A Dead Reckoning/Map Correlation System for Automatic Vehicle Tracking

THOMAS W. LEZNIAK, RICHARD W. LEWIS, AND
ROBERT A. McMILLEN, MEMBER, IEEE

Abstract—**An automatic vehicle locating system using self-contained dead reckoning techniques, corrected by central processor map correlation, has been successfully implemented in a production program. The design studies, development testing, and system implementation of the Fleet Location And Information Reporting System (FLAIR®) are described.**

INTRODUCTION

AUTOMATIC vehicle location systems employing communication techniques are presently under development by several companies [1]. This paper discusses the concept and development of the Fleet Location And Information Reporting System (FLAIR®) for law enforcement applications.

Characteristics of the Police Automatic Vehicle Locating System

Efficient command and control of police vehicles operating in major urban areas requires accurate location and vehicle/officer status information [2]. This data must be available to the central commander and/or dispatcher in a format that is readily usable and in near real time. Location information should be provided automatically, with little or no interaction with the vehicle officer. The system should also provide a means for the vehicle officer to rapidly transmit status or standard message data to the dispatcher on a noninterference basis with the voice communications. The system should provide the commander or dispatcher the capability to interact dynamically with the vehicle fleet in times of rapidly changing operational situations.

The location system must successfully operate in the urban environment which includes the multipath effects from high rise buildings on radio transmissions, radio and magnetic interference, and 24 h operation. A benefit from urban operation is that vehicle travel is on drivable surfaces that can be accurately defined for a given geographical area.

Automatic Vehicle Locator Concept Selection

The FLAIR system, consisting of mobile and base equipment (see Fig. 1), operates on the fundamental dead reckoning principle that if the initial location of a vehicle is known, its location at any later time can be determined when heading and distance changes are added vectorially to its initial location. The heading and incremental distance the vehicle moves in each report period are transmitted by radio from the vehicle to the base equipment. Here the information is processed in a minicomputer, which updates the vehicle's location and presents it to the dispatcher on a color TV-type display.

Selection of the dead reckoning/map correlation concept evolved from company research and studies to develop an accurate vehicle tracking system based on self contained sensors with central data processing. Preliminary study indicated this concept offered major potential for the following reasons.

a) The map correlation provides an accurate means of correcting the cumulative increasing errors usually characteristic of a dead reckoning system. It also provides a display of vehicle location in a format readily usable by the dispatcher.

b) Use of a central processor for the tracking computation and map correlation provides for incorporation of system improvements without major hardware redesign.

c) The concept is not susceptible to problems associated with radio measurement techniques encountered in an urban environment.

System development began as an internally funded program in February 1971. In November 1974, a contract was signed for a St. Louis Metropolitan Police Department AVM Pilot Program system for 25 vehicles. The majority of program funding was by a grant from the Justice Department's Law Enforcement Assistance Administration (LEAA). The system was delivered in August 1974 and evaluated by St. Louis over a one-year period. Public Systems Evaluation, Inc., of Winthrop, Ma, [3] monitored system progress for LEAA by contract through December 1975. Over one million vehicle miles of operation has been accomplished in the Pilot Program. A follow-on production contract was awarded by the city of St. Louis in 1975 for a city-wide system on 200 vehicles and for 6 dispatcher positions. Delivery of equipment under this contract began in May 1976.

A patent was granted for the FLAIR system on January 4, 1974 [4]. In May 1974 a successful tracking test of basic system equipment was conducted in the city of London, England, under contract to Scotland Yard. FLAIR was designated by the National Society of Professional Engineers as one of the ten Outstanding Engineering Achievements in the United States in 1975.

AVM SYSTEM DEVELOPMENT

Vehicle Tracking Technique

Given the inital position of a vehicle, it is possible to calculate its position at subsequent times when the heading of the vehicle is reported as a function of distance traveled

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The authors are with the Boeing Company, Wichita, KS 67210.
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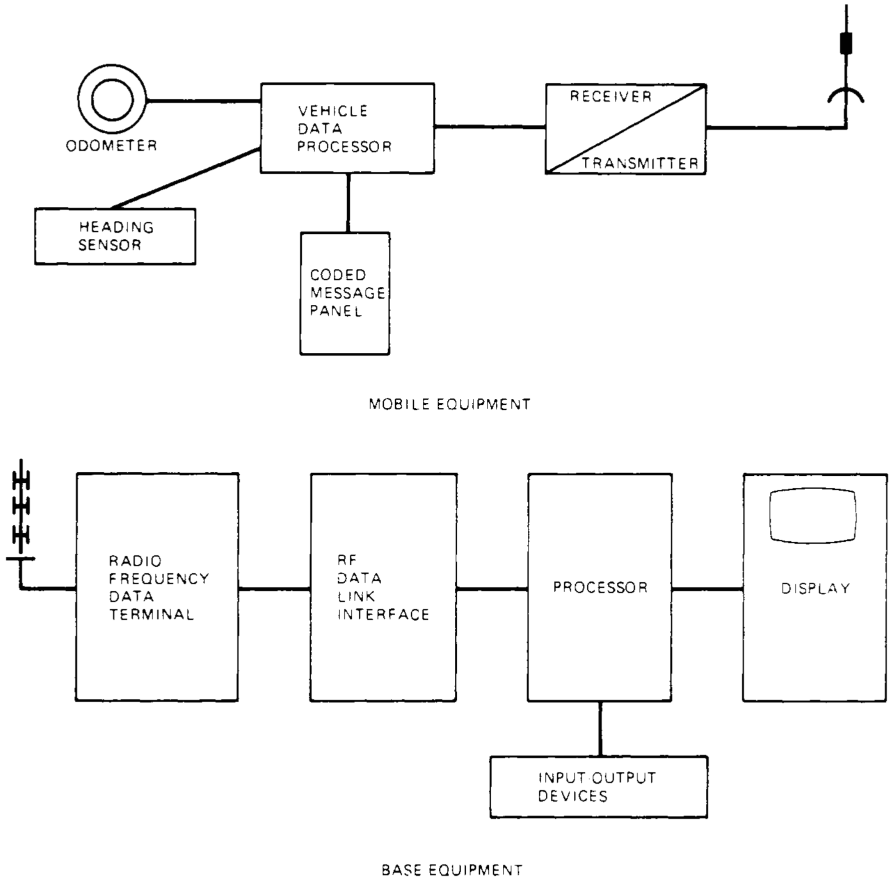

Fig. 1. FLAIR system.

from the initial position. More specifically, the coordinates (x,y) of the vehicle after it has moved from some initial position are calculated according to the following equations:

$$x = x_i + \int_0^s \cos\theta(s)\, ds$$

and

$$y = y_i + \int_0^s \sin\theta(s)\, ds$$

where

- (x_i,y_i) initial coordinates of the vehicle,
- s distance traveled by the vehicle since it left the initial position,
- $\theta(s)$ vehicle heading as a function of the distance traveled.

The term "open-loop tracking" refers to occasions when the heading $\theta(s)$ used in the coordinate computations is the heading measured and reported by the vehicle; "closed-loop tracking" refers to those occasions when the heading $\theta(s)$ used is the geometrical heading of the street to which the vehicle has been assigned by the tracking algorithm. The coordinates (x_i,y_i) are established by the process of "initialization."

The complete tracking algorithm operates primarily in the closed-loop mode. Measured vehicular heading is monitored at all times to determine when a vehicle is turning from its assigned street segment. At those times tracking switches to the open-loop mode. After an acceptable open-loop vector is established for the vehicle, the computer then searches the library of street segments and the vehicle is assigned to the proper new street segment. Tracking then switches back to the closed-loop mode.

The advantages of map correlation and combined open- and closed-loop tracking are readily demonstrated. Fig. 2 and 3 illustrate an example of a) the calculated trajectory of a vehicle using only open-loop tracking, and b) the trajectory calculated using the complete map-matching algorithm. (Both trajectories were calculated from the same data.)

Sensor Development

Key components of the tracking system are the distance and heading sensors. A simple magnetic pickoff odometer and a magnetometer heading sensor were selected as offering the most cost effective mechanization for vehicle application. The basic odometer pickoff was available from commerical sources, and the principle development effort was associated with investigation of error sources and effects on tracking accuracy. Initial tests utilizing available magnetic heading sensors verified the concept, but the hardware was not accept-

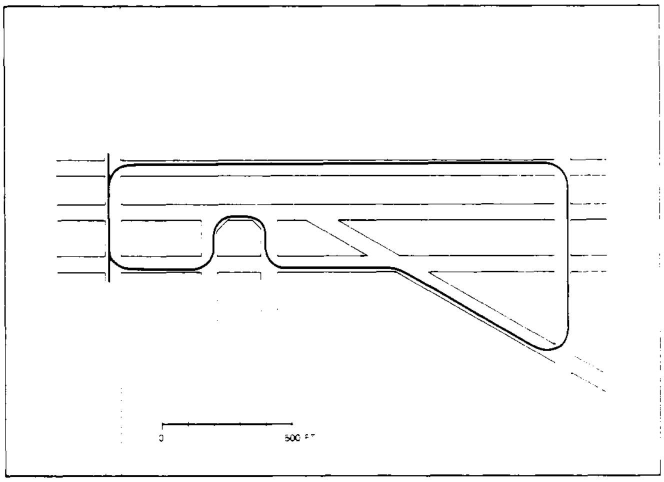

Fig. 2. Simulator street configuration and vehicle trajectory.

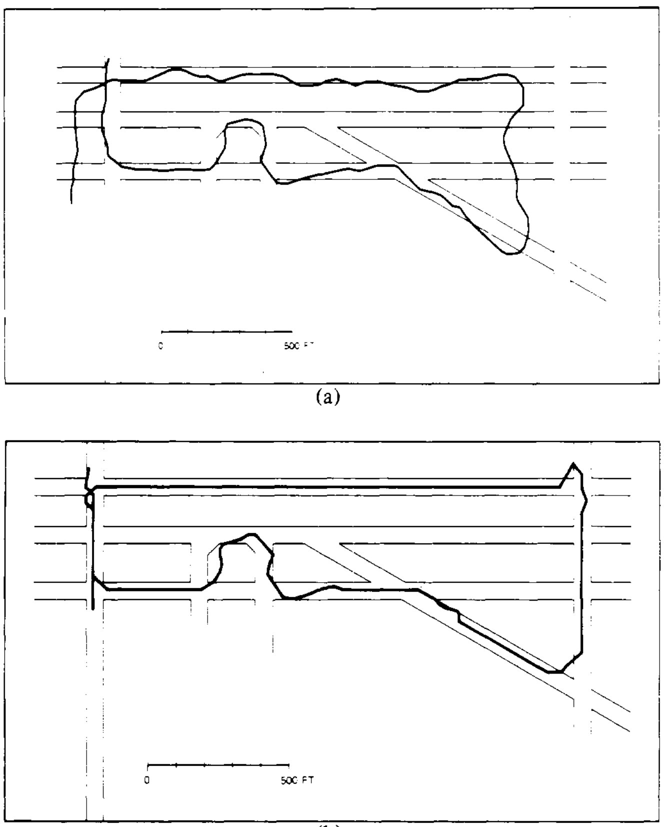

Fig. 3. Calculated vehicle trajectories. (a) Open-loop tracking only. (b) FLAIR map matching technique.

able for vehicle use. This led to the development of a magnetometer which provides a direct digital readout and can be electronically compensated.

The odometer pickoff senses angular rotation of the vehicle wheel; this angular rotation is converted to distance traveled by multiplying the number of odometer counts by a calibration constant which is proportional to the radius of the tire. The fact that tire radius is not strictly constant but varies slightly as the vehicle travels, introduces several potential sources of error into the distance computation. The major sources of tire radius variation are the following.

1) Tire radius tends to increase as vehicle velocity increases (because of increasing centrifugal force on the tire).

2) Tire radius tends to increase as air pressure within the tire increases (tire pressure increases may be due to increased tire temperature or other factors).

3) Tire radius tends to decrease as tread is worn off during the lifetime of the tire.

Several tests have been conducted to determine the magnitude of the velocity and air pressure effects. A vehicle was driven over an accurately measured 1100-ft course with a high resolution (2.35 in) odometer (i.e., the individual brake cooling fins on the vehicle's wheel were counted as the wheel turned). Odometer counting was initiated and terminated by light beams at the ends of the course. These tests were accomplished with two tire types: nonbelted bias ply tires and steel belted radial ply tires.

The tire pressure tests were run at pressures varying from 18 to 34 lbs/in^2. Figs. 4 and 5 illustrate the results of the pressure tests. The odometer error rate for a vehicle with bias ply tires calibrated at one pressure (e.g., 26 lbs/in^2) but operating at a pressure 4 lbs/in^2 higher or lower is 24 ft/mi; if the vehicle uses steel belted radial ply tires the error is only 5 ft/mi.

The velocity tests were run at speeds varying from 5 to 75 mi/h forward, and up to 25 mi/h in reverse. Figs. 6 and 7 illustrate the results of the velocity tests. The odometer error rate for a vehicle with bias ply tires traveling at 55 mi/h is 78 ft/mi; if the vehicle uses steel belted radial tires, the error is only 12 ft/mi. Regardless of the magnitude of the velocity error, the computer software calculates the vehicle velocity, determines the proper odometer correction factor, and eliminates this source of error.

The effects of tread wear are readily calculable, and apply to all tire types. A typical tire has a nominal radius of 13 in and a nominal total new tread depth of 3/8 in. Thus as tread is worn off over the life of the tire, there can be a total reduction in tire radius (and, therefore, odometer calibration constant) of approximately 3 percent. If the tire was calibrated only once when new, near the end of the tire's life the odometer error would amount to about 158 ft/mi. This error is eliminated by occasional recalibration of the tire when the vehicle undergoes routine maintenance. (Since the computer determines daily the total mileage driven by each fleet vehicle, the software could also automatically correct the odometer constant of each vehicle for this effect.) Table I summarizes the potential odometer error sources, the magnitude of the uncorrected error, and the error impact upon the system.

It should be reiterated that, regardless of the odometer error source, the magnitude of the error does not grow indefinitely; the error accumulates only to a maximum amount proportional to the straight line distance driven by the vehicle. When the vehicle executes a turn, the odometer error accumulated up to that time is reduced to zero as the algorithm assigns the vehicle to a new street segment for closed-loop tracking.

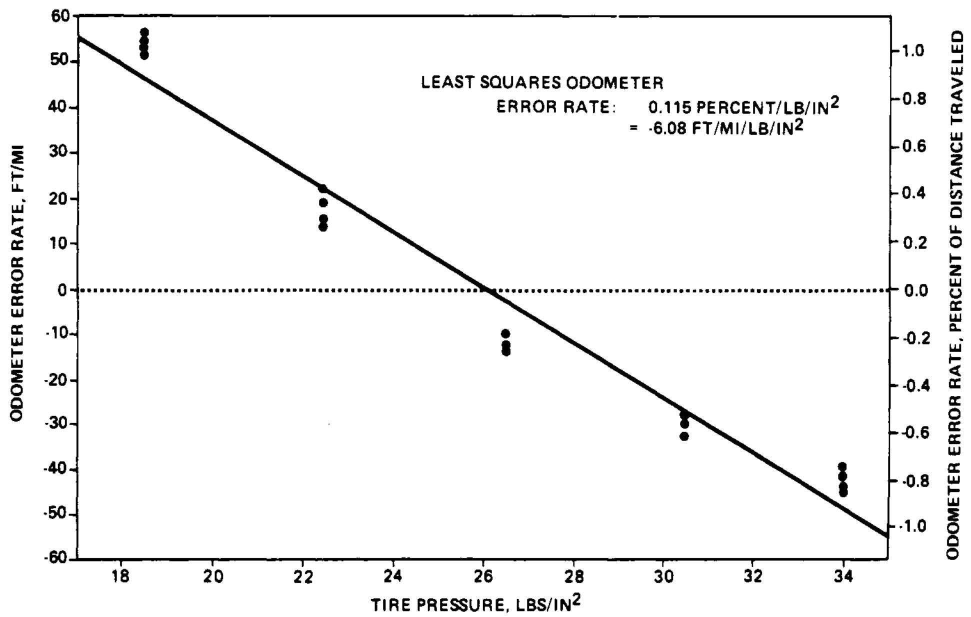

Fig. 4. Pressure error rate—Standard bias-ply tires.

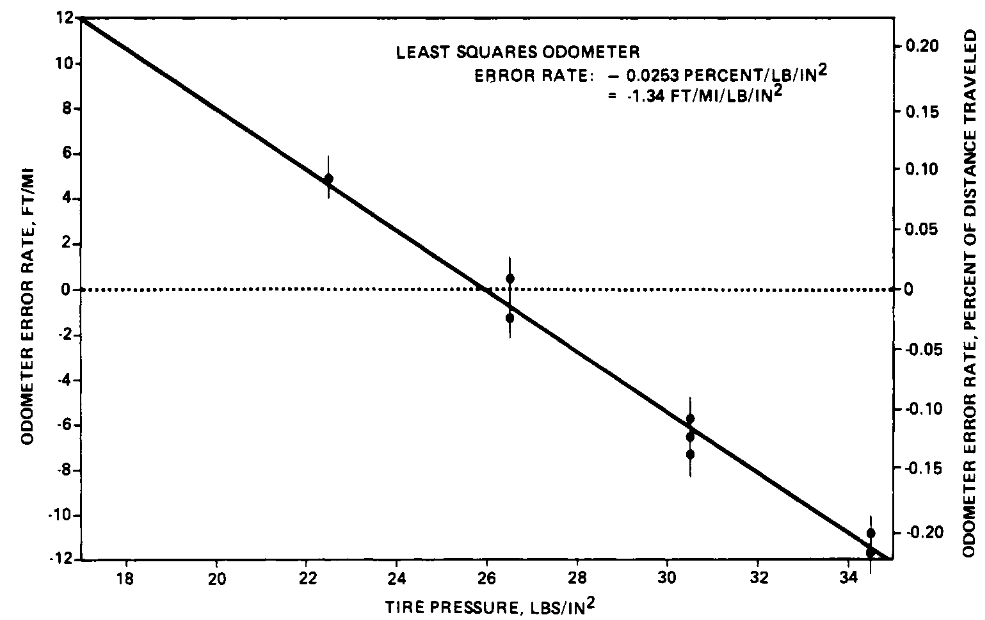

Fig. 5. Pressure error rate—Steel belted radial tires.

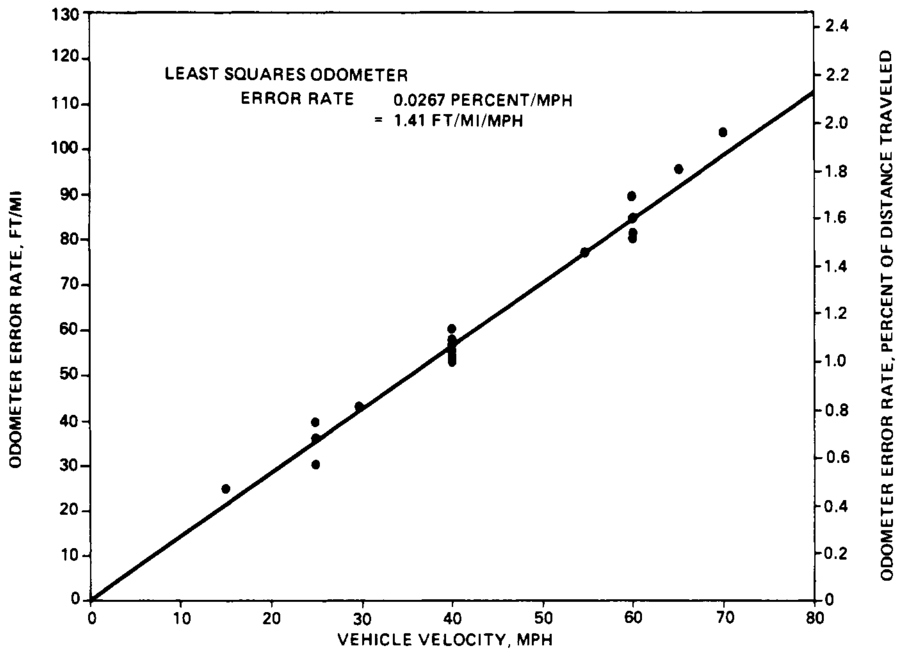

Fig. 6. Velocity error rate–Standard bias-ply tires.

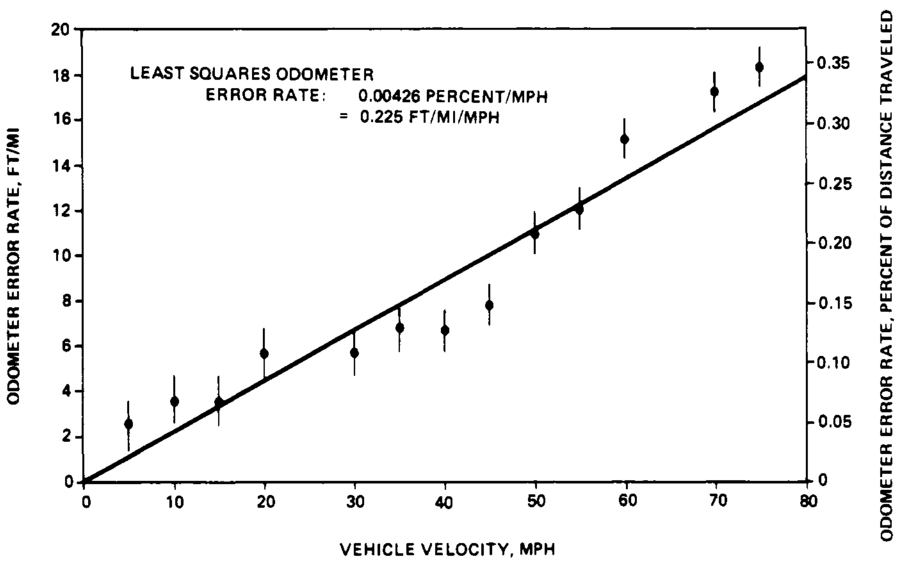

Fig. 7. Velocity error rate–Steel belted radial tires.

TABLE I
ODOMETER ERROR SOURCES–TIRE

Error Source	Magnitude	System Impact
Tire slippage due to slick surface	Undriven tire has negligible slippage	None - Odometer mounted on front wheel for rear driven vehicles
Tire wear	A reduction of about 3% in tire size is possible over the life of the tire (3/8 inch tread wear)	Negligible with recalibration during normal tire maintenance (rebalance, realignment, flat repair); computer correction is possible
Tire pressure	6.1 ft/mile/lb/in^2 for non-belted bias ply tires, 1.3 ft/mile/lb/in^2 for steel belted radial tires; Approximate linear error over the range 18 lbs/in^2 to 34 lbs/in^2 (See Figures 4 and 5)	Negligible under normal operating variation in tire pressure and typical urban driving
Velocity	1.4 ft/mile/mph for nonbelted bias ply tires, 0.2 ft/mile/mph for steel belted radial ply tires; Vehicle velocity was found to have an approximate linear effect on odometer error over the range 0-75 MPH (See Figures 6 and 7)	Velocity compensation is incorporated in the tracking computation

Tracking Algorithm Development

The development of the tracking algorithm for the full scale, production phase of the St. Louis program has evolved from early conceptual simulation and test, pilot program tracking experience and software modifications, and extensive study and simulation during production software development. Three tracking error studies have been undertaken since the installation of the pilot program. The purpose of these studies was to identify, understand, and eliminate or minimize the sources of error in the tracking process.

Sensor Resolution Study

The purpose of the sensor resolution study was to understand the relative impact of odometer resolution upon the probability that a vehicle turning orthogonally onto one of several possible streets would be assigned to the correct street by the tracking computer.

The scenario for the study is illustrated in Fig. 8. The vehicle drives for some distance in the closed-loop mode along "Random Road" (from A to B). The vehicle then executes a 90° left turn onto Street Y. Streets X and Z run parallel to Street Y and lie distance d above and below. The measure of system tracking performance for this scenario was defined to be the probability that the vehicle would be assigned to the correct street after the turn (i.e., the probability that the accumulated error in calculated position was sufficiently small that the tracking algorithm would not err). Some of the effects incorporated into this study were those of odometer resolution, report period length, velocity dependence of the odometer constant, velocity correction to the odometer constant, and accuracy of odometer calibration.

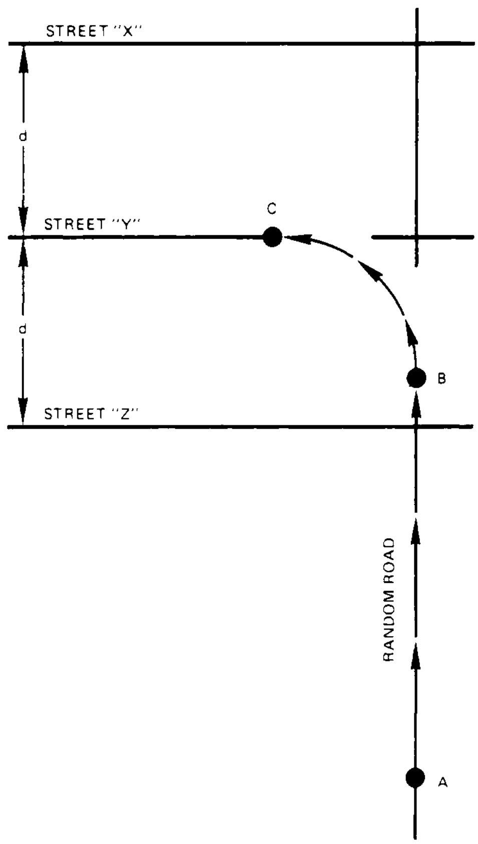

Fig. 8. Sensor resolution study scenario.

Table II is a tabulation of the probability of correct street assignment for this scenario as a function of odometer resolution and report interval length. Note the considerable sensitivity of the probability of correct street assignment to odometer resolution: the probability of correct assignment increases considerably as odometer resolution becomes finer. (In Table II, the number of bits devoted to odometer data depends on odometer resolution and report interval length.)

TABLE II
PROBABILITY OF CORRECT STREET ASSIGNMENT

REPORT INTERVAL LENGTH	6 ft	12 ft	24 ft	36 ft	48 ft
0.50 sec	X=38 ft P=1.000 BIT RATE=36.0	X=73 ft P=1.000 BIT RATE=34.0	X=147 ft P=0.539 BIT RATE=32.0	X=221 ft P=0.045 BIT RATE=32.0	X=293 ft P=0.006 BIT RATE=30.0
0.75 sec	X=40 ft P=1.000 BIT RATE=25.3	X=76 ft P=1.000 BIT RATE=24.0	X=157 ft P=0.413 BIT RATE=22.7	X=222 ft P=0.047 BIT RATE=21.3	X=303 ft P=0.005 BIT RATE=21.3
1.00 sec	X=44 ft P=1.000 BIT RATE=19.0	X=81 ft P=1.000 BIT RATE=18.0	X=151 ft P=0.494 BIT RATE=17.0	X=221 ft P=0.047 BIT RATE=17.0	X=302 ft P=0.003 BIT RATE=16.0
1.25 sec	X=45 ft P=1.000 BIT RATE=16.0	X=83 ft P=1.000 BIT RATE=15.2	X=158 ft P=0.388 BIT RATE=14.4	X=228 ft P=0.026 BIT RATE=13.6	X=303 ft P=0.002 BIT RATE=13.6
1.50 sec	X=48 ft P=1.000 BIT RATE=13.3	X=85 ft P=1.000 BIT RATE=12.7	X=165 ft P=0.313 BIT RATE=12.0	X=237 ft P=0.016 BIT RATE=11.3	X=311 ft P=0.006 BIT RATE=11.3
2.00 sec	X=58 ft P=1.000 BIT RATE=10.0	X=93 ft P=0.999 BIT RATE=9.5	X=166 ft P=0.295 BIT RATE=9.0	X=244 ft P=0.015 BIT RATE=9.0	X=323 ft P=0.001 BIT RATE=8.5

ODOMETER RESOLUTION

X: Street separation at which the probability of correct assignment is 0.500.
P: Probability of correct assignment if street separation is 150 ft.
BIT RATE: Required data rate, bits/sec/vehicle (assumes 7 bits for 10-code, 6 bits for heading).

The primary results/conclusions of the complete sensor resolution study were the following.

1) Tracking performance could be significantly improved by improving odometer resolution (e.g., from ±24 ft in the pilot program to ±6 ft in the production program).

2) Improved performance at a lower data rate could be attained by simultaneously improving odometer resolution and increasing report interval slightly (e.g, from 1.00 s in the pilot program to 1.215 s in the production program).

3) The tracking algorithm should correct the odometer constant for velocity effects (this is done in the production program).

Open-Loop Tracking Study

The purpose of the open-loop study was to concentrate attention on the techniques used to accomplish tracking in the open-loop mode and deal with any sources of error subsequently discovered. The scenario for the study assumed the following. The vehicle drove for a distance of 1 mi along each of three possible trajectories: a) two different random paths and b) a regular path similar to driving among city blocks. The vehicle was always tracked in the open-loop mode. It was assumed that heading was measured accurately to ±2.8° resolution, and that transmission noise was not present in the data. The measure of tracking performance was defined to be the accuracy of the calculated vehicle position.

The primary results/conclusions of the open-loop tracking study were the following.

1) A different computational technique was employed which reduces the computational error in the open loop tracking mode by a factor of 10.

2) A heading resolution of at least ±2.8° was found adequate to give good open loop tracking results when heading is measured accurately.

Closed-Loop Tracking Study

The purpose of the closed-loop study was to concentrate attention on the complete, complex tracking algorithm and the tracking errors associated with it. Because the tracking technique is complex (e.g., tracking alternates between open- and closed-loop modes, data is digital with finite resolution, magnetic heading is noisy, driveable surfaces have digital representations and approximations), simulation techniques are used to study it. A digital computer program has been developed to simulate the generation of data by vehicles driving over hypothesized trajectories. The data generated is then tracked with the tracking algorithm. Because the hypothesized position of the vehicle is known exactly at each report time, calculations of detailed tracking error statistics and distributions are readily accomplished.

The scenario for this study was the following. It is assumed that the vehicle drives over a 1-mi course of intersecting streets (see Fig. 2) and that the vehicle is tracked by the complete algorithm. Bad data (flagged and unflagged) is incorporated into the data stream. (Flagged bad data results from transmissions which do not pass receiver threshold tests.) Noise is also incorporated into the measured vehicle heading. A tracking map of the streets, equivalent in all respects to that used in the actual system, is provided to the algorithm. The measure of tracking performance is defined to be the accuracy of the calculated vehicle position at each report time.

The primary results/conclusions of the closed loop study were the following.

1) Several significant sources of error in the original pilot program algorithm were identified:

a) sensitivity to unflagged transmissions of erroneous odometer data,

b) delay in changing from closed-to open-loop tracking,

TABLE III
TRACKING IMPROVEMENTS

	Pilot System	Production System
Mapping		
Street Information	Undirected line segments No width information	Directed line segments Width information included
Parking lot search	Time consuming special search	Improved search technique similar to street search
Parking lot shapes	Rectangular only	Odd shape
Area Expandability	Single transceiver site	Remote sites possible
Tracking Algorithm		
Distance Traveled	Not velocity corrected	Velocity corrected
Open-Loop Tracking	Unimproved computational technique	Improved computational technique
Unflagged bad data	Error sensitive	Error insensitive
Closed-to-Open Criteria	Errors increase during decision process	Errors do not increase during decision process
Street Search	Ineffective use of heading information, criteria for candidate streets too broad	More effective use of heading information, improved weighting of heading and distance information, and better formula for determining candidate streets
Open-to-Closed Techniques	Nonorthogonal closures increase error	Nonorthogonal closure errors eliminated
Data Storage	Current and previous data point stored	Multidata point history maintained for more sophisticated decisions
Odometer Resolution	24 ft.	6 ft.
Heading Resolution	$\pm 5.6^{\circ}$	$\pm 1.4^{\circ}$

c) street search criteria did not utilize heading information efficiently,
d) tracking error increases when small angle turns were executed.

2) A very effective discriminator against unflagged bad odometer data was devised and tested (99.91 percent successful in a test of 200 000 total transmissions, 5 percent unflagged bad data rate).
3) The tracking simulator developed for this study provided a powerful objective measure of tracking system performance.

On the basis of the error sources identified in the closed-loop study, several new closed-loop tracking techniques were developed and incorporated into the final algorithm. Table III summarizes the improvements incorporated in the final production tracking software based on the above studies.

System Accuracy

Currently there are two basic measures of system tracking accuracy: 1) analysis of data generated by vehicles actually driven on the street and 2) results from computer simulations of the tracking process. To estimate system tracking accuracy of the pilot system with on-the-street data, a fixed 19.2-mi route was devised and driven 4 times by each of 3 FLAIR equipped vehicles. The route incorporated a wide variety of driving situations: freeways, wide streets, narrow streets, alleys,

TABLE IV
RESULTS OF FLAIR PILOT SYSTEM ON-THE-STREET ACCURACY TESTS

1. Results with no reinitializations
   - Average system error was 72 ft.
   - Vehicles on correct street 95.7% of distance traveled
   - Vehicles displayed with less than 1/2 block error 92.7% of distance traveled
2. Results with two runs reinitialized
   - Average system error was 56 ft.
   - Vehicles on correct street 97.3% of distance traveled
   - Vehicles displayed with less than 1/2 block error 93.7% of distance traveled

TABLE V
FLAIR PILOT PROGRAM SYSTEM TRACKING ACCURACY–SIMULATOR RESULTS

Heading Noise Std Dev. 10°:	μ = 40 ft.	(Mean Radial Error)
(Comparable to measured magnetic heading on Jefferson Street)	σ = 56 ft.	
Heading Noise Std Dev. 20°:	μ = 67 ft.	
(Comparable to measured magnetic heading on Chippewa St.)	σ = 75 ft.	

TABLE VI
FLAIR PRODUCTION SYSTEM TRACKING ACCURACY–SIMULATOR RESULTS

Heading Noise Std Dev. 10°:	μ = 33 ft.	(Mean Radial Error)
(Comparable to measured magnetic heading on Jefferson Street)	σ = 22 ft.	

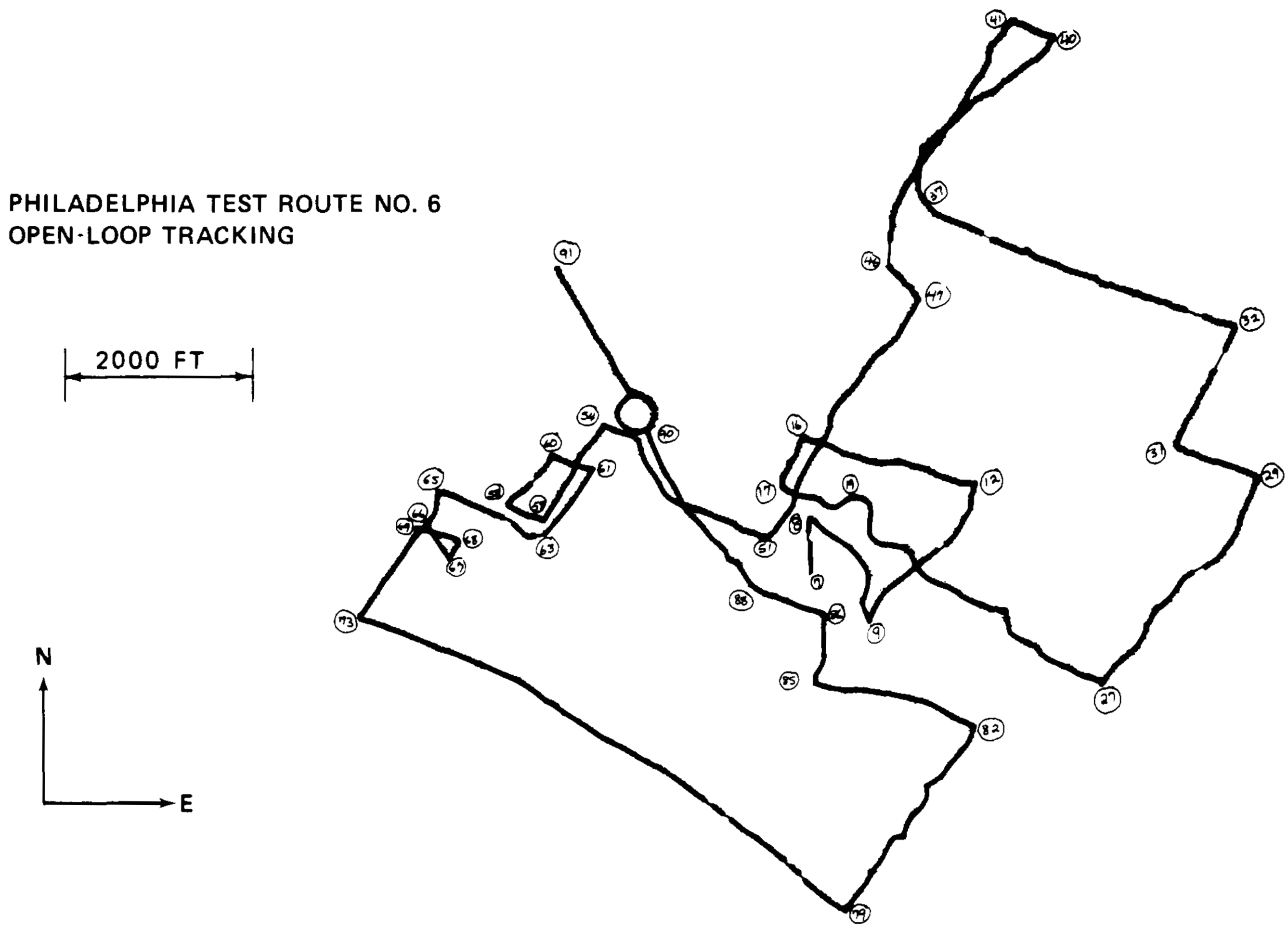

Fig. 9. Open-loop plot magnetometer heading.

high and low speed driving. Vehicular heading was measured with the magnetometer with a resolution of ±5.6°. The odometer resolution was ±24 ft, and each vehicle reported at 1.00-s intervals. The analyzed results of the test are summarized in Table IV.

A production mobile unit with instrumentation for recording the sensed tracking data was taken to St. Louis in February 1976 and Philadelphia in March 1976. Data was collected over a wide variety of routes and driving conditions using ±6 ft odometer resolution, ±1.4° heading resolution, and 1.215 s report interval. This recorded data was played back through the production hardware/software system to obtain an evaluation of the St. Louis production system. The data reduction was incomplete at the time this paper was submitted. However, the route used in the pilot system evaluation had been driven twice and played back with the vehicle on the correct street at all times with no reinitializations after the start of the run.

Table V is a tabulation of some tracking error statistics generated with the simulator for the pilot program. The mean and standard deviation of radial error in calculated vehicle position are tabulated for two hypothesized levels of heading noise. The 10° and 20° levels of heading noise (consistent with the levels measured with the magnetometer on Jefferson and Chippewa Streets in St. Louis) give mean errors consistent with the on-the-street measurements previously quoted. Table VI is a tabulation of system accuracy using the production algorithm in the simulator.

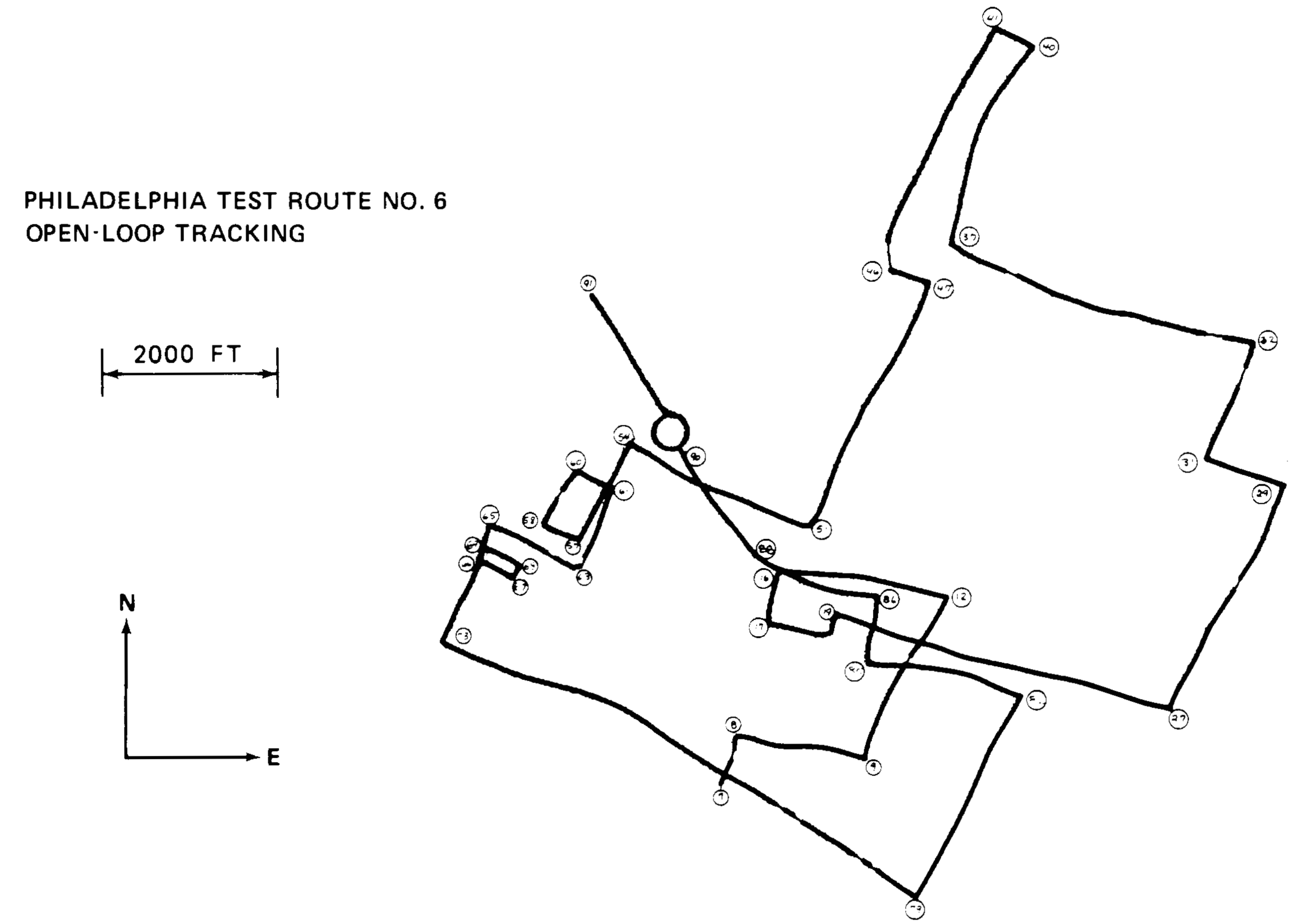

Fig. 10. Open-loop plot augmented heading.

Heading Data Improvement Techniques

Additional development has been conducted on heading augmentation techniques to improve tracking in operational locations where extensive magnetic anomalies exist. A prototype of one of these techniques, a dual wheel odometer, has been built and tested with the production tracking system. An odometer pickoff is mounted on each front wheel. Rapid fluctuations in magnetic sensor output are damped by comparison of the heading change indicated from differential wheel rotation with the magnetic heading change. Drift errors in the differential count are introduced due to tire size, wear and pressure, weight distribution, sharp and high-speed turns, slippage, velocity, and road characteristics. Testing has shown that a typical drift rate of 20° to 60° per mile can be corrected to less than 0.1° per mile when corrected by the long term magnetic heading. Fig. 9 shows the open loop (uncorrected plot of magnetic heading and distance) plot of data recorded in March 1976 in downtown Philadelphia with a production mobile unit incorporating the dual wheel odometer. Magnetic heading, augmented heading, and a directional gyro reference heading were simultaneously recorded. The test route shown in the following figures is in the central high rise area of Philadelphia. The central area of the plot is around the City Hall square. Fig. 10 shows the open-loop plot of the same test using augmented heading. The data represents an elapsed driving time of about 1.5h. The streets between points 8-9, 19-27, and 51-54 are areas of severe magnitic anomalies as indicated from the plot in Fig. 9. The effect of the augmented heading is seen by comparing these points in the plot of Fig. 10. The overall distortion in both plots is due to the long term error buildup. This effect is eliminated in the computer map correlation process when tracking closed-loop. Fig. 11 shows an open-loop plot of the same test using a reference directional gyro which is indicative of a resultant closed-loop plot.

Additional tests were conducted outside the central high rise area where severe magnetic anomalies were expected. Fig. 12 is a plot of the recorded magnetic, dual odometer augmented, and gyro headings taken in such a test. The wide fluctuations in magnetic heading in the central region of the plot are caused by electric trolley power lines and tracks. The large difference between the gyro heading and the magnetic heading on Broad Street is due to a long term bias in the magnetic field. In all cases, it is seen the augmented heading closely tracks the gyro heading and would result in improved tracking performance. The offset between the gyro trace and the augmented trace is due to gyro drift since initial test calibration (approximately 2-3 h prior to start of this run).

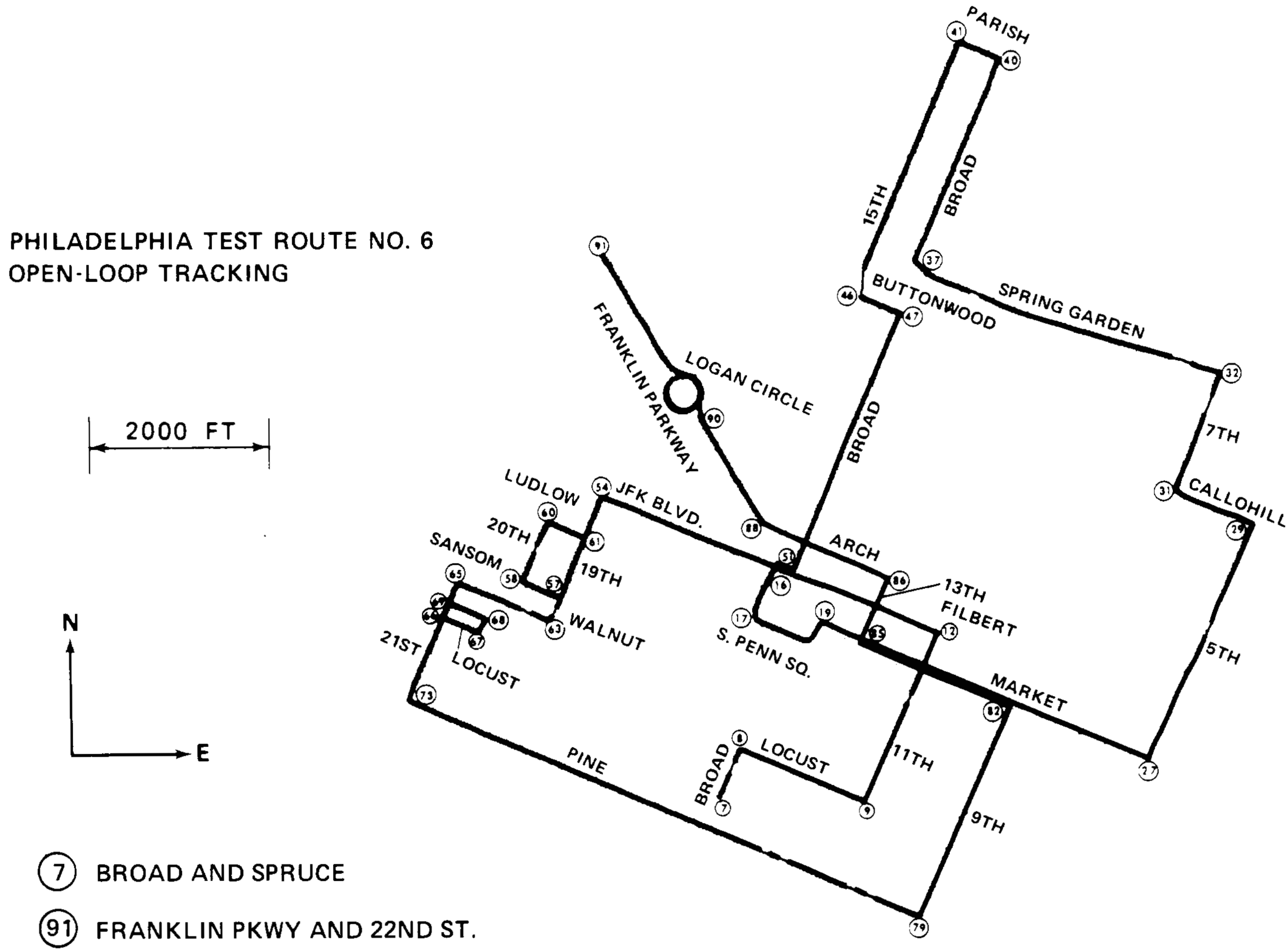

Fig. 11. Open-loop plot gyro heading.

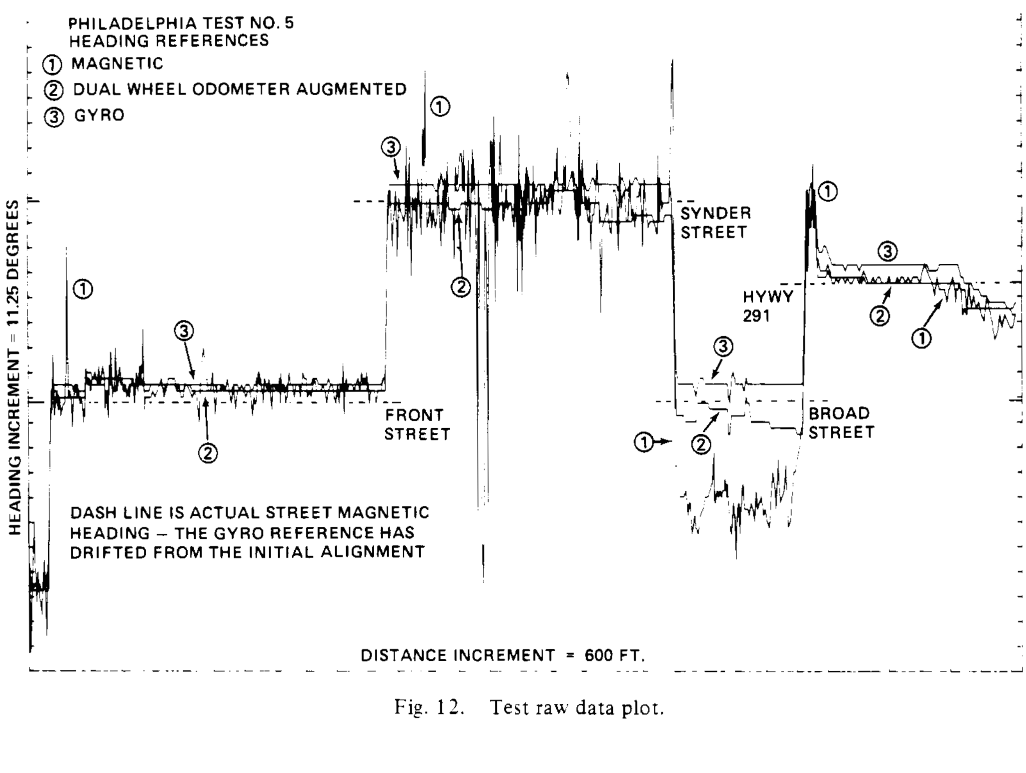

Fig. 12. Test raw data plot.

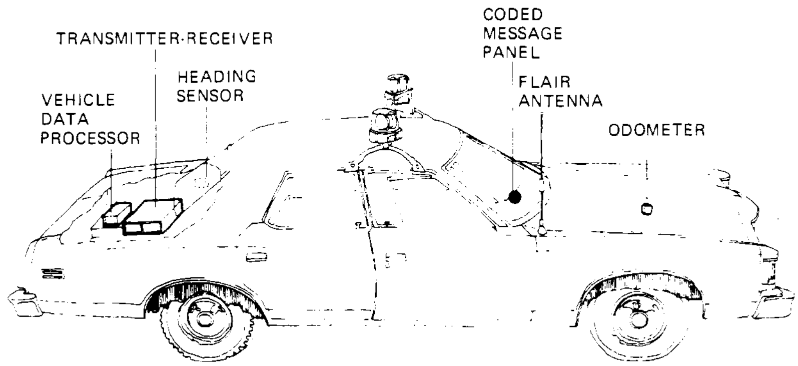

Fig. 13. FLAIR mobile installation.

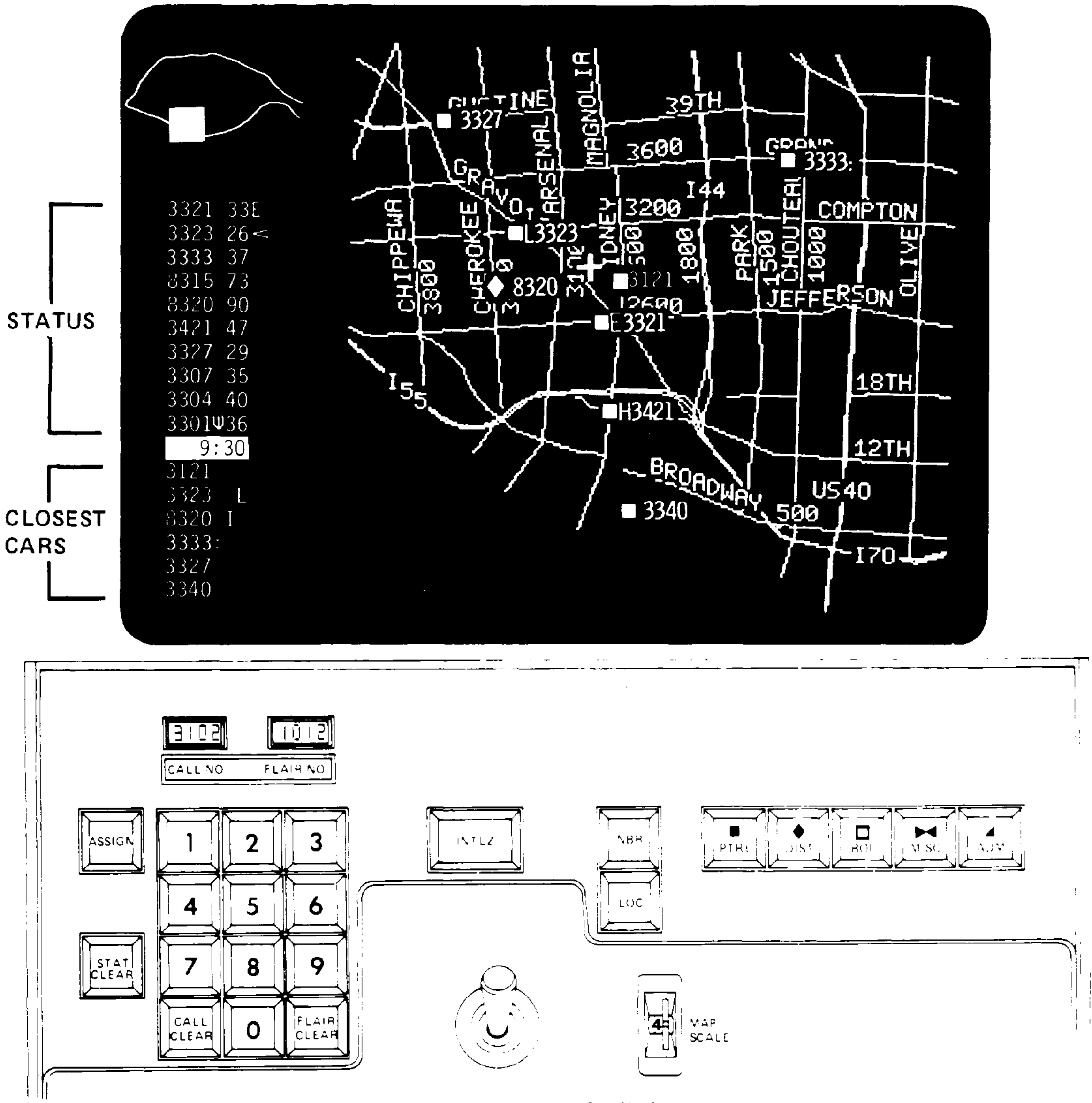

Fig. 14. FLAIR display.

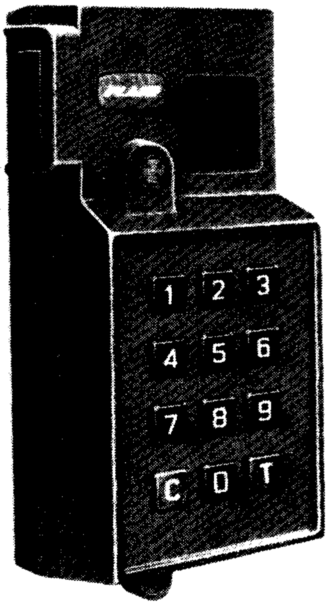

Fig. 15. Coded message unit.

Test data taken with a dual odometer on Jefferson and Chippewa streets in St. Louis resulted in a heading noise standard deviation of 2° (compared to 10° to 20° unaugmented magnetometer heading). When data with this low noise characteristic was used in the tracking simulator, tracking accuracy statistics improved to a mean radial error $\mu = 21$ ft and standard deviation $\sigma = 14$ ft (production algorithm). This is a significant improvement in tracking accuracy of 1.6 to 3.2 over the results shown in Tables V and VI.

SYSTEM IMPLEMENTATION

System Configuration

The production system is a result of the development and pilot program experience previously discussed. The system consists of the mobile unit, the base station data terminal, and central processor and display. The mobile equipment includes that portion of the system installed in the vehicle which develops the self-contained dead reckoning and vehicle/officer message information. A typical mobile equipment installation is shown in Fig. 13.

The base equipment includes all components of the system required to process the location and vehicle/officer message data received from the mobile equipment and display processed data to the dispatcher. The equipment includes a radio frequency (RF) data terminal and antenna, data link interface, a minicomputer and peripherals, a video processor and control console/display. Remote RF data terminals may also be used to obtain wide geographic area RF coverage. The data link operates in the UHF (450–470 MHz) frequency band. The system is time synchronized by the base transmitter and accommodates 200 vehicles per mobile transmit frequency. Each vehicle transmits a 20-bit data message every 1.215 s to the base receiver.

System Operation

The vehicle's initial position is entered in the central processor tracking table when the mobile unit is installed and the vehicle is assigned a report time slot. Vehicle position is then continuously maintained in the processor tracking table as long as the mobile unit is installed and operational. When the vehicle is parked and the mobile unit is turned off, the central processor retains the last position. When the vehicle is restarted, data transmission begins again, and tracking automatically continues from the last vehicle location without reinitialization. The system software is designed to monitor each mobile unit's tracking performance to detect potential location errors. If the vehicle tracking fails to pass the prescribed criteria, the dispatcher is alerted via the display to verify the present vehicle location by communicating with the operator. If this location differs significantly from that displayed, the dispatcher can reintialize the vehicle position through the display control panel.

The system provides a number of features to give the dispatcher rapid detailed information on individual vehicle location and officer/vehicle status. A specific officer/vehicle can be located by entering either the assigned officer's call number or the vehicle's number into the computer by using console controls. The computer automatically selects the proper maps to keep the located vehicle on the display as the vehicle moves about the area of coverage. Fig. 14 shows a typical display presentation.

To service an incident the dispatcher designates the point of interest with the cursor control. The call numbers of the six available officers in their order of proximity to the location, will be displayed in the message column on the dispatcher's display. Any combination of five categories of officer groups, such as detective, patrol, administrative, can be selected for display. Since the dispatcher can view the continuous movement of all field forces, data is available for dynamic command and control direction of the deployed vehicles when required.

In the vehicle, the officer has the capability to transmit up to 99 two-digit coded messages (see Fig. 15). The coded message unit allows communication to the dispatcher without the use of voice channels. In the St. Louis pilot program, an average of 2600 messages per day were transmitted from the 25 equipped cars leaving the voice channel clear for other communications. With the production system installed in 200 vehicles it is expected over 20 000 digital messages per day will be transmitted.

Reference Map

The map correlation process requires an accurate tracking map reference. These maps are prepared by digitizing the driveable surfaces (streets, alleys, parking lots) for the area of tracking coverage using 200 ft/in city maps; they are updated using aerial photographs to incorporate any changes to the basic map. Display maps are stored in three scales: a single map covering the total tracking area, an intermediate coverage with major streets shown, and a one square mile area with all streets shown. Overlap is provided in the latter two scale maps for continuity when changing maps as a vehicle moves off the displayed area. This scale change provides the dispatcher a step zoom capability from overall orientation to maximum detail.

SUMMARY

A state of the art automatic vehicle tracking system has been developed. The pilot system has had over one million miles of operational vehicle tracking. The present production system has incorporated major improvements in system tracking performance and hardware reliability.

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Evaluating a Police-Implemented AVM System: The St. Louis Experience (Phase I)

RICHARD C. LARSON, MEMBER, IEEE, KENT W. COLTON, AND GILBERT C. LARSON

***Abstract*—The St. Louis Metropolitan Police Department is the first major urban police department to implement an automatic vehicle monitoring (AVM) system. The AVM technology incorporates computer-aided dead-reckoning, thus facilitating vehicle tracking on individual streets in a city. Implemented as a Phase I prototype system in one police district early in 1975, the test system is evaluated in this paper utilizing a three-pronged approach. Focusing on 1) technology, 2) police operations, and 3) attitudes and organizational impact, attention is given to operational performance in Phase I, to ameliorative action for Phase II, and to the affects of AVM on response time, officer safety, voice-band congestion, and command and control.**

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R. C. Larson and K. W. Colton are with the Massachusetts Institute of Technology, Cambridge, MA, and with Public Systems Evaluation, Inc., Cambridge, MA 02139.

G. C. Larson is with Public Systems Evaluation, Inc., Cambridge, MA 02139.

I. INTRODUCTION

THE POTENTIAL police uses of automatic vehicle monitoring (AVM) systems were first highlighted by the President's Commission on Law Enforcement and Administration of Justice in 1967 [1], [2]. Studies at that time suggested that such systems might achieve cost-effective reductions in police response time. Some hypothesized that AVM would improve apprehension rates and thus serve as a deterrent to crime. Fully eight years after the President's Commission report, the installation of a computer-assisted dead-reckoning system[1] by the St. Louis Metropolitan Police Department (SLMPD) represents the first full-scale implementation of an AVM system in a major urban police department.

[1] The particular AVM system implemented in St. Louis and discussed in this paper is the Boeing-manufactured FLAIR System. FLAIR is a registered trademark of the Boeing Company, signifying Fleet Location And Information Reporting. It is important to recognize that the issues discussed herein pertain to a specific AVM system, namely the FLAIR system, and–perhaps the most important–to a Phase I prototype system, not an "off-the-shelf" production system.

Fig. 15. Coded message unit.