uncertainty in the estimate of a vehicle's location and thus increases the loss probability p. The unit of time quantization is t_Q, which means the vehicle is polled every t_Q seconds to obtain new distance and heading readings. Typically t_Q is one or two seconds.

Time quantization's effect on positional uncertainty at a turn can

Figure A-11

Positional Uncertainty at a Turn
Due to Time Quantization



$$W = t_Q \cdot (\text{speed of vehicle})$$

be seen in Figure 11, at the last polling the vehicle was estimated to be south of the intersection, headed north. At the current polling, the unit has travelled a distance W, which is equal to the speed of the vehicle times t_Q, and its heading has changed from north to east. If the computer tracking algorithm simply projected the vehicle north a distance W, the vehicle would be on a north-south street headed east, an obvious inconsistency. Thus, the algorithm assumes that a turn has occurred and positions the vehicle a travel distance W from the last estimated position* but on the east-west street headed east away from the intersection. Assuming that this particular street is the correct street on which the vehicle turned, the fact that the heading sensor changed between pollings means that the turn could have occurred at any time during the time interval t_Q. Thus, since the vehicle travelled a distance W during t_Q, the actual position of the vehicle at the last polling could have been anywhere south of the intersection up to a distance W away. Thus, the new (current) position of the vehicle could be anywhere east of the intersection up to a distance W away. As a numerical example, if t_Q = 2 seconds and the vehicular speed = 30 mph = 44 feet/second, then W = 2·44 = 88 feet.

If we imagine the vehicle entering the region of the intersection with estimated location described by a Gaussian random variable with variance $\sigma_d^2 + d_Q^2/6$, then part of this uncertainty persists after leaving the intersection. In the worst imaginable case, yet assuming a correctly

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*This is one reasonable procedure for positioning the vehicle on the east-west street. Another, which has been utilized in FLAIR, is to position the vehicle exactly at the exit point of the intersection, heading east.

interpreted turn, the persisting positional uncertainty could be described as a uniformly distributed random variable over the west-east interval W (extending from the intersection). This gives the vehicle an initial variance in estimated position of $W^2/12$, rather than 0 as is assumed in the renewal theory model of Section III. Upon entering the next intersection where a turn is to take place, after travelling a distance d', the variance in the position estimate will be $W^2/12 + \sigma_{d'}^2 + d_Q^2/6$. For reasonably small values of t_Q, the addition to the variance due to W (which is proportional to t_Q) should not be very large.

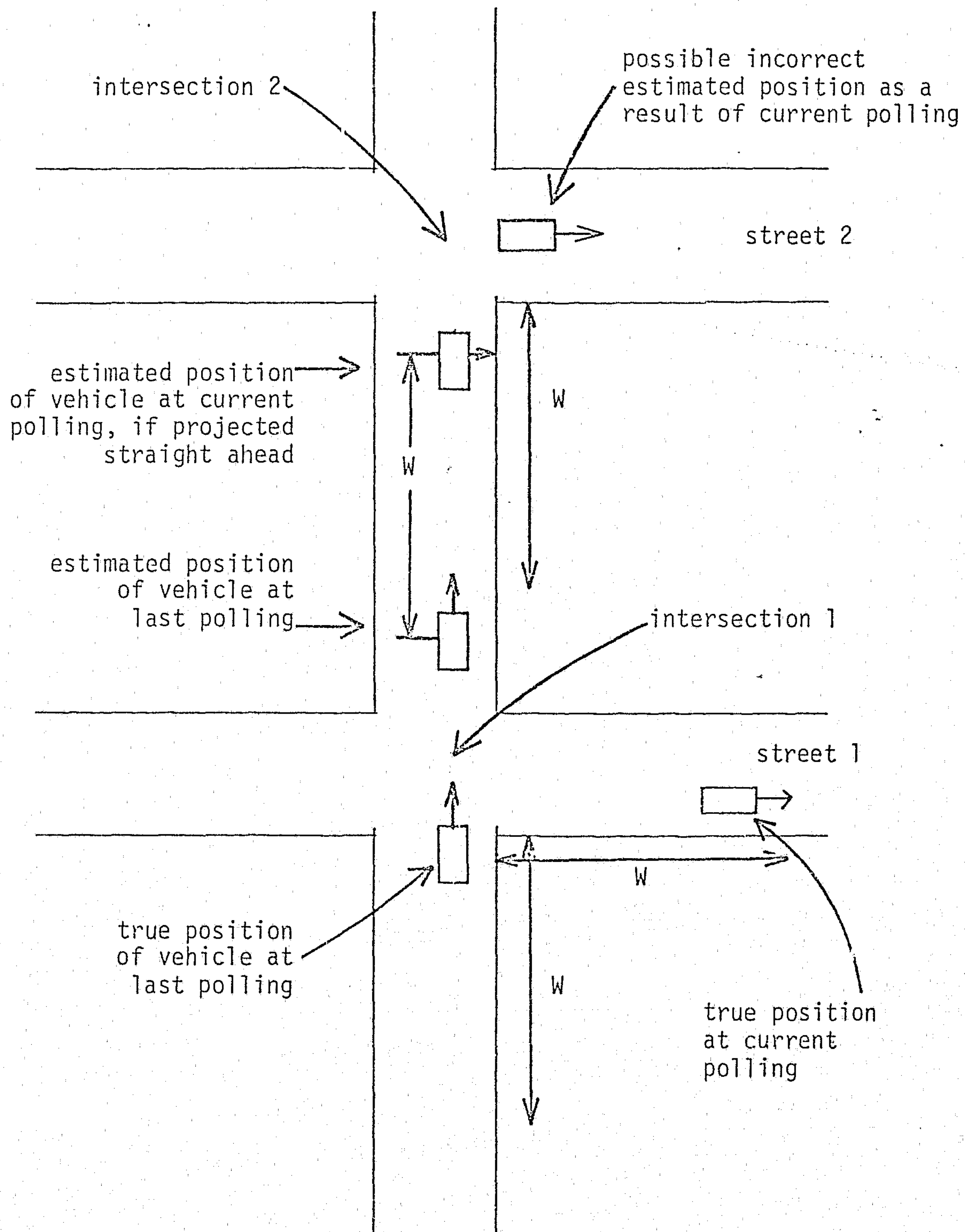
Additional insight on the effect of time quantization on loss probabilities can be gained by examining Figure 12. Here at the last polling the vehicle was just about to enter the intersection and execute a right turn. However, the estimated position of the vehicle was somewhat north of the intersection (heading sensor still reading north), perhaps one or two standard deviations from the mean (or perhaps nearer the mean in a system with systematic error). At the current polling the vehicle has travelled a distance W, and the heading has changed from north to east. Given that the vehicle has turned right, the computer tracking algorithm is confronted with a decision: Did the vehicle turn on street 1 (the first east-west street) or street 2? There are two alternative hypotheses: at the time of the last polling the vehicle was in the window of length W just south of either intersection 1 or intersection 2. For a vehicle such as this one which is estimated ahead of its actual position, the greater the value of W, the more likely it is that the computer tracking algorithm will choose (incorrectly)

intersection 2 (and thus street 2). This is due to the fact that as W increases the southern tip of the window of length W from intersection 2 gets closer to the last estimated position of the vehicle, while the window from intersection 1 (while getting larger) remains at a constant distance from this last estimated position. Thus, as W increases, it becomes more and more plausible that the vehicle was actually at the southern tip of the intersection 2 window rather than at the northern tip of intersection 1's.

Obviously, for fast moving vehicles moving on streets with relatively short block lengths (perhaps engaged in a criminal pursuit), these effects of time quantization could cause a measurable increase in vehicular loss probability.

Figure A-12

Possible Loss of Vehicle Due Directly to Time Quantization



V. Discussion

In this appendix we have developed several highly simplified models in order to analyze the factors that contribute to vehicle loss probability. Briefly summarizing, we have found the following:

(1) One component of vehicle drift from its true location is due to random error. This is due to many factors including tire slippage on streets, irregular (non-straight line) driving patterns, map errors, and, if uncorrected in the tracking algorithm, speed variations which change the tire circumference. This net effect of such random error is summarized in the parameter σ^2 which is the mean squared random displacement per unit of distance travelled.

(2) A second, often dominating component of vehicle drift is due to systematic error. This type of error creates a bias in the odometer readings and its magnitude is determined by temperature, tire wear and pressure, and speed (when the effect of speed on drift is viewed as correctable). The bias term is γ, which is the mean systematic displacement per unit of distance travelled.

(3) The vehicle loss probability will depend strongly on the particular street patterns of the city in question. In general the loss probability increases as the mean spacings between streets decreases, as the street pattern becomes more irregular (implying more very short blocks), and as the diverging angles at intersections become small (the definition of small depending on the number of bits used to transmit angular information).

(4) The number of binary digits (bits) used to transmit information on vehicular heading and distance can markedly affect vehicular loss probability. One can virtually

guarantee no increase in loss probability due to angular quantization if the corresponding number of bits N is sufficiently large so that $2\pi/2^N$ is smaller than the smallest diverging street angle in the city. The effect of distance quantization is to add to the variance of the random error a term proportional to the square of the distance quantization interval.

(5) The magnitude of the sampling interval (in time) can also affect the loss probabiilty. For those turns which are tracked correctly, the magnitude of the sampling interval determines the size of a window of positional uncertainty which characterizes the vehicle's estimated position until it next turns; this can often be crudely characterized as an increase in the variance of the estimate of position. However, the window of positional uncertainty can also have a direct effect on contributing to an incorrect interpretation of a turn; the larger the window [which means the larger the sampling interval], the larger is the probability of incorrect decision.

(6) In most cases we have developed simple equations to estimate at least the first order effects on vehicle loss probability of each of the key factors.

There are at least two important topics that also bear on system performance that have not been discussed in this appendix. The first is open loop tracking which occurs whenever the tracked vehicle leaves a mapped street or alleyway and enters a parking lot, an industrial property, etc. With open loop tracking, the tracking algorithm cannot use well-mapped street patterns to correct certain drifts in the vehicle's location. Thus, the estimation error becomes a two-dimensional error rather than a one-dimensional one. Moreover, angular, spatial, and temporal quantization can markedly increase the chance of losing a vehicle that is being tracked in the open loop mode. Recognizing the

extent of imperfect information received in the open loop mode, the tracking software in our currently implemented system automatically signals "Lost vehicle" as soon as the measured odometer distance in an open-loop situation exceeds some prespecified threshold value.

The second topic is system subvertability, which is defined as the susceptability of the system to deliberate acts aimed at increasing loss probability. These include reporting an incorrect address at time of "loss correction" (or "reinitialization"), momentarily switching off the power of the unit located in the vehicle. The system subvertability is increased by the presence of magnetic anomolies that create faulty (uncorrectable) heading sensor readings and the presence of intersections whose diverging street angles are sufficiently small so as to create a high chance of vehicular loss. This topic is discussed at greater length in Chapters V, XII of the main report.

Appendix B

MATHEMATICAL ANALYSIS FOR IMPLEMENTING MEAN TIME BETWEEN LOSSES MODEL

This appendix provides the mathematical underpinnings for those parts of Chapter V that are not specifically part of the "mean time between losses" model, which is derived in Appendix A. As an aid to the reader, the contents of the Appendix are sequenced in the same order in which they appear in Chapter V. It assumes that the reader is familiar with the contents of Chapter V.

1. Deriving an Unbiased Estimator for σ^2

In section B.3.d of Chapter V, Equation (3) is given for estimating σ^2, the mean square random displacement per unit of distance travelled. Recalling the definitions,

N = total number of test courses

d_i = actual length of i^{th} course, as computed by summing the lengths of the corresponding individual straight-line street segments of the computer map

D = total length = $\sum_{i=1}^{N} d_i$

$L(d_i)$ = measured length of i^{th} course (as measured by the odometer)

γd_i = systematic error term (bias), which must be subtracted from the measured length

$L(d_i)-\gamma d_i$ = unbiased measured length

Calling $\check{\sigma}^2$ the estimate for σ^2, the estimation formula is

$$\check{\sigma}^2 = \frac{1}{D} \sum_{i=1}^{N} (L(d_i) - \gamma d_i - d_i)^2. \qquad \text{(B-1)}$$

This estimate of σ^2 is an unbiased estimator.

Proof: By unbiased estimator, one means that the expected value of the estimator equals the expected value of the parameter being estimated, i.e.,

$$E\{\check{\sigma}^2\} = \sigma^2.$$

To prove this, write

$$E\{\check{\sigma}^2\} = E\{\frac{1}{D} \sum_{i=1}^{N} (L(d_i) - \gamma d_i - d_i)^2\}$$

$$= \frac{1}{D} \sum_{i=1}^{N} E\{(L(d_i) - \gamma d_i - d_i)^2\}$$

$$= \frac{1}{D} \sum_{i=1}^{N} (E\{L^2(d_i)\} - d_i^2(1+\gamma)^2) \qquad \text{(B-2)}$$

But the variance of the error accumulated over a distance d_i is

$$\sigma^2_{d_i} = E\{L^2(d_i)\} - E\{L(d_i)\}^2$$

$$= E\{L^2(d_i)\} - \{d_i(1+\gamma)\}^2. \qquad \text{(B-3)}$$

Substituting (B-3) into (B-2), we have

$$E\{\check{\sigma}^2\} = \frac{1}{D}\sum_{i=1}^{N} \{\sigma^2_{d_i} + d_i^2(1+\gamma)^2 - d_i^2(1+\gamma)^2\}$$

$$= \frac{1}{D}\sum_{i=1}^{N} \sigma^2_{d_i}$$

But the variance of the tracking position grows linearly with distance,

$$\sigma^2_{d_i} = d_i\sigma^2,$$

thus

$$E\{\sigma^2\} = \frac{1}{D}\sum_{i=1}^{N} d_i\sigma^2 = \sigma^2 \frac{1}{D}\sum_{i=1}^{N} d_i = \sigma^2.$$

This completes the proof.

In applying Equation (B-1), the accuracy of the estimation procedure tends to improve as the total distance D increases. This corresponds to increasing the sample size in discrete estimation situations, which in turn, decreases the variance of the estimator.

2. Extra Distance Travelled Due to Lane Switching

Here we derive Equation (4) of Chapter V, which estimates the extra distance (in feet) travelled per mile due to lane switching,

$$e = n^2w^2/10{,}560 \qquad \text{(feet)}, \qquad \text{(B-4)}$$

where

n = number of lane switches per mile

w = width of lane

The derivation assumes n is "large," say $n \geq 10$, and that switching occurs "smoothly." Suppose a vehicle is traveling along a two-lane roadway of length x, continually switching lanes, as shown in Figure B-1. Then, at virtually all times the vehicle is traveling at an angle θ to the direction of the roadway. If d is the total distance travelled by the vehicle while traversing a roadway length of x, then we have

$$x = d \cos\theta,$$

or

$$d = x/\cos\theta.$$

The extra distance travelled e due to the lane switching is

$$e = d - x = d(1 - \cos\theta).$$

Since θ is likely to be a very small angle, we use the small angle approximation for cosine,

$$\cos\theta \approx 1 - \theta^2/2 \qquad (\theta \text{ small}),$$

implying

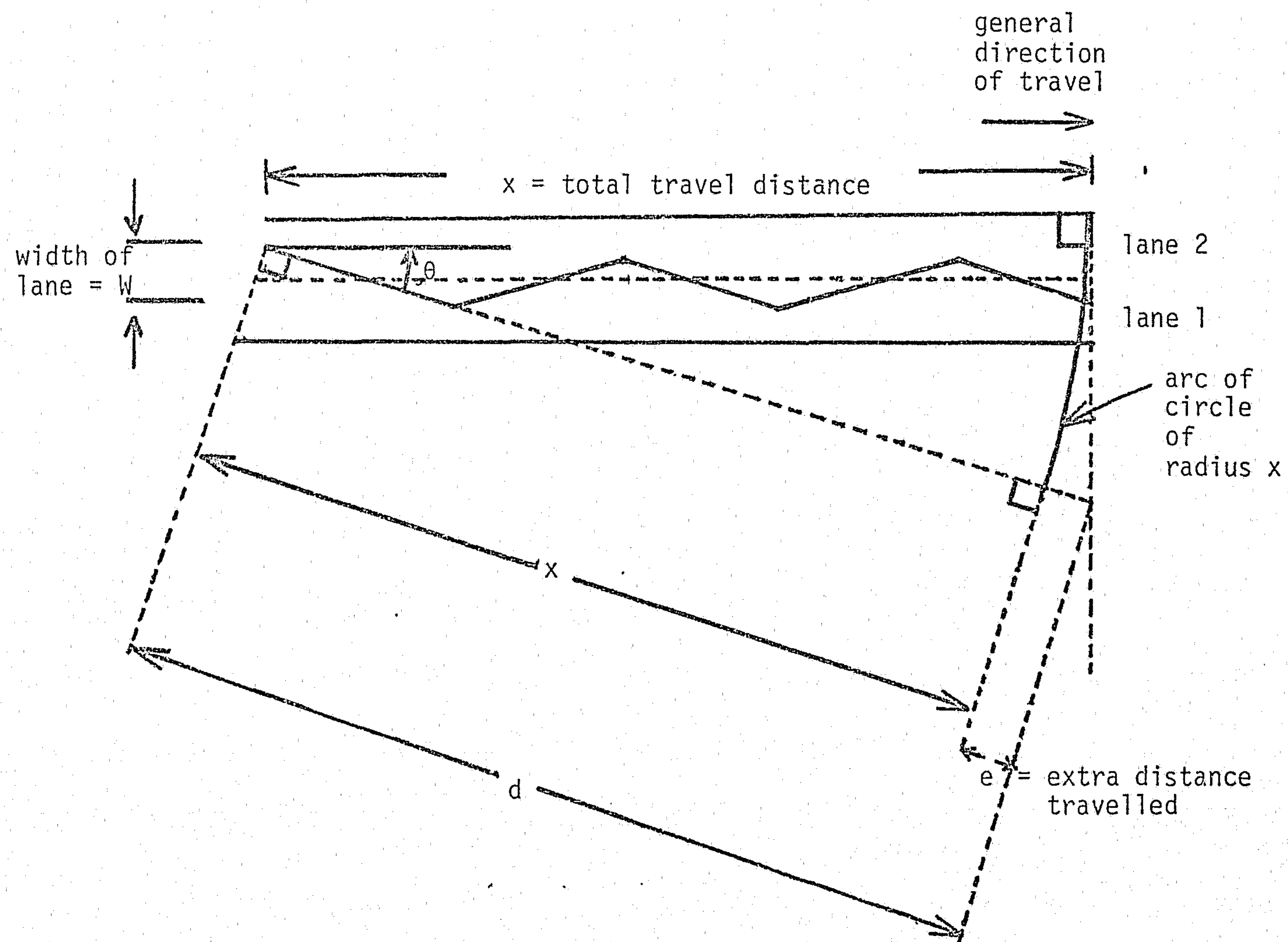
$$e \approx d\theta^2/2 \approx x\theta^2/2.$$

Suppose the vehicle makes n lane changes per mile and the width of a lane is w (feet). Then the vehicle's net travel distance perpendicular to the roadway is nw (per mile). This represents the length of the other leg of the right triangle shown in Figure B-1. Since for small θ, $\tan\theta \approx \theta$, we can write that angle θ is the ratio of the perpendicular distance travelled per mile to the length of the large leg of the triangle (per mile), which equals 5,280 feet; thus

$$\theta \approx nw/5{,}280.$$

Figure B-1

Simple Geometrical Depiction of
Exaggerated Lane Switching



Hence, the extra distance travelled per mile is

$$e = x\theta^2/2$$
$$= 5,280 \frac{n^2w^2}{2\cdot(5,280)^2}$$

or,

$$e = n^2w^2/10,560 \quad \text{(feet)}$$

This completes the derivation.

3. Simple Models of Mapping Inaccuracies

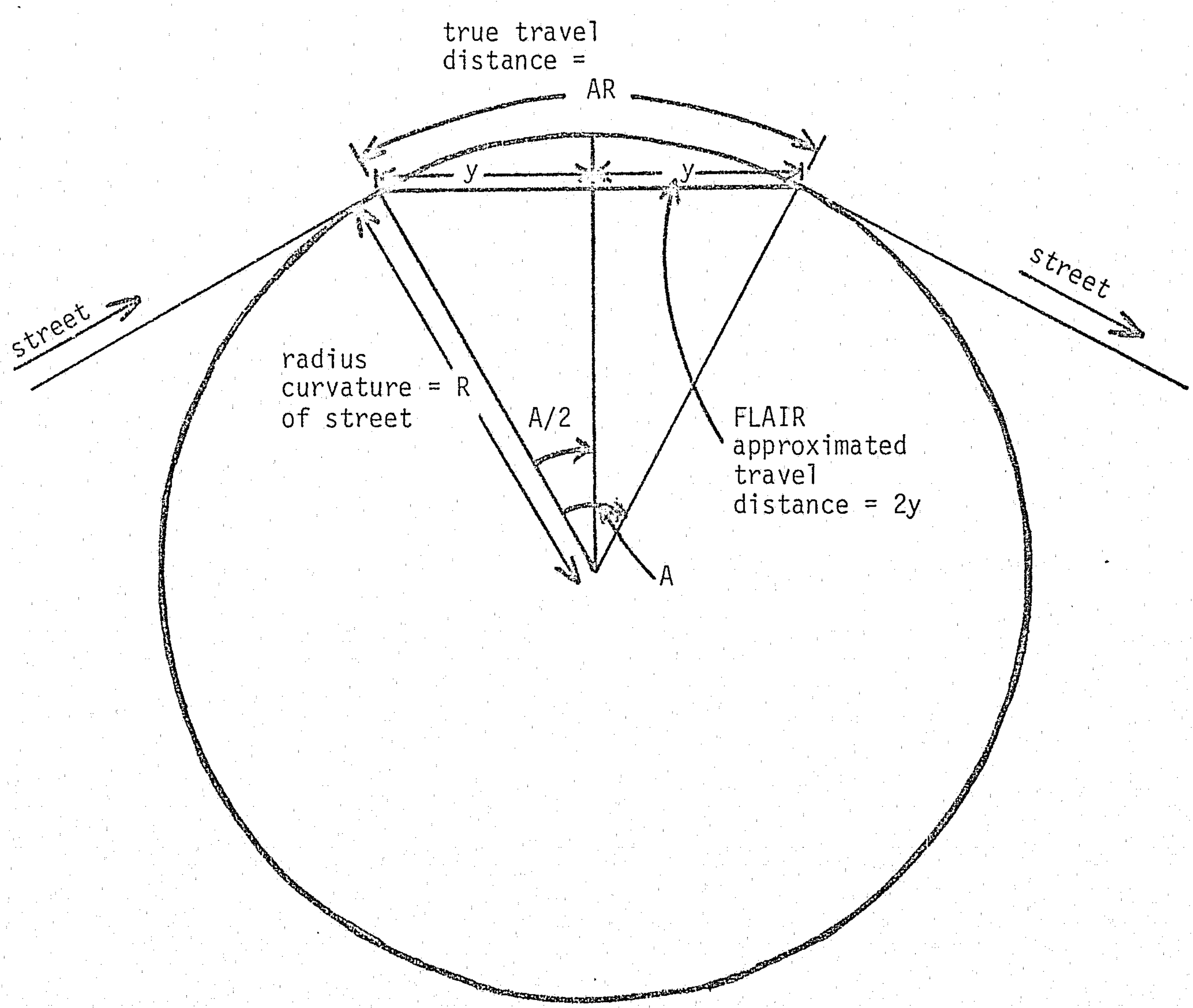
The following paragraphs develop several simple models used in Section B, 5b. of Chapter V to estimate the effects of distance estimation inaccuracies caused by straight-line segment maps.

Effect of Straight Line Approximations

By approximating a smoothly curving street by a sequence of connected straight line segments, one usually incurs errors in estimating the true distance travelled. A probable worse case is illustrated in Figure B-2 which shows a street that turns smoothly at a radius of curvature R (feet) through an angle A (radians). The true travel distance is the length of the arc of the circle that spans an angle A; this length is AR (feet). The estimated straight line distance is 2y = 2RsinA/2. If A/2 = 30° = $\pi/6$ radians, then 2y = 2R(sinπ/6 = 2R(1/2) = R. The true travel distance would be $(\pi/3)R \approx 1.0472R$, implying a distance estimation error of about 5 percent. If R = 2,000 feet, then the absolute error (in feet) would be about 94 feet in this case. This is sufficiently large so that it is unlikely that the FLAIR map incorporates such crude approximations to curving

Figure B-2

Effect of Straightline Approximation on Travel Distance Calculations



streets. Also, FLAIR positions the straight line segment in such a way as to leave approximately 50 percent of the segment on each side of the center line of the curving street. Still, it is highly plausible that errors in the 1-to-2-to-3 percent range could occur because of the straight line approximation method.

Effect on a One-Dimensional Model

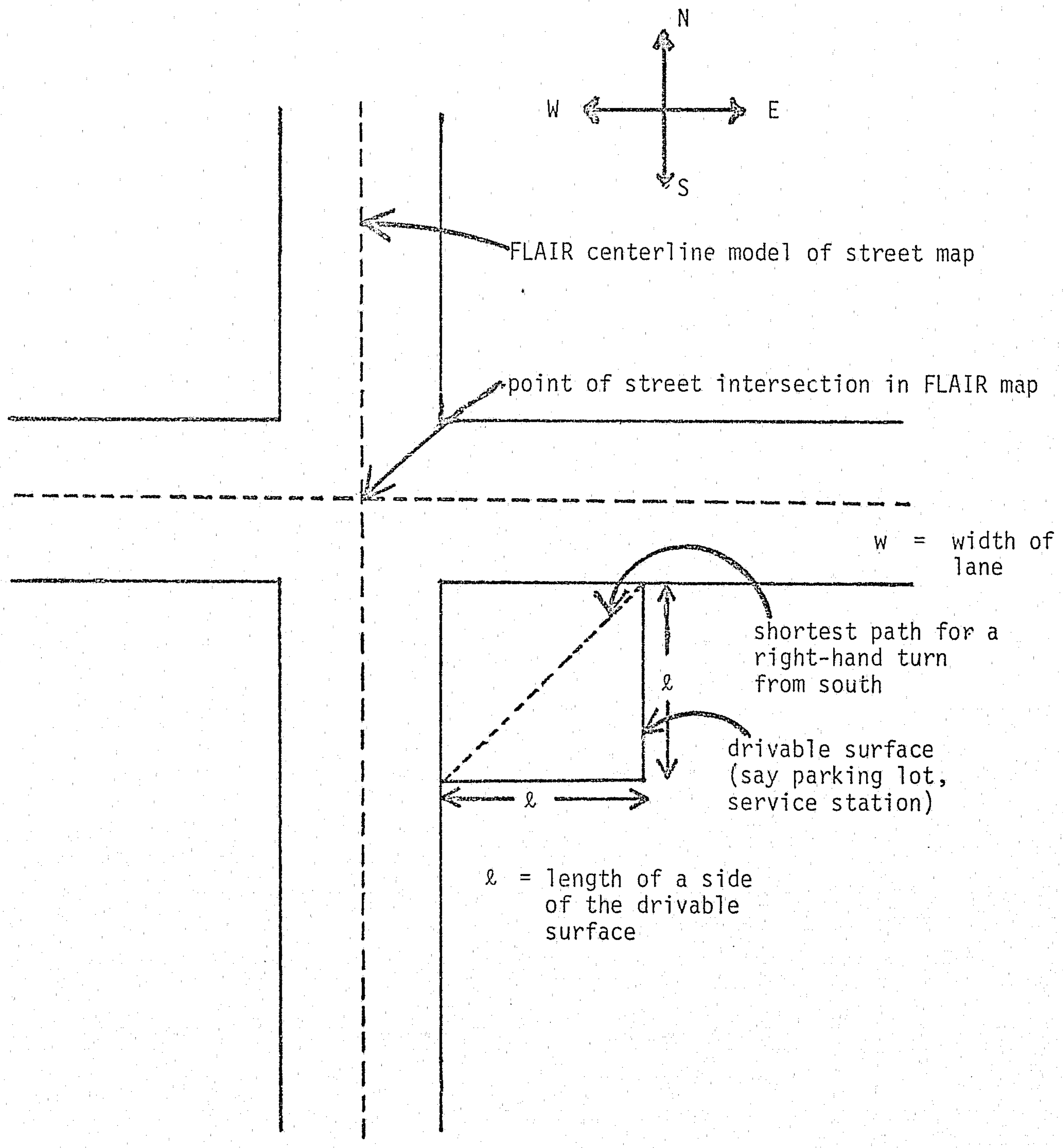
Since FLAIR models two-dimensional streets as one-dimensional entities, additional errors are possible. Here we consider again a street segment that has a radius of curvature (to the center line) R (feet), extending through an angle of A radians. Then the center-line travel distance is AR (feet). If a FLAIR-equipped vehicle travels this stretch of roadway at a radius of curvature $(R - \Delta)$, then the vehicle travels ΔA feet less than the center-line distance. Suppose $A = \pi/2$, $R = 1{,}000$ feet, and $\Delta = 20$ feet; then the centerline distance is $AR \cong 1{,}570$ feet and the long vehicle travels $\Delta A = 31.4$ feet less than the center-line distance. If the vehicle took a wide turn, 20 feet to the outside of the center line, then it would travel 31.4 feet more than the center-line distance. For this (not unreasonable) example, the error is near the 2 percent level. Naturally, a street with smaller radius of curvature (with all else constant) would yield higher percentage errors.

Corners

There are many different configurations for corners which could affect FLAIR accuracy, and we show a probable worst case in Figure B-3. Here, suppose a FLAIR-tracked vehicle is heading toward the intersection

Figure B-3

FLAIR Model of Street Intersection



from the south. At the southeastern corner of the intersection there is a square drivable surface (e.g., parking lot, service station) having area ℓ^2. Since the FLAIR computer models streets as straight line segments following, to the extent possible, the street center lines, the vehicle odometer distance when projected back onto the center line could yield significant positional error. For instance, the FLAIR distance from a point ℓ feet south of the intersection to a point ℓ feet east of the intersection is $2(\ell + w)$, where w is the width of a lane. If the vehicle, perhaps in pursuit, cuts across the drivable surface at a 45^0 angle, then the actual driving distance would be $\sqrt{2}\,\ell \approx 1.41\ell = 141$ feet, an error of 89 feet. Whether or not the entire error is perpetuated until the next turn, perhaps resulting in a lost vehicle, depends on the FLAIR positioning of the vehicle once a right-hand turn is detected by FLAIR (see also the section on quantization in Appendix A).

4. <u>Deriving a Lower Bound for the Turn Probability r</u>

In estimating the mean time between losses using Equation (1) of Chapter V, it is necessary to estimate r, the probability that a patrol vehicle will make a turn at a random intersection. Without collecting data, a particular city employing nonoverlapping beats can estimate a reasonable lower bound for r according to the following equation:

$$r \geq \frac{6}{\left(\begin{array}{l}\text{average number of street}\\ \text{miles/square mile}\end{array}\right)\sqrt{\begin{array}{l}\text{average beat}\\ \text{area (sq. mile)}\end{array}}} \qquad \text{(B-5)}$$

Such a lower bound is particularly useful since AVM system performance tends to deteriorate with lower turn probabilities, implying longer straight-line driving distances over which one-dimensional position estimation errors can accumulate.

Using data from Chapter V, the inequality given in (B-5) becomes

$$r \geq \frac{6}{(31.77)\sqrt{\frac{1}{2}}} \approx \frac{6(1.41)}{32} = \frac{8.46}{32}$$

or, roughly,

$$r \geq \tfrac{1}{4}$$

We now outline a model which argues the reasonableness of Equation (B-5).

Model

Consider a square beat of unit area with right-angle travel distances, and directions of travel parallel to the sides of the beat. Suppose the patrol unit traversing the beat (either as a result of random patrol or in response to a call for service) is travelling at a fixed value for x ($0 \leq x \leq 1$). Upon reaching some arbitrary value for y ($0 \leq y \leq 1$) the vehicle makes a 90^0 turn (in order to travel now in the x-direction). Invoking concepts of random patrol (or uniformly dispersed calls for service) it is likely that the unit will turn toward decreasing values of x with probability x and toward increasing values of x with probability (1-x). That is, the probability of turning in a particular direction is proportional (actually equal) to the "fraction of the beat on that side of the unit," an assumption which makes intuitive sense.

Given that the unit is travelling in a particular direction from x, say toward x=0, then a reasonable upper bound for the mean distance the unit would travel before turning again is x/2 (or (1-x)/2 for the case of travelling in the opposite direction). In other words, it is doubtful that the unit would travel an average of more than half the remaining straight-line distance within its beat before making a turn. Thus, given x, the mean x-distance that is travelled before again turning in a y direction is bounded above by

$\frac{x}{2}$ Prob {turns toward x=0/current position is x} + $(\frac{1-x}{2})$ Prob {turns toward x=1/current position is x}

which equals

$$\frac{x^2}{2} + \frac{(1-x)^2}{2}$$

But this behavior for the mean x-distance, given a value for x, is consistent with successive values of x being <u>independent and uniformly distributed</u>. Since this is true, then the expected x-distance between turns is 1/3 (beat length), as can be verified by integrating the conditional distance,

$$\int_0^1 1 \cdot \left(\frac{x^2}{2} + \frac{(1-x)^2}{2}\right) dx = 2\frac{x^3}{2 \cdot 3} \Big|_0^1 = \frac{1}{3}$$

By symmetry the same result holds for y-distances. The result can be stated intuitively as follows: <u>Following any particular 90° turn a patrol</u>

unit is not likely to average more than one-third of the patrol beat length before making its next 90° turn. This result is a correct upper bound for a uniformly positioned patrol unit responding to a uniformly (independently) distributed call for service; it allows the unit to make only one turn during route plus a turn following completing service at the scene of the call for service.

If we approximate the length of the side of a beat by $\sqrt{\text{beat area}}$, then the average straight-line distance travelled by the unit between successive turns is bounded above by $\sqrt{\text{beat area}/3}$. Now using arguments of Chapter V (section B. 6.), if there are η street miles per square mile, then we can assume that (roughly) $\eta/2$ street miles are parallel within the square mile, implying an average of $2/\eta$ (miles) between successive intersections. Combining the continuous model for travel distance with the discrete block length calculation, we find that (roughly) $\{\sqrt{\text{beat area}}/3\}/(2/\eta)$ is an upper bound for the number of blocks that are traversed (on the average) between successive turns. Using a result from Appendix A, $1/r$ is the mean number of blocks traversed between successive turns, so we must have

$$\frac{1}{r} \leq \{\sqrt{\text{beat area}}/3\}/2/\eta),$$

a result which obviously simplifies to Equation (B-5).

Appendix C

URBAN EMERGENCY SIMULATION: USER'S MANUAL

INTRODUCTION

This document is intended to serve as a user's manual for the Urban Emergency Service System Simulation developed by Public Systems Evaluation, Inc. (PSE) of Cambridge, Massachusetts, under Grant No. 75NI-99-0014 from the National Institute of Law Enforcement of the Law Enforcement Assistance Administration, Washington, D.C. This simulation model was developed by James C. Williamson of PSE under the overall direction of Dr. Richard C. Larson of M.I.T. and PSE. Extensive testing and debugging was performed by Mr. Mark A. McKnew of PSE.

This model was developed during the first half of 1975 and was subsequently used as part of PSE's evaluation of the Boeing Company's FLAIR Vehicle Location System as implemented at the St. Louis, Missouri Police Department.

This simulation consists of a package of interconnected PL/I programs. This package of programs is in the public domain and can be used by any individual or organization that wishes to do so. In future utilization of the program, we request acknowledgement of the supporting agency and documents which facilitate use of the model.

In designing the simulation, every possible attempt was made to retain compatibility with the hypercube analytical model as developed by Professor Larson under National Science Foundation Grant No. GI38004, "Innovative Resource Planning in Urban Public Safety Systems." Whenever possible, the input data format as well as the output formats are identical to those contained in the hypercube model. These formats are well documented in Reference 1. The potential user should obtain a copy of this reference and have it available for reference while reading this document. The minor changes which were made in the formats as described in Reference 1 are documented herein along with additions to the formats.

The user is also referred to Chapter 6 of Reference 2 for a very readable technical explanation of the mathematical model which was implemented as this simulation. Chapters VI and VIII of this report include a description of the motivation in generating the model, a comparison with previous simulation and analytical models, and a description of capabilities and features of the model. Also included as a part of Chapter VI is a description of the use of the simulation model in the evaluation of an implemented AVM System (Boeing's FLAIR) in St. Louis, Missouri.

This user's manual is organized as follows: Section 1 describes obtaining and implementing the model on various computer systems and a description of the author's experience with the model with sample execution times and costs. Section 2 describes the actual formats for the Input Data Set while Section 3 describes the output of the simulation. Section 4 demonstrates sample data deck and output. Section 5 provides a technical summary of program use.

1. USING THE SIMULATION

1.1 Obtaining and Installing the Simulation Model

As mentioned in the Introduction, this simulation program is in the public domain and interested parties can obtain a copy of the source programs. The simulation model is a set of five interrelated programs written entirely in the PL/I language. Although some of the initial work was performed using the IBM PL/I-F compiler, its high cost and inefficiency forced the author to switch all program development and subsequent use to the IBM Checkout and Optimizing Compilers. These two compilers are not standard IBM-supplied software but are classified as program products instead and are provided on a rental basis by IBM. Although a separate fee is required to obtain these programs, they are widely used and have a good reputation. The user of the simulation would have no need for the Checkout Compiler but it is recommended that, if possible, the user obtain access to the Optimizing Compiler for use with the simulation. This compiler will require a considerable one-time expense to compile the programs on the user's system, but will result in incredibly low execution costs for each run of the simulation.

It is the author's feeling that the source code, as supplied, can be directly compiled and executed "as is" on any IBM system using any operating system "higher" than DOS with the PL/I Optimizing Compiler installed. If the user desired to run the simulation with the PL/I-F compiler under the OS system, the only known changes would be to remove all pre-processor commands (statements being with a percent sign (%)),

and to remove the word REORDER from the first PL/I line in each program (the PROCEDURE statement). If the user desires to use the simulation with the IBM DOS PL/I-D compiler, the only known additional change would be to make the necessary alterations in the file declarations for the input file (SYSIN) and the output file (SYSPRINT). The user should be cautioned that these changes have not been tried. The author is confident, however, that if other changes are necessary, they would be minor and only a basic knowledge of PL/I, and no knowledge of the simulation algorithms, would be necessary. If any user finds that this is not the case, the author should be so notified.

1.2 Structure of the Simulation

The simulation was divided into five separate programs to ease debugging and to minimize the amount of memory required at any one time. There is very limited branching between programs so it would be a relatively easy matter to link-edit the program into an overlay structure with several phases, only one of which would be in memory at one time. The author's experience with the simulation was strictly on a large system with virtual memory and the simulation as implemented worked extremely well. It appears that the simulation is ideally suited to implementation on a virtual memory system. The five programs or phases of the simulation are as follows:

SIMIT	Main procedure (i.e., the simulation starts and ends with this.) All input and processing of the data base is accomplished in this routine except for one exception (see TRAVTM).

TRAVTM — Routine to calculate travel times. This phase is called by SIMIT before the actual event-paced simulation begins. The only I/O which is performed by this phase is the input of dispatch override commands if that option is used. When this routine is completed, execution is passed to PRTVAR.

PRTVAR — This routine is also called before the start of the actual simulation. Its function is to print tables indicating the values of variables which control the execution of the simulation as well as tables of travel times. Upon completion, control returns to SIMIT (via TRAVTM).

SIMGUTS — This routine, as the name implies, is the "guts" of the simulation. Once control passes to this phase it does not leave until the simulation is complete. The only I/O produced is that optionally printed under control of the simulation trace, dump and debug options. When this phase is complete, control returns to SIMIT.

CALCOUT — This routine calculates and prints the results of the simulation.

1.3 Costs of Running the Simulation

The costs of running the simulation are a function of the execution time and the core storage requirement. The core storage requirement depends largely on the number of response units and the number of geographical atoms. Virtually all arrays in the computer program have variable dimensions, their value depending on the number of response units, and the number of atoms. It is difficult to make an exact estimate of core storage requirements because all work to date has been in a time-sharing mode which requires considerable

overhead. However, it has been found that the simulation requires approximately 300k bytes on an IBM 370 for a small configuration of atoms and units. This could grow to as much as 500k for very large configurations. These figures could be reduced by using an overlay structure as mentioned in the previous section.

The charges for execution time arise from two sources: the actual execution time for running the simulation, and the charges to perform the I/O (process the input data set and print output results). The I/O charges are relatively independent of the length of the simulation but are a function of which options are requested and of the number of patrol units and the number of geographical 'atoms'. The execution time charges include a relatively fixed "start up" charge to load programs, establish the environment for the simulation, and perform all I/O. The rest of the charges should be an incremental charge which is strictly a function of the number of incidents generated during the simulation. Because the simulation is an event-paced model, the equivalent "simulation time" in hours has no direct effect on the costs of the simulation.

1.4 Author's Experience Implementing the Simulation

All initial testing and execution of the simulation was conducted on a nationwide time-sharing network owned by NCSS of Stamford, Connecticut. This system provides access to the IBM PL/I optimizing compiler on an IBM 370/168 using a virtual memory time-sharing system similar to MULTICS. The NCSS system proved to be a highly efficient system well suited to running the simulation. The author normally

created the input data base while on-line with the system and then submitted the actual run to be executed in the "overnight batch mode" which resulted in reduced charges.

A series of runs was conducted which included a relatively large geographical area (96 atoms), and a large number of units (19 units). The costs were as follows:

316 incidents	Total cost = $4.30
1,600 incidents	Total cost = $6.95

Rough calculations yield a start-up or overhead cost of $3.67 and an incremental cost per incident of approximately 2/10th of a cent. Some savings of the overhead costs could be accomplished by limiting the quantity of printing of that data which would not change from run to run, such as the inter-atom travel times, etc. Once this printout was obtained, the option controlling it could be "shut off." If a user was going to use a constant geometry in a large number of runs, it would be a relatively straightforward programming task to store that geometry and the resulting travel time matrices in an on-line file. However, the user may decide that the cost per run is so low that it would not be cost effective in terms of programmer time and recompilation costs to make that change. The costs mentioned here are for a commercial rate from a profit-making time-share organization. Obviously, the costs would be dramatically less on an in-house or university system if one is available.

2. INPUT DATA SET

The input data set provides the various variables and parameters that control the execution of the simulation. In a batch mode version this data would be provided as card input. In a time-sharing form, this data set would be established as a data file. As mentioned in the Introduction, this input data follows the conventions established by Dr. Richard C. Larson for the hypercube program, which is documented in Reference 1.

The simulation was designed such that the input data deck for the hypercube would work "as is" for a run of the simulation. However, because certain other information is vital to running the simulation, using a hypercube data deck would most likely provide a meaningless simulation. However, a hypercube data set is indeed a subset of the data required for the simulation (with only minor changes).

Note that in all of the explanations to follow that anytime alphabetic characters are used (except when followed by an equal sign) they must be included within single quotes (i.e., apostrophe). For example:

'SERVTIME'   'BYPRIORITY'   NPRI=3   'FCUN'

2.1 Changes in Hypercube Formats

Changes in Card Type #1

A value of ESTSTAT=3 indicates a simulation run. This value of ESTSTAT is assumed as the default by the simulation so it does not have to be provided. However, if ESTSTAT does appear on the first card,

it must have a value of 3.

An additional variable has been added to the first card. This is NPRI which indicates the number of different priority levels for calls. For example, if there are to be three priority levels, the following should appear on the first card: NPRI=3. A value of 1 is assumed as the default.

Changes in Card Type #7

An addition has been made to the dispatch options available in the simulation. In the hypercube the following options are presently allowed: SCM, MCM, ESCM, and EMCM. This new option is AVM, which stands for Automatic Vehicle Monitoring and causes the simulation to dispatch units using a zero resolution vehicle location system.

2.2 Additional Card Types for Use with the Simulation

SERVTIME

This option allows the user to specify the service time for each priority call. To retain compatibility with the hypercube, the simulation uses the service time specified by the SERVTM card. If the SERVTIME card is not present, the simulation will use the service time specified in the SERVTM card for all priorities of calls. Two options are available with the SERVTIME card:

a. UNIFORM (card should read: 'SERVTIME' 'UNIFORM')

   This assumes a uniform service time for all calls as specified in the SERVTM card. This is the default.

b. BYPRIORITY (card should read: 'SERVTIME' 'BYPRIORITY' w x y ... where w x y ... indicate NPRI numbers)

This option implies different service times by priority. The first number indicates the fraction of system service time (as specified by SERVTM card) for calls of priority 1, the second number is for priority 2, etc. These numbers can be any positive number including numbers greater than 1.

Fractions of Calls for Service Within Each Atom by Priority

a. FCUN (Fraction of Calls Uniform)

This option specifies that the fraction of calls for service is uniform for all priorities within each atom.

b. FCCW (Fraction of Calls City-Wide) (card should read 'FCCW' w x y ... where w x y ... indicate NPRI numbers)

This option must be followed by NPRI numbers each specifying the fraction of calls by priority throughout the city. The sum of these NPRI numbers must be 1.0 (e.g., for 3 priorities: 'FCCW' 0.3 0.5 0.2). This distribution will be used for all atoms.

c. FCAT (Fraction of Calls by ATom) (card should read 'FCAT' a b c d ... where a b c d ... indicate NPRIxR numbers)

This option allows the user to specify the exact fraction of calls by priority for each atom. Normally this option would not be used unless the distribution is available from empirical data. The form of the data following this card should be as follows: the first NPRI numbers are the fractions (which must sum to 1) for Atom 1, the next NPRI numbers are the fractions (which must sum to 1) for Atom 2, etc.

DISPOL (DISpatch POLicy)

This option allows the user to specify the dispatch policy as regards restriction to home sectors. The three sub-options are:

a. RESTRICT (card form should be: 'DISPOL' 'RESTRICT')

This option specifies that all dispatches must be made to a unit which "contains" the atom where the call originates. This could be called: "same sector dispatching."

b. NORESTRICT (card form should be: 'DISPOL' 'NORESTRICT')

As the name implies, this option specifies that there should be no restriction as to sector for any dispatching.

c. BYPRIORITY (card form should be: 'DISPOL' 'BYPRIORITY' w x y ... where w x y ... are NPRI numbers which indicate the policy for each priority)

This option allows the user to specify the dispatching policy by priority. Each priority is specified by the word RESTRICT or NORESTRICT. For example, if there are three priorities and the user desires to have no restriction of priority 1 and 2 calls but to queue all priority 3 calls until the sector car is available, this card should read:

'DISPOL' 'BYPRIORITY' 'NORESTRICT' 'NORESTRICT' 'RESTRICT'

QUEDIS (QUEue DIScipline)

This option allows the user to specify the queue discipline for the simulation. There are four suboptions:

a. FCFS (First Come First Served) (card form should be: 'QUEDIS' 'FCFS')

This option specifies the first-come/first-served queue discipline for all priorities. Note that, as documented in Reference 2, this specifies the oldest waiting call among those calls which are first in queue by each priority.

b. CCCC (Closest Car Closest Call) (card form should be: 'QUEDIS' 'CCCC')

This option specifies that when a unit completes an assignment that it should be assigned to the call which is closest (i.e., minimum travel time) regardless of the call's priority or length of time in queue.

c. NOQ (NO Queue) (card form should be: 'QUEDIS' 'NOQ')

This option specifies that no queue of calls is to be maintained for any priority.

d. BYPRIORITY (card form should be: 'QUEDIS' 'BYPRIORITY' w x y ... where w x y ... are the NPRI suboptions which indicate the policy for each priority)

This option allows the user to specify different queue disciplines for each priority. The queue discipline for each priority is specified by one of the options above: FCFS, CCCC or NOQ. For example, if four priorities are used and the highest priority should be handled by the first-come/first-served queue discipline and there should be no queue for lowest priority calls, and intermediate priorities should be handled by the closest-car/closest-call policy, the card form would be:

'QUEDIS' 'BYPRIORITY' 'FCFS' 'CCCC' 'CCCC' 'NOQ'

An even more specific queue discipline can be specified by using this option in conjunction with the weighted distance metric (see option 'DISMET').

DISMET (DIStance METric)

This option allows the user to specify the use of a distance metric for use in the dispatching policy. This is documented in Reference 2. There are two options:

a. STRICT (card form should be 'DISMET' 'STRICT')

This specifies that a strict (i.e., non-existent) distance metric should be used. This is the default.

b. WEIGHTED (card form should be 'DISMET' 'WEIGHTED' w x y ... where w x y ... are the NPRI weights)

This specifies the use of a weighted distance metric. The weight for each priority is specified exactly. The use of this option is complicated; the user is referred to Reference 2.

MAXTRAV (MAXimum TRAVel time restriction)

This option allows the user to specify a maximum travel time restriction for each priority type of dispatch interrogation. The default is 999 minutes; in other words, no restriction. There are two suboptions:

a. UNIFORM (card form is 'MAXTRAV' 'UNIFORM' w where w is the maximum travel time to any call for any interrogation)

This suboption specifies a uniform maximum travel time (in minutes) for all priorities and for each dispatch interrogation.

b. DETAIL (card form is 'MAXTRAV' 'DETAIL' a b c d ... where a b c d ... are 3xNPRI numbers)

This option allows the user to specify exactly each of the 3xNPRI values of the RAD array. This array is documented in Reference 2 (except the simulation uses travel times where Dr. Larson used distance), but briefly is: the first NPRI values are the maximum travel time for each priority for the initial dispatch of a call to a unit presently on preventive patrol. The next NPRI values are the maximum travel times for each priority for the reassignment interrogation for a unit still at the scene of his previous assignment. The last NPRI values are the maximum travel times for each priority for the reassignment interrogation when the unit has resumed preventive patrol.

SIMTIME (total SIMulation TIME) (card form is 'SIMTIME' x where x is in minutes)

This option specifies the total simulation time in minutes, which should be specified for each run. The default value is ten minutes which would in most cases result in a meaningless simulation.

DUMPTIME (status DUMP TIME) (card form is DUMPTIME' x with x in minutes)

This option specifies the length of time in minutes between status dumps. It is independent of the use of the TRACE option, although the two would normally be used together. The status dump gives the status of each unit as well as the list of calls waiting in queue. The default value for this is infinity, indicating no status dump. If the user specifies a value for DUMPTIME less than SIMTIME (total time of the simulation), a final status dump is automatically given when SIMTIME is reached, even if SIMTIME is not a multiple of DUMPTIME.

DEBUG (DEBUG flag)

This option performs the identical function as putting DEBUG=1 on the first data card in the hypercube format. However, to use this option only the single word 'DEBUG' need be included somewhere in the input data base.

TRACE (simulation TRACE control flag)

Including the word TRACE on a data card will cause a detailed trace of the simulation to be included in the simulation output.

PPP (Preventive Patrol Priority) (card form is 'PPP' a b c d ... where a b c d ... are M numbers)

This option is followed by M values which indicate the priority assigned to each unit when on preventive patrol. This value would indicate the highest level priority (lowest number) to which that unit could not

be dispatched. For example, if four priorities were being used, a response unit with a preventive patrol priority of three could only service calls of priority one or two. The default for this option is 99, indicating that each unit can be dispatched to any priority call.

Preemption Control Variable

This option controls preemption of calls during dispatching. The two suboptions are:

a. NOPREEMP (NO PREEMPtion is allowed)

This specifies no preemption is allowed.

b. PREEMP (PREEMPtion allowed) (card form is 'PREEMP' w x y ... where w x y ... are NPRI numbers)

This variable indicates that preemption of calls is allowed. The word PREEMP must be followed by the NPRI values of the PREEMP array. This array is documented in Reference 2, but in brief, PREEMP (I) is the least priority which cannot be preempted by a call of Priority I.

SAME-ATOM (SAME-ATOM dispatch restriction) (card form is 'SAME-ATOM' w x y ... where w x y ... are NPRI suboptions)

This option allows the user to specify by priority that all calls are restricted to units currently in the same atom as the call. Because the purpose of this option is to allow a means of modelling self-initiated incidents, it normally would be used in conjunction with the NO Queue ('NOQ') option of the queue discipline. This option is not mutually exclusive with other dispatch policies such as same-sector restriction.

The legal suboptions are YES and NO, indicating whether that priority is restricted to the same atom (YES) or whether there is no atom restriction (NO). For example, if there is same atom restriction only for the lowest of four priorities, the card form should be:

'SAME-ATOM' 'NO' 'NO' 'NO' 'YES'

CPH_FOR_SI (number of Calls Per Hour FOR Self-Initiated Activities) (card form is 'CPH_FOR_SI' x, where x is the number of calls per hour)

This option makes the assumption that the lowest priority of calls (that is, the highest number, equal to NPRI), is dedicated to self-initiated activities. Normally this option would be used in conjunction with the NOQ and SAME-ATOM options previously documented. The user should be cautioned that although the calls are generated separately from "normal" calls, they are generated in the same manner (that is, the atom is selected randomly, then the search is made for an available unit). Normally, this will mean that the number of calls per hour specified must be a considerably higher rate of calls per hour than will actually be dispatched as a self-initiated incident. The rate will most likely have to be determined by trial and error as it is based on a combination of the size of the force, number of geographical atoms, workload, and other simulation options in effect.

PRINT (controls simulation PRINTed output) (card form is PRINT n w x y ... where n is the number of suboptions specified, and w x y ... are the n suboptions)

This option allows the user to selectively specify which items will be printed when the simulation is run. Each option is independent

and the resulting printout will be a composite of all items specified. Note that because of their position in the original hypercube code, there are certain items which are always printed. These are the title block, giving the number of units, atoms, and priorities, etc. and certain "special printouts" which occur when the options RERUN or DEBUG are used. In addition, the TRACE and STATUS DUMP printouts are controlled by separate options.

The legal suboptions and their functions are:

TTAA	Travel Time Atom to Atom
TTUA	Travel Time Unit to Atom
COST	"COST" of Dispatching Matrix
SAWA	Spatial Allocation While Available
CFSD	Call For Service Distribution by Atom
STMA	STreet Miles per Atom
SIMV	SIMulation Variables
OSUM	Output SUMmaries
OUNT	Output Specific to Each UNiT
ODIS	Output Specific to Each DIStrict
OATM	Output Specific to Each AToM
OWBP	Output Workload By Priority
OSIM	Output Unique to SIMulation

PRI-SPEED (fraction of full SPEED by PRIority) (card form is 'PRI-SPEED' w x y ....where w x y ... are NPRI numbers)

This variable gives the fraction of full response speed (as specified on the 'SPEED' card) for each priority. The number for each

priority can be any positive number including a number larger than 1.

3. SIMULATION OUTPUT

As was the case with the Input Data Base, all output of the hypercube is provided by the simulation and is, in effect, a subset of the total simulation output. The output of the simulation is of three types: 1) output of the control parameters which is printed after reading the Input Data Base and before the start of the actual simulation, and 2) output generated during the execution of the simulation, and 3) output calculated after the simulation is completed. An example of each type of output is included in Section 4.

In the summary which follows, the suboption of the 'PRINT' option which controls printing of that particular output is enclosed in parentheses. If no suboption is specified, that particular output is always printed.

3.1 Output of the Control Parameters

This group includes those outputs which are printed prior to the actual execution of the simulation.

a. The first section of output is in the form of the hypercube output. The only change in the first block (which begins with the run title) is that the service times and numbers of calls per hour and per service time unit are calculated from simulation output rather than from the input parameters. What in the hypercube says, "Average Utilization Factor," now says, "Theoretical Average Utilization Factor" followed by the line "Simulated Average Utilization Factor."

b. Two special outputs are then generated by two special options, only when they are used. These options are DEBUG and RERUN.

c. (TTAA) Atom to Atom travel times

d. (TTUA) Travel times, each unit to each atom

e. (COST) "Cost" of dispatching matrix, each unit to each atom

f. (SAWA) Spatial allocation when available. (indicates preventive patrol area for each unit)

g. (CFSD) Call for service distribution by atom

h. (STMA) Street miles per atom (as read-in by 'PATROL' option)

i. (SIMV) Simulation variables. This option prints a listing of simulation variables used in the current run. In addition, it includes a few lines in the hypercube format. These lines specify the type of dispatching strategy used, and any special conditions on the dispatching order.

In addition, the following items are printed:

1. Mean Service Times
2. Geographical Distribution of Calls by Priority
3. Cross-Beat Dispatching Policy
4. Same-Atom Dispatching Restriction
5. Queue Discipline Policy
6. Distance Metric
7. Preventive Patrol Priority
8. Call Preemption Policy
9. Maximum Travel Time Restriction
10. Total Simulation Time

The output under each of these ten titles is generated in a type of tree logic analogous to that used to read in the corresponding data.

3.2 Output Generated During Execution

Three types of output can be generated during the execution of the simulation. These are status dumps, trace, and debugging

information. Each of these can be turned on or off by using the control variables: DUMPTIME, TRACE and DEBUG as discussed in the Input Data Section.

Status Dump

The format of the status dump is self-explanatory, giving a summary of unit numbers, geographical location (atom number) and status. The status consists of an abbreviation indicating the current status of the unit ("PREV. PAT." or "CALL - PRIOR 2", etc.). A list is also generated of any calls for service waiting in queue with their location, time placed in queue, priority, and projected service time. This list is in a decreasing priority by time of arrival order.

Trace

The simulation trace summarizes each step in the simulation in a self-explanatory format. The new user of the simulation should be aware of the fact that if a unit returns to his home sector and hence preventive patrol, and is then reassigned to a waiting call, this will appear in the trace output as two separate items, an assignment to preventive patrol followed immediately by a reassignment. No equivalent simulation time will have elapsed between these two events.

Debugging Information

The debugging information produced by the DEBUG option is voluminous and of no use to anyone except someone attempting to make changes in the simulation code itself.

3.3 Output Calculated After Completion

The following documents that output generated after the simulation is completed.

a. (OSUM) Simulation Output Summary

The following is calculated and printed:

1) Percentage of dispatches which were non-optimum
2) Mean extra travel time due to non-optimum dispatches
3) Mean number of calls in queue when call arrives (by priority)
4) Mean length of time in queue (by priority)
5) Percentage of calls preempted (by priority)
6) Mean travel time to all calls (by priority)

b. (OUNT) Performance measures that are specific to each patrol unit. This gives unit name, number, fraction and percent of mean for workload, fraction and percent of mean for out-of-district dispatches, and average travel time.

c. (ODIS) Performance measures that are specific to each district. This gives: district name and number, fraction and percent of mean for workload, fraction and percent of mean for number of dispatches into each district that is inter-district, and mean travel time.

d. (OATM) Performance measures that are specific to each atom. This gives: atom number, atom workload, travel time for calls into each atom, fraction of calls into each atom by each patrol unit, and, optionally, the frequency of preventive patrol passings per hour.

e. (OWBP) Workload by priority for each patrol unit. This gives the workload and number of calls (enclosed in parentheses) for each patrol unit by priority of call.

f. (OSIM) Additional output unique to the simulation. This includes: statistics on non-optimum dispatches, number of calls not serviced due to no-queue option, mean number of calls in queue when call arrives, mean length of time in queue, percentage of calls preempted and mean travel time to all calls by priority.

4. SAMPLE DATA DECKS AND OUTPUT

4.1 Sample Data Decks

Because the input data deck for the simulation is essentially a "super set" of that required for the hypercube, the user is referred to Tables 6.4 and 6.7 in Reference #1 for four examples. The only changes necessary to use these decks with the simulation would be to either change the value of ESTSTAT to 3 or to eliminate that variable from the first card (the default value is 3 so it is not necessary to include it). The user would also want to replace the 'RUN' 2.88 2.88 card with one just listing 'RUN' (because the starting and incremental call rates are meaningless to the simulation). Any other parameters which are unique to the hypercube (such as 'CAP' and 'VAR_SER_TM') would be ignored by the simulation and hence could be left in the deck if desired. The user would also want to include the equivalent simulation time. For example, 'SIMTIME' 600 would indicate an equivalent simulation time of 600 minutes (10 hours).

The user is referred to Table 4.1 for an additional example of an input data deck. This example is an unusually large data deck used in the study of the Boeing FLAIR system in St. Louis, Missouri (see Introduction). Besides illustrating a number of advanced hypercube features, this deck illustrates many of the advanced features of the simulation as well. Some of these are discussed below.

Figure 4.1 - Sample Input Data Deck

```
NUM=1, M=19, R=96, NPRI=4;
'GLOSSARY'
R_UNIT='POLICE VEHICLE' ATOM='PAULY BK'
NM_DIST(15)='CRUISER1' NM_DIST(16)='CRUISER2' NM_DIST(19)='STACK'
NM_DIST(1)='3322' NM_DIST(2)='3323' NM_DIST(3)='3324' NM_DIST(4)='3325'
NM_DIST(5)='3326' NM_DIST(6)='3327' NM_DIST(7)='3328' NM_DIST(8)='3330'
NM_DIST(9)='3331' NM_DIST(10)='3332' NM_DIST(11)='3333' NM_DIST(12)='3334'
NM_DIST(13)='3335' NM_DIST(14)='3336' NM_DIST(17)='3341' NM_DIST(18)='3342'
NM_UNIT(15)='CRUISER' NM_UNIT(16)='CRUISER' NM_UNIT(19)='STACK'
NM_UNIT(1)='BEAT CAR' NM_UNIT(2)='BEAT CAR' NM_UNIT(3)='BEAT CAR'
NM_UNIT(4)='BEAT CAR' NM_UNIT(5)='BEAT CAR' NM_UNIT(6)='BEAT CAR'
NM_UNIT(7)='BEAT CAR' NM_UNIT(8)='BEAT CAR' NM_UNIT(9)='BEAT CAR'
NM_UNIT(10)='BEAT CAR' NM_UNIT(11)='BEAT CAR' NM_UNIT(12)='BEAT CAR'
NM_UNIT(13)='BEAT CAR' NM_UNIT(14)='BEAT CAR' NM_UNIT(17)='AUX CAR'
NM_UNIT(18)='AUX CAR'
NO_UNIT(15)=306 NO_UNIT(16)=307 NO_UNIT(19)=321 NO_UNIT(1)=322
NO_UNIT(2)=323 NO_UNIT(3)=324 NO_UNIT(4)=325 NO_UNIT(5)=326
NO_UNIT(6)=327 NO_UNIT(7)=328 NO_UNIT(8)=330 NO_UNIT(9)=331
NO_UNIT(10)=332 NO_UNIT(11)=333 NO_UNIT(12)=334 NO_UNIT(13)=335
NO_UNIT(14)=336 NO_UNIT(17)=341 NO_UNIT(18)=342;
'TRACE'
'SIMTIME' 60.0
'DUMPTIME' 60.
'TITLE' 'GET MCM COSTS'
'SPEED' 16
'PRI_SPEED' 1.0 .5 .5 6.
'ATOM_NO' 246 247 248 249 250 251 252 253 254 255 256 345 346 347 348
349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 401 402 403
404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421
422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 501 502 503
504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 522 987 988
989 990 991 992 993 994 995 996 997
'LAM'
 249  154   41   63   52   48   72  122   50   86   97   34  100  138   57   73
 151  129   83   80  182  209   38   29  103  166  107   43  100  119  103   88
  57  176  102  100   68   38   41  187  161  169  176   97  134    9   69  185
 167   55  205   57   21   93  180   59  165   88   81  134  162   97   98  219
  71   60    0   44  242  132  161   20   90   86   49   53   67  227  190   94
  36  207   97  145  247   29   49   52   66   18   96   57   80   43   57   48
'TX'
  -69.96   56.76  -60.72   73.92  -73.92   91.08  -72.60  112.20  -59.40  110.88
  -56.76   91.08  -52.80   56.76  -36.96   56.76  -36.96   73.92  -38.28   89.76
  -39.60  110.88  -76.56  -31.68  -76.56  -15.84  -75.24    0.00  -75.24   15.84
  -73.92   26.40  -73.92   38.28  -58.08   38.28  -58.08   25.08  -58.08   15.84
  -59.40    0.00  -62.04  -18.48  -69.96  -43.56  -59.40  -54.12  -50.16  -35.64
  -46.20  -18.48  -42.24   -1.32  -40.92   15.84  -38.28   25.08  -39.60   38.28
  -19.80   38.28  -19.80   25.08  -21.12   15.84  -23.76   -2.64  -26.40  -14.52
  -29.04  -26.40  -33.00  -44.88  -42.24  -64.68  -19.80  -76.56  -13.20  -52.80
   -9.24  -33.00   -5.28  -17.16   -2.64   -2.64    0.00   18.48    0.00   34.32
   15.84   36.96   15.84   21.12   14.52    1.32   13.20  -25.08   10.56  -43.56
    5.28  -59.40   -2.64  -79.20    9.24  -88.44   17.16  -68.64   25.08  -44.88
   26.40  -23.76   27.72    0.00   27.72   19.80   29.04   36.96   43.56   34.32
   42.24   17.16   40.92   -1.32   38.28  -27.72   34.32  -52.80   30.36  -69.96
   26.40  -88.44  -21.12  106.92  -21.12   68.64   -1.32   54.12   -1.32   69.96
   -1.32   85.80   -1.32   97.68    1.32  112.20   19.80  108.24   18.48   84.48
```

```
  18.48   71.28   18.48   52.80   29.04   52.80   29.04   71.28   29.04   84.48
  30.36  109.56   40.92   50.16   52.44   84.48   46.20   51.48   55.44  10[illegible]56
  10.56  117.48   13.20   84.48   13.20   71.28   13.20   52.80   26.40   9[illegible]36
  43.56   68.64  -75.24    9.24  -58.08    9.24  -40.92    9.24  -21.12    9.24
 0.00     7.92
'S' 1 8 14 21 27 34 92 93 94 95
'S' 2 7 12 13 22 23 24 25 26
'S' 3 6 35 36 37 38 39 40
'S' 4 4 41 42 49 50
'S' 5 6 51 52 53 54 65 66
'S' 6 4 55 56 63 64
'S' 7 5 43 48 96 57 62
'S' 8 8 44 45 46 47 58 59 60 61
'S' 9 10 74 75 76 77 78 79 80 84 90 91
'S' 10 4 81 82 83 85
'S' 11 9 69 70 71 72 73 86 87 88 89
'S' 12 7 3 4 5 6 10 11 67
'S' 13 6 1 2 7 8 9 68
'S' 14 12 15 16 17 18 19 20 28 29 30 31 32 33
'S' 15 46 14 21 27 34 92 93 94 95 12 13 22 23 24 25 26 35 36 37
    38 39 40 3 4 5 6 10 11 67 1 2 7 8 9 68 15 16 17 18 19 20 28
    29 30 31 32 33
'S' 16 50 41 42 49 50 51 52 53 54 65 66 55 56 63 64 43 48 96 57
    62 44 45 46 47 58 59 60 61 74 75 76 77  78 79 80 84 90 91 81
    82 83 85 69 70 71 72 73 86 87 88 89
'S' 17 40 14 21 27 34 92 93 94 95 12 13 22 23 24 25 26 35 36 37
    38 39 40 41 42 49 50 51 52 53 54 65 66 55 56 63 64 43 48 96
    57 62
'S' 18 56 44 45 46 47 58 59 60 61 74 75 76 77 78 79 80 84 90 91
    81 82 83 85 69 70 71 72 73 86 87 88 89 3 4 5 6 10 11 67 1 2
    7 8 9 68 15 16 17 18 19 20 28 29 30 31 32 33
'S' 19 96 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
    22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
    42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61
    62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81
    82 83 84 85 86 87 88 89 90 91 92 93 94 95 96
'SERVTM' 28.27
'SERVTIME' 'BYPRIORITY' .4 1.0 .78 .78
'FCCW' 0.08 0.76 0.16 0.00
'DISPOL' 'BYPRIORITY' 'NORESTRICT' 'NORESTRICT' 'NORESTRICT' 'RESTRICT'
'MCM'
'FRST'
'SAME_ATOM' 'NO' 'NO' 'NO' 'YES'
'QUEDIS' 'BYPRIORITY' 'FCFS' 'FCFS' 'FCFS' 'NOQ'
'NOPREEMP'
'PRINT' 8 'COST' 'OWBP' 'SAWA' 'SIMV' 'OSUM' 'OUNT' 'ODIS' 'OSIM'
'CORTM' .667
  0.1381  0.1837  0.0650  0.1125  0.1544  0.1300  0.1275  0.1275  0.0975  0.0975
  0.1875  0.1000  0.0787  0.0562  0.0281  0.0562  0.0506  0.0787  0.0787  0.0394
  0.0787  0.1125  0.1125  0.1381  0.0975  0.1312  0.0750  0.0438  0.0925  0.0938
  0.0875  0.0887  0.0469  0.1000  0.0800  0.1531  0.1275  0.2494  0.2644  0.1300
  0.1600  0.1000  0.0938  0.0875  0.1312  0.0625  0.0938  0.0938  0.1650  0.0800
  0.1487  0.1250  0.1031  0.0956  0.0481  0.1125  0.0938  0.0938  0.0625  0.[illegible]75
  0.1050  0.0894  0.1625  0.0987  0.1050  0.1969  0.1687  0.2700  0.1487  0.1275
  0.1275  0.1312  0.1375  0.1031  0.0344  0.0375  0.0438  0.0962  0.0825  0.0756
```

```
  0.0683  0.1400  0.1200  0.1137  0.1356  0.0344  0.0343  0.0375  0.0437  0.0342
  0.1200  0.0281  0.0393  0.0437  0.0469  0.0437
'DISP_OV_RD'
'CONTROL'  8.0
 3.578  4.760  1.684  2.915  4.001  3.368  3.304  3.304  2.526  2.526  4.858  2.
591  2.039  1.456  0.728  1.456  1.311  2.039  2.039  1.021  2.039  2.915  2.915
  3.578  2.526  3.400  1.943  1.135  2.397  2.430  2.267  2.298  1.215  2.591  2
.073  3.967  3.304  6.462  6.851  3.368  4.146  2.591  2.430  2.267  3.400  0.00
0  2.430  2.430  4.275  2.073  3.853  3.239  2.671  2.477  1.246  2.915  2.430
2.430  1.619  2.526  2.721  2.316  4.211  2.557  2.721  5.102  4.371  6.996  3.8
53  3.304  3.304  3.400  3.563  2.671  0.891  0.972  1.135  2.493  2.138  1.959
 1.770  3.628  3.109  2.946  3.514  0.891  0.889  0.972  1.132  0.886  3.109  0.
728  1.018  1.132  1.215  1.132
'CPH_FOR_SI' 200.0
'RUN' 30.0
'BACK' 16 46 14 21 27 34 92 93 94 95 12 13 22 23 24 25 26 35 36 37
    38 39 40 3 4 5 6 10 11 67 1 2 7 8 9 68 15 16 17 18 19 20 28
    29 30 31 32 33
'BACK' 15 50 41 42 49 50 51 52 53 54 65 66 55 56 63 64 43 48 96 57
    62 44 45 46 47 58 59 60 61 74 75 76 77  78 79 80 84 90 91 81
    82 83 85 69 70 71 72 73 86 87 88 89
'MIDDLE' 15 30.0 46 14 21 27 34 92 93 94 95 12 13 22 23 24 25 26 35 36 37
    38 39 40 3 4 5 6 10 11 67 1 2 7 8 9 68 15 16 17 18 19 20 28
    29 30 31 32 33
'MIDDLE' 16 30.0 50 41 42 49 50 51 52 53 54 65 66 55 56 63 64 43 48 96 57
    62 44 45 46 47 58 59 60 61 74 75 76 77  78 79 80 84 90 91 81
    82 83 85 69 70 71 72 73 86 87 88 89
'MIDDLE' 1 .5 1 35
'MIDDLE' 1 1.1 5 36 37 38 39 40
'MIDDLE' 2 1.0 11 27 35 36 37 38 39 40 92 93 94 95
'MIDDLE' 2 2.1 1 34
'MIDDLE' 3 5.1 3 13 51 64
'MIDDLE' 3 3.8 2 14 22
'MIDDLE' 3 2.0 6 21 26 27 34 92 93
'MIDDLE' 3 7.05 2 52 53
'MIDDLE' 3 5.0 1 54
'MIDDLE' 3 3.9 1 55
'MIDDLE' 3 1.5 2 94 95
'MIDDLE' 4 .5 2 48 96
'MIDDLE' 4 .6 1 62
'MIDDLE' 5 .7 5 41 42 48 62 96
'MIDDLE' 5 2.1 1 43
'MIDDLE' 5 2.5 1 56
'MIDDLE' 5 4.1 1 57
'MIDDLE' 5 3.9 1 63
'MIDDLE' 6 .5 2 41 62
'MIDDLE' 6 .6 3 42 48 96
'MIDDLE' 6 2.0 1 43
'MIDDLE' 7 .6 1 41
'MIDDLE' 7 .5 1 42
'MIDDLE' 7 2.4 1 50
'MIDDLE' 7 5.5 1 65
'MIDDLE' 7 6.8 1 66
'MIDDLE' 8 .6 2 69 89
'MIDDLE' 8 .7 5 70 71 72 73 76
```

Figure 4.1 (con't)

```
'MIDDLE' 8 3.8 3 74 90 91
'MIDDLE' 8 3.2 3 75 79 80
'MIDDLE' 8 .5 2 77 78
'MIDDLE' 8 5.2 3 81 83 86
'MIDDLE' 8 7.0 1 85
'MIDDLE' 8 3.1 1 87
'MIDDLE' 9 .6 2 44 45
'MIDDLE' 9 .5 11 46 47 58 59 61 69 70 71 72 73 89
'MIDDLE' 10 .7 10 44 45 46 47 58 59 69 77 78 89
'MIDDLE' 10 .6 6 61 70 71 72 73 76
'MIDDLE' 11 4.5 1 8
'MIDDLE' 11 4.1 1 9
'MIDDLE' 11 5.1 1 10
'MIDDLE' 11 6.5 1 11
'MIDDLE' 11 .5 3 44 45 76
'MIDDLE' 11 .6 6 46 47 58 59 77 78
'MIDDLE' 11 3.92 3 60 82 84
'MIDDLE' 11 .7 1 61
'MIDDLE' 12 2.0 3 15 18 19
'MIDDLE' 12 3.4 1 16
'MIDDLE' 12 3.2 1 17
'MIDDLE' 12 2.0 2 18 19
'MIDDLE' 12 1.5 5 20 28 29 30 31
'MIDDLE' 12 1.0 3 32 33 68
'MIDDLE' 13 1.0 7 15 19 20 28 29 30 31
'MIDDLE' 13 .5 2 32 33
'MIDDLE' 13 3.35 2 16 67
'MIDDLE' 14 3.4 1 67
'MIDDLE' 14 1.5 1 68
'MIDDLE' 17 3.2 1 49
'MIDDLE' 17 5.2 1 51
'MIDDLE' 17 7.1 2 52 53
'MIDDLE' 18 4.4 1 8
'MIDDLE' 18 4.2 2 9 88
'MIDDLE' 18 5.2 1 10
'MIDDLE' 18 6.6 1 11
'MIDDLE' 18 .8 1 69
'END_OV_RD'
```

'PRI_SPEED' 1.0 .5 .5 6.

This card indicates the speed of response as a fraction of full speed as specified on the card 'SPEED' 16. Thus, units will respond at 16 mph (1.0 x 16) to priority 1 calls, 8 mph (.5 x 16) to priority 2 calls, 8 mph to priority 3 calls, and 96 mph (6. x 16) to priority 4 calls. The reason for this unrealistic speed to priority 4 calls is that this run of the simulation was including self-initiated incidents. However, intra-atom travel times were specified with the 'CORTM' option, so that in order to force travel times to essentially zero for the priority 4 self-initiated calls, it was necessary to put an unrealistic travel time.

'SERVTIME' 'BYPRIORITY' .4 1.0 .78 .78

This card specifies the service time by priority by specifying the fraction of the service time specified by the 'SERVTM' 28.27 card. Thus the service time for priority 1 calls is approximately 11.3 minutes (.4 x 28.27), 28.27 minutes (1.0 x 28.27) for priority 2, and 22 minutes (.78 x 28.27) for priority 3 and 4.

'FCCW' 0.08 0.76 0.16 0.00

This card specifies that 8% of the normal calls (i.e., non-self-initiated) should be priority 1 calls, 76% priority 2 and 16% for priority 3. No calls are to be priority 4 as the user has decided to dedicate priority 4 to self-initiated incidents.

'DISPOL' 'BYPRIORITY' 'NORESTRICT' 'NORESTRICT' 'NORESTRICT' 'RESTRICT'

This card indicates that no dispatching restriction is to be used for calls of priority 1, 2, or 3, while calls of priority 4 (in this

case self-initiated calls) should only be dispatched to a patrol unit containing the geographical atom of the incident (hence a "same-sector dispatching restriction").

'SAME ATOM' 'NO' 'NO' 'NO' 'YES'

This card specifies that there is no additional dispatching restriction for calls of priority 1, 2, or 3, but for priority 4 calls dispatch is restricted to units currently in that geographical atom. Calls unable to be dispatched are handled as specified in the Queue Discipline card (QUEDIS).

'QUEDIS' 'BYPRIORITY' 'FCFS' 'FCFS' 'FCFS' 'NOQ'

This card specifies that calls of priorities 1, 2, or 3 should be queued and handled on a first-come first-served basis, while priority 4 calls should not be queued (i.e., ignored).

'CPH_FOR_SI' 200.0

This card specifies that 200 calls per hour should be generated as self-initiated incidents. This rate is higher than the true number of self-initiated calls actually serviced because of the combination of same-atom restriction and no-queue options in effect for priority 4 calls.

4.2 Sample Simulation Output

This section includes examples of each of the types of simulation output. The various outputs were described in Section 3 and the variables which control their printing were described in Section 2.2 (see PRINT on page 14 and DUMPTIME and TRACE on page 12). For each

of the types of output the option which controls each item will be given in parentheses.

Opening Title Block/Figure 4.2

This opening title block is always printed and gives the name and number of units (variable "M"), the name and number of geographical atoms (variable "R") and the number of priorities (variable "NPRI").

Calls for Service Distribution/Figure 4.3

This one or two page output (controlled by option 'CFSD') gives the fraction of calls for service for each geographical atom.

Inter-Atom Travel Times/Figure 4.4

This output (controlled by option 'TTAA') gives the inter- and intra-atom travel times in minutes. These times are specified by the 'TR' option or are calculated as a function of the geographical information of the atoms (as specified by the 'TX' option), the full speed of response (as specified by the 'SPEED' option), and incorporating any modifications in intra-atom times (as specified by option 'CORTM') or in inter-atom times (as specified by 'TX_OV'). The user is warned that this output is voluminous, running to approximately 20 pages of output for 100 atoms. Normally this array would only be printed for one run or after a change in one of the controlling parameters has been specified.

Unit to Atom Travel Times/Figure 4.5

This output (controlled by option 'TTUA') specifies the calculated travel times from each unit to each atom. These times, which are

Figure 4.2 - Sample Output (Opening Title Block)

```
SPATIALLY DISTRIBUTED SIMULATION MODEL OF AN
URBAN EMERGENCY SERVICE SYSTEM
RESPONSE UNIT= POLICE VEHICLE          TOTAL NUMBER=  19
RESPONSE AREA= DISTRICT    TOTAL NUMBER=  19
GEOGRAPHICAL ATOM= PAULY BK        TOTAL NUMBER=  96
NUMBER OF PRIORITIES= 4
```

Figure 4.3 - Sample Output (Calls for Service Distribution)

CALLS FOR SERVICE	DISTRIBUTION, BY PAULY BK
246	0.02559
247	0.01583
248	0.00421
249	0.00648
250	0.00534
251	0.00493
252	0.00740
253	0.01254
254	0.00514
255	0.00884
256	0.00997
345	0.00349
346	0.01028
347	0.01418
348	0.00586
349	0.00750
350	0.01552
351	0.01326
352	0.00853
353	0.00822
354	0.01871
355	0.02148
356	0.00391
357	0.00298
358	0.0
359	
360	
361	
362	
363	

(The complete list is "R" (in this case 96) items long)

Figure 4.4 - Sample Output (Inter-Atom Travel Time Matrix)

TRAVEL TIME MATRIX: INTER-PAULY BK

PAULY BK NUMBER: ORIGIN	PAULY BK NUMBER:DESTINATION 246	247	248	249	250	251
246	0.02	1.88	2.72	4.13	4.59	3.38
247	1.88	0.02	2.16	3.56	2.72	1.50
248	2.72	2.16	0.01	1.59	2.44	1.22
249	4.13	3.56	1.59	0.02	1.03	2.63
250	4.59	2.72	2.44	1.03	0.02	1.59
251	3.38	1.50	1.22	2.63	1.59	0.02
252	1.22	1.78	3.94	5.34	4.31	2.72
253	2.34	2.91	5.06	6.47	5.44	3.84
254	3.56	1.69	3.84	5.25	4.22	2.62
255	4.59	2.72	2.62	4.03	3.00	1.41
256	6.00	4.13	3.84	2.44	1.41	2.63
345	6.75	8.63	8.91	10.50	11.34	10.13
346	5.63	7.50	7.78	9.38	10.22	9.00
347	4.41	6.28	6.56	8.16	9.00	7.78
348	3.28	5.16	5.44	7.03	7.88	6.66
349	2.44	4.31	4.59	6.19	7.03	5.81
350	1.59	3.47	3.75	5.34	6.19	4.97
351	2.16	2.72	4.88	6.28	5.25	3.84
352	3.09	3.66	5.81	7.22	6.19	4.78
353	3.75	4.31	6.47	7.88	6.84	5.44
354	4.78	5.34	7.50	8.91	7.88	[illegible]
355	5.91	6.66	8.63	10.03	9.38	
356	7.13	9.00	9.84	11.25	[illegible]	
357	8.63	9.19	11.34	12.75		
358	7.97	8.53	10.69			
359	7.03	7.59	[illegible]			
360	6.09	6.66	8.81			
361	4.97	5.53	7.69			
362	4.50	5.06	[illegible]			
363	3.47	[illegible]				
401	4.88					
402						
403						
404	[illegible]					
405						
406						

(The complete list is an "R by R" array. In this case it would be a 96 by 96 array requiring 20 pages of line printer output)

Figure 4.5 - Sample Output (Unit to Atom Travel Time Matrix)

MEAN TRAVEL TIMES FOR EACH POLICE VEHICLE
TO EACH PAULY BK

PAULY BK ID NO	ID OF POLICE VEHICLE BEAT CAR 322	BEAT CAR 323	BEAT CAR 324	BEAT CAR 325	BEAT CAR 326	BEAT CAR 327	BEAT CAR 328	BEAT CAR 330
246	5.51	6.68	10.31	10.96	14.84	14.25	10.14	8.85
247	6.37	7.63	10.88	11.52	15.40	14.81	10.70	9.42
248	8.09	9.29	13.03	13.67	17.56	16.97	12.85	11.57
249	9.54	10.73	14.44	15.08	18.96	18.37	14.26	12.98
250	8.95	10.27	13.41	14.05	17.93	17.34	13.23	11.95
251	7.54	8.90	11.81	12.46	16.34	15.75	11.64	10.35
252	5.13	6.52	9.10	9.74	13.62	13.03	8.92	7.64
253	5.35	7.36	8.02	8.61	12.49	11.91	7.79	6.51
254	6.57	8.58	9.24	9.83	13.71	13.12	9.01	7.73
255	7.65	9.61	10.45	11.05	14.93	14.34	10.23	8.95
256	9.11	11.02	12.03	12.64	16.52	15.94	11.82	10.54
345	4.29	2.05	5.11	6.06	9.02	8.66	8.83	11.27
346	3.16	1.81	5.66	6.27	10.15	9.56	7.71	10.14
347	2.05	2.88	6.66	7.30	11.18	10.59	6.61	8.92
348	2.80	4.00	7.78	8.42	12.31	11.72	7.60	7.80
349	3.50	4.69	8.44	9.08	12.96	12.37	8.26	7.54
350	4.34	5.54	9.28	9.92	13.81	13.22	9.10	7.82
351	3.78	5.13	8.16	8.80	12.68	12.09	7.98	6.70
352	2.85	4.19	7.22	7.86	11.74	11.16	7.04	6.41
353	2.19	3.54	6.56	7.21	11.09	10.50	6.39	6.58
354	1.45	2.39	5.53	6.17	10.06	9.47	5.49	7.80
355	2.75	1.12	4.51	5.11	8.93	8.34	6.86	9.30
356	4.84	2.36	4.43	6.21	7.71	7.82	9.21	
357	5.19	2.79	3.73	6.21	6.21	7.24		
358	3.91	1.79	3.16	4.35	6.87			
359	2.72	1.42	3.39	3.98	7.81			
360	1.57	2.86	4.22	4.86	8.74			
361	2.32	4.17	5.36	5.99				
362	3.06	5.02	5.85					
363	3.96	5.86						
401	4.71	7.27						
402	3.77	6.33						
403	3.02							
404								

(This complete list is an "M by R" array. In this case it would be a 19 by 96 array requiring 4 pages of line printer output)

specified in minutes, are a function of the atom-to-atom travel times as well as the geographical area patrolled by the unit.

Unit to Atom Cost of Dispatching/Figure 4.6

This output (controlled by option 'COST') specifies the "Cost" of dispatching each unit to each atom. This quantity is described in Reference 1 and is a function of both the unit to atom travel times and the dispatching strategy being used.

Spatial Allocation While Available/Figure 4.7

This output (controlled by option 'SAWA') specifies the fraction of time each unit spends in each atom when on preventive patrol. This array thus specifies each unit's home sector as specified by input options 'S' or 'SS'.

Simulation Control Variables/Figure 4.8

This output (controlled by option 'SIMV') specifies the input values for those variables which control the execution of the simulation but which are not a part of the normal hypercube data base.

Program Trace/Figure 4.9

This gives an example of the program trace (which is controlled by option 'TRACE'). This trace illustrates the two basic operations of the simulation: assignment of an available unit to an incident, and a reassignment of a unit completing an incident. The trace of the initial assignment of a unit to an incident lists the simulation time, atom of location of the incident, priority of the call, number of unit

Figure 4.6 - Sample Output (Unit to Atom "Cost" of Dispatching)

ESTIMATED "COST" OF DISPATCHING I_TH POLICE VEHICLE
TO J_TH PAULY BK

PAULY BK ID NO	ID OF POLICE VEHICLE BEAT CAR 322	BEAT CAR 323	BEAT CAR 324	BEAT CAR 325	BEAT CAR 326	BEAT CAR 327	BEAT CAR 328	BEAT CAR 330
246	5.33	6.49	10.31	10.96	14.84	14.25	10.14	8.85
247	5.89	7.06	10.88	11.52	15.40	14.81	10.70	9.42
248	8.05	9.21	13.03	13.67	17.56	16.97	12.85	11.57
249	9.46	10.62	14.44	15.08	18.96	18.37	14.26	12.98
250	8.43	9.61	13.41	14.05	17.93	17.34	13.23	11.95
251	6.83	8.39	11.81	12.46	16.34	15.75	11.64	10.35
252	4.11	6.24	9.10	9.74	13.62	13.03	8.92	7.64
253	4.81	7.36	7.97	8.61	12.49	11.91	7.79	6.51
254	6.02	8.58	9.19	9.83	13.71	13.12	9.01	7.73
255	7.06	9.61	10.41	11.05	14.93	14.34	10.23	8.95
256	8.46	11.02	12.00	12.64	16.52	15.94	11.82	10.54
345	4.29	0.00	4.50	5.84	9.02	8.44	8.83	11.27
346	3.16	0.00	5.10	6.27	10.15	9.56	7.71	10.14
347	0.00	2.84	3.80	7.30	11.18	10.59	6.49	8.92
348	2.80	3.96	7.78	8.42	12.31	11.72	7.60	7.80
349	3.46	4.62	8.44	9.08	12.96	12.37	8.26	6.98
350	4.30	5.46	9.28	9.92	13.81	13.22	9.10	7.82
351	3.18	4.55	8.16	8.80	12.68	12.09	7.98	6.70
352	2.24	3.61	7.22	7.86	11.74	11.16	7.04	5.92
353	1.58	2.95	6.56	7.21	11.09	10.50	6.39	6.58
354	0.00	1.74	2.00	6.17	10.06	9.47	5.36	7.80
355	2.32	0.00	3.80	5.05	8.93	8.34	6.86	9.30
356	4.66	0.00	3.38	6.21	7.71	7.24	9.21	11.64
357	4.66	0.00	3.38	6.21	6.21	7.24	9.21	11.64
358	2.69	0.00	2.35	4.24	6.87	6.28	7.24	9.67
359	1.70	0.00	2.00	3.92	7.81	7.22	5.74	
360	0.00	1.00	2.00	4.86	8.74	[illegible]		
361	1.62	4.17	5.35	5.99	9.87			
362	2.46	5.02	5.81	6.46	10.34			
363	3.31	5.86	6.85	7.49				
401	4.71	7.27	[illegible]					
402	3.77	6.33						
403	3.02	5.58						
404	0.00							

(This complete list is an "M by R" array. In this case it would be a 19 by 96 array requiring 4 pages of line printer output)

Figure 4.7 - Sample Output (Spatial Allocation While Available)

POLICE VEHICLE SPATIAL ALLOCATION, WHILE AVAILABLE

PAULY BK ID OF POLICE VEHICLE

NO.	BEAT CAR 322	BEAT CAR 323	BEAT CAR 324	BEAT CAR 325	BEAT CAR 326	BEAT CAR 327	BEAT CAR 328
246	0.000	0.000	0.000	0.000	0.000	0.000	0.000
247	0.000	0.000	0.000	0.000	0.000	0.000	0.000
248	0.000	0.000	0.000	0.000	0.000	0.000	0.000
249	0.000	0.000	0.000	0.000	0.000	0.000	0.000
250	0.000	0.000	0.000	0.000	0.000	0.000	0.000
251	0.000	0.000	0.000	0.000	0.000	0.000	0.000
252	0.000	0.000	0.000	0.000	0.000	0.000	0.000
253	0.000	0.000	0.000	0.000	0.000	0.000	0.000
254	0.000	0.000	0.000	0.000	0.000	0.000	0.000
255	0.000	0.000	0.000	0.000	0.000	0.000	0.000
256	0.000	0.000	0.000	0.000	0.000	0.000	0.000
345	0.000	0.050	0.000	0.000	0.000	0.000	0.000
346	0.000	0.147	0.000	0.000	0.000	0.000	0.000
347	0.164	0.000	0.000	0.000	0.000	0.000	0.000
348	0.000	0.000	0.000	0.000	0.000	0.000	0.000
349	0.000	0.000	0.000	0.000	0.000	0.000	0.000
350	0.000	0.000	0.000	0.000	0.000	0.000	0.000
351	0.000	0.000	0.000	0.000	0.000	0.000	0.000
352	0.000	0.000	0.000	0.000	0.000	0.000	0.000
353	0.000	0.000	0.000	0.000	0.000	0.000	0.000
354	0.217	0.000	0.000	0.000	0.000	0.000	0.000
355	0.000	0.308	0.000	0.000	0.000	0.000	0.000
356	0.000	0.056	0.000	0.000	0.000	0.000	0.000
357	0.000	0.043	0.000	0.000	0.000	0.000	0.000
358	0.000	0.152	0.000	0.000	0.000	0.000	0.000
359	0.000	0.244	0.000	0.000	0.000	0.000	0.000
360	0.127	0.000	0.000	0.000	0.000	0.000	0.000
361	0.000	0.000	0.000	0.000	0.000	0.000	
362	0.000	0.000	0.000	0.000	0.000		
363	0.000	0.000	0.000	0.000	0.000		
401	0.000	0.000	0.000	0.000	0.000		
402	0.000	0.000	0.000				
403	0.000	0.000					
404	0.210	0.000					
405	0.000						

(This complete list is an "M by R" array. In this case it would be a 19 by 96 array requiring 4 pages of line printer output)

Figure 4.8 - Sample Output (Simulation Control Variables)

```
SIMULATION CONTROL VARIABLES
---------- ------- ---------

MEAN SERVICE TIMES
------------------

PRIORITY:           1       2       3       4
SERV. TIME:       11.31   28.27   22.05   22.05

GEOGRAPHICAL DISTRIBUTION OF CALLS BY PRIORITY
----------------------------------------------

DISTRIBUTION IS CONSTANT CITY-WIDE
THE DISTRIBUTION BY PRIORITY IS:

PRIORITY:           1       2       3       4
FRACTION:         0.080   0.760   0.160   0.000

CROSS-BEAT DISPATCHING POLICY
-----------------------------

POLICY IS: RESTRICTED SELECTIVELY BY PRIORITY AS FOLLOWS:

PRIORITY:           1       2       3       4
POLICY:           NONE    NONE    NONE    RES.

SAME ATOM DISPATCH RESTRICTION
------------------------------

PRIORITY:           1       2       3       4
POLICY:            NO      NO      NO     YES

QUEUE DISCIPLINE POLICY
-----------------------

QUEUE DISCIPLINE IS SPECIFIED BY PRIORITY, AS FOLLOWS:

PRIORITY:           1       2       3       4
POLICY:           FCFS    FCFS    FCFS    NOQ
```

Figure 4.8 (con't)

DISTANCE METRIC

USE STRICT DISTANCE METRIC IN REASSIGNMENT

PREVENTIVE PATROL PRIORITY

UNIT:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
PRICAR:	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99

CALL PREEMPTION POLICY

NO PREEMPTION OF CALLS ALLOWED

MAXIMUM TRAVEL TIME RESTRICTION

NO MAXIMUM TRAVEL TIME RESTRICTION

TOTAL SIMULATION TIME

TOTAL SIMULATION TIME 60.00

Figure 4.9 - Sample Output (Example of Program Trace)

```
TIME:  35.685
CALL - ATOM NO.418     PRIORITY= 2
ASSIGN UNIT NO=328
TRAVEL TIME=  2.062
TIME AT SCENE= 49.714
TOTAL SERVICE TIME= 24.325

TIME:  36.024
CALL - ATOM NO.505     PRIORITY= 2
ASSIGN UNIT NO=333
TRAVEL TIME=  2.250
TIME AT SCENE= 36.874
TOTAL SERVICE TIME= 23.986

TIME:  37.522
ASSIGN TO PREVENTIVE PATROL
UNIT=342 ATOM NO.=517

TIME:  39.139
ASSIGN TO PREVENTIVE PATROL
UNIT=335 ATOM NO.=247

TIME:  39.151
CALL - ATOM NO.404     PRIORITY= 1
ASSIGN UNIT NO=325
TRAVEL TIME=  4.219
TIME AT SCENE=  7.839
TOTAL SERVICE TIME= 12.058

TIME:  39.482
CALL - ATOM NO.414     PRIORITY= 2
ASSIGN UNIT NO=331
TRAVEL TIME= 12.000
TIME AT SCENE=  9.169
TOTAL SERVICE TIME= 20.528

TIME:  40.307
CALL - ATOM NO.404     PRIORITY= 3
ASSIGN UNIT NO=336
TRAVEL TIME= 11.250
TIME AT SCENE= 29.776
TOTAL SERVICE TIME= 19.703
```

assigned, travel time to reach the incident, the on-the-scene service time, and the total service time (including on-the-scene and travel time). The reassignment of a unit will yield one of two formats. The first (which is illustrated in this example) will indicate that the unit has been reassigned to preventive patrol. This format lists the simulation time, the unit number, and the atom where that unit will start patrolling. The other possible format for reassignment (which is not illustrated here) indicates that a unit is assigned to a call which has been waiting in queue. This format is similar to that of an assignment except that it also specifies the length of time that the call had been waiting in queue. Under certain conditions another combination of formats may be seen. This is the special case where a unit returnes to his sector and resumes preventive patrol before calling in as being available for service. If upon calling in the unit is immediately assigned to a waiting call, this will appear in the trace as two separate items with the same simulation time: the first the reassignment to preventive patrol and the second the assignment to a call. This situation would only occur when the user was intentionally trying to model this type of behavior by using the Weighted Distance Metric Option ('DISMET'). One last possible format for the trace (not illustrated here) can occur if the user has specified that preemption of calls can occur (option 'PREEMP'). This will appear with information similar to that for an assignment with the additional information of PREEMPTION ASSIGNMENT. When this call is reassigned to an available unit, this reassignment will appear with the additional message ASSIGN TO PREEMPTED CALL.

CONTINUED

8 OF 10

Status Dump/Figure 4.10

This output (controlled by variable 'DUMPTIME') gives the status of all units at a particular time. In the example shown, the unit number, geographical location and status are given. If the unit is assigned to preventive patrol, the words 'PREV. PAT.' appear in the status column. If the unit is assigned to a call, this fact is stated with the call's priority ('CALL-PRIOR X'). This option will also print a list of all calls waiting in queue. (No calls were waiting in queue in the example shown.) The following information is given for waiting calls: sequence number in queue, atom number of incident, priority, time placed in queue, and on-the-scene service time.

Output Summary/Figure 4.11

This output (controlled by option 'OSUM') gives a summary of information about the simulation run. The user should find this information to be self-explanatory.

Unit Specific Performance Measures/Figure 4.12

This output (controlled by option 'OUNT') gives a summary of performance measures which are specific to each unit. The user should find this list self-explanatory.

Area Specific Performance Measures/Figure 4.13

This output (controlled by option 'ODIS') gives a summary of performance measures which are specific to each geographical grouping of atoms (normally a district or comparable area). The user should find this information self-explanatory.

Figure 4.10 - Sample Output (Status Dump)

```
-------------------------------------
STATUS DUMP - TIME= 60.000

UNIT  ATOM     STATUS
 22    404     CALL - PRIOR  2
 23    358     CALL - PRIOR  4
 24    410     PREV.PAT
 25    411     CALL - PRIOR  4
 26    435     PREV.PAT
 27    434     PREV.PAT
 28    418     CALL - PRIOR  4
 30    414     CALL - PRIOR  2
 31    518     CALL - PRIOR  2
 32    515     CALL - PRIOR  3
 33    989     CALL - PRIOR  3
 34    256     PREV.PAT
 35    253     CALL - PRIOR  4
 36    363     CALL - PRIOR  3
 06    362     CALL - PRIOR  2
 07    513     PREV.PAT
 41    996     PREV.PAT
 42    255     PREV.PAT
 21    435     PREV.PAT

QUEUE OF WAITING CALLS:

** NO WAITING CALLS **
-------------------------------------
```

Figure 4.11 - Sample Output (Output Summary)

```
SPATIALLY DISTRIBUTED SIMULATION MODEL OF AN
URBAN SERVICE SYSTEM:  COMPUTED PERFORMANCE MEASURES
PROBLEM TITLE: GET MCM COSTS
POLICE VEHICLE        ...TOTAL NUMBER OF = 19
PAULY BK  ...TOTAL NUMBER OF =  96
AVERAGE SERVICE TIME=  19.62 MINUTES
AVERAGE NUMBER OF CALLS FOR SERVICE  PER HOUR=  45.000
AVERAGE NUMBER OF CALLS FOR SERVICE  PER  19.62 MINUTES= 14.718
SPEED OF PATROL=   8.00 MPH
THEORETICAL AVERAGE UTILIZATION FACTOR=  0.744
SIMULATED AVERAGE UTILIZATION FACTOR=  0.775


REGION-WIDE AVERAGE TRAVEL TIME=   6.324 MINUTES
REGION-WIDE AVERAGE WORKLOAD (% TIME BUSY)= 0.77461
STANDARD DEVIATION OF WORKLOAD=   0.115
MAXIMUM WORKLOAD IMBALANCE= 0.41659
FRACTION OF DISPATCHES THAT ARE INTER-DISTRICT =  0.37778

REGION-WIDE AVERAGE PATROL FREQUENCY=    0.136 PASSES PER HOUR
```

Figure 4.12 - Sample Output (Unit Specific)

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH POLICE VEHICLE

ID OF POLICE VEHICLE NAME	NO	WORKLOAD OF UNIT	% OF MEAN	FRACTION OF DISPATCHES OUT OF DISTRICT	% OF MEAN	AVERAGE TRAVEL TIME
BEAT CAR	322	0.835	107.855	0.000	0.000	0.099
BEAT CAR	323	0.834	107.695	0.500	132.321	5.221
BEAT CAR	324	0.725	93.553	0.333	88.233	7.300
BEAT CAR	325	0.722	93.199	0.600	158.812	2.236
BEAT CAR	326	0.859	110.906	0.500	132.321	3.965
BEAT CAR	327	0.752	97.094	0.333	88.233	2.702
BEAT CAR	328	0.978	126.309	0.000	0.000	2.531
BEAT CAR	330	0.981	126.647	0.500	132.321	12.349
BEAT CAR	331	0.564	72.866	0.500	132.343	5.743
BEAT CAR	332	0.774	99.893	1.000	264.706	18.724
BEAT CAR	333	0.641	82.754	0.000	0.000	1.202
BEAT CAR	334	0.886	114.321	1.000	264.706	10.312
BEAT CAR	335	0.851	109.894	0.250	66.162	6.047
BEAT CAR	336	0.677	87.341	0.500	132.321	5.683
CRUISER	306	0.740	95.493	0.500	132.321	13.012
CRUISER	307	0.653	84.322	0.000	0.000	4.654
AUX CAR	341	0.812	104.805	0.000	0.000	3.045
AUX CAR	342	0.587	75.748	0.333	88.233	8.513
STACK	321	0.847	109.305	0.000	0.000	19.500

Figure 4.13 - Sample Output (Area Specific)

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH DISTRICT

ID OF DISTRICT NAME	NO	WORKLOAD OF DISTRICT	% OF MEAN	FRACTION OF DISPATCHES INTER-DISTRICT	% OF MEAN	AVERAGE TRAVEL TIME
3322	1	1.75301	226.309	0.600	158.812	3.448
3323	2	1.38736	179.104	0.750	198.513	17.223
3324	3	1.71680	221.635	0.500	132.321	9.447
3325	4	0.71589	92.420	0.333	88.233	4.419
3326	5	0.65654	84.757	0.000	0.000	3.965
3327	6	0.87181	112.548	0.333	88.192	8.702
3328	7	1.02262	132.018	0.333	88.192	2.500
3330	8	1.29150	166.730	0.667	176.449	7.608
3331	9	1.14474	147.783	0.200	52.889	3.231
3332	10	0.12674	16.361	1.000	264.706	7.875
3333	11	0.64102	82.754	0.000	0.000	1.202
3334	12	0.00000	0.000	0.000	0.000	0.000
3335	13	1.08602	140.202	0.000	0.000	2.241
3336	14	2.30353	297.379	0.400	105.844	9.081
CRUISER1	15	0.00000	0.000	0.435	115.057	7.849
CRUISER2	16	0.00000	0.000	0.318	84.186	4.729
3341	17	0.00000	0.000	0.458	121.297	7.446
3342	18	0.00000	0.000	0.286	75.584	5.041
STACK	19	0.00000	0.000	0.378	99.965	6.324

Atom Specific Performance Measures/Figure 4.14

This output (controlled by option 'OATM') gives a summary of performance measures which are specific to each geographical atom. In the example shown, the name PAULY BK is the user-specified name for each atom. The right-most column of information specifies the calculated (not simulated) frequency of preventive patrol passing per hour. This column will appear only if option 'PATROL' is used as well as option 'OATM'.

Workload by Priority for Each Unit/Figure 4.15

This output (controlled by option 'OWBP') gives the workload for each patrol unit by priority of call. The number in parentheses is the actual number of calls of each priority serviced by each unit, and the number with four decimal places specifies the workload (fraction of 1) for the same information.

Output Unique to Simulation/Figure 4.16

This output (controlled by option 'OSIM') gives a summary of information for those parameters and performance measures which apply only to the simulation and not to any of the hypercube data base. The user should find this information to be self-explanatory.

Figure 4.14 - Sample Output (Atom Specific)

PERFORMANCE MEASURES THAT ARE SPECIFIC TO EACH PAULY BK

ID # PAULY BK	WORKLOAD OF PAULY BK	AVE TRAV TIME	322	323	324	325	326	32		321	FREQUENCY OF PREVENTIVE PATROL PASSINGS (#/HOUR) (#CALLS/100HR)
246	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0	0	0.00	0.45
247	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0	0	0.00	0.28
248	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.	00	0.00	0.12
249	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.	00	0.00	0.19
250	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.	00	0.00	0.15
251	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0	.00	0.00	0.14
252	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0	.00	0.00	0.13
253	100.00	0.034	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.22
254	0.00	0.000	0.00	0.00	0.00	0.00	0.00		0	0.00	0.09
255	0.00	0.000	0.00	0.00	0.00	0.00	0.00		0	0.00	0.26
256	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0	0	0.00	
345	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0	00	0.00	
346	0.00	0.000	0.00	0.00	0.00	0.00	0.00	0.0	00	0.	
347	0.00	0.000	0.00	0.00	0.00						
348	0.00	0.000									
349	0.00	0									
350	0										

FRACTION OF CALLS FOR SERVICE FROM PAULY BK SERVICED BY UNIT NUMBER: (columns 322–321)

(This complete list is an "R by M" array. In this case it would be a 96 by 19 array requiring 4 pages of line printer output)

Figure 4.15 - Sample Output (Workload by Priority)

WORKLOAD BY PRIORITY FOR EACH POLICE VEHICLE

ID OF POLICE VEHICLE NAME	NO	PRIORITY 1	2	3	4
BEAT CAR	322	0.0000(0)	0.0000(0)	0.0000(0)	0.8355(1)
BEAT CAR	323	0.0000(0)	0.3005(1)	0.0000(0)	0.5337(1)
BEAT CAR	324	0.0000(0)	0.3716(2)	0.0000(0)	0.3530(1)
BEAT CAR	325	0.2010(1)	0.5010(3)	0.0000(0)	0.0199(1)
BEAT CAR	326	0.0000(0)	0.8591(2)	0.0000(0)	0.0000(0)
BEAT CAR	327	0.1267(1)	0.0000(0)	0.0000(0)	0.6254(2)
BEAT CAR	328	0.0000(0)	0.9784(2)	0.0000(0)	0.0000(0)
BEAT CAR	330	0.0000(0)	0.2217(1)	0.0000(0)	0.7593(1)
BEAT CAR	331	0.0000(0)	0.5322(2)	0.0000(0)	0.0323(2)
BEAT CAR	332	0.0000(0)	0.7738(2)	0.0000(0)	0.0000(0)
BEAT CAR	333	0.0000(0)	0.3998(1)	0.0000(0)	0.2413(1)
BEAT CAR	334	0.0000(0)	0.8855(1)	0.0000(0)	0.0000(0)
BEAT CAR	335	0.0000(0)	0.8512(4)	0.0000(0)	0.0000(0)
BEAT CAR	336	0.0000(0)	0.0000(0)	0.3284(1)	0.3482(1)
CRUISER	306	0.0000(0)	0.2464(1)	0.0000(0)	0.4933(1)
CRUISER	307	0.0000(0)	0.2563(1)	0.0000(0)	0.3969(1)
AUX CAR	341	0.0000(0)	0.4850(1)	0.0000(0)	0.3268(1)
AUX CAR	342	0.0000(0)	0.0000(0)	0.3182(1)	0.2685(2)
STACK	321	0.0000(0)	0.8467(1)	0.0000(0)	0.0000(0)

Figure 4.16 - Sample Output (Output Unique to Simulation)

```
STATISTICS UNIQUE TO SIMULATION
-------------------------------

PERCENTAGE OF DISPATCHES WHICH WERE NON-OPTIMUM=  0.156%

MEAN EXTRA TRAVEL TIME DUE TO NON-OPTIMUM DISPATCHES=  7.860

NUMBER OF CALLS NOT SERVICED DUE TO NO_QUEUE OPTION=843

MEAN NUMBER OF CALLS IN QUEUE WHEN CALL ARRIVES
-----------------------------------------------

PRIORITY:        1        2        3        4
               0.000    0.000    0.000    1.000

MEAN LENGTH OF TIME IN QUEUE
----------------------------

PRIORITY:        1        2        3        4
               0.000    0.000    0.000    0.000

PERCENTAGE OF CALLS PREEMPTED:
------------------------------

PRIORITY:        1        2        3        4
               0.000    0.000    0.000    0.000

MEAN TRAVEL TIME TO ALL CALLS
-----------------------------

PRIORITY:        1        2        3        4
               6.047    9.356   18.256    0.129
```

5. TECHNICAL SUMMARY

Table 5.1 is intended to be an addendum to Table 6.1 in Reference 1.

There is no equivalent to Table 6.2, Ordering of Instructions, as there is no restriction on ordering of items in the data deck except for those already listed in Table 6.2.

Table 5.2 is an addendum to Table 6.3 in Reference 3. There are no changes to those items in Table 6.3 except that it should be noted that there are no call rates on either the RUN or RERUN card.

Table 5.1

Index of Instructions

Instructions	Function	Optional?	Relevant Default (if optional)	Described in Section #
'AVM'	One of five preprog. dispatch strategies	yes	'ESCM'	2.1
'CPH_FOR_SI'	CfS rate for self-initiated activities	yes	no printout (that is controlled by this variable)	2.2, 3.1, 3.3, 4.4
'DEBUG'	Prints detailed programming debugging information	yes	no debug information	2.2
'DISMET'	Use of a distance metric	yes	STRICT	2.2
'DISPOL'	Same-sector dispatch restriction policy	yes	NORESTRICT	2.2, 4.1
'DUMPTIME'	Time between	yes	no dump	2.2
'FCAT'	Fraction of cfs by priority for each atom	yes	FCUN	2.2
'FCCW'	Fraction of cfs by priority for all atoms	yes	FCUN	2.2, 4.1
'FCUN'	Uniform fraction of cfs by priority with each atom	yes	FCUN	2.2

Table 5.1 (cont.)

Index of Instructions

Instructions	Function	Optional?	Relevant Default (if optional)	Described in Section #
'MAXTRAV'	Maximum travel time restriction by priority	yes	no restriction	2.2
'NOPREEMP'	No preemption of calls allowed	yes	NOPREEMP	2.2
'PPP'	Preventive patrol priority	yes	=99	2.2
'PREEMP'	Preemption of calls allowed	yes	NOPREEMP	2.2
'PRINT'	Controls printout of data set and simulation output	yes	no printout (that is controlled by this variable)	2.2, 3.1, 3.3, 4.4
'PRI_SPEED'	Fraction of full-speed response by priority	yes	=1.0	2.2, 4.1
'QUEDIS'	Queue discipline	yes	FCFS	2.2, 4.1
'SAME-ATOM'	Same atom dispatching restrictions	yes	no restriction	2.2, 4.1
'SERVTIME'	Service time by priority	yes	SERVTM	2.2
'SIMTIME'	Total simulation time in minutes	yes	10 minutes	2.2
'TRACE'	Controls printing of simulation trace	yes	no trace	2.2

Table 5.2

Units of Measurement

Card Label	Definition of Relevant Variable	Variable Name	Units of Measurement	Default Value
DISMET	Weights for distance	IREASN	none	none
MAXTRAV	Maximum travel time restriction	RAD(I)	minutes	999
SIMTIME	Total simulation time	RMAX	minutes	10
DUMPTIME	Time between status dumps	TREPOS	minutes	1,000,000
PPP	Preventive patrol priority	PRICAR	none	99
CPH_FOR_SI	Calls for service rate for self-initiated activities	ROSI	calls/hour	0

References

1. Larson, Richard C., Computer Program for Calculating the Performance of Emergency Service Systems: User's Manual (Batch Processing) Program Version 75-001 (BATCH), Technical Report No.: TR-14-75, "Innovative Resource Planning in Urban Public Safety Systems," Operations Research Center, MIT, Cambridge, Massachusetts 02139, 1975.

2. Larson, Richard C., Urban Police Patrol Analysis, MIT Press, Cambridge, Massachusetts, 1972.

3. Public Systems Evaluation, Inc., Evaluation of an Implemented AVM System: Final Report, LEAA Grant No. 75NI-99-0014, Public Systems Evaluation, Inc., Cambridge, Massachusetts, 1976.

Appendix D

SURVEYS USED IN THE
ATTITUDINAL AND ORGANIZATIONAL ANALYSIS

Survey 1: First Patrolmen's Survey in District 3. Administered before the implementation of FLAIR.

DISTRICT 3

PATROLMEN'S SURVEY

This survey is designed to help evaluate the Fleet Locator and Information Retrieval System (FLAIR) and to provide the opportunity for field officers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a policeman? ______________yrs.

2. Please indicate the highest level of education completed:
   - ☐ High school diploma or equivalency
   - ☐ Some college
   - ☐ Bachelors degree
   - ☐ Some graduate work
   - ☐ Graduate degree

3. Are you currently taking any courses for credit toward a degree?

   ☐ Yes ☐ No

4. Overall, how satisfying do you find your profession as a policeman?
   - ☐ Very satisfying
   - ☐ Fairly satisfying
   - ☐ Not very satisfying

5. From what source did you first hear of the FLAIR car locator system?

   ☐ A patrolman ☐ A sergeant ☐ A command officer

   ☐ A Boeing Rep. ☐ Patrolman's association ☐ Newspaper or radio

   ☐ Other (Please state:________________________________)

6. Were you able to attend the July orientation seminars on FLAIR?

   ☐ Yes ☐ No

7. How well informed do you feel about:
   (please answer parts a, b, and c.)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

8. Do you feel that patrolmen have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

☐ Yes ☐ No

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

☐ Good idea ☐ Not a good idea

10. How do you think patrolmen will feel about the FLAIR system once they have used it? Do you think:

☐ Most will be for it

☐ About half and half

☐ Most will be against it

11. How important do you think each of these goals is in implementing the FLAIR system? (please answer parts a-e)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state:	☐	☐	☐

____

____

12. Of the goals listed in question 11, please circle the letter of the one that you feel is the most important

13. How do you think the FLAIR system will affect performance in each of these areas? (please answer parts a-e)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐

	Improve	No effect	Worsen
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ______________	☐	☐	☐

14. What do you see as the main potential problem that the FLAIR system will encounter?

- ☐ Equipment and computer problems
- ☐ Lack of support from policemen on the street
- ☐ Disciplinary abuses
- ☐ Difficulty in operating the system
- ☐ Other. Please state: ______________

15. How do you think the FLAIR system will affect your ability to do your job well? Will it:

- ☐ Help you
- ☐ Make no difference
- ☐ Make it harder

16. How do you think that your task as a patrolman will be altered in each of the following areas: (please answer a-d)

	Increase	Stay the same	Decrease
a. Preventative patrol time	☐	☐	☐
b. Flexibility to follow individual hunches	☐	☐	☐
c. Coordinated operations with fellow officers	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Other. Please state: ______________	☐	☐	☐

17. How do you think the FLAIR system will affect the way you feel about your job? CIRCLE ANSWER ON NEXT PAGE

More satisfying   No difference   Less satisfying

18. How do you think the FLAIR system will influence your relationship with your patrol supervisors? Do you think it will:

☐ Make it better   ☐ Make no difference   ☐ Make it worse

19. How do you think the FLAIR system will affect discipline in the department. Will it:

☐ Make it fairer

☐ Make no difference

☐ Make it less fair

20. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel:

☐ More favorably toward the police

☐ No different than now

☐ Less favorably toward the police

21. What is your guess about how the department administration will evaluate the FLAIR system? Do you think it is more likely to:

☐ Decide to keep it

☐ Decide to drop it

22. Overall, do you think the benefits of the FLAIR system will justify the cost?

☐ Yes   ☐ No

23. Do you have any suggestions or general comments about FLAIR?

Survey 2: First Sergeant's Survey in District 3. Administered before the implementation of FLAIR.

DISTRICT 3

SERGEANT'S SURVEY

This survey is designed to help evaluate the Fleet Locator and Information Retrieval System (FLAIR) and to provide the opportunity for field officers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be,

1. How many years have you been a policeman? ______________ yrs.

2. Please indicate the highest level of education completed:
   - ☐ High school diploma or equivalency
   - ☐ Some college
   - ☐ Bachelors degree
   - ☐ Some graduate work
   - ☐ Graduate degree

3. Are you currently taking any courses for credit toward a degree?
   ☐ Yes ☐ No

4. Overall, how satisfying do you find your profession as a policeman?
   - ☐ Very satisfying
   - ☐ Fairly satisfying
   - ☐ Not very satisfying

5. From what source did you first hear of the FLAIR car locator system?
   - ☐ A patrolman
   - ☐ A sergeant
   - ☐ A command officer
   - ☐ A Boeing representative
   - ☐ Patrolman's association
   - ☐ Newspaper or radio
   - ☐ Other (Please state: ______________________________)

6. Were you able to attend the July orientation seminars on FLAIR?
   ☐ Yes ☐ No

7. How well informed do you feel about:
   (Please answer parts a, b, and c.)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

8. Do you feel that sergeants have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

☐ Yes ☐ No

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

☐ Good idea

☐ Not a good idea

10. How do you think sergeants will feel about the FLAIR system once they have used it? Do you think:

☐ Most will be for it

☐ About half and half

☐ Most will be against it

11. How important do you think each of these goals is in implementing the FLAIR system? (Please answer parts a-e)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ____________ ____________	☐	☐	☐

12. Of the goals listed in question 11, please circle the letter of the one that you feel is the most important.

13. How do you think the FLAIR system will affect performance in each of these areas? (please answer parts a-e)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ______ ______	☐	☐	☐

14. What do you see as the main potential problem that the FLAIR system will encounter?

☐ Equipment and computer problems

☐ Lack of support from policemen on the street

☐ Disciplinary abuses

☐ Difficulty in operating the system

☐ Other. Please state ______________________________

____

15. How do you think the FLAIR system will affect your ability to do your job well? Will it:

☐ Help you

☐ Make no difference

☐ Make it harder

16. How do you think that your task as a sergeant will be altered in each of the following areas: (please answer a-d)

	Increase	Stay the same	Decrease
a. Preventative patrol time	☐	☐	☐
b. Flexibility to follow individual hunches	☐	☐	☐

	Increase	Stay the same	Decrease
c. Coordinate operations with fellow officers	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Other. Please state: ______ ______	☐	☐	☐

17. How do you think the FLAIR system will affect the way you feel about your job?

☐ More satisfying ☐ No difference ☐ Less satisfying

18. How do you think the FLAIR system will influence your relationship with your patrolmen? Do you think it will:

☐ Make it better ☐ Make no difference ☐ Make it worse

19. How do you think the FLAIR system will affect discipline in the department. Will it:

☐ Make it fairer

☐ Make no difference

☐ Make it less fair

20. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel:

☐ More favorably toward the police

☐ No different than now

☐ Less favorably toward the police

21. What is your guess about how the department administration will evaluate the FLAIR system? Do you think it is more likely to:

☐ Decide to keep it

☐ Decide to drop it

22. Overall, do you think the benefits of the FLAIR system will justify the costs?

☐ Yes ☐ No

23. Do you have any suggestions or general comments about FLAIR? (Use an additional sheet, if necessary.)

Survey 3: First Patrolmen's Survey in District 5. Administered before the implementation of FLAIR.

DISTRICT 5

PATROLMEN'S SURVEY

This survey is designed to help evaluate the Fleet Locator and Information Retrieval System (FLAIR) and to provide the opportunity for field officers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a policeman? ______________yrs.

2. Please indicate the highest level of education completed:
   - ☐ High school diploma or equivalency
   - ☐ Some college
   - ☐ Bachelors degree
   - ☐ Some graduate work
   - ☐ Graduate degree

3. Are you currently taking any courses for credit toward a degree?

   ☐ Yes ☐ No

4. Overall, how satisfying do you find your profession as a policeman?
   - ☐ Very satisfying
   - ☐ Fairly satisfying
   - ☐ Not very satisfying

5. From what source did you first hear of the FLAIR car locator system?
   - ☐ A patrolman
   - ☐ A sergeant
   - ☐ A command officer
   - ☐ A Boeing representative
   - ☐ Patrolman's association
   - ☐ Newspaper or radio
   - ☐ Don't know what it is
   - ☐ Other. (Please state:______________________________)

6. Were you able to attend the July orientation seminars on FLAIR?

   ☐ Yes ☐ No

7. How well informed do you feel about:
   (please answer parts a, b, and c.)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

8. Do you feel that patrolmen have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

☐ Yes ☐ No

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

☐ Good idea ☐ Not a good idea

10. How do you think patrolmen will feel about the FLAIR system once they have used it? Do you think

☐ Most will be for it

☐ About half and half

☐ Most will be against it

11. How important do you think each of these goals is in implementing the FLAIR system? (please answer parts a-e)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ____________ ____________	☐	☐	☐

12. Of the goals listed in question 11, please circle the letter of the one that you feel is the most important

13. How do you think the FLAIR system will affect performance in each of these areas? (please answer parts a-e)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availibility of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ____________	☐	☐	☐

14. What do you see as the main potential problem that the FLAIR system will encounter?

- ☐ Equipment and computer problems
- ☐ Lack of support from policemen on the street
- ☐ Disciplinary abuses
- ☐ Difficulty in operating the system
- ☐ Other. Please state ____________

15. How do you think the FLAIR system would affect your ability to do your job well? Will it:

☐ Help you ☐ Make no difference ☐ Make it harder

16. How do you think that your task as a patrolman would be altered in each of the following areas: (please answer a-d)

	Increase	Stay the same	Decrease
a. Preventative patrol time	☐	☐	☐
b. Flexibility to follow individual hunches	☐	☐	☐
c. Coordinated operations with fellow officers	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Other. Please state: ____________	☐	☐	☐

17. How do you think the FLAIR system would affect the way you feel about your job?

☐ More satisfying ☐ No difference ☐ Less satisfying

18. How do you think the FLAIR system would influence your relationship with your patrol supervisors? Do you think it will:

☐ Make it better ☐ Make no difference ☐ Make it worse

19. How do you think the FLAIR system will affect discipline in the department. Will it:

☐ Make it fairer

☐ Make no difference

☐ Make it less fair

20. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel:

☐ More favorably toward the police

☐ No different than now

☐ Less favorably toward the police

21. What is your guess about how the department administration will evaluate the FLAIR system? Do you think it is more likely to:

☐ Decide to keep it

☐ Decide to drop it

22. Overall, do you think the benefits of the FLAIR system will justify the cost?

☐ Yes ☐ No

23. Do you have any suggestions or general comments about FLAIR?

Survey 4: First Sergeant's Survey in District 5. Administered before the implementation of FLAIR.

DISTRICT 5

SERGEANT'S SURVEY

This survey is designed to help evaluate the Fleet Locator and Information Retrieval System (FLAIR) and to provide the opportunity for field officers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a policeman? ________________yrs.

2. Please indicate the highest level of education completed:

   ☐ High school diploma or equivalency

   ☐ Some college

   ☐ Bachelors degree

   ☐ Some graduate work

   ☐ Graduate degree

3. Are you currently taking any courses for credit toward a degree?

   ☐ Yes ☐ No

4. Overall, how satisfying do you find your profession as a policeman.

   ☐ Very satisfying

   ☐ Fairly satisfying

   ☐ Not very satisfying

5. From what source did you first hear of the FLAIR car locator system?

   ☐ A patrolman

   ☐ A sergeant

   ☐ A command officer

   ☐ A Boeing representative

   ☐ Patrolman's association

   ☐ Newspaper or radio

   ☐ Don't know what it is

   ☐ Other (Please state:________________________________)

6. Were you able to attend the July orientation seminars on FLAIR?

   ☐ Yes ☐ No

7. How well informed do you feel about:
   (please answer parts a, b, and c.)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

8. Do you feel that sergeants have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

☐ Yes ☐ No

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

☐ Good idea

☐ Not a good idea

10. How do you think sergeants will feel about the FLAIR system once they have used it? Do you think:

☐ Most will be for it

☐ About half and half

☐ Most will be against it

11. How important do you think each of these goals is in implementing the FLAIR system? (Please answer parts a-e)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐

g. Other. Please state: ____________ ____________	☐	☐	☐

12. Of the goals listed in question 11, please circle the letter of the one that you feel is the most important.

13. How do you think the FLAIR system will affect performance in each of these areas? (Please answer parts a-e)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availioility of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ____________ ____________	☐	☐	☐

14. What do you see as the main potential problem that the FLAIR system will encounter?

- ☐ Equipment and computer problems
- ☐ Lack of support from policemen on the street
- ☐ Disciplinary abuses
- ☐ Difficulty in operating the system
- ☐ Other: Please state ______________________________

____

15. How do you think the FLAIR system would affect your ability to do your job well? Will it:

- ☐ Help you
- ☐ Make no difference
- ☐ Make it harder

16. How do you think that your task as a sergeant would be altered in each of the following areas: (please answer a-d)

	Increase	Stay the same	Decrease
a. Preventative patrol time	☐	☐	☐
b. Flexibility to follow individual hunches	☐	☐	☐
c. Coordinated operations with fellow officers	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Other. Please state: ______ ______	☐	☐	☐

17. How do you think the FLAIR system would affect the way you feel about your job?

☐ More satisfying ☐ No difference ☐ Less satisfying

18. How do you think the FLAIR system would influence your relationship with your patrolmen? Do you think it will:

☐ Make it better ☐ Make no difference ☐ Make it worse

19. How do you think the FLAIR system will affect discipline in the department. Will it:

☐ Make it fairer ☐ Make no difference ☐ Make it less fair

20. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel:

☐ More favorably toward the police

☐ No different than now

☐ Less favorably toward the police

21. What is your guess about how the department administration will evaluate the FLAIR system? Do you think it is more likely to:

☐ Decide to keep it ☐ Decide to drop it

22. Overall, do you think the benefits of the FLAIR system will justify the costs?

☐ Yes ☐ No

23. Do you have any suggestions or general comments about FLAIR? (Use an additional sheet, if necessary.)

Survey 5: "After" Survey in District 3. (Used for both patrol officers and sergeants.)

DISTRICT 3

SECOND FLAIR SURVEY

This survey is designed to help evaluate the Fleet Locator and Information Retrieval System (FLAIR) and to provide the opportunity to field officers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a policeman? ________________ years

2. Please check your rank.

   ☐ Patrolman ☐ Sergeant

3. Please indicate the highest level of education completed:

   ☐ High school diploma or equivalency
   ☐ Some college
   ☐ Bachelors degree
   ☐ Some graduate work
   ☐ Graduate degree

4. Are you currently taking any courses for credit toward a degree?

   ☐ Yes ☐ No

5. Overall, how satisfying do you find your profession as a policeman?

   ☐ Very satisfying
   ☐ Fairly satisfying
   ☐ Not very satisfying

6. How well informed do you feel about: (please answer parts a, b, and c.)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

7. Do you feel that patrolmen have had an opportunity to provide feedback for, or make a meaningful contribution to, the FLAIR system in St. Louis?

   ☐ Yes ☐ No

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

   ☐ Good idea ☐ Not a good idea

9. Overall, how has FLAIR's performance over the past three months compared with your early expectations?

- ☐ Better than what I expected
- ☐ About what I expected
- ☐ Not as good as I expected

10. How important do you think each of these goals has been in implementing the FLAIR system? (please answer parts a - f)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state:	☐	☐	☐

____

____

11. Of the goals listed in question 11, please circle the letter of the one that you feel is the most important.

12. How do you think the FLAIR system has affected performance in each of these areas? (please answer parts a - f)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state:	☐	☐	☐

____

____

13. What do you see as the main potential problems that the FLAIR system has encountered?

- ☐ Equipment and computer problems
- ☐ Lack of support from policemen on the street
- ☐ Disciplinary abuses
- ☐ Difficulty in operating the syst~~
- ☐ Communications problems
- ☐ Other. Please state: ______________________________

____

14. How easy has it been to use the FLAIR coded message unit?

- ☐ Very easy
- ☐ Fairly easy
- ☐ Difficult

15. How do you think the FLAIR system has affected your ability to do your job well? Has it:

- ☐ Helped you
- ☐ Made no difference
- ☐ Made it harder

16. As a result of FLAIR, how do you think that your task as a patrolman has been altered in each of the following areas: (please answer a - e)

	Increase	Stay the same	Decrease
a. Preventative patrol time	☐	☐	☐
b. Flexibility to follow individual hunches	☐	☐	☐
c. Coordinated operations with fellow officers	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Pursuits	☐	☐	☐
f. Other. Please state: ______ ______________	☐	☐	☐

17. How do you think the FLAIR system will affect the way you feel about your job?

- ☐ More satisfying
- ☐ No difference
- ☐ Less satisfying

18. How do you think the FLAIR system has influenced your relationship with your patrol supervisors? Do you think it has:

- ☐ Made it better
- ☐ Made no difference
- ☐ Made it worse

19. How do you think the FLAIR system has affected discipline in the department. Has it:

- ☐ Made it fairer
- ☐ Made no difference
- ☐ Made it less fair

20. How much of the time when you are on patrol do you think the FLAIR system would accurately locate you in an emergency?

- ☐ Almost all of the time
- ☐ Most of the time
- ☐ Some of the time
- ☐ Not much of the time

21. Overall, do you think the benefits of the FLAIR system will justify the cost?

☐ Yes ☐ No

22. Do you have any suggestions or general comments about FLAIR? (Additional paper will be provided if desired.)

Survey 6: "After" Survey in District 5
(Used for both patrol officers and sergeants.)

SECOND FLAIR SURVEY

This survey is designed to help evaluate the Fleet Location and Information Reporting System (FLAIR) and to provide the opportunity for field officers to make suggestions on its operation. Listed below is a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a policeman? _____ years

2. Please check your rank.

   ☐ Police Officer ☐ Sergeant

3. Please indicate the highest level of education completed:

   ☐ High school diploma or equivalency
   ☐ Some college
   ☐ Bachelors degree
   ☐ Some graduate work
   ☐ Graduate degree

4. Are you currently taking any courses for credit toward a degree?

   ☐ Yes ☐ No

5. Overall, how satisfying do you find your profession as a policeman?

   ☐ Very satisfying
   ☐ Fairly satisfying
   ☐ Not very satisfying

6. How well informed do you feel about: (please answer parts a, b, and c)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

7. Do you feel that patrolmen have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

   ☐ Yes ☐ No

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

   ☐ Good idea ☐ Not a good idea

9. How do you think patrolmen will feel about the FLAIR system once they have used it? Do you think

- ☐ Most will be for it
- ☐ About half and half
- ☐ Most will be against it

10. How important do you think each of these goals is in implementing the FLAIR system? (please answer parts a-g)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ____________ ____________	☐	☐	☐

11. Of the goals listed in question 10, please circle the letter of the one that you feel is the most important.

12. How do you think the FLAIR system will affect performance in each of these areas? (please answer parts a-g)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Officer safety	☐	☐	☐
c. Availability of non-patrol officers for high priority calls	☐	☐	☐
d. Preventing crime	☐	☐	☐
e. Keeping track of the patrol force	☐	☐	☐
f. Reducing radio congestion	☐	☐	☐
g. Other. Please state: ____________ ____________	☐	☐	☐

13. What do you see as the main potential problem that the FLAIR system will encounter?

- [ ] Equipment and computer problems
- [ ] Lack of support from policemen on the street
- [ ] Disciplinary abuses
- [ ] Difficulty in operating the system
- [ ] Communication problems
- [ ] Other. Please state: ____________________

14. How do you think the FLAIR system would affect your ability to do your job well? Will it

- [ ] Help you
- [ ] Make no difference
- [ ] Make it harder

15. How do you think that your task as a patrolman would be altered in each of the following areas? (please answer a-f)

	Increase	Stay the same	Decrease
a. Preventative patrol time	☐	☐	☐
b. Flexibility to follow individual hunches	☐	☐	☐
c. Coordinated operations with fellow officers	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Pursuits	☐	☐	☐
f. Other. Please state: ____________________	☐	☐	☐

16. How do you think the FLAIR system would affect the way you feel about your job?

- [ ] More satisfying
- [ ] No difference
- [ ] Less satisfying

17. How do you think the FLAIR system would influence your relationship with your patrol supervisors? Do you think it will

- ☐ Make it better
- ☐ Make no difference
- ☐ Make it worse

18. How do you think the FLAIR system will affect discipline in the department? Will it

- ☐ Make it fairer
- ☐ Make no difference
- ☐ Make it less fair

19. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel

- ☐ More favorable toward the police
- ☐ No different from now
- ☐ Less favorable toward the police

20. Overall, do you think the benefits of the FLAIR system will justify the cost?

- ☐ Yes
- ☐ No

21. Do you have any suggestions or general comments about FLAIR?

Survey 7: First Survey administered to the Dispatchers.

DISPATCHERS' SURVEY

This survey is designed to help evaluate the Fleet Locator And Information Retrieval System (FLAIR) and to provide the opportunity for dispatchers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a dispatcher? __________ years

2. Please indicate your position in the department.

   ☐ Civilian ☐ Cadet ☐ Patrolman ☐ Sergeant

3. Are you trained on the FLAIR console?

   ☐ Yes ☐ No

4. Have you worked at the FLAIR console?

   ☐ Yes ☐ No

5. Overall, how satisfying do you find your profession as a dispatcher?

   ☐ Very satisfying
   ☐ Fairly satisfying
   ☐ Not very satisfying

6. From what source did you first hear of the FLAIR car locator system?

   ☐ A patrolman ☐ A sergeant ☐ A command officer
   ☐ A Boeing Rep. ☐ A dispatcher ☐ Newspaper or radio
   ☐ Other (Please state:________________________________)

7. How well informed do you feel about: (please answer parts a, b, and c.)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

8. Do you feel that dispatchers have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

   ☐ Yes ☐ No

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

   ☐ Good idea ☐ Not a good idea

10. How do you think dispatchers will feel about the FLAIR system once they have used it? Do you think:

- ☐ Most will be for it
- ☐ About half and half
- ☐ Most will be against it

11. How important do you think each of these goals is in implementing the FLAIR system? (please answer parts a-h)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Reduce dispatch time	☐	☐	☐
c. Officer safety	☐	☐	☐
d. Availability of non-patrol officers for high priority calls	☐	☐	☐
e. Preventing crime	☐	☐	☐
f. Keeping track of the patrol force	☐	☐	☐
g. Reducing radio congestion	☐	☐	☐
h. Other. Please state:	☐	☐	☐

____

____

12. Of the goals listed in question 11, please circle the letter of the one you feel is the most important.

13. How do you think the FLAIR system will affect performance in each of these areas? (please answer parts a-h)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Reduce dispatch time	☐	☐	☐
c. Officer safety	☐	☐	☐
d. Availability of non-patrol officers for high priority calls	☐	☐	☐
e. Preventing crime	☐	☐	☐
f. Keeping track of the patrol force	☐	☐	☐
g. Reducing radio congestion	☐	☐	☐
h. Other. Please state:	☐	☐	☐

____

____

14. What do you see as the main potential problems that the FLAIR system will encounter?

- ☐ Equipment and computer problems
- ☐ Lack of support from policemen on the street
- ☐ Disciplinary abuses
- ☐ Difficulty in operating the system
- ☐ Lack of support from dispatchers
- ☐ Other. Please state: ______________________________

____

15. How do you think the FLAIR system will affect your ability to do your job well? Will it:

- ☐ Help you
- ☐ Make no difference
- ☐ Make it harder

16. How do you think that your task as a dispatcher will be altered in each of the following areas: (please answer a-e)

	Increase	Stay the same	Decrease
a. Ease of locating proper car	☐	☐	☐
b. Quickness of dispatching cars	☐	☐	☐
c. Quality of handling pursuits	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Other. Please state:	☐	☐	☐

____

____

17. How do you think the FLAIR system will affect the way you feel about your job?

- ☐ More satsifying
- ☐ No difference
- ☐ Less satisfying

18. How do you think the FLAIR system will influence your relationship with your supervisors? Do you think it will:

- ☐ Make it better
- ☐ Make no difference
- ☐ Make it worse

19. How do you think the FLAIR system will affect discipline in the department? Will it:

- ☐ Make it fairer
- ☐ Make no difference
- ☐ Make it less fair

20. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel:

- ☐ More favorably toward the police
- ☐ No different than now
- ☐ Less favorably toward the police

21. What is your guess about how the department administration will evaluate the FLAIR system? Do you think it is more likely to:

- ☐ Decide to keep it
- ☐ Decide to drop it

22. Overall, do you think the benefits of the FLAIR system will justify the cost?

☐ Yes ☐ No

23. What degree of confidence do you have in the FLAIR system?

- ☐ Much confidence
- ☐ Some confidence
- ☐ No confidence

24. Which <u>one</u> of the following best characterizes your view of a dispatcher's task?

- ☐ A dispatcher's duty is to serve and assist the patrol force.
- ☐ A dispatcher's duty is to direct the actions of the patrol force because they often are not aware of the district-wide situation.
- ☐ A dispatcher's duty is to act as a go-between for the patrol force and the command staff.

25. Do you have any suggestions or general comments about FLAIR? (Additional paper will be provided if desired.)

Survey 8: Second Survey administered to the Dispatchers.

SECOND DISPATCHERS' SURVEY

This survey is designed to help evaluate the Fleet Location and Information Reporting System (FLAIR) and to provide the opportunity for dispatchers to make suggestions on its operation. Listed below are a series of questions. In each case, please check the appropriate box or boxes. Please feel free to make any comments or to speculate on what the results of the system might be.

1. How many years have you been a dispatcher? _______ years

2. Please indicate your position in the department.

   ☐ Civilian ☐ Cadet ☐ Patrolman ☐ Sergeant

3. Are you trained on the FLAIR console?

   ☐ Yes ☐ No

4. Have you worked at the FLAIR console?

   ☐ Yes ☐ No

5. Overall, how satisfying do you find your profession as a dispatcher?

   ☐ Very satisfying
   ☐ Fairly satisfying
   ☐ Not very satisfying

6. How well informed do you feel about: (please answer parts a, b, and c)

	Very well	Fairly well	Not very well
a. The stated goals of the system	☐	☐	☐
b. How you will operate the system	☐	☐	☐
c. How the supervisors will use the system	☐	☐	☐

7. Do you feel that dispatchers have had an opportunity to provide feedback for or make a meaningful contribution to the FLAIR system in St. Louis?

   ☐ Yes ☐ No

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

   ☐ Good idea ☐ Not a good idea

9. How do you think dispatchers will feel about the FLAIR system once they have used it? Do you think

☐ Most will be for it
☐ About half and half
☐ Most will be against it

10. How important do you think each of these goals is in implementing the FLAIR system? (please answer parts a-h)

	Very important	Fairly important	Not important
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Reduce dispatch time	☐	☐	☐
c. Officer safety	☐	☐	☐
d. Availability of non-patrol officers for high priority calls	☐	☐	☐
e. Preventing crime	☐	☐	☐
f. Keeping track of the patrol force	☐	☐	☐
g. Reducing radio congestion	☐	☐	☐
h. Other. Please state:	☐	☐	☐

____

____

11. Of the goals listed in question 10, please circle the letter of the one you feel is the most important.

12. How do you think the FLAIR system will affect performance in each of these areas? (please answer parts a-h)

	Improve	No effect	Worsen
a. Dispatching nearest officer (reduce response time)	☐	☐	☐
b. Reduce dispatch time	☐	☐	☐
c. Officer safety	☐	☐	☐
d. Availability of non-patrol officers for high priority calls	☐	☐	☐
e. Preventing crime	☐	☐	☐
f. Keeping track of the patrol force	☐	☐	☐
g. Reducing radio congestion	☐	☐	☐
h. Other. Please state:	☐	☐	☐

____

____

13. What do you see as the main potential problems that the FLAIR system will encounter?

- ☐ Equipment and computer problems
- ☐ Lack of support from policemen on the street
- ☐ Disciplinary abuses
- ☐ Difficulty in operating the system
- ☐ Lack of support from dispatchers
- ☐ Other. Please state: ______________________________

____

14. How do you think the FLAIR system will affect your ability to do your job well? Will it

- ☐ Help you
- ☐ Make no difference
- ☐ Make it harder

15. How do you think that your task as a dispatcher will be altered in each of the following areas: (please answer a-e)

	Increase	Stay the same	Decrease
a. Ease of locating proper car	☐	☐	☐
b. Quickness of dispatching cars	☐	☐	☐
c. Quality of handling pursuits	☐	☐	☐
d. Quickness of response to emergency calls	☐	☐	☐
e. Other. Please state:	☐	☐	☐

____

____

16. How do you think the FLAIR system will affect the way you feel about your job?

- ☐ More satisfying
- ☐ No difference
- ☐ Less satisfying

17. How do you think the FLAIR system will influence your relationship with your supervisors? Do you think it will

- ☐ Make it better
- ☐ Make no difference
- ☐ Make it worse

18. How do you think the FLAIR system will affect discipline in the department? Will it

- ☐ Make if fairer
- ☐ Make no difference
- ☐ Make it less fair

19. How do you think the FLAIR system will influence the way the public feels about the police? Will the public feel

- ☐ More favorably toward the police
- ☐ No different from now
- ☐ Less favorably toward the police

20. What is your guess about how the department administration will evaluate the FLAIR system? Do you think it is more likely to

- ☐ Decide to keep it
- ☐ Decide to drop it

21. Overall, do you think the benefits of the FLAIR system will justify the cost?

☐ Yes ☐ No

22. What degree of confidence do you have in the FLAIR system?

- ☐ Much confidence
- ☐ Some confidence
- ☐ No confidence

23. Which one of the following best characterizes your view of a dispatcher's task?

- ☐ A dispatcher's duty is to serve and assist the patrol force.
- ☐ A dispatcher's duty is to direct the actions of the patrol force because they often are not aware of the district-wide situation.
- ☐ A dispatcher's duty is to act as a go-between for the patrol force and the command staff.

24. Do you have any suggestions or general comments about FLAIR? (Additional paper will be provided if desired.)

END