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A COMPREHENSIVE FIELD TEST AND EVALUATION OF AN ELECTRONIC SIGNPOST AVM SYSTEM
Volume I: Test Results

G. W. Gruver

Hoffmann Information Identification Inc.
Fort Worth TX 76107

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FINAL REPORT

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16. Abstract

A comprehensive test of a direct proximity electronic signpost AVM system was conducted under operational conditions in downtown Philadelphia. Tests involved operation of a test vehicle while operating as a random route vehicle; e.g., police, taxi; and a fixed route vehicle; e.g., a transit bus. During random route tests, the vehicle operated on an unrestricted basis in a designated area in which the Hoffman overlapping signpost AVM system was installed. The vehicle's location was computed every 0.5 second by the AVM system and compared with its actual location at designated "checkpoints" in the random route area. In the random route tests, the system showed the capability of locating the vehicle to within 282 feet, at 95 percent of the sample points under a wide range of urban and environmental conditions.

Fixed route tests involved operation as a transit bus. An odometer and 15 signposts provided the vehicle's location to within 105 feet at 95% of the sample points along a 13 mile route. The time of passage of designated bus schedule "timepoint" was automatically determined to within 11 seconds 95 percent of the time.

This report contains two volumes. Volume II is an appendix.

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PREFACE

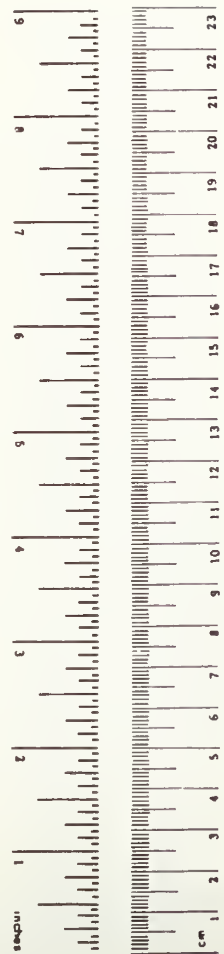
During the winter of 1976-77, four different techniques for automatically locating land vehicles were tested in both the low- and high-rise regions in Philadelphia, Pa. The tests were carried out by four different companies under separate contracts to the United States Department of Transportation, Transportation Systems Center. The tests were designed to evaluate the techniques for their applicability as location subsystems for automatic vehicle monitoring systems. This document represents one of the contractors' final report. A summary report on all systems tested is available as Report No. UMTA-MA-06-0041-77-2. This report describes the Phase I program which involved the installation and test of the Hoffman AVM System. Dr. George W. Gruver, the program director for Hoffman, prepared the report and personally conducted most of the testing. Ron Waits developed all of the program software and processed the test data. Jerry McKinney was in charge of the location and test equipment deployment and also performed most of the driving during formal tests.

We want to thank all of the technical, program, and contract personnel at the DOT. In particular the personnel in the offices of Messrs Blood, Symes, and Nelson were very helpful and enthusiastic. A special thanks is given to Bernie Kliem, our technical monitor and Joe Herlihy, who helped monitor our test. Also, Mr. Jack Ludwick of the Mitre Corporation helped make our software task much easier. We would also like to thank the many people in the City of Philadelphia who assisted us in deploying and housing our equipment.

METRIC CONVERSION FACTORS

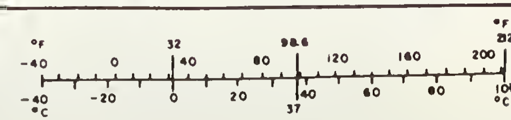
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The application of Automatic Vehicle Monitoring (AVM) to enhance the management of mobile resources has, in recent years, become a subject of continued interest to all types of fleet vehicle operations. Transit, police, cargo, and mining operations have been involved in the development of AVM systems and are currently gathering data pertinent to quantifying the cost/benefits of AVM in a variety of commercial and service operations.

The United States Department of Transportation (DOT) has been interested in AVM for nearly a decade; this interest being directed, in particular, to improving transit and para-transit management activities. Under the sponsorship of the Urban Mass Transportation Authority (UMTA), the DOT is currently attempting to quantify the improvements which AVM can provide to transit, para-transit, and other types of fleet operations. This report contains the interim results obtained by Hoffman Information Identification, Inc. (HI^3) of Fort Worth, Texas, as a contractor to the Transportation Systems Center of the DOT on the UMTA Multi-User AVM Contract DOT-TSC-1237. This report covers the activities of Phase I which involved the installation and test of a HI^3 AVM System in the City of Philadelphia during the winter of 1976-1977. These tests represent the most extensive tests ever performed on an AVM system which can locate vehicles which operate either as fixed-route vehicles (transit) or as random-route vehicles (police, para-transit, taxi, etc.).

This volume contains a description of all test configurations, test procedures, location algorithms, data processing, and test results. An Appendix, Volume II, contains the test data and detailed data processing results.

2. EXECUTIVE SUMMARY

In September 1976, the Transportation Systems Center of the U.S. Department of Transportation entered into contracts with four companies for the design, development and deployment of a multi-user Automatic Vehicle Monitoring (AVM) System which can be deployed in any city. Hoffman Information Identification Incorporated (HI^3) of Fort Worth, Texas, a wholly owned subsidiary of Hoffman Electronics Corporation and its subcontractor, IBM, received one of these contracts. The program, sponsored by the Urban Mass Transportation Administration (UMTA) is referred to as Multi-User AVM since it is intended to provide AVM benefits to a multiplicity of users, including those fleets of vehicles which generally travel on fixed routes (transit) and those which may travel random routes (taxis, para-transit, dial-a-ride, police, pick-up and delivery, etc.).

The objectives of the Multi-User AVM program were to design, implement, and operate a multi-user AVM system in Los Angeles for the purpose of making a quantitative evaluation of AVM effectiveness, first for transit and para-transit, and second for other AVM users. From the outset, the program was divided into two phases. Phase I, which Hoffman completed on 28 February 1977, involved the demonstration and test of each contractor's vehicle location subsystem in Philadelphia, Pa. Phase II, which will be performed by one of the four contractors, will include the design, development, implementation, test, and operational support of a modern transit management system using a reliable, economical AVM system. The Phase II program will be conducted in conjunction with the Southern California Rapid Transit District (SCRTD) and other users, to be specified, in the Los Angeles area. The primary objective set for Phase I was that of quantifying through formal controlled tests, the ability of each contractor's AVM system to meet specified vehicle location and bus time-of-passage requirements.

The results presented in this report show that the HI^3 AVM system proposed for Phase II can provide a transit dispatcher with the location of all buses to within an accuracy of 105 feet 95 percent of the time. The average error in bus location was less than 50 feet for all Phase I tests. As an aid to providing improved service through adherence to schedule, the HI^3 AVM system can provide the time-of-passage of buses to within 11 seconds for 95 percent of the occurrences in which the bus fleet passes predesignated "timepoints". The average time-of-passage error for Phase I was 3.9 seconds. The same HI^3 AVM system can provide a dispatcher with the location of each unit of a fleet of random route vehicles, e.g., police, taxi, etc., to within 282 feet 95 percent of the time.

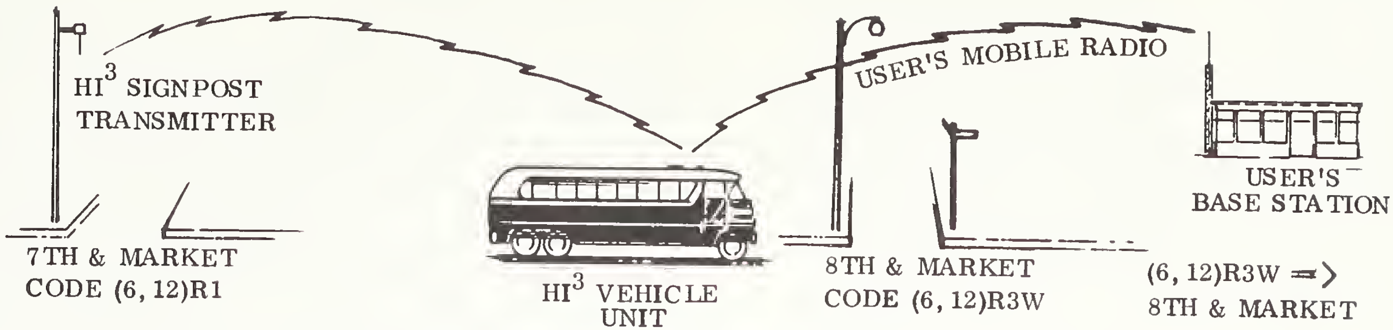
The overall goal of HI^3 during Phase I was to demonstrate the reliable and accurate performance of the HI^3 nationwide AVM system under conditions to be expected in the operation of a multi-user AVM system in any city in the United States. During previous UMTA AVM development programs, beginning in 1970 with the "Monitor CTA" and including tests of several different location techniques in Philadelphia in 1972, UMTA and TSC developed a high degree of understanding of the requirements for a multi-user AVM system. In establishing the Statement of Work for Phase I, these requirements were translated into an explicit set of vehicle location test requirements. In response to these requirements, HI^3 prepared a Location Subsystem Test Requirements Plan which formed the basis for all Phase I tests, data processing and analyses.

Phase I tests were divided into two primary categories: (1) random route tests, and (2) fixed route tests. This report is organized in the same order, which was the order in which the HI^3 tests were conducted.
A third category involved special case tests. These tests were conducted at various times throughout Phase I in Fort Worth, Texas, and in Philadelphia, Pa. The random route test equipment, data acquisition techniques and test data are described in Section 3. Random route data processing is described in Section 4. The results of the data processing and analysis are contained in Section 5. Similar information appropriate to fixed route tests, data processing and results are presented in Sections 6, 7, and 8 respectively. The special case tests are described and results are presented in Section 9. Section 10 has been dedicated to the presentation of a number of items which pertain directly to Phase II. These items include (1) the relationship between Phase I and Phase II equipment, (2) a proposed method for eliminating the use of an odometer on fixed route vehicles, (3) FCC requirements and the status of HI^3 equipment, (4) Federal, State, and local requirements for Phase II, (5) a discussion of a hybrid signpost-Loran system for "over-the-road" vehicles, and (6) special considerations pertinent to Phase II.

2.1 HI^3 AVM TECHNIQUE

HI^3 proposed to use a direct proximity signpost AVM system during Phase II and all Phase I tests were conducted through the use of a Phase II signpost system. As illustrated in Figure 2-1, the HI^3 AVM system receives basic location information, in the vehicle, as a result of the vehicle equipment receiving digitally coded RF transmissions from electronic "signposts." Each signpost transmits a unique 16-BIT code which represents an address (or an X, Y coordinate) in the city analogous to visual street sign identification. The vehicle's proximity to one or more of the signposts results in a simple location region code being stored in the vehicle. This location region code is transmitted to the base station over a mobile radio under base station computer control. At the base station, a simple table look-up by the computer determines a unique street address or X, Y coordinate pair as the vehicle's current location.

HI^3 signposts are powered by Lithium batteries and transmit at a frequency of 49.860 MHz. As a result of the extremely low power output requirements, they may be operated without a license as low power devices under Part 15 of the FCC rules. The use of lithium batteries provides a 7-10 year operating lifetime without battery replacement, and this is achieved over the temperature environment from -55 to 175 degrees F.



SIGNPOST SYSTEM PROVIDES EACH VEHICLE WITH LOCATION REGION CODE

LOCATION REGION CODE IS TRANSMITTED TO USER'S BASE STATION OVER USER'S ASSIGNED MOBILE RADIO FREQUENCY

USER'S BASE STATION TRANSLATES LOCATION REGION CODE INTO A UNIQUE STREET ADDRESS

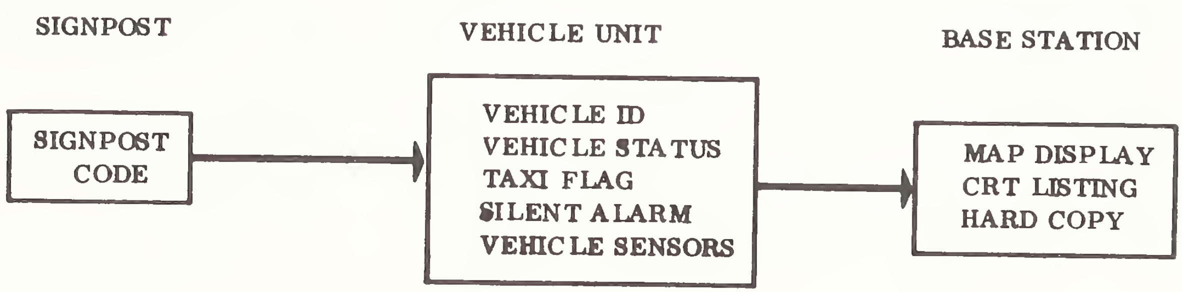


FIG. 2-1 HI^3 MULTI-USER AVM BASIC PRINCIPLE OF OPERATION

When installed in a city, all users (transit, para-transit, taxi, police, pick-up and delivery, etc.) simultaneously share the use of the HI^3 signpost system. This is illustrated in Figure 2-2. Although a number of companies have proposed the use of signposts, a unique feature of the HI^3 approach is the use of overlapping signposts to create additional location regions, thereby reducing the number of signposts required to achieve a specified location accuracy within a given area.

The overlap technique has been previously tested by HI^3 in Los Angeles as part of the Cargo Security System and an overlapping signpost AVM system developed by HI^3 is currently operational in the Huntington Beach, California Police Department. Although proven during those two programs, the UMTA Phase I test program required the most comprehensive demonstration of the HI^3 overlap technique to date. The results obtained prove conclusively that the HI^3 AVM system proposed for Phase II can meet all of the vehicle location subsystem and system level specificiations set forth in the UMTA Multi-User AVM Specification. In addition, the HI^3 AVM system is a nation-wide system and can be operated in any city (where 99.99% of users operate) and can be interfaced with wide area type systems, e.g., Loran for special "over the road" applications. The nationwide feature is a result of the use of 49.86 MHz which may be used throughout the United States.

2.2 PHASE I TEST PROGRAM

The Phase I test program involved the installation of a HI^3 AVM location subsystem in Philadelphia to provide random-route coverage of an area and fixed-route coverage of a simulated bus route. The area and the route were selected by TSC. The location subsystem was to provide a basic location accuracy of at least 300 feet at 95 percent and 450 feet at 99.5 percent of all locations in the random route coverage area and along the specified fixed route. In order to establish the performance of the HI^3 location subsystem, a test vehicle, with an AVM vehicle unit and a recording system installed was repeatedly driven over routes selected by TSC while recording on cassettes every half-second, the output of the vehicle unit location register. During each test run, manual event markers were used to mark (record on cassette) the passage of physical landmarks called "checkpoints". Checkpoints were designated by TSC after installation of the location subsystem was complete. The X, Y coordinates of these checkpoints become the reference against which the performance of the AVM system was measured. During off-line data processing, the radial error between the X, Y coordinates of the checkpoint and the X, Y coordinates as computed through use of the AVM technology was computed. For example, during each of 10 random route test runs, each of which was over 11 miles in length, the passage of 62-63 checkpoints was recorded. All information necessary to compute the X, Y coordinates of the vehicle, as determined by the AVM system, were also recorded on cassette. At the end of 10 such runs, the cassettes were processed to determine the location error at each point. The location algorithm utilized was identical to that proposed for use in Phase II.

DIRECT RF PROXIMITY SIGNPOSTS PROVIDE ALL USER VEHICLES WITH LOCATION ADDRESSES AND ARE BASIC SOURCE OF BUS SCHEDULE INFORMATION.

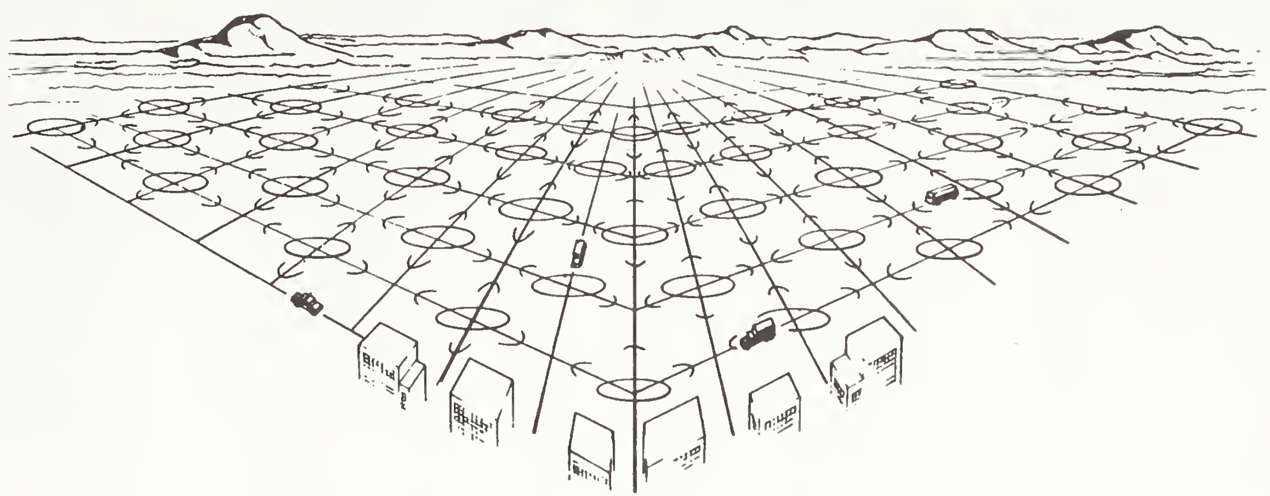


FIG. 2-2 HI^3 MULTI-USER AVM BASIC APPROACH

Fixed route tests involved the same activities as random route tests, however, an odometer was used to determine the vehicle's location along the fixed route after being automatically reset at signposts spaced approximately one mile apart along the route. In addition to the marking of TSC checkpoints, manual entries were made to document passage of the vehicle by "timepoints" which were designated by TSC to represent typical transit route timepoints. Also, the opening and closing of the door was simulated at approximately one-half of the 15 timepoints on each of the fixed route test runs. During off-line processing, the location errors and the errors between the actual time of passage by each timepoint and the time of passage estimated by use of the AVM system were computed. The AVM system was to determine the time of passage of the vehicle at timepoints to $\pm$ 15 seconds for 95 percent and $\pm$ 60 seconds for 99.5 percent of all such occurrences.

A total of 10 random route test runs were performed. This resulted in 622 checkpoint samples at which location errors were computed. When these same data were also processed through an AVM system simulation a total of 2235 samples were obtained corresponding to 1 sample every 20 seconds during the 10 runs. This simulation included the injection of communication errors into 5 percent of the samples. The HI^3 Phase II technique for detection and correction of these errors was simulated. Two different random routes were traveled involving passage through tunnels, along narrow streets through high-rise "canyons" and along wide boulevards. All tests were conducted under normal traffic conditions in downtown Philadelphia. A TSC Monitor was in the test vehicle during all tests.

A total of 33 fixed route test runs were performed over a 13 mile route. Each test provided data at 76 checkpoints and 15 timepoints. When processed through the AVM system simulation, a total of 7459 pseudo checkpoint samples were obtained.

Formal demonstrations of the HI^3 AVM system were conducted in Philadelphia on 15 and 28 December 1976 for UMTA personnel and their guests. These demonstrations involved operation of the HI^3 test vehicle in the random route area with 6-8 observers on board. All such demonstrations involved operation as a random-route vehicle with the vehicle location being provided in real-time on the on-board CRT. All demonstrations were 100 percent successful.

2.3 TEST RESULTS

All random route and fixed route data taken during the Phase I tests were processed by HI^3 to determine the AVM system performance. Data processing was performed off-line using an exact simulation of the proposed Phase II location subsystem and AVM communication system. These data show conclusively that the HI^3 AVM system can meet or exceed all performance criteria set for Phase II. Phase I results are summarized in Table 2-1. Detailed discussions of these results are contained in Sections 5 and 8.

TABLE 2-1 SUMMARY RESULTS OF PHASE I TESTING

LOCATION SUBSYSTEM LOCATION ACCURACY:	Specification (feet)	HI^3 Results (feet)
Random Route: 622 samples		
95% of samples less than	300	242
99.5% of samples less than	450	461
Average error, all samples	---	91
Maximum Average Error Over One-Tenth Mile Segment	450	315
Fixed Route: 2313 samples		
95% of all samples less than	300	107
99.5% of all samples less than	450	156
Average error, all samples	---	50
Maximum Average Error Over One-Tenth Mile Segment:	450	256
AVM SYSTEM LOCATION ACCURACY:		
Random Route: 2235 samples		
95% of samples less than	300	282
99.5% of samples less than	450	464
Average error, all samples	---	114
Fixed Route: 7459 samples		
95% of samples less than	300	105
99.5% of samples less than	450	188
Average error, all samples	---	48
	Specification (seconds)	HI^3 Results (seconds)
AVM TIMEPOINT PERFORMANCE: 451 samples		
95% of samples less than	15	11
99.5% of samples less than	60	24
Average error	--	3.9

Figure 2-3 contains cumulative error distributions of random route and fixed route test data results. When translated into an operational system for random route vehicles, these data indicate that under similar urban conditions, a police dispatcher would know, with a 95 percent confidence level, the location of each and every AVM-equipped vehicle to within 282 feet. Similarly, the fixed route data indicates that a bus dispatcher would have at his fingertips the location and schedule performance of every bus on all routes to within 105 feet and to within 11 seconds at a 95 percent confidence level. The application of this information to providing increased service, improved response time, better schedule adherence, etc., forms the basis for the entire Phase II program.

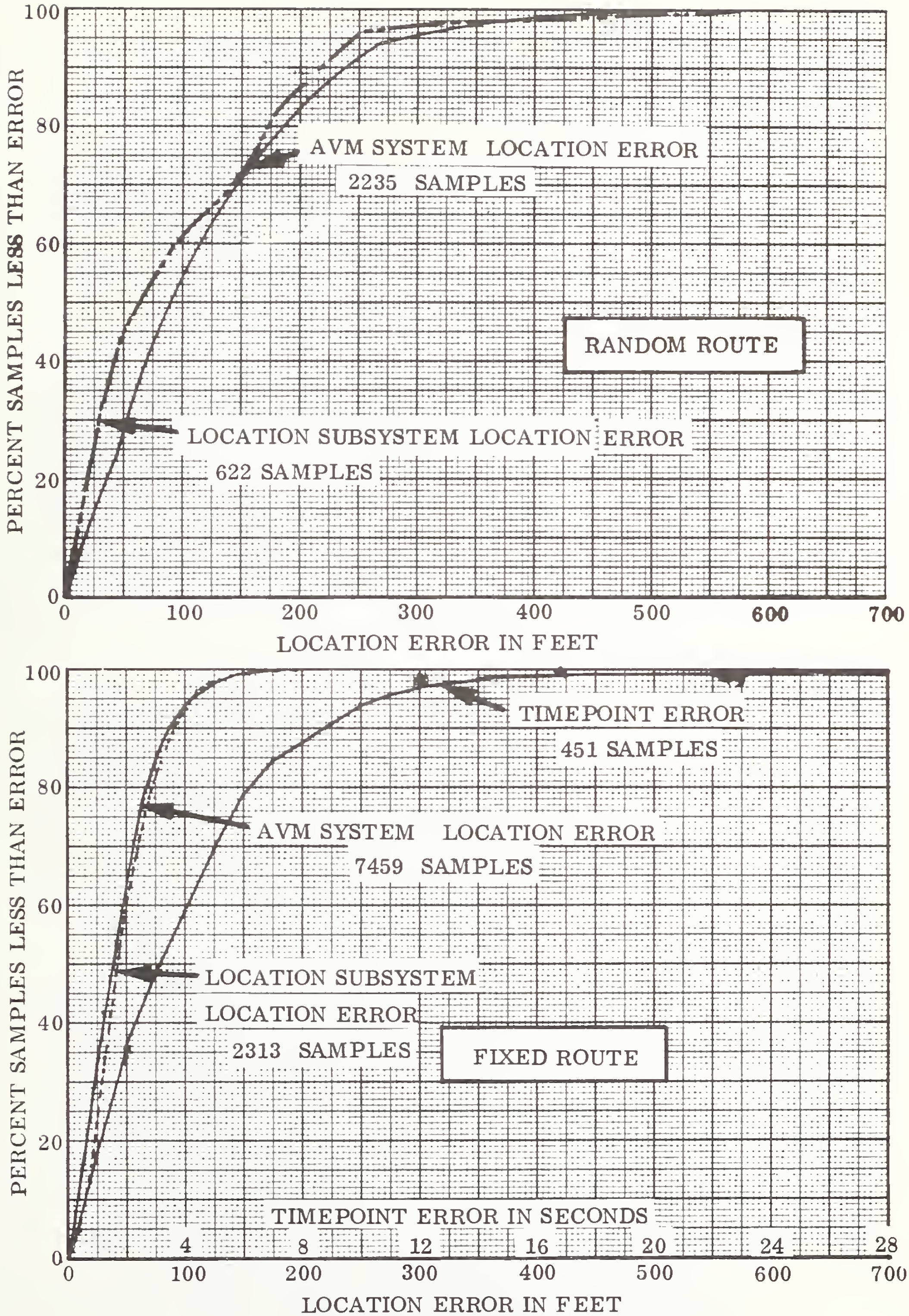


FIG. 2-3 DEMONSTRATED AVM SYSTEM PERFORMANCE

3. RANDOM ROUTE TESTS

3.1 RANDOM ROUTE TEST CONFIGURATION

The test system configuration used in the Phase I random route tests consisted of (1) the HI^3 test Location Subsystem (LS) and (2) a Data Acquisition System (DAS). The HI^3 test LS tested during Phase I random route tests is functionally identical to that proposed for Phase II.

3.1.1 Test Vehicle

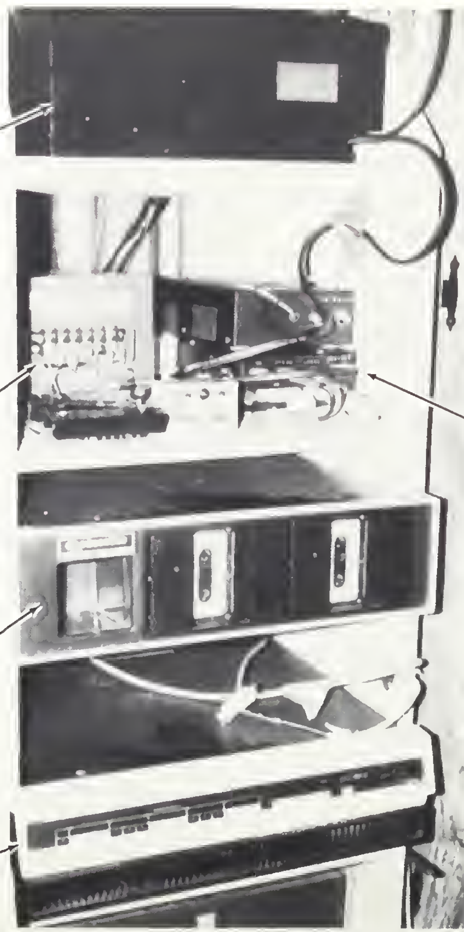
The Phase I test vehicle was a 1976 Winnebago equipped with a 4-KVA, 110-volt, auxiliary power unit. A special rack was provided for the DAS equipment. Figure 3-1 is the layout of the test vehicle which was so designed that the DAS operator was seated facing forward at the table on the right-hand side. The CRT/keyboard was located on the table. The DAS operator and the TSC Monitor could sit side-by-side during test runs.

3.1.2 Location Subsystem Equipment

In the random route configuration, the LS consists of (1) signposts and (2) a vehicle unit.

3.1.2.1 Signposts. HI^3 signposts are small, lithium-battery-powered transmitters which transmit a digitally coded message at 49 MHz at an interval of approximately 2/3 of a second. Signpost electrical specifications are presented in Figures 3-2 and 3-3. Only 20 KHz of spectrum are utilized in order to comply with the most recent FCC rule (Docket No. 20119). Signpost mechanical specifications are shown in Figure 3-4. Test LS signposts are production HI^3 signposts (Model SP-03) and are identical to those proposed for installation in Phase II.

During the test program, the signposts utilized in Philadelphia were operated at 49.860 MHz. However, a number of special tests were conducted in Fort Worth by using signposts which were operated at 27.095 MHz with a corresponding vehicle unit receiver. HI^3 currently has a signpost system operating at Huntington Beach, California, and is in the second phase of a Cargo Security System, under LEAA sponsorship, in Los Angeles; this system also contains 27.095-MHz signposts. These units are operated as low power devices under Part 15 of the FCC rules in effect in November 1975. HI^3 has applied for type certification of the HI^3 signpost by the FCC in accordance with FCC Docket 20119 which was released 12 February 1976. In correspondence with Mr. Raymond Spence, FCC Chief Engineer, we have received assurance that there is no proposal pending before the FCC which would affect the operation of non-voice devices such as the HI^3 signpost in the 27-MHz band chosen for operation.



EQUIPMENT RACK

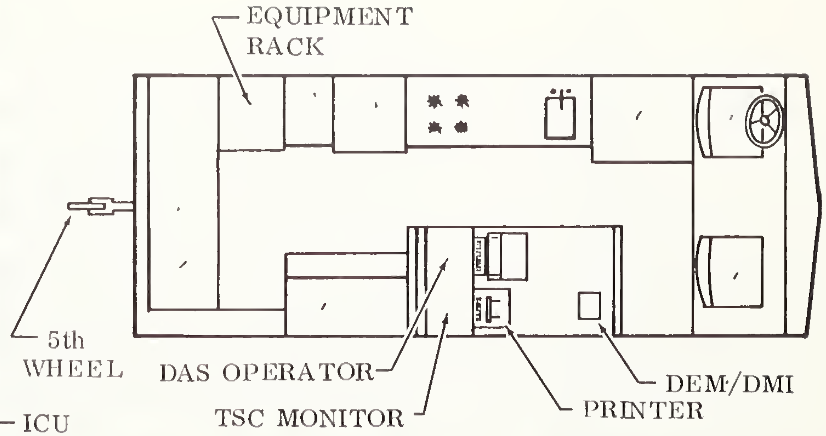


FIG. 3-1 HI^3 TEST VEHICLE EQUIPMENT LAYOUT

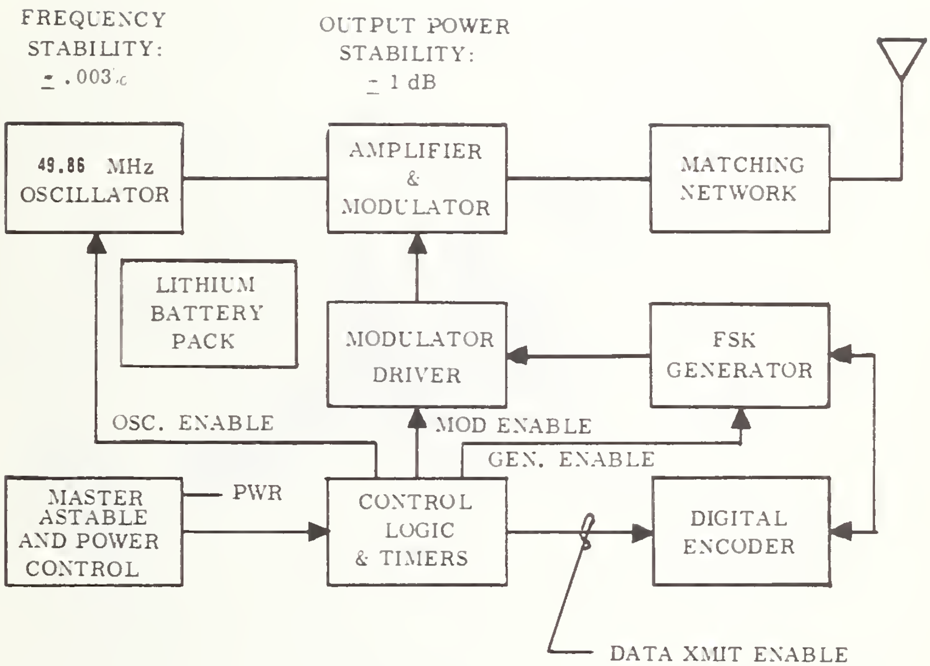


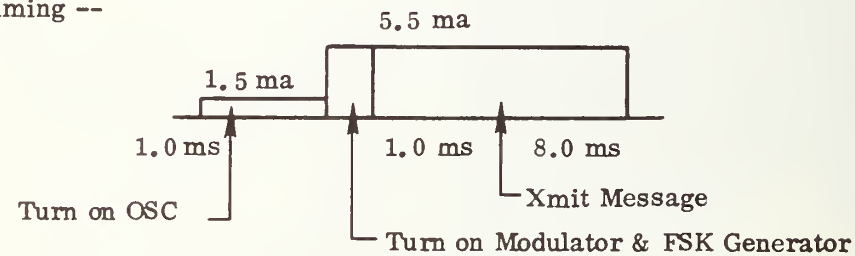
FIG. 3-2 HI^3 SIGNPOST BLOCK DIAGRAM

Communication Method -- Coherent FSK with BIT - $\overline{\text{BIT}}$ Technique

Message Length -- (16 Information Bits + 16 Bit Complements + 2 Error Bits)
= 34 Bits

Data Rate -- 4.5K BITS/Sec.

Transmitter Timing --



Bandwidth -- 20 KHz

Duty Cycle -- .015

Battery Capacity -- 10 AH

Average Current Drain = .015 x 5.0ma + 50ua = 125ua

Antenna Gain -- -14 dBI

Signpost PRF -- 1.5 Hz

Transmitter Frequency -- f_c = 49.860 MHz

SPECIAL SIGNPOST BITS

N_7	N_6	N_5	N_4	N_3	N_2	N_1	N_0	E_7	E_6	E_5	E_4	E_3	E_2	E_1	E_0

NORTH FIELD EAST FIELD

FIG. 3-3 HI^3 SIGNPOST ELECTRICAL SPECIFICATIONS

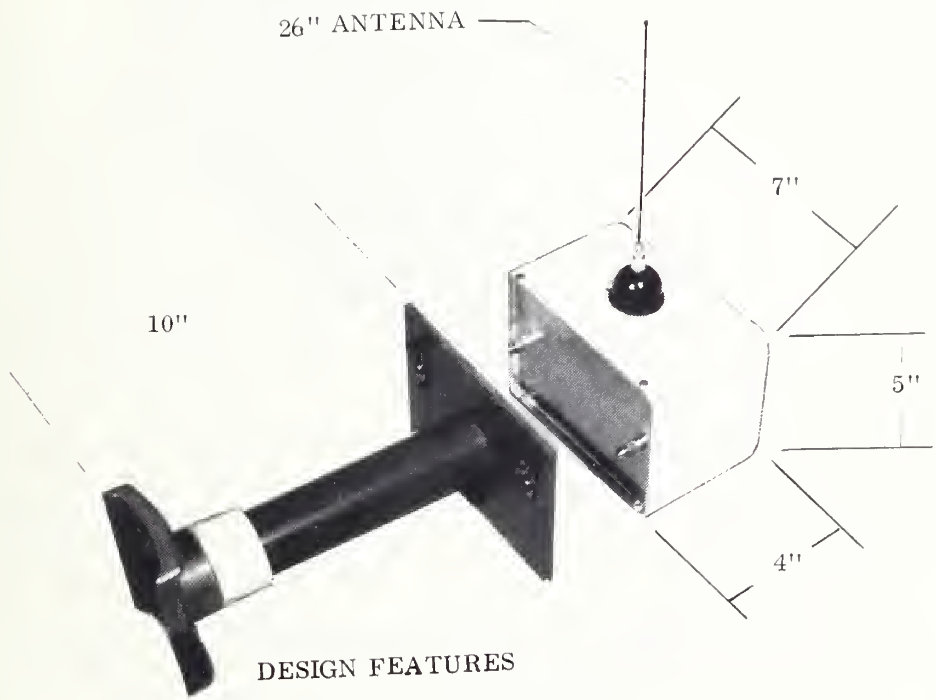


FIG. 3-4 HI^3 SIGNPOST MECHANICAL SPECIFICATIONS

However, low power operation at 27 MHz is contingent upon not producing harmful interference to licensees in the 27 MHz band. At 49.86 MHz, there are no licensees, and each user must operate within the environment created by all other users; consequently, any constraints on operation in any city are eliminated. The 49.86-MHz system tested during Phase I demonstrated superior AVM performance over 27 MHz. As a result of the test results obtained, it is proposed to utilize 49.86 MHz signposts in HI^3 during Phase II. Signposts operated at 49.86 MHz are subject to the same type of certification as that required for low-power devices operated at 27 MHz. HI^3 has applied for such certification. This action is discussed in Section 10.3.

HI^3 signposts are mounted on any available utility poles or street and traffic light standards in such a manner that the HI^3 vehicle equipment is able to receive the coded transmissions from one or more signposts and, through simple code and signal level comparisons in the vehicle unit, to determine a unique 18-bit code which corresponds to the center of a unique location region. This capability is explained fully in Paragraph 3.2.1. Forty-one signposts were available for use during Phase I testing. An odometer was utilized during fixed route tests to supplement the signpost system so that signposts were only needed at or near TSC designated timepoints. The use of the odometer in Phase I is fully explained in Section 6. A method of eliminating the need for an odometer in Phase II is discussed in Section 10.2.

3.1.2.2 Vehicle Equipment. In the random route configuration, HI^3 LS vehicle equipment consists of two items: (1) a 49.860-MHz antenna and a coax cable, and (2) a HI^3 vehicle unit. During Phase I, a standard, monopole (Antenna Specialist Model 303) was mounted on the roof of the test vehicle. The same vehicle unit was used during fixed route tests without modification.

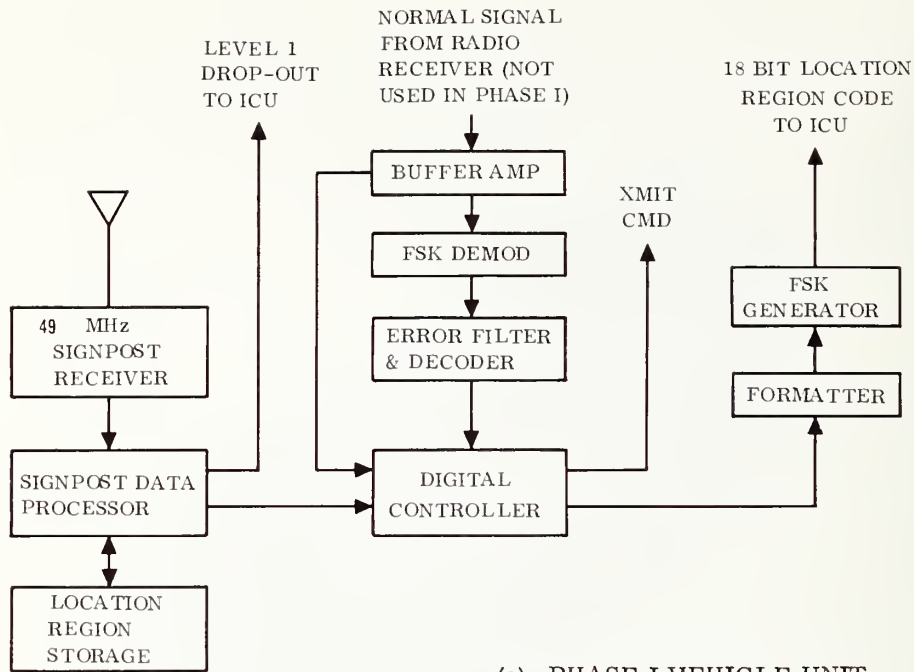
The HI^3 vehicle unit shown in Figure 3-5 is a single electronic package which consists of the following equipment:

49.860-MHz Signpost Receiver	Digital Controller
Signpost Data Processor	Formatter
Location Region Storage	FSK Generator

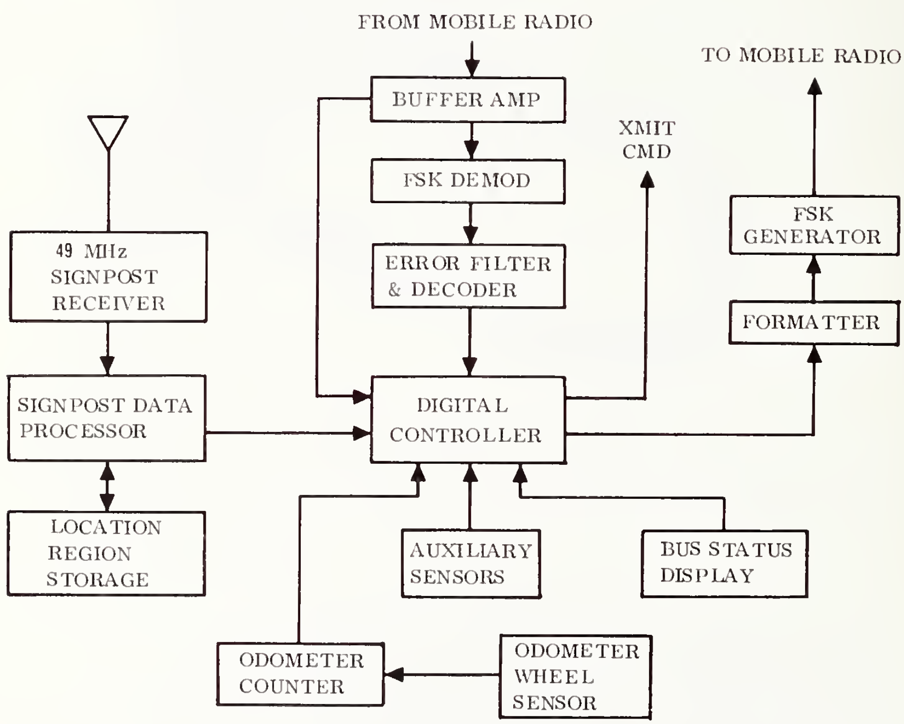
The test LS vehicle unit draws its power directly from the test vehicle 12-volt system just as it will in the Phase II system. The vehicle unit is fused to prevent equipment damages and contains a built-in voltage regulator to compensate for voltage fluctuations.

Figure 3-6 is a block diagram of the major functions performed in the HI^3 vehicle unit. This unit is a standard HI^3 AVL vehicle unit which normally interfaces with a mobile radio. In the Phase I system, the normal radio interface is replaced with a hardwired interface to the HI^3 Interface Controller Unit (ICU).

FIG. 3-5 HI^3 TEST L.S. VEHICLE UNIT



(a) PHASE I VEHICLE UNIT



(b) PHASE II VEHICLE UNIT

FIG. 3-6 HI^3 VEHICLE UNIT BLOCK DIAGRAM

The 49.860-MHz signpost receiver performs the following functions:

a. Receives the coherent FSK transmissions from signposts.

b. Synchronizes the information stream.

c. Performs demodulation of the FSK signal.

d. Determines the signal amplitude via the threshold detection circuitry.

e. Checks the signpost message for errors.

f. Decodes the 16-BIT signpost code.

g. Supplies the threshold level (Level 1, 2, or 3), a "data good" signal (if the signal passes the error filter) and the signpost code to the signpost data processor.

h. Supplies a "Level 1" or "NOT Level 1" logical signal to the ICU.

The hardwired signpost data processor performs the following functions, as illustrated in Figure 3-7 Information Flow Diagram:

1. In conjunction with the "last" signpost code, processes the "new" signpost code to derive an 18-BIT location region code which is comprised of the following information:

   7-BIT East Code from nearest (highest level) signpost
   7-BIT North Code from nearest (highest level) signpost
   4-BIT Region Code which identifies the overlap region between signposts.

   NOTE: Section 3.2.1 contains a detailed description of the process through which the 18-BIT location region code is generated.

2. Identifies timepoint signpost through bits E_7 and N_7 (this function was simulated during fixed route testing).

3. Stores the 18-BIT location region code as the vehicle's "current" location in the Location Region Storage.

4. Compares each newly computed 18-BIT location region code with the stored value and, if a difference is indicated, replacement of the previous code with the new code.

5. Supplies the "current" location region code to the digital controller for transmittal to the ICU.

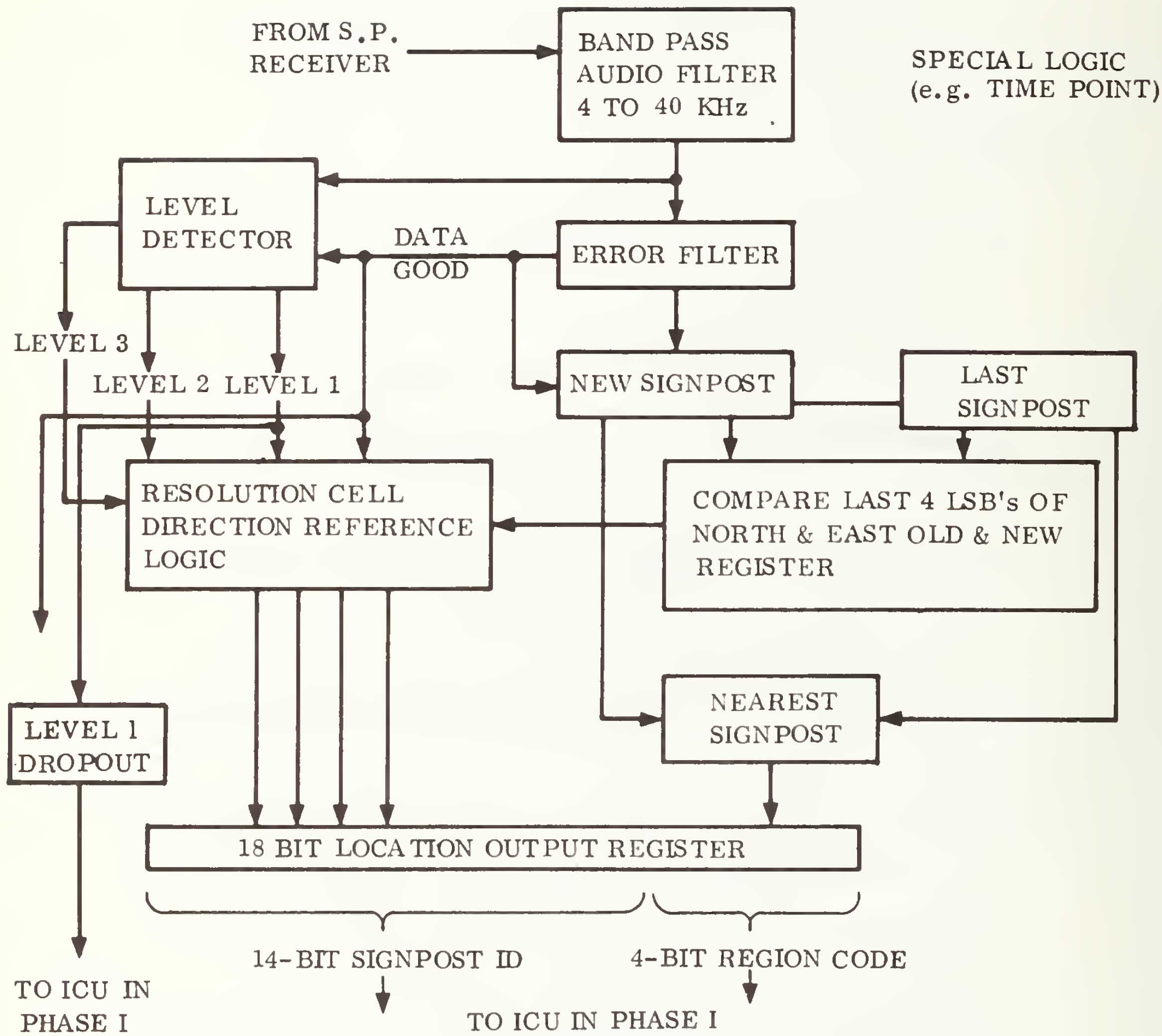


FIG. 3-7 HI^3 VEHICLE UNIT INFORMATION FLOW DIAGRAM

The Digital Controller controls the sampling of the location region storage and controls the transmission of location region data to the ICU.

The formatter encodes the message to the ICU in the B-$\overline{B}$ format. B corresponds to the bit (logical 1 or logical 0) and $\overline{B}$ corresponds to the bit complement. The B-$\overline{B}$ format requires that each bit be followed by the bit complement. For example, if a logical 1 were to be encoded, a 1-bit followed by a 0-bit would actually be encoded. This encoding technique provides effective error control through the use of an error filter at the base station. Note that a similar encoding scheme and error filters are incorporated in the signpost-to-vehicle unit link. The FSK generator generates the two audio frequencies, f_{high} and f_{low}, which correspond to the B and $\overline{B}$ respectively.

During Phase I, the vehicle unit operated in the "Automatic" mode in that all changes in the current location region code were automatically transmitted to the ICU. The ICU in turn stored this information until it was requested by the computer (every 0.5 second). During Phase II, the vehicle unit will operate in a functionally identical manner, i.e., data will only be supplied to the base station over the communication subsystem when it is requested by the computer.

The addition of the odometer, auxiliary sensors, bus status display, and radio receiver interfaces which will be implemented in Phase II is shown in the lower figure (Figure 3-6b). Actually, the Buffer Amplifier and Channel Open Detector, the PSK Demodulator, and the Error Filter and Decoder were included in the Phase I vehicle unit. However, they were not utilized since a radio link was not implemented. Thus, the only difference between the Phase I and Phase II vehicle units is in the Digital Controller Unit.

In Phase II, the digital controller unit will perform all of the functions performed in Phase I, plus the following additional functions:

a. Receive commands from the base station and control the message response via the radio transmitter.

b. Receive and accumulate pulses from the odometer and control the encoding of the odometer accumulator into the vehicle-to-base message. (Fixed Route only). Refer to Section 10 for a proposed means of eliminating the odometer from Phase II.

c. Receive inputs from auxiliary sensors (doors, passenger counters, etc.) and control the encoding of these data into the vehicle-to-base message.

d. Control the message traffic to and from the bus status display.

e. Identify timepoint signposts and the Level 1 drop-out signal and thereby control the generation of timepoint performance data.

f. Compare incoming message addresses to stored vehicle ID and control message response.

In the Phase I system, the contents of the location register were sent to an Interface Controller Unit (ICU) where they were sampled by the DAS as the "computed" vehicle location at the sample time. Under operational conditions (Phase II), the contents of the location register would be encoded by the Digital Controller and formatter as part of the vehicle-to-base message and transmitted via the communication subsystem to the base station under base station computer control. However, in the HI^3 design, this process was quite simple to simulate since vehicle location computations performed at the base station do not depend on any past history since only the last transmitted location data are used. Thus, the achievement of an exact system simulation is only a matter of the sampling rate (i.e., 20 seconds for Phase II versus every 1/2 second in the Phase I tests). Consequently, HI^3 LS accuracy is not influenced.

3.1.3 Data Acquisition System (DAS)

In the random route configuration, the DAS included the following equipment:

- HI^3 Interface Control Unit (ICU)
- PDP 11/05
- DECassette
- Cassettes
- CB Monitor Unit (used during special 27 MHz tests only)
- 5th Wheel System
- ADM-2 CRT/Keyboard
- TI 743 Terminal.

Figure 3-8 is an interface block diagram of the DAS and its interface with the LS.

During random route testing, the DAS controlled the sampling of the LS location register as well as the 5th wheel. Tests were conducted by recording (1) a complete data record every 1/2 second and (2) each event marker entered manually by the DAS operator.

3.1.3.1 Recording Equipment. Recording equipment included the PDP 11/05 minicomputer, the DECassette, and the ADM-2 CRT/Keyboard. Under software control the PDP 11/05 caused data from the ICU and the keyboard to be recorded on cassette tapes.

Data were recorded on Mylar Cassettes (Dual Drive). A pair of cassettes were used to record all data on each test run.

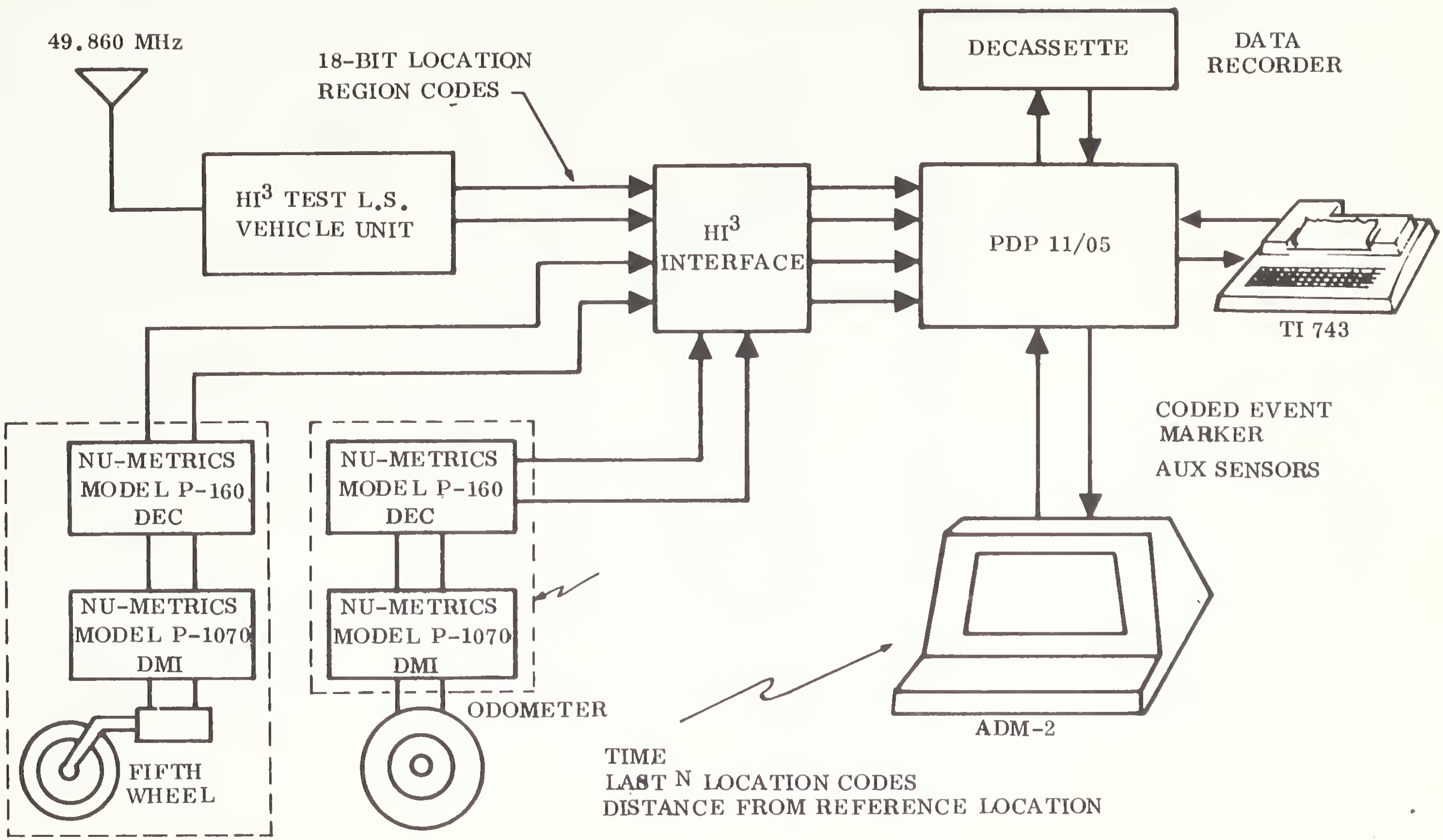


FIG. 3-8 HI^3 VEHICLE EQUIPMENT INTERFACE DIAGRAM

Data were recorded single-bit-serial sequentially. Each data sample consisted of a 80-BIT record as follows:

Item	Bits
Location Code	18
Odometer	12
5th Wheel	14
Clock	10 (ticks only)
Event Codes	8
Spare	18
TOTAL	80

Figure 3-9 reflects the basic DAS record format as it was divided into five 16-BIT words. Cassettes were duplicated onto IBM compatible magnetic tapes at the Blue Bell, Pennsylvania facility of Digital Equipment Corporation, for processing by MITRE Corporation.

3.1.3.2 Fifth Wheel Equipment. The fifth wheel was used (1) for verifying checkpoint relative X, Y coordinate distance from known locations and (2) for generating "pseudo" checkpoints during data analysis to simulate Phase II polling rates. The fifth wheel equipment included a Nucleus Corporation Model NC-7 fifth wheel, a Nu-Metrics Model P-1070 distance measuring instrument (DMI), and a Nu-Metrics Model P-160 Distance Event Controller (DEC). The configuration is shown in Figure 3-10.

3.1.3.3 Event Marking Equipment. Event marking was accomplished through use of the ADM-2 keyboard. Manual input of an event code via the keyboard caused a new record to be recorded. Event codes were entered by pressing, in sequence, the appropriate event function key, the event ID number, e.g., checkpoint number, and the RETURN key. A complete 80-BIT data record was recorded on cassette whenever the RETURN key was pressed. The following event codes were available.

	Function Key	Event ID	Return
Mark Passage of Checkpoint XX	CP	XX	"
Mark Passage of Signpost NN, EE (Only used during calibration runs)	SP	NN, EE	"
Mark Turn Intersection for use with "Pseudo" signposts	TA	XX	"
Signify Door Open at Timepoint YY	DO	YY	"
Signify Door Close at Timepoint YY	DC	YY	"
Signify Error in preceding event ZZ	EE	ZZ	"
Mark Time of Departure from Timepoint YY	TD	YY	"

HEADER RECORD	
Run Number	1st Word
Year	2nd Word
Month	3rd Word
Day	4th Word
Hour	5th Word
Minutes	6th Word
Seconds	7th Word
Tick (1/60 of second)	8th Word

DATA RECORD	
S S S S S S T_9 T_8 T_7 T_6 T_5 T_4 T_3 T_2 T_1 T_0	1st Word
S S S S O_{11} O_{10} O_9 O_8 O_7 O_6 O_5 O_4 O_3 O_2 O_1 O_0	2nd Word
S S N_6 N_5 N_4 N_3 N_2 N_1 N_0 E_6 E_5 E_4 E_3 E_2 E_1 E_0	3rd Word
V_7 V_6 V_5 V_4 V_3 V_2 V_1 V_0 S S S S B_3 B_2 B_1 B_0	4th Word
S S F_{13} F_{12} F_{11} F_{10} F_9 F_8 F_7 F_6 F_5 F_4 F_3 F_2 F_1 F_0	5th Word

where

T - Time
V - Event
B - Region Field
N - North Field
E - East Field
F - 5th Wheel
S - Spare
O - Odometer

FIG. 3-9 BASIC DAS RECORD FORMAT

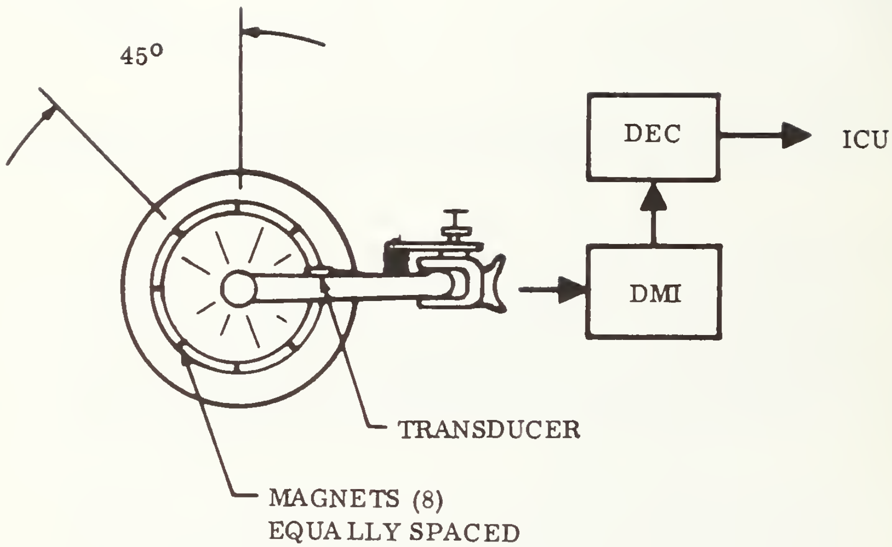


FIG. 3-10 FIFTH WHEEL CONFIGURATION

When the RETURN was depressed, an 80-BIT data record corresponding to the event key stroke time was added to the data stream in the appropriate time sequence, and the contents of the ICU output buffer were simultaneously written to the cassette and displayed on the CRT.

The Error Event was used to signify that an error had occurred in the previous event code, presumably an operator error, e.g., wrong checkpoint ID entered, etc. When the Error Event was used, an entry was made into the Run Log in terms of the nature of the error. During off-line data processing, such errors were flagged to the computer by the occurrence of the Error Event and ignored by the Data Processing Routine. A log of such errors is contained in the Appendix in association with the raw data.

3.1.3.4 Interface Controller Unit. The ICU controlled the acquisition of data for recording via the PDP 11/05 and DECassette and performed the function of a high-speed communication link between a vehicle and the base station. The input and output functions of the ICU are identified in Figure 3-11. During operation under control of the PDP 11/05, the ICU received a request-data pulse from the 11/05, set a flag which froze all data registers, caused an interrupt to the 11/05, and responded with a serial bit stream of 48 bits in the following sequence:

First Word (MSB at left)

N_6	N_5	N_4	N_3	N_2	N_1	N_0	E_6	E_5	E_4	E_3	E_2	E_1	E_0	B_3	B_2
North Field							East Field							Direction	

2nd Word (MSB at F_{13})

B_1	B_0	F_{13}	F_{12}	F_{11}	F_{10}	F_9	F_8	F_7	F_6	F_5	F_4	F_3	F_2	F_1	F_0
Level		Fifth Wheel													

3rd Word (MSB at left)

O_{11}	O_{10}	O_9	O_8	O_7	O_6	O_5	O_4	O_3	O_2	O_1	O_0	S	S	S	S
Odometer (Fixed Route only)												Spare			

NOTE: These three words were output from the ICU to the DAS where they were reformatted and merged with time and event data to form the 5-word record shown in Figure 3-9. This word was recorded on cassette. This sequence relates only to the output of the ICU to the computer. The data was reformatted, as shown in Figure 3-9, for recording on cassette.

In Figure 3-11, the Signpost Location Region Register contains the most recent 18-BIT Location Region code generated by the Digital Controller Unit in

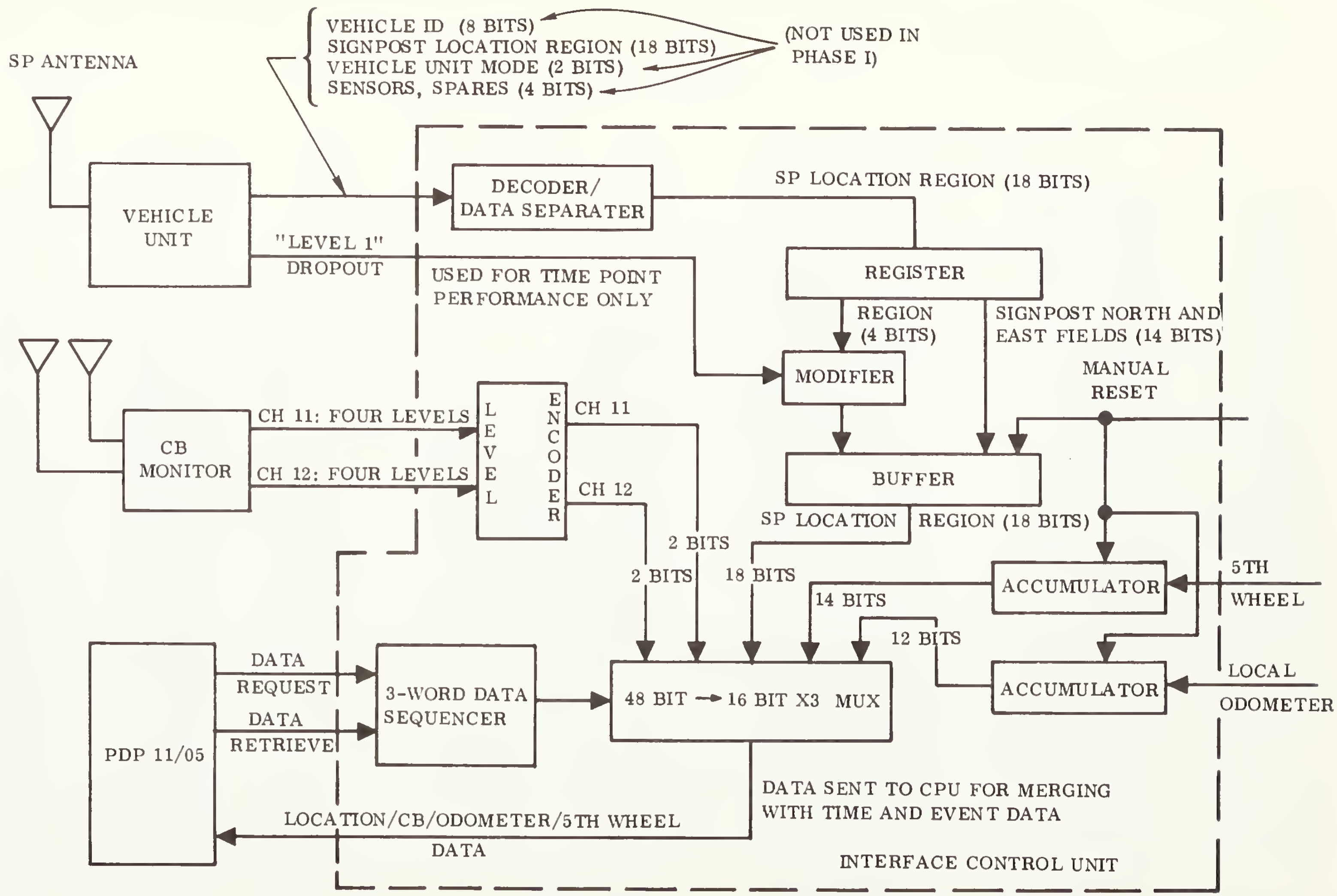


FIG. 3-11 HI^3 INTERFACE CONTROLLER UNIT (ICU)

the vehicle unit. This code includes a 7-BIT North code, a 7-BIT East Code, and a 4-BIT region or "B" code as follows:

North Code								East Code								Region Code			
N_7	N_6	N_5	N_4	N_3	N_2	N_1	N_0	E_7	E_6	E_5	E_4	E_3	E_2	E_1	E_0	B_3	B_2	B_1	B_0

Valid Region Codes which could be generated by the Phase I vehicle unit included the following:

Region Code				Region
B_3	B_2	B_1	B_0	
0	0	0	0	Region 1
0	0	0	1	Region 2 South
0	1	0	1	Region 2 East
1	1	0	1	Region 2 North
1	0	0	1	Region 2 West
0	0	1	0	Region 3 South
0	1	1	0	Region 3 East
1	1	1	0	Region 3 North
1	0	1	0	Region 3 West

(The physical meaning of these codes and their method of generation relative to signpost placement is discussed in detail in Paragraph 3.2.1).

The modifier block in Figure 3-11 caused an additional Region code, "0011", to be generated; this code corresponds to a Level 1 drop-out. This code was only used in computing timepoint performance. It is discussed in detail in paragraph 6.1.2.2. Thus, the buffer block in Figure 3-11 contains the 18-BIT signpost location region (with the region field possibly having been modified to a 0011) which became part of the recorded data.

3.1.3.5 Recording Software. Operation of the DAS was under software control through use of the CAPS operating system. Random Route data were recorded by using the program RANDOM which performed data recording and provided two displays as follows:

a. Display 1: Quick Look Verification Display

b. Display 2: Location Accuracy Summary Display.

3.1.3.6 In-Vehicle Displays. The DAS provided the capability of displaying selected data on the CRT for use in the testing, calibration, and verification of operation of the LS system. These displays were independent of and had no effect whatsoever on the cassette data recording function.

a. Quick Look Verification Display. To aid in the initial LS installation and calibration and in formal tests, a real-time display was used to examine the following parameters:

Event Code	North Field	East Field	Region Code		Odometer Distance	5th Wheel Distance	Time	
							Min	Sec
-			---	---				
-	6	8	R2	West	1900	1900	08	42
1	6	8	R2	West	1920	1920	09	12
-								
-	6	8	R2	East	2104	2108	10	01
2	6	8	R3	East	2216	2218	10	32
-				---				
-	8	8	R1	---	2542	2542	11	17

The occurrence of each new location region or event marker caused a new line to be printed; the most current line was printed at the bottom of the screen.

b. Location Accuracy Summary Display. Another aid in the initial installation and testing was an in-the-vehicle display which provided a real-time estimate of performance. This display indicated (1) the X and Y values corresponding to each checkpoint (vehicle actual location), (2) the X and Y values of each recorded location region (vehicle's estimated location), and (3) the computed delta distance or error between these two X, Y values. The format was the following:

Checkpoint Number	Checkpoint Location X	Checkpoint Location Y	Signpost Region X	Signpost Region Y	Error (feet)
1	720300	403631	720100	403630	200
2	721731	402245	721700	402250	31
3	722190	401806	722185	401770	36
4	722729	401257	722730	401285	28
5	723195	400606	723150	400580	52

NOTE: The checkpoints provided by TSC were not loaded into the data recording software at any time during the Phase I test and calibration activities.

In generating this display, input data consisted of (1) the ICU output data, (2) the stored signpost data base, and (3) a stored checkpoint data base. The signpost data base consisted of approximately 369 locations (refer to Section 4) stored on cassette and read into memory as part of the program "RANDOM".

Similarly, a set of 79 checkpoints generated by HI^3 (not the TSC primary or secondary checkpoints) were read into memory prior to running the program.

3.2 RANDOM ROUTE LOCATION SUBSYSTEM DEPLOYMENT

3.2.1 Signpost Deployment

Signposts were installed in the HI^3 random route test area in accordance with a pattern which provided the specified coverage of the test area and is that proposed for the Phase II program. Thus, no location support equipment simulation, such as the expected Phase II S/N conditions vs. Philadelphia deployment S/N conditions, was required for the HI^3 system. The test area was selected by TSC and was composed of 40 square blocks which included virtually all conditions of a typical metropolitan environment. The area included high-rise, low-rise, narrow and wide streets, underpasses, tunnels, trolleys, commercial, industrial, and residential areas. The area was surveyed by HI^3 and poles tentatively selected on 10 September 1976; pole agreements for these selected poles were contracted with the City of Philadelphia and the Philadelphia Electric Company. On 21 September, a data package was submitted to these agencies requesting permission to use selected poles. This permission was granted on 7 October 1976. A preliminary signpost layout was completed by utilizing 36 signposts (15 of which were used to simulate the infinite space of a wide area coverage). The signposts were coded and installed in a comparable area (street patterns and environment) of Fort Worth for preliminary checkout. These signposts allowed a determination of location to be made at any point within the random route test area (infinite space simulation). Originally, these signposts were operated at 27 MHz. However, after special tests in Fort Worth showed the superiority of 49 MHz, all were converted to 49.860 MHz. This conversion process required only three (3) working days. Five additional signposts were later added in Philadelphia in order to provide complete random route coverage within and in the vicinity of the 9 railroad overpasses and covered streets within the selected test area.

The test vehicle was used to perform preliminary and special tests of the LS in Fort Worth. Upon completion of these tests, the signposts were transported to Philadelphia and installed by HI^3 personnel in accordance with the original layout. Installation of the signposts required an average of 3.2 minutes per signpost including parking of the installation vehicle. This short time can be realized because HI^3 signposts need not be located at any specific height and installation methods have been perfected on such programs as the Huntington Beach AVM System. Refinements of the layout included the movement of 5 signposts in order to take advantage of or to reduce the effects of peculiar structures which were encountered, particularly in and near tunnels. Such refinements were routine and were fully documented prior to the initiation of formal tests. No signposts were moved or adjusted in any manner after the initiation of formal tests.

The HI^3 Random Route test area is shown in Figure 3-12 along with the signpost locations and the signpost codes. Figure 3-13 contains photographs of all installed random-route signposts.

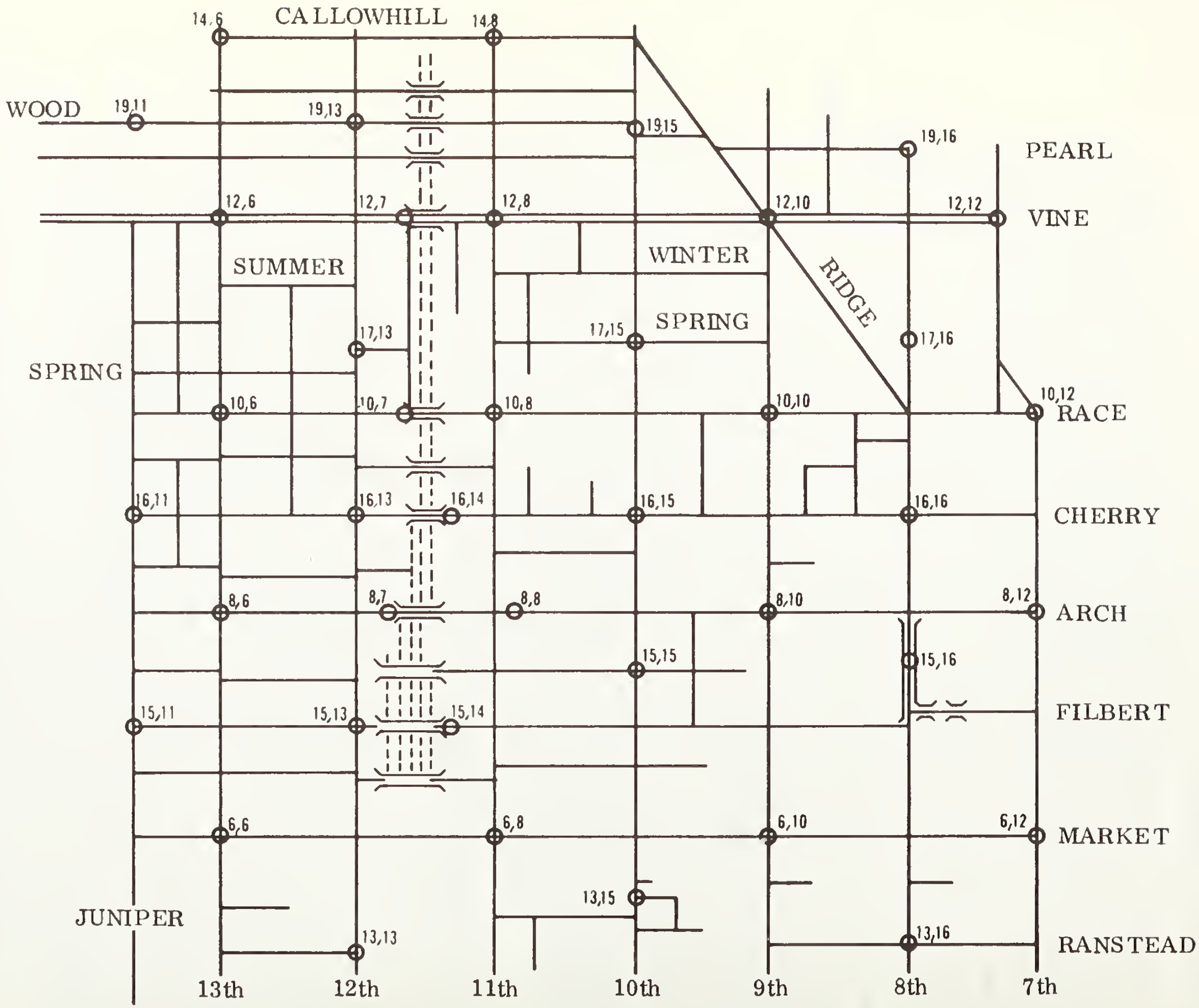


FIG. 3-12 HI[3] RANDOM ROUTE TEST AREA AND SIGNPOST LAYOUT

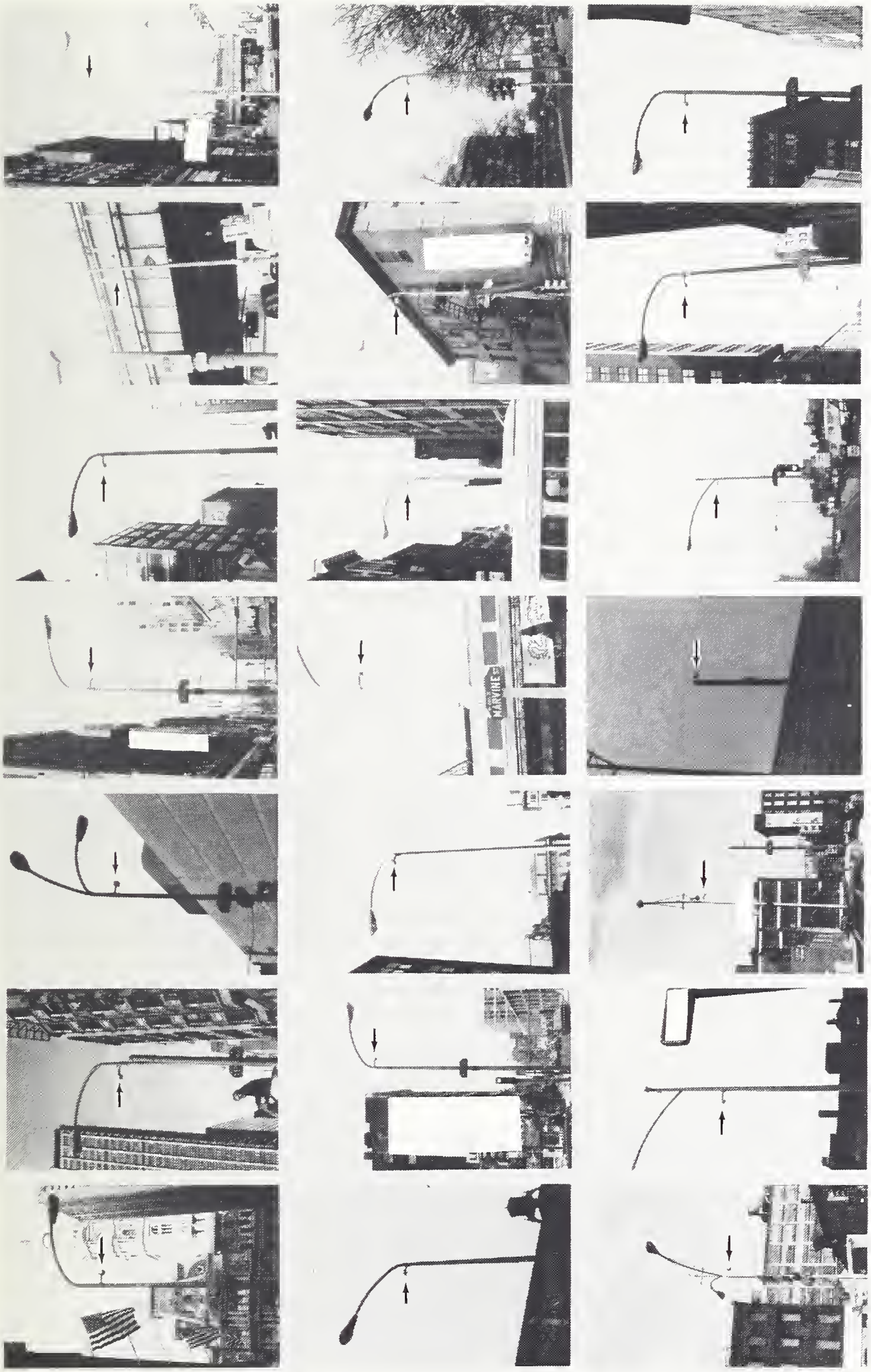


FIG. 3-13 RANDOM ROUTE SIGNPOSTS

FIG. 3-13 RANDOM ROUTE SIGNPOSTS (CONT'D)

Signposts were deployed in a grid and are coded so as to create North-South and East-West chains. Along a North-South chain, only the 7-BIT North-South fields of the signpost codes change, increasing from South to North. Along an East-West chain, only the 7-BIT East-West fields of the signpost codes change, increasing from West-to-East. Examples of these respective cases are clearly evident on 13th Street which is a (North-South chain) and Market Street which is an (East-West chain).

Along any chain, receipt in the vehicle of the transmission from each of the two adjacent signposts provides sufficient information to allow the vehicle to identify up to 5 different location regions. This arrangement is depicted in Figure 3-14. The region nearest a signpost is called Region 1 and is declared as a result of receiving a valid signpost signal which exceeds a predetermined signal level, Level 1. Thus, a vehicle near signpost (6, 6) at 13th and Market would store a "6" in its North register, a "6" in its East register and a "Region 1" code in its Region register. The resulting 18-BIT code would be as follows:

North Field							East Field							Region Field			
0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0
MSB						LSB	MSB						LSB				

In the region between two signposts, (6, 6) and (6, 8), for example, the vehicle may receive signals from both signposts at equal or at different signal levels. Two types of information are used to determine the three overlap regions between chaining signposts. First, the direction from a signpost is determined in the vehicle by comparing the 4 LSB's of the North and East fields received from two different signposts. The following truth table is used to determine direction in the vehicle:

<u>Result of Comparing 4 LSB's of North/South and East/West Fields</u>

North/South	East/West	Declaration
Increasing	No Change	North of
Decreasing	No Change	South of
No Change	Increasing	East of
No Change	Decreasing	West of
Not Same	Not Same	No Decision

Thus, a vehicle leaving 13th and Market, signpost (6, 6), traveling East would receive a signal from signpost (6, 8) at 11th and Market which, when the 4 LSB's of the North-South and East-West fields were compared, indicate that only the East-West field was changing, and that it was increasing. Therefore, the vehicle would declare that it was "East of" signpost (6, 6), e.g., East of the intersection of 13th and Market, and on Market Street.

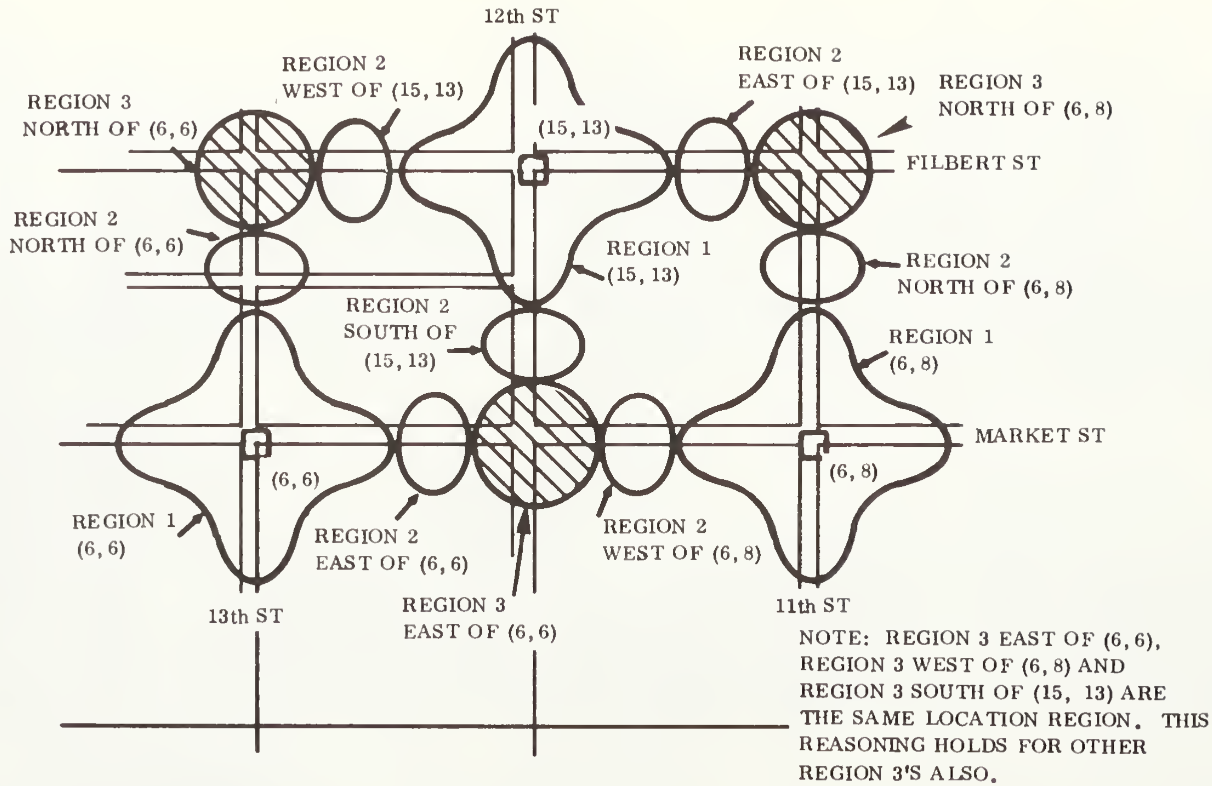


FIG. 3-14 OVERLAP REGION CREATED BY ADJACENT "CHAINING" SIGNPOSTS

The distance along Market would be determined (simultaneously with the determination of direction) by comparing the strength of the received signals from signposts (6,6) and (6,8). The following table identifies the results of this level comparison and Figure 3-15 illustrates the location of Region(s) 1, Region(s) 2, and Region(s) 3 relative to a pair of signposts:

		Signpost A		
		Greater than -58 dBm*	Between -72 and -58 dBm	Between -82 and -72 dBm
Signpost B	Greater than -58 dBm	$R1_{A \text{ or } B}$	$R1_B$	$R1_B$
	Between -72 and -58	$R1_A$	$R3_{A \text{ or } B}$	$R2_B$
	Between -82 and -72	$R1_A$	$R2_A$	$R3_{A \text{ or } B}$

*dBm refers to the power level in decibels above a milliwatt and is $P(dBm) = 10 \log_{10} p(\text{milliwatts})$. Thus power level of 1 mw corresponds to 0 dBm. -60 dBm corresponds to a power level of 10^{-6} milliwatts or 10^{-9} watts.

Thus, if a Level 1 (signal greater than -58 dBm) is received from a signpost, the vehicle declares itself within the "Region 1" of that signpost or "at" the signpost. If a Level 2 or Level 3 is received, then either a Region 2 or Region 3 is declared, depending on the relative field strength received from the chaining signpost. If signals are received from two non-chaining signposts, e.g., signposts (6,6) and (15,13) the information is ignored and the previous location region is retained in the vehicle unit.

Combining the signpost code, region, and direction information allows each signpost to contribute to the formation of nine (9) location regions. For signpost (8,8) in Figure 3-12, these regions are as follows:

Signpost	Signpost Location Region	Approximate Center of Location Region
8, 8	Region 1	11th and Arch
	Region 2 North of (8, 8)	11th and Appletree
	Region 2 South of (8, 8)	11th and Cuthbert
	Region 2 East of (8, 8)	290 feet East of 11th and Arch
	Region 2 West of (8, 8)	290 feet West of 11th and Arch
	Region 3 North of (8, 8)	11th and Cherry
	Region 3 South of (8, 8)	11th and Filbert
	Region 3 East of (8, 8)	10th and Arch
	Region 3 West of (8, 8)	12th and Arch

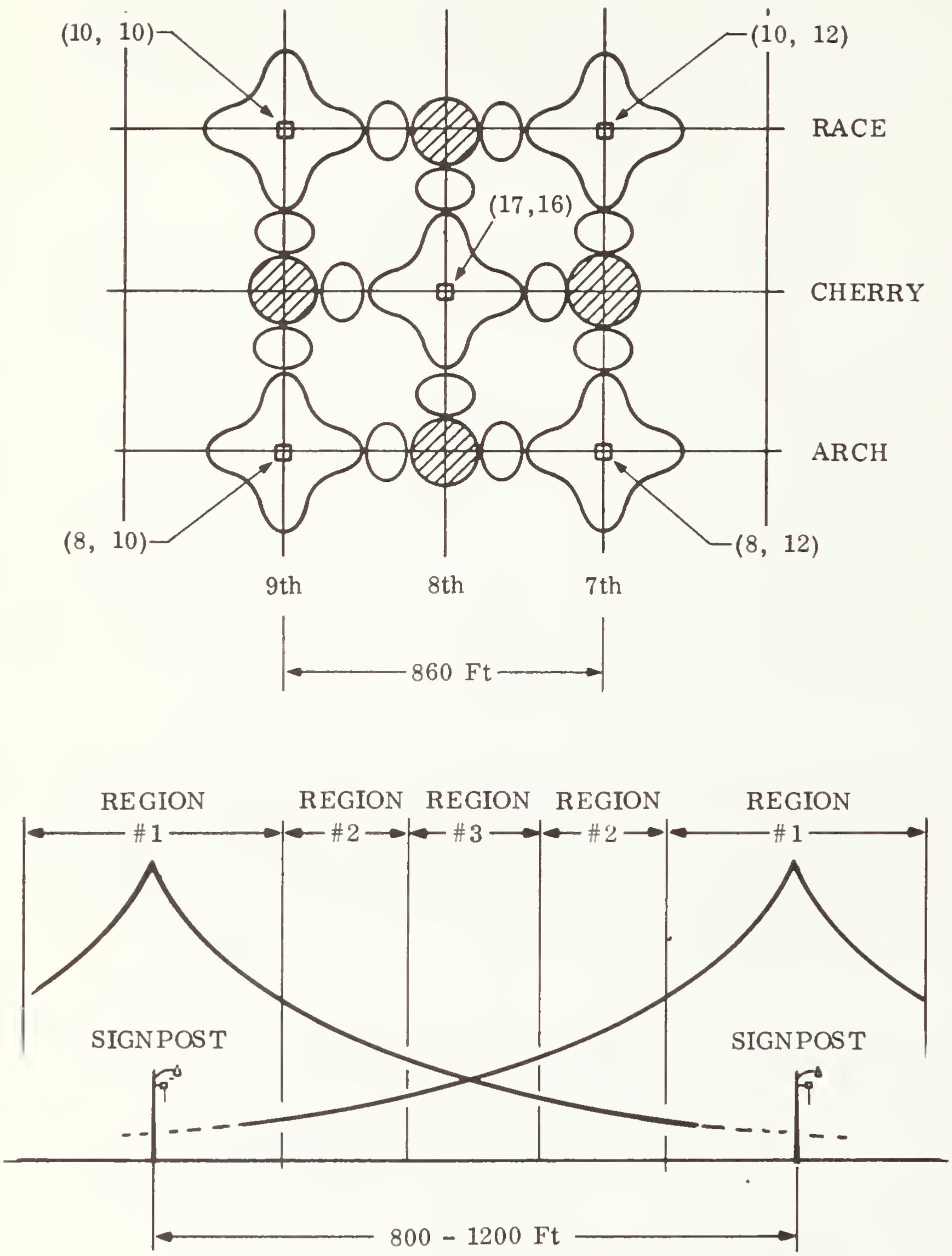


FIG. 3-15 HI^3 LS LOCATION REGIONS

Note that the location region identified as "Region 3 East of signpost (6, 6) would also be located at 12th and Market, the only difference between this region and Region 3 West of (6, 8) being the referenced signpost. Thus, in general, only five of the nine location regions associated with a signpost are unique, all Region 3's being duplicated. During Phase I, a set of X, Y stateplane coordinates were assigned to each location region in the coverage area. Whenever a new 18-BIT location code was received, the vehicle was assumed to be located at the corresponding X, Y stateplane coordinates.

Repeating, for clarity, the makeup of the 18-BIT location region code for random route location with signpost (8, 10) was:

Signpost Code		Region Field				
North Field	East Field	Direction Field		Level Field		Region Name
0 0 0 1 0 0 0	0 0 0 1 0 1 0	X	X	X	X	
		0	0	0	0	R1
		0	0	0	1	R2 South
		0	1	0	1	R2 East
		1	1	0	1	R2 North
		1	0	0	1	R2 West
		0	0	1	0	R3 South
		0	1	1	0	R3 East
		1	1	1	0	R3 North
		1	0	1	0	R3 West

Also, the HI^3 LS requires only one measurement to determine a new vehicle position, exactly as proposed for Phase II.

3.2.2 Random Route Area Mapping

After deployment of the signposts in Philadelphia, the system was calibrated to determine the location at which the boundaries between adjacent location regions occurred. After determining these boundary locations, through use of the in-vehicle display and manual analysis of listings of test cassettes, each location region was assigned a specific location region center, corresponding to a physical X, Y location in the test area. These locations were then utilized to create the signpost location region data base. During subsequent data processing, when an 18-BIT code recorded on cassette was processed, the vehicle's estimated location was given by the data base location corresponding to that 18-BIT code. Thus, a simple table look-up algorithm allowed the vehicle to be located at one of the 194 unique locations in the test area.

The generation of these 194 locations was accomplished by recording signpost location region codes, fifth wheel distance data, and event codes while driving the test vehicle over all streets within the test area. The boundary transitions were referenced (via the fifth wheel) to known X, Y locations supplied by the MITRE Corporation (locations identified by use of event codes). Analysis at Fort Worth allowed these boundaries to be located on a test area map. This map, presented in Figure 3-16, reflects the "Center" of all location regions on the basis of compiling multiple test runs through each region, including runs through different lanes. The map "center" of a location region was selected so as to minimize the location error on the basis of test and calibration data through the use of the HI^3 checkpoints. The centroid of a location region was selected as the point to be used in locating the vehicle when it declares a particular region code. In general, if a location region contained a street intersection, the center of the intersection was selected as the center of the location region.

Checkpoint Location and Marking. On 2 December 1976, TSC provided HI^3 with a list of sixty-three (63) primary checkpoints forty-eight (48) hours prior to initiating test runs 1 through 5. These checkpoints were identified in general (e.g., on Race East of 12th Street, West of Reading Railroad). HI^3 then identified specific landmarks: e.g., nearby street light, utility pole, sign, traffic standards, etc., which were approved by TSC as checkpoints. Each such point was identified by number, description, and location in terms of offset distances (X and Y) from the center of the nearest intersection. Subsequent to the completion of Test Runs 1 through 5, these offsets were translated into stateplane X, Y coordinates and became a part of the HI^3 Data Processing Software Data Base. Random Route Runs 1 through 5 were completed on 7 December 1976. On 12 December, TSC provided a list of 62 secondary checkpoints which were used during Random Route Runs 6 through 10. Random Route Runs 6 through 10 were conducted on 14 December 1976.

3.2.3 Location Subsystem Calibration

Calibration of the LS for random route testing involves (1) the establishment of the threshold levels for Levels 1, 2, and 3 in the vehicle unit, (2) the calibration of the fifth wheel over a measured distance calibration range, and (3) the use of the calibrated vehicle unit and fifth wheel to map the location area and generate the location region data base. Subsequently, only the threshold levels in the vehicle unit and the fifth wheel needed to be verified prior to the tests each day.

X and Y coordinate offset distances of checkpoints were determined through the use of the fifth wheel and DMI and a Measure Master manual device; when this measuring device was rolled along the pavement, it provided a direct counter readout of elapsed distance in feet.

3.2.3.1 Vehicle Unit Calibration. The calibration of the vehicle unit was verified on each test day with a calibrated signpost signal simulator and variable attenuator. Calibration involved attaching the output of the battery-powered

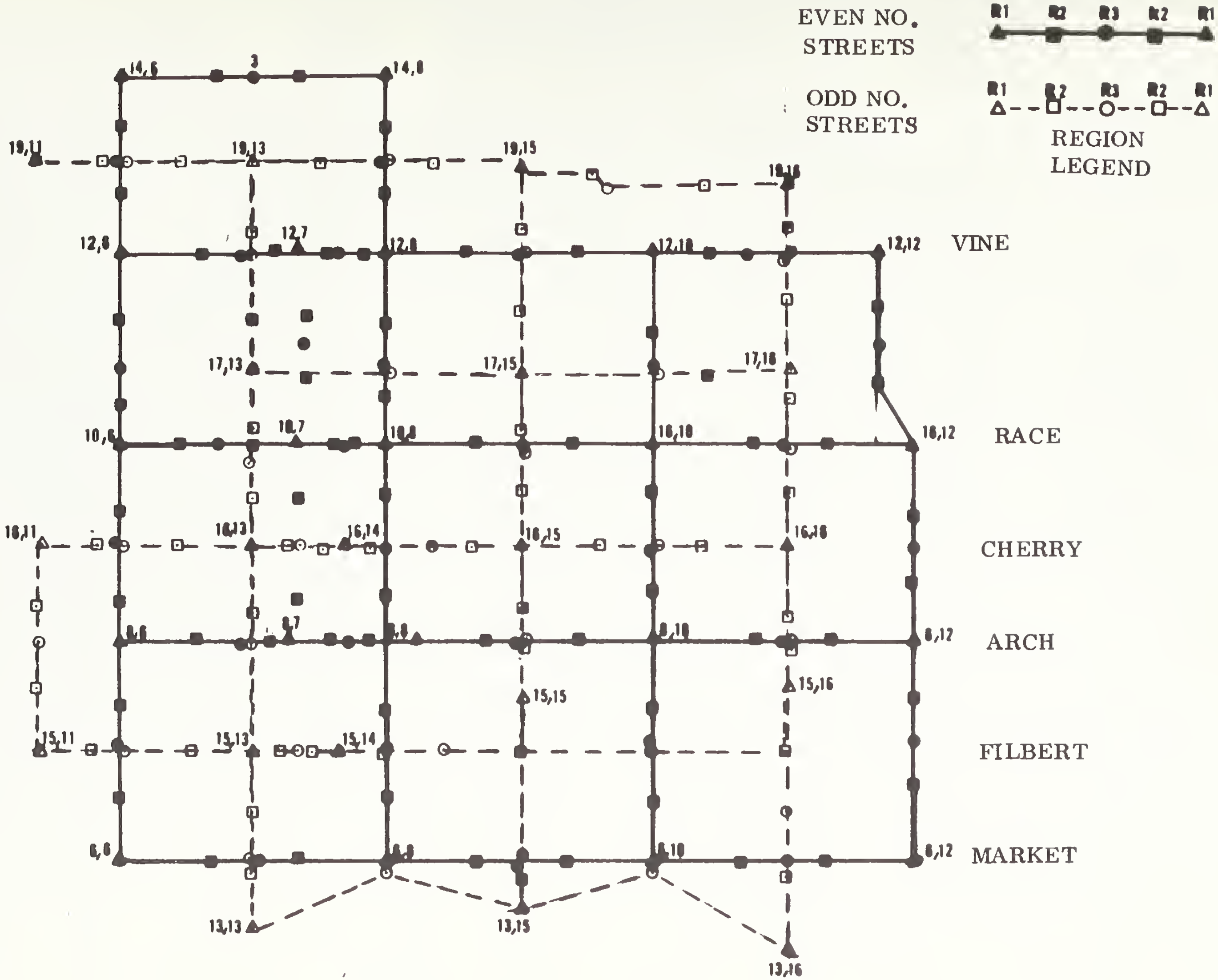


FIG. 3-16 MAP OF HI^3 LOCATION REGIONS

simulator to the vehicle unit antenna input connector with a short length of coax and a variable attenuator. The output of the simulator is -23 dBm. During calibration, the top of the vehicle unit box was removed in order to allow observation of three Light Emitting Diodes (LED's) which lighted whenever Level 3, 2, and 1 were respectively tripped. The trip level, in dBm, was obtained by subtracting the attenuation setting required to cause a level light (LED) to be extinguished from the -23 dBm value. Vehicle unit threshold level settings were not changed during random route testing. Threshold levels were -82, -72, and -58 dBm, respectively, for Levels 3, 2, and 1.

The threshold levels selected for use in the LS were determined so that they would provide adequate operation throughout a city (in this case the test area). Two factors influence the value of these thresholds: (1) the nominal spacing between signposts and (2) the RF background noise. The nominal spacing between signposts is primarily dictated by the street and block layout in a city. In most instances, HI^3 signposts are placed at intersections so as to take advantage of propagation down both streets in orthogonal directions. However, in some instances (e.g., signpost (15, 16) in the tunnel near Filbert and 8th) use of this method was not practical. Still, the threshold levels are set so as to divide the space between the signposts into location regions which allow the LS and system location accuracy specifications to be met.

The influence of RF background noise within the bandwidth of a signpost receiver is such that the signal-to-noise ratio at the receiver is reduced and the probability of an error in a received signpost transmission is increased. Although such an error will be detected and rejected by the vehicle unit's error filter, a missed transmission can cause an error if it occurs at or near a location region boundary. A survey of the in-band RF noise was made by HI^3 as part of Special Case Tests and is subsequently discussed in subsection 9.2. Analysis of this data demonstrates that the normal urban RF noise environment has been properly accounted for in the HI^3 system S/N design.

3.2.3.2 Fifth Wheel Calibration. The fifth wheel and odometer were calibrated each test day by driving a measured 1000-foot distance along Delaware Street. Neither odometer or fifth wheel calibrations were changed after initially being set at 979 and 872, respectively. With the exception of driving on ice and slush (when the fifth wheel introduced errors), both systems were always accurate within 0.2 percent of 1000 feet when the calibration was verified.

3.2.3.3 Location Region Data Base Calibration. The initial calibration of the location region data base was established through the use of the calibrated vehicle unit and the calibrated fifth wheel in the manner described in Paragraph 3.2.1. During the 48-hour period prior to commencing each series of tests, the operation of the signpost system was checked to verify its operation by driving the test area and simultaneously observing the CRT display. During calibration runs, a set of HI^3 checkpoints were used for which X, Y locations were available.

3.3 RANDOM ROUTE DATA ACQUISITION

Test data were recorded on cassettes during all test runs. The sequence of events concerning data handling logistics is shown in Figure 3-17. Prior to a test run, header data identifying the test run parameters (refer to paragraph 3.1.3.1) were recorded on each pair of cassettes under the control of the RANDOM computer program.

A corresponding data log sheet was manually filled out by the Program Test Director and signed by the TSC Monitor after each Test Run. Figure 3-18 reflects a typical log sheet. At the conclusion of the Random Route test runs, all data cassettes were duplicated onto IBM compatible magnetic tapes. The master cassettes were retained by TSC until HI^3 software was validated at MITRE.

After keystroking the header data in response to prompters on the CRT display, the test vehicle driver proceeded to traverse the specified route. Passage of each designated checkpoint and each turn was recorded by keystroking the coded event marker. This action caused a time-coincident data record to be recorded on cassette. As a checkpoint or turn was approached, the test vehicle driver informed the test director/DAS operator to prepare for checkpoint NN. The DAS operator pressed first the CHECKPOINT function key and then keystroked the number NN. He then prepared to depress the RETURN key. As the test vehicle approached the checkpoint, the driver called out "standby", and then, as the front bumper of the test vehicle passed the designated checkpoint, he called out "MARK." Upon hearing this MARK, the DAS operator depressed the RETURN key. This action produced a data record and the appropriate checkpoint or turn number to be recorded on cassette. The Random Route Test Procedures are illustrated in Figure 3-19. All recorded data were retained and processed. No data were eliminated as poor or potentially poor.

All Random Route Tests commenced at 7th and Market heading North on 7th and ended at 7th and Market heading East on Market. The beginning and end of each run was indicated by entry of TA 64 (Turn 64) which was the number assigned by HI^3 to the intersection of 7th and Market.

The route traveled during Random Route Runs 1 through 5 is shown in Figure 3-20. TSC primary checkpoints are indicated by CP1, CP2, etc. Turn intersections are indicated by TA7, TA44, etc. The specific locations and landmarks selected by TSC as primary checkpoints are identified in Table 3-1. When the test vehicle left the random route test area and headed West at 13th and Market, TA58 was entered. TA58 was subsequently entered again when the vehicle re-entered the test area at 13th and Market and headed East after completing a turn-around at the City Hall. HI^3 Data Processing Software was designed to ignore data between successive entries of the same turn intersection number. This algorithm was authorized by TSC and was designed to keep from processing data outside of the random route test area during "pseudo" checkpoint processing for system simulation.

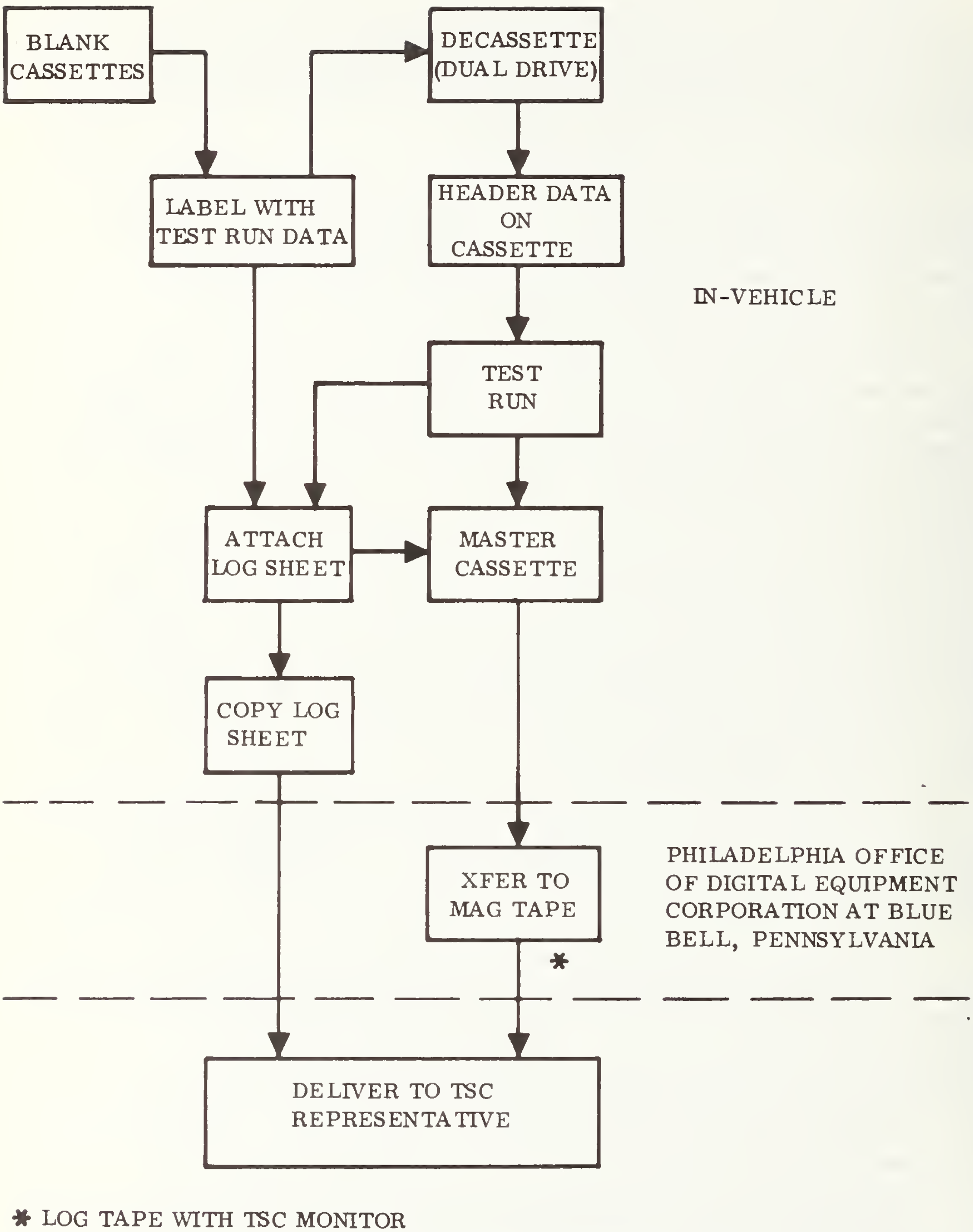


FIG. 3-17 HI^3 DATA HANDLING LOGISTICS

TEST DATA LOG

TEST RUN NO. 4 SHEET NO. 1 OF 1

TYPE OF TEST: Huffman Random Route DATE: 12-7-76

BRIEF NARRATIVE DESCRIPTION OF TEST TIME START 2025 END 2150
TEMP 46°F, DRY WINDY.

ROUTE IDENTIFICATION: TSC Primary Route

EVENT MARKER NUMBER: 1-63 in sequence
TIME 31 MIN 41 SEC. AT C.P. 25 THRU C.P. 28 TROLLEY CAR
FOLLOWING DIRECTLY BEHIND TEST VEHICLE.

EQUIPMENT UTILIZED/TEST CONDITION: VEHICLE UNIT NO.: 2

VEHICLE UNIT THRESHOLD LEVELS: 1 -59 dBm 2 -72 dBm 3 -82 dBm

ODOMETER CAL: 997 FPP 2 5TH WHEEL CAL X FPP X

R1 DROPOUT SWITCH: Off/On Off OTHER:

TEMPERATURE: 45° PRECIPITATION: none ROAD CONDITIONS: Wet

TEST TAPE NO(S). 4-1, 4-2 FILE NO. 1

SAMPLE RATE: 0.5

RUN TIME: 1 HR - 25 MIN. TEST DIRECTOR George W. Kruse

TSC MONITOR R. W. A. Klein

FIG. 3-18 HI^3 TEST DATA LOG

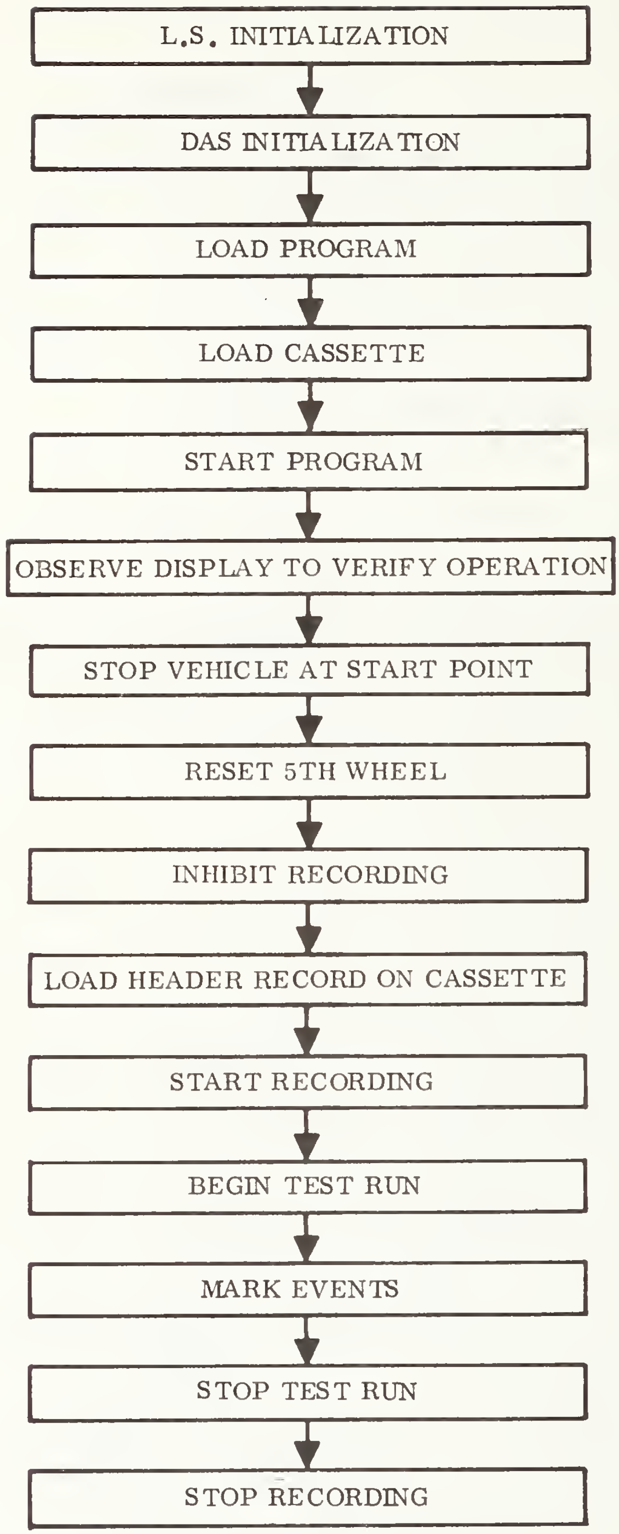


FIG. 3-19 HI^3 RANDOM ROUTE TEST PROCEDURES

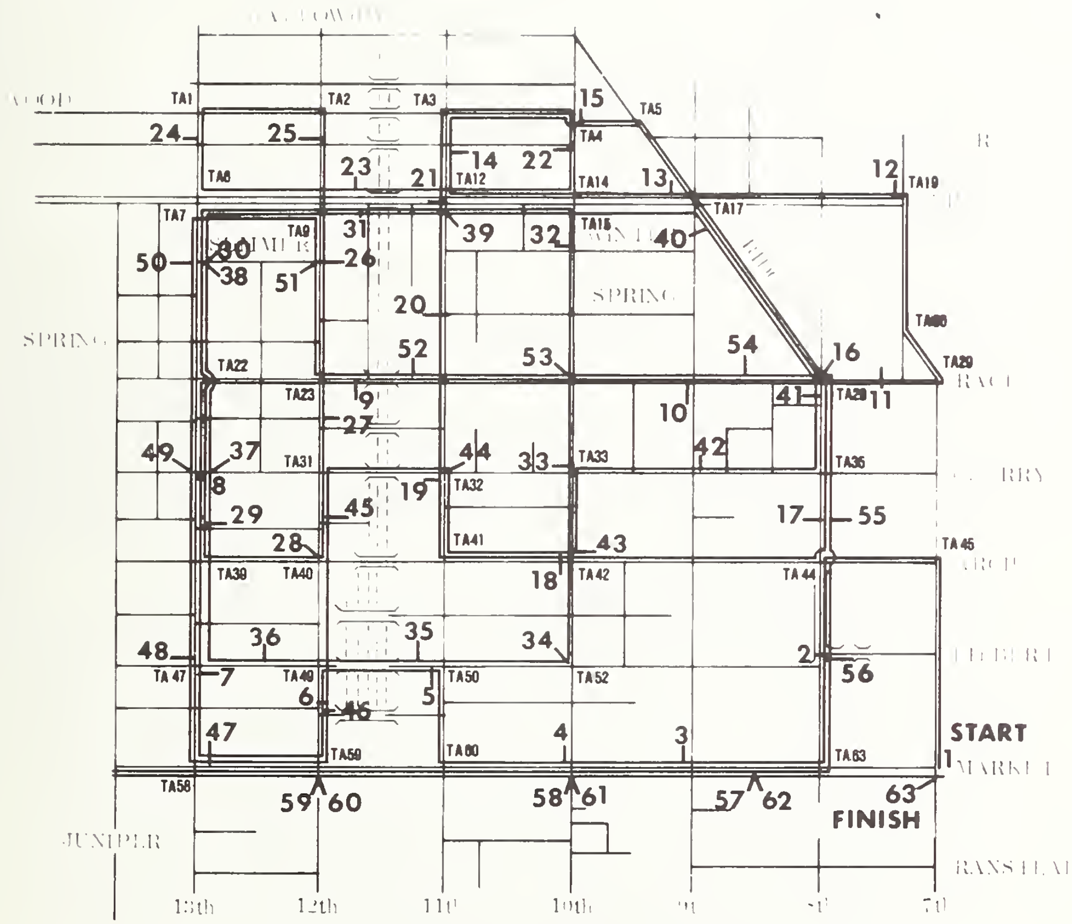


FIG. 3-20 PRIMARY RANDOM ROUTE AND CHECKPOINTS

TABLE 3-1 PRIMARY CHECKPOINTS

C. P. #	LOCATION/ LANDMARK
1	on 7th, curb northside of Market
2	on 8th, Center of Filbert
3	on Market, Center of 9th
4	on Market, Westside curb of 10th
5	on Filbert, Fireplug after West Turn from 11th
6	on 12th, Center of Commerce
7	on 13th, Center of Filbert
8	on 13th, Center of Cherry
9	on Race, St. Light West of Reading Tunnel, Between 11th & 12th
10	on Race, Center of 9th
11	on Race, Freeway sign between 7th & 8th
12	on Vine, Traffic Standard, Corner of 7th
13	on Vine, Traffic Standard, Northwest Corner of Ridge
14	on 11th, Center of Pearl
15	on Wood, Center of 10th, Manhole Cover
16	on Ridge, Center of Race
17	on 8th, Center of Appletree
18	on Arch, Center of 10th
19	on 11th, Center of Cherry
20	on 11th, Center of Spring
21	on 11th, Center of Vine
22	on 10th , Center of Pearl
23	on Vine, St. Light Northwest of Train Overpass Between 11th&12th
24	on 13th, Center of Pearl
25	on 12th, Center of Pearl
26	on 12th, Stop Sign, Southside of Summer
27	on 12th, North East Curb of Quarry
28	on 12th, Curb, Northside of Arch
29	on 13th, Center of Appletree
30	on 13th, Center of Summer, Fireplug
31	on Vine, St. Light Northeast of Elevated Train Overpass Between 11th & 12th
32	on 10th, Pole, Center of Winter
33	on 10th, Center of Cherry
34	on 10th, Northwest Curb of Filbert
35	on Filbert, After 11th at East Edge of Overpass
36	on Filbert, Black Pole Northside between 12th & 13th
37	on 13th, Center of Cherry
38	on 13th, Center of Summer Fireplug (westside)
39	on Vine, Center of 11th
40	on Vine, Center of 9th
41	On Ridge, Center of Race
42	on 9th, Center of Cherry
43	on 10th, North Curb of Arch
44	on 11th, Center of Cherry
45	on 12th, Center of Appletree
46	on 12th, Center of Commerce
47	on Market Curb Eastside of 13th
48	on 13th, Center of Filbert
49	on 13th, Center of Cherry
50	on 13th, Center of Summer Fireplug (westside)
51	on 12th, Stop Sign, South side of Summer
52	on Race, between 11th & 12th, St. Light South Eastside of Train Overpass
53	on Race, Center of 10th
54	on Race, Sign Southside , Between 8th & 9th
55	on 8th, Center of Appletree
56	on 8th, Center of Filbert
57	on Market, St. Light southside between 8th & 9th
58	on Market, Curb, westside of 10th
59	on Market, Center of 12th
60	on Market, Center of 12th
61	on Market, Center of 10th
62	on Market, Pole, Southside between 8th & 9th
63	on Market, Center of 7th

The test route, secondary checkpoints, and turn intersections used during random route test runs 6 through 10 are shown in Figure 3-21. The specific secondary checkpoint locations are identified in Table 3-2.

3.4 RANDOM ROUTE TEST DATA

As previously discussed in Section 3.1.3, test data were recorded on cassette every 0.5 second. This operation resulted in over 90,000 records, which, if printed out, would produce over 90,000 lines of print. In order to reduce the volume of data for this report, HI^3 wrote a computer program which prints out only those records which (1) contain an event marker or (2) contain a change in location region code. Only data of the type (1) and (2) are of interest during location subsystem data processing since only data at checkpoints are processed. During system level processing, all records or tape are of interest. However, in the interest of keeping this report manageable, complete listings of random route tapes have been provided to TSC separately. Listings of Random Route Test Runs 1 through 10 which show records of types (1) and (2) above are included in the Appendix. However, a listing of Run 7 is presented in Table 3-3 in order to show typical random route data. A list of column headings has been inserted; otherwise data is a direct dump of Run 7. However, only records which contain a location region change and/or a manual event entry are listed. Note that the odometer/fifth wheel columns are presented in terms of the number of pulses. To convert these columns to feet, they must be multiplied by the FPP calibration number which indicates the number of feet per pulse. In all cases during Phase I, this multiplier is two (2), so that the column values, when multiplied by 2 are converted to feet.

By recalling that the HI^3 vehicle unit stores the last received 18-BIT location code until a new valid code is received, it will be observed that either or both time and distance may change without a change in location code. In addition, the location code may change "toggle" while the vehicle is not moving, particularly if it is stopped in the vicinity of a boundary between two regions or in a location in which more than one 18-BIT code (e.g., Region 3) is used to describe a region. For example, between Time 34 minutes 14 seconds, and Time 34 minutes 25 seconds, Run 7 data in Table 3-3 is observed to toggle between the three codes (12,06) R2N, (14,06) R2S, and (14,06) R3S. By referring to Figure 3-12 and Table 3-2, it can be seen that Secondary Checkpoint 27 is located at 13th and Pearl, which is approximately 1/3 of the distance North of signpost (12,06), between signpost (12,06) and signpost (14,06). Reference to Table 5-7 will indicate that the location error incurred at CP 27 during Run 9 was 51 feet. If, for example, the CP had been marked at a time in which the location code was (12,06) R2N, i.e., 2 seconds and 38 feet later, the location error would have been 26 feet. However, in either case, the error would be considerably less than 300 feet.

Another typical case occurs at Times 11 minutes 7 seconds and 11 minutes 9 seconds in Table 3-3. In this case, the odometer readings are the same but the location codes are different. Note, however, that (13,15) R2N and (15,15) R3S are regions which share a common boundary as illustrated in Figure 3-16.

(Text Continues on 3-47)

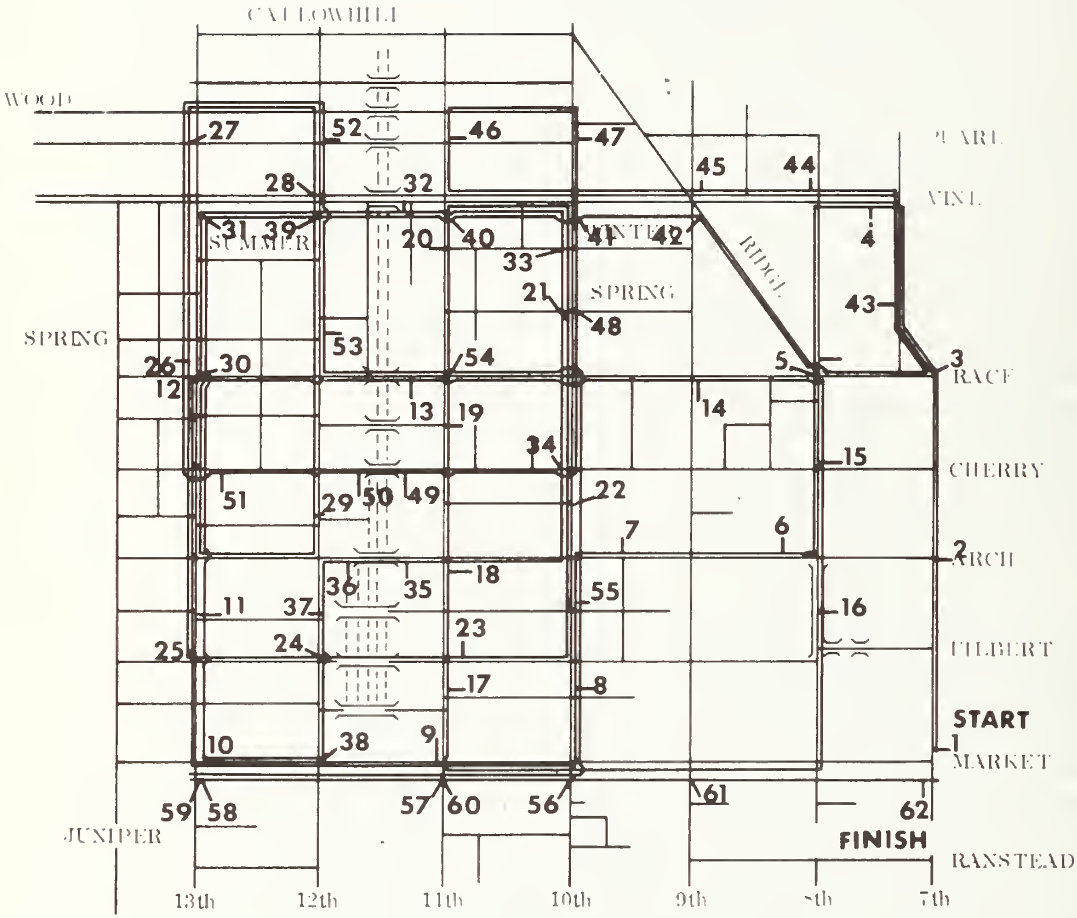


FIG. 3-21 SECONDARY RANDOM ROUTE AND CHECKPOINTS

TABLE 3-2 SECONDARY CHECKPOINTS

C.P. #	LOCATION/ LANDMARK
1	on 7th, Fire Plug, Northwest side of Market
2	on 7th, Center of Arch
3	on 7th, Center of Race
4	on Vine, Light Pole, North Side, between 7th &8th
5	on 8th, Center of Race
6	on Arch, After west turn on Arch, Fire Plug Southside
7	on Arch, Center of Hutchison
8	on 10th, Center of Filbert
9	on Market, Center of 11th
10	on Market, Overhead Signal Between 12th & 13th
11	on 13th, Center of Cuthbert
12	on Race, Wastebasket, North Side, After turn on Race
13	on Race, Light Pole, East Side of Elevated Train Overpass
14	on Race, Center of 9th
15	on 8th, Center of Cherry
16	on 8th, "NO STOPPING" sign east side between Arch & Filbert
17	on 11th, Center of Commerce
18	on 11th, Center of Arch
19	on 11th, Center of Quarry
20	on 11th, "ONE WAY " sign, west side of Winter
21	on 10th, Center of Spring
22	on 10th, Center of Appletree
23	on Filbert, South side "NO STOPPING" sign, between 10th and 11th
24	on Filbert, at west edge of Tunnel
25	on Filbert, Black Pole, North East Side of 13th
26	on 13th, Center of Spring
27	on 13th, Center of Pearl
28	on 12th, Center of Vine
29	on 12th, Center of Appletree
30	on 13th, Center of Race
31	on 13th, Pole, South Eastside of Vine
32	on Vine, "NO PARKING" sign, south Eastside of elevated Train Overpass
33	on 10th, Center of Winter
34	on 10th, Center of Cherry
35	on Arch, "NO PARKING" sign, west of 11th & East of Elevated Train Overpass
36	on Arch, Overhead Traffic Signal, West of Elevated Train Overpass, & East of 12th
37	on 12th, Center of Cuthbert
38	on 12th, Edge of Building, Northside of Market
39	on Vine, Center of 12th
40	on Vine, Center of 11th
41	on Vine, Center of 10th
42	on Vine, Center of 9th
43	on 7th, Telephone Booth, Westside, Between Race & Vine
44	on Vine, Center of 8th
45	on Vine, Center of 9th
46	on 11th, Center of Pearl
47	on 10th, Center of Pearl
48	on 10th, Center of Spring
49	on Cherry, Light Pole, Eastside of Elevated Train Overpass, & West of 11th
50	on Cherry, Light Pole, Westside of Elevated Train Overpass, East of 12th
51	on Cherry, Center of Iseminger
52	on 12th, Center of Pearl
53	on 12th, Center of Spring
54	on Race, Center of 11th
55	on 10th, Center of Cuthbert
56	on Market, Traffic Light, Nothwest Corner of 10th
57	on Market, Center of 11th
58	on Market, Overhead Signal, Between 12th & 13th
59	on Market, Overhead Signal, Between 13th & 12th
60	on Market, Center of 11th
61	on Market, Center of 9th
62	on Market, Center of 7th

TABLE 3-3 LISTING OF RECORDED RANDOM ROUTE TEST DATA

RUN [illegible] SAMPLE RATE 00.5 YEAR 76 MONTH 12 DAY 14 HOUR

FIFTH WHEEL FEET/PULSE 0002 ODOMETER FEET/PULSE 0002

	000	06	12	R1	0 00116	F 00000	T 00 50
TA	064	06	12	R1	0 00206	F 00000	T 01 37
CF	001	06	12	R1	0 00262	F 00000	T 01 44
	000	06	12	R2 N	0 00338	F 00000	T 01 51
	000	08	12	R2 S	0 00379	F 00000	T 01 54
	000	06	12	R2 N	0 00403	F 00000	T 01 56
	000	06	12	R3 N	0 00416	F 00000	T 01 57
	000	06	12	R2 N	0 00452	F 00000	T 02 00
	000	08	12	R2 S	0 00469	F 00000	T 02 02
	000	08	12	R1	0 00509	F 00000	T 02 26
CF	002	08	12	R1	0 00582	F 00000	T 0 40
	000	08	12	R2 N	0 00683	F 00000	T 03 14
	000	08	12	R1	0 00687	F 00000	T 03 14
	000	08	12	R2 N	0 00707	F 00000	T 03 18
	000	08	12	R1	0 00714	F 00000	T 03 19
	000	08	12	R2 N	0 00717	F 00000	T 03 20
	000	08	12	R1	0 00720	F 00000	T 03 21
	000	08	12	R3 N	0 00730	F 00000	T 03 24
	000	08	12	R2 N	0 00731	F 00000	T 03 26
	000	10	12	R3 S	0 00744	F 00000	T 03 27
	000	08	12	R2 N	0 00761	F 00000	T 04 00
	000	10	12	R3 S	0 00786	F 00000	T 04 06
	000	10	12	R2 S	0 00848	F 00000	T 04 15
	000	10	12	R1	0 00852	F 00000	T 04 16
	000	10	12	R2 S	0 00856	F 00000	T 04 16
	000	10	12	R1	0 00860	F 00000	T 04 17
	000	10	12	R2 S	0 00872	F 00000	T 04 18
	000	10	12	R1	0 00883	F 00000	T 04 20
	000	10	12	R2 S	0 00885	F 00000	T 04 21
	000	10	12	R1	0 00888	F 00000	T 04 22
CF	003	10	12	R1	0 009[illegible]	F 00000	T 05 14
TA	029	10	12	R1	0 00948	F 00000	T 05 19
	000	10	12	R2 N	0 01053	F 00000	T 05 30
	000	10	12	R3 N	0 01116	F 00000	T 05 35
TA	080	10	12	R3 N	0 01123	F 00000	T 05 36
	000	12	12	R2 S	0 01155	F 00000	T 05 38
	000	12	12	R	0 01222	F 00000	T 05 45
TA	019	12	12	R1	0 01266	F 00000	T 06 01
CF	004	12	12	R1	0 01351	F 00000	T 06 12
	000	12	12	R2 W	0 01387	F 00000	T 06 16
TA	018	12	12	R2 W	0 01416	F 00000	T 06 21
	000	19	16	R2 [illegible]	0 01426	F 00000	T 06 23
	000	19	16	R3 S	0 01459	F 00000	T 06 26
	000	19	16	R2 S	0 01471	F 00000	T 06 27
	000	17	16	R2 N	0 01477	F 00000	T 06 28
	000	17	16	R1	0 01523	F 00000	T 06 31
	000	10	10	R3 F	0 01635	F 00000	T 07 13
	000	17	16	R1	0 01636	F 00000	T 07 14
CF	005	17	16	R1	0 01721	F 00000	T 07 27
	000	16	16	R3 N	0 01801	F 00000	T 07 34
	000	16	16	R2 N	0 01836	F 00000	T 07 37
	000	16	16	R1	0 01847	F 00000	T 07 38
	000	15	16	R2 N	0 020[illegible]	F 00000	T 07 57
	000	16	16	R3 S	0 02046	F 00000	T 08 03
TA	044	16	16	R3 S	0 02059	F 00000	T 08 06
	000	15	16	R1	0 02070	F 00000	T 08 08
	000	08	12	R2 W	0 02077	F 00000	T 08 10
CF	006	08	12	R2 W	0 02080	F 00000	T 08 10
	000	08	10	R3 E	0 02087	F 00000	T 08 12
	000	08	10	R2 E	0 02167	F 00000	T 09 21
	000	08	10	R2 N	0 02173	F 00000	T 08 22
	000	08	10	R2 E	0 02179	F 00000	T 08 22
	000	08	10	R1	0 02214	F 00000	T 08 [illegible]
CF	007	08	10	R1	0 02408	F 00000	T 08 3[illegible]
	000	08	10	R2 W	0 02441	F 00000	T 08 48
	000	08	10	R3 W	0 02461	F 00000	T 08 57
TA	042	08	10	R3 W	0 02497	F 00000	T 09 [illegible]
	000	15	15	R1	0 02509	F 00000	T 09 05
	000	16	15	R3 S	0 02522	F 00000	T 09 08
	000	15	15	R2 N	0 02529	F 00000	T 09 09
	000	15	15	R1	0 025[illegible]	F 00000	T 09 10
CF	008	15	15	R1	0 026[illegible]4	F 00000	T 09 25
	000	13	15	R3 N	0 02711	F 00000	T 09 31
	000	13	15	R2 N	0 02830	F 00000	T 11 05
	000	15	15	R3 S	0 02833	F 00000	T 11 06
	000	13	15	R2 N	0 02838	F 00000	T 11 07
	000	15	15	R3 S	0 02838	F 00000	T 11 09
TA	061	13	15	R1	0 02856	F 00000	T 11 16
	000	06	10	R2 W	0 02883	F 00000	T 11 21
	000	06	08	R2 E	0 02909	F 00000	T 11 25
	000	06	10	R2 W	0 02915	F 00000	T 11 25
	000	06	08	R2 E	0 02941	F 00000	T 11 28
	000	06	08	R1	0 02952	F 00000	T 11 29
	000	06	08	R2 E	0 02964	F 00000	T 11 30
	000	06	08	R3 E	0 02975	F 00000	T 11 31
	000	06	08	R1	0 02992	F 00000	T 11 34
CF	009	06	08	R1	0 03076	F 00000	T 11 41
	000	06	08	R2 W	0 03182	F 00000	T 11 59
	000	06	06	R3 E	0 03193	F 00000	T 12 02
	000	06	08	R2 W	0 03238	F 00000	T 12 08
	000	06	06	R3 E	0 03295	F 00000	T 12 25
	000	06	06	R1	0 03449	F 00000	T 12 43
CF	010	06	06	R1	0 03476	F 00000	T 13 14
TA	058	06	06	R1	0 03529	F 00000	T 13 36
	000	06	06	R2 N	0 03615	F 00000	T 14 01
	000	08	06	R2 S	0 03692	F 00000	T 14 03
CF	011	08	06	R2 S	0 03786	F 00000	T 14 20
	000	08	06	R1	0 03803	F 00000	T 14 33
	000	16	11	R1	0 04042	F 00000	T 15 13
	000	10	06	R2 S	0 00045	F 00000	T 15 27
	000	10	06	R1	0 00091	F 00000	T 15 54
TA	022	10	06	R1	0 00139	F 00000	T 16 00
CF	012	10	06	R1	0 00155	F 00000	T 16 04
	000	10	06	R2 E	0 00251	F 00000	T 16 28
	000	10	06	R3 W	0 00251	F 00000	T 16 29
	000	10	07	R1	0 00390	F 00000	T 16 54
	000	10	07	R2 W	0 00507	F 00000	T 17 04
	000	10	07	R3 E	0 00523	F 00000	T 17 06
CF	013	10	07	R3 E	0 00529	F 00000	T 17 06
	000	10	08	R1	0 00544	F 00000	T 17 08
	000	10	08	R2 E	0 00795	F 00000	T 17 44
	000	17	15	R2 S	0 00815	F 00000	T 18 05
	000	16	15	R3 N	0 00818	F 00000	T 18 06
	000	10	08	R2 E	0 00845	F 00000	T 18 09
	000	10	08	R3 E	0 00868	F 00000	T 18 12
	000	10	10	R2 W	0 00877	F 00000	T 18 13
	000	10	10	R1	0 00994	F 00000	T 18 25
CF	014	10	10	R1	0 01033	F 00000	T 18 29
	000	10	10	R2 [illegible]	0 01188	F 00000	T 18 43
TA	028	1[illegible]	10	R3 [illegible]	0 01243	F 00000	T 19 33
	000	17	16	R2 S	0 01312	F 00000	T 19 39
	000	16	16	R3 N	0 01327	F 00000	T 19 41
	000	16	16	R2 N	0 01386	F 00000	T 19 46
	000	16	16	R1	0 01392	F 00000	T 19 47
CF	015	16	16	R1	0 01426	F 00000	T 19 50
	000	15	16	R3 N	0 01572	F 00000	T 20 04
	000	15	16	R1	0 01601	F 00000	T 20 06
CF	016	15	16	R1	0 01693	F 00000	T 20 15
	000	15	16	R2 S	0 01803	F 00000	T 20 25
	000	13	16	R3 N	0 01898	F 00000	T 20 34
TA	063	13	16	R3 N	0 019[illegible]	F 00000	T 20 43
	000	06	12	R2 W	0 01978	F 00000	T 20 45
	000	06	10	R3 F	0 01985	F 00000	T 20 46
	000	06	10	R2 E	0 0203[illegible]	F 00000	T 20 54
	000	06	10	R1	0 0208[illegible]	F 00000	T 20 58
	000	06	10	R2 E	0 021[illegible]	F 00000	T 21 02
	000	06	10	R1	0 02142	F 00000	T 21 03
	000	06	10	R2 W	0 023[illegible]	F 00000	T 22 00
	000	06	08	R2 F	0 02434	F 00000	T 22 15
	000	06	10	R3 W	0 02450	F 00000	T 22 17
	000	13	21	R1	0 02455	F 00000	T 22 47
	000	06	08	R2 E	0 02466	F 00000	T 22 48
	000	06	10	R3 W	0 02484	F 00000	T 22 50
	000	06	08	R2 E	0 02502	F 00000	T 22 51
	000	06	08	R1	0 02526	F 00000	T 22 53
	000	06	08	R2 E	0 02574	F 00000	T 22 57
	000	06	08	R1	0 02589	F 00000	T 22 59
TA	060	06	08	R1	0 02650	F 00000	T 23 41
CF	017	06	08	R1	0 02764	F 00000	T 23 57
	000	15	14	R1	0 02824	F 00000	T 24 04
	000	08	08	R2 S	0 02977	F 00000	T 24 20
	000	08	08	R1	0 03021	F 00000	T 24 25
CF	018	08	08	R1	0 03026	F 00000	T 24 25
	000	16	14	R1	0 031[illegible]	F 00000	T 24 41
CF	019	16	14	R1	0 0328[illegible]	F 00000	T 25 00
	000	10	08	R2 W	0 03290	F 00000	T 25 01
	000	10	08	R1	0 033[illegible]	F 00000	T 25 05
	000	10	08	R3 W	0 03345	F 00000	T 25 07
	000	10	08	R1	0 0334[illegible]	F 00000	T 25 07
	000	10	08	R2 N	0 03484	F 00000	T 25 20
	000	10	08	R1	0 03489	F 00000	T 25 20
	000	10	08	R2 N	0 03498	F 00000	T 25 21
	000	12	08	R3 S	0 03515	F 00000	T 25 23
	000	10	08	R2 N	0 03526	F 00000	T 25 24
	000	12	08	R3 S	0 03534	F 00000	T 25 25
	000	12	08	R2 S	0 03549	F 00000	T 25 27
	000	10	08	R3 N	0 03556	F 00000	T 25 28
	000	12	08	R2 S	0 03558	F 00000	T 25 29
	000	10	08	R3 N	0 03561	F 00000	T 25 30
	000	12	08	R2 S	0 03562	F 00000	T 25 30

TABLE 3-3 LISTING OF RECORDED RANDOM ROUTE TEST DATA (CONT'D)

000	10	08	R3 N	0 03564	F 00000	T 25 32
000	10	08	R2 N	0 03569	F 00000	T 25 34
000	12	08	R3 S	0 03570	F 00000	T 25 34
000	12	08	R2 S	0 03578	F 00000	T 25 38
CF 020	12	08	R2 S	0 03603	F 00000	T 26 15
000	12	08	R1	0 03610	F 00000	T 26 16
TA 013	12	08	R1	0 03705	F 00000	T 26 28
000	12	08	R2 W	0 03762	F 00000	T 26 33
000	12	08	R1	0 03769	F 00000	T 26 34
000	19	15	R3 S	0 03820	F 00000	T 26 38
000	12	08	R2 E	0 03876	F 00000	T 27 15
TA 015	12	08	R2 E	0 03891	F 00000	T 27 17
000	17	15	R2 N	0 03904	F 00000	T 27 19
000	19	15	R3 S	0 03941	F 00000	T 27 24
000	17	15	R1	0 03945	F 00000	T 27 24
000	17	15	R2 N	0 03960	F 00000	T 27 26
000	17	15	R1	0 03971	F 00000	T 27 27
000	19	15	R3 S	0 03981	F 00000	T 27 28
000	17	15	R1	0 03987	F 00000	T 27 28
CF 021	17	15	R1	0 04052	F 00000	T 27 34
000	17	15	R3 S	0 00070	F 00000	T 28 20
000	17	15	R2 S	0 00102	F 00000	T 28 24
000	16	15	R3 N	0 00121	F 00000	T 28 26
000	16	15	R2 N	0 00155	F 00000	T 28 29
000	17	15	R3 S	0 00166	F 00000	T 28 30
000	16	15	R1	0 00196	F 00000	T 28 32
CF 022	16	15	R1	0 00308	F 00000	T 29 00
000	15	15	R3 N	0 00351	F 00000	T 29 11
000	15	15	R2 N	0 00434	F 00000	T 29 21
000	16	15	R3 S	0 00438	F 00000	T 29 22
000	15	15	R2 N	0 00448	F 00000	T 29 23
000	15	15	R3 N	0 00455	F 00000	T 29 24
000	15	15	R1	0 00460	F 00000	T 29 25
000	15	15	R2 S	0 00585	F 00000	T 29 36
000	15	15	R1	0 00595	F 00000	T 29 38
TA 052	15	15	R1	0 00603	F 00000	T 29 39
000	15	15	R2 S	0 00606	F 00000	T 29 40
000	15	15	R2 W	0 00626	F 00000	T 29 44
000	15	14	R3 E	0 00639	F 00000	T 29 46
000	15	14	R2 E	0 00682	F 00000	T 29 51
CF 023	15	14	R2 E	0 00784	F 00000	T 30 02
000	15	14	R1	0 00787	F 00000	T 30 03
000	15	13	R2 E	0 00981	F 00000	T 30 35
000	15	13	R1	0 01015	F 00000	T 30 39
CF 024	15	13	R1	0 01052	F 00000	T 31 26
000	15	13	R2 W	0 01178	F 00000	T 31 41
000	15	13	R3 W	0 01212	F 00000	T 31 44
CF 025	15	13	R3 W	0 01250	F 00000	T 31 48
TA 047	15	13	R3 W	0 01283	F 00000	T 31 53
000	08	06	R2 S	0 01335	F 00000	T 32 02
000	08	06	R1	0 01364	F 00000	T 32 07
000	16	11	R1	0 01630	F 00000	T 32 46
000	10	06	R1	0 01770	F 00000	T 33 04
000	10	06	R2 N	0 01866	F 00000	T 33 14
CF 026	10	06	R2 N	0 01882	F 00000	T 33 16
000	10	06	R1	0 01887	F 00000	T 43 16
000	10	06	R2 N	0 01903	F 00000	T 33 18
000	10	06	R1	0 01913	F 00000	T 33 19
000	10	06	R2 N	0 01923	F 00000	T 33 20
000	12	06	R3 S	0 01957	F 00000	T 33 23
000	10	06	R2 N	0 01962	F 00000	T 33 24
000	10	06	R3 N	0 01979	F 00000	T 33 26
000	12	06	R2 S	0 01987	F 00000	T 43 27
000	12	06	R1	0 02016	F 00000	T 43 31
000	12	06	R2 N	0 02213	F 00000	T 34 11
000	14	06	R2 S	0 02223	F 00000	T 34 15
000	14	06	R3 S	0 02228	F 00000	T 34 16
CF 027	14	06	R3 S	0 02259	F 00000	T 34 19
000	12	06	R2 N	0 02278	F 00000	T 34 21
000	14	06	R2 S	0 02297	F 00000	T 34 23
TA 001	14	06	R2 S	0 02308	F 00000	T 34 25
000	19	11	R1	0 02312	F 00000	T 34 26
000	19	11	R2 S	0 02320	F 00000	T 34 28
000	19	11	R1	0 02322	F 00000	T 34 28
000	12	06	R3 N	0 02345	F 00000	T 34 32
000	19	11	R1	0 02358	F 00000	T 34 34
000	19	13	R2 W	0 02390	F 00000	T 34 37
000	17	11	R3 E	0 02395	F 00000	T 34 37
000	19	13	R1	0 02434	F 00000	T 34 43
000	19	13	R2 W	0 02449	F 00000	T 34 45
000	19	13	R1	0 02454	F 00000	T 34 45
000	19	13	R2 W	0 02468	F 00000	T 34 47
000	19	13	R1	0 02483	F 00000	T 34 48

TA 00[illegible]	19	13	R1	0 026[illegible]	F 00000	T 35 [illegible]
000	12	07	R2 E	0 02636	F 00000	T 35 26
000	19	13	R2 S	0 02637	F 00000	T 35 30
000	12	07	R2 W	0 02637	F 00000	T 35 36
000	12	07	R2 E	0 02637	F 00000	T 35 36
000	19	13	R2 S	0 02637	F 00000	T 35 40
000	12	07	R2 E	0 02637	F 00000	T 35 43
000	19	13	R2 S	0 02637	F 00000	T 35 45
000	12	07	R2 E	0 02637	F 00000	T 35 46
000	19	13	R2 S	0 02637	F 00000	T 35 58
000	12	07	R2 E	0 02637	F 00000	T 36 00
000	19	13	R2 S	0 02637	F 00000	T 36 04
000	12	07	R2 E	0 02637	F 00000	T 36 04
000	19	13	R2 S	0 02637	F 00000	T 36 05
000	12	07	R2 E	0 02637	F 00000	T 36 06
000	19	13	R2 S	0 02642	F 00000	T 36 11
000	12	07	R1	0 02645	F 00000	T 36 12
000	12	07	R2 E	0 02653	F 00000	T 36 13
000	12	07	R2 W	0 02667	F 00000	T 36 15
000	12	06	R3 F	0 02671	F 00000	T 36 16
000	12	07	R2 W	0 02679	F 00000	T 36 17
000	17	13	R3 N	0 02687	F 00000	T 36 18
CF 028	17	13	R3 N	0 02696	F 00000	T 36 19
000	12	07	R2 W	0 02742	F 00000	T 36 24
000	17	13	R2 N	0 02769	F 00000	T 36 26
000	17	13	R1	0 02774	F 00000	T 36 27
000	10	07	R3 N	0 02885	F 00000	T 37 13
000	17	13	R1	0 02885	F 00000	T 37 14
000	10	07	R3 N	0 02885	F 00000	T 37 15
000	17	13	R1	0 02885	F 00000	T 37 15
000	10	07	R3 N	0 02885	F 00000	T 37 21
000	17	13	R1	0 02885	F 00000	T 37 26
000	12	07	R3 S	0 02885	F 00000	T 37 33
000	17	13	R1	0 02885	F 00000	T 37 34
000	12	07	R3 S	0 02949	F 00000	T 37 50
000	17	13	R1	0 02954	F 00000	T 37 50
000	17	13	R3 S	0 03036	F 00000	T 37 58
000	17	13	R2 S	0 03077	F 00000	T 38 08
000	16	13	R3 N	0 03079	F 00000	T 38 08
000	17	13	R2 S	0 03083	F 00000	T 38 09
000	16	13	R3 N	0 03086	F 00000	T 38 10
000	16	13	R1	0 03147	F 00000	T 38 24
000	16	13	R3 N	0 03147	F 00000	T 38 24
000	16	13	R1	0 03147	F 00000	T 38 26
000	17	13	R3 S	0 03147	F 00000	T 38 27
000	16	13	R1	0 03148	F 00000	T 38 28
000	16	13	R3 N	0 03148	F 00000	T 38 28
000	16	13	R1	0 03152	F 00000	T 38 30
000	32	27	R1	0 03213	F 00000	T 38 51
000	16	13	R1	0 03213	F 00000	T 38 52
000	32	27	R1	0 03213	F 00000	T 38 57
000	16	13	R1	0 03213	F 00000	T 38 58
CF 029	16	13	R1	0 03265	F 00000	T 39 15
000	08	07	R1	0 03310	F 00000	T 39 22
000	16	13	R2 S	0 03319	F 00000	T 39 23
000	15	13	R3 N	0 03321	F 00000	T 39 24
000	16	13	R2 S	0 03322	F 00000	T 39 24
000	08	07	R2 W	0 03323	F 00000	T 39 25
000	16	13	R3 S	0 03331	F 00000	T 39 30
000	08	07	R1	0 03331	F 00000	T 39 30
000	16	13	R3 S	0 03331	F 00000	T 39 31
000	08	07	R1	0 03331	F 00000	T 39 32
000	16	15	R1	0 03331	F 00000	T 39 34
000	08	07	R1	0 03331	F 00000	T 39 35
000	16	13	R3 S	0 03331	F 00000	T 39 36
000	08	07	R1	0 03331	F 00000	T 39 37
000	16	13	R3 S	0 03331	F 00000	T 39 37
000	08	07	R1	0 03331	F 00000	T 39 38
000	16	13	R3 S	0 03331	F 00000	T 39 39
000	00	07	R1	0 03331	F 00000	T 39 40
000	15	13	R3 N	0 03331	F 00000	T 39 44
000	15	13	R2 N	0 03331	F 00000	T 39 45
000	08	07	R1	0 03331	F 00000	T 39 46
000	15	13	R3 N	0 03331	F 00000	T 39 47
000	08	07	R1	0 03331	F 00000	T 39 50
000	15	13	R3 N	0 03331	F 00000	T 39 51
000	08	07	R1	0 03331	F 00000	T 39 53
000	16	13	R3 S	0 03331	F 00000	T 39 54
000	08	07	R1	0 03331	F 00000	T 39 55
000	16	13	R3 S	0 03345	F 00000	T 40 00
000	08	07	R1	0 03345	F 00000	T 40 01
TA 040	16	13	R3 S	0 03350	F 00000	T 40 02
000	08	07	R1	0 03351	F 00000	T 40 02

TABLE 3-3 LISTING OF RECORDED RANDOM ROUTE TEST DATA (CONT'D)

000	16	15	R1	0 03353	F 00000	T 40 03
000	08	07	R1	0 03358	F 00000	T 40 05
000	08	07	R2 W	0 03417	F 00000	T 40 13
000	08	06	R2 E	0 03426	F 00000	T 40 15
000	08	06	R3 E	0 03434	F 00000	T 40 16
000	08	07	R2 W	0 03437	F 00000	T 40 17
000	08	07	R3 W	0 03444	F 00000	T 40 18
000	08	07	R2 W	0 03446	F 00000	T 40 19
000	08	06	R3 E	0 03451	F 00000	T 40 20
000	08	06	R1	0 03493	F 00000	T 40 25
000	08	06	R3 E	0 03514	F 00000	T 40 27
000	08	06	R1	0 03525	F 00000	T 40 28
TA 039	08	06	R1	0 03572	F 00000	T 41 11
000	16	11	R1	0 03729	F 00000	T 41 28
000	10	06	R1	0 03884	F 00000	T 41 57
CF 030	10	06	R1	0 03908	F 00000	T 41 55
000	10	06	R2 N	0 03993	F 00000	T 42 06
000	10	06	R1	0 04001	F 00000	T 42 07
000	10	06	R2 N	0 04018	F 00000	T 42 09
000	12	06	R3 S	0 04073	F 00000	T 42 15
000	12	06	R2 S	0 04078	F 00000	T 42 16
000	10	06	R3 N	0 00007	F 00000	T 42 25
000	12	06	R1	0 00018	F 00000	T 42 29
CF 031	12	06	R1	0 00051	F 00000	T 42 48
TA 007	12	06	R1	0 00114	F 00000	T 43 48
000	12	06	R2 E	0 00193	F 00000	T 43 58
000	12	06	R1	0 00197	F 00000	T 43 58
000	12	06	R2 E	0 00214	F 00000	T 44 00
000	12	07	R3 W	0 00232	F 00000	T 44 03
000	12	06	R2 E	0 00238	F 00000	T 44 04
000	12	07	R3 W	0 00244	F 00000	T 44 05
000	12	07	R2 W	0 00250	F 00000	T 44 18
000	12	07	R3 W	0 00265	F 00000	T 44 21
000	12	07	R2 W	0 00311	F 00000	T 44 26
000	12	08	R3 W	0 00321	F 00000	T 44 27
000	12	07	R1	0 00326	F 00000	T 44 27
000	12	06	R2 E	0 00364	F 00000	T 44 30
000	12	07	R2 W	0 00371	F 00000	T 44 31
000	12	07	R1	0 00384	F 00000	T 44 32
000	12	08	R2 W	0 00398	F 00000	T 44 33
000	12	08	R3 W	0 00413	F 00000	T 44 34
000	12	07	R1	0 00421	F 00000	T 44 34
000	12	07	R2 E	0 00451	F 00000	T 44 36
000	12	08	R3 W	0 00459	F 00000	T 44 37
000	12	08	R2 W	0 00474	F 00000	T 44 38
000	12	08	R1	0 00490	F 00000	T 44 39
000	12	08	R2 W	0 00497	F 00000	T 44 39
000	12	08	R1	0 00504	F 00000	T 44 40
CF 032	12	08	R1	0 00526	F 00000	T 44 41
000	12	08	R2 E	0 00724	F 00000	T 45 05
000	17	15	R3 N	0 00732	F 00000	T 45 06
000	19	15	R2 S	0 00755	F 00000	T 45 08
TA 015	19	15	R2 S	0 00792	F 00000	T 45 13
000	17	15	R3 N	0 00799	F 00000	T 45 14
000	17	15	R2 N	0 00814	F 00000	T 45 17
000	17	15	R3 N	0 00831	F 00000	T 45 19
000	17	15	R2 N	0 00839	F 00000	T 45 20
CF 033	17	15	R3 N	0 00846	F 00000	T 45 21
000	17	15	R1	0 00875	F 00000	T 45 25
000	17	15	R2 S	0 01031	F 00000	T 45 50
000	17	15	R1	0 01038	F 00000	T 45 51
000	16	15	R3 N	0 01107	F 00000	T 45 59
000	16	15	R2 N	0 01182	F 00000	T 46 07
000	16	15	R1	0 01186	F 00000	T 46 08
000	16	15	R2 N	0 01191	F 00000	T 46 09
000	16	15	R1	0 01193	F 00000	T 46 09
CF 034	16	15	R1	0 01251	F 00000	T 46 17
000	32	31	R1	0 01340	F 00000	T 46 26
000	15	15	R3 N	0 01356	F 00000	T 46 29
TA 042	15	15	R3 N	0 01419	F 00000	T 46 37
000	15	15	R2 N	0 01431	F 00000	T 46 39
000	08	08	R2 E	0 01445	F 00000	T 46 42
000	08	08	R1	0 01449	F 00000	T 46 42
000	17	17	R* C	0 01469	F 00000	T 46 45
000	08	08	R1	0 01504	F 00000	T 46 48
CF 035	08	08	R1	0 01689	F 00000	T 47 23
000	08	08	R2 W	0 01734	F 00000	T 47 28
000	08	07	R1	0 01785	F 00000	T 47 34
CF 036	08	07	R1	0 01830	F 00000	T 48 1[illegible]
000	08	06	R3 E	0 01849	F 00000	T 48 18
000	08	07	R1	0 01850	F 00000	T 48 19
000	04	03	R3 S	0 01863	F 00000	T 48 24
000	08	07	R1	0 01865	F 00000	T 48 25
TA 040	08	07	R1	0 01869	F 00000	T 48 26
000	08	07	R2 N	0 01879	F 00000	T 48 28
000	16	13	R3 S	0 01887	F 00000	T 48 30
000	15	13	R2 N	0 01925	F 00000	T 48 35
000	15	13	R1	0 01931	F 00000	T 48 36
000	15	13	R2 N	0 01936	F 00000	T 48 37
000	15	13	R1	0 01953	F 00000	T 48 46
CF 037	15	13	R1	0 01970	F 00000	T 49 09
000	15	13	R2 N	0 01995	F 00000	T 49 39
000	15	13	R1	0 01995	F 00000	T 49 42
000	15	13	R2 N	0 02010	F 00000	T 50 12
000	15	13	R1	0 02027	F 00000	T 50 19
000	15	13	R2 S	0 02136	F 00000	T 51 22
000	15	13	R1	0 02137	F 00000	T 51 24
000	15	13	R2 S	0 02143	F 00000	T 51 27
000	15	13	R1	0 02144	F 00000	T 51 27
000	60	55	R1	0 02148	F 00000	T 51 36
000	15	13	R1	0 02148	F 00000	T 51 37
000	15	13	R3 S	0 02179	F 00000	T 51 51
000	15	13	R2 S	0 02191	F 00000	T 51 52
000	15	13	R3 S	0 02195	F 00000	T 51 53
000	15	13	R2 S	0 02206	F 00000	T 51 54
CF 038	13	13	R3 N	0 02214	F 00000	T 51 56
TA 059	13	13	R3 N	0 02233	F 00000	T 52 00
000	06	06	R2 E	0 02311	F 00000	T 52 11
000	06	06	R1	0 02352	F 00000	T 52 14
TA 058	06	06	R1	0 02456	F 00000	T 53 04
000	06	06	R2 N	0 02584	F 00000	T 53 20
000	08	06	R3 S	0 02623	F 00000	T 53 27
000	08	06	R2 S	0 02623	F 00000	T 53 28
000	08	06	R3 S	0 02623	F 00000	T 53 31
000	08	06	R2 S	0 02623	F 00000	T 53 35
000	08	06	R3 S	0 02647	F 00000	T 53 41
000	08	06	R2 S	0 02667	F 00000	T 53 43
000	08	06	R1	0 02740	F 00000	T 53 51
000	16	11	R1	0 02978	F 00000	T 54 11
000	10	06	R2 S	0 03089	F 00000	T 54 24
000	10	06	R1	0 03142	F 00000	T 54 36
000	10	06	R2 N	0 03262	F 00000	T 54 47
000	12	06	R3 S	0 03310	F 00000	T 54 50
000	12	06	R2 S	0 03351	F 00000	T 54 53
000	12	06	R1	0 03404	F 00000	T 54 58
TA 007	12	06	R1	0 03476	F 00000	T 55 09
000	12	06	R2 E	0 03567	F 00000	T 55 20
000	12	07	R3 W	0 03606	F 00000	T 55 24
000	12	06	R1	0 03612	F 00000	T 55 24
000	12	06	R3 E	0 03617	F 00000	T 55 25
CF 039	12	06	R3 E	0 03709	F 00000	T 55 38
000	12	07	R1	0 03714	F 00000	T 55 38
000	24	15	R1	0 03750	F 00000	T 55 42
000	12	07	R1	0 03756	F 00000	T 55 42
000	12	08	R3 W	0 03831	F 00000	T 55 48
000	12	07	R1	0 03838	F 00000	T 55 48
000	12	07	R3 E	0 03846	F 00000	T 55 49
000	12	08	R1	0 03861	F 00000	T 55 50
000	12	07	R3 E	0 03883	F 00000	T 55 51
000	48	35	R1	0 03891	F 00000	T 55 52
000	12	08	R1	0 03906	F 00000	T 55 53
CF 040	12	08	R1	0 03940	F 00000	T 55 55
000	12	08	R2 E	0 04088	F 00000	T 56 10
CF 041	12	08	R3 E	0 00062	F 00000	T 56 20
000	19	15	R2 S	0 00125	F 00000	T 56 25
000	12	10	R2 W	0 00169	F 00000	T 56 29
000	19	16	R3 W	0 00200	F 00000	T 56 31
000	12	10	R1	0 00219	F 00000	T 56 33
CF 042	12	10	R1	0 00296	F 00000	T 56 39
TA 017	12	10	R1	0 00336	F C0000	T 56 42
000	17	16	R3 N	0 00371	F 00000	T 56 45
000	17	16	R2 N	0 00590	F 00000	T 57 01
TA 028	17	16	R2 N	0 00650	F 00000	T 57 5[illegible]
000	16	16	R3 N	0 00698	F 00000	T 57 57
000	10	12	R2 W	0 00751	F 00000	T 58 01
000	10	12	R1	0 00812	F 00000	T 58 05
TA 029	10	12	R1	0 00864	F 00000	T 58 25
000	10	12	R2 N	0 00985	F 00000	T 58 40
TA 080	10	12	R2 N	0 01004	F 00000	T 58 42
000	10	12	R3 N	0 01029	F 00000	T 58 45
CF 043	10	12	R3 N	0 01041	F 00000	T 58 47
000	12	12	R1	0 01156	F 00000	T 59 05
TA 019	12	12	R1	0 01183	F 00000	T 59 08
000	12	12	R2 W	0 01321	F 00000	T 59 26

TABLE 3-3 LISTING OF RECORDED RANDOM ROUTE TEST DATA (CONT'D)

CF 044	12	12	R2 W	0 01342	F 00000	T 59 51	000	19	13	R3 S	0 00680	F 00000	T 71 26
000	12	10	R3 E	0 01420	F 00000	T 59 58	000	12	07	R2 W	0 00695	F 00000	T 71 30
000	12	10	R2 E	0 01466	F 00000	T 60 01	000	19	13	R3 S	0 00700	F 00000	T 71 30
000	17	16	R3 N	0 01505	F 00000	T 60 04	000	12	07	R2 W	0 00706	F 00000	T 71 31
000	12	10	R1	0 01538	F 00000	T 60 07	000	19	13	R3 S	0 00716	F 00000	T 71 32
CF 045	12	10	R1	0 01562	F 00000	T 60 09	000	17	13	R2 N	0 00737	F 00000	T 71 34
000	12	10	R2 W	0 01755	F 00000	T 60 23	000	17	13	R1	0 00741	F 00000	T 71 34
000	12	10	R3 W	0 01777	F 00000	T 60 24	CF 053	17	13	R1	0 00896	F 00000	T 71 51
000	12	08	R2 E	0 01791	F 00000	T 60 25	000	17	13	R2 N	0 00946	F 00000	T 71 58
000	19	15	R3 S	0 01904	F 00000	T 60 35	000	17	13	R1	0 00950	F 00000	T 71 58
000	12	08	R2 W	0 01946	F 00000	T 60 39	TA 023	17	13	R1	0 00981	F 00000	T 72 03
000	12	08	R1	0 01951	F 00000	T 60 40	000	10	07	R1	0 00999	F 00000	T 72 07
000	12	08	R2 W	0 01966	F 00000	T 60 41	000	10	07	R3 E	0 01126	F 00000	T 72 19
000	12	08	R1	0 01971	F 00000	T 60 42	000	10	08	R1	0 01136	F 00000	T 72 20
000	12	08	R2 W	0 02030	F 00000	T 60 49	000	10	08	R2 W	0 01145	F 00000	T 72 21
TA 012	12	08	R1	0 02032	F 00000	T 60 50	000	10	08	R1	0 01148	F 00000	T 72 22
000	12	08	R3 N	0 02060	F 00000	T 60 55	000	10	07	R3 E	0 01156	F 00000	T 72 24
000	12	08	R2 W	0 02071	F 00000	T 60 57	000	10	08	R1	0 01156	F 00000	T 72 24
000	12	08	R1	0 02074	F 00000	T 60 57	CF 054	10	08	R1	0 01197	F 00000	T 72 54
000	12	08	R3 N	0 02086	F 00000	T 60 59	000	10	08	R2 E	0 01423	F 00000	T 74 12
CF 046	12	08	R3 N	0 02105	F 00000	T 61 01	TA 026	10	08	R2 E	0 01426	F 00000	T 74 13
000	12	08	R2 W	0 02115	F 00000	T 61 03	000	16	15	R3 N	0 01441	F 00000	T 74 15
000	12	08	R3 N	0 02119	F 00000	T 61 03	000	17	15	R2 S	0 01447	F 00000	T 74 16
000	14	08	R1	0 02157	F 00000	T 61 09	000	16	15	R3 N	0 01468	F 00000	T 74 19
000	14	08	R3 S	0 02159	F 00000	T 61 10	000	16	15	R2 N	0 01507	F 00000	T 74 26
TA 003	14	08	R2 S	0 02162	F 00000	T 61 10	000	16	15	R1	0 01514	F 00000	T 74 27
000	14	08	R3 S	0 02167	F 00000	T 61 11	000	16	15	R2 N	0 01518	F 00000	T 74 28
000	12	08	R2 N	0 02185	F 00000	T 61 15	000	16	15	R1	0 01522	F 00000	T 74 28
000	19	15	R1	0 02276	F 00000	T 61 25	000	16	15	R2 S	0 01688	F 00000	T 75 30
TA 004	19	15	R1	0 02394	F 00000	T 62 10	000	16	15	R1	0 01698	F 00000	T 75 32
CF 047	19	15	R1	0 02438	F 00000	T 62 16	000	16	15	R2 S	0 01702	F 00000	T 75 32
000	19	15	R2 S	0 02591	F 00000	T 63 26	000	15	15	R3 N	0 01712	F 00000	T 75 33
000	17	15	R3 N	0 02595	F 00000	T 63 26	000	15	15	R2 N	0 01740	F 00000	T 75 36
000	17	15	R2 N	0 02635	F 00000	T 63 30	000	15	15	R3 N	0 01753	F 00000	T 75 38
000	17	15	R1	0 02656	F 00000	T 63 3[illegible]	000	15	15	R1	0 01775	F 00000	T 75 41
CF 048	17	15	R1	0 02745	F 00000	T 63 41	000	15	15	R2 N	0 01795	F 00000	T 75 44
000	16	15	R3 N	0 02855	F 00000	T 64 13	000	15	15	R1	0 01821	F 00000	T 75 47
000	17	15	R2 S	0 02862	F 00000	T 64 14	P 055	15	15	R1	0 01865	F 00000	T 75 52
000	16	15	R3 N	0 02866	F 00000	T 64 14	000	15	15	R2 S	0 02034	F 00000	T 76 21
000	17	15	R2 S	0 02898	F 00000	T 64 19	000	13	15	R3 N	0 02082	F 00000	T 76 28
000	16	15	R3 N	0 02906	F 00000	T 64 20	000	15	15	R2 S	0 02088	F 00000	T 76 29
000	16	15	R1	0 02965	F 00000	T 64 30	000	15	15	R3 S	0 02093	F 00000	T 76 30
TA 033	16	15	R1	0 03033	F 00000	T 64 38	000	13	15	R2 N	0 02096	F 00000	T 76 31
000	16	15	R2 W	0 03139	F 00000	T 64 54	000	15	15	R3 S	0 02097	F 00000	T 76 59
000	16	14	R3 E	0 03150	F 00000	T 64 55	000	13	15	R2 N	0 02109	F 00000	T 77 02
000	16	14	R1	0 03253	F 00000	T 65 11	000	15	15	R3 S	0 02117	F 00000	T 77 03
000	16	14	R3 E	0 03265	F 00000	T 65 13	000	13	15	R2 N	0 02127	F 00000	T 77 05
000	16	14	R1	0 03276	F 00000	T 65 15	000	13	15	R1	0 02137	F 00000	T 77 08
CF 049	16	14	R1	0 03317	F 00000	T 65 20	000	13	15	R2 N	0 02138	F 00000	T 77 08
000	16	14	R2 W	0 03376	F 00000	T 65 27	A 061	13	15	R2 N	0 02141	F 00000	T 77 10
000	16	13	R2 E	0 03381	F 00000	T 65 28	000	13	15	R1	0 02144	F 00000	T 77 11
CF 050	08	07	R3 N	0 03399	F 00000	T 65 30	000	06	08	R3 E	0 02147	F 00000	T 77 17
000	16	13	R2 E	0 03416	F 00000	T 65 32	000	13	15	R1	0 02150	F 00000	T 77 18
000	16	13	R1	0 03435	F 00000	T 65 34	P 056	13	15	R1	0 02151	F 00000	T 77 18
000	10	06	R3 S	0 03653	F 00000	T 66 58	000	06	10	R3 W	0 02162	F 00000	T 77 21
CF 051	10	06	R3 S	0 03657	F 00000	T 66 59	000	06	10	R2 W	0 02167	F 00000	T 77 22
000	16	11	R1	0 03687	F 00000	T 67 02	000	06	08	R2 E	0 02175	F 00000	T 77 24
TA 030	16	11	R1	0 03710	F 00000	T 67 13	000	06	08	R3 E	0 02191	F 00000	T 77 26
000	10	06	R1	0 03839	F 00000	T 67 39	000	06	08	R2 E	0 02216	F 00000	T 77 29
000	10	06	R2 N	0 03974	F 00000	T 67 51	000	06	08	R1	0 02258	F 00000	T 77 33
000	12	06	R3 S	0 04029	F 00000	T 67 57	000	06	08	R2 E	0 02264	F 00000	T 77 34
000	10	06	R2 N	0 04042	F 00000	T 67 59	000	06	08	R1	0 02281	F 00000	T 77 35
000	10	06	R3 N	0 04046	F 00000	T 67 59	CF 057	06	08	R1	0 02366	F 00000	T 78 20
000	12	06	R2 S	0 04050	F 00000	T 68 00	000	06	08	R2 W	0 02436	F 00000	T 78 30
000	12	06	R1	0 00003	F 00000	T 68 06	000	06	08	R1	0 02444	F 00000	T 78 31
000	12	06	R2 N	0 00196	F 00000	T 69 21	000	06	08	R2 W	0 02575	F 00000	T 78 49
000	14	06	R3 S	0 00201	F 00000	T 69 22	000	06	06	R3 E	0 02575	F 00000	T 78 52
000	14	06	R2 S	0 00250	F 00000	T 69 28	000	06	08	R2 W	0 02575	F 00000	T 78 56
000	12	06	R2 N	0 00258	F 00000	T 69 29	000	06	06	R3 E	0 02575	F 00000	T 78 57
000	12	06	R3 N	0 00261	F 00000	T 69 30	000	06	06	R1	0 02708	F 00000	T 79 20
TA 001	12	06	R3 N	0 00270	F 00000	T 69 31	000	06	06	R2 E	0 02714	F 00000	T 79 21
000	14	06	R2 S	0 00272	F 00000	T 69 32	000	06	06	R1	0 02726	F 00000	T 79 22
000	19	11	R1	0 00275	F 00000	T 69 32	CF 058	06	06	R1	0 02768	F 00000	T 79 26
000	19	13	R3 W	0 00339	F 00000	T 69 41	TA 058	06	06	R1	0 02821	F 00000	T 80 08
000	19	13	R1	0 00400	F 00000	T 69 47	000	15	11	R1	0 03058	F 00000	T 80 59
TA 002	19	13	R1	0 00493	F 00000	T 70 07	000	06	06	R1	0 00190	F 00000	T 85 15
CF 052	19	13	R1	0 00539	F 00000	T 70 21	TA 058	06	06	R1	0 00272	F 00000	T 85 38
000	12	07	R1	0 00607	F 00000	T 70 29	CF 059	06	06	R1	0 00322	F 00000	T 86 06
000	19	13	R2 S	0 00616	F 00000	T 70 31	000	06	06	R2 E	0 00367	F 00000	T 86 11
000	12	07	R2 E	0 00639	F 00000	T 71 24	000	06	06	R3 E	0 00397	F 00000	T 86 48
000	19	13	R3 S	0 00647	F 00000	T 71 25	000	06	06	R2 E	0 00421	F 00000	T 86 51
000	12	07	R2 W	0 00652	F 00000	T 71 25	000	06	06	R3 E	0 00468	F 00000	T 86 55
000	17	13	R3 N	0 00666	F 00000	T 71 27	000	06	08	R1	0 00625	F 00000	T 87 09
000	12	07	R2 W	0 00670	F 00000	T 71 27	CF 060	06	08	R1	0 00723	F 00000	T 87 21

TABLE 3-3 LISTING OF RECORDED RANDOM ROUTE TEST DATA (CONT'D)

	000	06	08	R2 E	0 00886	F 00000	T 88 39
	000	06	08	R3 E	0 00904	F 00000	T 88 42
	000	06	08	R2 E	0 00909	F 00000	T 88 43
	000	13	15	R1	0 00941	F 00000	T 89 23
	000	06	08	R3 E	0 00944	F 00000	T 89 24
	000	06	08	R2 E	0 00970	F 00000	T 89 27
	000	06	10	R3 W	0 00977	F 00000	T 89 28
	000	06	10	R2 W	0 01000	F 00000	T 89 31
	000	06	08	R3 E	0 01009	F 00000	T 89 33
	000	06	10	R2 W	0 01012	F 00000	T 89 33
	000	06	10	R3 W	0 01023	F 00000	T 89 41
	000	06	10	R2 W	0 01036	F 00000	T 89 56
	000	06	10	R1	0 01047	F 00000	T 90 03
	000	06	10	R2 W	0 01047	F 00000	T 90 08
	000	06	10	R1	0 01047	F 00000	T 90 41
	000	06	10	R2 W	0 01047	F 00000	T 90 43
	000	06	10	R1	0 01047	F 00000	T 90 44
	000	06	10	R2 W	0 01047	F 00000	T 90 49
	000	06	10	R1	0 01047	F 00000	T 90 57
	000	06	10	R2 W	0 01047	F 00000	T 90 59
	000	06	10	R1	0 01047	F 00000	T 91 02
	000	06	10	R2 W	0 01047	F 00000	T 91 04
	000	06	10	R1	0 01053	F 00000	T 91 08
	000	06	10	R2 W	0 01091	F 00000	T 92 01
	000	06	10	R1	0 01098	F 00000	T 92 02
CP	061	06	10	R1	0 01171	F 00000	T 92 55
	000	06	10	R2 E	0 01251	F 00000	T 93 34
	000	06	10	R1	0 01260	F 00000	T 93 35
	000	06	10	R2 E	0 01278	F 00000	T 93 38
	000	06	10	R1	0 01280	F 00000	T 93 39
	000	06	10	R2 E	0 01287	F 00000	T 93 40
	000	06	10	R3 E	0 01312	F 00000	T 94 01
	000	06	10	R2 E	0 01312	F 00000	T 94 04
	000	06	10	R3 E	0 01370	F 00000	T 94 21
	000	06	10	R2 E	0 01392	F 00000	T 94 24
	000	06	10	R3 E	0 01408	F 00000	T 94 26
	000	06	12	R2 W	0 01428	F 00000	T 94 28
	000	06	12	R1	0 01505	F 00000	T 94 35
CP	062	06	12	R1	0 01631	F 00000	T 94 46
TA	064	06	12	R1	0 01650	F 00000	T 94 49

At Time 22 minutes 47 seconds, the reason for signpost code (13,21), which is an invalid code, cannot be explicitly determined. It is thought to be a power transient in the auxiliary generator. This and other occurrences of invalid code had no influence on the test results since only one invalid code was recorded at a TSC checkpoint, and this occurrence (CP 18 during Run 8) was automatically screened out by the data processing screening algorithm in exactly the same manner as that proposed for use in Phase II. It should be noted that only 9 out of 11,476 records on Run 7 contained an invalid data record signpost code, 0.078 percent. It should be noted that, during use of CPMAIN, only 1 of 1,563 samples required use of the screening algorithm, 0.064 percent compared to the allowable 2 percent.

4. RANDOM ROUTE DATA PROCESSING

The processing of random route data was accomplished in three parts by the three computer programs depicted in Figure 4-1. Program CPMAIN was used to compute LS location errors at TSC checkpoints. Program RRSL was used to compute AVM System Level errors at pseudo checkpoints which were representative of a simulated polling interval of 20 seconds with a simulated communication system error rate of 5 percent. Program RRTEN was used to compute the average location error over each one-tenth mile segment of the random route.

4.1 SAMPLE SIZE

The end result of Phase I was directed toward evaluating the performance of the HI^3 LS and AVM system. The performance specifications were stated in terms of 95 and 99.5 percentile values of the data samples. The sample space for the random route tests was selected by TSC to be representative of a typical urban environment which covered approximately 40 square blocks of downtown Philadelphia (previously shown in Figure 3-12).

In the HI^3 proposal and in the HI^3 memorandum to TSC of April 15, 1976, HI^3 addressed sample size requirements in terms of 2σ and 3σ values, based on the normal distribution. In actuality, the 2σ value of the normal distribution is the 97.7 percent point and the 3σ value is the 99.87 percentile value. Thus, if a sufficient number of samples were obtained to reflect the 2σ and 3σ values accurately, then the 95 and 99.5 percentile requirements should have automatically been satisfied, provided that the sample size is sufficiently large to invoke the law of large numbers; e.g., the ultimate normality of the distribution in question. Use of the 2σ and 3σ values allowed explicit mathematical expressions to be used in deriving the required sample size under the assumption that, in the limit, the distribution of location errors approaches the normal distribution.

In order to arrive at an explicit formulation, normality of the HI^3 location error density function was assumed. As noted subsequently, Phase I tests showed that this assumption was not strictly valid.

HI^3 rationale for use in the 2α and 3α values in determining sample size was based on Mood, Introduction to the Theory of Applied Statistics, (McGraw-Hill, 1950) p. 214.

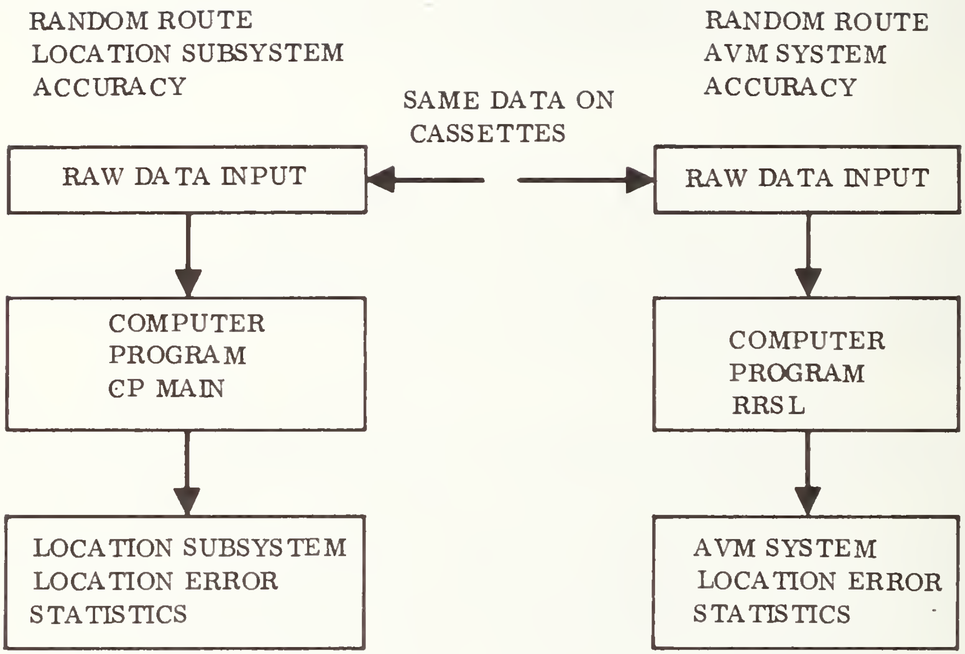


FIG. 4-1 RANDOM ROUTE DATA PROCESSING

Following Mood, and assuming that the radial error is normally distributed with mean α_1, and variance α_2, the distribution can be written as

$$f(X; \alpha_1, \alpha_2) = \frac{1}{\sqrt{2\pi\alpha_2}} e - (\frac{1}{2\alpha_2})(X - \alpha_1)^2$$

Then the estimators of α_1 and α_2 are given by

$$\hat{\alpha}_1 = \frac{1}{N} \sum X_i \quad \text{(mean estimate)}$$

$$\hat{\alpha}_2 = \frac{1}{N} \sum (X_i - \hat{\alpha}_1)^2 \quad \text{(variance estimate)}$$

In accordance with the theorem, these two estimates will themselves be normally distributed for large samples. It can be shown that the exact distribution of $\hat{\alpha}_2$, the variance estimator, approaches the normal form,

$$f(\hat{\alpha}_2; \mu_s \sigma_s) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sqrt{\frac{2}{n}}\, 2\alpha_2} e \frac{-(\hat{\alpha}_2 - \alpha_2)^2}{2\alpha_2^2 \sqrt{\frac{2}{n}}}$$

Thus, as n becomes large, the sample standard deviation σ_s of the distribution of $\hat{\alpha}_2$ becomes

$$\sigma_s = \sqrt{\frac{2}{n}}\, \alpha_2 \qquad (4\text{-}1)$$

and the sample mean, μ_s of the distribution of $\hat{\alpha}_2$, becomes α_2 where α_2 is the variance of the parent distribution ($\sqrt{\alpha_2}$ would then be the parent distribution's standard deviation). Use of equation 4-1 allows us to bound the sample σ_s. For example, assume that there will be no more than 0.26 percent chance that the standard deviation, σ_s, of the sample distribution differs from the standard deviation, $\sqrt{\alpha_2}$, of the parent distribution by more than X percent. Then we want

$$P \left\{ \left[(1-X)\sqrt{\alpha_2}\right]^2 \leq \sigma_s^2 \leq \left[(1+X)\sqrt{\alpha_2}\right]^2 \right\} \geq (1-0.0026) = 0.9974$$

or

$$P \left\{ (1-X)^2 \alpha_2 \leq \sigma_s^2 \leq (1+X)^2 \alpha_2 \right\} \geq 0.9974$$

Thus, we want σ_S^2, the sample variance, to be within a specified percentage of α_2 the parent distribution's variance, 99.74 percent of the time.

If X = 15 percent, then

$$P\left\{ .7225\ \alpha_2 \le \sigma_S^2 \le 1.3225\ \alpha_2 \right\} \ge 0.9974$$

This is true if the 3 sigma value of the sample distribution, 3 σ_S, is less than 0.2775 α_2.

$$3\ \sigma_S < 0.2775\ \alpha_2$$

By substituting from Equation 4-1, then

$$3 \sqrt{\frac{2}{n}}\ \alpha_2 < 0.2775\ \alpha_2, \quad \text{or} \quad n > \frac{18}{\left(1-(1-X)^2\right)^2}$$

and, subsequently solving for n gives the required sample size, n, for the standard deviation of the sample population to differ from the standard deviation of the parent population by no more than 15 percent.

In this case

$$3 \sqrt{\frac{2}{n}} < 0.2775 \qquad n > \frac{18}{\left(1-(1-.15)^2\right)^2}$$

and

$$n > 233.$$

This statement also holds for the 2 σ_S value of the sample population. The data in the following table indicate the number of independent samples, n, necessary to assure that the sample 2 σ_S differs from the actual 2σ by no more than X percent with a confidence of 99.74 percent.

X(Percent Error in 2 σ_S) of the sample	N(Number of Samples)
0.20	139
0.15	233
0.11	416
0.10	499
0.05	1894

Therefore, 499 independent samples will verify with 99.74 percent confidence that the sample 2 σ_S will deviate from the actual 2σ by no more than 10 percent.

In order to relate the sample size more directly to the AVM specification and to minimize the dependence of the analysis on an assumed density function, MITRE and TSC investigated the use of a non-parametric approach. The basis for this approach was simply that a sample would pass an accuracy requirement with a probability p (and fail with a probability of 1-p). Then in a set of repeated Bernouilli trials, the probability that a specific number of data points (r) out of a sample of size (n) do not meet the accuracy requirement can be represented by the binomial probability distribution e(n, r, p):

$$e(n, r, p) = \frac{n!}{r!(n-r)!} (1-p)^{n-r} p^{r}$$

where

n = sample size
r = number of unsuccessful samples
p = the system error probability

The probability that at least r unsuccessful data points will occur is represented by the cumulative binomial probability distribution E(n, r, p):

$$E(n, r, p) = \sum_{x=r}^{n} e(n, x, p)$$

Using "Tables of the Cumulative Binomial Probability Distribution" published by the Computation Laboratory of Harvard University in 1955, TSC generated Table 4-1. Sample sizes from 50 to 1000 were considered. For each sample size, a value of r was selected such that the Type I error* was as near to 0.05 as could be obtained from the cumulative binomial distribution tables. This was to insure that the probability of rejecting a good system was only 5 percent. The column of Type I errors in Table 4-1 corresponds to a 95% system, one which has a system error probability p_0, equal to 0.05. For example, for n = 300, the system will fail the test if the test sample contains 22 or more unsuccessful data points (22 or more samples with errors equal to or exceeding 300 feet). Thus, there is a 0.049 probability (Type I error) that an actual 95 percent system will fail the test.

However, of equal concern is the Type II error. For example, Table 4-1 shows that for n = 300 there is a 0.05 probability (Type II error) that a 90 percent system (one with an error rate of $p_1 = 0.1$) will pass the test and a 0.56 probability that a 93 percent system ($p_1 = 0.07$) will pass the test.

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* A Type I error is the probability of rejecting the null hypothesis (e.g., the system error probability is less than 5 percent) when it is indeed true. A Type II error is the probability of accepting the null hypothesis when it is actually false.

TABLE 4-1 TYPE I (δ) AND TYPE II (β) ERRORS FOR VARIOUS SAMPLE SIZES

No. of Samples n	No. of Failures r	Type I Error α p^* = .05	Type II Errors for Values of p_1**				
			β_1 p_1^* = .06	β_1 p_1 = .07	β_1 p_1 = .08	β_1 p_1 = .09	β_1 p_1 = .10
50	6	.038	.92	.86	.79	.69	.62
100	9	.063	.85	.64	.59	.45	.32
200	16	.044	.85	.67	.46	.28	.14
220	17	.051	.83	.63	.41	.22	.11
260	20	.039	.85	.64	.40	.20	.09
300	22	.049	.81	.56	.30	.13	.05
340	25	.037	.83	.57	.30	.12	.04
380	27	.044	.79	.50	.23	.08	.02
400	28	.047	.77	.47	.21	.06	.01
420	29	.052	.76	.44	.18	.05	.01
460	32	.04	.78	.46	.18	.05	.01
500	34	.045	.75	.40	.14	.03	.005
550	37	.044	.74	.38	.12	.02	.003
600	40	.042	.73	.35	.10	.02	.002
650	43	.04	.72	.33	.08	.01	.001
700	45	.054	.66	.26	.05	.005	.000
750	48	.051	.66	.24	.04	.004	.000
800	51	.048	.65	.23	.04	.003	.000
850	54	.046	.65	.21	.03	.002	.000
900	57	.043	.64	.19	.03	.001	.000
1000	62	.051	.59	.15	.01	.000	.000

*p_o is the assumed failure rate of the system

**p_1 is the actual failure rate of the system

In contrast, if the sample size n were 600, there would be only a 0.002 probability that a 90 percent system would pass the tests; however, a 0.73 probability would exist for a 94 percent system passing.

TSC developed a measure of Type II error severity which it used in quantifying the effects of Type II errors in order to more clearly define the sample size requirements. This measure was

$$M_\beta = \sum \beta_1 \frac{(p_1 - p_0)}{0.1}$$

where

M_β = the measure of potential Type II error severity for a given sample size

β_1 = the Type II error associated with a system error probability (e.g., $_1$ = 0.21 for p_1 = 0.08 and n = 400 from Table 4-2.)

p_1 = system error probability

p_0 = maximum allowable system error probability.

The number of terms in the summation for M_β is equal to the number of p's that have a Type II error of approximately 0.05 or more. For example, for 700 samples (reference Table 4-1).

$$M_\beta = \frac{0.66 \times (.06 - .05) + 0.26(.07 - .05) + 0.5(.08 - 0.5)}{0.01}$$

or

$$M_\beta = 1.3$$

A plot of M_β versus (n) is shown in Figure 4-2. The sample size to be used is not clearly obvious since the knee of the curve is not well defined. However, the major bend in the curve is completed somewhere between 500 and 700 samples.

The results obtained by HI[3] and the non-parametric results obtained by TSC were both indicative of a required sample size greater than 450. This material, when weighed with the costs of requiring a much larger sample size (as a means of minimizing the Type I and Type II errors) resulted in TSC approving the following minimum sample size requirements.

Random Route Checkpoints	600
Fixed Route Checkpoints	600
Fixed Route Timepoints	450.

Test routes, checkpoints, and timepoints were selected by TSC as a means of assuring that these minimum sample sizes were realized.

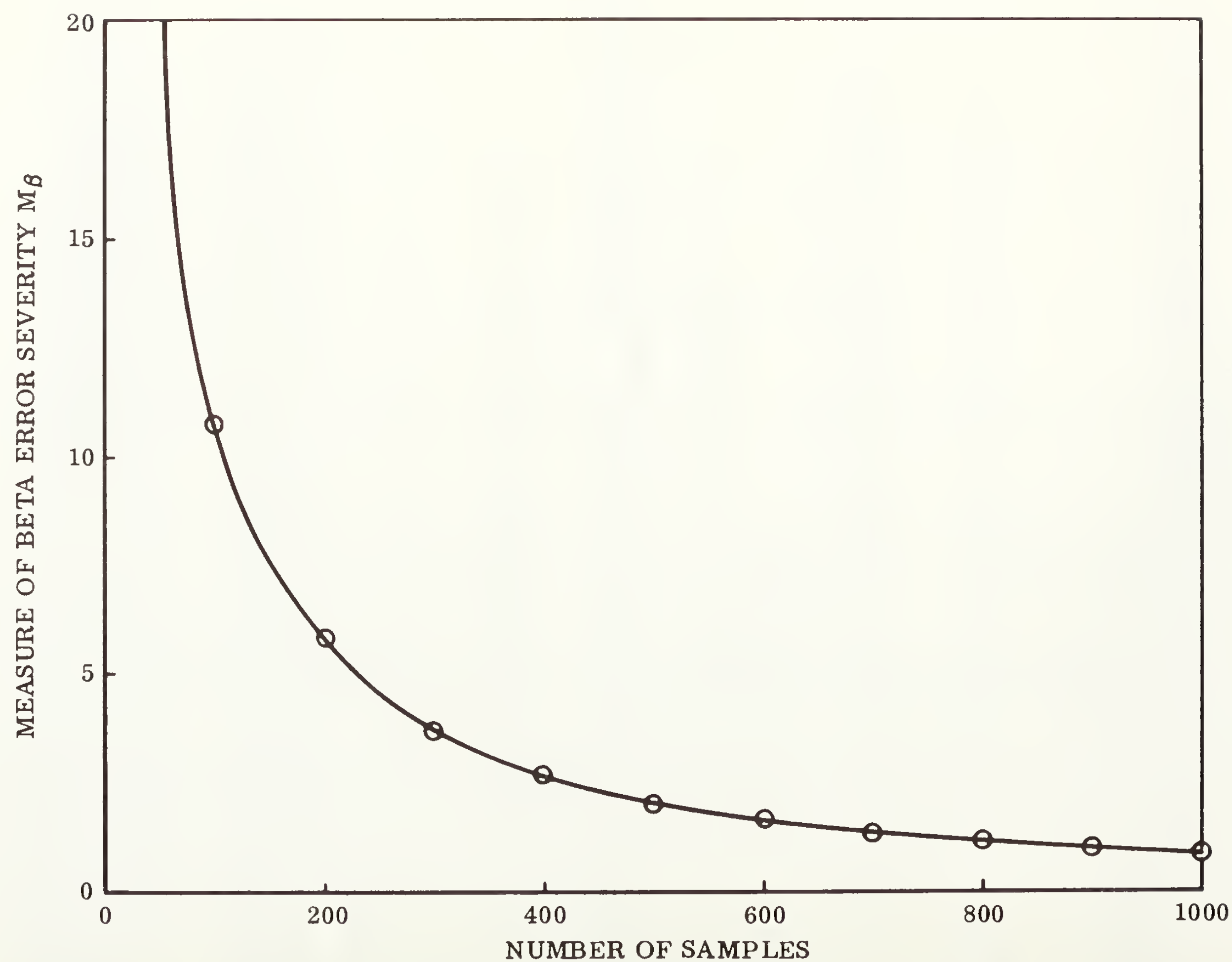


FIG. 4-2 M_β VS. SAMPLE SIZE

Subsequent to the tests, HI^3 analyzed test data to determine the actual distribution of the location subsystem errors. These data are presented in Section 10.

To insure that the samples are random, TSC chose the sample points (checkpoints) in the test area prior to the installation of the location subsystem. However, the location subsystem was installed by HI^3 without knowledge of the checkpoint locations. To further insure that the samples were independent, the checkpoints were located more than 500 feet apart; consequently, the samples were independent at both time and space for a designed 300-foot location system. Also, the samples were obtained during a number of random route tests taken on different days and at different times during the day. Performance of the tests at different times during the day resulted in the elimination of potential time of day biases (e.g., morning and evening rush hours) which might have been otherwise incurred.

In order to assure that the sample size was more than adquate, a total of 622 samples were taken during 10 test runs by using two different sets of TSC designated checkpoints. 622 samples corresponds to a 9 percent error in the $2\sigma_s$ of the sample.

4.2 RANDOM ROUTE DATA PROCESSING

Data processing of random route data involved (1) the determination of the vehicles actual location at each checkpoint specified by TSC and (2) the calculation of the radial location error at each checkpoint by using the location subsystem calculated location. In addition, steps (1) and (2) were repeated at points separated by 20 seconds to simulate the Phase II polling scheme as well as communication errors.

4.2.1 Vehicle Actual Location at Checkpoints

The actual vehicle position was always assumed to be the X, Y coordinates of the checkpoint at the time the checkpoint event was recorded on the raw data tape. The actual vehicle location was determined from the CPTABL file contained in Table 4-2.

4.2.2 Vehicle Computed (Location Subsystem) Location

In the case of random route data processing at TSC checkpoints, the computed location of the vehicle was also determined directly from a table look-up in the Signpost File (SPTABL). As a result of HI^3 pretest mapping and calibration, each possible 18-BIT location region code had been assigned a specific pair of stateplane coordinates. Figure 4-3 is an illustration of the algorithm used to determine the vehicle's computed (Location Subsystem) location.

TABLE 4-2 RANDOM ROUTE CHECKPOINT FILE (BASES FOR CPTABL)

Primary CP#	State Plane Coordinates		Secondary CP#	State Plane Coordinates	
	X(feet)	Y(feet)		X(feet)	Y(feet)
1	2728180	235705	1	2728183	235731
2	2727835	236136	2	2728277	236397
3	2727321	235782	3	2728354	237054
4	2726852	235848	4	2728150	237778
5	2726455	236268	5	2727969	237159
6	2726009	236222	6	2727830	236470
7	2725585	236389	7	2727140	236596
8	2725705	237100	8	2726918	236223
9	2726369	237383	9	2726427	235897
10	2727500	237204	10	2725645	236003
11	2728211	237127	11	2725618	236511
12	2728298	237738	12	2725771	237426
13	2727515	237919	13	2726509	237341
14	2726741	238159	14	2727500	237204
15	2727147	238153	15	2727910	236813
16	2727969	237159	16	2727860	236290
17	2727891	236661	17	2726451	236137
18	2726956	236572	18	2726530	236631
19	2726580	236988	19	2726600	237104
20	2726655	237544	20	2726693	237755
21	2726714	237933	21	2727090	237458
22	2727157	238093	22	2726981	236811
23	2726464	238014	23	2726545	236276
24	2725867	238275	24	2726046	236355
25	2726296	238232	25	2725646	236397
26	2726239	237764	26	2725745	237541
27	2726156	237203	27	2725867	238275
28	2726075	236713	28	2726247	237988
29	2725684	236934	29	2726102	236886
30	2725809	237838	30	2725730	237421
31	2726459	237919	31	2725813	237865
32	2727090	237702	32	2726638	237895
33	2726996	236930	33	2727090	237702
34	2726920	236239	34	2726996	236930
35	2726316	236285	35	2726453	236641
36	2725756	236411	36	2726147	236705
37	2725705	237100	37	2726044	236446
38	2725809	237838	38	2725994	235984
39	2726710	237886	39	2726267	237988
40	2727589	237840	40	2726714	237933
41	2727969	237159	41	2727121	237879
42	2727444	236878	42	2727591	237859
43	2726958	236590	43	2728288	237464
44	2726580	236988	44	2728059	237803
45	2726102	236885	45	2727591	237859
46	2725996	236139	46	2726741	238159
47	2725553	236009	47	2727157	238093
48	2725585	236389	48	2727090	237458
49	2725705	237100	49	2726427	237006
50	2725809	237838	50	2726284	237063
51	2726239	237764	51	2725830	237115
52	2726507	237341	52	2726396	238232
53	2727055	237376	53	2726192	237484
54	2727715	237176	54	2726627	237326
55	2727891	236661	55	2726909	236376
56	2727837	236109	56	2726838	235874
57	2727561	235756	57	2726427	235897
58	2726865	235846	58	2725645	236003
59	2725988	235938	59	2725645	236003
60	2725988	235938	60	2726427	235897
61	2726865	235846	61	2727321	235782
62	2727561	235756	62	2728176	235673
63	2728176	235673			

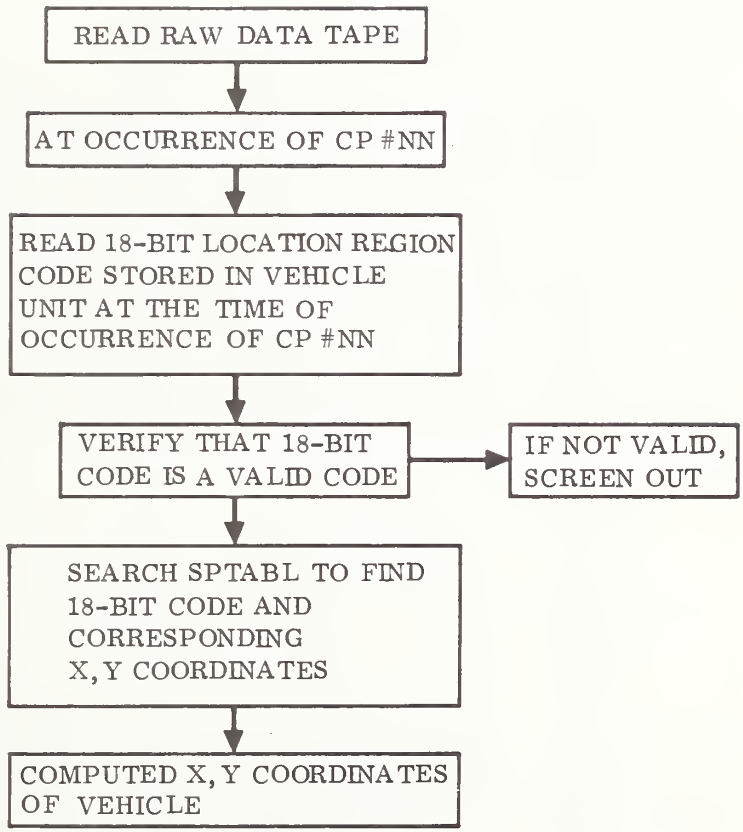


FIG. 4-3 METHOD OF COMPUTING (LS) VEHICLE LOCATION IN RANDOM ROUTE TESTS

During the data reduction process, a "reasonableness" or screening algorithm was used to check the 18-BIT location region code recorded at each checkpoint for validity against the stored data base. If the code were not valid, that data record was rejected and subsequently printed out as a "bad data" record The table, SPTABL, of valid 18-BIT codes and X, Y coordinates was supplied to the TSC Monitor prior to recording and data processing, and the data became part of the computer data base. SPTABL is contained in Table 4-3. The X, Y locations of each checkpoint, relative to the closest intersection center, were also determined and supplied to the TSC Monitor prior to commencing the tests. Thus, all of the data listed in Tables 4-2 and 4-3 were supplied to the TSC Monitor prior to the actual test runs.

4.2.3 Vehicle Actual Location at Pseudo Checkpoints

During AVM System level data processing, Program RRSL, raw data on tape was used to take samples every 20 seconds. Each such sample, in order, was assigned a pseudo checkpoint number (PCP). The actual location of the vehicle at each PCP was determined through use of the fifth wheel in terms of the distance from a known location, Turn (TA) or Checkpoint (CP), and the passage of the vehicle was recorded on cassette by a manual entry. The algorithm used to determine the actual vehicle location at PCP's is shown in Figure 4-4. The geometry associated with this algorithm is illustrated in Figure 4-5.

Note that four possible situations can be used for locating a PCP

Between two successive CP's

Between two successive TA's

After a TA and prior to a CP

After a CP and prior to a TA.

The case illustrated in Figure 4-5 corresponds to (3) in which the PCP (the sample) occurred after a turn and prior to a checkpoint. As shown in Figure 4-4, the marking of turns (TA's) in no way affects the operation of the location subsystem or the AVM system. The sole function of the location subsystem is to determine, at the sample point (either checkpoint or pseudo checkpoint), the signpost location region code which, through the use of the SPTABL, uniquely determines the X, Y location assigned to the vehicle at the sample point. The turn event serves only as a means of establishing the vehicle's actual or reference location at those locations (pseudo checkpoints) which were not determined by physical measurement prior to the tests.

In summary, the TA and CP events, in conjunction with the 5th wheel, determine the actual location of pseudo checkpoints. The signpost location region code associated with the pseudo checkpoint sample determines the AVM system and LS location.

TABLE 4-3 RANDOM ROUTE SIGNPOST FILE (SPTABL)

.BYTE 06.,06.	.BYTE 08.,07.	.BYTE 10.,07.	.BYTE 12.,07.
R1 5553.,06009.	R1 6298.,06690.	R1 6379.,07344.	R1 6523.,07974.
R2S 5553.,06009.	R2S 6298.,06690.	R2S 6352.,07126.	R2S 6475.,07764.
R2E 5844.,05972.	R2E 6298.,06690.	R2E 6503.,07335.	R2E 6623.,07965.
R2N 5565.,06245.	R2N 6325.,06908.	R2N 6463.,07556.	R2N 6523.,07974.
R2W 5553.,06009.	R2W 6080.,06705.	R2W 6176.,07358.	R2W 6294.,07997.
R3S 5553.,06009.	R3S 6298.,06690.	R3S 6339.,07017.	R3S 6451.,07659.
R3E 5988.,05938.	R3E 6414.,06661.	R3E 6503.,07335.	R3E 6623.,07965.
R3N 5585.,06389.	R3N 6339.,07017.	R3N 6451.,07659.	R3N 6523.,07974.
R3W 5553.,06009.	R3W 5971.,06713.	R3W 6055.,07383.	R3W 6193.,08011.
.BYTE 06.,08.	.BYTE 08.,08.	.BYTE 10.,08.	.BYTE 12.,08.
R1 6427.,05897.	R1 6530.,06631.	R1 6627.,07326.	R1 6714.,07933.
R2S 6427.,05897.	R2S 6496.,06386.	R2S 6595.,07094.	R2S 6685.,07731.
R2E 6725.,05859.	R2E 6821.,06590.	R2E 6918.,07285.	R2E 7006.,07908.
R2N 6461.,06142.	R2N 6562.,06862.	R2N 6656.,07528.	R2N 6742.,08141.
R2W 6135.,05934.	R2W 6453.,06651.	R2W 6503.,07335.	R2W 6623.,07965.
R3S 6427.,05897.	R3S 6468.,06266.	R3S 6580.,06988.	R3S 6671.,07630.
R3E 6865.,05846.	R3E 6956.,06572.	R3E 7055.,07276.	R3E 7133.,07896.
R3N 6468.,06266.	R3N 6580.,06988.	R3N 6671.,07630.	R3N 6739.,08205.
R3W 5988.,05938.	R3W 6414.,06661.	R3W 6503.,07335.	R3W 6623.,07965.
.BYTE 06.,10.	.BYTE 08.,10.	.BYTE 10.,10.	.BYTE 12.,10.
R1 7321.,05782.	R1 7403.,06509.	R1 7500.,07204.	R1 7591.,07859.
R2S 7321.,05782.	R2S 7375.,06267.	R2S 7468.,06972.	R2S 7618.,07641.
R2E 7606.,05746.	R2E 7694.,06584.	R2E 7785.,07154.	R2E 7834.,07813.
R2N 7348.,06024.	R2N 7435.,06741.	R2N 7720.,07422.	R2N 7591.,07859.
R2W 7023.,05820.	R2W 7112.,06550.	R2W 7209.,07245.	R2W 7296.,07884.
R3S 7321.,05782.	R3S 7374.,06159.	R3S 7444.,06878.	R3S 7691.,07532.
R3E 7779.,05728.	R3E 7882.,06463.	R3E 7969.,07159.	R3E 7956.,07803.
R3N 7374.,06159.	R3N 7444.,06878.	R3N 7691.,07532.	R3N 7591.,07859.
R3W 6865.,05846.	R3W 6956.,06572.	R3W 7055.,07276.	R3W 7133.,07896.
.BYTE 06.,12.	.BYTE 08.,12.	.BYTE 10.,12.	.BYTE 12.,12.
R1 8176.,05673.	R1 8277.,06397.	R1 8354.,07054.	R1 8321.,07721.
R2S 8176.,05673.	R2S 8243.,06156.	R2S 8328.,06835.	R2S 8283.,07499.
R2E 8176.,05673.	R2E 8277.,06397.	R2E 8354.,07054.	R2E 8321.,07721.
R2N 8210.,05914.	R2N 8303.,06616.	R2N 8246.,07276.	R2N 8321.,07721.
R2W 7891.,05709.	R2W 7986.,06434.	R2W 8069.,07104.	R2W 8059.,07803.
R3S 8176.,05673.	R3S 8241.,06069.	R3S 8336.,06743.	R3S 8263.,07388.
R3E 8176.,05673.	R3E 8277.,06397.	R3E 8354.,07054.	R3E 8321.,07721.
R3N 8241.,06069.	R3N 8336.,06743.	R3N 8263.,07388.	R3N 8321.,07721.
R3W 7779.,05728.	R3W 7882.,06463.	R3W 7969.,07159.	R3W 7956.,07803.
.BYTE 08.,06.	.BYTE 10.,06.	.BYTE 12.,06.	.BYTE 14.,06.
R1 5644.,06735.	R1 5730.,07421.	R1 5837.,08045.	R1 5916.,08533.
R2S 5618.,06511.	R2S 5701.,07192.	R2S 5801.,07837.	R2S 5881.,08456.
R2E 5862.,06571.	R2E 5946.,07395.	R2E 6065.,08021.	R2E 6201.,08626.
R2N 5673.,06964.	R2N 5766.,07629.	R2N 5859.,08250.	R2N 5916.,08533.
R2W 5644.,06735.	R2W 5730.,07421.	R2W 5837.,08045.	R2W 5916.,08533.
R3S 5585.,06389.	R3S 5705.,07100.	R3S 5784.,07733.	R3S 5871.,08326.
R3E 5971.,06713.	R3E 6055.,07383.	R3E 6193.,08011.	R3E 6339.,08600.
R3N 5705.,07100.	R3N 5784.,07733.	R3N 5871.,08326.	R3N 5916.,08533.
R3W 5644.,06735.	R3W 5730.,07421.	R3W 5837.,08045.	R3W 5916.,08533.

TABLE 4-3 RANDOM ROUTE SIGNPOST FILE (SPTABL) (CONT'D)

```
      .BYTE   14.,08.
R1    6761.,08397.
R2S   6770.,08348.
R2E   6798.,08556.
R2N   6761.,08397.
R2W   6761.,08397.
R3S   6739.,08205.
R3E   6798.,08556.
R3N   6761.,08397.
R3W   6761.,08397.
      .BYTE   13.,13.
R1    5953.,05737.
R2S   5953.,05737.
R2E   6427.,05897.
R2N   5938.,05938.
R2W   5953.,05737.
R3S   5953.,05737.
R3E   6427.,05897.
R3N   5990.,06048.
R3W   5953.,05737.
      .BYTE   13.,15.
R1    6842.,05691.
R2S   6842.,05691.
R2E   7321.,05782.
R2N   6865.,05846.
R2W   6427.,05897.
R3S   6842.,05691.
R3E   7321.,05782.
R3N   6876.,06034.
R3W   6427.,05897.
      .BYTE   13.,16.
R1    7729.,05507.
R2S   7729.,05507.
R2E   7729.,05507.
R2N   7779.,05728.
R2W   7321.,05782.
R3S   7729.,05507.
R3E   7729.,05507.
R3N   7793.,05844.
R3W   7321.,05782.
      .BYTE   15.,11.
R1    5286.,06454.
R2S   5286.,06454.
R2E   5508.,06417.
R2N   5323.,06659.
R2W   5286.,06454.
R3S   5286.,06454.
R3E   5585.,06389.
R3N   5349.,06815.
R3W   5286.,06454.
      .BYTE   15.,13.
R1    6026.,06358.
R2S   5996.,06139.
R2E   6109.,06336.
R2N   6044.,06446.
R2W   5779.,06379.
R3S   5990.,06049.
R3E   6174.,06328.
R3N   6073.,06695.
R3W   5585.,06389.
      .BYTE   15.,14.
R1    6321.,06307.
R2S   6321.,06307.
R2E   6468.,06266.
R2N   6350.,06682.
R2W   6252.,06319.
R3S   6321.,06307.
R3E   6693.,06245.
R3N   6350.,06682.
R3W   6174.,06328.
      .BYTE   15.,15.
R1    6909.,06376.
R2S   6913.,06225.
R2E   7218.,06223.
R2N   6956.,06572.
R2W   6614.,06370.
R3S   6876.,06034.
R3E   7374.,06159.
R3N   6956.,06572.
R3W   6693.,06245.
      .BYTE   15.,16.
R1    7856.,06280.
R2S   7814.,05909.
R2E   7856.,06280.
R2N   7883.,06463.
R2W   7830.,06095.
R3S   7793.,05844.
R3E   7856.,06280.
R3N   7883.,06463.
R3W   7374.,06159.
      .BYTE   16.,11.
R1    5553.,07099.
R2S   5359.,06907.
R2E   5743.,07080.
R2N   5553.,07099.
R2W   5553.,07099.
R3S   5349.,06815.
R3E   5837.,07071.
R3N   5553.,07099.
R3W   5553.,07099.
      .BYTE   16.,13.
R1    6122.,07042.
R2S   6090.,06814.
R2E   6275.,07024.
R2N   6144.,07215.
R2W   5932.,07051.
R3S   6073.,06695.
R3E   6275.,07024.
R3N   6170.,07301.
R3W   5837.,07071.
      .BYTE   16.,14.
R1    6427.,07006.
R2S   6555.,06810.
R2E   6580.,06983.
R2N   6427.,07006.
R2W   6275.,07024.
R3S   6530.,06631.
R3E   6712.,06968.
R3N   6427.,07006.
R3W   6275.,07024.
      .BYTE   16.,15.
R1    6996.,06930.
R2S   6967.,06745.
R2E   7301.,06871.
R2N   7027.,07196.
R2W   6806.,06955.
R3S   6956.,06572.
R3E   7444.,06878.
R3N   7045.,07181.
R3W   6712.,06968.
      .BYTE   16.,16.
R1    7910.,06813.
R2S   7863.,06574.
R2E   7910.,06813.
R2N   7942.,07016.
R2W   7605.,06852.
R3S   7882.,06463.
R3E   8336.,06743.
R3N   7969.,07159.
R3W   7444.,06878.
      .BYTE   17.,13.
R1    6219.,07561.
R2S   6176.,07358.
R2E   6489.,07527.
R2N   6202.,07764.
R2W   6008.,07556.
R3S   6170.,07301.
R3E   6640.,07590.
R3N   6273.,07989.
R3W   5789.,07510.
      .BYTE   17.,15.
R1    7090.,07468.
R2S   7058.,07262.
R2E   7395.,07446.
R2N   7083.,07662.
R2W   6790.,07492.
R3S   7045.,07181.
R3E   7548.,07440.
R3N   7133.,07896.
R3W   6640.,07590.
      .BYTE   17.,16.
R1    8006.,07422.
R2S   7937.,07283.
R2E   8006.,07422.
R2N   8024.,07610.
R2W   7701.,07434.
R3S   7969.,07159.
R3E   8006.,07422.
R3N   8059.,07750.
R3W   7548.,07440.
      .BYTE   19.,11.
R1    5689.,08331.
R2S   5689.,08331.
R2E   5893.,08315.
R2N   5689.,08331.
R2W   5689.,08331.
R3S   5689.,08331.
R3E   5995.,08307.
R3N   5689.,08331.
R3W   5689.,08331.
      .BYTE   19.,13.
R1    6300.,08282.
R2S   [illegible].,08041.
R2E   6582.,08239.
R2N   6300.,08282.
R2W   6096.,08301.
R3S   6276.,07989.
R3E   6739.,08205.
R3N   6300.,08282.
R3W   5995.,08307.
      .BYTE   19.,15.
R1    7147.,08153.
R2S   7135.,07922.
R2E   7457.,08054.
R2N   7147.,08153.
R2W   6865.,08196.
R3S   7133.,07896.
R3E   7457.,08054.
R3N   7147.,08153.
R3W   6739.,08205.
      .BYTE   19.,16.
R1    8059.,07803.
R2S   8059.,07803.
R2E   8059.,07803.
R2N   8059.,07803.
R2W   7755.,08042.
R3S   8059.,07750.
R3E   8059.,07803.
R3N   8059.,07803.
R3W   7457.,08054.
```

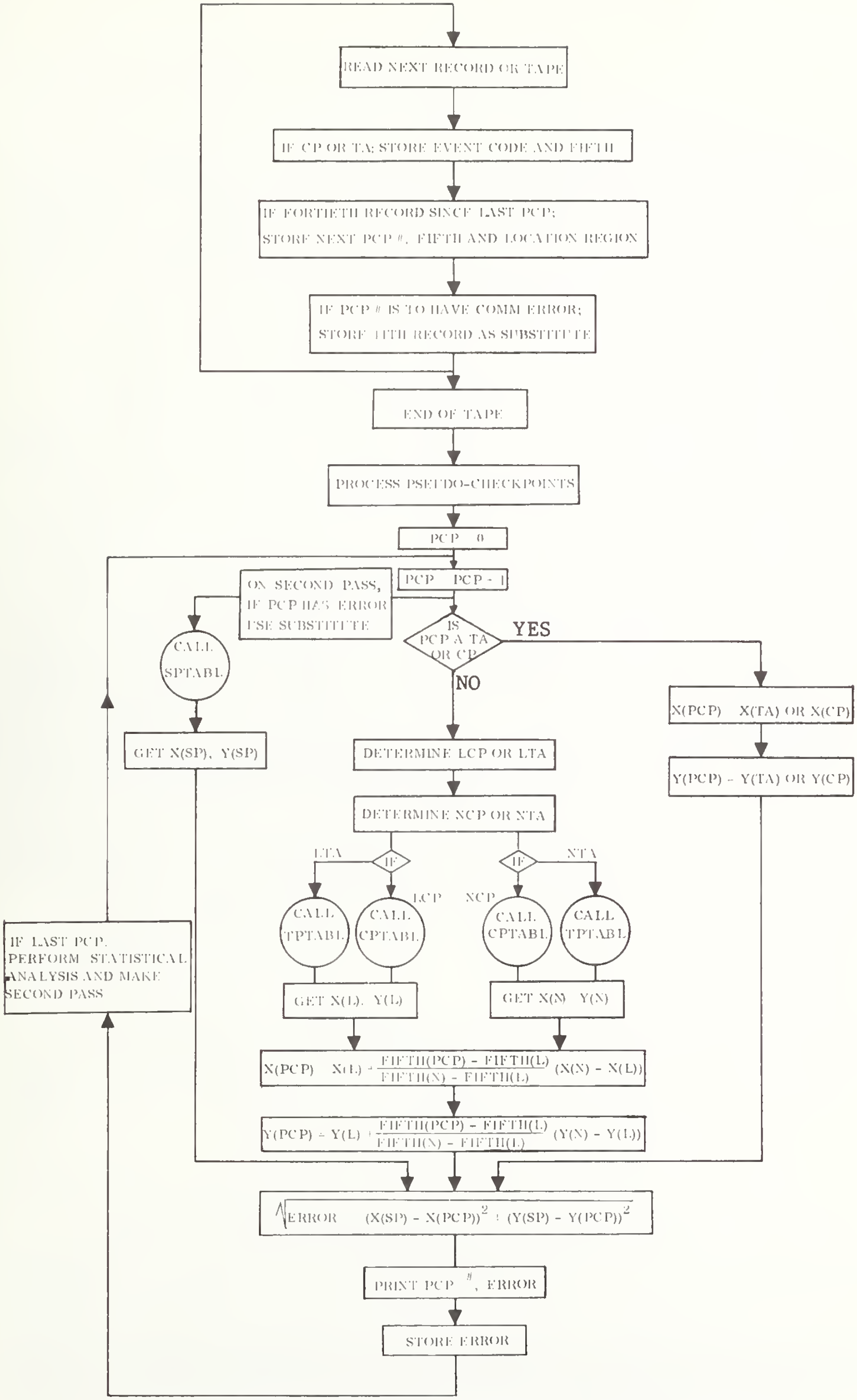


FIG. 4-4 FIXED ROUTE LOCATION ERROR ALGORITHM

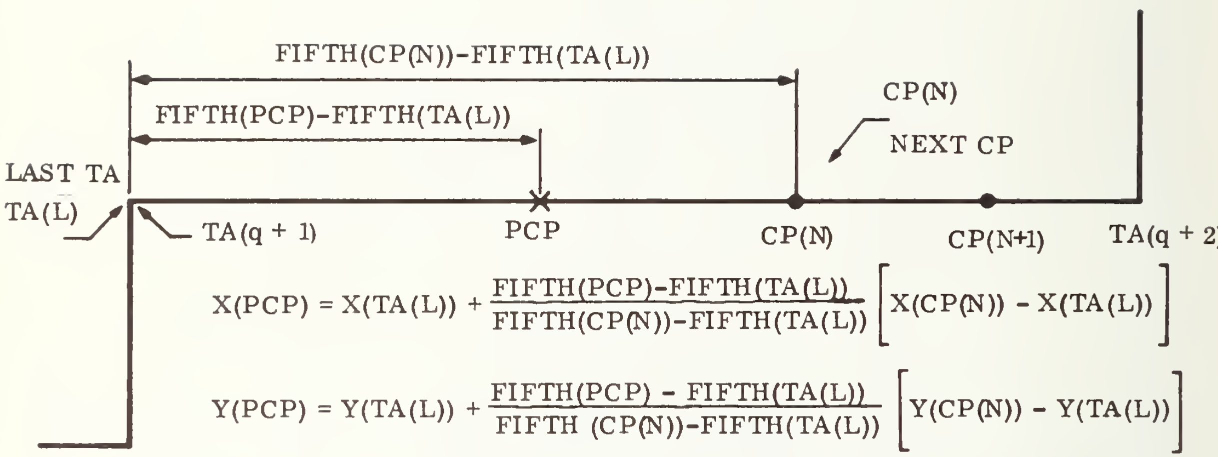


FIG. 4-5 USE OF TA AND CP EVENTS WITH 5TH WHEEL TO DETERMINE PSEUDO CHECKPOINT LOCATION

4.2.4 Vehicle Computed (AVM System) Location at Pseudo Checkpoints

As summarized in the previous paragraph, the random route vehicle's location, as computed by the AVM system, is always determined solely by the signpost location region code stored in the vehicle at the sample time. This identification is true whether the sample time is determined by a manual checkpoint entry or by offline sampling of the data recorded at half-second intervals.

4.2.5 AVM System Simulation

During the first pass through the recorded data, as shown in Figure 4-3, a pseudo checkpoint was selected every 20 seconds (40 records). This operation simulated the 20-second polling interval proposed for Phase II. In addition, the effects of a base-to-vehicle-to-base communication link were simulated in terms of simulating a 5-percent communication error rate. This simulation was affected by selecting in a random manner, 5 percent of the pseudo checkpoints and by assuming that the base station detected an error in the polling response or did not receive a response. When such an error is detected, the proposed Phase II system would poll the vehicle in question during the next 1-second guard-band time interval set aside for the transit route under consideration. For each route, this guard-band would occur within a maximum of two (2) seconds after the route poll began. Thus, within two seconds of detecting the error, the base station would poll the affected vehicle again. This was simulated by substituting the 18-BIT location code from the record occurring two (2) seconds (four records) further into the tape for the location code associated with the PCP. The proposed Phase II Polling scheme is illustrated in Figure 4-6 and was exactly simulated by the routine summarized in Figure 4-7.

In this simulation, the actual vehicle location is that computed for the original PCP. The AVM system location is the location region associated with the record (PCP) occurring two (2) seconds later.

A third routine, RRTEN, processed random route data to compute the average location error over 528 foot segments. This routine treats each sample record as a PCP, thereby processing approximately 9600 samples during each run.

4.3 RANDOM ROUTE DATA PROCESSING SOFTWARE

Random Route Data Processing Software was developed as three separate programs: (1) Random Route Location Subsystem Data Processor (CPMAIN), (2) Random Route System Level Data Processor (RRSL), and (3) Random Route One-Tenth Mile Average (RRTEN) routine. These programs were used to perform the data processing associated with the items discussed in subsection 4.2. Software was coded in FORTRAN IV for use on the HI^3 PDP-11/05 computer and, after checkout, converted for running on the IBM 370/145 at MITRE.

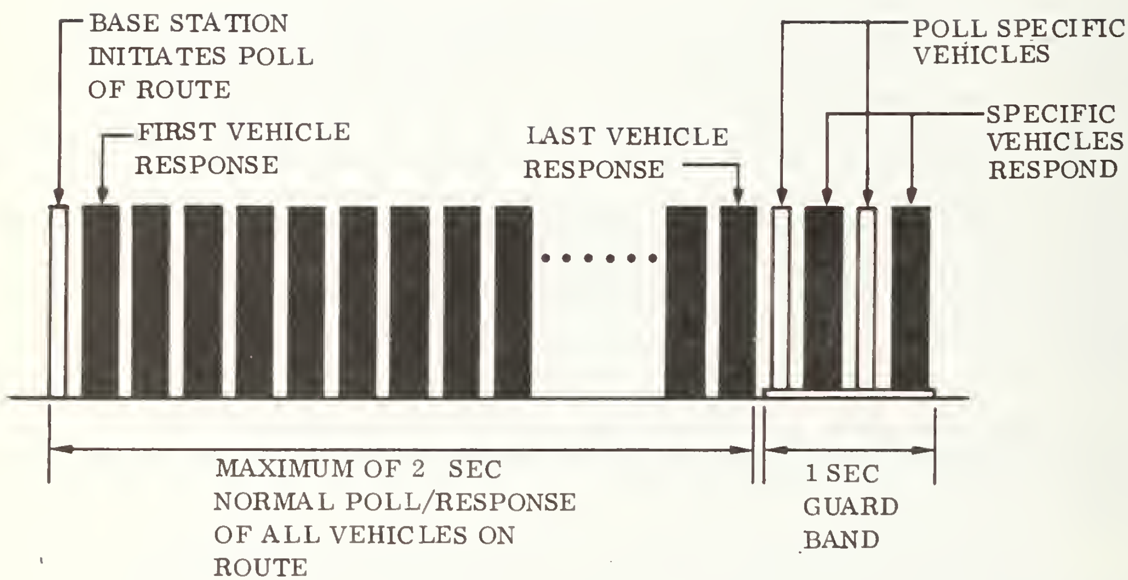


FIG. 4-6 USE OF GUARD BAND TO POLL SPECIFIC VEHICLES IN WHICH COMMUNICATION ERROR DETECTED

RANDOM NUMBER GENERATOR

100 NUMBERS IRANUM(I) GENERATED AT RANDOM ON THE INTERVAL I = 1 - 360

THESE 100 NUMBERS ARE PART OF THE DATA BASE

FROM THIS SET OF RANDOM NUMBERS, A SET OF 0.05 X 3 X T NUMBERS WAS SELECTED TO ACCOUNT FOR 5 PERCENT OF THE PSEUDO CHECKPOINTS (3 PER MINUTE OVER THE RUN TIME T)

DURING SYSTEM SIMULATION, OCCURRENCE OF A PCP NUMBER, NNNN, CORRESPONDING TO ONE OF THE SELECTED RANDOM ROUTE NUMBERS IRANUM CAUSED THE LOCATION REGION SAMPLE OCCURRING 2 SECONDS LATER ON TAPE TO BE SUBSTITUTED FOR THE ORIGINAL PCP'S LOCATION REGION

THUS, AT A SUBSTITUTE PCP, (PCP') THE ERROR IS GIVEN BY

ERROR (SYSTEM SIMULATION) =

$$\sqrt{X(\text{SP at PCP}')-X(\text{PCP})^{2} + Y(\text{SP at PCP}')-Y(\text{PCP})^{2}}$$

PCP = ORIGINAL PSEUDO CHECKPOINT SAMPLE

PCP' = SUBSTITUTE SAMPLE OCCURING 2 SECONDS LATER

FIG. 4-7 GENERAL METHOD FOR SIMULATING COMMUNICATION ERRORS

Figure 4-8 contains a flow chart of the CPMAIN routine used to process random route checkpoint data. A complete FORTRAN listing and documentation of CPMAIN was submitted to TSC and MITRE. Section 5 contains output data from this program which were used to process HI^3 Random Route Data Runs 1 through 10 The data base requirements for this routine are as follows:

1. SPTABL - X, Y state plane coordinates of each signpost location region 18-bit code

2. CPTABL - X, Y state plane coordinates of each TSC designated checkpoint (primary or secondary) (Table 4-1).

Figure 4-9 contains a flow chart of the RRSL routine used to process Random Route AVM System level data. A complete listing and documentation of RRSL was also provided to TSC and MITRE. Section 5 contains output data from this routine. In addition to SPTABL and CPTABL, this routine involves the use of TPTABL, and the X, Y state plane coordinates of each run on TSC designated primary and secondary random routes.

The overall methodology of the HI^3 software, including data recording, data handling, and data processing is shown in Figure 4-10.

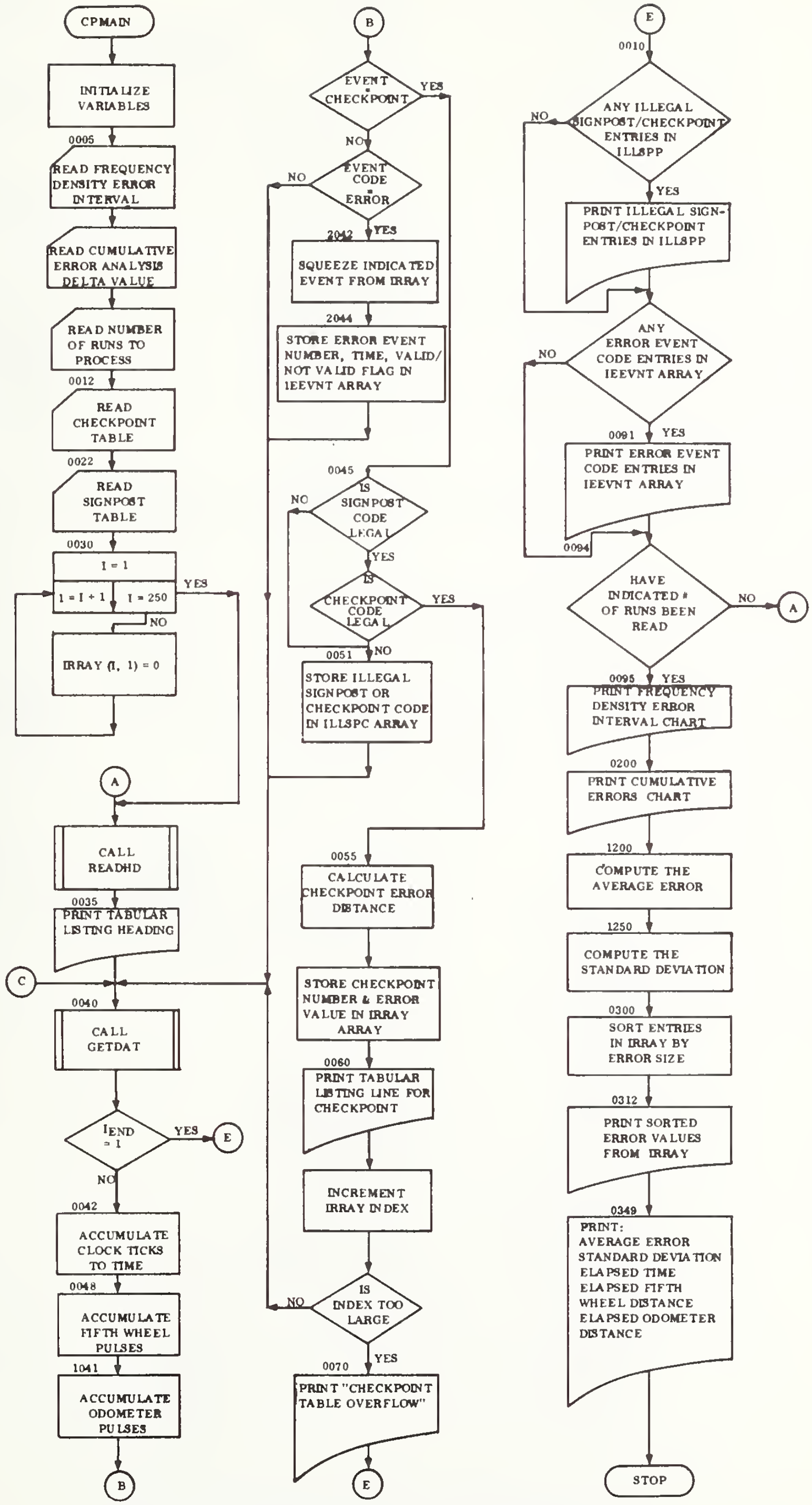


FIG. 4-8 FLOW CHART OF CPMAIN

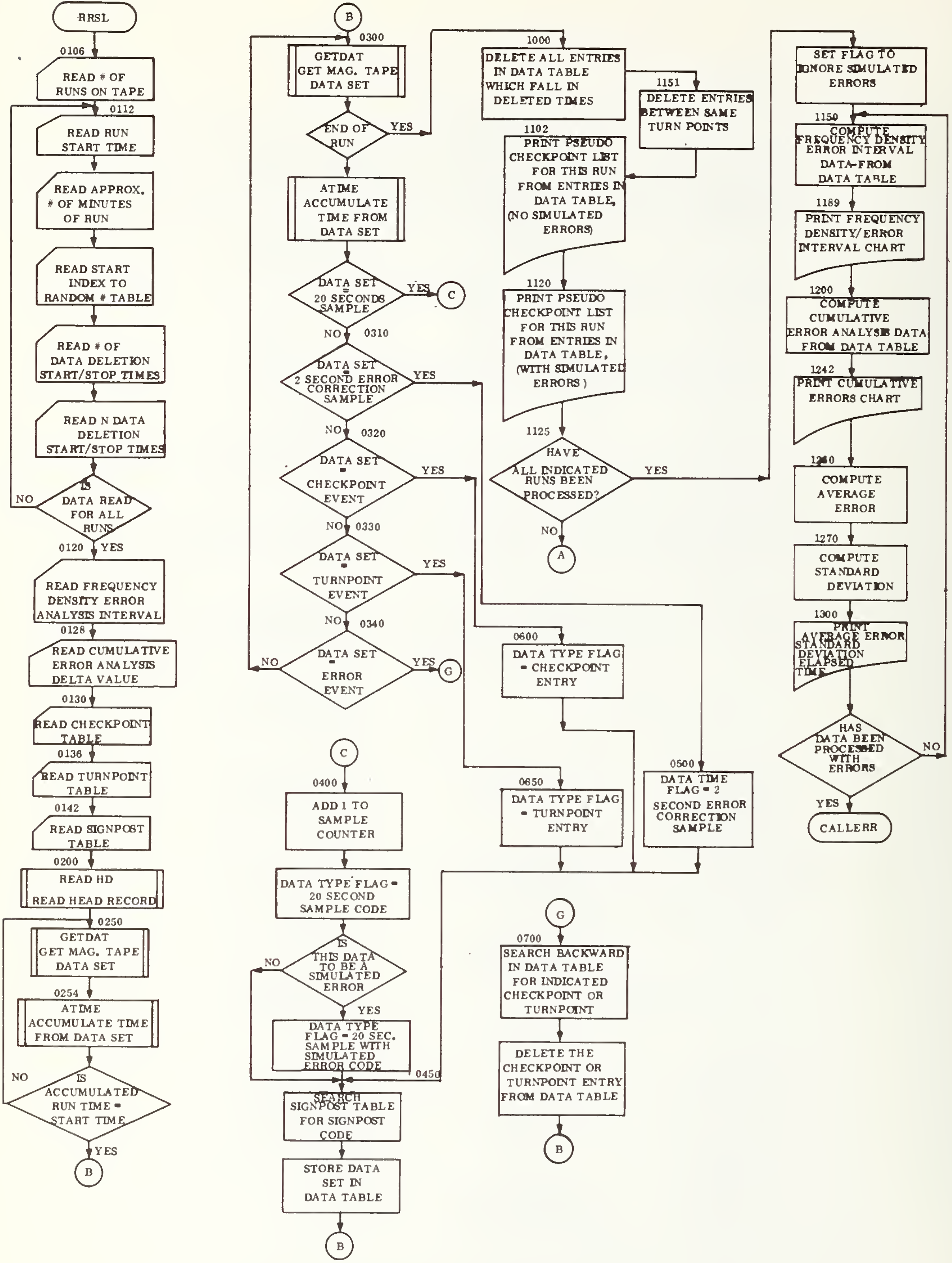


FIG. 4-9 FLOW CHART OF RRSL

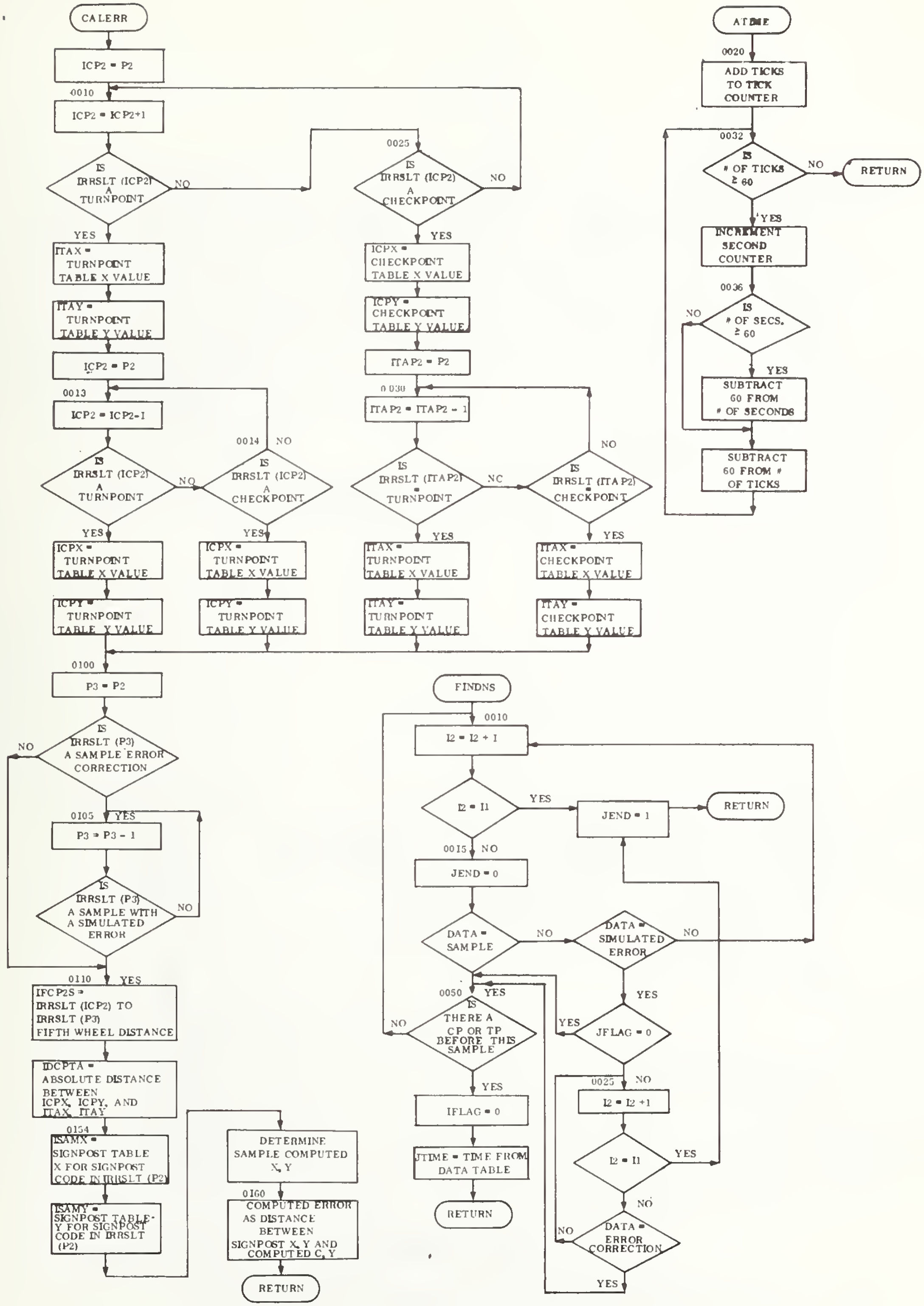
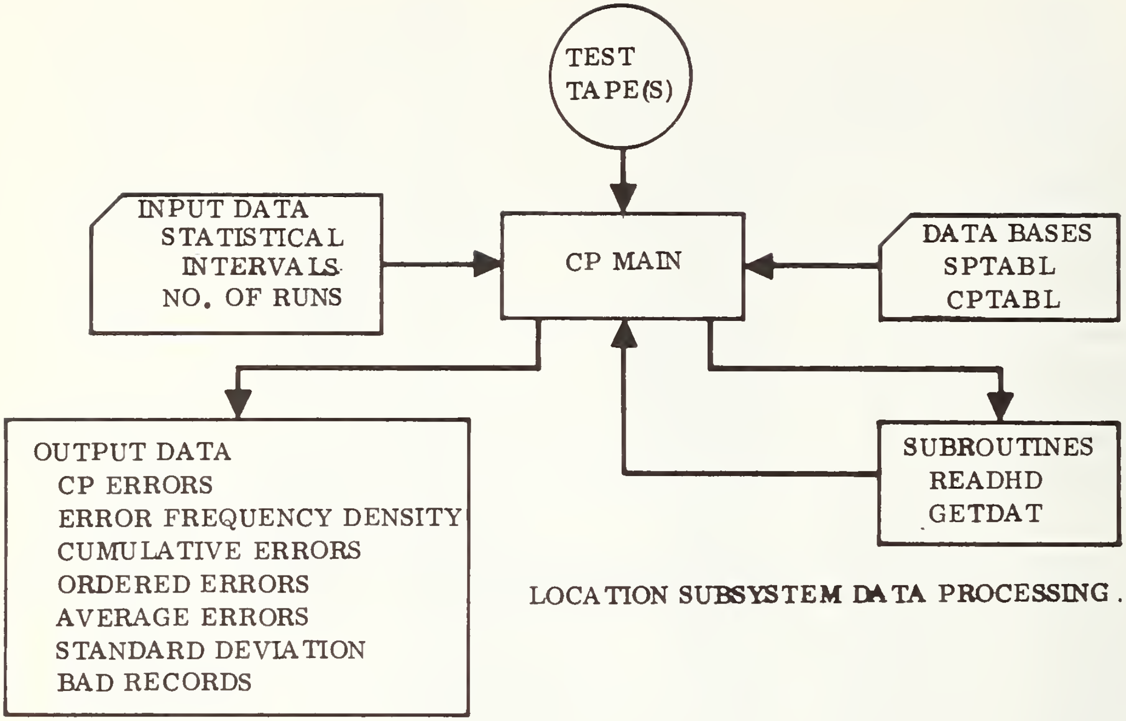
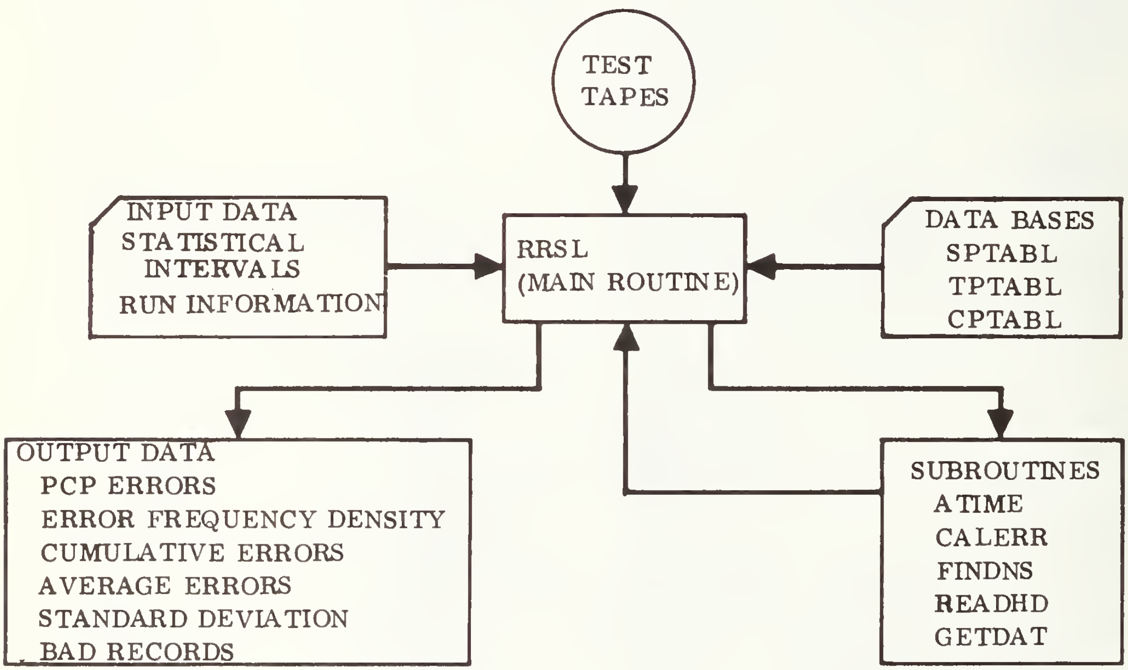


FIG. 4-9 FLOW CHART OF RRSL (CONT'D)



LOCATION SUBSYSTEM DATA PROCESSING.



AVM SYSTEM LEVEL DATA PROCESSING

FIG. 4-10 RANDOM ROUTE DATA PROCESSING SOFTWARE

5. RANDOM ROUTE TEST RESULTS

The results obtained by processing Random Route Runs 1 through 10 by use of data processing routines CPMAIN, RRSL, and RRTEN are presented in this section. Location error data, associated with the location subsystem in which TSC checkpoints are the reference, are shown separately from the data associated with pseudo checkpoints that represent AVM System Level errors. In each instance, however, the error incurred at each individual checkpoint and the statistics of the errors are presented. The results obtained for both the location subsystem and the AVM system simulation presented in this section are summarized in the following table.

SUMMARY OF RANDOM ROUTE TEST RESULTS

	Location Subsystem	AVM System
No. of Samples	622	2235
Average Error	91 Feet	114 Feet
95% Error	242 Feet	289 Feet
99.5% Error	461 Feet	460 Feet
% Samples Less than 300 Feet	97.26	95.66
% Samples Less than 450 Feet	98.87	99.38

The impact of simulating 5 percent communication errors was negligible.

Maximum average error over any 1/10th mile segment was 315 feet.

5.1 LOCATION SUBSYSTEM ERRORS

The location errors incurred at each Primary Checkpoint on each of Runs 1 through 5 are presented in Table 5-1. Of the 313 samples (CP 30 on Run 1 was not processed because it was incorrectly entered and CP 18 on Run 3 was screened out because of an invalid signpost code; refer to Subsection 3.7). Of the 313 samples, the error for 11 samples exceeded 300 feet and the error for 6 samples exceeded 450 feet. Thus, for TSC Primary Checkpoints, Runs 1 through 5, the following error statistics were obtained:

95 percent of samples were less than 245 feet

99.5 percent of samples were less than 466 feet

TABLE 5-1 LOCATION SUBSYSTEM ERRORS AT PRIMARY CHECKPOINTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	32	145	0	157	139	455	0	152	40	0	153	28	96	46	0	0	153	0	154	219	0
2	32	145	0	13	139	137	0	152	40	0	143	28	96	46	0	0	153	0	154	16	0
3	32	145	0	13	139	137	0	152	40	0	153	28	96	46	0	0	153	-	154	258	0
4	32	145	460	13	139	137	0	152	40	0	143	28	96	46	0	0	153	0	154	16	0
5	32	145	0	13	139	455	0	152	40	0	244	351	96	46	0	114	153	0	154	219	0
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1	60	71	231	50	203	98	9	202	-	86	40	0	137	22	172	152	8	47	19	184	0
2	60	71	231	50	203	363	224	202	8	86	244	0	137	22	39	152	8	47	19	465	97
3	60	71	231	50	203	98	224	202	208	86	40	0	137	22	275	152	208	47	19	0	0
4	60	71	231	50	203	98	224	202	208	86	244	0	137	22	172	152	8	47	19	0	0
5	432	71	231	50	203	363	224	202	8	179	198	0	137	22	275	152	208	47	19	0	137
	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
1	18	0	157	221	92	126	152	8	203	7	6	216	153	122	46	0	147	147	156	241	0
2	18	154	157	221	92	0	152	208	203	7	137	216	153	122	241	0	0	0	156	241	0
3	18	154	157	221	92	0	152	208	203	7	6	320	153	172	46	156	147	111	160	241	0
4	18	154	157	221	92	0	152	208	203	7	95	73	153	122	241	156	147	0	156	241	0
5	18	133	157	561	92	115	152	8	203	120	137	73	153	172	241	0	0	0	0	241	0

Average error was 109 feet

Maximum average error over one-tenth mile segment: 315 feet.

Individual output error statistics obtained by use of CPMAIN for Runs 1 through 5 are contained in Tables 5-2 through 5-6. Figure 5-1 is a plot of the error histograms for each of these runs and Figure 5-2 is a plot of the error histogram for all five primary runs, as well as a cumulative error distribution based on all five runs. The 95 percent and 99.5 percent points are indicated on the cumulative distribution. Note that a number of errors are zero. This zero error condition is obtained because of the discrete nature of the HI^3 location subsystem. Generally, the X, Y location coordinates assigned to a location region are coordinates of the center of the nearest intersection. Thus, in those cases in which the TSC checkpoints were associated with the center of an intersection, the resulting error may be zero. (Note: The X, Y stateplane coordinates of intersections in central Philadelphia was provided to HI^3 by TSC.) These coordinates were generated by MITRE through the process of digitizing the intersections of a 2000:1 scale map of Philadelphia. The stated error of this process was 40 feet RMS.

Table 5-7 contains a list of the location errors incurred at each Secondary Checkpoint on each of Runs 6 through 10. Of these 309 samples (CP 18 was missed on Run 8), only 6 exceeded 300 feet and only one exceeded 450 feet. For Runs 6 through 10, the following error statistics were obtained:

95 percent of samples less than 242 feet

99.5 percent of samples less than 411 feet

Average error was 73 feet.

Maximum average error over one-tenth mile segment: 234 feet.

Individual output error statistics obtained using CPMAIN for Runs 6 through 10 are contained in Tables 5-8 through 5-12. As a result of a bad cassette on Run 10, CPMAIN was unable to process the last 21 checkpoints of Run 10. However, a dump of this cassette was obtained by using the CAPS operating system. The first 41 were processed successfully. The last 21 were processed manually as follows:

1. Read location region code at each checkpoint from the dump of Run 10

2. Manually look up X, Y coordinates from signpost data base SPTABL

3. Manually look up X, Y coordinates of secondary checkpoint from CPTABL

(Text continued on 5-17)

TABLE 5-2 RANDOM ROUTE ERROR STATISTICS, RUN 1

ERROR FREQUENCY DENSITY

ERROR INTERVAL		NUMBER POINTS	PERCENT OF POINTS
0-	25	21	33.87%
25-	50	7	11.29%
50-	75	3	4.84%
75-	100	3	4.84%
100-	125	1	1.61%
125-	150	6	9.68%
150-	175	11	17.74%
175-	200	1	1.61%
200-	225	6	9.68%
225-	250	2	3.23%
450-	475	1	1.61%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	13	20.97%
25	21	33.87%
50	29	46.77%
75	31	50.00%
100	34	54.84%
125	35	56.45%
150	41	66.13%
175	52	83.87%
200	53	85.48%
225	59	95.16%
250	61	98.39%
475	62	100.00%

TABLE 5-3 RANDOM ROUTE ERROR STATISTICS, RUN 2

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	22	34.92%
25- 50	6	9.52%
50- 75	3	4.76%
75- 100	3	4.76%
100- 125	1	1.59%
125- 150	6	9.52%
150- 175	9	14.29%
200- 225	7	11.11%
225- 250	4	6.35%
350- 375	1	1.59%
450- 475	1	1.59%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	14	22.22%
25	22	34.92%
50	29	46.03%
75	31	49.21%
100	34	53.97%
125	35	55.56%
150	41	65.08%
175	50	79.37%
225	57	90.48%
250	61	96.83%
375	62	98.41%
475	63	100.00%

TABLE 5-4 RANDOM ROUTE ERROR STATISTICS, RUN 3

ERROR FREQUENCY DENSITY

ERROR INTERVAL		NUMBER POINTS	PERCENT OF POINTS
0-	25	18	29.03%
25-	50	7	11.29%
50-	75	3	4.84%
75-	100	3	4.84%
100-	125	1	1.61%
125-	150	5	8.06%
150-	175	11	17.74%
200-	225	8	12.90%
225-	250	2	3.23%
250-	275	1	1.61%
275-	300	1	1.61%
300-	325	1	1.61%
450-	475	1	1.61%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	12	19.35%
25	18	29.03%
50	26	41.94%
75	28	45.16%
100	31	50.00%
125	32	51.61%
150	37	59.68%
175	48	77.42%
225	56	90.32%
250	58	93.55%
275	60	96.77%
325	61	98.39%
475	62	100.00%

TABLE 5-5 RANDOM ROUTE ERROR STATISTICS, RUN 4

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	20	31.75%
25- 50	5	7.94%
50- 75	4	6.35%
75- 100	4	6.35%
100- 125	1	1.59%
125- 150	6	9.52%
150- 175	11	17.46%
200- 225	7	11.11%
225- 250	4	6.35%
450- 475	1	1.59%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	13	20.63%
25	20	31.75%
50	26	41.27%
75	29	46.03%
100	33	52.38%
125	34	53.97%
150	40	63.49%
175	51	80.95%
225	58	92.06%
250	62	98.41%
475	63	100.00%

TABLE 5-6 RANDOM ROUTE ERROR STATISTICS, RUN 5

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	21	32.81%
25- 50	4	6.25%
50- 75	3	4.69%
75- 100	1	1.56%
100- 125	2	3.12%
125- 150	7	10.94%
150- 175	8	12.50%
175- 200	2	3.12%
200- 225	6	9.37%
225- 250	4	6.25%
275- 300	1	1.56%
350- 375	2	3.12%
425- 450	1	1.56%
450- 475	1	1.56%
550- 575	1	1.56%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	15	23.44%
25	21	32.81%
50	26	40.62%
75	28	43.75%
100	29	45.31%
125	31	48.44%
150	38	59.37%
175	46	71.87%
200	48	75.00%
225	54	84.37%
250	58	90.62%
275	59	92.19%
375	61	95.31%
450	62	96.87%
475	63	98.44%
575	64	100.00%

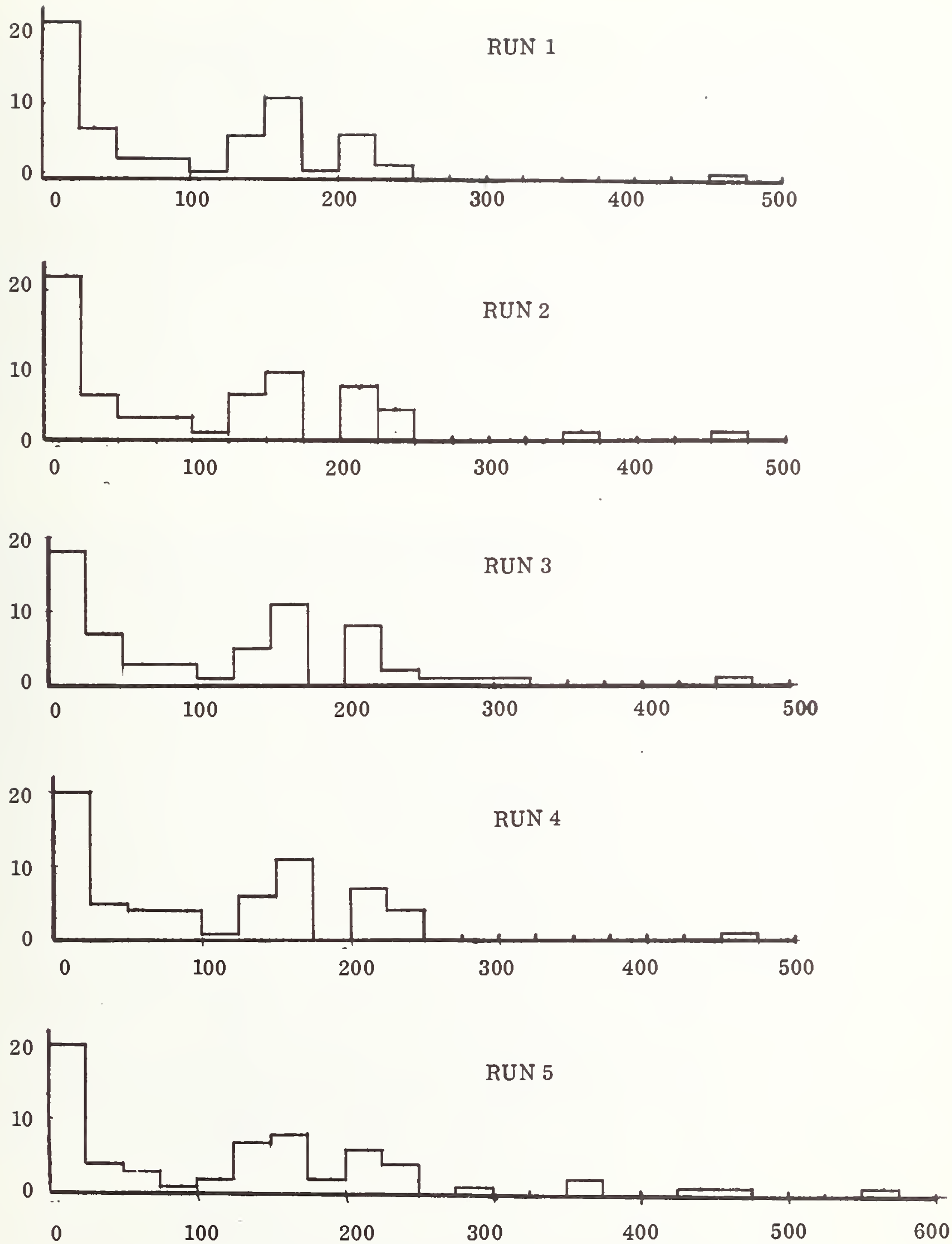


FIG. 5-1 RANDOM ROUTE LOCATION SUBSYSTEM ERRORS, RUNS 1-5

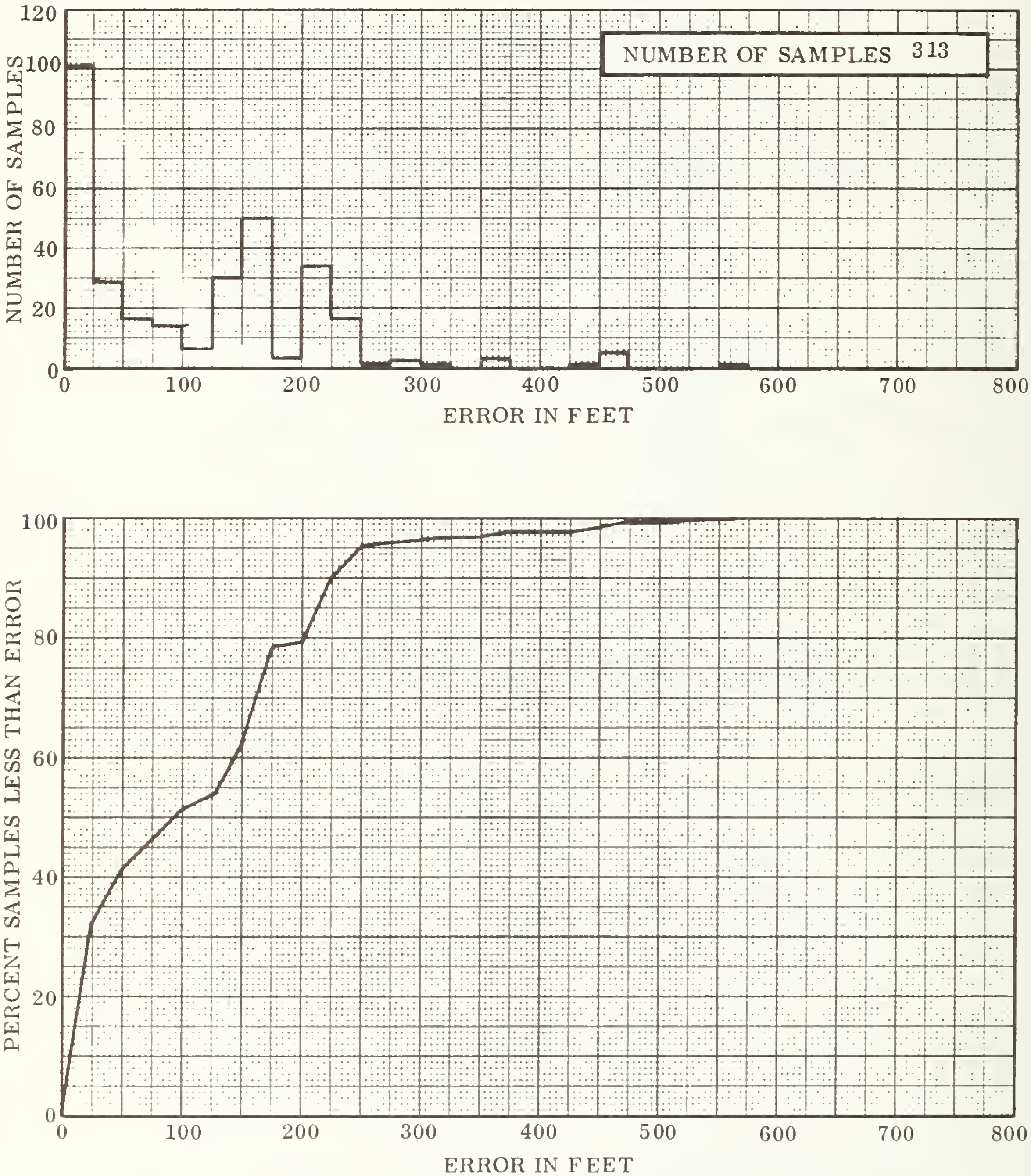


FIG. 5-2 RANDOM ROUTE LOCATION SUBSYSTEM ERRORS, RUNS 1-5

TABLE 5-7 LOCATION SUBSYSTEM ERRORS AT SECONDARY CHECKPOINTS

CHECKPOINTS

RUNS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
6	58	0	0	180	128	191	277	153	0	92	0	41	8	0	0	10	241	0	198	25	0
7	58	0	0	180	265	160	277	153	0	92	0	41	8	0	0	10	241	0	198	25	0
8	58	0	0	180	0	191	53	153	0	92	225	41	8	0	0	10	241	-	250	25	0
9	58	0	0	94	128	52	53	153	0	92	0	41	8	0	0	10	241	79	198	179	0
10	58	0	0	180	128	52	277	153	0	92	225	41	8	0	0	10	241	370	250	25	0
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
6	119	77	20	61	120	26	47	157	0	181	84	40	0	77	151	89	64	9	0	410	0
7	119	77	20	61	90	51	29	157	0	181	84	198	0	77	151	89	64	77	0	20	0
8	119	226	20	61	90	51	29	157	0	181	84	40	0	10	151	89	64	77	0	410	0
9	119	77	20	139	120	51	47	157	0	181	84	198	0	10	151	89	64	9	0	20	0
10	119	77	20	139	90	51	376	157	0	181	84	40	0	43	151	89	155	77	0	45	0
	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	
6	192	0	0	46	60	0	0	40	115	50	81	0	0	38	0	92	92	0	0	0	
7	80	0	0	46	60	0	0	71	115	50	81	0	0	183	0	92	92	0	0	0	
8	80	0	0	46	60	0	0	40	47	50	312	0	0	183	0	92	92	0	0	0	
9	192	274	0	46	60	0	0	40	47	50	81	0	0	192	0	92	92	0	0	0	
10	80	274	0	227	60	0	0	160	47	50	81	0	0	192	0	92	92	0	460	0	

TABLE 5-8 RANDOM ROUTE ERROR STATISTICS, RUN 6

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	26	41.94%
25- 50	8	12.90%
50- 75	5	8.06%
75- 100	8	12.90%
100- 125	3	4.84%
125- 150	1	1.61%
150- 175	3	4.84%
175- 200	5	8.06%
225- 250	1	1.61%
275- 300	1	1.61%
400- 425	1	1.61%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	22	35.48%
25	27	43.55%
50	35	56.45%
75	39	62.90%
100	47	75.81%
125	50	80.65%
150	51	82.26%
175	54	87.10%
200	59	95.16%
250	60	96.77%
300	61	98.39%
425	62	100.00%

TABLE 5-9 RANDOM ROUTE ERROR STATISTICS, RUN 7

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	26	41.94%
25- 50	4	6.45%
50- 75	7	11.29%
75- 100	11	17.74%
100- 125	2	3.23%
150- 175	4	6.45%
175- 200	5	8.06%
225- 250	1	1.61%
250- 275	1	1.61%
275- 300	1	1.61%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	22	35.48%
25	27	43.55%
50	31	50.00%
75	37	59.68%
100	48	77.42%
125	50	80.65%
175	54	87.10%
200	59	95.16%
250	60	96.77%
275	61	98.39%
300	62	100.00%

TABLE 5-10 RANDOM ROUTE ERROR STATISTICS, RUN 8

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	25	40.98%
25- 50	7	11.48%
50- 75	7	11.48%
75- 100	8	13.11%
100- 125	1	1.64%
150- 175	3	4.92%
175- 200	4	6.56%
225- 250	3	4.92%
250- 275	1	1.64%
300- 325	1	1.64%
400- 425	1	1.64%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	21	34.43%
25	26	42.62%
50	33	54.10%
75	39	63.93%
100	47	77.05%
125	48	78.69%
175	51	83.61%
200	55	90.16%
225	56	91.80%
250	59	96.72%
325	60	98.36%
425	61	100.00%

TABLE 5-11 RANDOM ROUTE ERROR STATISTICS, RUN 9

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	26	41.27%
25- 50	5	7.94%
50- 75	7	11.11%
75- 100	9	14.29%
100- 125	2	3.17%
125- 150	2	3.17%
150- 175	3	4.76%
175- 200	6	9.52%
225- 250	1	1.59%
250- 275	1	1.59%
9950- 9975	1	1.59%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	20	31.75%
25	26	41.27%
50	32	50.79%
75	38	60.32%
100	47	74.60%
125	49	77.78%
150	51	80.95%
175	54	85.71%
200	60	95.24%
250	61	96.83%
275	62	98.41%
9975	63	100.00%

TABLE 5-12 RANDOM ROUTE ERROR STATISTICS, RUN 10

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	12	28.57%
25- 50	5	11.90%
50- 75	3	7.14%
75- 100	6	14.29%
100- 125	1	2.38%
125- 150	2	4.76%
150- 175	4	9.52%
175- 200	2	4.76%
225- 250	2	4.76%
250- 275	1	2.38%
275- 300	1	2.38%
350- 375	1	2.38%
375- 400	1	2.38%
1350- 1375	1	2.38%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	9	21.43%
25	13	30.95%
50	17	40.48%
75	20	47.62%
100	26	61.90%
125	27	64.29%
150	29	69.05%
175	33	78.57%
200	35	83.33%
225	36	85.71%
250	38	90.48%
300	39	92.86%
375	40	95.24%
400	41	97.62%
1375	42	100.00%

4. Compute error:

$$\text{ERROR (CP)} = \sqrt{\left(X(SP) - X(CP)\right)^2 + \left(Y(SP) - Y(CP)\right)^2} \; .$$

Table 5-13 contains the results obtained by using CPMAIN to compute the location error at CP 1 through CP 41 and manual computation necessary to compute the location error at CP 42 through CP 62. The tabular results obtained for all random route runs are contained in the Appendix.

Figure 5-3 contains error histograms of the results obtained during each of Runs 6 through 10. Figure 5-4 is an error histogram for Runs 6 through 10 combined and a cumulative error distribution.

Figure 5-5 contains the overall results obtained during Runs 1 through 10 inclusive, in terms of the frequency of errors over 25-foot error intervals and the cumulative error distribution for all 622 samples.

It is significant to note that, of the 6 errors which exceeded 450 feet, three occurred at the same location, CP 6 on Run 1 and Run 5 and CP 46 on Run 5 (primary checkpoints 6 and 46 were at the same location). In each of the cases, analysis of the cassette dumps shows that a Region 1 from signpost (15, 13) was not received, even though the test vehicle passed within 40 feet of the signpost just prior to approaching the checkpoint. Subsequent to the completion of Runs 1 through 5, it was determined (refer to Section 3 for details) that the vehicle unit clock frequency had been slightly maladjusted and caused a slight degradation in the ability of the unit to lock up on all signposts as their FSK changed (within design tolerance) as a function of temperature. This phenomenon was noticed as the temperature was rapidly dropping towards freezing during Run 5. Prior to Run 6, the vehicle unit clock frequency was correctly set. Subsequent test runs were made in temperatures as low as 8^{o}F, following overnight low temperatures of 0^{o}F.

This adjustment reduced the location subsystem error significantly, i.e., whereas Runs 1 through 5 incurred 5 errors, exceeding 450 feet, Runs 6 through 10 incurred only 1 such error, and whereas Runs 1 through 5 incurred 11 errors exceeding 300 feet, Runs 6 through 10 incurred only 6 such errors.

5.2 RANDOM ROUTE AVM SYSTEM ERRORS

The results obtained by processing Random Route Runs 1 through 10 by use of data processing routine RRSL are presented in this subsection. Location errors associated with the HI^3 AVM System in which pseudo checkpoints serve as the reference are also presented. Pseudo checkpoints were determined by simulating a 20-second polling interval. This simulation was affected by selecting every 40th data record from the test data. The methodology for computing the reference location at each pseudo checkpoint is described in paragraph 4.2.3.

(Text continued on 5-22)

TABLE 5-13 TABULAR LISTING OF LOCATION SUBSYSTEM ERRORS, RUN # 10

CF	X(CF)	Y(CF)	LOCATION	REGION	X(SL)	Y(SL)	ERROR
1	8183	5731	6,12	R1	8176	5673	58
2	8277	6397	8,12	R1	8277	6397	0
3	8354	7054	10,12	R1	8354	7054	0
4	8150	7778	12,12	R1	8321	7721	180
5	7969	7159	17,16	R2S	7937	7283	128
44	8059	7803	15,16	R3N	7882	6463	1351
6	7830	6470	15,16	R2N	7882	6463	52
7	7140	6596	8,10	R1	7403	6509	277
8	6918	6223	15,15	R1	6909	6376	153
9	6427	5897	6, 8	R1	6427	5897	0
10	5461	6021	6, 6	R1	5553	6009	92
11	5618	6511	8, 6	R1	5644	6735	225
12	5771	7426	10, 6	R1	5730	7421	41
13	6509	7341	10, 8	R2W	6503	7335	8
14	7500	7204	10,10	R1	7500	7204	0
15	7910	6813	16,16	R1	7910	6813	0
16	7860	6290	15,16	R1	7856	6280	10
17	6451	6137	6, 8	R1	6427	5897	241
18	6530	6631	8, 8	R3S	6468	6266	370
19	6600	7104	10, 8	R2W	6503	7335	250
20	6693	7755	12, 8	R2S	6685	7731	25
21	7090	7458	17,15	R1	7090	7458	0
22	6981	6811	16,15	R1	6996	6930	119
23	6545	6276	15,14	R2E	6468	6266	77
24	6046	6355	15,13	R1	6026	6358	20
25	5646	6397	15,11	R2E	5508	6417	139
26	5745	7541	10, 6	R2N	5766	7629	90
27	5867	8275	14, 6	R3S	5871	8326	51
28	6247	7988	12, 8	R3W	6623	7965	376
29	6102	6886	16,13	R1	6122	7042	157
30	5730	7421	10, 6	R1	5730	7421	0
31	5813	7865	12, 6	R1	5837	8045	181
32	6638	7895	12, 8	R1	6714	7933	84
33	7090	7702	17,15	R2N	7083	7662	40
*34	6996	6930	16,15	R1	6996	6930	0

CT1:RUN010.001

35	6453	6641	8, 8	R3W	6414	6661	43
36	6147	6705	8, 7	R1	6298	6690	151
37	6041	6446	15,13	R1	6026	6358	89
38	5994	5984	15,13	R2S	5996	6139	155
39	6267	7988	12, 6	R3E	6193	8011	77
40	6714	7933	12, 8	R1	6714	7933	0
41	7121	7879	19,15	R2S	7135	7922	45
42	7591	7859	12, 10	R1	7591	7859	0
43	8288	7464	10, 12	R3N	8263	7388	80
44	8059	7803	12, 12	R1	8321	7721	274
45	7591	7859	12, 10	R1	7591	7859	0
46	6741	8159	12, 8	R2W	6623	7965	227
47	7157	8093	19, 15	R1	7147	8153	60
48	7090	7458	17, 15	R1	7090	7458	0
49	6427	7006	16, 14	R1	6427	7006	0
50	6284	7063	8, 7	R2N	6325	6908	160
51	5820	7115	16, 13	R3W	5837	7071	47
52	6296	8232	19, 13	R1	6300	8282	50
53	6192	7484	17, 13	R1	6219	7561	81
54	6627	7326	10, 8	R1	6627	7326	0
55	6909	6376	15, 15	R1	6909	6376	0
56	6838	5874	6, 10	R2W	7023	5820	192
57	6427	5897	6, 18	R1	6427	5897	0
58	5461	6021	6, 16	R1	5553	6009	92
59	5461	6021	6, 6	R1	5553	6009	92
60	6427	5897	6, 8	R1	6427	5897	0
61	7321	5782	6, 8	R3E	6865	5846	460
62	8178	5673	6,12	R1	8176	5673	0

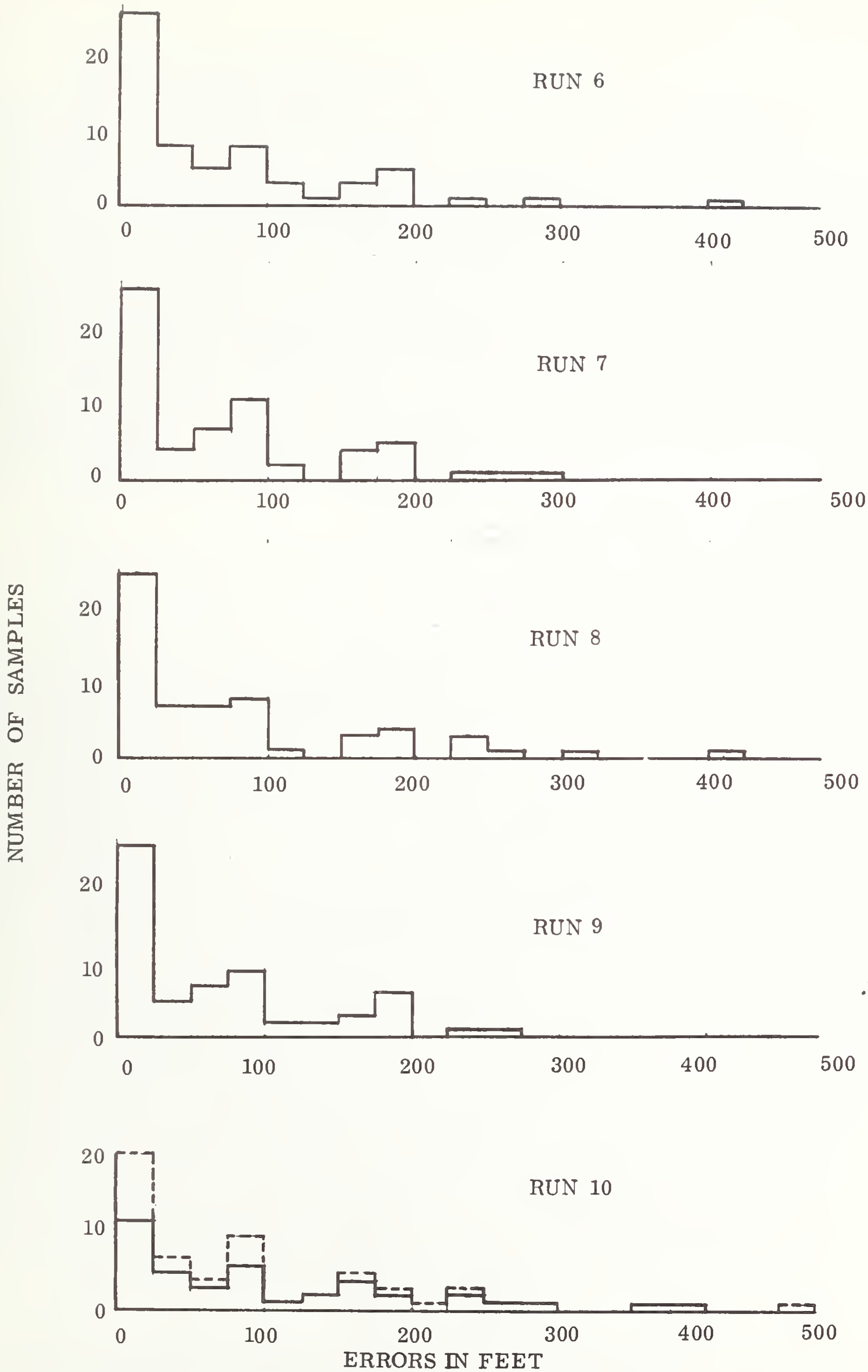


FIG. 5-3 RANDOM ROUTE LOCATION SUBSYSTEM ERRORS, RUNS 6-10

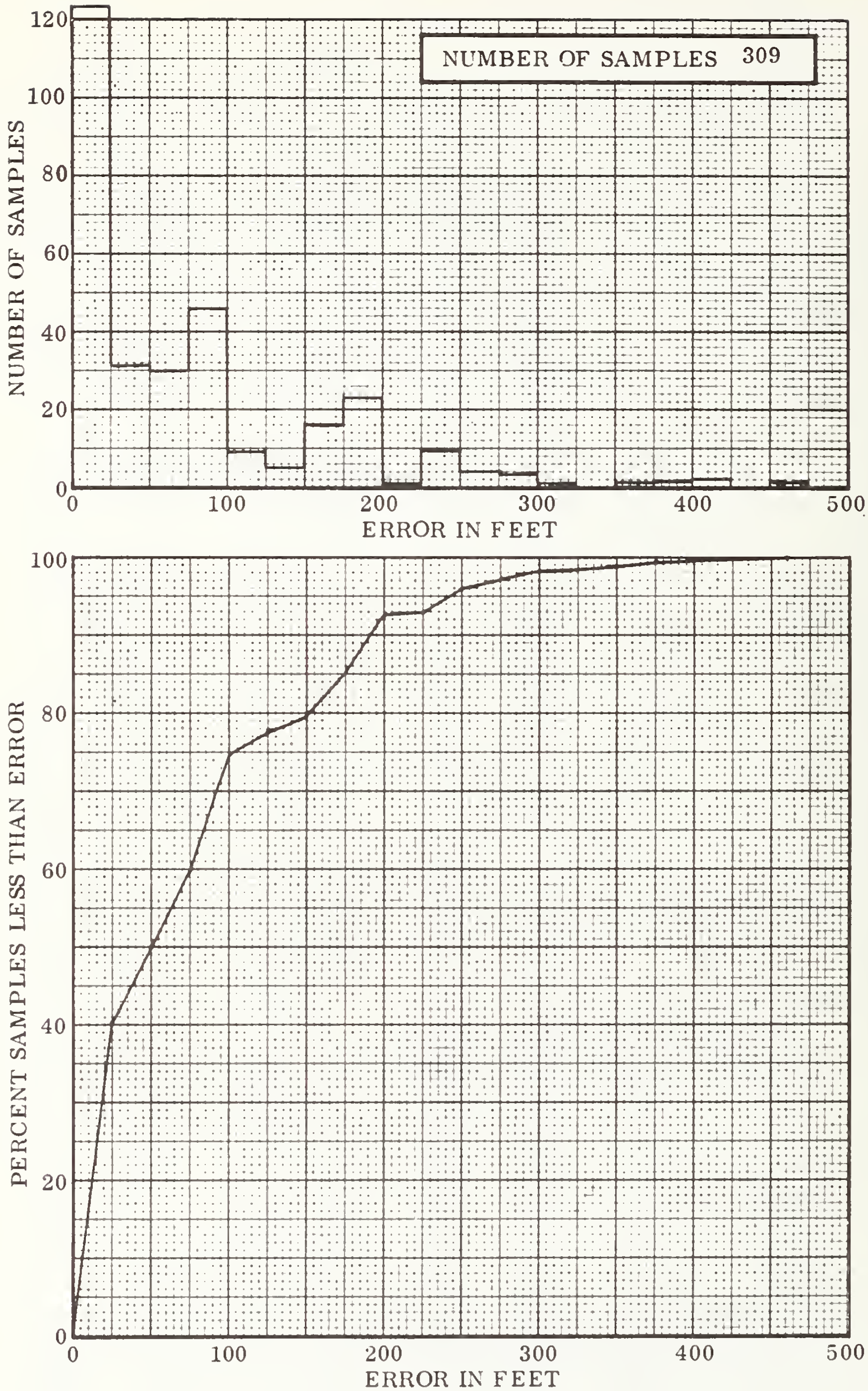


FIG. 5-4 RANDOM ROUTE LOCATION SUBSYSTEM ERRORS, RUNS 6-10

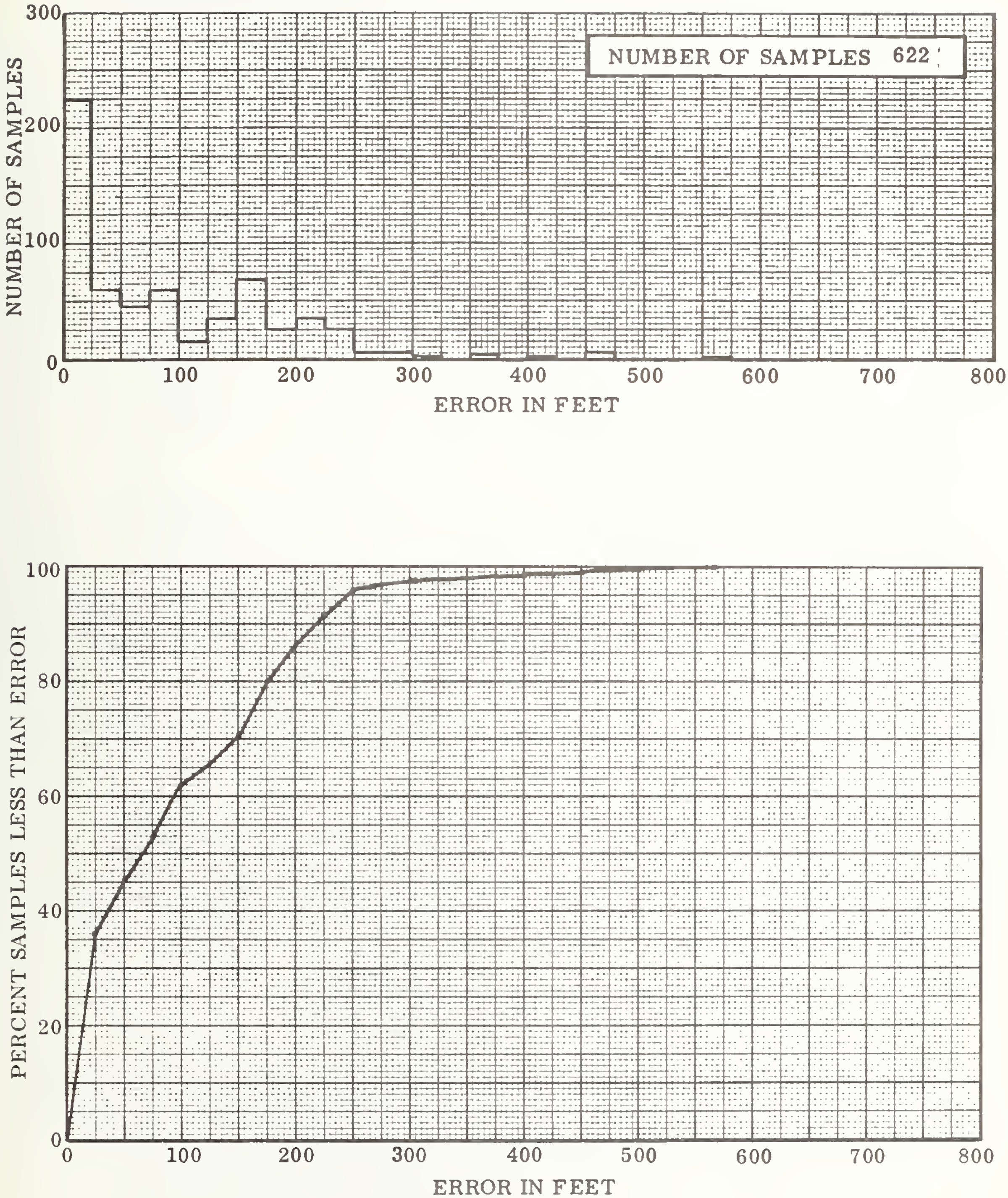


FIG. 5-5 RANDOM ROUTE LOCATION SUBSYSTEM ERRORS, RUNS 1-10

Individual listing of pseudo checkpoint errors for Runs 1 through 10 are presented in the Appendix. However, for illustration, Table 5-14 contains a copy of the RRSL output listing for Run 10. This listing represents the first pass through the program which simulates the 20-second polling interval but does not simulate communication errors. Table 5-15 contains the error statistics for these data as well as those for the results obtained when a 5-percent communication error was to shift one error from the 50-75 foot interval to the 325-350 foot interval.

Figures 5-6 through 5-15 contain error histograms and cumulative error distributions of Random Route AVM System Errors for Runs 1 through 10. As in the case of Location Subsystem data processing of Run 10, the last portion (CP 41 to end of tape) of the run was processed manually. In Figures 5-6 through 5-15, the solid lines represent the results obtained with no communication errors simulated. Where a difference occurred, a dashed line has been used to represent the results obtained when a 5-percent communication error rate was simulated. Note that, in general, this difference is hardly perceptible.

Table 5-16 contains a summary of the Random Route AVM System error statistics for Runs 1 through 10. Note that Run 5, during which the maladjusted vehicle unit clock frequency produced the most location subsystem errors (as a result of the temperature being the lowest), contributed 17 system level errors which exceeded 300 feet whereas the other 9 runs contributed only 81 such errors. Thus, Run 5, representing only 7.6 percent of the total samples processed, produced 17.3 percent of the errors exceeding 300 feet. Similarly only 7.6 percent of the data produced 3 samples, or 21 percent of the errors exceeding 450 feet. Subsection 9.2.4 contains a detailed discussion of this frequency maladjustment. Section 10 contains a discussion of pertinent problems in recording, processing, and analyzing test data.

Figure 5-16 contains a histogram and cumulative distribution of Random Route AVM system errors, both with and without communication errors, for Random Route Runs 1 through 10. As a result of the HI^3 communication error detection and correction technique, the impact of 5 percent communication errors is negligible. In Table 5-17, the impact of 5 percent communication errors on AVM system accuracy are quantified.

5.3 AVERAGE ERROR OVER ONE-TENTH MILE SEGMENTS

The results obtained by processing Runs 1 through 10 by use of the RRTEN routine are tabulated in Tables 5-18 and 5-19. Table 5-18 contains results associated with Runs 1 through 5 and the Primary Route. Table 5-19 contains results associated with Runs 6 through 10 and the Secondary Route. The largest single one-tenth mile average on any single run was 455 feet. This occurred during the 64th segment on Run 8. The average error obtained over this segment during Runs 6, 7, 8, and 9 (Run 10 could not be processed past the 60th segment) was 234 feet. Tables 5-18 and 5-19 also contain data averaged over these corresponding five runs. The

(Text continued on 5-45)

TABLE 5-14 RRSL OUTPUT LISTING FOR RANDOM ROUTE RUN # 3

SIMULATED ERRORS PSEUDO CP #	ERROR	TIME	ODOM
1	0	2:34	553
2	14	2:52	560
3	70	3:14	737
4	3	3:32	771
5	2	3:52	866
6	65	4:32	1177
7	37	4:52	1356
8	279	5:12	1519
9	85	5:32	1572
10	211	5:52	1724
11	27	6:12	1816
12	199	6:32	1928
13	47	6:52	2063
14	153	7:12	2163
15	97	7:34	2297
16	46	7:52	2422
17	162	8:12	2584
18	48	8:32	2625
19	19	8:52	2635
20	236	9:12	2744
21	22	9:32	2805
22	22	9:52	2805
23	56	10:12	2964
24	8	10:34	2988
25	21	10:52	3003
26	152	11:12	3181
27	226	11:32	3336
28	229	11:52	3361
29	18	12:12	3524
30	69	12:32	3556
31	36	12:52	3702
32	122	13:12	3885
33	56	13:32	4068
34	32	13:52	154
35	28	14:12	156
36	48	14:32	210
37	15	14:54	447
38	24	15:12	611
39	24	15:32	611
40	139	15:52	693
41	372	16:12	869
42	113	16:32	886
43	180	16:52	1041
44	82	17:12	1237
45	221	17:32	1433
46	99	17:52	1662
47	142	18:12	1823
48	31	18:32	1942
49	92	18:52	2117
50	91	19:12	2209
51	217	19:32	2272
52	139	19:52	2382

TABLE 5-14 RRSL OUTPUT LISTING FOR RANDOM ROUTE RUN # 3 (Cont'd)

53	137	20:12	2383
54	137	20:32	2383
55	196	20:54	2575
56	133	21:12	2782
57	0	21:32	2867
58	10	21:52	3049
59	68	22:12	3186
60	216	22:34	3284
61	58	22:52	3476
62	161	23:12	3649
63	335	23:32	3777
64	107	23:52	3891
65	155	24:12	4050
66	44	24:32	122
67	42	24:52	123
68	12	25:12	138
69	6	25:32	312
70	112	25:52	406
71	67	26:12	496
72	7	26:32	641
73	57	26:52	814
74	53	27:12	916
75	197	27:32	989
76	197	27:52	989
77	78	28:12	1048
78	67	28:32	1206
79	62	28:52	1209
80	122	29:12	1287
81	127	29:32	1498
82	48	29:52	1676
83	48	30:12	1676
84	42	30:32	1788
85	217	30:52	1943
86	13	31:12	2072
87	214	31:32	2180
88	74	31:52	2180
89	362	32:12	2180
90	182	32:32	2311
91	56	32:52	2476
92	381	33:12	2536
93	77	33:32	2619
94	163	33:52	2801
95	269	34:12	2936
96	58	34:32	3100
97	34	34:52	3112
98	166	35:12	3261
99	205	35:32	3452
100	168	35:52	3655
101	49	36:12	3761
102	119	36:32	3884
103	95	36:52	4066
104	201	37:12	202
105	111	37:32	359
106	48	37:52	518

TABLE 5-14 RRSL OUTPUT LISTING FOR RANDOM ROUTE RUN # 3 (Cont'd)

107	118	38:12	594
108	109	38:32	750
109	233	38:52	941
110	26	39:12	1108
111	92	39:32	1241
112	170	39:52	1391
113	66	40:12	1511
114	21	40:32	1619
115	21	40:54	1619
116	38	41:12	1648
117	321	41:32	1791
118	220	41:52	1924
119	103	42:12	2086
120	158	42:32	2263
121	40	42:52	2427
122	177	43:12	2637
123	103	43:32	2674
124	258	43:52	2833
125	154	44:12	2981
126	88	44:32	3211
127	238	44:52	3438
128	36	45:12	3598
129	36	45:32	3598
130	2	45:52	3624
131	570	46:33	3858
132	0	46:53	4025
133	53	47:13	79
134	175	47:33	200
135	136	47:53	278
136	190	48:13	418
137	72	48:33	542
138	6	48:53	683
139	12	49:46	692
140	12	50: 3	692
141	141	50:23	704
142	65	50:43	886
143	17	51: 3	910
144	158	51:23	1053
145	29	51:43	1179
146	106	52: 3	1294
147	246	52:23	1402
148	249	52:45	1514
149	40	53: 3	1604
150	257	53:23	1753
151	102	53:43	1831
152	143	54: 3	1853
153	250	54:23	1986
154	140	54:43	2041
155	110	55: 3	2056
156	72	55:23	2075
157	9	55:43	2181
158	164	56: 3	2342
159	117	56:23	2494
160	159	56:43	2653

TABLE 5-14 RRSL OUTPUT LISTING FOR RANDOM ROUTE RUN # 3 (Cont'd)

161	48	57: 3	2774
162	72	57:23	2831
163	198	57:43	3033
164	224	58: 0	3097
165	147	58:20	3272
166	169	58:40	3398
167	187	59: 0	3576
168	42	59:20	3714
169	114	59:42	3911
170	127	60: 0	4046
171	179	60:20	104
172	46	60:40	171
173	46	61: 0	171
174	47	61:20	316
175	103	61:40	389
176	103	62: 0	389
177	5	62:20	413
178	24	62:40	574
179	61	63: 0	750
180	120	63:20	927
181	30	63:40	1072
182	111	64: 0	1166
183	69	64:20	1336
184	242	64:40	1492
185	48	65: 0	1545
186	230	65:20	1720
187	107	65:40	1782
188	213	66: 0	1942
189	24	66:20	1993
190	56	66:42	2098
191	82	67: 0	2235
192	10	67:20	2281
193	20	68: 0	4035
194	249	68:20	117
195	62	68:40	211
196	62	69: 0	211
197	75	69:20	354
198	18	69:40	542
199	113	70: 0	740
200	122	70:20	931
201	18	70:40	1148

TABLE 5-15 ERROR STATISTICS FOR RUN #3

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	31	15.50%
25- 50	32	16.00%
50- 75	26	13.00%
75- 100	15	7.50%
100- 125	21	10.50%
125- 150	13	6.50%
150- 175	18	9.00%
175- 200	10	5.00%
200- 225	11	5.50%
225- 250	8	4.00%
250- 275	4	2.00%
275- 300	3	1.50%
300- 325	1	0.50%
325- 350	2	1.00%
350- 375	2	1.00%
375- 400	1	0.50%
400- 425	1	0.50%
550- 575	1	0.50%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	3	1.50%
25	31	15.50%
50	63	31.50%
75	89	44.50%
100	104	52.00%
125	125	62.50%
150	139	69.50%
175	157	78.50%
200	166	83.00%
225	177	88.50%
250	186	93.00%
275	189	94.50%
300	192	96.00%
325	193	96.50%
350	195	97.50%
375	197	98.50%
400	198	99.00%
425	199	99.50%
575	200	100.00%

AVERAGE ERROR = 113.59

STANDARD DEVIATION = 92.84

ELAPSED TIME = 4111

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NUMBER POINTS	PERCENT OF POINTS
0- 25	31	15.50%
25- 50	32	16.00%
50- 75	27	13.50%
75- 100	15	7.50%
100- 125	21	10.50%
125- 150	13	6.50%
150- 175	18	9.00%
175- 200	10	5.00%
200- 225	11	5.50%
225- 250	8	4.00%
250- 275	4	2.00%
275- 300	3	1.50%
300- 325	1	0.50%
325- 350	1	0.50%
350- 375	2	1.00%
375- 400	1	0.50%
400- 425	1	0.50%
550- 575	1	0.50%

CUMULATIVE ERRORS

ERROR FEET	# ERRORS LT FEET	PERCENT ERRORS
0	3	1.50%
25	31	15.50%
50	63	31.50%
75	90	45.00%
100	105	52.50%
125	126	63.00%
150	140	70.00%
175	158	79.00%
200	167	83.50%
225	178	89.00%
250	187	93.50%
275	190	95.00%
300	193	96.50%
325	194	97.00%
350	195	97.50%
375	197	98.50%
400	198	99.00%
425	199	99.50%
575	200	100.00%

AVERAGE ERROR = 112.29

STANDARD DEVIATION = 91.61

ELAPSED TIME = 4111

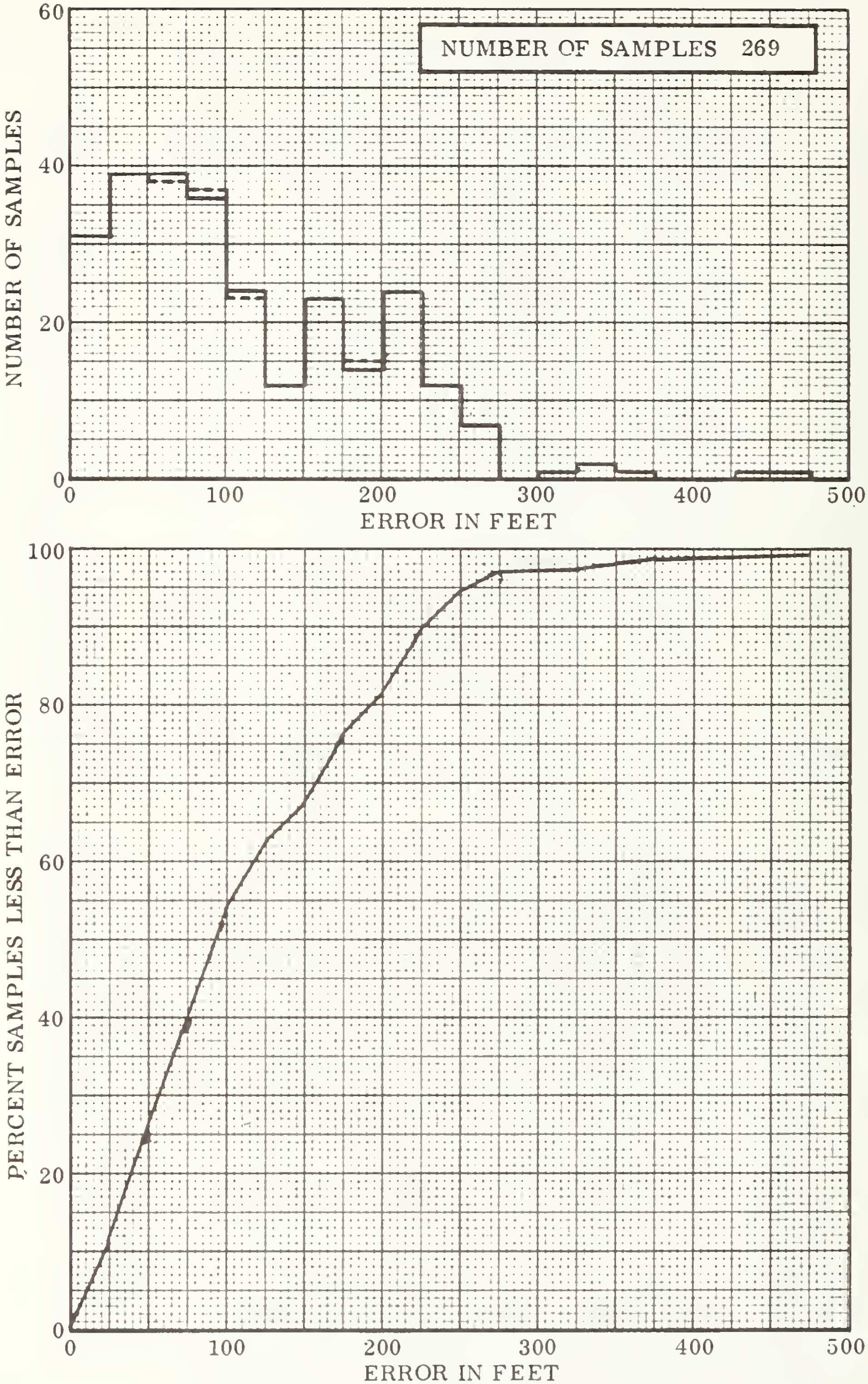


FIG. 5-6 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #1

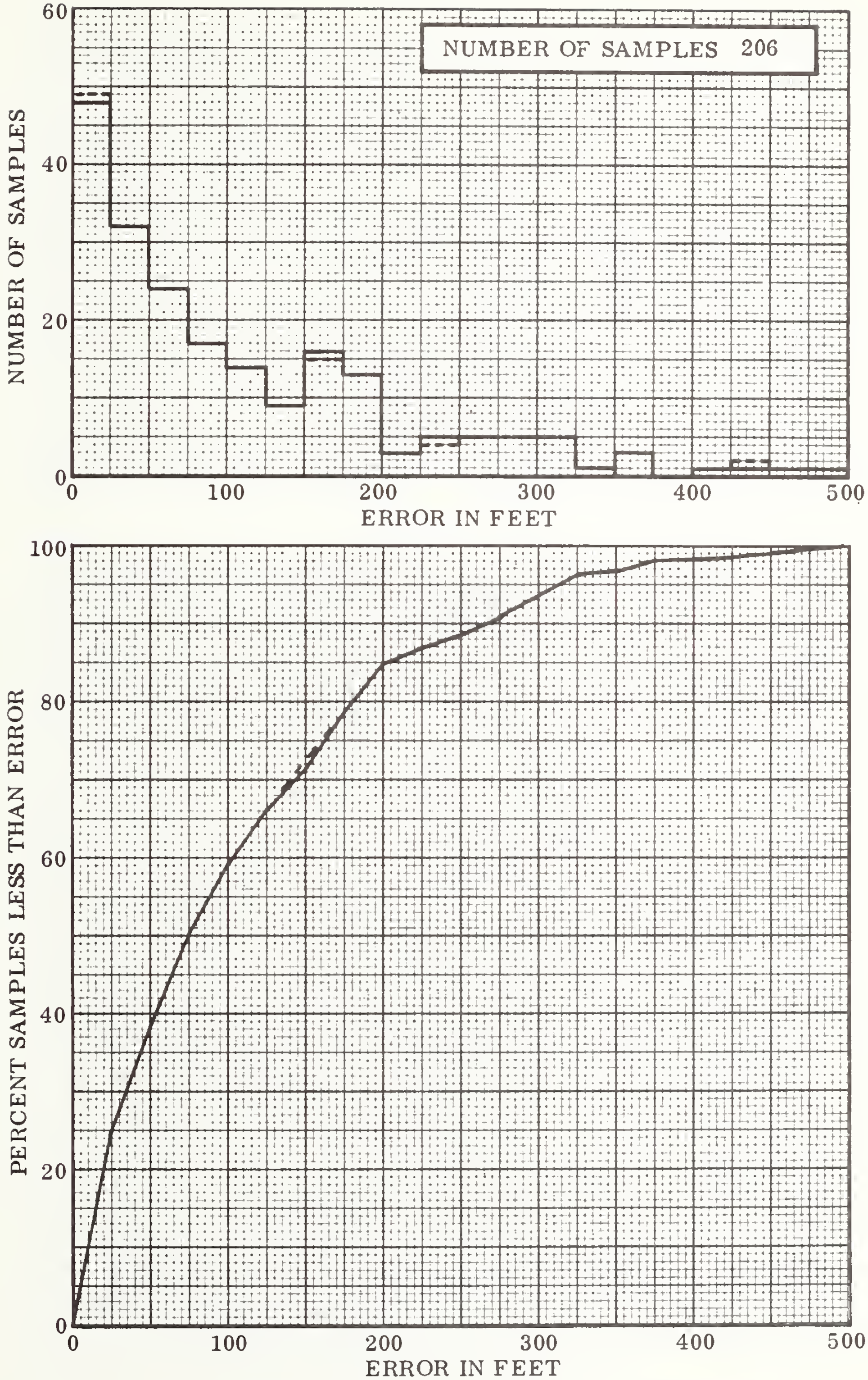


FIG. 5-7 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #2

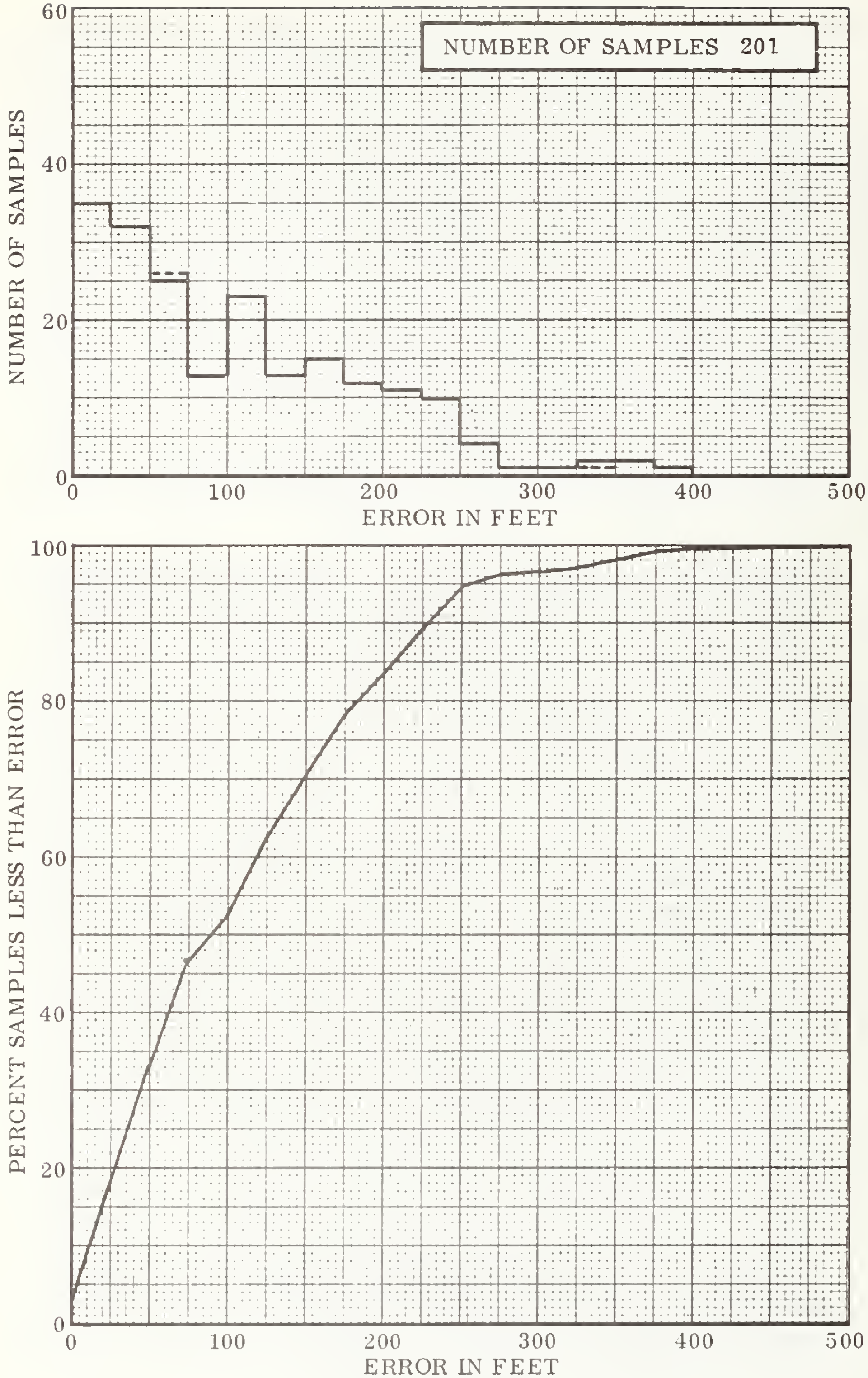


FIG. 5-8 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #3

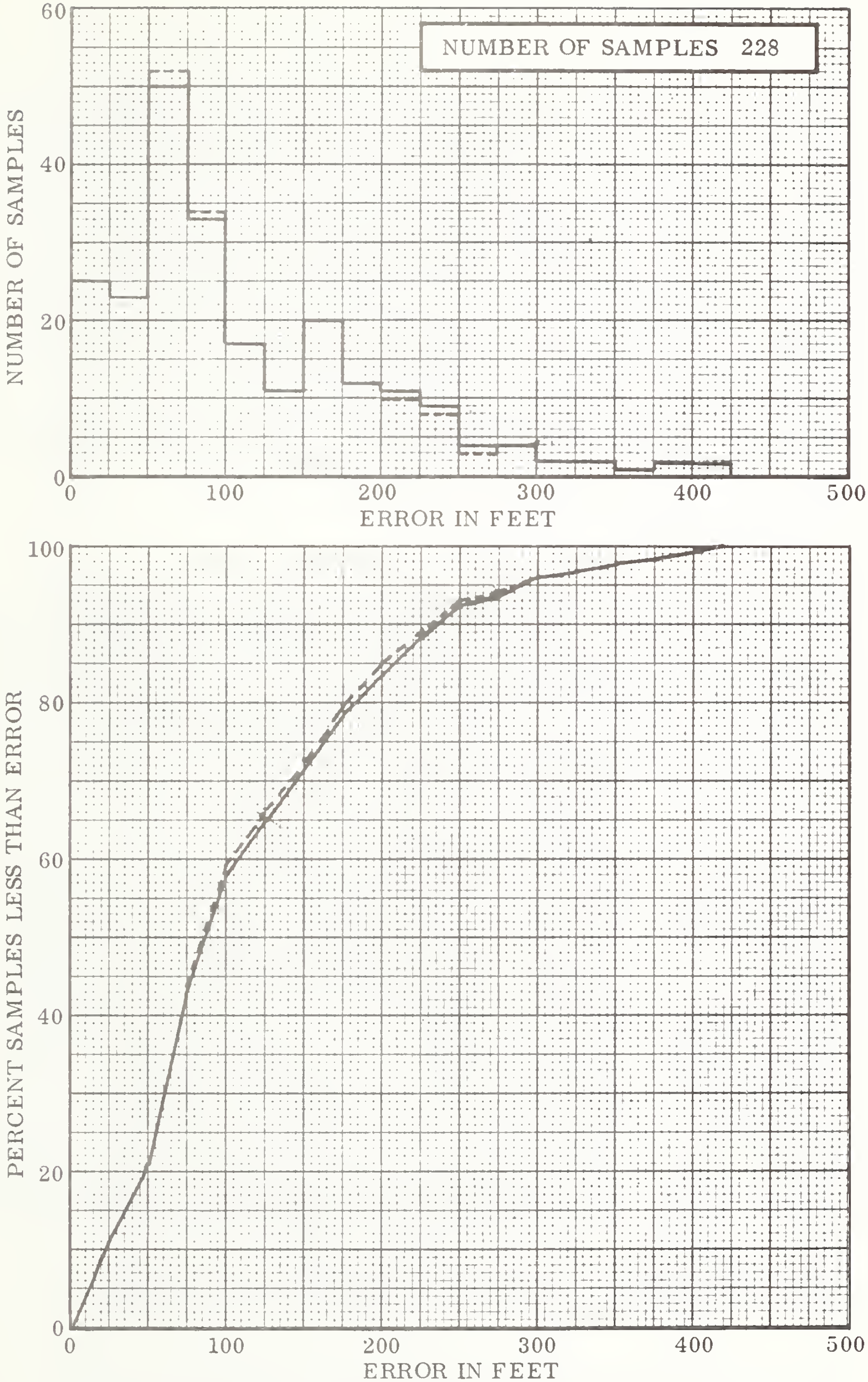
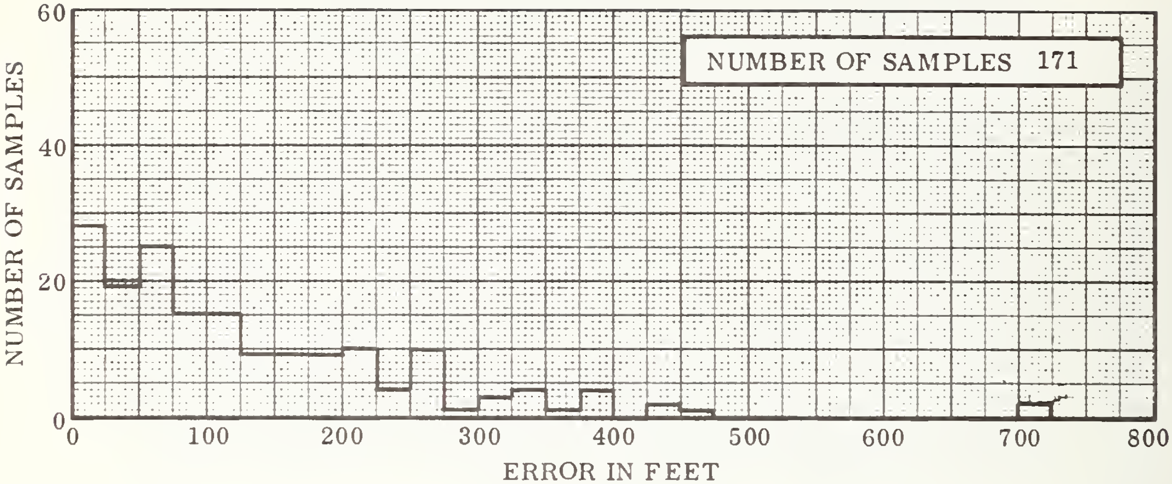


FIG. 5-9 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #4



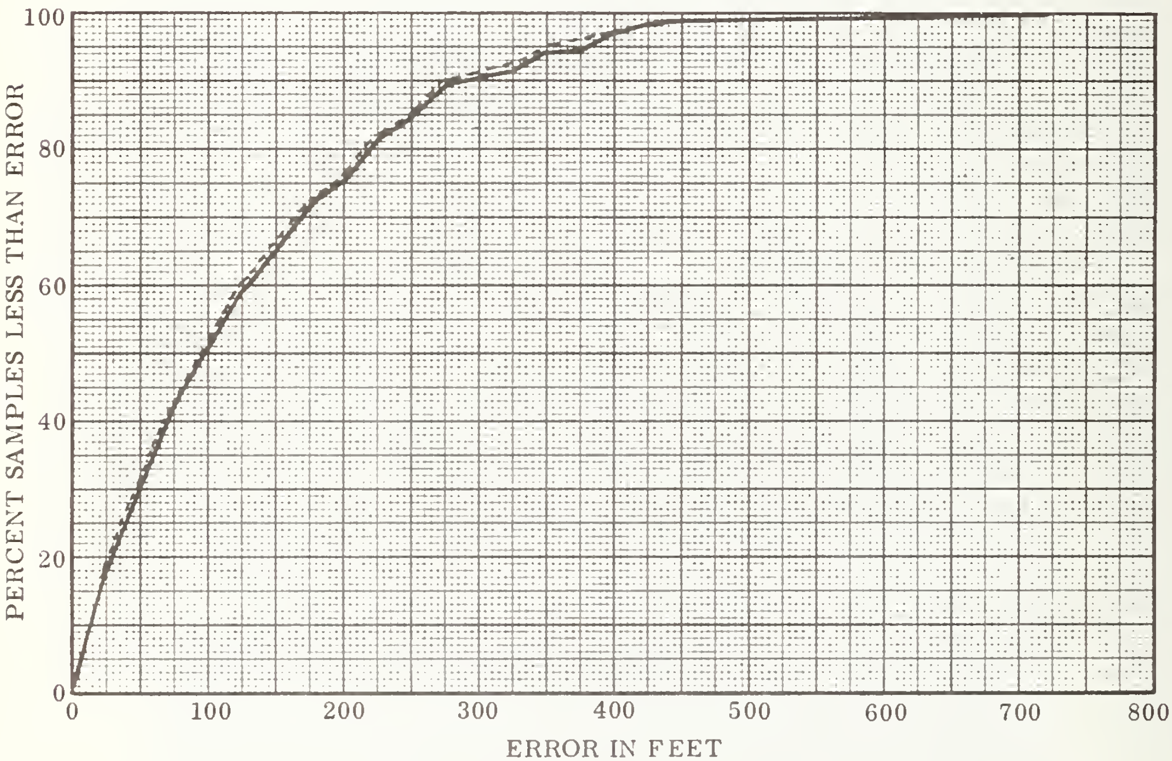


FIG. 5-10 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #5

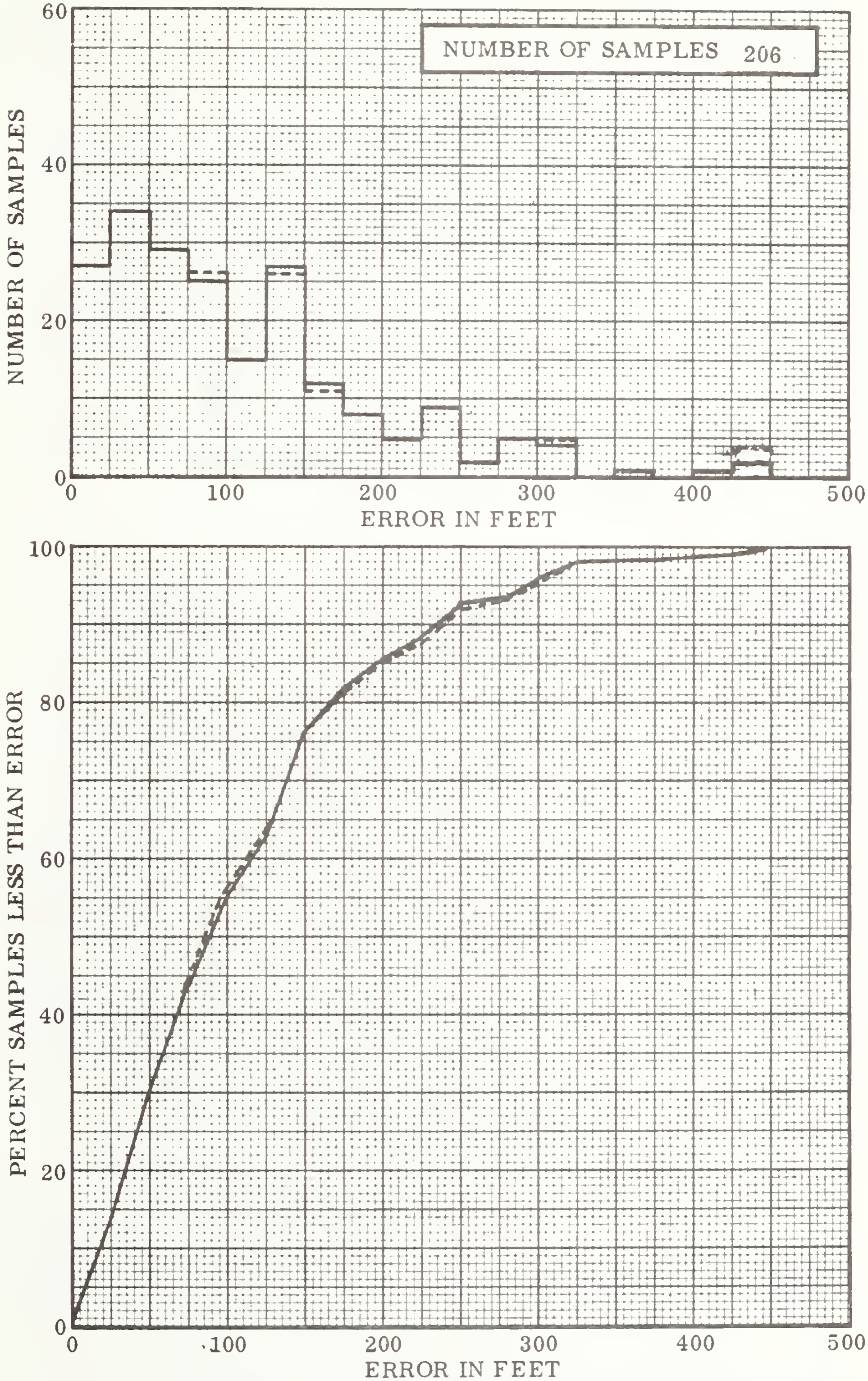


FIG. 5-11 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #6

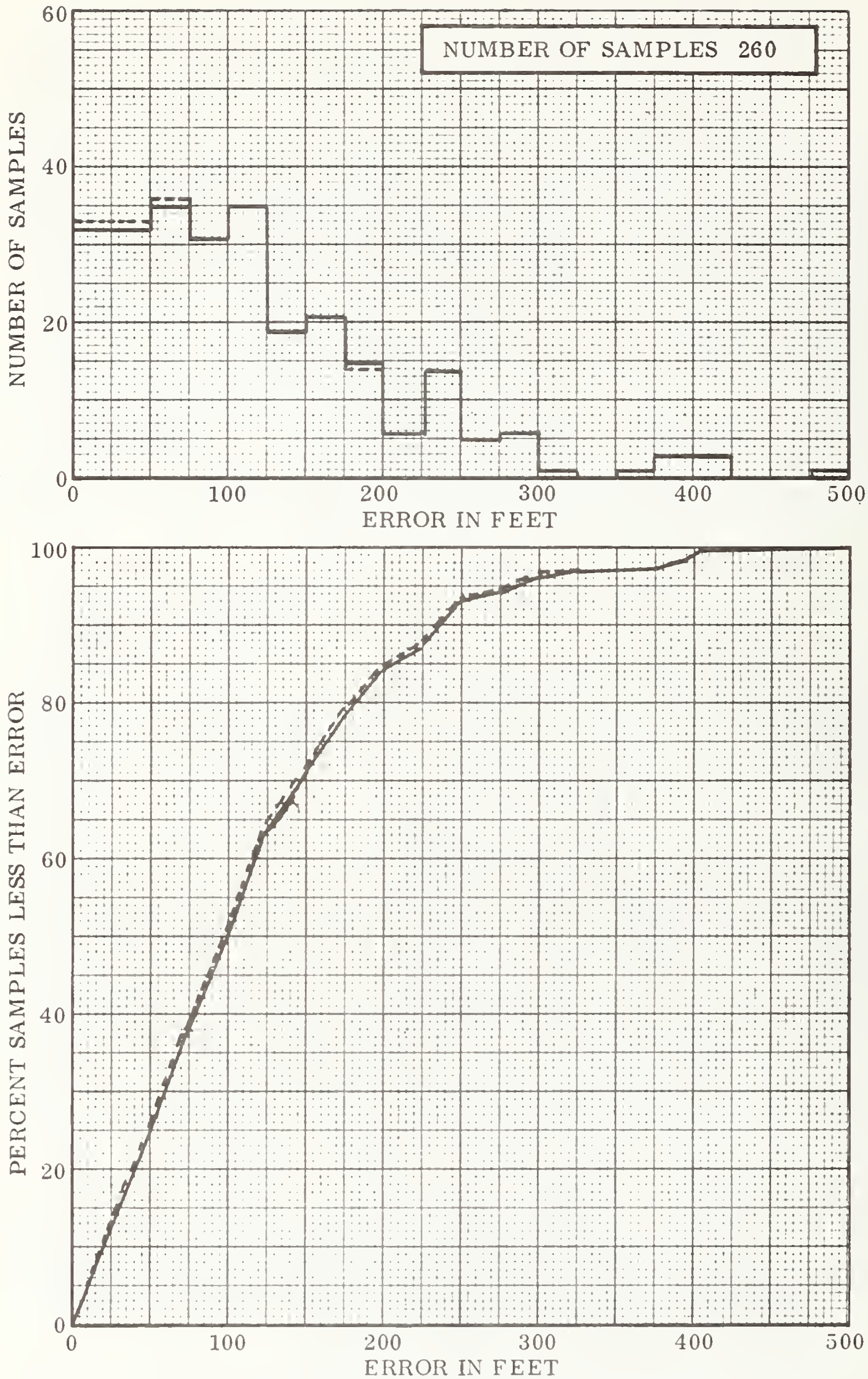


FIG. 5-12 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #7

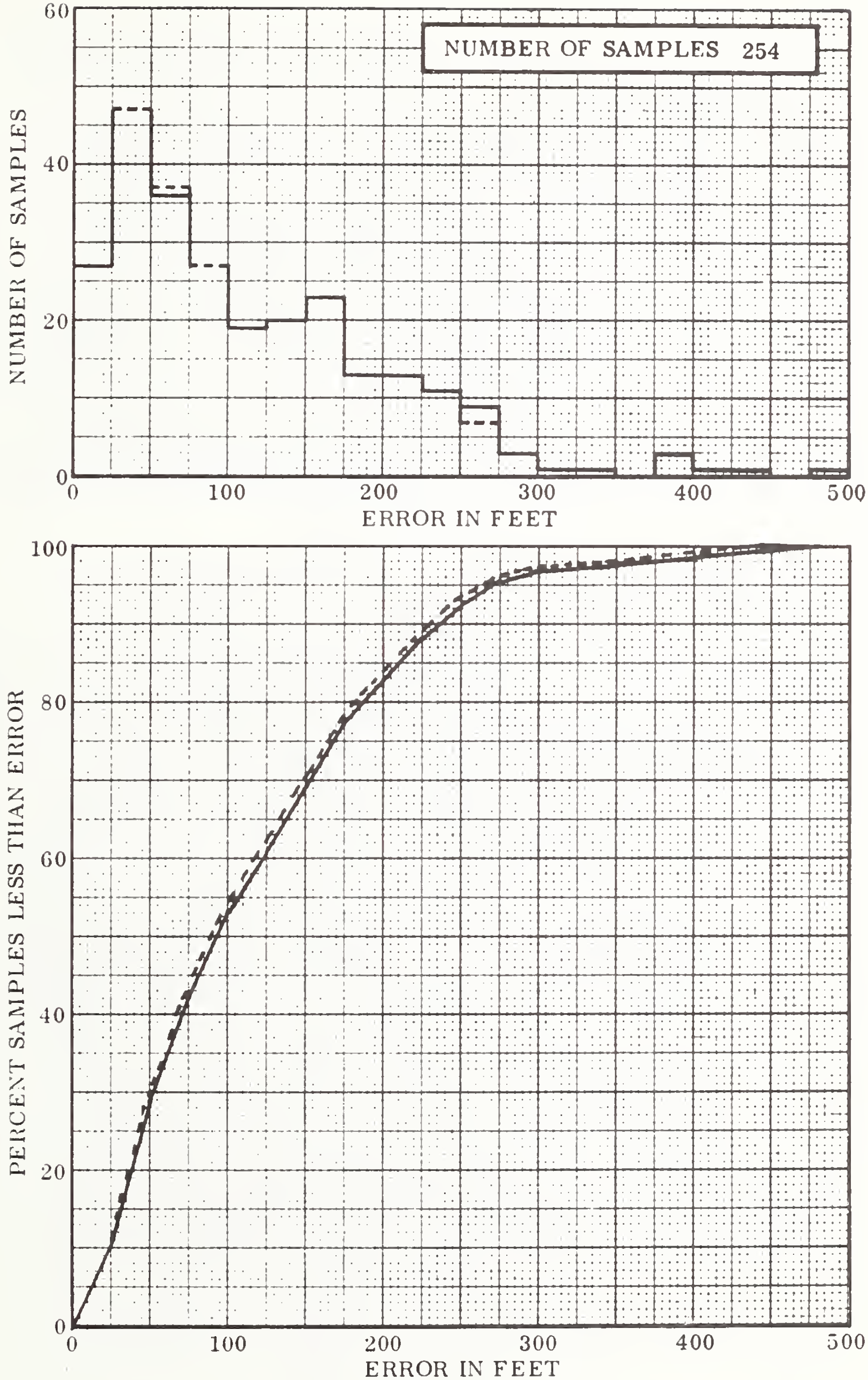


FIG. 5-13 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #8

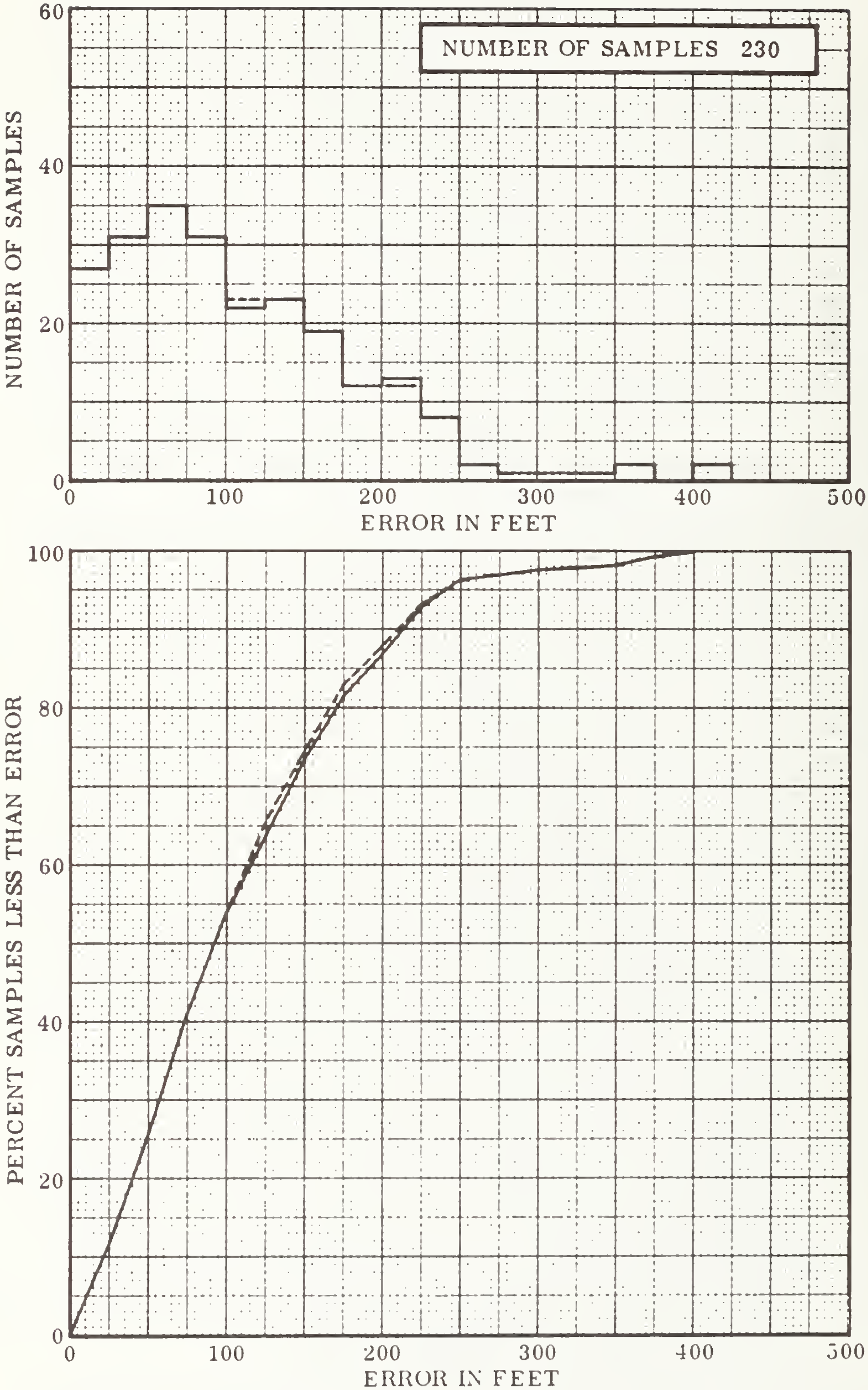


FIG. 5-14 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #9

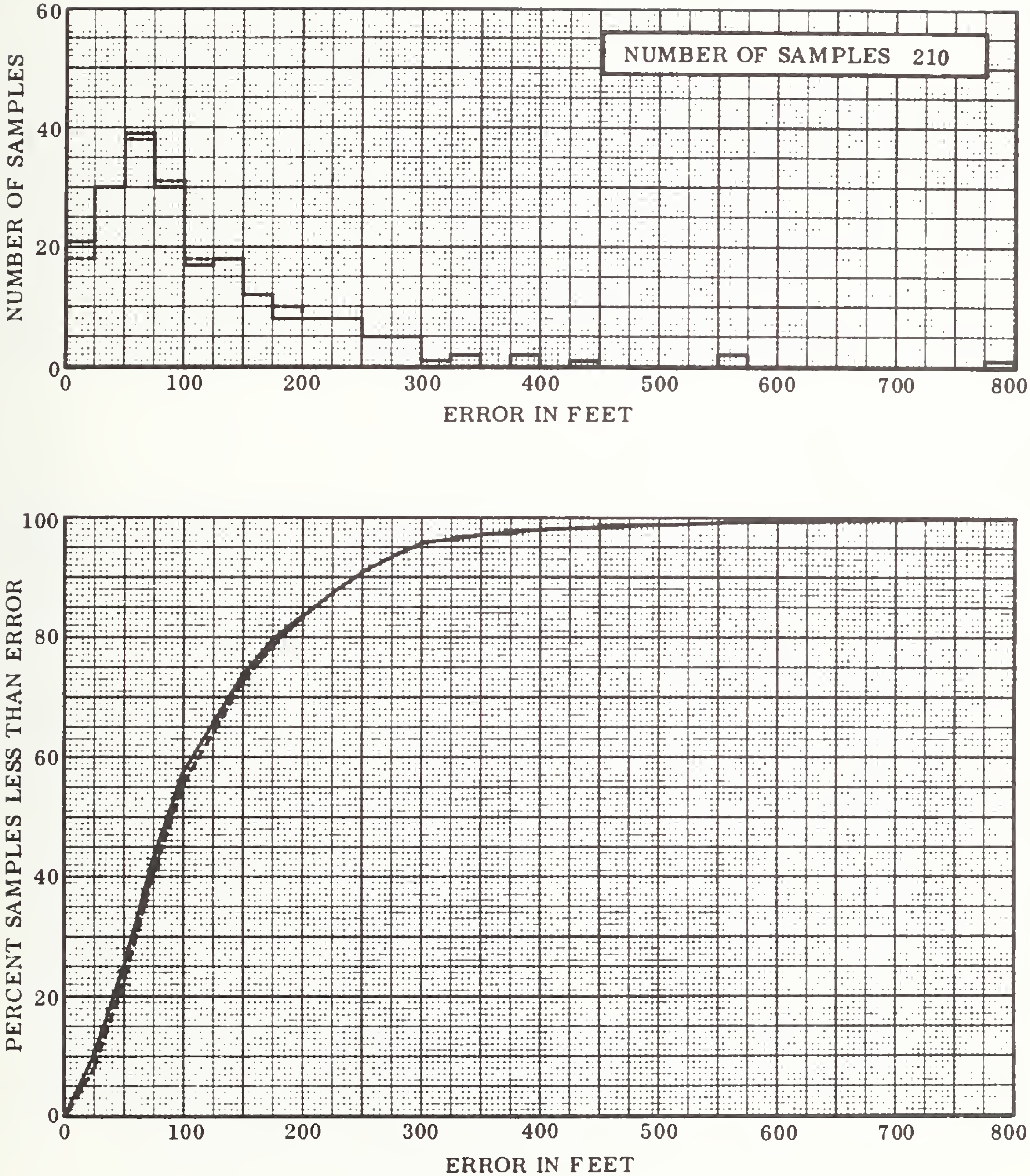


FIG. 5-15 RANDOM ROUTE AVM SYSTEM LEVEL ERROR RUN #10

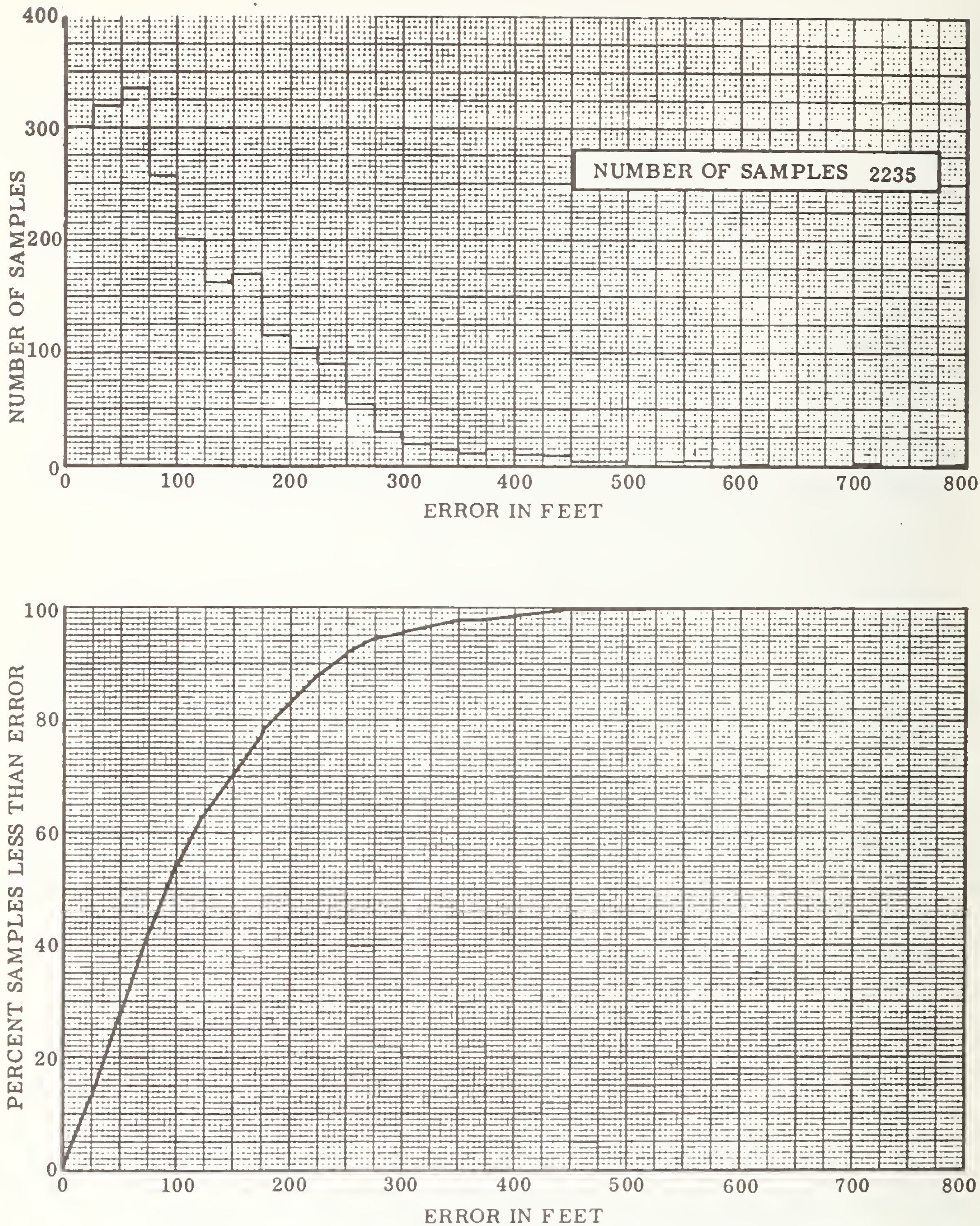


FIG. 5-16 RANDOM ROUTE AVM SYSTEM LEVEL ERROR, RUNS #1-10

TABLE 5-16 SUMMARY RANDOM ROUTE AVM SYSTEM ERROR STATISTICS, NO COMMUNICATION ERRORS

Run #	Average Error (feet)	% Samples < 300'	% Samples < 450'	Max Error (feet)
1	115	97.03	98.88	617
2	109	93.89	99.13	496
3	110	96.0	99.50	570
4	114	96.05	100.00	420
5	133	90.06	98.25	721
6	109	95.15	100.00	446
7	116	96.54	99.62	480
8	114	96.85	99.61	482
9	109	97.39	100.00	794
10	112	95.69	98.56	794
All Runs Com-bined	114	95.66	99.38	794
All Runs Exclud-ing Run #5	112	96.16	99.47	794

TABLE 5-17 IMPACT OF 5 PERCENT COMMUNICATION ERRORS ON AVM SYSTEM ACCURACY

Run #	No. PCP's	No Errors which Increased	No Errors which Decreased	% Less than 300' - No Com Error	% Less than 300' - 5% Com Errors
1	269	3	1	97.03	97.03
2	206	1	1	93.69	93.20
3	201	0	1	97.01	97.01
4	228	0	4	96.05	96.05
5	171	0	1	90.64	91.23
6	206	1	1	96.12	95.63
7	260	0	4	96.54	96.92
8	254	1	3	96.85	97 24
9	230	0	1	97.39	97.39
10	210	4	0	95.71	95.71
Combined 1-10	2235	10	17	95.79	95.88

TABLE 5-18 AVERAGE ERROR OVER ONE-TENTH MILE SEGMENTS OF RANDOM ROUTE RUNS 1-5

RUN 1 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

59	179	113	102	122	214	106	227	184	56
73	114	96	84	188	51	115	226	78	105
258	100	151	205	367	84	142	152	171	75
* 79	47	154	136	110	158	90	114	161	103

CT1:RUN001.001

122	93	188	173	93	116	117	105	75	75
197	119	57	57	102	128	121	94	113	125
193	118	131	73	137	137	147	105	119	68
51	111	111	155	129	74	204	67	124	114
131	75	122	115	85	121	148	135	174	78

RUN 2 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

168	99	127	76	179	90	75	83	98	68
91	89	51	55	227	43	76	158	106	175
146	114	89	209	358	105	99	142	139	104
86	71	127	144	94	140	76	85	143	146
*198	134	179	60	75	117	225	123	71	83

CT1:RUN002.001

149	89	122	144	194	70	153	161	142	255
208	389	145	119	81	110	73	231	172	71
102	93	132	90	195	142	76	239	67	102
120	79	99	149	115	69	61	96	223	114
74									

RUN 3 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

126	81	57	68	84	102	133	51	72	28
173	152	78	140	45	85	83	236	80	102
88	117	165	142	154	113	324	129	207	125
116	93	70	161	94	71	148	146	146	173
*176	95	129	117	121	181	121	103	151	131

CT1:RUN003.001

110	125	107	129	112	200	96	139	52	335
113	118	110	143	106	104	177	139	116	73
188	62	115	151	110	152	66	99	98	119
81	83	107	81	88	71	77	97	89	

TABLE 5-18 AVERAGE ERROR OVER ONE-TENTH MILE SEGMENTS OF RANDOM ROUTE RUNS 1-5 (CONT'D)

RUN 4 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

144	134	95	78	103	80	125	65	75	57
77	263	120	76	169	85	116	202	64	81
148	70	87	166	259	105	112	111	119	151
74	85	114	135	94	160	83	236	190	132
*162	148	129	122	94	100	145	94	87	87

CT1:RUN004.001

123	88	80	125	100	93	113	88	158	160
147	149	110	64	107	139	186	191	116	66
54	118	113	156	118	62	141	91	72	148
63	88	95	80	108	44	76	172	149	101

.

RUN 5 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

253	149	127	108	75	93	102	295	160	85
46	89	84	78	208	119	212	142	248	139
177	153	93	174	437	359	174	185	97	104
139	106	164	228	103	180	115	125	188	191
231	177	285	102	97	115	270	91	60	119
*110	117	167	147	83	149	194	214	134	75

CT1:RUN005.001

85	151	101	41	153	155	330	406	103	65
139	69	101	149	145	135	85	148	110	119
163	88	60	50	39	82	126	117	88	

.

COMPOSITE PRIMARY RUNS 1-5
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

150	128	104	87	113	116	108	144	118	59
92	141	85	112	167	107	120	193	115	120
163	110	117	179	315	153	170	144	147	112
99	80	126	161	99	142	102	141	166	149
178	129	182	115	96	126	176	103	89	99
138	107	86	120	118	128	135	139	139	190
149	185	119	88	117	129	182	214	125	69
107	114	114	140	139	113	114	129	94	120
112	82	97	95	87	77	98	123	145	97
74									

TABLE 5-18 AVERAGE ERROR OVER ONE-TENTH MILE SEGMENTS OF RANDOM ROUTE RUNS 6-10

RUN 6 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

138	68	71	189	140	145	96	182	83	168
106	128	110	92	139	96	62	247	115	103
62	59	77	95	97	194	162	94	117	107
75	98	152	51	63	90	122	89	101	93
*125	115	181	80	103	119	121	158	85	109

CT1:RUN006.001

117	63	99	128	77	49	89	59	77	78
228	141	266	72	81	117	131	167	100	80
94	69	75	94	89	86	104	127	141	109
132	90	97	105	83	158	91	96	125	78
67									

RUN 7 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

92	71	76	134	82	132	103	136	102	110
110	115	80	105	84	214	73	199	75	106
113	74	69	51	103	160	171	45	108	85
*118	85	154	60	73	109	134	130	133	171

CT1:RUN007.001

134	81	185	65	144	114	132	160	98	106
77	135	135	90	163	59	86	132	68	83
77	107	165	312	65	98	93	157	101	119
175	88	72	93	84	171	122	112	57	48
123	129	236	121	125	56	154	52	95	129
105	83								

RUN 8 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

117	83	98	72	97	117	159	119	92	136
63	139	59	93	164	88	58	226	49	82
76	50	104	93	85	162	176	78	91	81
* 71	68	174	57	49	89	161	117	123	61

CT1:RUN008.001

106	126	123	91	113	85	101	161	146	59
85	147	142	171	121	54	125	150	78	116
73	205	63	466	75	72	77	94	84	106
51	133	77	77	94	158	77	94	237	129
157	102	89	82	218	81	109	42	67	145
77	124								

TABLE 5-18 AVERAGE ERROR OVER ONE-TENTH MILE SEGMENTS OF RANDOM ROUTE RUNS 6-10 (CONT'D)

RUN 9 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

67	83	85	116	116	158	124	101	94	122
65	83	90	99	149	84	73	154	138	104
77	76	70	80	107	184	165	60	119	86
55	108	146	108	50	117	110	110	100	92
*138	104	175	112	129	91	133	90	122	69

CT1:RUN009.001

112	108	98	135	77	67	180	85	108	107
156	119	276	86	91	135	119	156	80	152
119	131	103	79	109	132	99	97	162	101
110	142	67	163	96	82	72	94	131	73
71									

RUN 10 RANDOM ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

55	76	49	118	117	122	96	128	100	120
100	96	89	122	106	45	98	124	122	74
69	94	151	75	85	184	177	87	91	106
166	68	89	143	77	66	99	109	82	87
*119	166	90	133	160	103	141	117	182	176

CT1:RUN010.001

95	100	148	84	120	180	57	83	149	98

?ERR 61 ILLEGAL MEMORY REFERENCE
IN ROUTINE ".MAIN." LINE 40

COMPOSITE SECONDARY RUNS 6-10
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

94	76	76	126	110	134	115	133	94	131
89	112	86	102	128	105	73	190	100	94
79	71	94	79	95	177	170	73	105	93
97	85	143	84	62	94	125	111	108	101
124	118	151	96	130	102	126	137	127	104
97	110	124	122	112	82	107	102	96	96
134	143	193	234	78	106	105	144	91	114
110	105	82	86	94	137	101	108	149	97
131	116	122	118	131	94	107	71	105	106
80	104								

largest segment average was 315 feet and 234 feet respectively for the Primary and Secondary Routes respectively.

Processing with RRTEN began at Checkpoint 1 and ended at TA 64 on each run. The turnaround route around City Hall between TA 58 and TA 58 was not processed since this area was not within the designated random route area.

As noted in subsection 5.1 and 5.2, Run 10 could not be processed past Checkpoint 41. Whereas both checkpoints and pseudo checkpoints corresponding to the remainder of Run 10 were processed manually, no attempt was made to process the 2310 individual records manually as a supplement to RRTEN. HI^3 believes that the approximately 87,000 samples processed by RRTEN and the subsequent results were sufficient to warrant this decision.

5.4 RANDOM ROUTE DATA PROCESSING ANOMALIES

During the recording of random route data, a few manual entry errors were made. These errors were flagged through entry of the EE event and, in four cases, subsequently corrected via card input to the CPMAIN, RRSL and RRTEN programs. These errors are identified in Table 5-20.

As noted in Table 5-20, Run 10 could not be processed past CP 41. A listing of the data recorded during Run 10 is shown in Figure 5-13. The data recorded during the five records following Time 53:04 are erroneous. Note that the signpost codes are non-existent, the odometer has jumped over 2100 counts, the fifth wheel column contains data, and time is erratic. Since time is recorded via the CPU and is independent of the location subsystem and ICU, this indicates that this is a data recording problem and not a system problem. A more detailed discussion of this problem is contained in Subsection 8.3 in association with fixed route data.

TABLE 5-20 RANDOM ROUTE DATA PROCESSING ANOMALIES

RUN NO.	PROBLEM	SOLUTION
1	TA 63 entered two times following CP56	Deleted second entry of TA63 after CP56 via card input to RRSL and RRTEN
1	CP30 entered in error early	EE30 followed by correct entry of CP30
3	TA34 entered in error following CP17, should have been TA44	EE34 followed by TA44
3	Missed entry of CP18	Missed checkpoint
4	TA58 entered in error at beginning of tape	EE58 followed by TA64
5	TA64 entered too early at beginning of tape	EE64 followed by correct entry of TA64
7	TA64 entered twice	No effect
8	TA64 entered twice	No effect
9	CP64 entered in error for TA64	Replace CP64 with TA64 via card input
10	CP44 entered in error for TA44 following CP5	Replace CP44 with TA44 via card input
10	CP61 entered in error for TA61 following CP55	Replace CP61 with TA61 via card input
10	Couldn't process past checkpoint 41	Computed 21 checkpoint and 57 pseudo checkpoint manually

6. FIXED ROUTE TESTS

6.1 FIXED ROUTE TEST CONFIGURATION

The fixed route system configuration tested in Philadelphia consisted of (1) the test LS as proposed in the HI^3 Proposal, and (2) a Data Acquisition System (DAS). The LS tested in the fixed route tests was functionally identical to that proposed for Phase II, and such factors as deployment technique, signal-to-noise ratios, and signpost design are exactly those proposed for Phase II.

6.1.1 Test Vehicle

The test vehicle used during fixed route tests is the same vehicle described in paragraph 3.1.1.

6.1.2 Location Subsystem Equipment

In the fixed route configuration, the LS consisted of (1) signposts and (2) vehicle equipment functionally identical to that proposed for Phase II.

6.1.2.1 Signposts. The signposts used during the fixed route tests were identical to those described in paragraph 3.1.2.1 and used during the random route tests.

During fixed route tests, signposts were mounted on available utility poles or street and traffic light standards in such a manner that the HI^3 vehicle equipment was able to receive the coded transmissions from each signpost. Fifteen signposts were used, one near each timepoint. Thus, signposts were separated, on the average, by 4,900 feet.

6.1.2.2 Vehicle Equipment. In the fixed route configuration, HI^3 test LS vehicle equipment consisted of three items: (1) a 49.860-MHz antenna and coax cable, (2) a HI^3 vehicle unit, and (3) an odometer. For the Philadelphia tests, a standard, monopole (Antenna Specialist Model M303) tuned to 49.860 MHz was mounted on the roof of the test vehicle. The vehicle unit and antenna were the same as those used during random route tests and described in detail in paragraph 3.1.2.2.

During operation as a fixed route vehicle, the operation of the Phase II vehicle unit is identical to that of a Phase II random route vehicle unit in that all received signpost codes are received and processed to determine an 18-bit location region code. The only difference is that when a valid signpost Region 1 code is received onboard a Phase II vehicle operating in the fixed route mode, the vehicle unit would check to determine if this were the first occurrence of a Region 1 code from that signpost, and, if so, it would (1) automatically generate a signal that resets, to zero, an odometer counter, (2) store the 18-BIT location region code, and (3) check the two special signpost bits, E_7 and N_7, to determine the type of signpost used in the proposed Phase II system.

	North Field								East Field							
	N_7	N_6	N_5	N_4	N_3	N_2	N_1	N_0	E_7	E_6	E_5	E_4	E_3	E_2	E_1	E_0
Random Route	0	X	X	X	X	X	X	X	0	X	X	X	X	X	X	X
Timepoint	1	X	X	X	X	X	X	X	1	X	X	X	X	X	X	X

In this way, the vehicle unit always knows if timepoint performance is to be reported. The action then in each case is shown in the following table:

BIT PATTERN (N_7, E_7)	TYPE SIGNPOST	PHASE II VEHICLE LOGIC
0, 0	Random Route or Fixed Route	When Region 1 is first received: Store 18-BIT location region code Reset odometer When next polled, transmit 18-BIT location region code and odometer reading
1, 1	Timepoint	When Region 1 is first received: Store 18-BIT location region code When next polled transmit 18-BIT location region code and odometer reading Compute timepoint information and store When next polled, transmit 18-BIT location region code, odometer reading and timepoint information

The Phase II fixed route vehicle unit logic is shown in Figure 6-1. All signposts in the Phase I tests were coded with a (0, 0) in the (N_7, E_7) bits; therefore, the DAS was used to simulate the (1, 1) in the (N_7, E_7) bits for all fixed route runs. This simulation was effected by having the Data Processing Routine check all received signpost codes against a table of valid fixed-route signposts.

When fixed route test data were being recorded, the modifier block shown in Figure 3-11 was enabled so that R1 dropout (R1D) was recorded upon receipt of a not Level 1 signal after receipt of a Level 1 signal. In the ideal case, a vehicle passing in close proximity to a signpost would encounter a Level 1

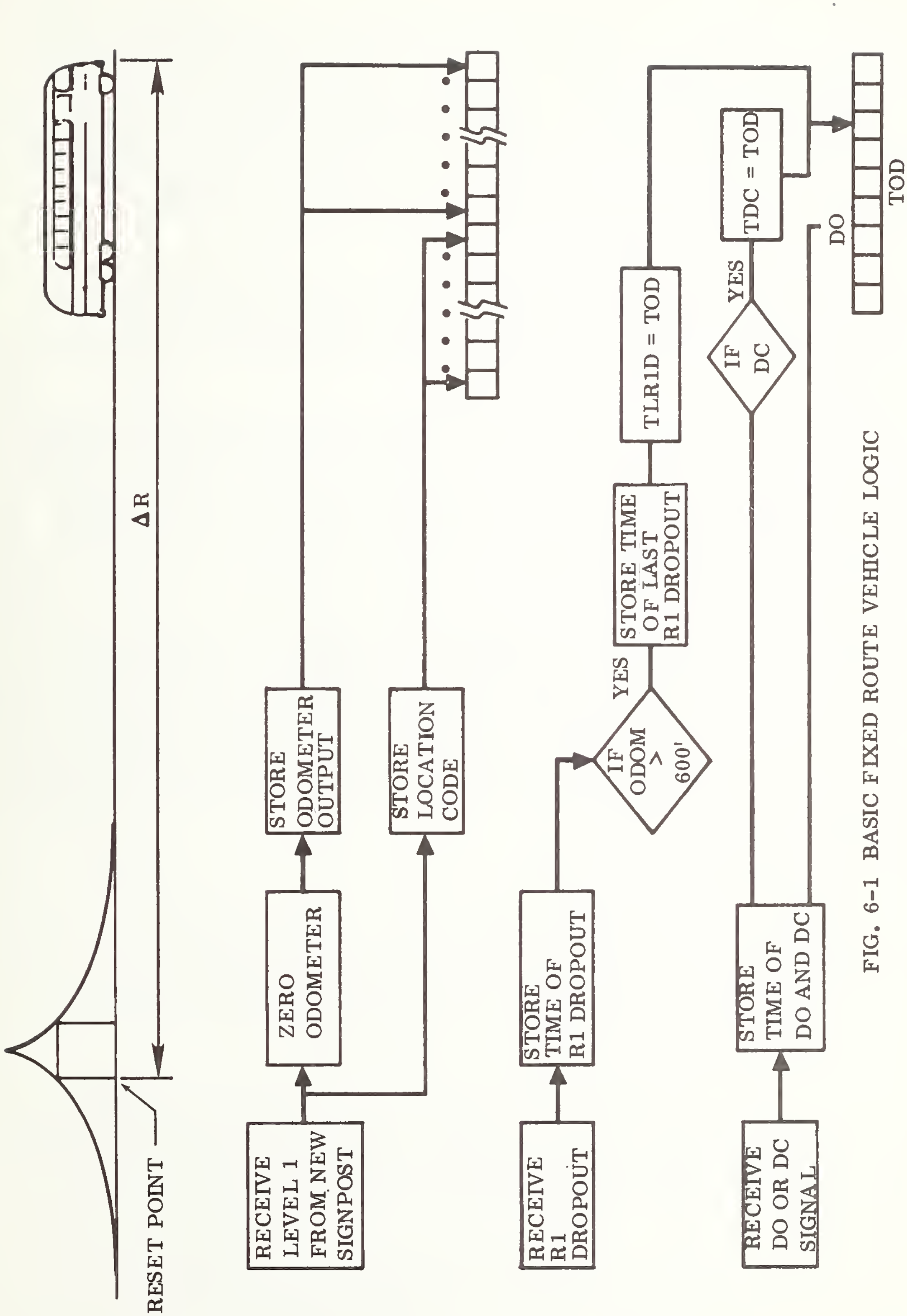


FIG. 6-1 BASIC FIXED ROUTE VEHICLE LOGIC

signal at the R1 radius as it approached the signpost and a not Level 1 signal just past the R1 radius on the far side of the signpost. In actual practice, the effects of local structures create nulls and dips in the signpost field pattern. In a few instances, these cause more than one R1D. However, the location of the R1 and the last R1D are extremely stable as can easily be shown from observation of the test data. Refer to Table 6-1 for R1 stability. The stability of the R1D location is evidenced in the results obtained for the timepoint performance subsequently presented in Section 8.

The LS vehicle unit drew its power directly from the test vehicle 12-volt system just as it would in the Phase II system. The vehicle unit was fuzed to prevent damage, and it included a built-in voltage fluctuation in the vehicle power system.

The contents of the ICU were sampled by the DAS. Those data constituted the "computed" vehicle location at the sample time (checkpoint or pseudo checkpoint). Under operational conditions, (Phase II), the contents of the vehicle unit location register and odometer would be encoded as part of the vehicle-to-base message and transmitted via the communications subsystem to the base station under base station computer control.

6.1.2.3 Odometer. In fixed route tests, an odometer was used to determine vehicle location between signposts. This instrument consisted of eight permanent magnets attached to the left front wheel and a magnetic pickup coil. The odometer senses revolutions of the front wheel through a magnetic pickup as the magnets pass across the pickup coil. The odometer was powered from the vehicle 12-volt DC power system. Pulses from the calibrated odometer were accumulated in the ICU and recorded on cassette through the interface shown in Figure 3-11.

6.1.3 DAS Equipment

The DAS hardware used during fixed route tests was identical to that used in random route tests. Only the functions of event marking, software, and in-vehicle displays were different. Only during the fixed route tests, a switch on the ICU enabled the modifier block (Figure 3-11) so that it could generate the 0011 code in the "B" field whenever an R1 dropout occurred.

6.1.3.1 Fixed Route Event Marking. The event codes described in paragraph 3.1.3.4 and the method of marking events were the same used for fixed route testing. During fixed route testing, the following events were "marked" to cause a time-coincident record of vehicle and DAS data to be recorded on cassette.

TABLE 6-1 EXPERIMENTAL DETERMINATION OF R(i)

SP	TP	Distance From R1 to Next Timepoint : 12-28-76 # 6	12-28-76 # 7	12-17-76 # 5	12-12-76 # 4	12-29-76 # 10	12-29-76 # 11	Average $\widehat{R}(i)$	STD Deviation σ
7, 13	1	198	250	234	264	244	246	239	20.5
14, 6	2	326	324	316	342	364	354	338	17.2
15, 13	3	258	286	288	308	270	276	281	15.7
		1-11-77 # 1	1-11-77 #1	1-11-77 #2	1-11-77 #3				
12, 6	4	272	266	258	260			264	14.0
6, 8	5	268	288	282	282	310	290	287	10.6
6, 6	6	212	214	228	258	220	202	222	17.8
16, 13	7	220	256	-	-	228	230	234	13.5
12, 10	8	214	220	-	224	166	200	205	20.9
14, 8	9	262	256	276	314	244	320	279	28.6
15, 11	10	394	404	390	-	378	398	393	8.7
19, 13	11	326	324	304	326	318	322	320	10.6
16, 11	12	274	288	322	302	324	292	300	18.0
13, 13	13	276	292	274	348	264	300	292	27.6
8, 7	14	256	214	208	252	260	246	239	20.6
10, 6	15	208	268	210	206	-	260	230	27.6

Average STD Deviation : 18.1 feet

Function	Function Key	Event ID	Return
Mark Passage of Checkpoint XX	CP	XX	"
Mark Passage of Signpost NN, EE	SP	NN, EE	"
Mark Turn Intersection YY	TA	YY	"
Mark Departure from Timepoint XX	TD	XX	"
Signify Door Open at Timepoint XX	DO	XX	"
Signify Door Close at Timepoint XX	DC	XX	"
Signify Error in Preceding Event ZZ	EE	ZZ	"

The door open/close events and the departure times were recorded under the direction of the TSC Monitor.

6.1.3.2 Fixed Route Recording Software. The only basic difference between fixed and random route DAS recording software was that associated with generation of the in-vehicle displays and the number of records recorded on cassette No. 1. Computer program FROUTE was used to record Fixed Route Data.

6.1.3.3 In-Vehicle Displays. Three display formats were implemented for use in the test vehicle. These displays included (1) a "Quick-Look Verification Display", (2) a "Fixed Route Location Accuracy Summary Display," and (3) a "Timepoint Performance Display." Only the "Quick-Look Verification Display" was used during formal test runs.

a. Fixed Route Quick-Look Verification Display. Typical display format corresponding to Fixed Route Run #40 is shown in Figure 6-2. All event codes were manually entered via the CRT keyboard. Note the occurrence of R1 dropouts (R1D). The method in which the R1D is used in computing timepoint performance has been discussed in paragraph 6.1.2.2. The quick-look display allowed the DAS operator to verify operation of the LS and the DAS. The odometer reading was not actually reset in the vehicle during the Phase I tests, but during off-line processing. If used during Phase II, the odometer would be reset automatically.

b. Fixed Route Location Accuracy Summary Display. The Location Accuracy Summary Display was intended to provide a real-time estimate of location during test calibration. The display actually showed both computed and actual locations and the location error at each checkpoint. However, as a result of the fact that the PDP cassette operating system did not allow the use of floating point arithmetic, implementation of this process was too coarse in terms of computed error values to be of value. Therefore, it was not used.

c. Timepoint Performance Display. This display provided, in real time, the timepoint performance error including full implementation of the timepoint performance algorithm described in paragraph 7.2.3. This display was extensively used during HI^3 test and calibration runs to verify timepoint performance.

EVENT	NORTH	EAST	REGION	ODOMETER	5TH WHEEL	TIME
TA 001	00	00	R1	O 00004	F 00004	T 00 06
TA 002	00	00	R1	O 00073	F 00073	T 00 16
000	17	13	R1	O 00130	F 00128	T 00 23
000	17	13	R1 D	O 00135	F 00133	T 00 23
CP 001	17	13	R1	O 00139	F 00137	T 00 24
TD 001	17	13	R1	O 00215	F 00213	T 00 31
000	17	13	R1 D	O 00252	F 00249	T 00 35
000	17	13	R1	O 00256	F 00254	T 00 35
000	17	13	R1 D	O 00266	F 00263	T 00 36
000	17	13	R1	O 00271	F 00268	T 00 37
000	17	13	R1 D	O 00275	F 00272	T 00 37
000	17	13	R1	O 00280	F 00277	T 00 38
000	17	13	R1 D	O 00322	F 00319	T 00 42
000	17	13	R1	O 00327	F 00324	T 00 42
TA 003	17	13	R1	O 00472	F 00470	T 01 17
CP 002	17	13	R1	O 00763	F 00760	T 02 07
CP 003	17	13	R1	O 01140	F 01136	T 02 39
000	14	06	R1	O 01753	F 01746	T 04 22
000	14	06	R1 D	O 01765	F 01757	T 04 23
CP 004	14	06	R1	O 01771	F 01763	T 04 24
DO 002	14	06	R1	O 01870	F 01862	T 04 35
DC 002	14	06	R1	O 01870	F 01862	T 04 46
TD 002	14	06	R1	O 01901	F 01893	T 04 52
000	14	06	R1 D	O 01913	F 01905	T 04 54
TA 004	14	06	R1	O 01915	F 01908	T 04 [illegible]

FIG. 6-2 TYPICAL QUICK LOOK VERIFICATION DISPLAY

However, this display was called only one time during formal fixed route testing, and that time was as a demonstration for the TSC Monitor during Run 11, the first fixed route test run. Figure 6-3 contains a sketch of this display.

6.2 FIXED ROUTE LOCATION SUBSYSTEM DEPLOYMENT

6.2.1 Signpost Deployment

Fifteen signposts were installed along the test route near the timepoints designated by TSC. The test route and the fifteen timepoint locations were selected by TSC. The area was surveyed by HI^3 personnel, poles selected, and a pole agreement for the selected poles obtained from the City of Philadelphia. These 15 signposts, in conjunction with the odometer, allowed a determination of location to be made at any point along the selected test route. Upon completion of the random route tests, the 15 signposts were installed along the fixed route. All 15 were installed within less than two hours including driving time by HI^3 personnel.

Figure 6-4 reflects the test route, the signpost locations, and the signpost codes. Figure 6-5 contains photographs of all 15 fixed route signposts.

6.2.2 Fixed Route Mapping

Even though fixed route location can be determined as a computed location in terms of the elapsed odometer distance along a fixed route, HI^3 provided computed X, Y locations of the vehicle during data processing. This action necessitated the determination of X, Y coordinates for Region 1 reset points and measurement of offset coordinates for those checkpoints which were not at the centered intersections.

Determination of Region 1 Reset Points. For each fixed route signpost, a reset point (Ri) was determined experimentally. The reset point of a fixed route signpost is the average location, including effects of different traffic lanes, time of day, etc., at which the Region 1 boundary occurs when the signpost is approached along the fixed route. This value would be used in the base station computer in Phase II (in the data processing algorithm in Phase I) as a reference for the odometer, which would be reset to zero at each Region 1 reset point. The reset point and its relationship to the signpost and the odometer have been shown in Figure 6-1.

The reset location for each signpost was determined by repeatedly driving the test vehicle past the signpost, each time recording the distance between (1) the occurrence of the Region 1 and (2) the point of passage of the timepoint (the latter a known X, Y location). The Fixed Route Quick Look Verification Display was used to accumulate a number of such recordings with the test vehicle traveling in all possible lanes and at different speeds. From each set of values, a value of Ri was selected for the i^{th} fixed route signpost for use during off-line processing as part of the permanent data base.

Timepoint	Estimated TOD	Actual TOD	Error	Door
1	0:58.5	0:57.0	1.5	
2	5:33.0	5:31.0	2.0	
3	13:23.5	13:27.5	-4.0	Yes
4	20:00.5	20:12.5	-12.0	Yes
5	31:15.0	31:42.5	-27.5	Yes
6	35:37.5	35:45.5	-8.0	Yes
7	41:29.0	41:28.5	0.5	
8	48:51.0	48:56.5	-5.5	Yes
9	56:43.5	56:45.5	-2.0	
10	66:32.0	66:34.5	-2.5	Yes
11	71:23.5	71:26.0	-2.5	Yes
12	75:37.0	75:37.5	-0.5	
13	85:20.5	85:29.0	-4.0	Yes
14	90:38.0	90:40.0	-2.0	
15	99:38.5	99:38.5	0.0	

FIG. 6-3 TIMEPOINT PERFORMANCE DISPLAY

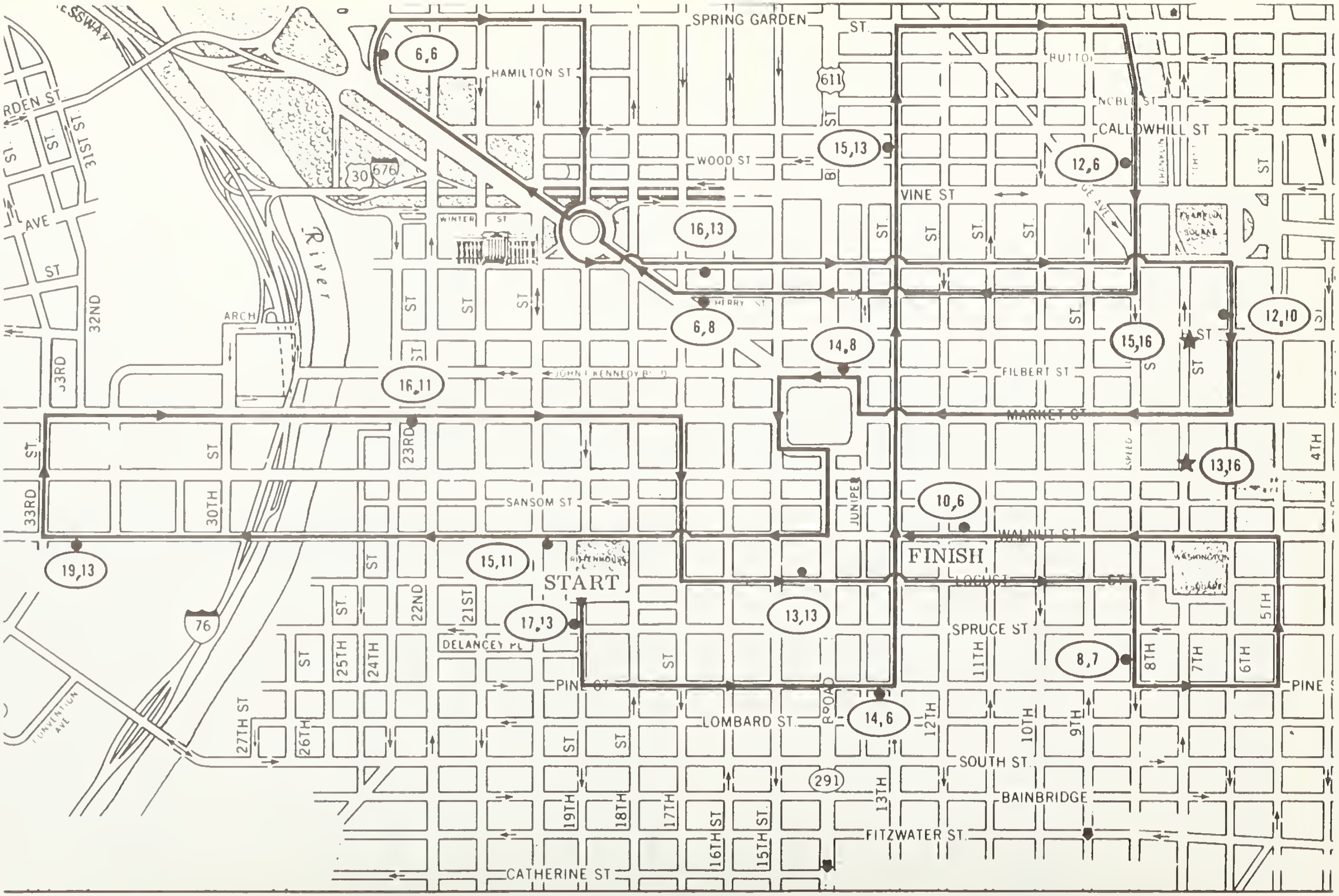


FIG. 6-4 HI^3 FIXED ROUTE & FIXED ROUTE SIGNPOSTS

FIG. 6-5 FIXED ROUTE SIGNPOSTS

Table 6-1 contains the results of these calibration runs. In each case, at least four passes by each signpost were made, and the FROUTE Program was used to record the odometer values at which the Region 1 was received and upon the occurrence of the event marking the passage of the timepoint. The X, Y location of the Ri point was computed as an offset from the timepoint location, which was known in terms of stateplane coordinates. The radius at signpost "i" was the average, Ri, presented in Table 6-1 and computed on the basis of the four or more passes. The small variance in Ri at each signpost, as well as the small average variance (18.1 feet for all 15 signposts), is significant in that it represents the stability of the Region 1 radius of HI^3 signposts. Once the offset distance was established, the stateplane coordinates of the Ri points were computed by using the following pair of equations:

$$X'(Ri) = X'(TPi) + X \cos 7.3^{o} + Y \sin 7.3^{o}$$

$$Y'(Ri) = Y'(TPi) + Y \cos 7.3^{o} + X \sin 7.3^{o}$$

where X and Y are the street offset coordinates of the Ri point relative to the timepoint; X' (TPi), Y' (TPi) are the stateplane coordinates of the i^{th} timepoint and 7.3^{o} is the angle between the stateplane coordinate system and the nominally North-South and East-West oriented streets in downtown Philadelphia. The location of each fixed route timepoint and the associated Ri are identified in Table 6-2.

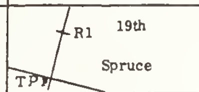
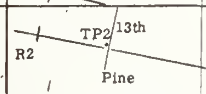
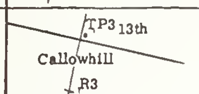
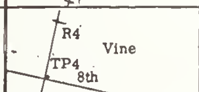
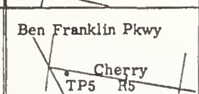
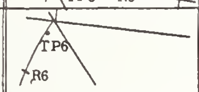
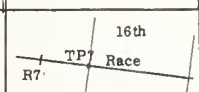
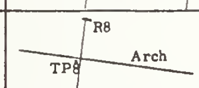
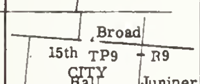
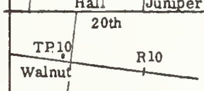
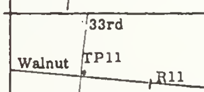
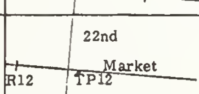
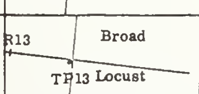
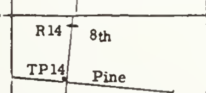
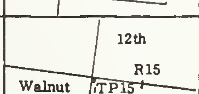
Determination of ΔT_L. This parameter is used during off-line processing (and in the Phase II base station) to compute the time of departure whenever the vehicle door is not opened and closed at a transit timepoint. ΔT_L is defined in association with Figure 6-6. During off-line data processing, the time of departure, TOD, is computed as follows:

Door Opens/Closes	TOD Set Equal to --
Yes	Time Door Closes (TDC)
No	TLR1D - ΔT_L

where TLR1D is the time of occurrence of the last R1 dropout from the signposts (the last time the "B" field is set to 0011 at the signpost code).

Values of ΔT_L were determined experimentally by repeatedly measuring the times of TD and TLR1D under typical traffic conditions. Table 6-3 contains experimental data taken to determine the values of ΔT_L for use in computing the time of departure. These data were obtained by driving the test vehicle past each timepoint while using FROUTE to record all data, including marking the passage of the timepoint NN with a TD(NN) event. For each timepoint, the average difference between occurrence of the last R1 dropout (TLR1D) and the TD marker

TABLE 6-2 FIXED ROUTE TIME POINTS AND R(i) RESET POINTS

TIMEPOINT	GEOMETRY OF R1 RELATION TO TIMEPOINT	R1 DISTANCE TO TIMEPOINT	STATE PLANE COORDINATES OF TIMEPOINT	OFFSET IN FT. TO TP	CORRECTED STATE PLANE COORDINATES OF R
#1		Y = 239	X = 2722388 Y = 234383	Δ X' = 30 Δ Y' = 237	X' = 2722418 Y' = 234620
#2		X = -338	X = 2725180 Y = 233508	Δ X' = -335 Δ Y' = 43	X' = 2724845 Y' = 233551
#3		Y = -281	X = 2725921 Y = 238663	Δ X' = -36 Δ Y' = -279	X' = 2725885 Y' = 238384
#4		Y = 264	X = 2728078 Y = 237808.3	Δ X' = 33 Δ Y' = 262	X' = 2728111 Y' = 238070
#5		X = 287	X = 2723857 Y = 237304.9	Δ X' = 285 Δ Y' = -36	X' = 2724142 Y' = 237289
#6		R = 222'	X = 2721134 Y = 240231	Δ X = -71' Δ Y = -131'	X' = 2721063 Y' = 240100
#7		X = -234	X = 2724216 Y = 237591.6	Δ X' = -232 Δ Y' = 30	X' = 2723984 Y' = 237622
#8		Y = 205	X = 2728698 Y = 236314.2	Δ X' = 26 Δ Y' = 203	X' = 2728724 Y' = 236517
#9		R = 279'	X = 2725101 Y = 236454.3	Δ X' = 168 Δ Y' = -183	X' = 2725269 Y' = 236271
#10		X = +393'	X = 2721955 Y = 235324.0	ΔX' = 390' ΔY' = -50	X' = 2722345 Y' = 235274
#11		X = +320'	X = 2717519 Y = 235944	ΔX' = 317 ΔY' = -41	X' = 2717836 Y' = 235903
#12		X = -300	X = 2721257 Y = 236561.2	ΔX' = -297 ΔY' = 38	X' = 2720960 Y' = 236599
#13		X = -292	X = 2724675 Y = 234527	ΔX' = -290 ΔY' = 37	X' = 2724385 Y' = 234564
#14		X = +239'	X = 2727418 Y = 233227	Δ X' = 30 Δ Y' = 237	X' = 2727448 Y' = 233464
#15		X = +230	X = 2725844 Y = 234799	Δ X' = 228 Δ Y' = -29	X' = 2726072 Y' = 234770

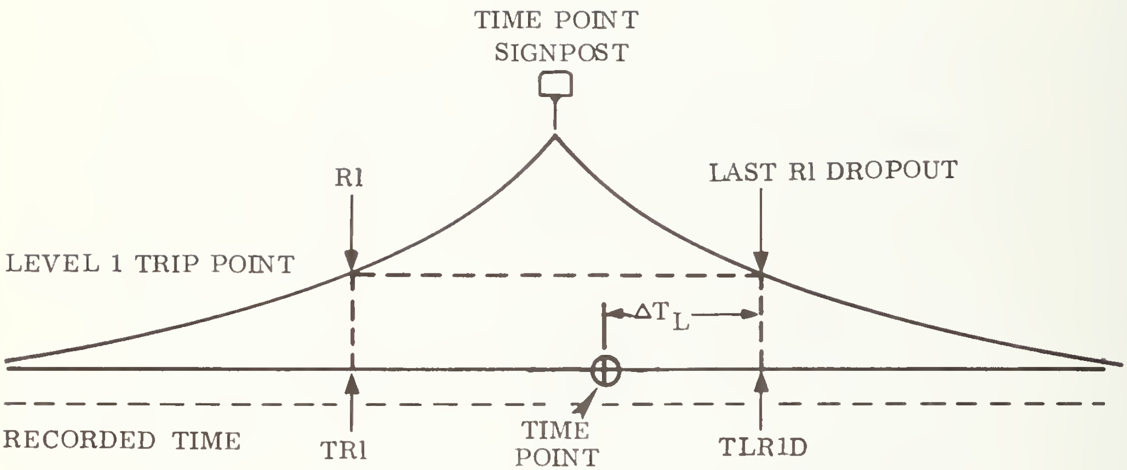


FIG. 6-6 HI^3 TIMEPOINT PARAMETERS

TABLE 6-3 EXPERIMENTAL DETERMINATION OF ΔT_L

TIME POINT NUMBER	Run No. and Date					AVERAGE TIME	SELECTED VALUE OF ΔT_L
	RUN # 5 12-12-76	RUN # 6 12-28-76	RUN # 7 12=28-76	RUN # 10 12-29-76	RUN # 11 12-29-76		
	Time in Seconds						
1	9	-	4	9	6	7	7
2	5	8	7	8	7	7	7
3	6	8	6	8	9	7.4	7
4		8		3	5	5.3	5
	Run # 1 1-11-77		Run # 5 1-11-77		Run # 6 1-11-77		
5	5	5	6	6	8	6	6
6	1	0	6	-1	2	1.6	2
7	-	-1	-	-3	-3	-2.3	-2
8	-	1	1	3	3	2	2
9	11	10	10	7	8	9.2	9
10	3	7	-	5	4	4.8	5
11	4	3	-	4	8	4.8	5
12	0	1	1	0	1	0.6	1
13	3	1	1	0	1	1.2	1
14	8	1	5	8	4	5.2	5
15	5	3	4	-	6	4.5	5

was taken as the value of ΔT_L to be used in the data processing program. These values became the timepoint data base, TPDELT.

6.2.3 Timepoint Location and Marking

Timepoint locations were selected by TSC. Specific landmarks, i.e., signs, street lights, etc. which served as timepoints were selected by HI^3 and approved by TSC. The landmarks selected as timepoints are identified in Table 6-4.

6.2.4 Location Subsystem Calibration

Calibration of the LS for the fixed route test involved (1) the establishing of the vehicle unit Level 1 threshold, (2) the calibrating of the fifth wheel against a measured distance, (3) the calibration of the odometer against a measured distance, and (4) the use of the vehicle unit and DAS to determine the values of the Region 1 boundaries and ΔT_L for each timepoint for use in the data base. On the day of each formal test run, only the calibration of the vehicle unit Level 1 threshold and the fifth wheel and odometer had to be verified. Calibration of the items was accomplished in the same manner as that primarily described in paragraph 3.2.2 for random route tests. The fifth wheel was calibrated in exactly the same manner as the odometer. Except in those instances in which snow and ice caused an accumulation of the fifth wheel, the odometer and fifth wheel were calibrated to within 1 foot in 1000 feet on the calibration run.

6.3 FIXED ROUTE DATA ACQUISITION

Fixed route test data were recorded on cassettes during Runs 11 through 43. The sequence of events depicted in Figure 3-17 was utilized during data acquisition and handling. Header data were recorded on each cassette pair under the control of program FROUTE just prior to commencing a test run. A data log sheet was filled out for each run and signed by the HI^3 Test Director and the TSC Monitor. Figure 6-7 contains a typical fixed route data log. Copies of all log sheets are contained in the Appendix. At the conclusion of the 33 fixed route test runs, all cassettes were duplicated onto magnetic tapes for use at MITRE. Since HI^3 data processing software was not checked out and running at MITRE, all cassettes were retained by the TSC Monitor until February, 1977, when software checkout was completed at MITRE.

Checkpoint, Door Open, Door Close, Timepoint, and Turn Event were manually entered at designated locations during each run. Locations of fixed route checkpoints, turns, and timepoints are shown in Figure 6-8. The following entries were required for a typical run.

1. Timepoint (TD's) -------------- 15

2. Door Open -------------------- 7-8

TABLE 6-4 HI^3 TIMEPOINTS

TP Number	Identification/Landmarks
1	Traffic light on S. W. corner 19th & Spruce
2	Traffic Light on N. W. corner of 13th & Pine
3	Traffic Light on N. E. corner of 13th & Callowhill
4	Street Light on N. E. corner of 8th & Vine
5	Last ornamental Street Light Pole on Cherry at S. E. Corner of Cherry and Ben Franklin Parkway
6	Street light on Crescent at S. E. corner of Crescent and Spring Garden
7	Center of 16th & Race
8	Street light on S. W. corner of 6th & Arch
9	No Parking Sign on north side of JFK Blvd. at N. E. corner of Broad & JFK
10	SEPTA STOP (sign) at N. W, corner of 20th & Walnut
11	Street Light at N. E. corner of 33rd and Walnut
12	SEPTA STOP (sign) at S. E. Corner of 22nd and Market
13	Street Light at S. W. corner of Broad and Locust
14	SEPTA STOP (sign) at N. W. corner of 8th & Pine
15	Street Light at S. E. corner of 12th & Walnut

START 1015
END 1135

TEST DATA LOG

TEST RUN NO. 39 SHEET NO. 1 OF 1

TYPE OF TEST: HI^3 FIXED ROUTE DATE: 1-17-77

BRIEF NARRATIVE DESCRIPTION OF TEST

ROUTE IDENTIFICATION:

EVENT MARKER NUMBER:

DOOR CLOSED AT
TP 2
TP 3
TP 4
TP 5
TP 6
TP 8
TP 11
TP 19

1. Overnight temperatures (signposts) were 0°F with wind chillfactor -42°F.

2. Entered CP#27 at 20th St. in error (should have been just prior to 19th). Entered EE27 and then entered CP#27 at correct location

4. Received overlays from 13,16 and 15,16 at 7th and Market as off-route declaration.
13,16 at 7th and Ranstead
15,16 at 7th and Filbert.
5. Entered CP 58 ≈ 50 feet late

EQUIPMENT UTILIZED/TEST CONDITION: VEHICLE UNIT NO.: 1

VEHICLE UNIT THRESHOLD LEVELS: 1 -55dBm 2 -72dBm 3 -82dBm

ODOMETER CAL: 979 FPP 2 5TH WHEEL CAL 872 FPP 2

R1 DROPOUT SWITCH: Off/(On) OTHER:

TEMPERATURE 8° PRECIPITATION: NONE ROAD CONDITIONS: ICE AND SLUSH

TEST TAPE NO(S). 39-1 and 39-2 FILE NO.

SAMPLE RATE: 0.5

TEST DIRECTOR George W. Grun

RUN TIME: 1HR - 30MIN

TSC MONITOR Bernard A. Klein

DISTANCE: Odometer 13mi 230
5th wheel 12mi 5125

FIG. 6-7 HI^3 FIXED ROUTE TEST DATA LOG

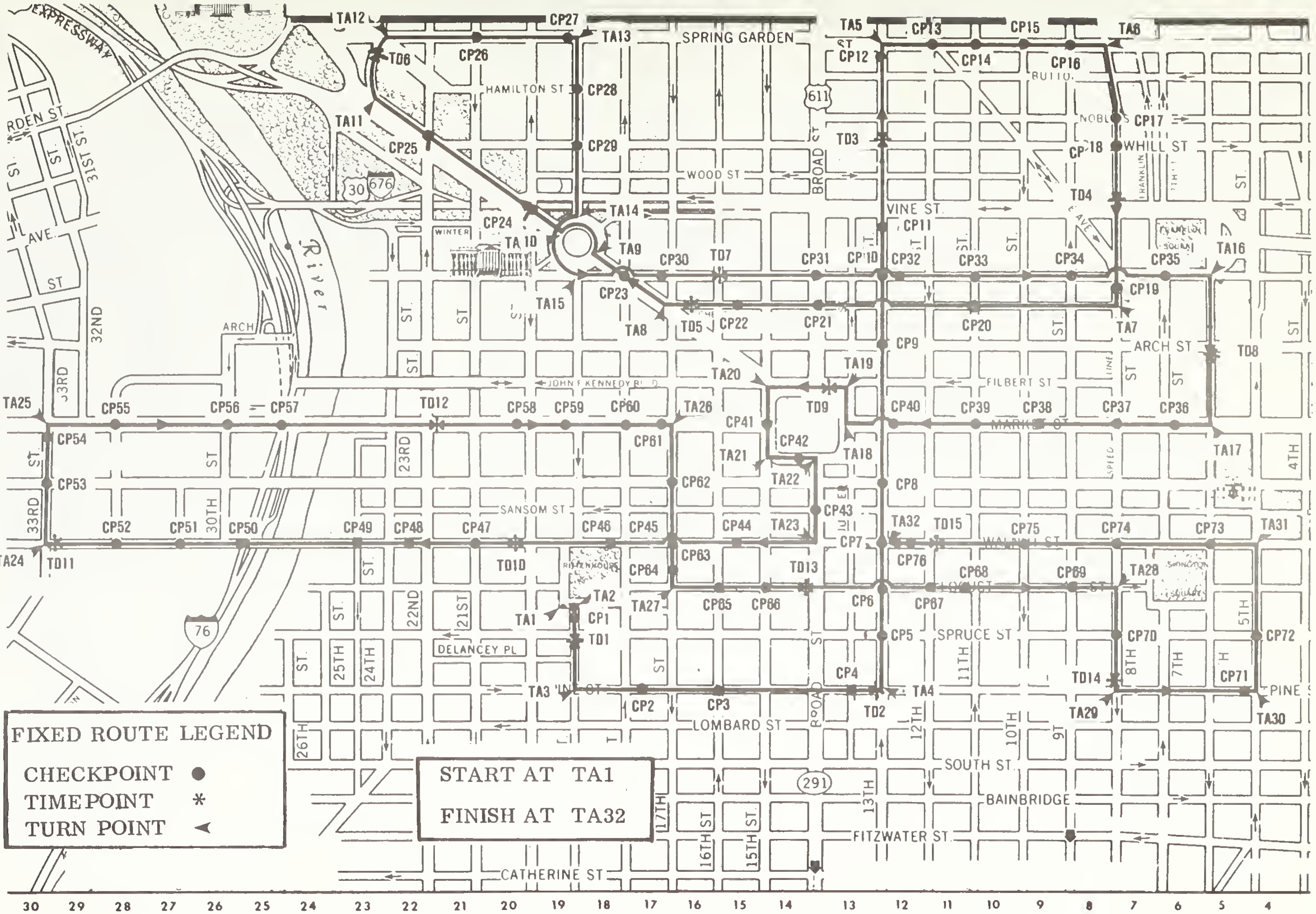


FIG. 6-8 FIXED ROUTE EVENT MARKERS

3. Door Close (DC's) ---------- 7-8

4. Checkpoints (CP's) --------- 76

5. Turnpoints (TA's) ---------- 32

Total --------------------- 139 Events per run.

Entry of these 139 events involved the use of approximately 521 separate keystroking entries during each run for a total of over 17,000 separate keyboard entries during the fixed route test program. As a result of manual entry errors (wrong event or event at wrong time), the Error Event (EE) was used 22 times during the 33 runs. In conjunction with these errors, Table 6-5 contains a list of the anomalies which occurred during manual data entry. The card input corrections required for data processing are also included. Note that in cases in which a TD or a CP were missed, these entries were simply not processed, no attempt being made to insert these entries into the data. However, since the TA's are necessary for pseudo checkpoint computation of the reference location of the vehicle, these were inserted at the approximate location of the associated turn.

After each test, the fixed route cassette run was dumped in the test vehicle, by using program FRUMP. During this process it was found that Runs 19 and 33 could not be dumped. It was subsequently found by reference to the printer output during the FROUTE loading cycle that the Test Director failed to zero the Run 33 cassettes prior to beginning the run. Run 20 could not be dumped past checkpoint 46, as a result of an auxiliary generator failure at that point. Because of these problems and loss of a magnet from the fifth wheel during Run 32, three additional fixed route runs were made in order to assure an adequate number of timepoint samples.

Formal fixed route test procedures involved the following procedures. After loading the fixed route data recording program FROUTE, the test vehicle driver proceeded to traverse the specified route. Coincident with passage of each designated checkpoint, turn, and timepoint, a coded event marker, CP(NN), TA(XX), or TD(YY), respectively, and a time coincident data record were recorded on cassette. As a checkpoint, turn, or timepoint was approached, the driver informed the DAS operator to prepare for event NN. The DAS operator pressed first the appropriate event function key and then keystroked the number NN. He then prepared to depress the "RETURN" key. As the test vehicle approached the event, the driver called out "standby" and then, as the front bumper of the test vehicle passed the designated event he called out "MARK." Upon hearing this MARK, the DAS operator depressed the RETURN key and thus caused a data record and the event number to be recorded on cassette. Door Open (DO) and Door Close (DC) events were similarly recorded. The fixed route test procedures are shown in Figure 6-9. Automatic switch-over from cassette No. 1 to cassette No. 2 occurred at the end of 60 minutes of recording when program FROUTE was used.

TABLE 6-5 FIXED ROUTE MANUAL DATA ENTRY ANOMALIES

RUN NO.	ANOMALIE	ACTION REQUIRED TO PROCESS DATA
14	Missed TA16	Card Input of TA16 at proper location
16	Missed TA24	Card Input of TA24 at proper location
17	Missed TD11	None Required
18	Missed CP43	None Required
20	Missed CP37	None Required
21	Missed CP6	None Required
22	Missed CP11	None Required
26	Missed TD15	None Required
27	Missed CP48	None Required
27	Missed TA10	Card Input of TA10 at proper location
27	Entered TD10 in error	Card Input of Delete TD10
30	Entered DC13 for DC11	None Required
31	Missed TA10	Card Input of TA10 at proper location
32	Entered TD13 for DO13	Card Input of DO13 for first TD13
33	Couldn't enter DO10 and noted that cassette was not turning during 10-30 second period	None Required
34	Missed CP40 and 54	
34	DO2, DC2, and TD2 entered 1 block early	Deleted with EE events
40	Entered CP40 twice	Card Input to Delete first occurrence
37	Entered DC7 in Error	Card Input to Delete first DC7

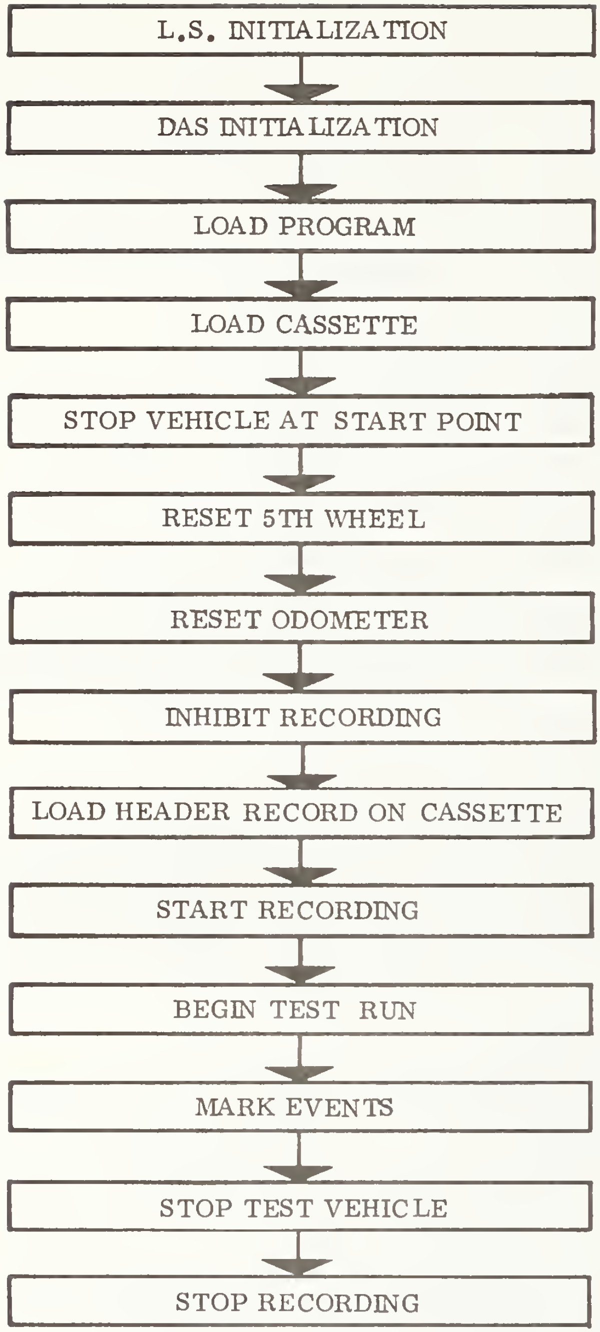


FIG. 6-9 FIXED ROUTE TEST PROCEDURE

No adjustments were made in the LS during a test run. However, minor adjustments of the fifth wheel were required twice during the fixed route test program. A log of all such adjustments was made a part of the test results and is summarized in Table 6-6. All data recorded were retained and processed. No data were eliminated as poor or potentially poor.

Twenty four hours prior to the scheduled commencement of the first fixed route test run and 24 hours after receipt of the fixed route checkpoint locations, HI^3 informed the TSC Monitor that the test was "go." Run 11 began at 1310 on 13 January 1977. The final test run, Run 43 ended at 2140 on 17 January 1977. The average run time was 1 hour and 23 minutes. Thus, nearly 46 hours of formal test runs were completed during a 104 hour period. Snow began falling during Run No. 18. All subsequent test runs encountered slick slushy streets, snow, sleet, or freezing rain and temperatures as low as 8°F and as high as 38°F.

The TSC Monitor was in the test vehicle during all fixed route test runs.

6.4 FIXED ROUTE TEST DATA

Fixed route test data were recorded every 0.5 seconds during the test runs. Except as noted in subsection 6.3, all data were listed by using program FRUMP to certify that the data were recorded on the cassettes. As in the case of random route data, only "change" data and event data records were dumped or listed. Copies of these listings are provided in the Appendix. As an example, Table 6-7 contains a listing of typical fixed route test data dump corresponding to Run 27. Note the occurrence of TA's, CP's, TD's, DO's, DC's, and signpost codes. With regard to the signpost codes, only the R1 and R1D codes were significant. For example, the fact that the R3N code occurs after CP 7 is a result of overlap between signposts (14,06) and (10,06). Although all signpost data were recorded, the occurrence of overlap regions had no effect on the fixed route tests since only the R1 and R1D were used during data processing.

Note that the R1D record is followed by an R1 record. This combination results from the fact that the last valid location code is always stored in the vehicle. The R1D code is a special code used only for fixed route vehicles and is not a location region code per se. As soon as the R1D code is sampled by the computer, the ICU clears the 0011 code from the "B" field, and since the resulting 0000 code corresponds to the Region 1, this location code is automatically recorded as the subsequent sample.

As previously discussed in paragraph 6.1.3.1, more than one R1D may occur, particularly if the test vehicle should stop near a Region 1 boundary. However, the timepoint performance algorithm used during Phase I (and proposed for use during Phase II) has been designed to use only the last R1D occurring for each timepoint signpost.

TABLE 6-6 ADJUSTMENTS REQUIRED TO DAS DURING FIXED ROUTE TESTS

Run #	Problem	Required Action
20	Auxiliary Generator Stalled after CP#46	Repaired automatic choke. Required approximately 5 minutes to wire choke open
32	Lost magnet from 5th Wheel 36 minutes into Run due to heavy ice on streets	Replaced magnet with spare magnet. Required 20 minutes to replace.
26	Connector to 5th Wheel sensor filled with water due to melting ice and water thrown up from fifth wheel	Dried out connector and sealed with tape.

TABLE 6-7 TYPICAL FIXED ROUTE DATA LISTING

L TRUMP.LBA
LST 14155

1/18/77 B. Klein

RUN 027 SAMPLE RATE 00.5 YEAR 77 MONTH 01 DAY 15 HOUR 12 MIN 10

FIFTH WHEEL FEET/PULSE 0002 ODOMETER FEET/PULSE 0002

TA 001	00	00	R1		O 00004	F 00004	T 00 13
TA 002	00	00	R1		O 00074	F 00075	T 00 23
000	17	13	R1		O 00114	F 00112	T 00 23
000	17	13	R1	D	O 00119	F 00117	T 00 23
000	17	13	R1		O 00124	F 00122	T 00 29
CP 001	17	13	R1		O 00134	F 00132	T 00 30
TD 001	17	13	R1		O 00213	F 00215	T 00 37
000	17	13	R1	D	O 00255	F 00253	T 00 40
000	17	13	R1		O 00261	F 00259	T 00 40
000	17	13	R1	D	O 00274	F 00271	T 00 41
000	17	13	R1		O 00280	F 00277	T 00 42
000	17	13	R1	D	O 00325	F 00323	T 00 45
000	17	13	R1		O 00332	F 00330	T 00 46
TA 003	17	13	R1		O 00471	F 00470	T 01 23
CP 002	17	13	R1		O 00755	F 00755	T 02 03
CP 003	17	13	R1		O 01139	F 01139	T 02 33
000	14	05	R1		O 01754	F 01759	T 04 35
CP 004	14	05	R1	D	O 01767	F 01765	T 04 36
000	14	05	R1		O 01773	F 01772	T 04 37
DO 002	14	05	R1		O 01359	F 01963	T 04 43
DC 002	14	05	R1		O 01370	F 01370	T 04 51
TD 002	14	05	R1		O 01394	F 01394	T 04 56
000	14	05	R1	D	O 01910	F 01910	T 04 59
TA 004	14	05	R1		O 01913	F 01913	T 04 59
000	14	05	R1	D	O 01930	F 01931	T 05 02
000	14	05	R1		O 01933	F 01934	T 05 03
CP 005	14	05	R1		O 02159	F 02150	T 05 25
CP 006	14	05	R1		O 02337	F 02333	T 05 50
CP 007	14	05	R1		O 02595	F 02595	T 07 35
000	10	05	R3	N	O 02602	F 02602	T 07 36
CP 008	10	05	R3	N	O 02832	F 02831	T 08 05
CP 009	10	05	R3	N	O 03535	F 03533	T 09 37
CP 010	10	05	R3	N	O 03830	F 03877	T 10 03
CP 011	10	05	R3	N	O 00005	F 04093	T 10 23
000	15	13	R1		O 00273	F 04370	T 10 50
TD 003	15	13	R1		O 00415	F 04507	T 11 04
000	15	13	R1	D	O 00417	F 04533	T 11 05
000	15	13	R1		O 00453	F 04544	T 11 07
000	15	13	R1	D	O 00505	F 04595	T 11 10
000	15	13	R1		O 00513	F 04604	T 11 11
000	14	13	R3	N	O 00602	F 04734	T 11 23
CP 012	14	13	R3	N	O 00821	F 04912	T 11 33
TA 005	14	13	R3	N	O 00993	F 04933	T 11 51
CP 013	14	13	R3	N	O 01113	F 05201	T 12 20
CP 014	14	13	R3	N	O 01332	F 05419	T 12 43
CP 015	14	13	R3	N	O 01554	F 05551	T 13 07
CP 016	14	13	R3	N	O 01736	F 05873	T 13 25
TA 006	14	13	R3	N	O 01954	F 06039	T 13 39
CP 017	14	13	R3	N	O 02460	F 06543	T 14 13
CP 018	14	13	R3	N	O 02514	F 06599	T 14 22
000	12	05	R1		O 02612	F 06725	T 14 33
DO 004	12	05	R1		O 02753	F 06842	T 14 49
DC 004	12	05	R1		O 02753	F 06842	T 15 05
TD 004	12	05	R1		O 02779	F 06861	T 15 15
000	12	05	R1	D	O 02913	F 06897	T 15 19
000	12	05	R1		O 02920	F 06903	T 15 19
CP 019	12	05	R1		O 03227	F 07311	T 16 03
TA 007	12	05	R1		O 03307	F 07339	T 16 12
CP 020	12	05	R1		O 03976	F 08041	T 17 41
CP 021	12	05	R1		O 00692	F 08733	T 20 03
CP 022	12	05	R1		O 01022	F 09159	T 21 55
000	06	03	R1		O 01100	F 09240	T 22 43
TD 005	06	03	R1		O 01249	F 09377	T 23 00
000	06	03	R1	D	O 01297	F 09424	T 23 04
000	06	00	R1		O 01303	F 09430	T 23 05
TA 008	06	00	R1		O 01323	F 09450	T 23 07
CP 023	06	03	R1		O 01595	F 09722	T 23 24
TA 009	06	03	R1		O 01729	F 09954	T 23 33
TD 010	06	03	R1		O 02053	F 10190	T 24 25
CP 024	06	00	R1		O 02206	F 10332	T 25 03
CP 025	06	03	R1		O 02322	F 10943	T 25 45
000	06	06	R3	E	O 03219	F 11343	T 25 09
TA 011	06	06	R3	E	O 03245	F 11370	T 25 11
000	06	06	R1		O 03329	F 11453	T 26 13
TD 006	06	06	R1		O 03424	F 11547	T 26 27
000	06	06	R1	D	O 03434	F 11557	T 26 29
000	06	06	R1		O 03436	F 11559	T 26 29
DO 006	06	06	R1		O 03450	F 11573	T 26 33
DC 006	06	06	R1		O 03450	F 11573	T 26 41
TA 012	06	06	R1		O 03436	F 11609	T 26 51
CP 026	06	06	R1		O 03940	F 12062	T 27 36
CP 027	06	06	R1		O 00320	F 12539	T 28 40
TA 013	06	06	R1		O 00346	F 12554	T 29 44
CP 028	06	06	R1		O 00591	F 12793	T 29 09
CP 029	06	06	R1		O 00843	F 13064	T 29 50
TA 014	06	06	R1		O 01232	F 13447	T 30 22
TA 015	06	06	R1		O 01531	F 13750	T 30 45
CP 030	06	06	R1		O 01974	F 14194	T 32 06
000	16	13	R1		O 02092	F 14913	T 32 16
000	16	13	R1	D	O 02206	F 14426	T 32 27
000	16	13	R1		O 02209	F 14430	T 32 28
TD 007	16	13	R1		O 02213	F 14434	T 32 28
CP 031	16	13	R1		O 02673	F 14899	T 33 52
CP 032	16	13	R1		O 03093	F 15313	T 34 26
CP 033	16	13	R1		O 03434	F 15653	T 34 53
CP 034	16	13	R1		O 03897	F 16104	T 35 37
CP 035	16	13	R1		O 00240	F 00170	T 36 50
TA 016	16	13	R1		O 00474	F 00403	T 37·09
000	12	10	R3	W	O 00501	F 00429	T 37 12
000	12	10	R1		O 00729	F 00659	T 37 30
DO 003	12	10	R1		O 00750	F 00673	T 37 37
DC 003	12	10	R1		O 00771	F 00699	T 37 47
TD 003	12	10	R1		O 00814	F 00743	T 37 52
000	12	10	R1	D	O 00843	F 00772	T 37 55
000	12	10	R1		O 00843	F 00777	T 37 56
TA 017	12	10	R1		O 01173	F 01100	T 41 36
CP 036	12	10	R1		O 01934	F 01259	T 41 52
CP 037	12	10	R1		O 01613	F 01543	T 42 33
CP 038	12	10	R1		O 02045	F 01971	T 44 19
CP 039	12	10	R1		O 02296	F 02222	T 45 05
CP 040	12	10	R1		O 02690	F 02615	T 45 14
TA 019	12	10	R1		O 02999	F 02929	T 47 13
000	14	03	R1		O 02965	F 02396	T 47 20
000	14	03	R1	D	O 02971	F 02999	T 47 21
000	14	03	R1		O 02974	F 02896	T 47 22
000	14	03	R1	D	O 02990	F 02912	T 47 35
000	14	03	R1		O 02992	F 02914	T 47 36
000	14	03	R1	D	O 02999	F 02922	T 47 37
000	14	09	R1		O 03003	F 02926	T 47 38
TA 010	14	03	R1		O 03035	F 02957	T 47 42
000	14	03	R1	D	O 03043	F 02971	T 47 44
000	14	09	R1		O 03051	F 02974	T 47 44
DO 009	14	03	R1		O 03103	F 03027	T 47 52
DC 009	14	03	R1		O 03106	F 03030	T 47 59
TD 009	14	03	R1		O 03122	F 03045	T 48 03
000	14	03	R1	D	O 03137	F 03062	T 48 05
000	14	03	R1		O 03142	F 03067	T 49 05
000	14	09	R1	D	O 03133	F 03103	T 48 09
000	14	03	R1		O 03190	F 03115	T 48 09
TA 020	14	09	R1		O 03373	F 03303	T 48 23
CP 041	14	03	R1		O 03534	F 03462	T 49 12
TA 021	14	03	R1		O 03662	F 03539	T 49 27
CP 042	14	09	R1		O 03737	F 03717	T 49 39
TA 022	14	03	R1		O 03959	F 03795	T 49 47
CP 043	14	03	R1		O 00091	F 04054	T 50 27
TA 023	14	03	R1		O 00173	F 04135	T 50 55
CP 044	14	03	R1		O 00505	F 04523	T 51 43
CP 045	14	09	R1		O 00912	F 04364	T 52 12
CP 046	14	03	R1		O 01127	F 05143	T 52 46
000	15	11	R1		O 01335	F 05405	T 53 05
000	15	11	R1	D	O 01407	F 05423	T 53 07
000	15	11	R1		O 01415	F 05436	T 53 07
000	15	11	R1	D	O 01546	F 05557	T 53 13
000	15	11	R1		O 01550	F 05572	T 53 13
DO 010	15	11	R1		O 01572	F 05593	T 53 23
DC 010	15	11	R1		O 01572	F 05593	T 53 35
000	15	11	R1	D	O 01574	F 05596	T 53 37
000	15	11	R1		O 01576	F 05597	T 53 38
TD 010	15	11	R1		O 01590	F 05602	T 53 39
000	15	11	R1	D	O 01616	F 05637	T 53 43
000	15	11	R1		O 01622	F 05643	T 53 43
CP 047	15	11	R1		O 01799	F 05812	T 54 14
CP 048	15	11	R1		O 02109	F 06131	T 54 43
CE 048	15	11	R1		O 02153	F 06190	T 54 49
CP 049	15	11	R1		O 02329	F 06352	T 55 00
CP 050	15	11	R1		O 02315	F 06333	T 55 10
CP 051	15	11	R1		O 03193	F 07213	T 56 05
CP 052	15	11	R1		O 03510	F 07535	T 56 27
000	19	13	R1		O 03646	F 07671	T 56 36
DO 011	19	13	R1		O 03795	F 07320	T 57 03
DC 011	19	13	R1		O 03300	F 07326	T 57 13
000	19	13	R1	D	O 03302	F 07323	T 57 13
000	19	13	R1		O 03303	F 07329	T 57 14
TD 011	19	13	R1		O 03313	F 07339	T 57 16
TA 024	19	13	R1		O 03331	F 07356	T 57 19
000	19	13	R1	D	O 03340	F 07363	T 57 20
000	19	13	R1		O 03344	F 07353	T 57 20
CP 053	19	13	R1		O 00003	F 08123	T 57 43
CP 054	19	13	R1		O 00252	F 08371	T 58 02
TA 025	19	13	R1		O 00273	F 08991	T 58 05
CP 055	19	13	R1		O 00692	F 08719	T 58 34
CP 056	19	13	R1		O 01125	F 09243	T 59 26
CP 057	19	13	R1		O 01409	F 09522	T 59 43
000	16	11	R1		O 01959	F 10079	T 60 34
000	16	11	R1	D	O 01963	F 10089	T 60 35
000	16	11	R1		O 01967	F 10087	T 60 35
DO 012	16	11	R1		O 02109	F 10229	T 60 43
000	16	11	R1	D	O 02116	F 10236	T 60 51
000	16	11	R1		O 02116	F 10236	T 60 51
000	16	11	R1	D	O 02116	F 10236	T 60 59
000	16	11	R1		O 02116	F 10236	T 61 00
DC 012	16	11	R1		O 02116	F 10236	T 61 01
000	16	11	R1	D	O 02117	F 10237	T 61 02
000	16	11	R1		O 02118	F 10239	T 61 03
TD 012	16	11	R1		O 02120	F 10240	T 61 03
CP 058	16	11	R1		O 02551	F 10673	T 61 33
CP 059	16	11	R1		O 02756	F 10877	T 62 31
CP 060	16	11	R1		O 03041	F 11162	T 63 01
CP 061	16	11	R1		O 03211	F 11991	T 63 17
TA 026	16	11	R1		O 03269	F 11399	T 63 26
CP 062	16	11	R1		O 03536	F 11655	T 64 17
CP 063	16	11	R1		O 03316	F 11935	T 64 43
CP 064	16	11	R1		O 03951	F 12030	T 64 57
TA 027	16	11	R1		O 04027	F 12147	T 65 17
CP 065	16	11	R1		O 00141	F 12353	T 66 09
CP 066	16	11	R1		O 00365	F 12532	T 66 33
000	13	13	R1		O 00453	F 12669	T 66 41
000	13	13	R1	D	O 00550	F 12766	T 66 49
000	13	13	R1		O 00555	F 12772	T 66 49
TD 013	13	13	R1		O 00535	F 12302	T 66 52
000	13	13	R1	D	O 00604	F 12321	T 66 54
000	13	13	R1		O 00609	F 12926	T 66 55
CP 067	13	13	R1		O 01135	F 13354	T 68 36
CP 068	13	13	R1		O 01397	F 13554	T 69 54
CP 069	13	13	R1		O 01309	F 14026	T 69 45
TA 028	13	13	R1		O 02050	F 14266	T 70 07
CP 070	13	13	R1		O 02253	F 14479	T 70 43
000	03	07	R1		O 02375	F 14539	T 70 52
000	03	07	R1	D	O 02339	F 14602	T 70 53
000	03	07	R1		O 02395	F 14603	T 70 54
TD 014	03	07	R1		O 02509	F 14723	T 71 19
000	03	07	R1	D	O 02525	F 14740	T 71 22
TA 029	03	07	R1		O 02523	F 14743	T 71 22
CP 071	09	07	R1		O 03160	F 15377	T 72 59
TA 030	09	07	R1		O 03191	F 15410	T 73 23
CP 072	03	07	R1		O 03440	F 15659	T 74 41
TA 031	03	07	R1		O 03931	F 16099	T 75 31
CP 073	03	07	R1		O 04095	F 16315	T 76 19
CP 074	09	07	R1		O 00447	F 00330	T 77 59
CP 075	03	07	R1		O 00339	F 00322	T 79 43
000	02	06	R3	N	O 01096	F 01023	T 79 31
000	10	06	R1		O 01243	F 01191	T 80 03
TD 015	10	06	R1		O 01332	F 01264	T 80 11
000	10	06	R1	D	O 01379	F 01311	T 80 15
000	10	06	R1		O 01334	F 01317	T 80 16
CP 076	10	06	R1		O 01459	F 01391	T 80 22
TA 032	10	06	R1		O 01562	F 01493	T 80 33
DO 095	42	35	R2	E	O 01365	F 21945	T 86 29

Both odometer and fifth wheel values recorded on cassette and shown in Table 6-7 are recorded in pulses and must be multiplied by 2 in order to be converted to feet. Both units were calibrated to provide one pulse every two feet. Note also that whereas the odometer rolls over after CP's 11, 20, 26, and 34, the fifth wheel does not roll over until after CP 34. This action occurs since only 12 bits ($2^{12} = 4096$) were used to record odometer data and 14 bits ($2^{14} = 16,384$) were used to record fifth wheel data. During data processing, all such modulo 2^N features are recognized by the data processing routine. The time printed out in Table 6-7 is correct to the second although the data recorded on cassette and used during data processing are correct to the half-second.

The DO 085 codes observed in the last two records are the end-of-file marks. All data processing is terminated upon the occurrence of the last TA entry, TA 32, which signifies the end of run. The DO 085 code is written on tape automatically as a result of action of the Close Tape function key.

The odometer was driven from magnets attached to the left front wheel, whereas the fifth wheel was mounted on the centerline of the test vehicle. As a result, they traveled different distances when the vehicle turned. This is evident in the data shown in Table 6-7. For example, at time 00:28, the odometer is 4 feet ahead of the fifth wheel. At TA3, a left turn was made, subsequently, the fifth wheel caught up with the odometer. The left turn at TA4 caused the fifth wheel to exceed the odometer (see time 06:05). Note that, at the end of the run, the odometer indicates a total elapsed distance of 68,660 feet in comparison to the 68,522 feet indicated by the fifth wheel, a difference of 138 feet, or 0.2 percent. Analysis of the test route indicates that 5 more 90-degree right turns are made than left turns. This action would result in the odometer's traveling a greater distance than the fifth wheel. Theoretically, an offset of X feet from the center line of the vehicle would result in $\pi/2$ X feet difference for each 90-degree turn. By using an offset value of X = 4 feet and five turns, $5 \times \pi/2 \times 4 = 31$ feet of this difference are accounted for. The remaining difference (107 feet or 0.156 percent) is attributed to calibration of the two units over only a 1000-foot range.

Within human judgment, each test run was started at the same location and ended at the same location. Table 6-8 is a summary of the elapsed distances indicated by the odometer and fifth wheel during the fixed route runs. The temperature during the run and the street conditions are also appended.

Table 6-9 contains a typical odometer/fifth wheel calibration run over the 1000-foot Delaware Street range. CP 1 signified the start of the run. CP2 signified the end of the run. The TA events were used to record data at interim times. This run was made after replacing the magnet which was lost from the fifth wheel during Run 32. The indicated odometer distance was 2 x 502 = 1004 feet. The indicated fifth wheel distance was 2 x 500 = 1000 feet. No attempt was made to "improve" the calibration by changing the DEM calibration numbers as a result of these tests since street conditions were uncertain.

TABLE 6-8 ODOMETER AND 5TH WHEEL TEST DATA

Run No.	Total Run Elapsed Distance		ODOM-Fifth	Temperature	Street Conditions
	Odometer (ft)	5th Wheel (ft)			
11	68562	68610	-48	24	Dry
12	68336	68608	-272	23	Dry
13	68736	68770	-34	24	Dry
14*	49800	49816	-16	24	Dry
15	68478	68596	-118	23	Dry
17	68408	68598	-190	30	Dry
18	68490	68596	-106	32	Began Snowing
21	68950	68092	858	33	Slush
23 24*	69048	67714	1334	32	Freezing Rain
25*	23234	22912	322	32	Rain
26	68776	68510	266	33	Slush
27	68650	68512	138	34	Slush
28	68596	68512	84	38	Slush
30	68680	68610	70	34	Slush
31	68576	68900	-324	34	Slush
34*	36684	36364	320	26	Snow
35	68876	68320	556	26	Snow
36	68802	68456	446	28	Snow
38	68894	68356	540	15	Slush
39	68872	68474	398	8	Ice
40*	38552	38368	184	8	Ice
41	68760	68536	224	12	Ice
42	68838	68516	322	12	Ice
43*	56718	56492	226	12	Ice

*Data incomplete due to record errors during run.

TABLE 6-9 TYPICAL ODOMETER/5th WHEEL CALIBRATION DATA

TEST DATA LOG

TEST RUN # 32 CONTINUED SHEET 4 OF 4

```
.L FRUMP.LDA

.ST 14156

RUN 001   SAMPLE RATE 00.5   YEAR 77   MONTH 01   DAY 16   HOUR 10   MIN 25

FIFTH WHEEL FEET/PULSE   0002    ODOMETER FEET/PULSE   0002
CP 001      00      00      R1      O 00000     F 00000     T 00 03
TA 002      00      00      R1      O 00057     F 00057     T 00 17
TA 003      00      00      R1      O 00100     F 00101     T 00 21
TA 004      00      00      R1      O 00140     F 00140     T 00 24
TA 005      00      00      R1      O 00181     F 00180     T 00 28
TA 006      00      00      R1      O 00220     F 00220     T 00 31
TA 006      00      00      R1      O 00258     F 00257     T 00 35
TA 006      00      00      R1      O 00295     F 00295     T 00 38
TA 007      00      00      R1      O 00322     F 00321     T 00 41
TA 001      00      00      R1      O 00353     F 00353     T 00 44
TA 001      00      00      R1      O 00384     F 00384     T 00 47
TA 001      00      00      R1      O 00419     F 00419     T 00 50
TA 001      00      00      R1      O 00447     F 00446     T 00 53
TA 001      00      00      R1      O 00472     F 00471     T 00 56
TA 001      00      00      R1      O 00495     F 00494     T 01 00
CP 002      00      00      R1      O 00502     F 00500     T 01 03
DO 085      42      85      R2 E    O 01365     F 21845     T 08 03
DO 085
```

DATA DUMP AS DESCRIBED ON SHEET 3 OF 4

1/16/77 [signature]

7. FIXED ROUTE DATA PROCESSING

The processing of fixed route data was accomplished in three parts by use of three computer programs FRLS, FRSYS, and FRTEN. The same data were input to the three programs. The programs were coded separately in order to accommodate the PDP 11/05 processor at HI^3. As shown in Figure 7-1, FRLS processed timepoint and checkpoint data, whereas FRSYS processed AVM System Level Errors (pseudo checkpoints) and FRTEN processed each record to generate average errors over 528 foot street segments.

7.1 SAMPLE SIZE

The sample size for fixed route data was determined through the use of the processes described in Subsection 4.1. Since TSC designated 76 checkpoints, 30 runs would result in processing of 2280 checkpoints, considerably more than the number of samples required. However, since only 15 timepoints could be accommodated per run during a 13-mile run and be representative of the spacing between timepoints on actual transit routes, the number of timepoint samples dictated the number of runs. As discussed in subsection 4.1, the sample size analyses coupled with the cost of requiring additional runs, resulted in TSC requiring 30 runs, for a total of 450 timepoint samples. HI^3 actually processed exactly 451 timepoint samples.

7.2 FIXED ROUTE DATA PROCESSING

7.2.1 <u>Fixed Route Location Errors</u>

Location error data processing of fixed route data involved computing (1) the vehicle's actual location (at checkpoints and pseudo checkpoints), (2) the vehicle's estimated location (using the location subsystem or AVM system), and (3) the radial error between the locations determined in (1) and (2).

7.2.1.1 Vehicle Actual Location at Checkpoints. The actual location of the vehicle was assumed to be the X, Y location of the TSC checkpoint at the time the appropriate CP event was recorded on tape. The CPTABL file contained the X, Y location of each checkpoint as determined by (1) the digitized intersections provided by MITRE and (2) the offset distances measured by HI^3. The actual values used in CPTABL were the X' and Y' values of the stateplane coordinates shown in the Appendix except that 2,710,000 was subtracted from X' values and 230,000 was subtracted from Y' values. Table 7-1 contains actual CPTABL stateplane entries.

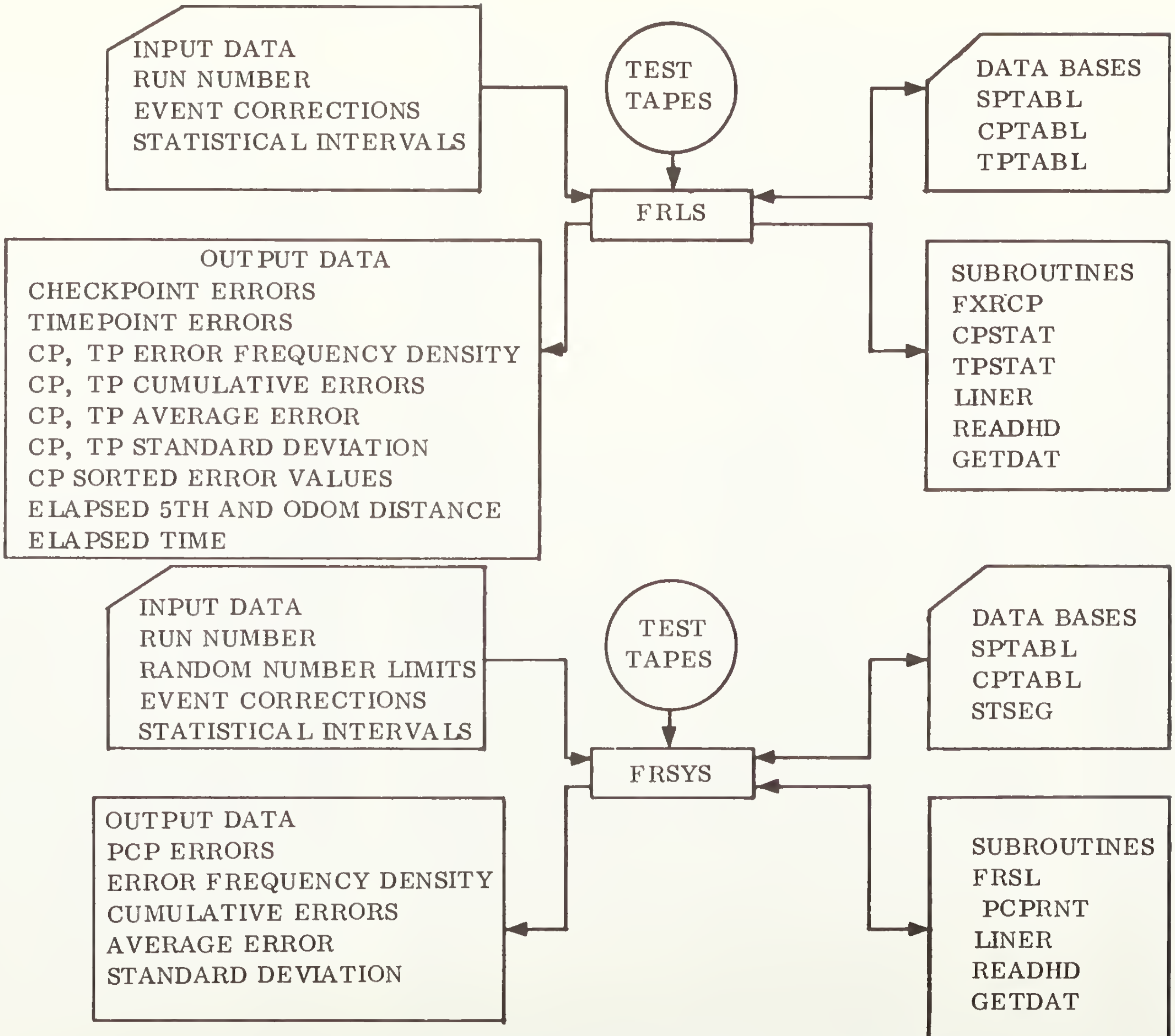


FIG. 7-1 FIXED ROUTE DATA PROCESSING SOFTWARE

TABLE 7-1 FIXED ROUTE CHECKPOINT STATEPLANE COORDINATES

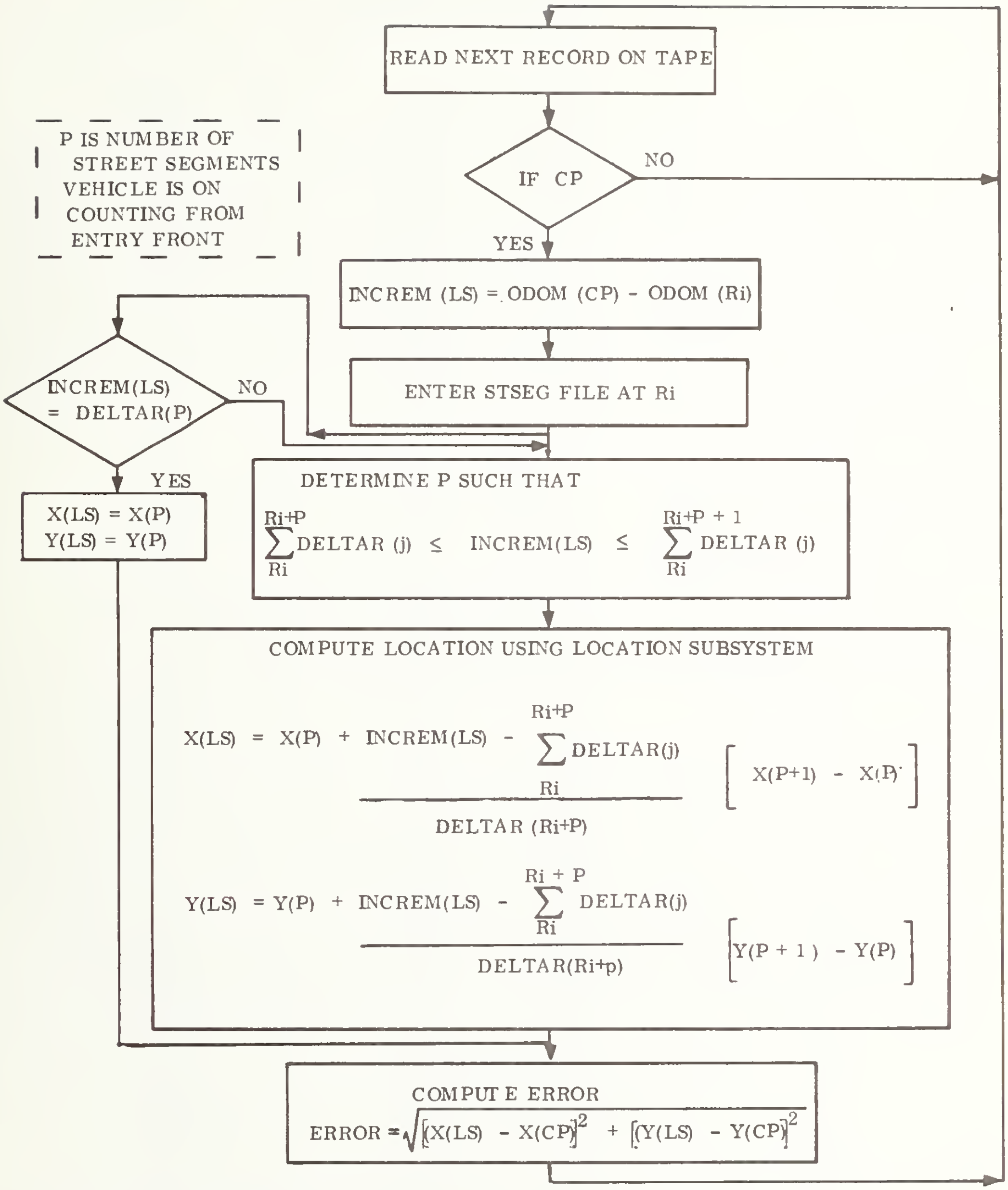
Checkpoint No.	State Plane Coordinates X (feet)	State Plane Coordinates Y (feet)	Checkpoint No.	State Plane Coordinates X (feet)	State Plane Coordinates Y (feet)
1	2722431	234529	44	2724055	235037
2	2722895	233792	45	2723388	235138
3	2723632	233698	46	2722862	235200
4	2724904	233541	47	2721518	235369
5	2725277	234035	48	2720787	235472
6	2725334	234441	49	2720462	235513
7	2725383	234869	50	2719558	235647
8	2725475	235453	51	2718740	235757
9	2725644	236735	52	2718145	235840
10	2725730	237421	53	2717537	236481
11	2725809	237838	54	2717652	236971
12	2776042	239499	55	2718320	236948
13	2726512	239618	56	2719345	236825
14	2726941	239578	57	2719894	236731
15	2727368	239554	58	2722136	236444
16	2727811	239507	59	2722561	236405
17	2728095	238454	60	2723099	236331
18	2728109	238343	61	2723452	236271
19	2727929	236962	62	2723455	235695
20	2726580	236988	63	2723388	235138
21	2725087	237167	64	2723372	234812
22	2724282	237260	65	2723787	234668
23	2723313	237718	66	2724242	234594
24	2722500	238500	67	2725770	234381
25	2721590	239350	68	2726152	234347
26	2722190	240181	69	2727121	234202
27	2723151	240036	70	2727491	233736
28	2723130	239554	71	2728691	233072
29	2723052	239039	72	2729268	233498
30	2723699	237663	73	2728484	234477
31	2725123	237495	74	2727621	234597
32	2725948	237393	75	2726706	234705
33	2726627	237326	76	2725624	234856
34	2727500	237204			
35	2728354	237054			
36	2728300	235657			
37	2727779	235728			
38	2726908	235840			
39	2726427	235897			
40	2725645	236003			
41	2724638	236127			
42	2724717	235780			
43	2724816	235222			

7.2.1.2 Vehicle Actual Location at Pseudo Checkpoints. In Fixed Route Data Processing, pseudo checkpoints were selected in exactly the same manner as in Random Route Data Processing, i.e., by sampling the recorded data every 20 seconds. The technique used to determine the vehicle location at a pseudo checkpoint was also exactly the same as that used in the Random Route System Level routine RRSL, as previously discussed in paragraph 4.2.3. As in the case of RRSL, the vehicle's actual location (i.e., that of the pseudo checkpoint) was determined explicitly through use of (1) the last TA or CP, (2) the next TA or CP, and (3) the 5th wheel distance from the last TA or CP to the pseudo checkpoint.

7.2.1.3 Vehicle Computed Location. The estimated location of the vehicle was computed through use of the last reset signpost code, and the elapsed odometer distance from that signpost's region 1 boundary (R(i)). The simplified flow chart in Figure 7-2 shows the process incorporated in FRLS to compute location errors. The odometer is first used to compute the vehicle's distance along the route from the last reset point to establish on which street segment the vehicle is located, and then it is used to compute the X, Y location on the basis of the distance the vehicle has traveled along the street segment. Table 7-2 contains the street segment file STSEG. Each point in the STSEG file is identified in Figure 6-8.

7.2.1.4 Vehicle Computed (AVM System) Location at Pseudo Checkpoints. At pseudo checkpoints, the exact same algorithm discussed in paragraph 7.2.1.3 was used to determine the vehicle's computed location. This approach was used regardless of whether or not a communication error has been simulated. Thus, as in the case of checkpoints, the vehicle's computed location was determined totally on the basis of the elapsed odometer distance from the last encountered fixed route signpost. Note that the marking of turns in no way influences the computation of vehicle location through the use of the location subsystem.

7.2.1.5 Off-Route Declaration. During off-line data processing, each recorded signpost code is checked against a valid signpost file. If an invalid code is observed, it is ignored as part of the screening algorithm. Each recorded signpost code is also checked against the fixed route signpost file. If a valid signpost code is not a fixed route signpost for the route in question, an "off-route" declaration is made. This function was simulated during runs 38 through 43 by installing a pair of signposts along the route so that their codes would be recorded in the test vehicle. In each instance, the data processing routine declared an off-route condition upon the first occurrence of a code from either of these signposts. The locations of these signposts are indicated in Figure 6-4. The actual algorithm by which the vehicle's estimated location was determined, off-line, is indicated in the flow chart in Figure 7-2.



WHERE: CP IS CHECKPOINT

INCREM(LS) IS THE ELAPSED ODOMETER READING (IN FEET) SINCE LAST RESET

STSEG FILE IS AS SHOWN IN TABLE 7-2

DELTAR(j) IS THE LENGTH IN FEET OF THE jth STREET SEGMENT

$\sum_{Ri}^{Ri+p}$ DELTAR(j) IS THE DISTANCE FROM THE LAST RESET TO THE Ri+pth STREET SEGMENT

DELTAR(Ri+p) IS THE STREET SEGMENT ON WHICH THE VEHICLE IS ON

X(LS) IS COMPUTED X BY LS, Y(LS) IS COMPUTED Y BY LS

X(CP), Y(CP) IS X, Y FROM CPTABL

FIG. 7-2 SIMPLIFIED FLOW CHART OF FRLS LOCATION ERROR ALGORITHM

TABLE 7-2 FIXED ROUTE STSEG FILE

Street Segment Index	State Plane Coordinates * X(feet)	State Plane Coordinates * Y(feet)	Deltar (feet)
TA1	12305	4700	140
TA2	12444	4683	68
R1	12418	4620	745
TA3	12332	3880	2534
R2	14845	3551	361
TA4	15201	3489	4943
R3	15885	8384	1298
TA5	16064	9670	2057
TA6	18115	9510	1581
R4	18094	7929	1131
TA7	17910	6813	3795
R5	14142	7269	433
TA8	13711	7308	839
TA9	13145	7928	533
TA 10	12745	8280	2258
TA 11	11085	9810	291
R6	11063	10100	279
TA 12	11235	10320	1977
TA 13	13195	10061	1775
TA 14	12922	8307	521
TA 15	12888	7787	1108
R7	13984	7622	4883
TA 16	1832	7038	532
R8	18724	6517	913
TA 17	18642	5608	3436
TA 18	15234	6043	231
R9	15269	6271	109
TA 19	15277	6380	602
TA20	14681	6467	685
TA21	14595	5787	296
TA22	14890	5758	811
TA23	14788	4953	2464
R10	12345	5274	4553
R11	7836	5903	368
TA24	7469	5924	1127
TA25	7660	7035	3329
R12	10960	6599	2626
TA26	13564	6256	1563
TA27	13358	4707	1037
R13	14385	4564	3200
TA28	17560	4161	706
R14	17448	3464	276
TA29	17425	3189	1333
TA30	18752	3064	1383
TA31	18914	4437	2861
R15	16072	4770	696
TA32	15383	4869	00000

* Add 2710, 000 to X and 230, 000 to Y to get State Plane Coordinate.

7.2.2 AVM System Simulation

During the first pass, when fixed route test data were processed through the use of program FRSYS, the location error was computed for every 40th record (20-second sampling interval). On the second pass, 5 percent of the samples (selected in a random manner) were assumed to contain a communcation error. In these cases, the vehicle's actual location (fifth wheel) was not changed; however, detection of a communication error (simulated) caused the AVM system to poll the vehicle within 2 seconds to obtain a new AVM computed location. As in the random route case, this correction technique was implemented by computing the vehicle's location on the basis of the fourth record (2 seconds) subsequent to the originally selected PCP. The error was then computed as follows for the two cases:

No Communication Error Detected

$$\text{Location Error} = \sqrt{\left(X(\text{LS at PCP}) - X(\text{PCP})\right)^2 + \left(Y(\text{LS at PCP}) - Y(\text{PCP})\right)^2}$$

Communication Error Detected at PCP

$$\text{Location Error} = \sqrt{\left(X(\text{LS at PCP} + 2\text{ sec}) - X(\text{PCP})\right)^2 + \left(Y(\text{LS at PCP} + 2\text{sec}) - Y(\text{PCP})\right)^2}$$

7.2.3 Timepoint Performance Computation

The computation of timepoint performance was performed by use of the FRLS routine at each event-marked timepoint recorded on cassette during each fixed route test run. Figure 7-2 contains the algorithm used to determine timepoint passage. The TDO, TDC, and TLRID information would be stored in the Phase II vehicle until requested by the base station. This information consists of values for TDO and TDC or a value for TLR1D. These values are stored in the vehicle until the next timepoint is encountered. If a communication error is detected during transmission of timepoint data to the base station, it will be retrieved on a subsequent poll; however, the values would not be changed.

7.2.4 Average Error Over One-Tenth Mile Segments

Computer program FRTEN was used to compute the average location error over 528 foot segments of the fixed route tests. This program treated each record as if it were a pseudo checkpoint thereby computing each location error in exactly the same manner as FRSYS. The average of all such errors over each 528 foot long segment of the 13-mile route was then determined.

7.3 FIXED ROUTE DATA PROCESSING SOFTWARE

Flow charts of fixed route data processing software routines FRSYS, and FRTEN are contained in the Appendix.

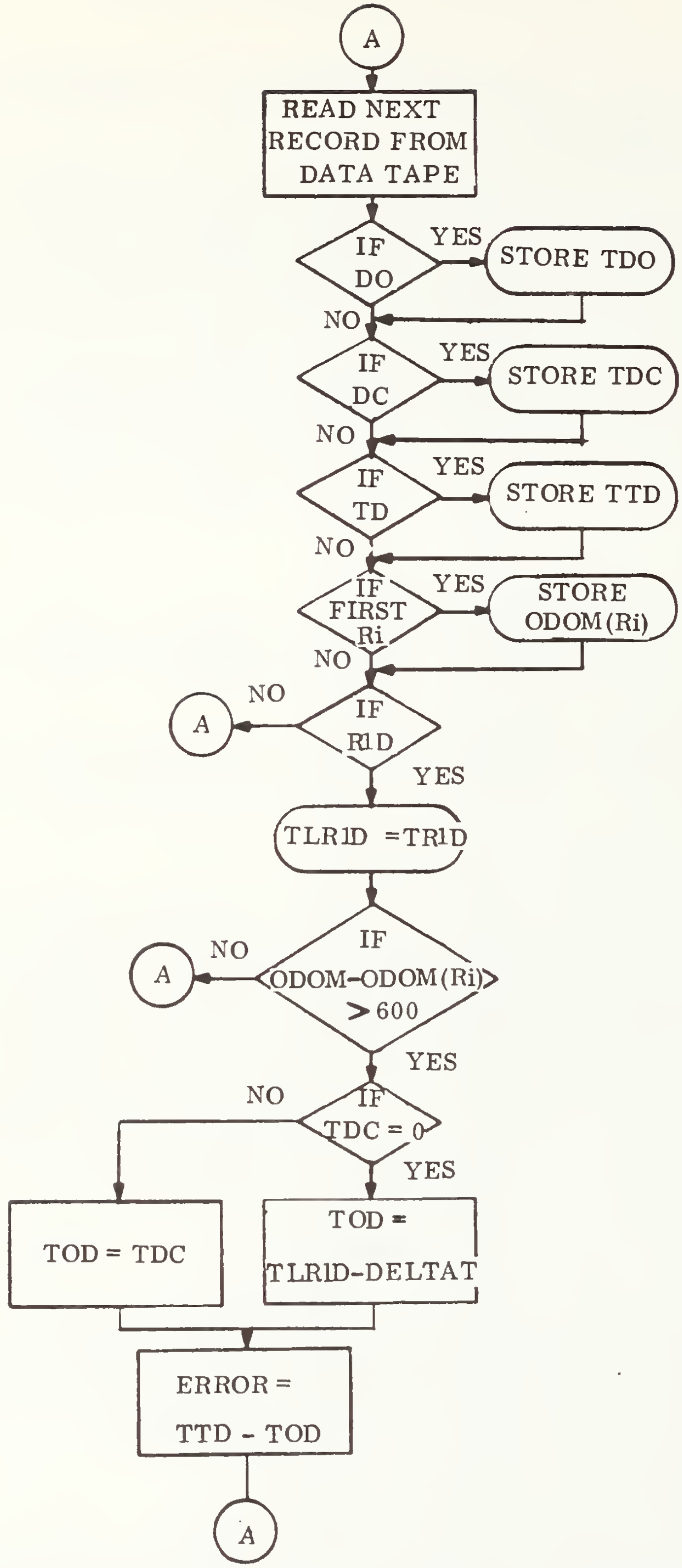


FIG. 7-3 SIMPLIFIED FLOW CHART OF TIMEPOINT PERFOMANCE ALGORITHM

8. FIXED ROUTE TEST RESULTS

The results obtained by processing Fixed Route Runs 11 through 43 through the use of the data processing routines FRLS, FRSYS, and FRTEN are presented in this section. Location error data are presented separately from timepoint performance error data. The results obtained for both the location subsystem and the AVM system simulation are summarized in the following table:

SUMMARY OF FIXED ROUTE TEST RESULTS

Location Subsystem:	
No. of Samples	2313
Average Error	50 feet
95% Error	107 feet
99.5% Error	156 feet
% Errors Less Than 300 Feet	99.91
% Errors Less Than 450 Feet	99.96
Maximum Average Error over 1/10th Mile Segment	256 feet
AVM System (Location Error): With 5% Comm Errors	
No. of Samples	7459
Average Error	48 feet
95% Error	105 feet
99.5% Error	188 feet
% Errors Less Than 300 Feet	99.84
% Errors Less Than 450 Feet	99.97
AVM System (Timepoint Performance)	
No. of Samples	451
Average Error	3.9 seconds
95% Error	11 seconds
99.5% Error	24 seconds
% Errors Less Than 15 Seconds	98.67
% Errors Less Than 60 Seconds	100.00

8.1 LOCATION SUBSYSTEM TEST RESULTS

The vehicle location results obtained by processing fixed route data tapes through the Fixed Route Location Subsystem (FRLS) routine are summarized in Table 8-1. As a result of certain anomalies, some of which were described in Section 6, all 33 data runs could not be processed in total. Table 8-2 contains a brief description of the problems encountered in processing each data run. In

TABLE 8-1 FIXED ROUTE LOCATION SUBSYSTEM TEST RESULTS

Run No.	No. of Checkpoints Processed	Average Error (feet)	95% of Errors Less than (feet)	99.5% of Errors Less than (feet)
11	76	51.48	104	128
12	76	56.79	115	143
13	76	52.44	107	142
14	76	49.16	102	119
15	76	50.28	108	140
16	76	48.86	100	117
17	76	50.88	102	119
18	75	54.13	119	130
19	Bad Tape	---	---	---
20	45	58.47	125	162
21	73	41.06	106	144
22	76	45.14	107	152
23	76	46.73	135	174
24	75	67.60	145	1509 *
25	76	62.84	244	309
26	76	38.16	91	101
27	76	48.10	102	126
28	75	45.54	92	113
29	74	43.58	99	104
30	76	44.23	89	120
31	76	56.60	105	405
32	75	42.73	95	125
33	Bad Tape	---	---	---
34	75	46.04	97	139
35	75	40.94	87	131
36	76	50.16	115	156
37	76	51.72	111	148
38	76	53.81	101	119
39	76	53.35	103	144
40	76	47.44	103	111
41	76	37.45	79	118
42	76	53.60	107	306
43	75	61.10	127	185
Total	2313	49.85	107	156

*Computation error: Manual computation yields 12 feet at CP3.

TABLE 8-2 FIXED ROUTE DATA PROCESSING ANOMALIES (FRLS)

RUN NO.	PROBLEM	RESULT
14	Couldn't Process Past CP54	22 Checkpoints Processed manually
18	Missed CP 43	75 Checkpoints
19	Bad Tape, couldn't dump in vehicle	No Results
20	Generator Stalled after CP46	45 Checkpoints
21	CP66 entered for CP6; CP111 entered for CP11; Missed CP36; Entry Error at CP47; Missed CP49	Replaced CP66 with CP6 Replaced CP11 with CP111 72 Total Checkpoints
24	Didn't Process CP54 from Tape: Recording Error in Odometer Between CP53 and CP55	13 Checkpoints Processed manually
28	Missed CP9	75 Checkpoints
29	Missed CP1; Missed CP28	74 Checkpoints
31	CP7 Entered Early	Produced 4051 Error at CP7
32	First TD13 should be DO13	Card Input Change
33	Bad Tape, couldn't dump in vehicle	No Results
34	Couldn't read past CP37	37 Checkpoints Processed manually
35	Missed CP1	75 Checkpoints
39	"Off Route" During CP37-CP40	4 Checkpoints Processed manually
40	Couldn't Process Past CP40 due to bad records on tape	38 Checkpoints Processed manually
41	"Off Route" During CP37-CP40	4 Checkpoints Processed manually
42	" " "	4 Checkpoints Processed manually
43	" " "	4 Checkpoints Processed manually

most cases, the information contained in Table 8-2 applies to use of the AVM system simulation routine also. Pertinent differences are described in Subsection 8.2. A detailed discussion of processing anomalies is contained in subsection 8.3.

As a result of the problems described in Table 8-2, only 31 of 33 runs were successfully processed through use of FRLS. Two runs, Runs 19 and 33, could not be processed at all. Runs 19 and 33 were known to have contained recording errors which were confirmed in the test vehicle immediately after each run. Also, Run 20 was cut short due to failure of the auxiliary generator just after checkpoint 46. Run 20 could not be processed through the FRSYS routine. Runs 24, 25, 34, 40, and 43 also could not be processed completely due to data recording errors. All of these problems were noted on the appropriate test data logs or made known to the TSC Monitor while at DEC transferring data from cassettes to magnetic tape. Details are discussed in subsection 8.3

Assuming that 30 runs were processed, the number of checkpoints would then be 30 x 76 = 2280 checkpoints minus the 20 (4 during each of 5 runs), which were not processed due to an "off-route" declaration on Runs 39 through 43, leaves 2260 possible checkpoints. A total of 2171 checkpoints representing 98 percent of these possible samples were actually processed through the use of FRLS. A total of 142 checkpoints were processed manually (as noted in Table 8-2) for a grand total of 2313 checkpoints.

Table 8-3 contains typical results obtained as output data from the FRLS routine when Run 27 was processed. Figure 8-1 contains a plot of the error statistics of all fixed route location subsystem data combined. These results document conclusively the performance obtained through use of the HI^3 location subsystem as a means of maintaining the location of fixed route transit vehicles. Note that the average error of 50 feet is approximately the length of a standard bus.

Figures 8-2 through 8-32 contain error histograms and cumulative error distributions corresponding to each set of test data which were processed. These results, coupled with the results obtained during random route tests, also demonstrate the ability of the HI^3 fixed route AVM system which is described in Subsection 10.2 (odometer eliminated) to meet the fixed route transit AVM requirements of the UMTA Multi-User AVM Program. The HI^3 fixed route system was installed, calibrated, and data recording software checked out in the test vehicle, during only five working days. Output data corresponding to each set of processed data are contained in the Appendix.

Table 8-4 contains typical results obtained by processing test data through use of the FRTEN routine. During each such run, every recorded data record on the test tape was processed as a pseudo checkpoint for a total of approximately 10,000 points per run using the FRTEN routine. Although similar results for all runs would be too voluminous to present in this volume, Table 8-5 contains a

(Text continued on 8-42)

TABLE 8-3 FIXED ROUTE RUN #27 CHECKPOINT ERRORS

FIXED ROUTE RUN # 27 CHECKPOINT ERRORS

CP#	X(CP)	Y(CP)	SP#	SEG.	INCREM	COMP X	COMP Y	ERROR
1	12431	4529	1	3	40.	12413.	4580.	54.
2	12895	3792	1	4	559.	12886.	3807.	18.
3	13632	3698	1	4	1305.	13626.	3711.	14.
4	14904	3541	2	5	26.	14871.	3547.	34.
5	15277	4035	2	6	449.	15263.	3934.	102.
6	15334	4441	2	6	905.	15326.	4385.	56.
7	15383	4869	2	6	1321.	15384.	4797.	72.
8	15475	5453	2	6	1895.	15463.	5366.	88.
9	15644	6735	2	6	3203.	15644.	6661.	74.
10	15736	7421	2	6	3891.	15739.	7342.	79.
11	15809	7838	2	6	4335.	15801.	7782.	57.
12	16042	9499	3	7	1086.	16035.	9460.	40.
13	16512	9618	3	8	372.	16435.	9641.	80.
14	16941	9578	3	8	810.	16872.	9607.	75.
15	17368	9554	3	8	1274.	17334.	9571.	38.
16	17811	9507	3	8	1718.	17777.	9536.	45.
17	18095	8454	3	9	1009.	18112.	8501.	50.
18	18109	8343	3	9	1117.	18112.	8393.	50.
19	17929	6962	4	10	1170.	17926.	6915.	47.
20	16580	6988	4	11	1395.	16525.	6981.	56.
21	15087	7167	4	11	2899.	15032.	7161.	56.
22	14282	7260	4	11	3679.	14257.	7255.	25.
23	13313	7718	5	13	551.	13339.	7715.	26.
24	12500	8500	5	15	401.	12450.	8552.	72.
25	11590	9350	5	15	1633.	11544.	9387.	58.
26	12190	10181	6	18	943.	12170.	10196.	25.
27	13151	10036	6	18	1895.	13114.	10072.	52.
28	13130	9554	6	19	440.	13127.	9626.	72.
29	13052	9039	6	19	974.	13045.	9099.	60.
30	13699	7663	6	21	930.	13808.	7649.	110.
31	15123	7495	7	22	1172.	15148.	7482.	28.
32	15948	7393	7	22	2012.	15982.	7381.	36.
33	16627	7326	7	22	2684.	16649.	7301.	33.
34	17500	7204	7	22	3590.	17548.	7193.	50.
35	18345	7054	7	22	4488.	18440.	7085.	100.
36	18300	5657	8	25	297.	18347.	5646.	49.
37	17779	5728	8	25	865.	17784.	5718.	12.
38	16908	5840	8	25	1719.	16937.	5826.	32.
39	16427	5897	8	25	2221.	16439.	5889.	14.
40	15645	6003	8	25	3009.	15658.	5989.	19.
41	14638	6127	9	29	427.	14627.	6043.	85.
42	14717	5780	9	30	248.	14842.	5763.	126.
43	14816	5222	9	31	632.	14811.	5131.	91.
44	14055	5037	9	32	771.	14024.	5053.	35.
45	13388	5138	9	32	1443.	13357.	5141.	31.
46	12862	5200	9	32	2013.	12792.	5215.	71.

TABLE 8-3 FIXED ROUTE RUN #27 CHECKPOINT ERRORS (CONT'D)

CP#	X(CP)	Y(CP)	SP#	SEG.	INCREM	COMP X	COMP Y	ERROR
47	11518	5369	10	33	810.	11543.	5386.	30.
48	10787	5472	10	33	1448.	10911.	5474.	124.
49	10462	5513	10	33	1888.	10475.	5535.	26.
50	9558	5647	10	33	2860.	9513.	5669.	50.
51	8740	5757	10	33	3616.	8764.	5774.	29.
52	8145	5840	10	33	4250.	8136.	5861.	23.
53	7537	6481	11	35	538.	7560.	6454.	35.
54	7652	6971	11	35	1036.	7645.	6945.	27.
55	8320	6948	11	36	609.	8264.	6955.	57.
56	9345	6825	11	36	1655.	9301.	6818.	45.
*57	9894	6731	11	36	2211.	9852.	6745.	45.

CT1:RUN027.001

CP#	X(CP)	Y(CP)	SP#	SEG.	INCREM	COMP X	COMP Y	ERROR
58	12136	6444	12	37	1184.	12134.	6444.	2.
59	12561	6405	12	37	1594.	12541.	6391.	25.
60	13099	6331	12	37	2164.	13106.	6316.	16.
61	13452	6271	12	37	2504.	13443.	6272.	9.
62	13455	5695	12	38	528.	13494.	5733.	55.
63	13388	5138	12	38	1088.	13421.	5178.	51.
64	13372	4812	12	38	1378.	13382.	4890.	79.
65	13787	4668	12	39	367.	13721.	4656.	67.
66	14242	4594	12	39	815.	14165.	4595.	77.
67	15770	4381	13	40	1366.	15740.	4392.	32.
68	16152	4347	13	40	1768.	16139.	4341.	14.
69	17121	4202	13	40	2712.	17076.	4222.	50.
70	17491	3736	13	41	410.	17495.	3756.	21.
71	18691	3072	14	43	1294.	18713.	3068.	23.
72	18782	3565	14	44	521.	18813.	3581.	35.
73	18484	4477	14	45	448.	18469.	4489.	19.
74	17621	4597	14	45	1344.	17579.	4593.	42.
75	16706	4705	14	45	2228.	16701.	4696.	10.
76	15624	4856	15	46	420.	15656.	4830.	42.

TABLE 8-3 FIXED ROUTE RUN #27 CHECKPOINT ERRORS (CONT'D)

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NO. SAMPLES	PERCENT OF SAMPLES
0- 10	2	2.63
10- 20	9	11.84
20- 30	11	14.47
30- 40	12	15.79
40- 50	9	11.84
50- 60	14	18.42
60- 70	1	1.32
70- 80	9	11.84
80- 90	3	3.95
90- 100	2	2.63
100- 110	2	2.63
120- 130	2	2.63

CUMULATIVE ERRORS

ERROR	# SAMPLES LT ERROR	PERCENT SAMPLES LT ERROR
10	2	2.63
20	11	14.47
30	22	28.95
40	34	44.74
50	43	56.58
60	57	75.00
70	58	76.32
80	67	88.16
90	70	92.11
100	72	94.74
110	74	97.37
120	74	97.37
130	76	100.00

AVERAGE ERROR	=	48.10	
STANDARD DEVIATION	=	27.26	
ELAPSED TIME	=	80: 0	
ELAPSED DISTANCE	=	68512.	(5TH WHEEL)
ELAPSED DISTANCE	=	68650.	(ODOMETER)

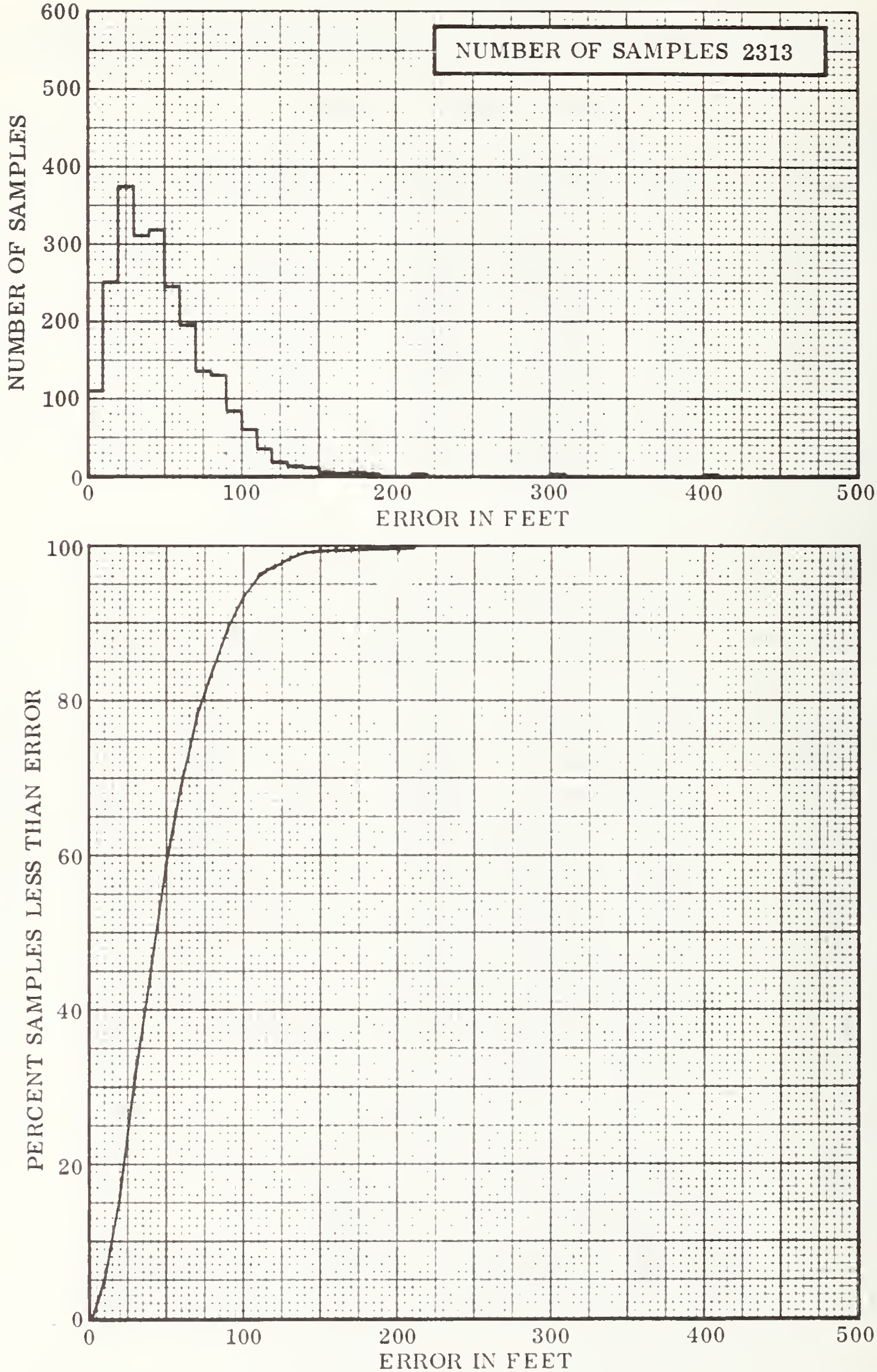


FIG. 8-1 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, ALL RUNS

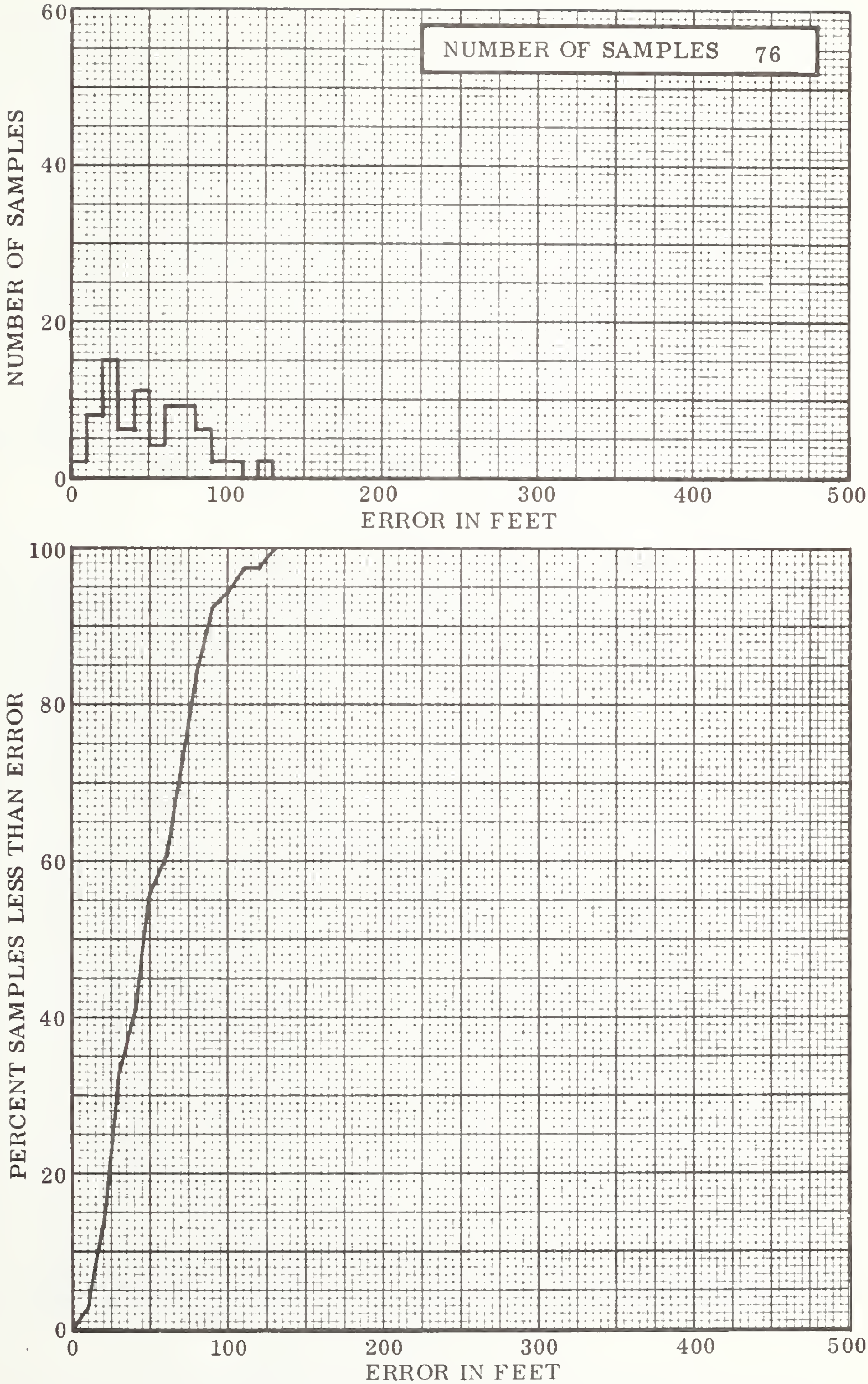


FIG. 8-2 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 11

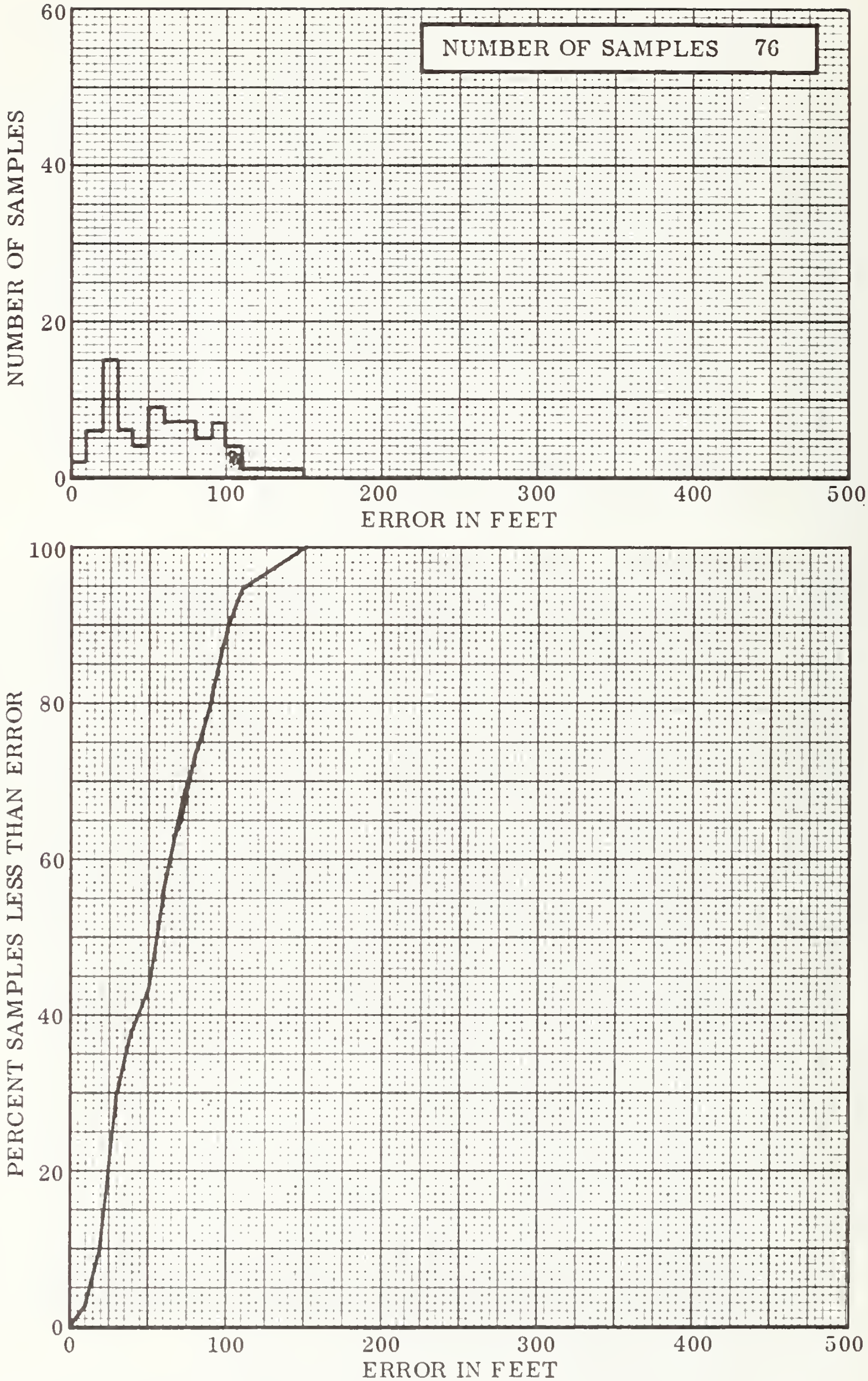


FIG. 8-3 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 12

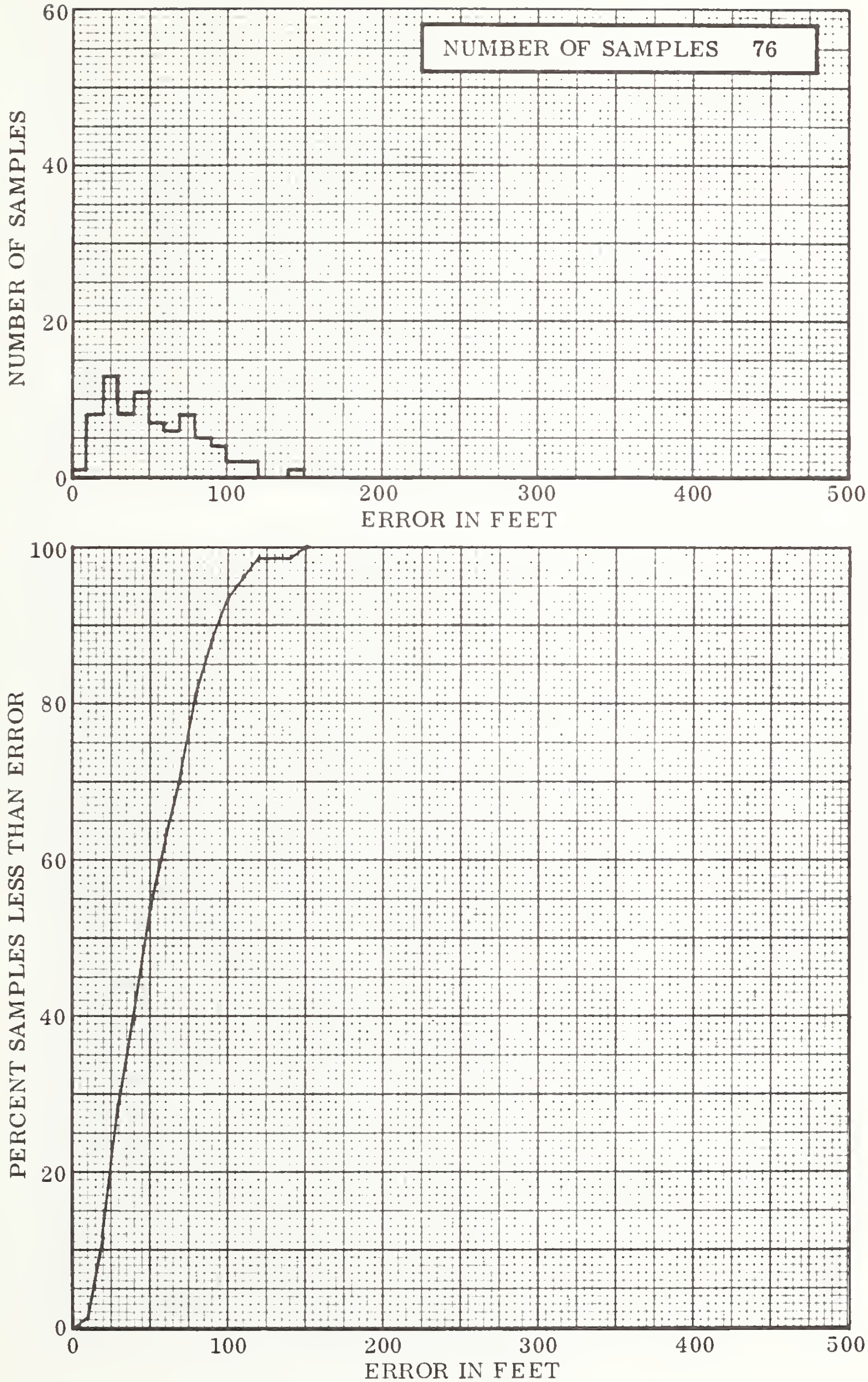


FIG. 8-4 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 13

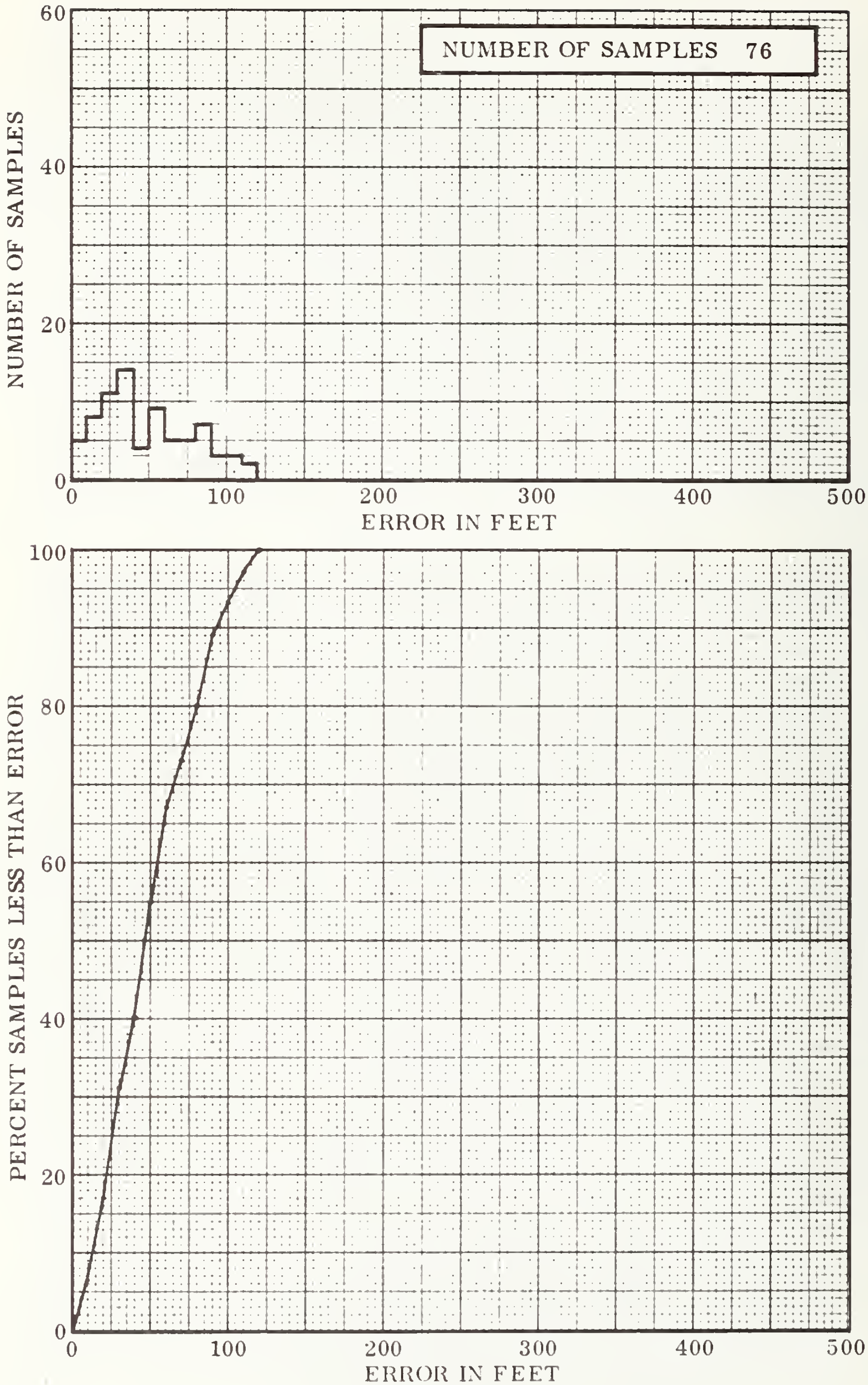


FIG. 8-5 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 14

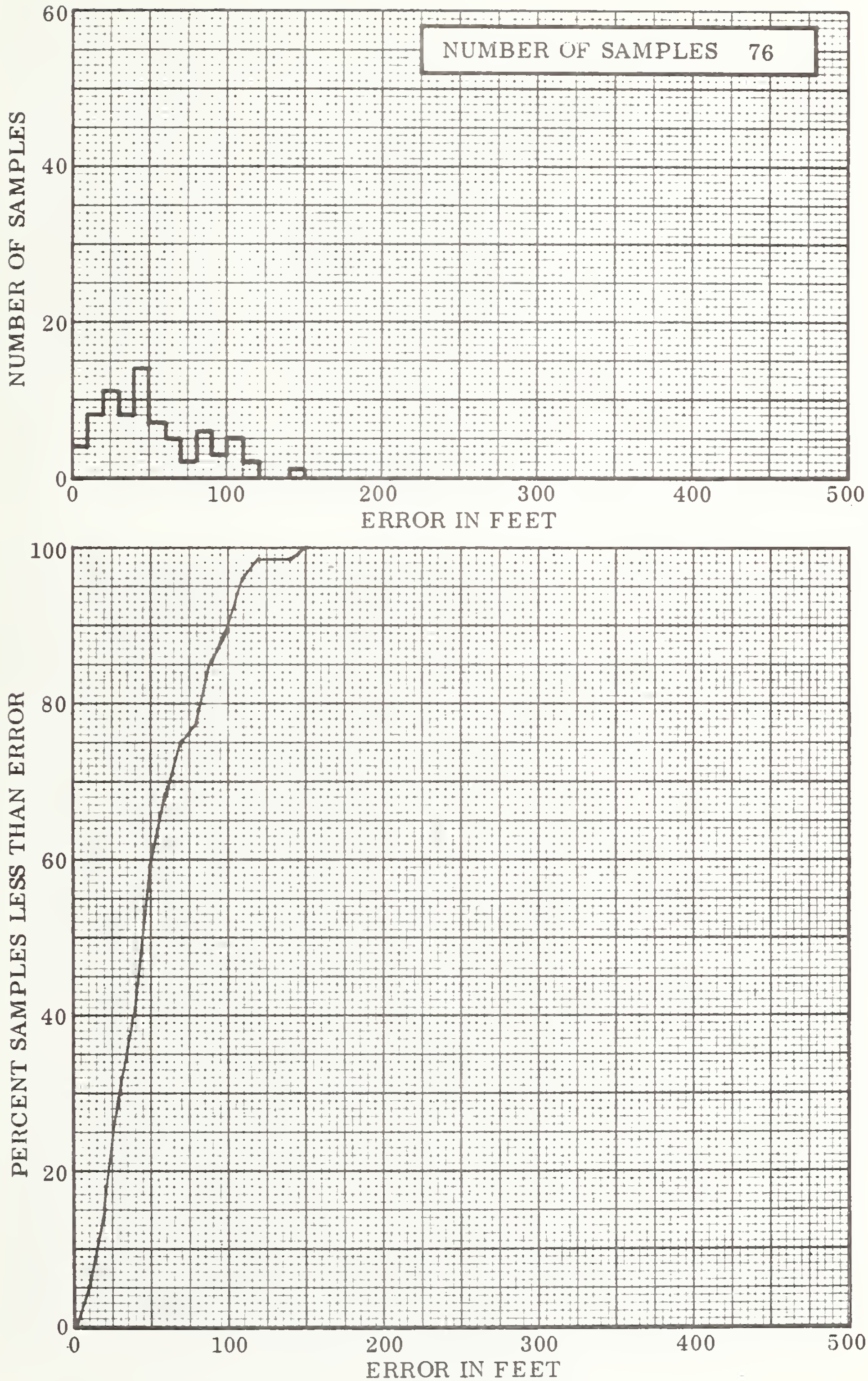
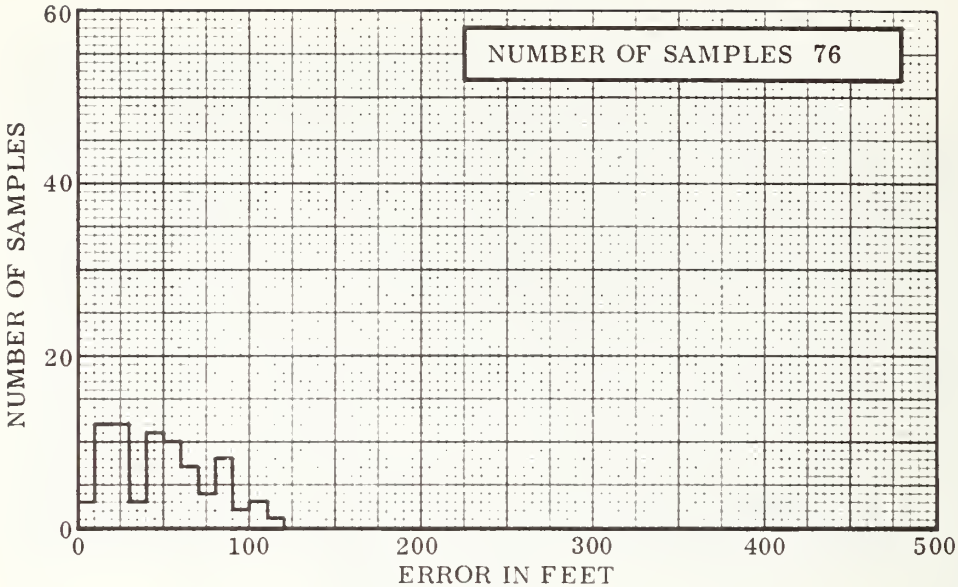


FIG. 8-6 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 15



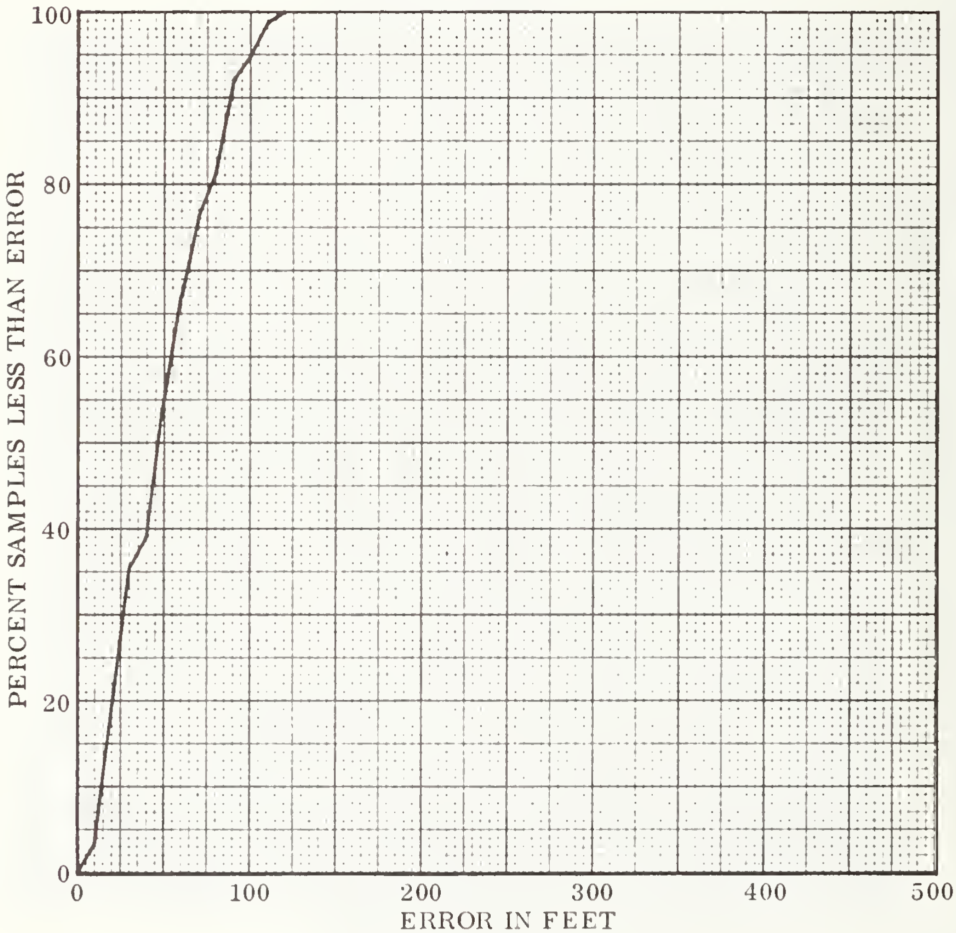


FIGURE 8-7 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 16

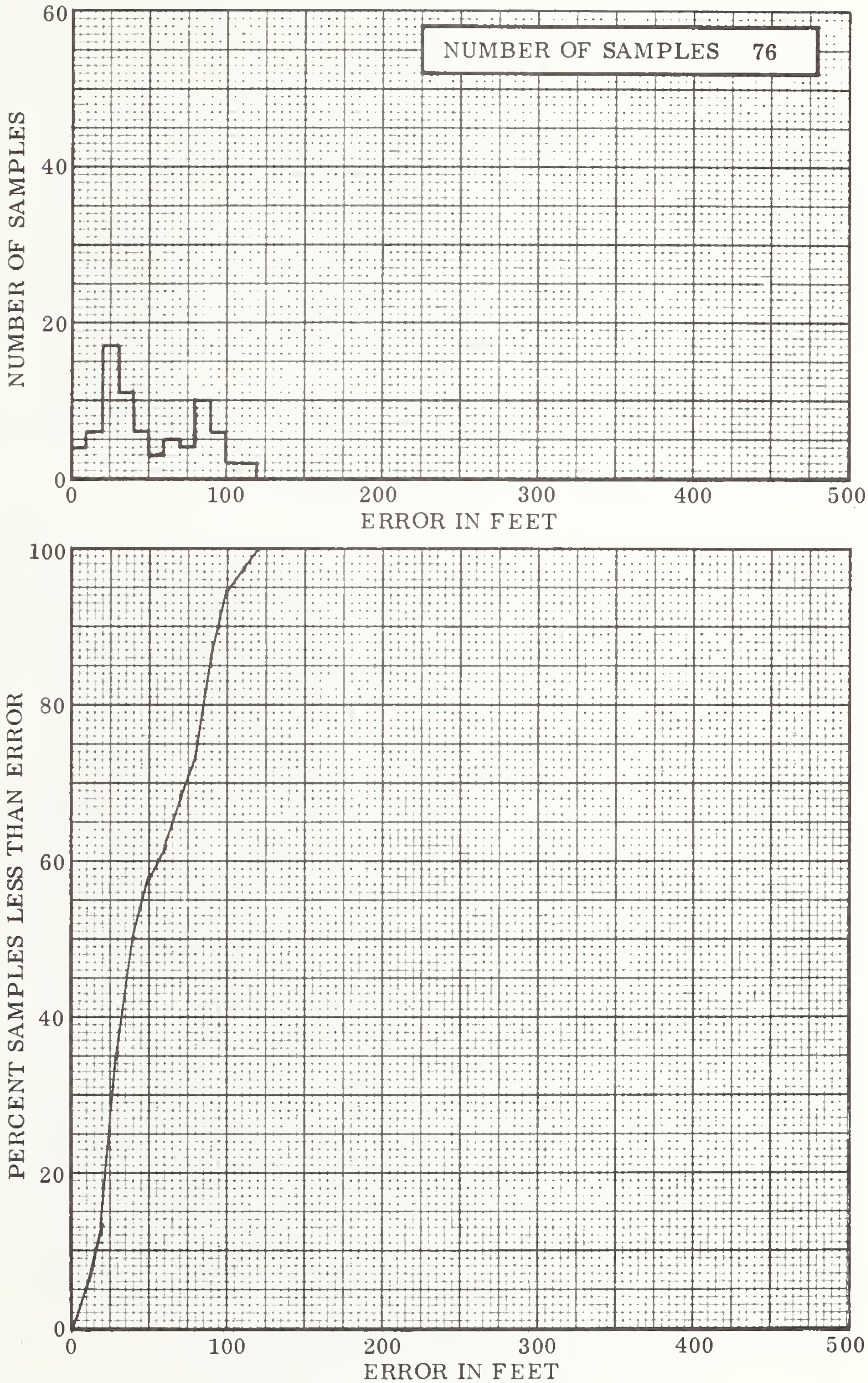


FIG. 8-8 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 17

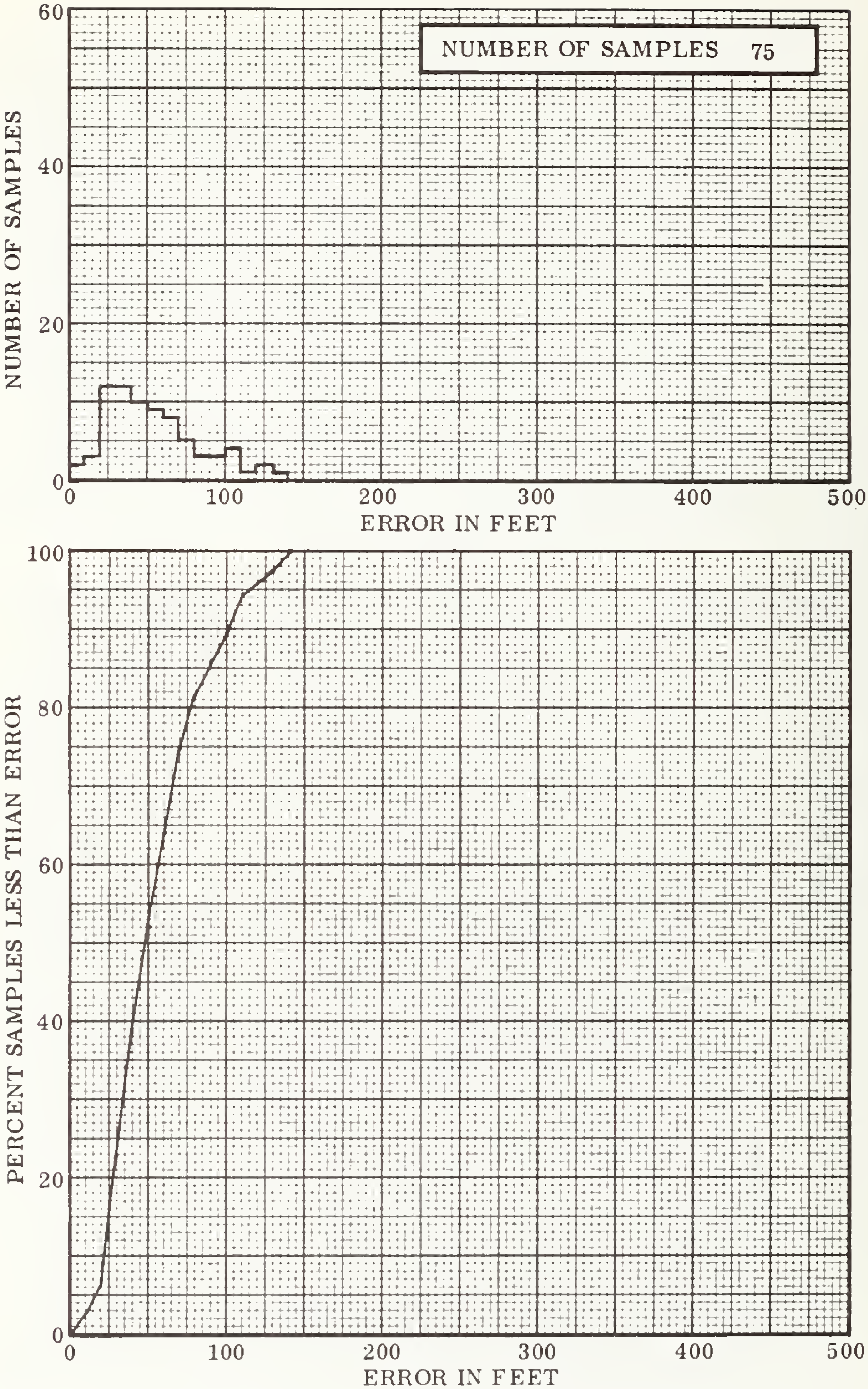


FIG. 8-9 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 18

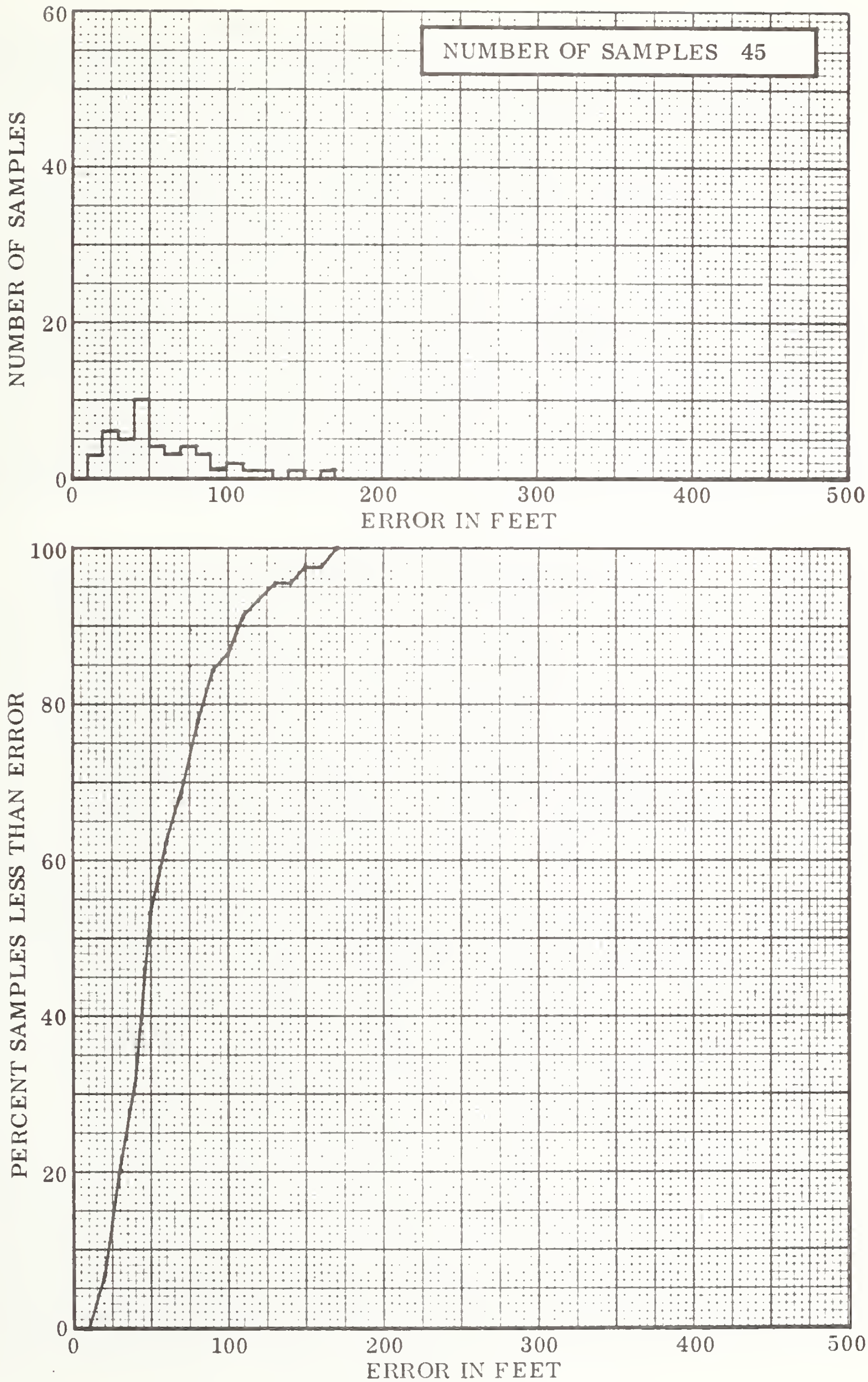


FIG. 8-10 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 20

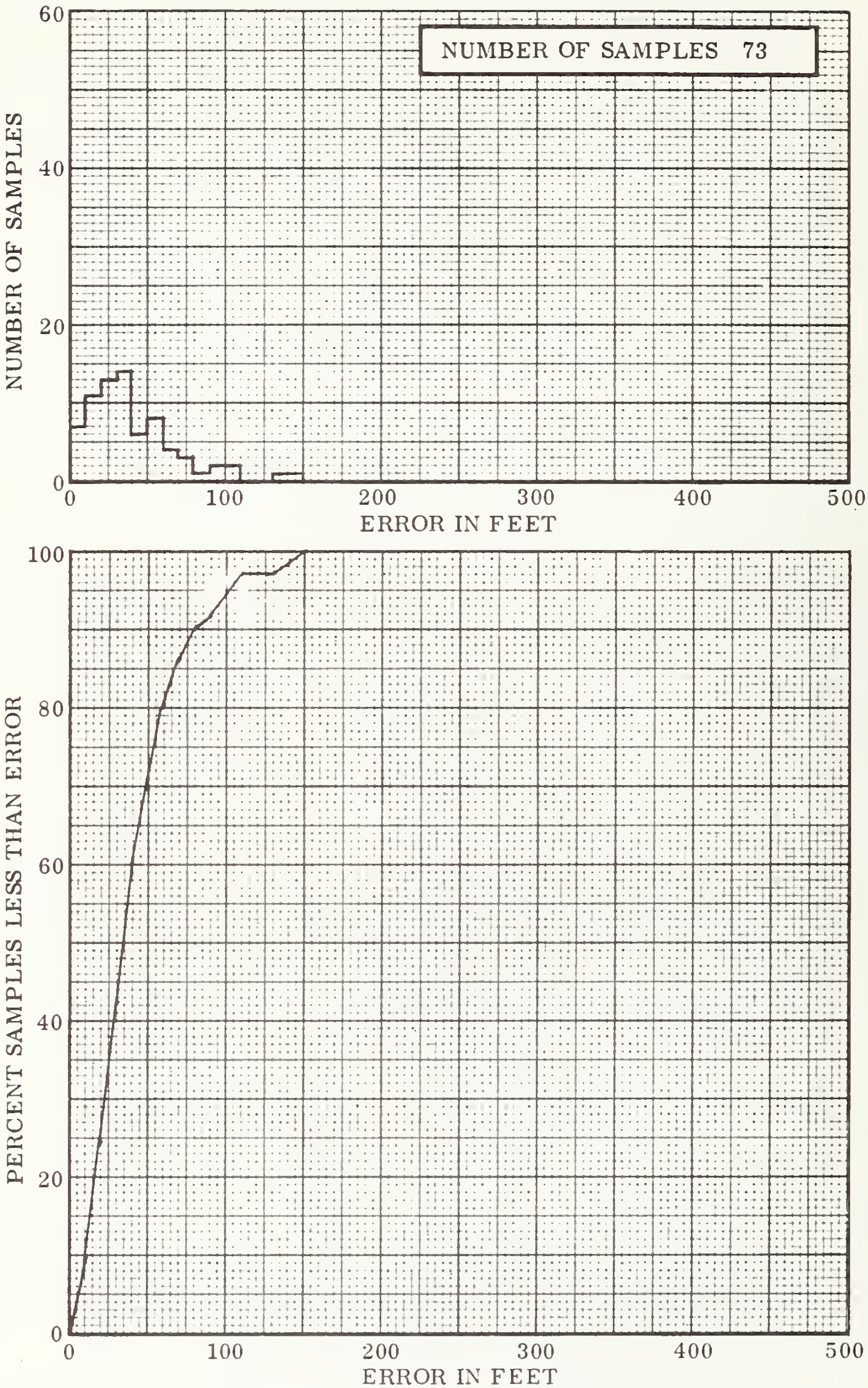


FIG. 8-11 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 21

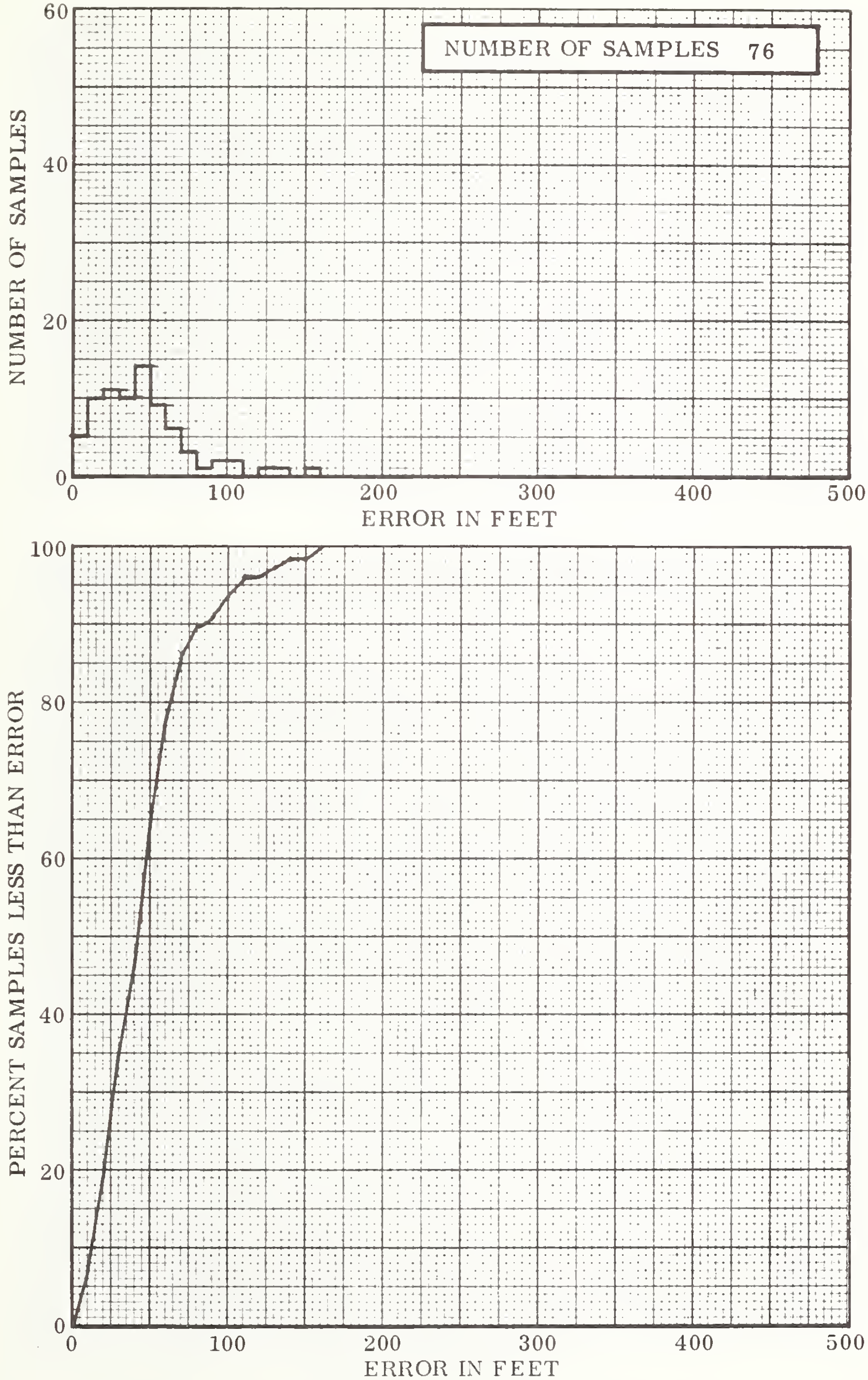


FIG. 8-12 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 22

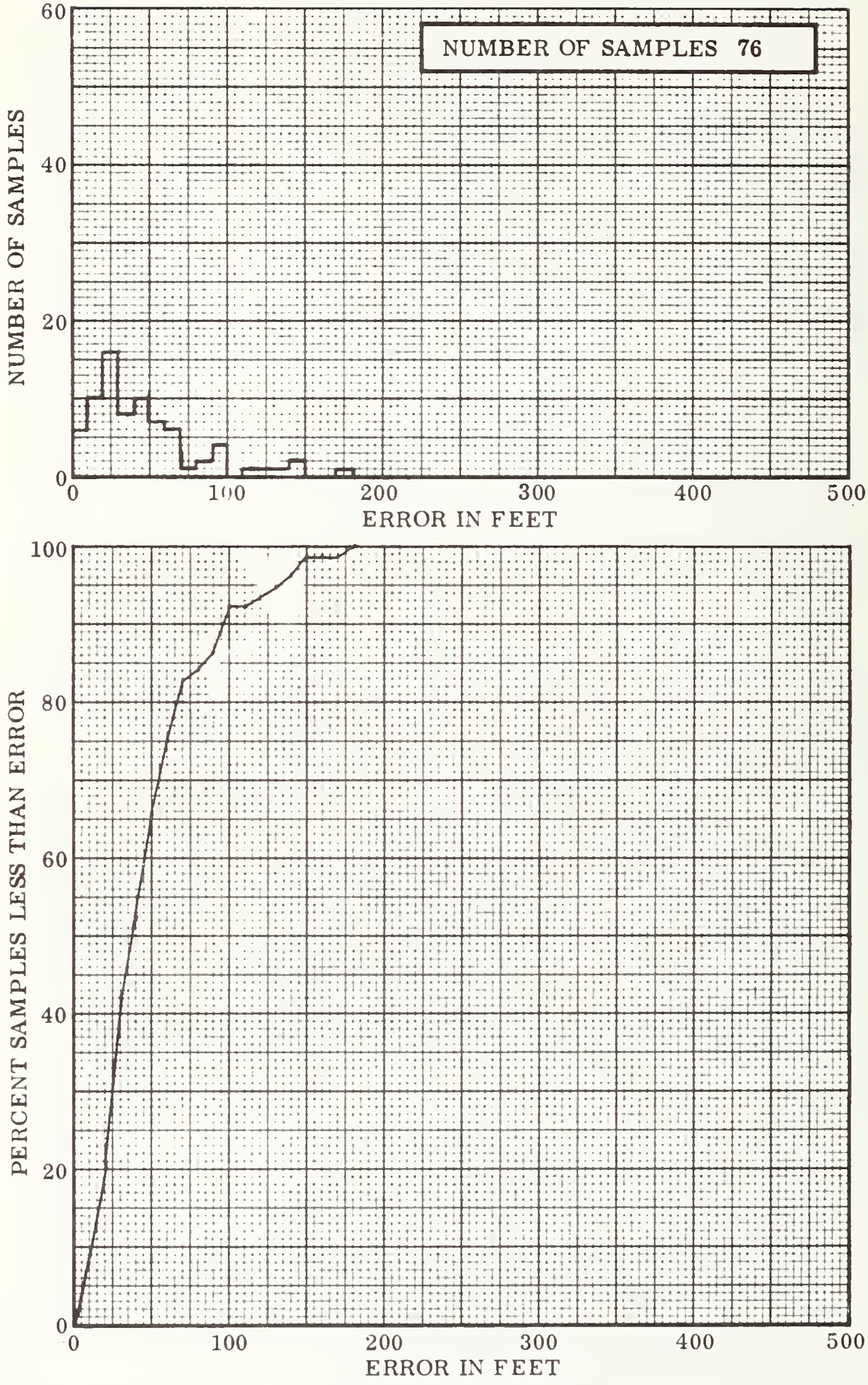


FIG. 8-13 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 23

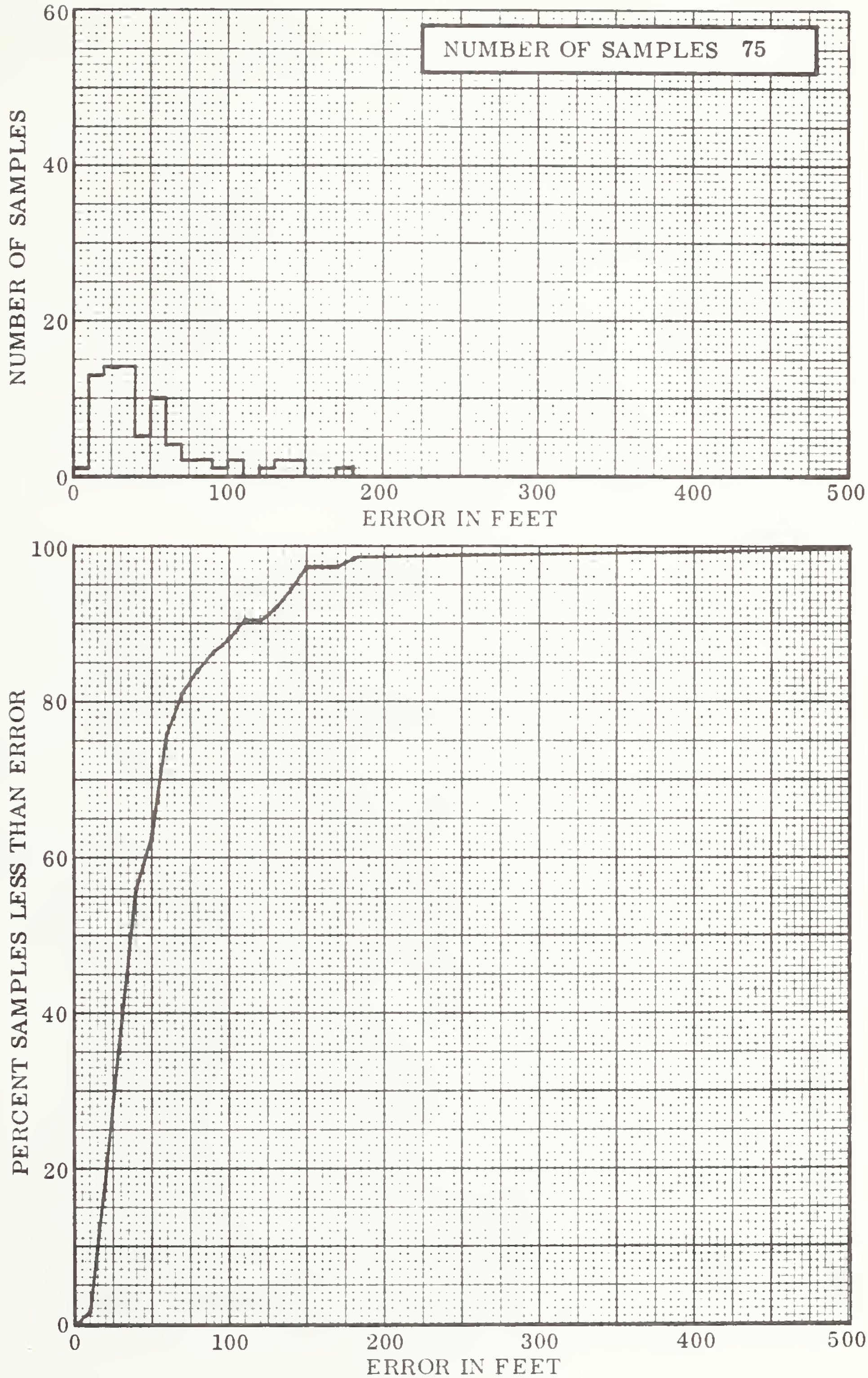


FIG. 8-14 FIXED ROUTE LOCATION SUBSYSTEM ERROR STATISTICS, RUN 24

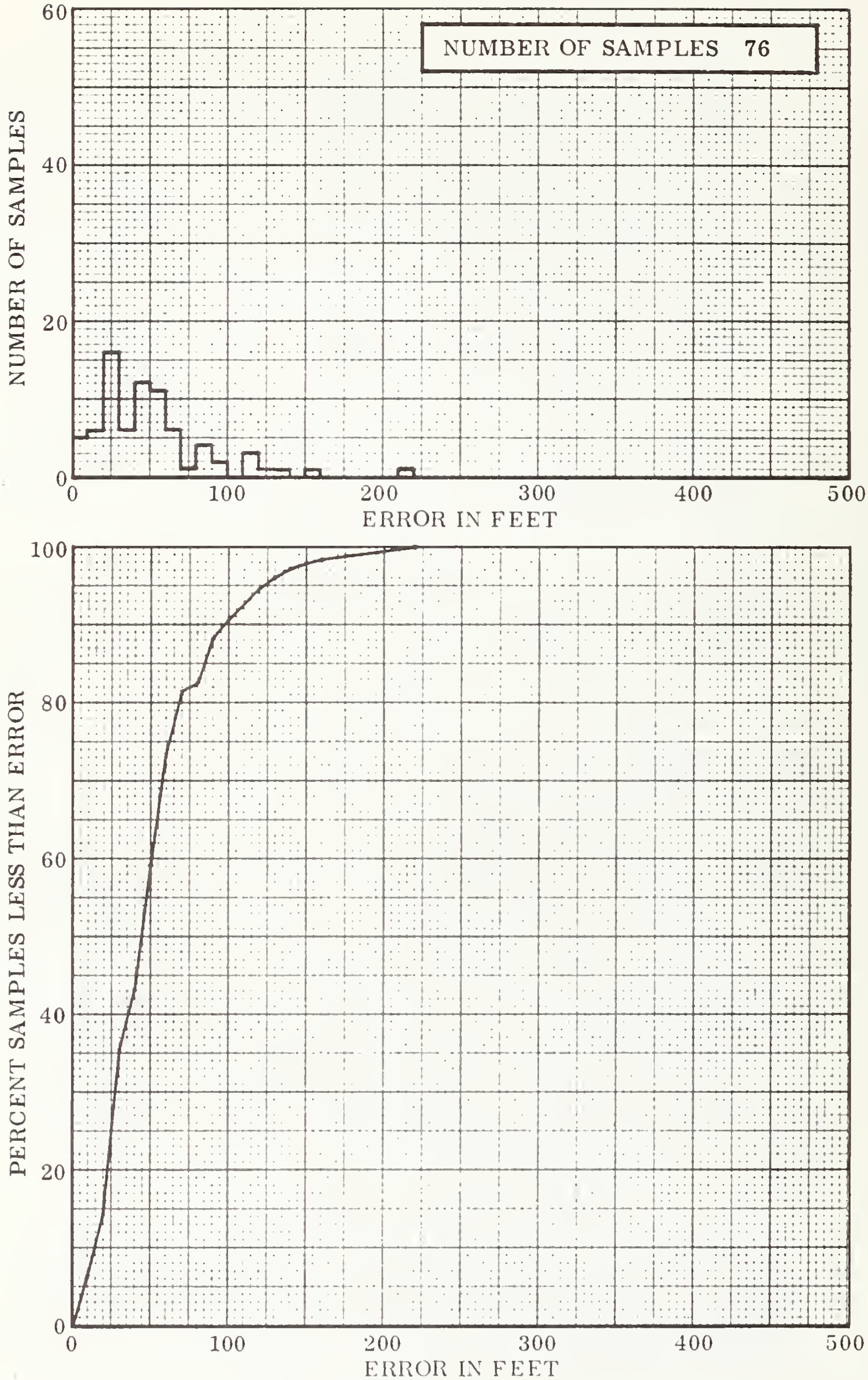


FIG. 8-15 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 25

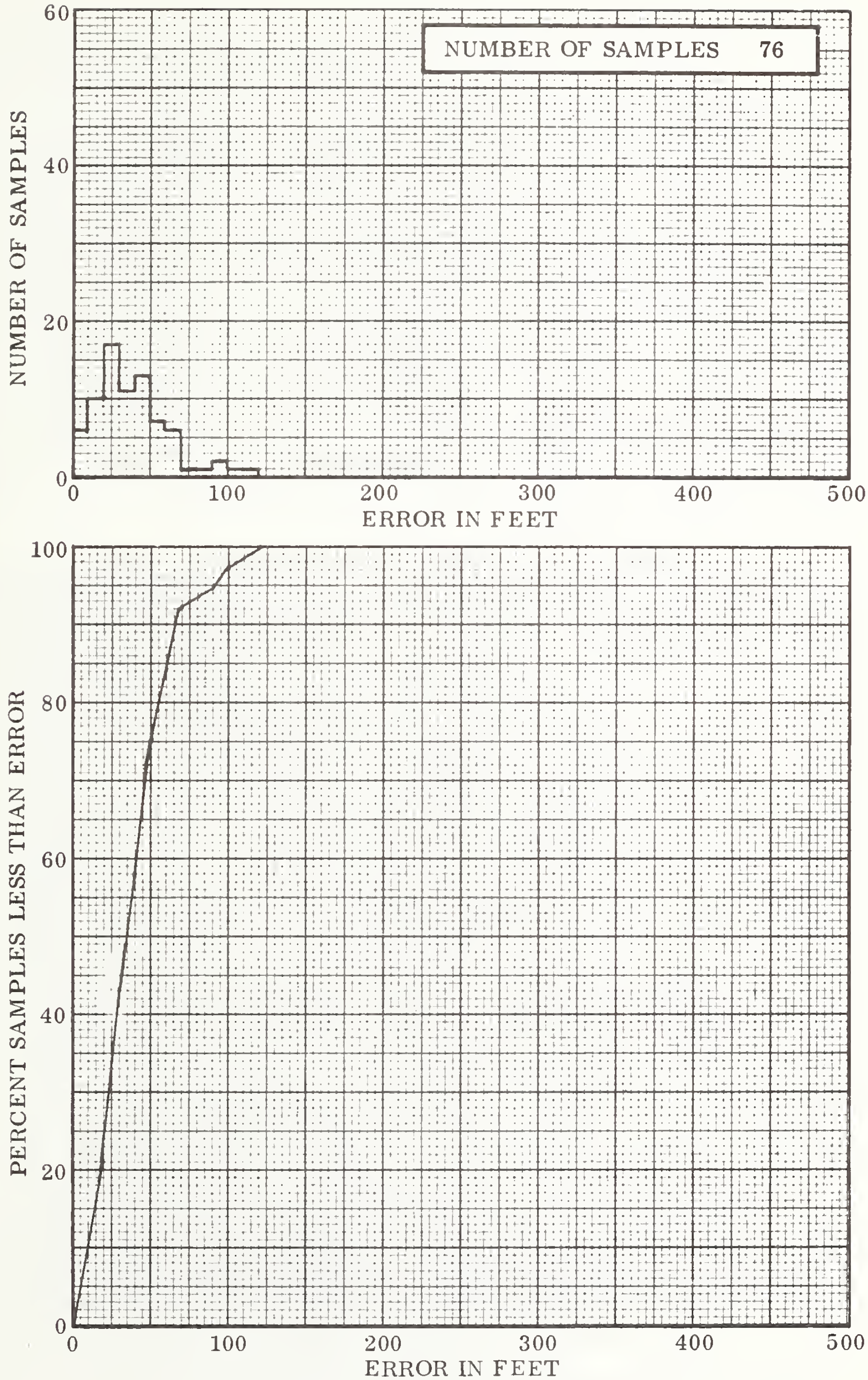
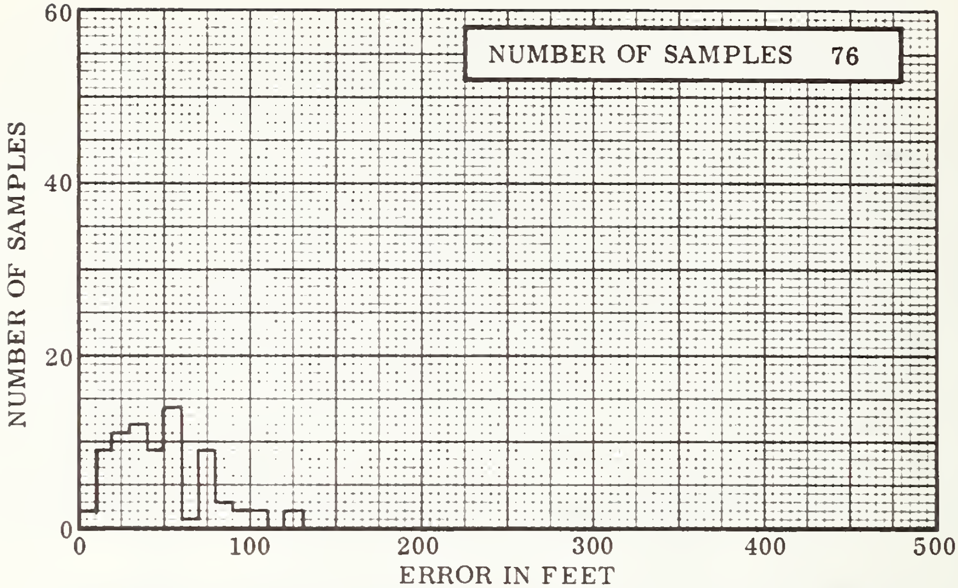


FIG. 8-16 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 26



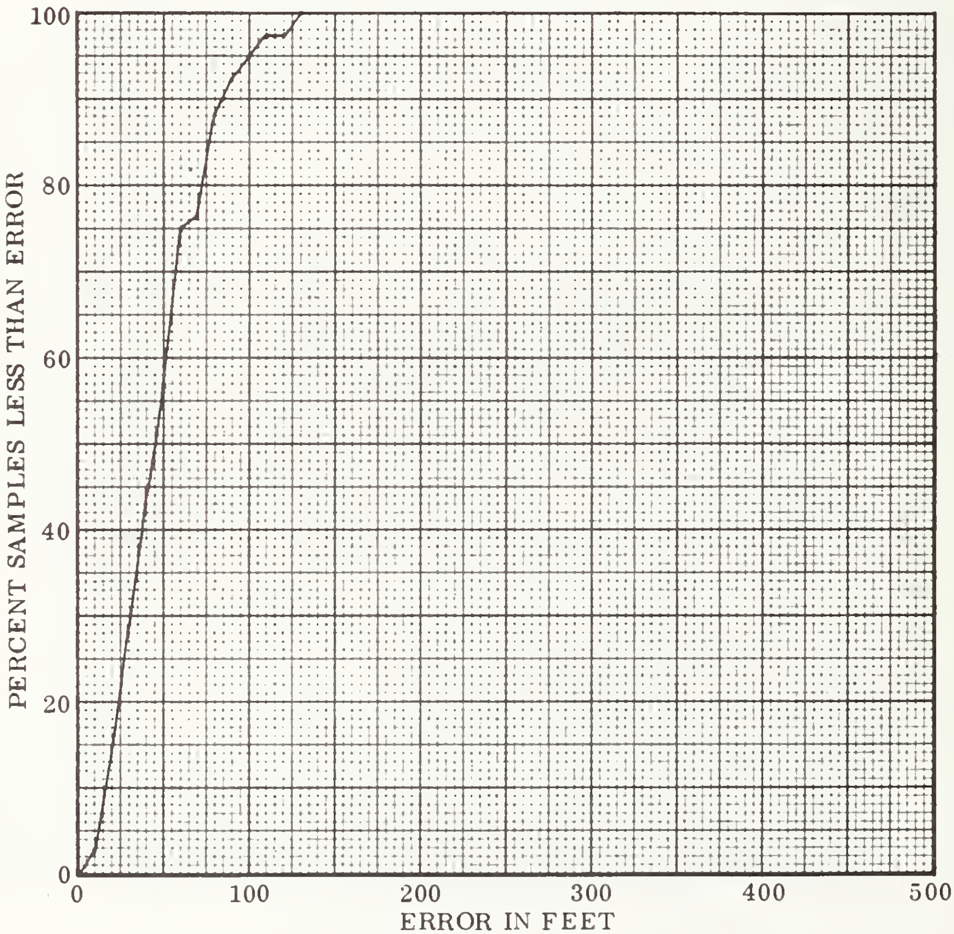


FIG. 8-17 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 27

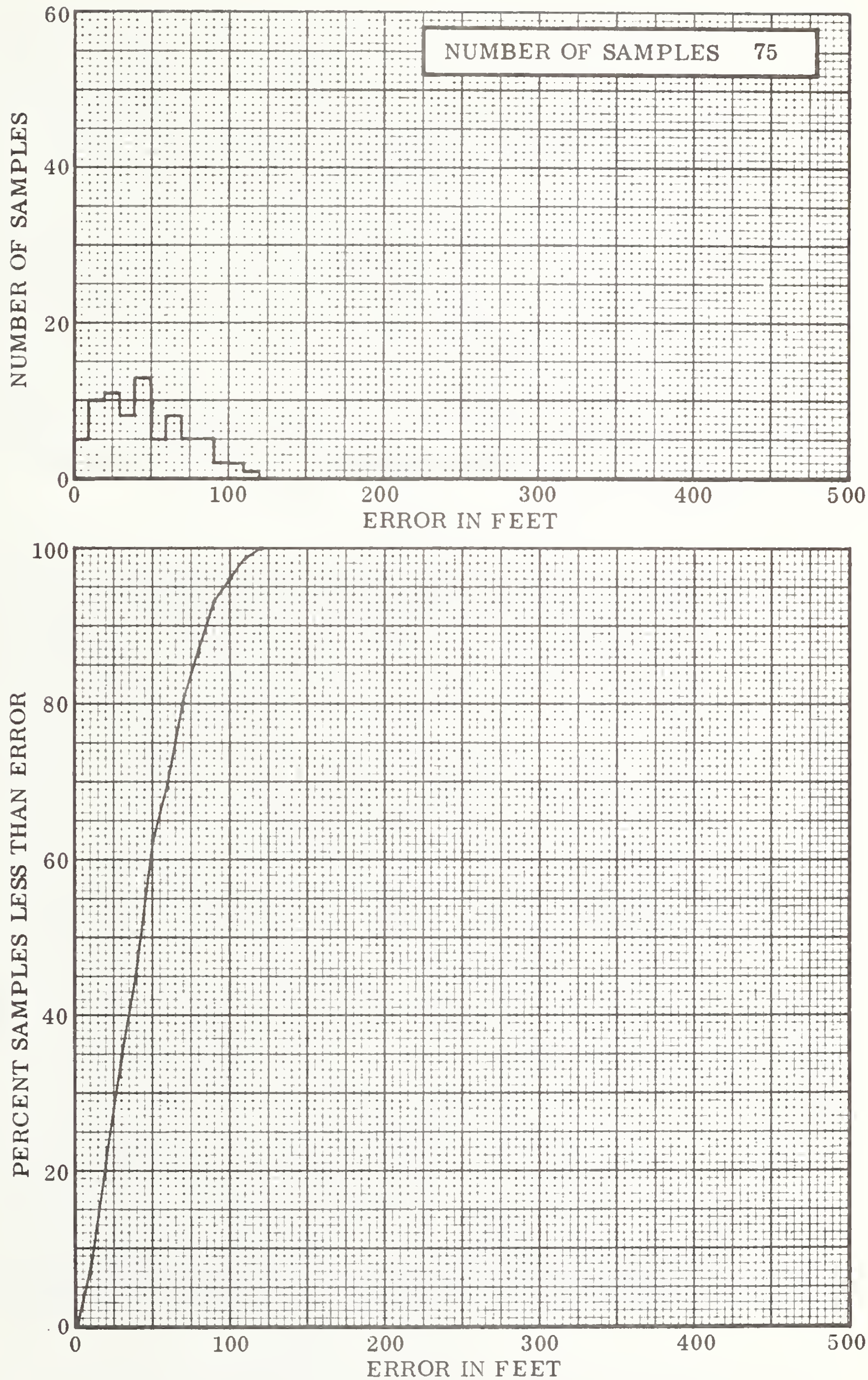


FIG. 8-18 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 28

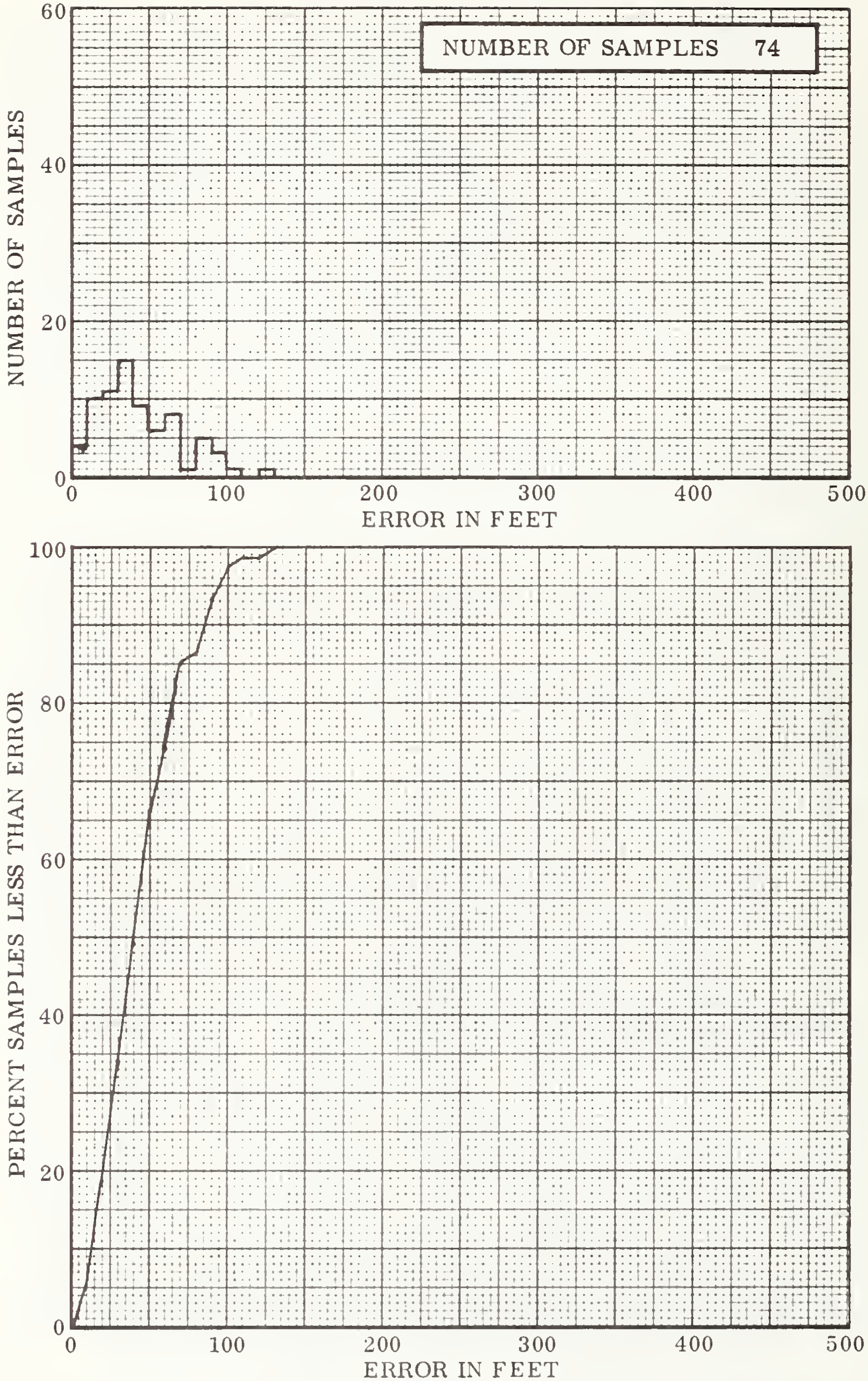


FIG. 8-19 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 29

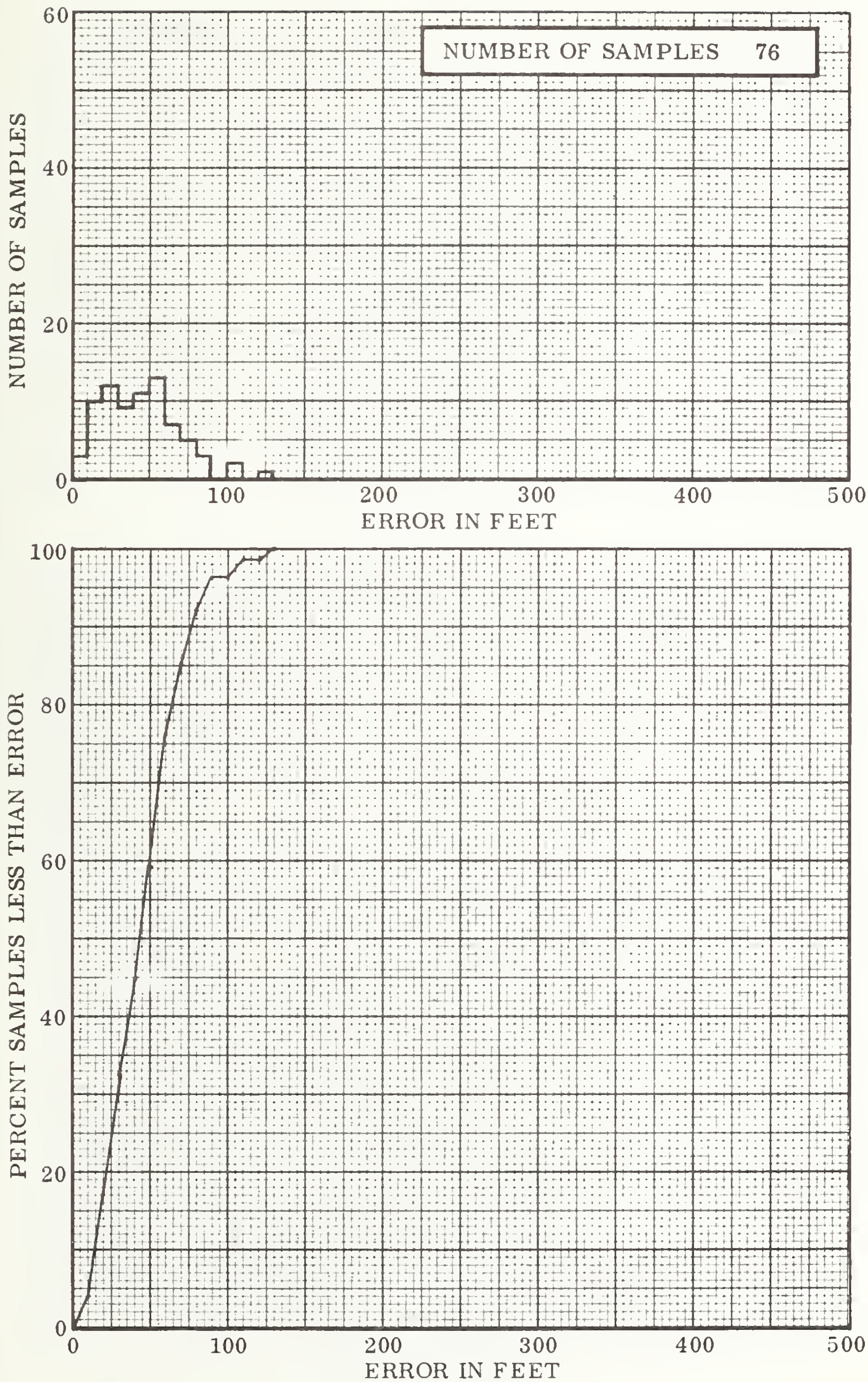


FIG. 8-20 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 30

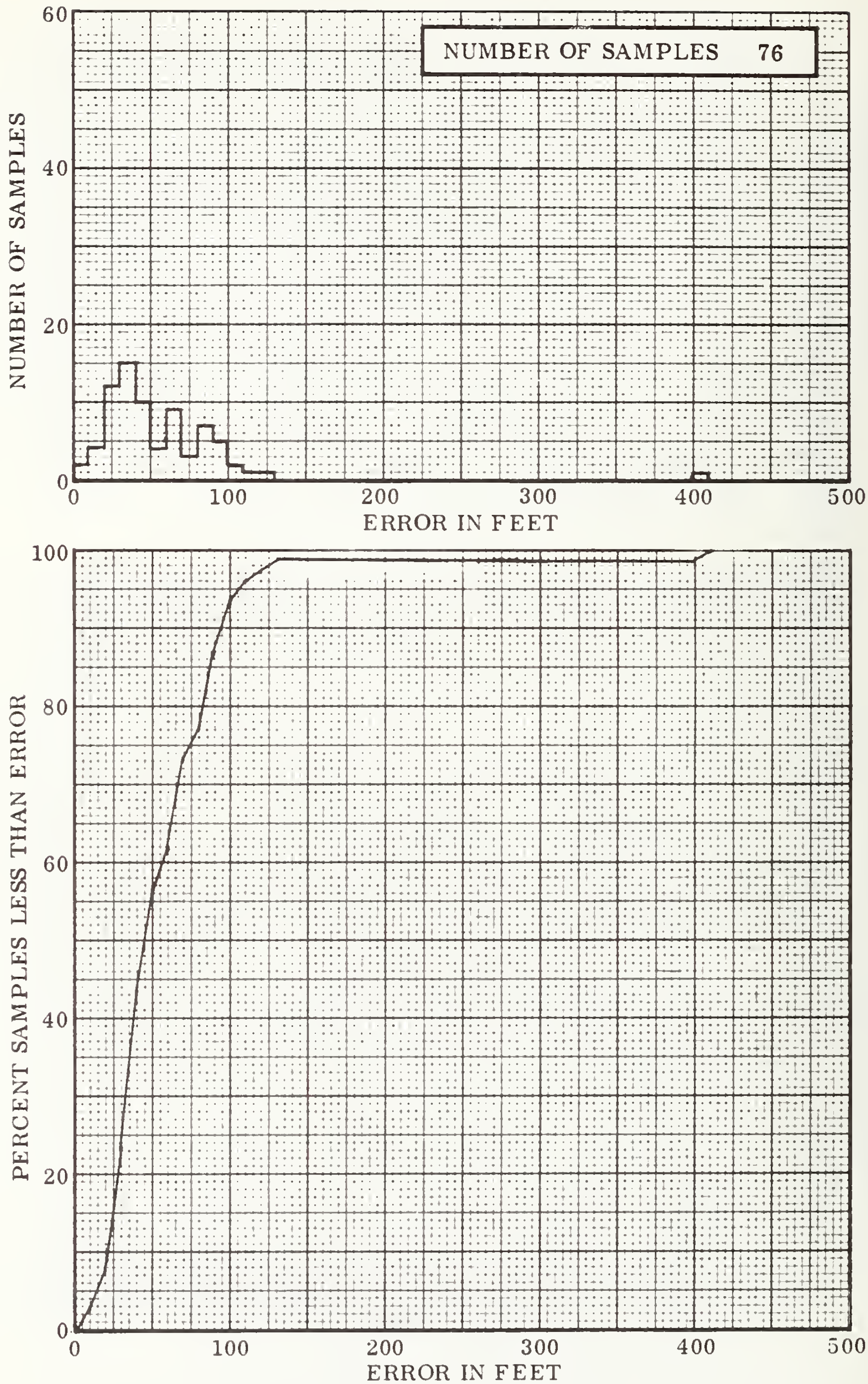


FIG. 8-21 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 31

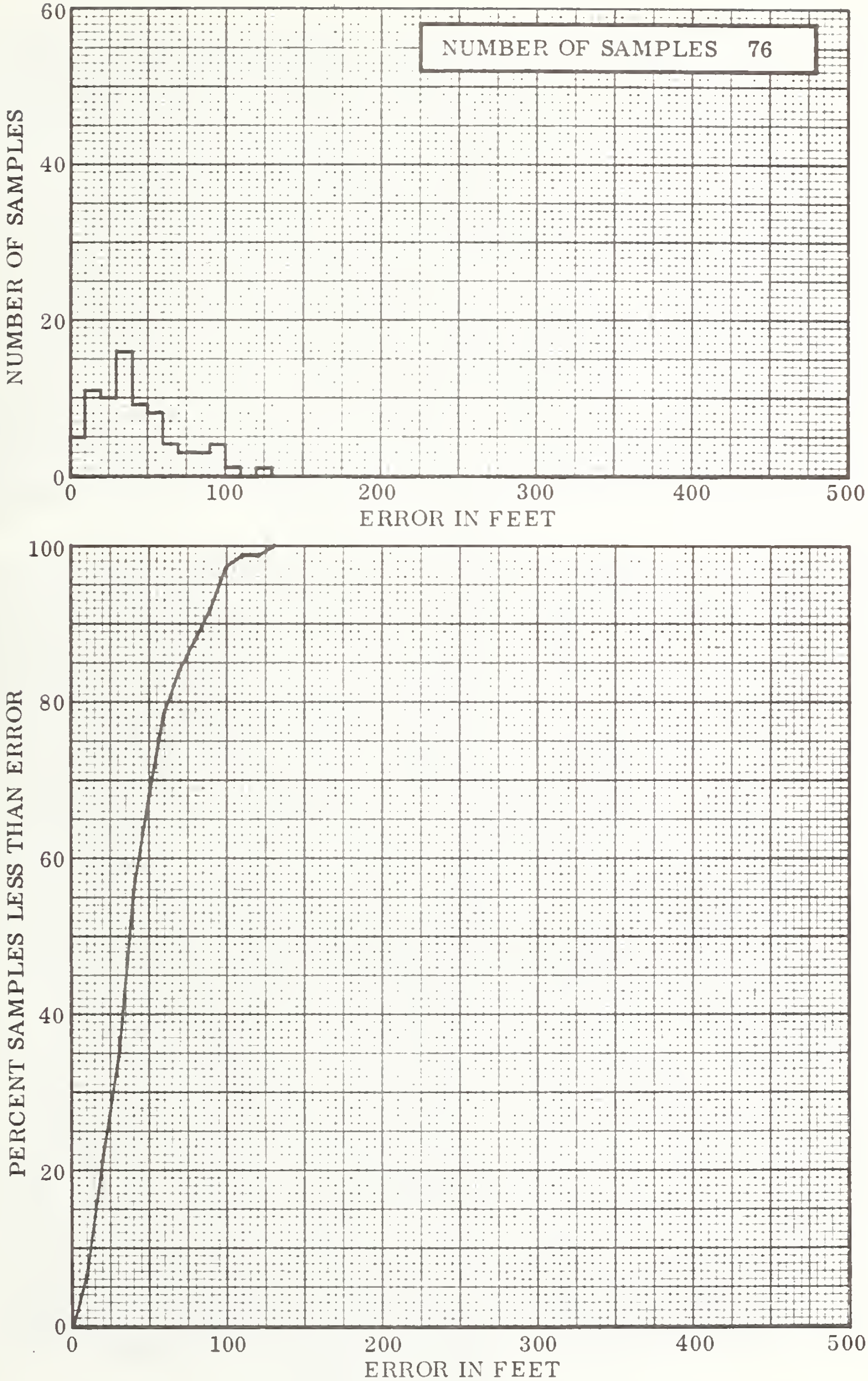


FIG. 8-22 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 32

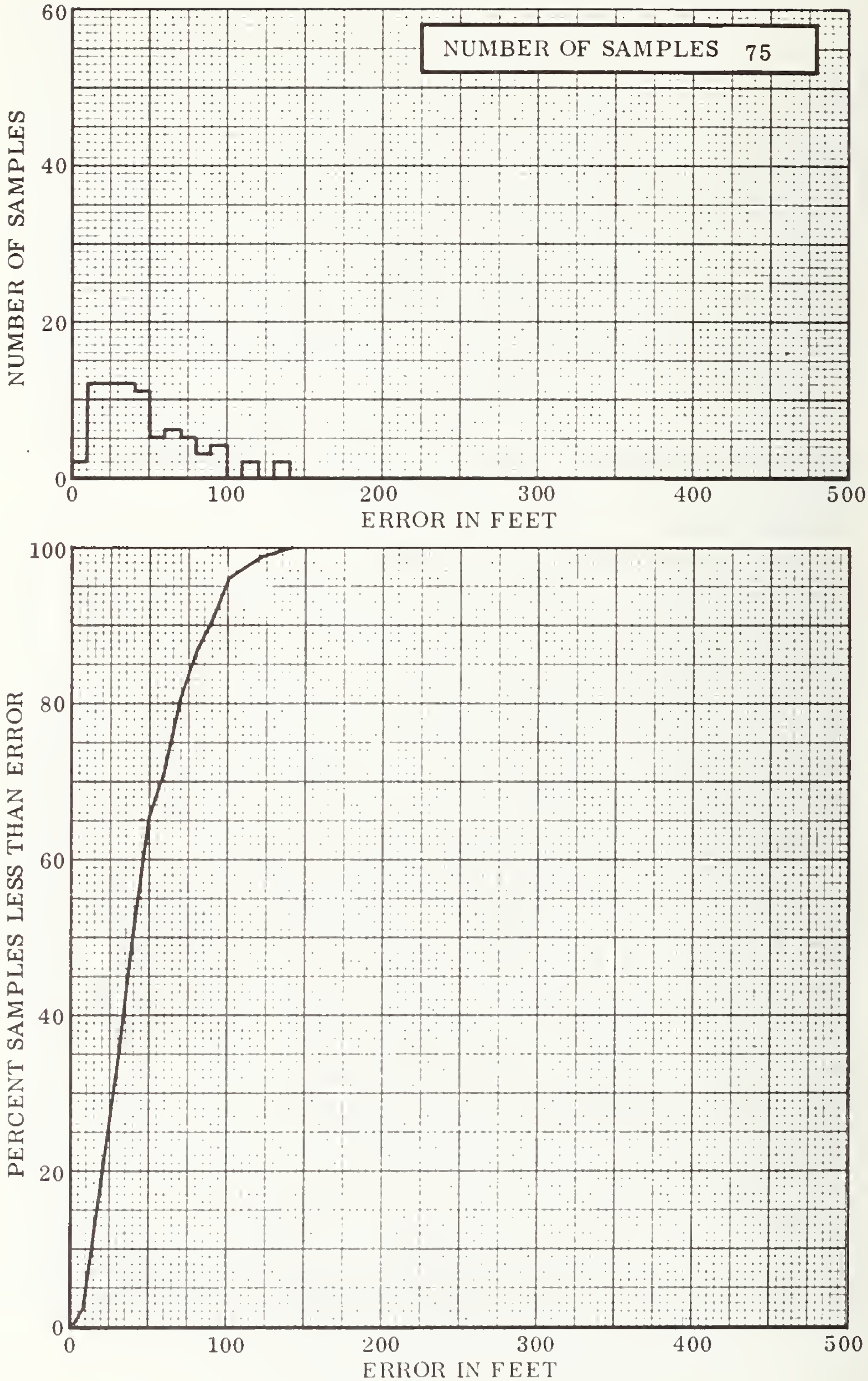
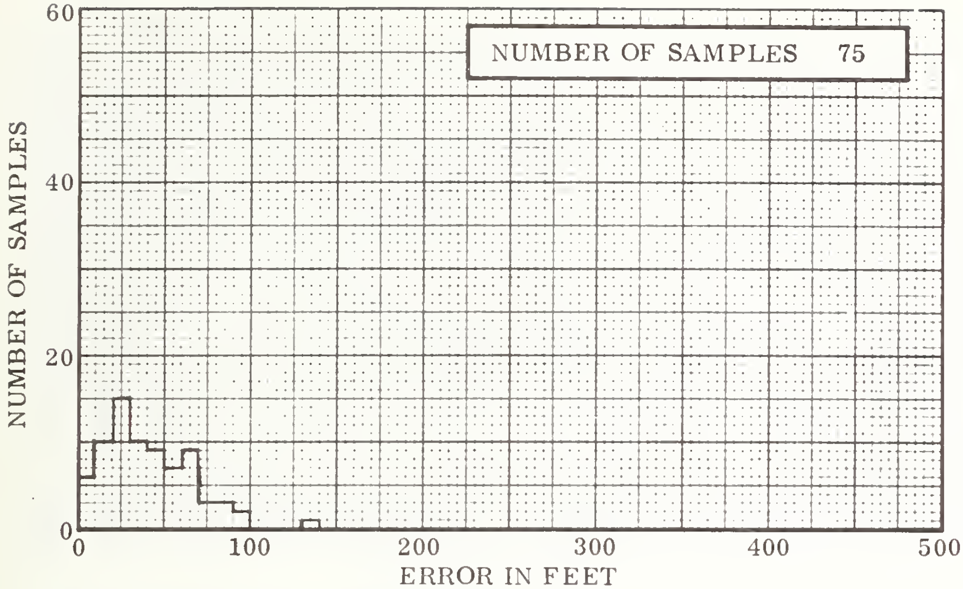


FIG. 8-23 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 34



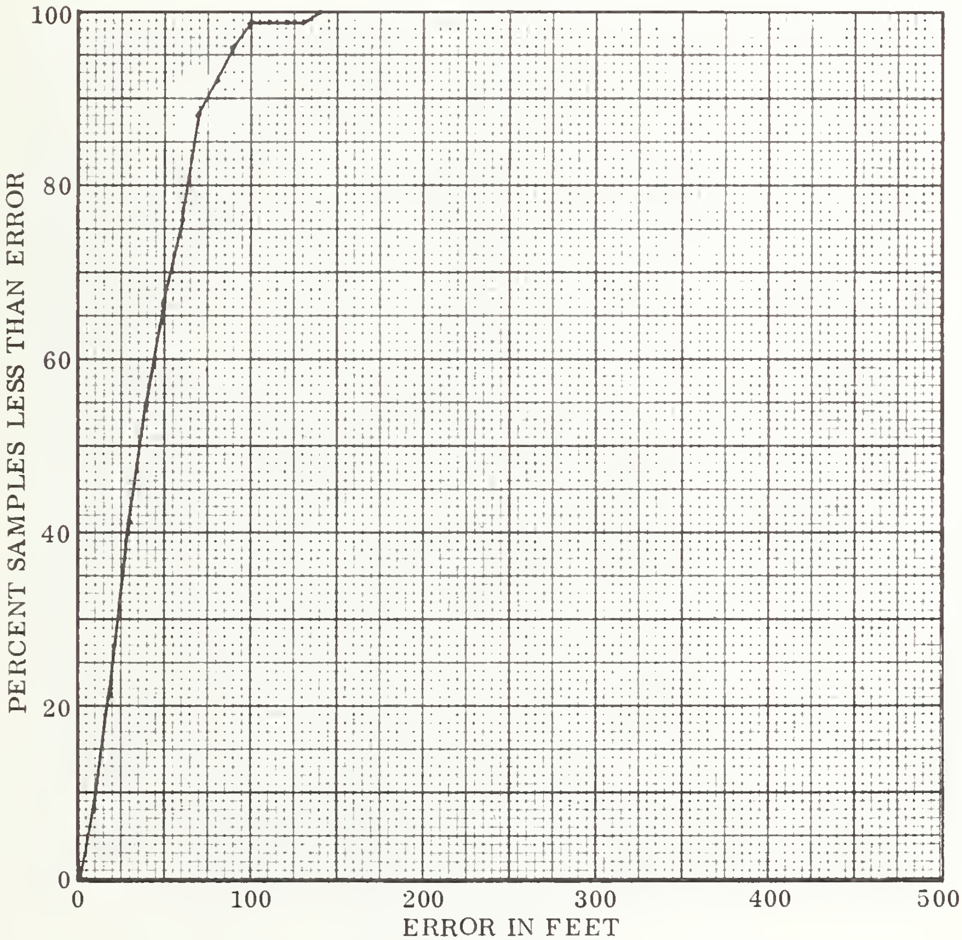


FIG. 8-24 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 35

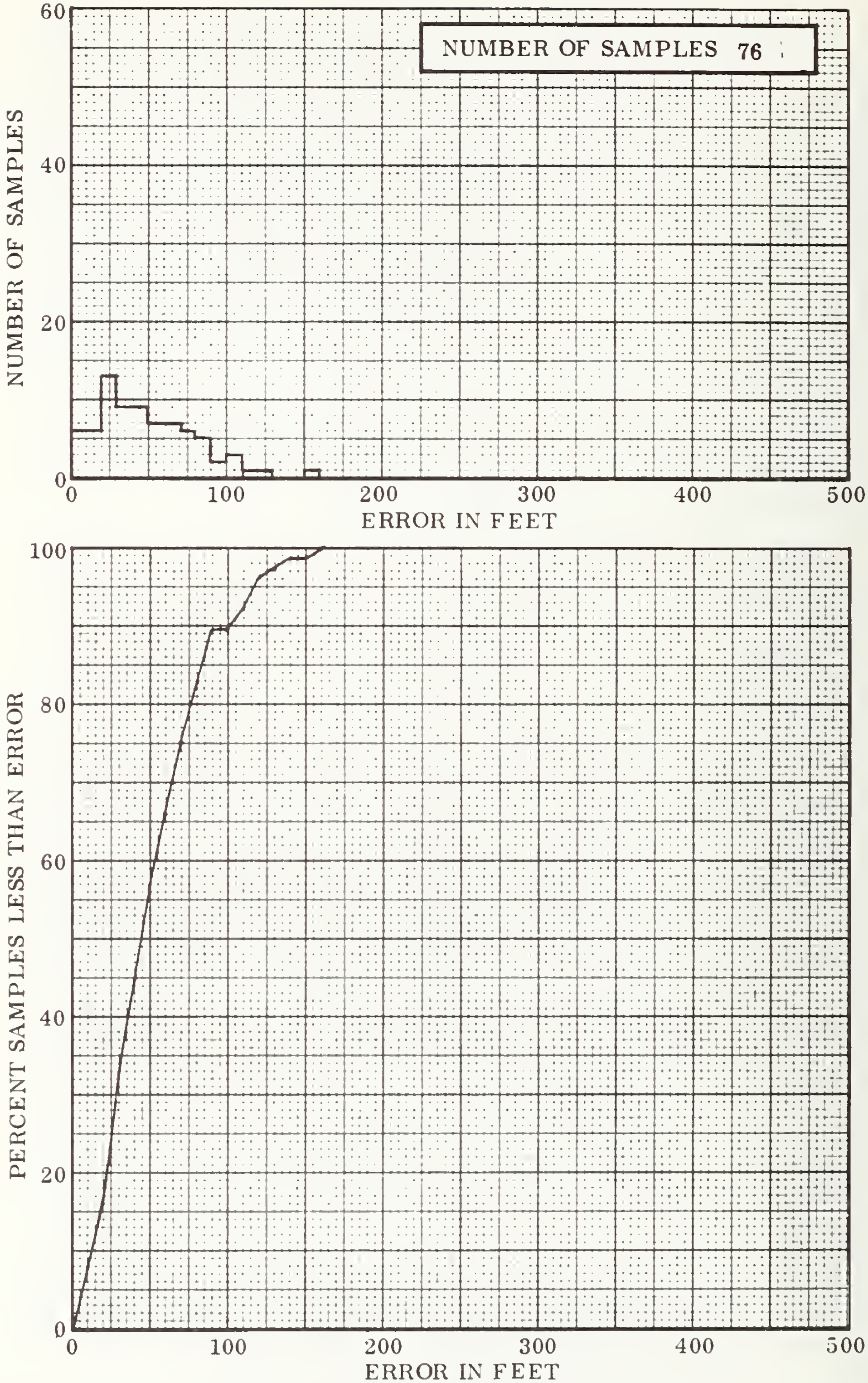


FIG. 8-25 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 36

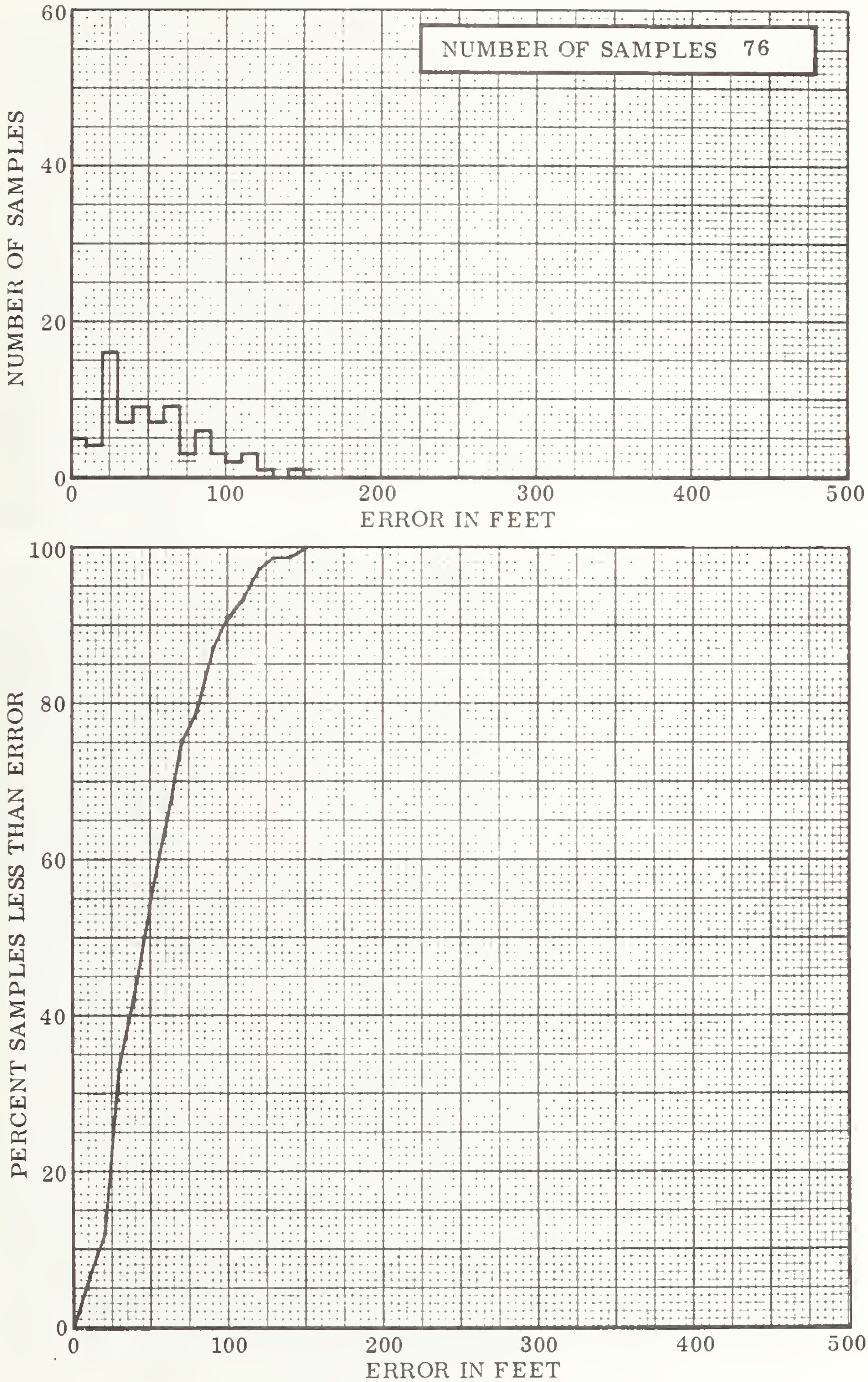


FIG. 8-26 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 37

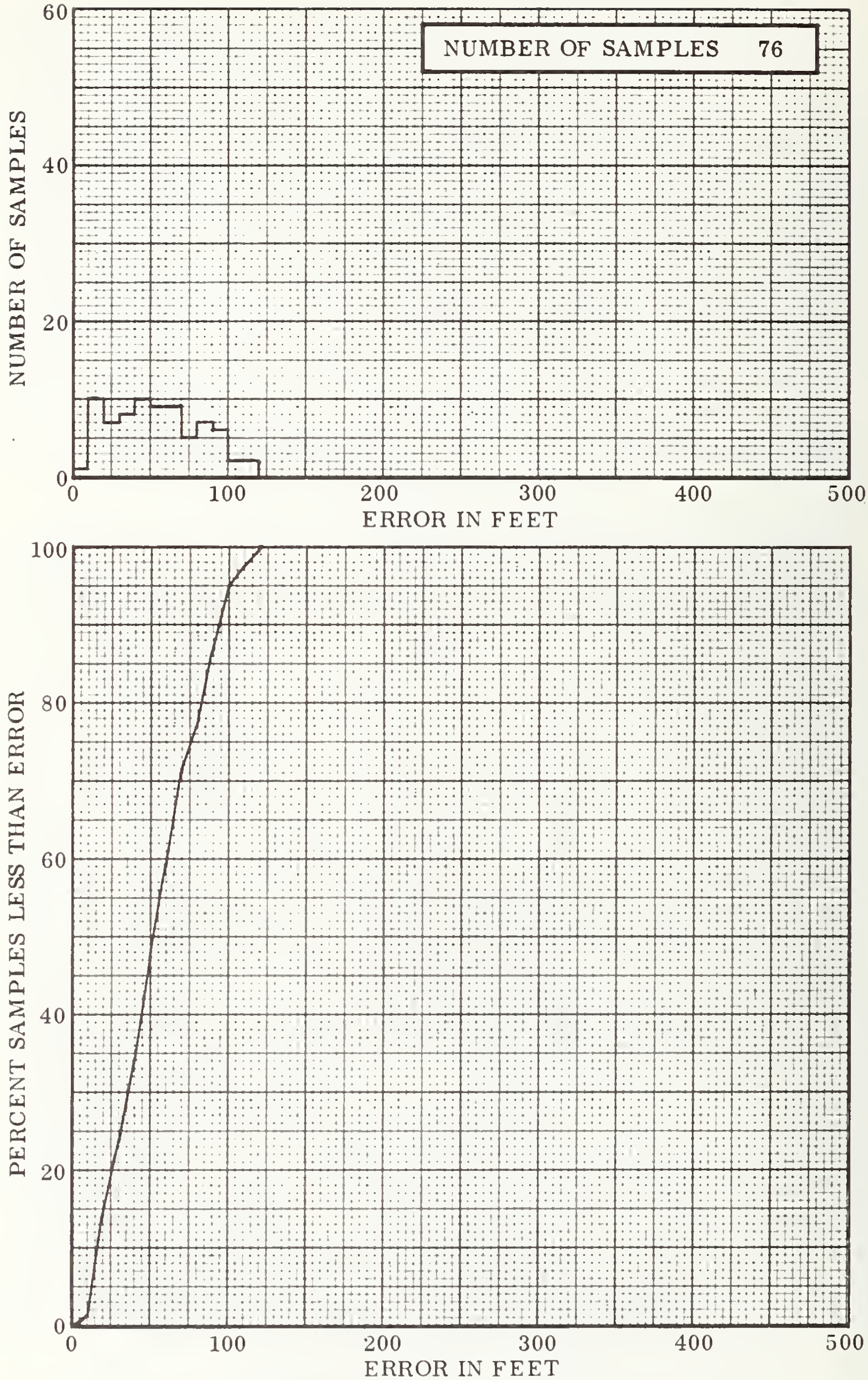


FIG. 8-27 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 38

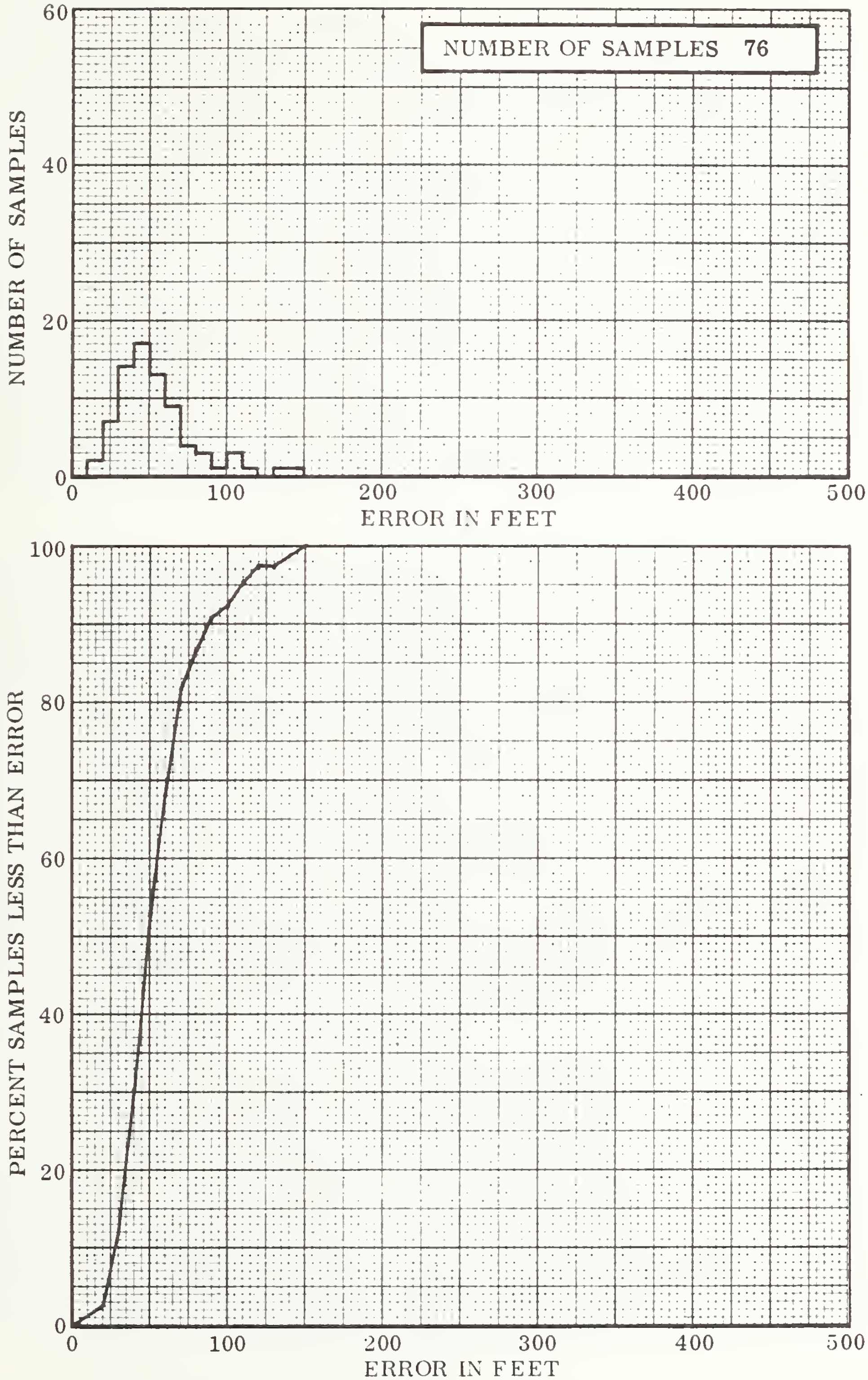


FIG. 8-28 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 39

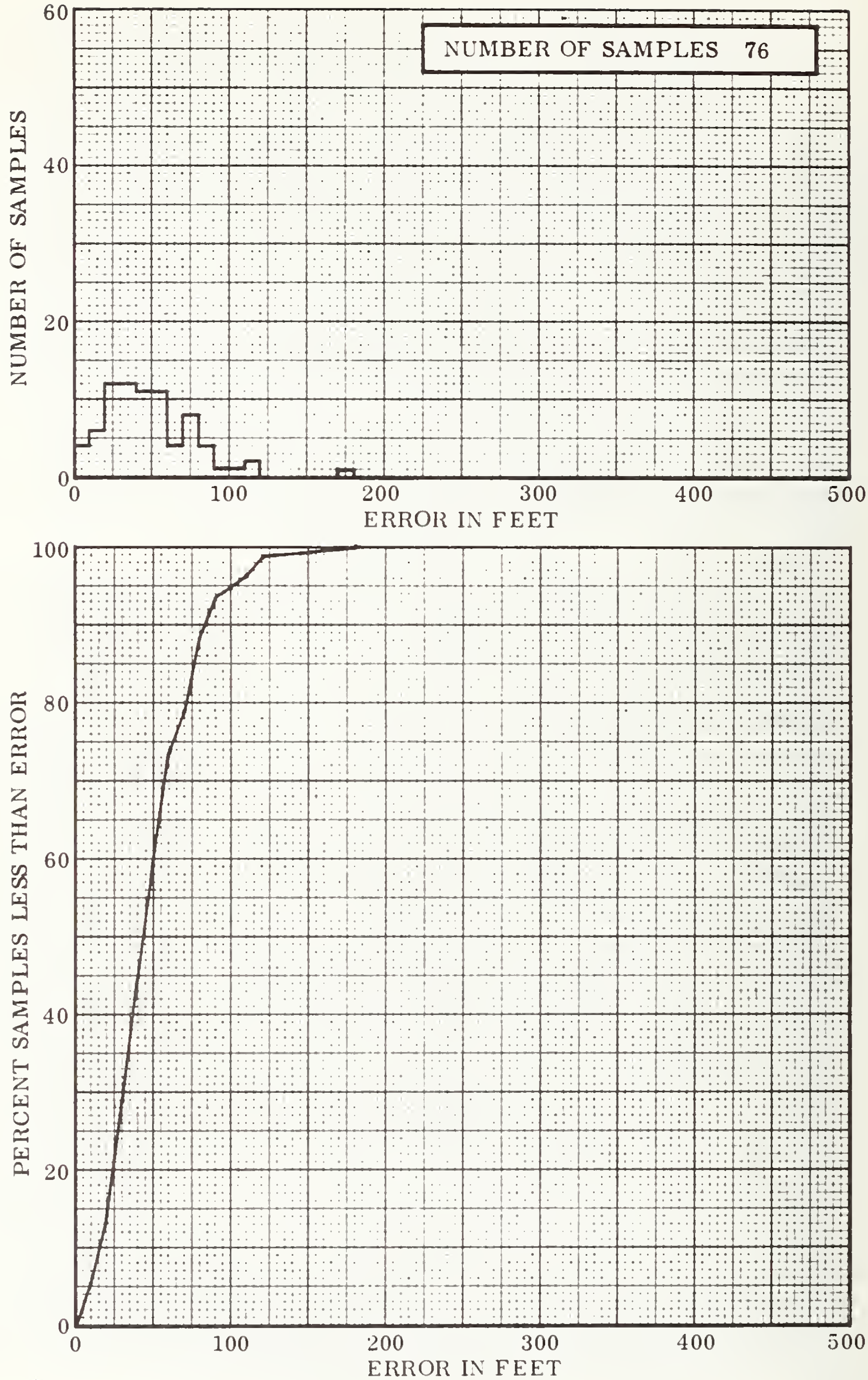


FIG. 8-29 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 40

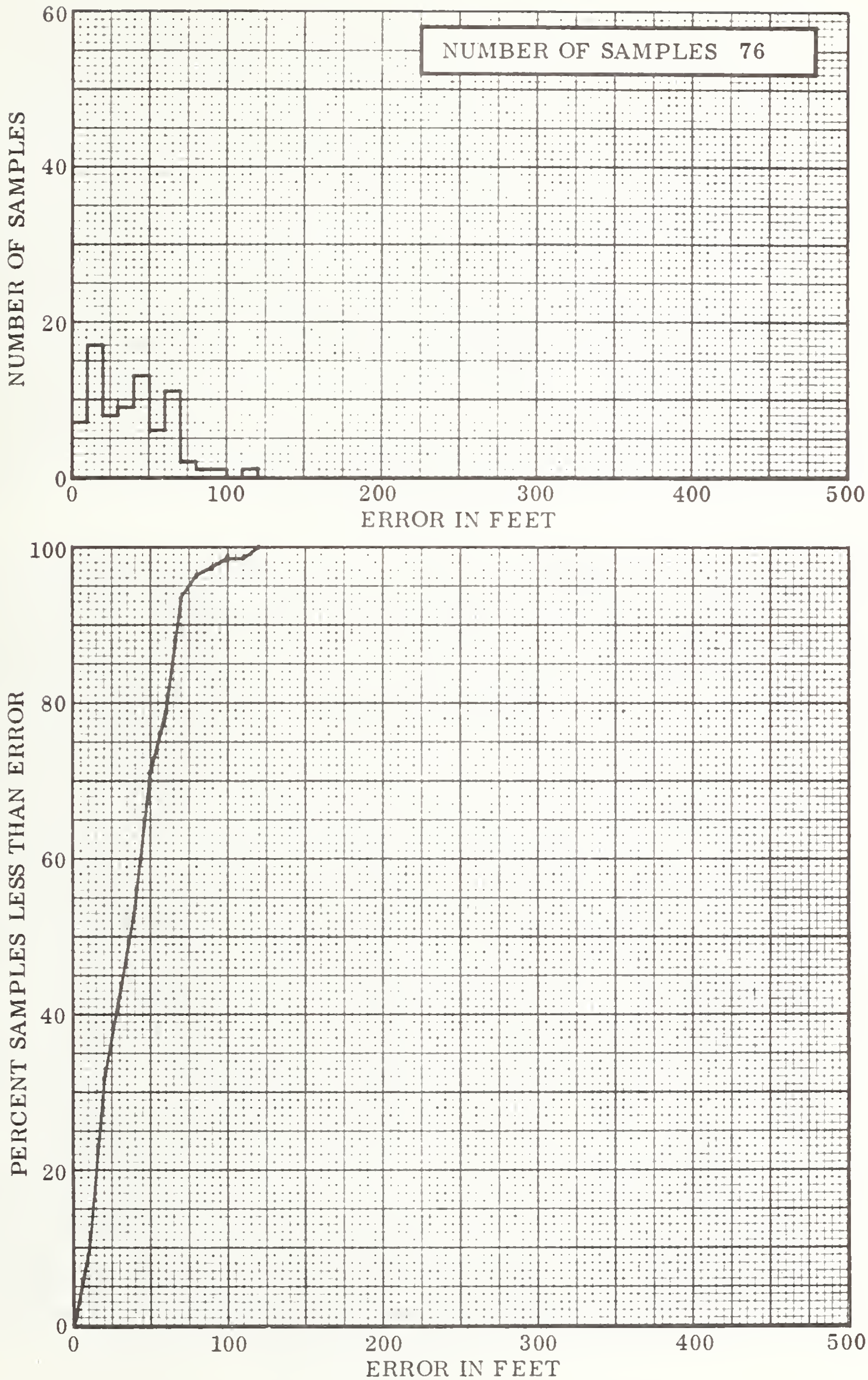


FIG. 8-30 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 41

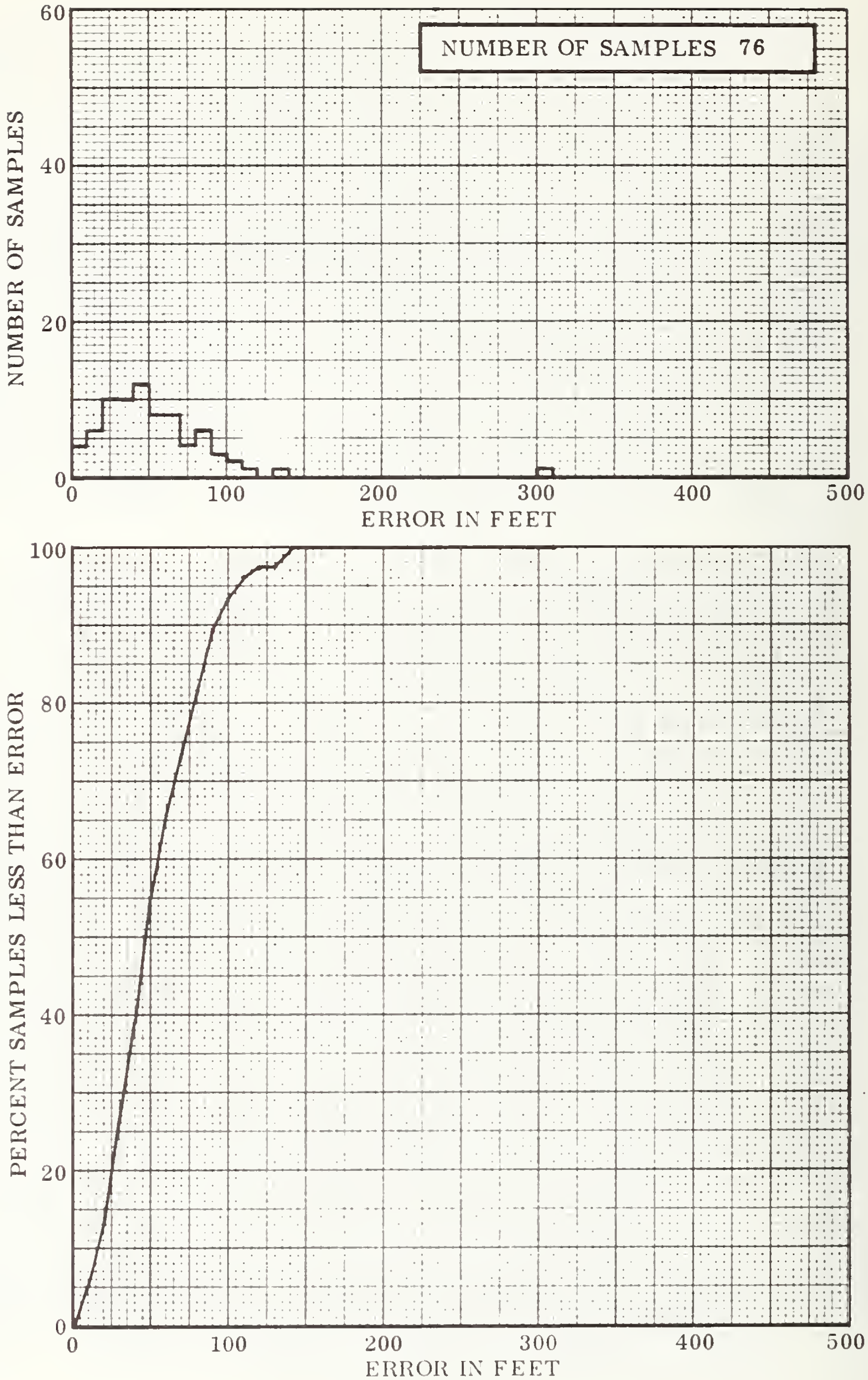


FIG. 8-31 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 42

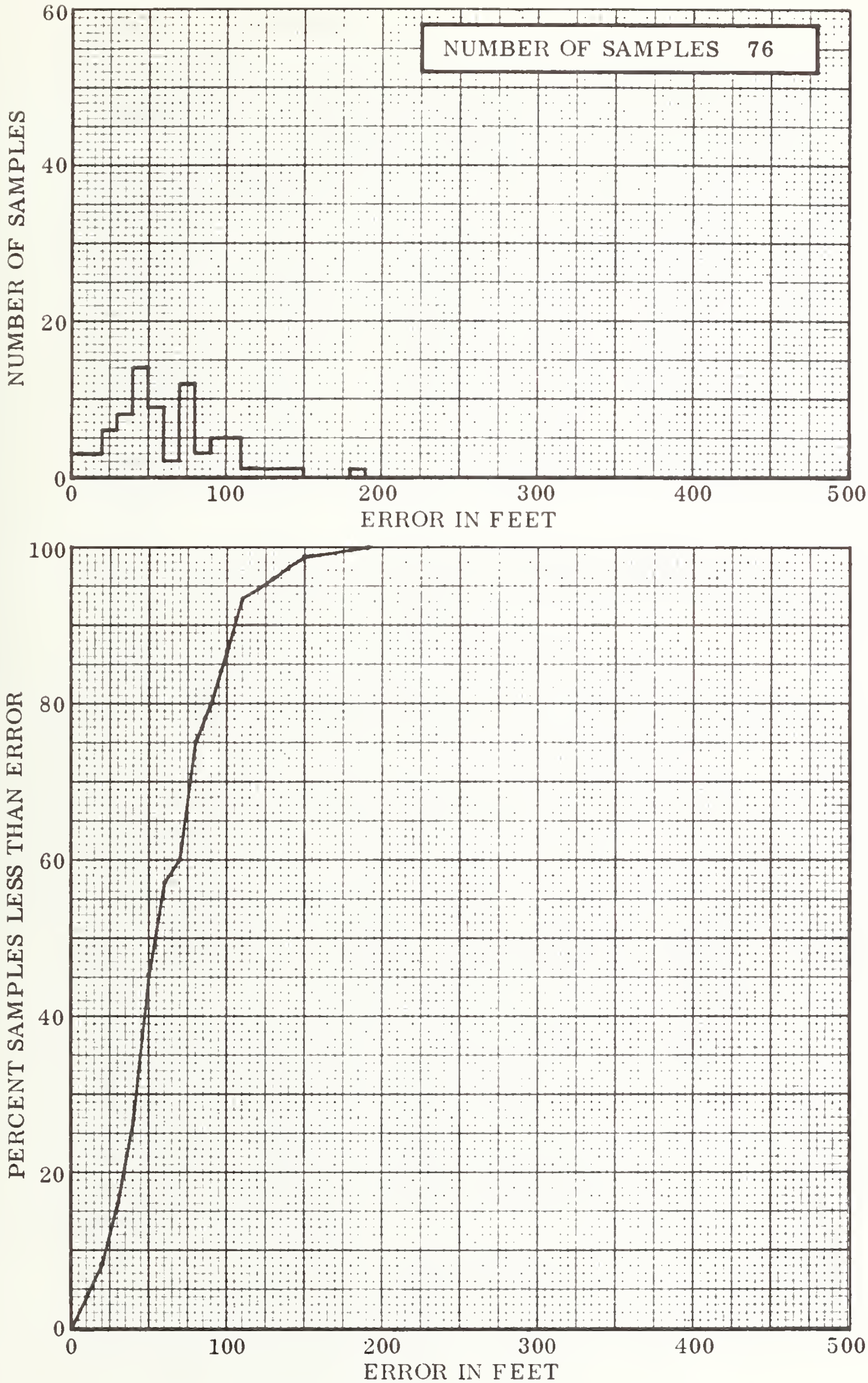


FIG. 8-32 FIXED ROUTE LOCATION SUBSYSTEM ERRORS, RUN 43

TABLE 8-4 AVERAGE ERRORS OVER ONE-TENTH MILE SEGMENTS OF FIXED ROUTE RUNS 13 AND 18

RUN 13 FIXED ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

	28	25	18	16	14	13	4	34	25	31
	59	61	60	43	44	19	2	36	65	87
	76	57	23	39	60	30	17	47	49	49
	45	45	42	26	14	20	17	39	105	85
	80	73	115	142	155	31	34	49	71	52
	40	50	58	54	34	29	13	24	19	10
*	23	52	55	36	16	36	71	19	27	38

CT1:RUN013.001

39	57	52	130	78	124	116	132	53	43
72	35	17	27	38	33	34	44	29	34
32	43	68	80	82	83	75	94	93	68
67	34	45	27	44	87	87	89	50	19
17	19	15	21	41	22	20	36	38	47
46	44	49	48	29	37	53	41		

.

RUN 18 FIXED ROUTE
AVERAGE ERROR IN FEET OVER ONE-TENTH MILE SEGMENTS

	57	58	59	52	42	41	5	27	42	29
	51	59	60	52	47	37	16	34	106	111
	98	71	45	63	87	28	18	54	54	47
	33	31	28	30	14	11	27	42	85	72
	66	57	93	51	41	20	25	39	54	37
	48	45	54	49	32	28	16	32	25	15
*	21	49	51	38	20	44	88	45	53	59

CT1:RUN018.001

56	61	39	256	55	105	106	142	38	46
63	23	19	27	30	31	34	47	35	32
27	33	53	69	68	70	64	71	72	65
65	55	55	30	44	92	104	104	95	31
30	29	18	23	42	24	15	19	19	36
33	24	24	24	18	10	29	57		

.

TABLE 8-5 SUMMARY RESULTS OF ONE-TENTH MILE SEGMENTS, FIXED ROUTE

Run No.	Max Avg. Error (feet)	Segment Number	Run No.	Max Avg. Error (feet)	Segment Number
11	116	43	27	113	76
12	121	107	28	169	77
13	155	145	29	159	43
14	999**	75	30	135	43
15	127	74	31	390*	10
16	140	43	34	159	43
17	113	20	35	140	43
18	256	74	36	152	77
20	154	74	37	133	84
21	155	44	38	108	20
22	149	42	39	126	43
23	169	77	40	109	43
24	158	77	41	105	53
25	123	42	42	122	43
26	156	61	43	137	76

* 5th wheel error between CP2 and CP4 caused large error during segments 10 and 11.

** As noted in Table 6-5, and as recorded on the Run 14 log sheet, TA16 was erroneously not entered during Run 14. As noted in Table 4.3-2 of the Appendix, TA16 was inserted via card input during processing with the FRSYS routine. Inadvertently, however, the card input was not used when FRTEN was used to process Run 14. This allowed large errors to be generated when the vehicle was between TA16 and TA17. The fifth wheel value at TA17 was 6.64 miles. The three one-tenth mile segments which indicate large errors on Run 14 are the three segments ending in 6.4, 6.5, and 6.6 miles respectively. The street segment between TA16 and TA17 is 1466 feet in length which includes the three effected one-tenth mile segments which exhibited maximum errors of 743, ***, (the computer prints out *** if 999 feet is exceeded), and 752 feet respectively. As a result of the obvious card input error, these three large values may be disregarded as resulting from a data recording/processing error rather than an AVM error.

This error was discovered just prior to submittal, coincident with the unavailability of the HI^3 computer at Fort Worth.

summary of these data. The Appendix contains individual results obtained for each run. Note that of all data processed, the largest average error on any one-tenth mile segment on any run was 256 feet, nearly 200 feet less than the AVM specification.

8.2 AVM SYSTEM TEST RESULTS

The results obtained by simulating a complete AVM system through imposition of a 20-second polling interval and 5 percent communication errors are presented in this subsection. The timepoint performance results are also presented.

8.2.1 AVM System Vehicle Location

The results obtained by processing fixed route data through use of the FRSYS routine are summarized in Table 8-6. The cases in which no communication errors were present and in which a 5 percent communication error rate was simulated are both presented. Data processing problems associated with use of the FRSYS program are described in Table 8-7 and in subsection 8.3.

A total of 7,139 pseudo checkpoint samples were processed through the FRSYS routine. Runs 19 and 33 could not be processed. Run 20 (power failure and Run 32 (magnet lost from fifth wheel) were not processed. Table 8-7 summarizes all such problems associated with system level processing. A total of 320 pseudo checkpoints were processed manually, for a grand total of 7459 pseudo checkpoint samples. During the recording of fixed route test data it was observed that a total of 5 turns (TA events) were erroneously recorded or not recorded at all on six runs. In order to run these tapes through FRSYS (and FRTEN), card input data had to be utilized so that each and every TA event was available for processing each run. In cases in which a TA was not recorded on tape, it was inserted by use of one of the following processes:

1. On Run 14, TA 16 was inserted 478 feet (on the fifth wheel) after CP 35.

2. On Run 16, TA 24 was inserted 54 feet (on the fifth wheel) after TD 11.

3. On Run 21, first occurrence of TA 16 changed to TA 6.

4. On Run 24, TA 33 was deleted.

5. On Run 27, first occurrence of TD 10 changed to TA 10.

Items 1, 2, and 3 were noted on their respective data logs at the time of occurrence. Items 4 and 5 were not discovered until a dump of the recorded data was examined. All fixed route data processing anomalies are discussed in subsection 8.4.

TABLE 8-6 FIXED ROUTE AVM SYSTEM LOCATION ACCURACY RESULTS

Run No.	No. of Pseudo Checkpoints Processed	No Communication Errors			5% Communication Errors		
		Average Error (feet)	95% Error (feet)	99.5% Error (feet)	Average Error (feet)	95% Error (feet)	99.5% Error (feet)
11	307	48.96	104	150	48.63	104	150
12	300	51.48	106	138	50.75	106	138
13	283	48.78	111	177	48.98	111	177
14	234	44.88	98	108	44.74	98	108
15	219	46.14	125	131	46.06	125	131
16	200	41.22	97	123	40.78	97	123
17	260	43.43	94	121	42.82	94	121
18	322	53.05	108	303	53.61	108	303
19	*						
20	**						
21	272	42.59	128	165	43.36	128	165
22	239	45.50	125	140	46.87	125	140
23	252	47.70	127	169	48.57	127	169
24	239	51.25	146	177	51.25	144	177
25	241	50.17	133	216	50.76	135	227
26	238	43.62	105	188	44.30	107	188
27	240	43.20	96	126	42.23	101	126
28	259	39.30	82	116	39.85	103	125
29	261	39.97	90	123	40.01	90	123
30	257	43.50	82	110	43.70	88	110
31	259	54.62	129	407	54.37	129	406
32	***						
33	*						
34	289	41.22	87	199	40.80	87	199
35	255	39.05	83	128	38.74	87	128
36	229	47.85	109	154	48.20	116	154
37	247	50.84	117	151	51.07	117	151
38	222	54.62	91	867	53.75	91	867
39	281	55.81	109	383	55.82	109	383
40	269	46.50	90	267	46.58	90	267
41	329	37.26	80	116	37.37	80	116
42	231	45.44	94	150	44.80	94	150
43	225	58.52	138	243	58.46	138	243
Total	7459	48.09	105	188	46.79	105	188

* Bad Tape
** Power Failure
*** Lost Magnet

TABLE 8-7 FIXED ROUTE DATA PROCESSING ANOMALIES (FRSYS)

RUN NO.	PROBLEM	RESULT
14	Missed TA 16	Inserted TA 16 at FIFTH = 33678 feet*
16	Missed TA 24	Inserted TA 24 at TD 11**
19	Bad Tape, Couldn't dump in vehicle	No Results
20	Generator Stalled	Not Processed
24	TA 33 entered in error	Deleted TA 33
	Couldn't read past CP 62	39 PCP's Processed Manually
31	5th Wheel problem between CP3 and CP 4	406 foot errors ***
32	Lost magnet during run	Didn't process
33	Bad Tape, Couldn't dump in vehicle	No Results
34	Couldn't read past CP 37	122 PCP's Processed Manually
37	CP 30 entered in error	Deleted 2nd CP 30
38	CP 71 entered in error	Deleted 1st CP 71
40	Couldn't read past CP 36	119 PCP's Processed Manually
42	CP 40 Entered in error	Deleted 1st CP 40

* The value of FIFTH was estimated by adding the distance, (from the data base) from the preceding event marker to Turn 16, to the fifth wheel reading at the preceding event marker.

** TD 11 was approximately 54 feet from TA 24 and was a convenient entry point for inserting TA 24.

*** As noted on log sheet, 5th wheel gained over 300 feet between CP3 and CP4. The resulting errors were not modified and are included in Phase I results.

Table 8-8 contains typical results obtained as output data from the FRSYS routine when Run 28 was processed.

Figure 8-33 contains an error histogram and a cumulative error distribution of all AVM system location data which were processed. The impact of 5 percent communication errors is so small as to be imperceptible in these statistics so only one curve is shown, that corresponding to a perfect communication system. Reference to Table 8-6 supports the fact that the HI^3 communication error detection and correction technique proposed for Phase II works effectively to minimize the impact of communication errors on vehicle location accuracy. Figures 8-34 to 8-62 contain the plotted error statistics corresponding to each individual fixed route test run. Figure 8-63 contains a plot of the 259 pseudo checkpoints computed for Run 28.

Output data corresponding to each set of processed test data are contained in the Appendix.

8.2.2 AVM System Timepoint Performance Results

Each data run was also processed to determine the capability of the HI^3 AVM system to accurately determine the time of departure from timepoints. During each test run, 15 timepoints were marked, through use of the TD event marker, as the front bumper of the test vehicle passed the predetermined timepoint location. Including missed or erroneous data entries, these 33 runs resulted in a total of 418 timepoint samples which were processed. An additional 32 were processed manually from the run listings.

The time of departure error results obtained by processing 451 timepoints are summarized as follows:

In 95 percent of the samples, the error was less than 11 seconds

In 99.5 percent of the samples, the error was less than 24 seconds

Percent samples with error less than 15 seconds: 98.67 percent

Percent samples with error less than 60 seconds: 100 percent

Average error: 3.9 seconds

Maximum error: 42.5 seconds

Of the 451 timepoint performance computations, 226 involved the use of the Door Close event, and the AVM system algorithm involving the R1 dropout was used to process the remaining 225. Table 8-9 contains a typical set of output data on timepoint performance for Run 27. Table 8-10 contains a tabulation of the computed errors corresponding to each timepoint and each test run.

(Text continued on 8-86)

TABLE 8-8 AVM SYSTEM TEST RESULTS, RUN 28

RUN # 28 SYSTEM LOCATION ERRORS (NO COMMUNICATION ERRORS)

PCP	ODOM	TIME	FIFTH	STSEG	SSG5	AVM X	AVM Y	REF X	REF Y	ERROR
1	396.	0:31.0	394.	3	CP 1	12396	4435	12413	4414	27
2	556.	0:51.0	554.	3	CP 1	12378	4276	12389	4256	22
3	994.	1:11.0	998.	4	TA 3	12370	3874	12375	3873	5
4	1332.	1:31.0	1334.	4	TA 3	12705	3831	12707	3821	10
5	1664.	1:51.0	1666.	4	CP 2	13035	3787	13027	3775	14
6	1964.	2:11.0	1968.	4	CP 2	13332	3748	13327	3736	13
7	2474.	2:31.0	2476.	4	CP 3	13838	3682	13822	3674	17
8	2970.	2:51.0	2970.	4	CP 3	14330	3618	14312	3613	18
9	3120.	3:11.0	3122.	4	CP 3	14479	3598	14463	3595	16
10	3120.	3:31.0	3122.	4	CP 3	14479	3598	14463	3595	16
11	3356.	3:51.0	3356.	4	CP 3	14713	3568	14695	3566	18
12	3650.	4:11.0	3652.	5	CP 4	15010	3522	15016	3521	6
13	3774.	4:31.0	3776.	5	CP 4	15132	3500	15138	3499	6
14	4128.	4:51.0	4134.	6	TA 4	15240	3771	15242	3788	17
15	4272.	5:11.0	4278.	6	TA 4	15260	3913	15262	3930	17
16	4272.	5:31.0	4278.	6	TA 4	15260	3913	15262	3930	17
17	4524.	5:51.0	4532.	6	CP 5	15295	4163	15305	4237	74
18	4792.	6:11.0	4802.	6	CP 6	15332	4428	15336	4458	30
19	5166.	6:31.0	5178.	6	CP 6	15384	4799	15378	4832	33
20	5166.	6:51.0	5178.	6	CP 6	15384	4799	15378	4832	33
21	5428.	7:11.0	5438.	6	CP 7	15420	5058	15419	5102	44
22	5862.	7:31.0	5872.	6	CP 8	15480	5488	15488	5554	66
23	6236.	7:51.0	6248.	6	CP 8	15532	5858	15537	5926	68
24	6458.	8:11.0	6468.	6	CP 8	15562	6078	15566	6145	67
25	6600.	8:31.0	6612.	6	CP 8	15582	6219	15585	6287	68
26	6670.	8:51.0	6680.	6	CP 8	15592	6288	15593	6355	67
27	7114.	9:11.0	7124.	6	CP 8	15653	6728	15651	6795	67
28	7648.	9:31.0	7660.	6	CP 8	15727	7257	15722	7326	69
29	8178.	9:51.0	8190.	6	CP10	15800	7781	15808	7832	51
30	8538.	10:11.0	8548.	6	CP11	15850	8138	15856	8176	38
31	8910.	10:31.0	8922.	7	CP11	15904	8526	15908	8547	21
32	9316.	10:51.0	9328.	7	CP11	15960	8928	15964	8949	21
33	9596.	11:11.0	9608.	7	CP11	15999	9206	16003	9226	20
34	9926.	11:31.0	9938.	7	CP12	16044	9533	16056	9608	75
35	9934.	11:51.0	9946.	7	CP12	16046	9541	16057	9616	75
36	9934.	12:11.0	9946.	7	CP12	16046	9541	16057	9616	75
37	10186.	12:31.0	10194.	8	TA 5	16185	9660	16276	9645	92
38	10248.	12:51.0	10256.	8	TA 5	16247	9655	16338	9638	92
39	10660.	13:11.0	10668.	8	CP13	16658	9623	16760	9594	106
40	11088.	13:31.0	11096.	8	CP14	17085	9590	17172	9564	90
41	11580.	13:51.0	11588.	8	CP15	17575	9552	17636	9525	66
42	12068.	14:11.0	12076.	8	CP16	18062	9514	18114	9510	52
43	12656.	14:31.0	12658.	9	TA 6	18113	8975	18104	8940	36
44	13172.	14:51.0	13176.	9	CP17	18112	8459	18104	8378	81
45	13570.	15:11.0	13572.	10	CP18	18094	7965	18061	7980	36
46	13722.	15:31.0	13724.	10	CP18	18070	7815	18042	7829	31
47	13722.	15:51.0	13724.	10	CP18	18070	7815	18042	7829	31
48	13984.	16:11.0	13988.	10	CP18	18028	7556	18007	7567	23
49	14286.	16:31.0	14292.	10	CP18	17981	7258	17968	7266	15

TABLE 8-8 AVM SYSTEM TEST RESULTS, RUN 28 (CONT'D)

PCP	ODOM	TIME	FIFTH	STSEG	SSG5	AVM X	AVM Y	REF X	REF Y	ERROR
50	14740.	16:51.0	14744.	11	CP19	17907	6813	17914	6848	35
51	15040.	17:11.0	15038.	11	TA 7	17609	6849	17668	6844	59
52	15340.	17:31.0	15336.	11	TA 7	17311	6885	17372	6883	61
53	15648.	17:51.0	15636.	11	TA 7	17005	6922	17075	6922	70
54	15938.	18:11.0	15918.	11	TA 7	16717	6957	16795	6959	78
55	16200.	18:31.0	16180.	11	CP20	16457	6988	16490	6998	34
56	16570.	18:51.0	16544.	11	CP20	16090	7033	16129	7042	40
57	16990.	19:11.0	16958.	11	CP20	15673	7083	15718	7091	45
58	17260.	19:31.0	17228.	11	CP20	15404	7116	15450	7123	46
59	17568.	19:51.0	17538.	11	CP20	15099	7153	15142	7160	43
60	17572.	20:11.0	17544.	11	CP20	15095	7153	15136	7161	41
61	17874.	20:31.0	17838.	11	CP21	14795	7189	14842	7195	47
62	18080.	20:51.0	18042.	11	CP21	14590	7214	14639	7218	49
63	18080.	21:11.0	18042.	11	CP21	14590	7214	14639	7218	49
64	18392.	21:31.0	18342.	11	CP21	14281	7252	14341	7253	60
65	18528.	21:51.0	18480.	11	CP22	14145	7268	14154	7270	9
66	18528.	22:11.0	18480.	11	CP22	14145	7268	14154	7270	9
67	18654.	22:31.0	18604.	12	CP22	14058	7276	14030	7281	28
68	19140.	22:51.0	19074.	13	TA 8	13618	7409	13609	7412	9
69	19604.	23:11.0	19538.	13	CP23	13305	7752	13286	7750	19
70	20126.	23:31.0	20060.	14	TA 9	12931	8115	12909	8135	29
71	20214.	23:51.0	20150.	14	TA 9	12865	8173	12841	8194	31
72	20584.	24:11.0	20520.	15	TA10	12591	8421	12661	8354	96
73	20692.	24:31.0	20630.	15	TA10	12511	8494	12579	8428	94
74	20856.	24:51.0	20792.	15	CP24	12391	8605	12435	8560	62
75	21592.	25:11.0	21532.	15	CP24	11850	9104	11894	9065	58
76	22134.	25:31.0	22074.	15	CP25	11451	9471	11493	9437	54
77	22716.	25:51.0	22654.	16	CP25	11078	9892	11065	9828	65
78	23174.	26:11.0	23108.	17	TA11	11171	10238	11173	10111	127
79	23268.	26:31.0	23200.	17	TA11	11229	10312	11199	10199	116
80	23596.	26:51.0	23526.	18	TA12	11551	10278	11529	10277	22
81	23748.	27:11.0	23678.	18	TA12	11701	10258	11680	10255	21
82	24138.	27:31.0	24070.	18	TA12	12088	10207	12068	10198	21
83	24202.	27:51.0	24134.	18	TA12	12152	10198	12131	10189	22
84	24326.	28:11.0	24258.	18	CP26	12274	10182	12286	10166	20
85	24744.	28:31.0	24676.	18	CP26	12689	10127	12700	10104	25
86	24760.	28:51.0	24690.	18	CP26	12705	10125	12714	10101	25
87	25210.	29:11.0	25140.	18	CP27	13151	10066	13170	10046	27
88	25634.	29:31.0	25562.	19	TA13	13136	9685	13142	9650	35
89	25994.	29:51.0	25920.	19	CP28	13081	9329	13085	9263	66
90	26216.	30:11.0	26144.	19	CP28	13047	9110	13052	9041	69
91	26380.	30:31.0	26310.	19	CP29	13021	8948	13027	8901	47
92	26776.	30:51.0	26708.	19	CP29	12960	8557	12957	8509	48
93	26986.	31:11.0	26916.	19	CP29	12928	8349	12921	8304	45
94	27330.	31:31.0	27262.	20	TA14	12902	8006	12900	7971	35
95	27748.	31:51.0	27684.	21	TA15	13083	7757	13028	7765	55
96	27902.	32:11.0	27838.	21	TA15	13236	7734	13180	7742	56
97	27902.	32:31.0	27838.	21	TA15	13236	7734	13180	7742	56
98	28164.	32:51.0	28102.	21	TA15	13495	7695	13441	7702	54
99	28548.	33:11.0	28486.	21	CP30	13875	7638	13768	7654	108
100	28934.	33:31.0	28870.	22	CP30	14200	7595	14149	7609	52
101	29228.	33:51.0	29166.	22	CP30	14492	7560	14443	7575	51
102	29512.	34:11.0	29450.	22	CP30	14774	7526	14725	7541	51
103	29852.	34:31.0	29786.	22	CP30	15111	7486	15059	7502	54

TABLE 8-8 AVM SYSTEM TEST RESULTS, RUN 28 (CONT'D)

PCP	ODOM	TIME	FIFTH	STSEG	SSG5	AVM X	AVM Y	REF X	REF Y	ERROR
104	30368.	34:51.0	30304.	22	CP31	15624	7424	15603	7435	23
105	30852.	35:11.0	30786.	22	CP32	16104	7366	16061	7381	45
106	31354.	35:31.0	31288.	22	CP32	16603	7306	16561	7332	49
107	31640.	35:51.0	31574.	22	CP33	16887	7272	16856	7293	37
108	31752.	36:11.0	31686.	22	CP33	16998	7258	16967	7278	36
109	31752.	36:31.0	31686.	22	CP33	16998	7258	16967	7278	36
110	31924.	36:51.0	31858.	22	CP33	17169	7238	17138	7254	34
111	32160.	37:11.0	32094.	22	CP33	17403	7210	17371	7221	33
112	32470.	37:31.0	32402.	22	CP34	17711	7173	17663	7174	48
113	32936.	37:51.0	32868.	22	CP34	18173	7117	18122	7093	56
114	33484.	38:11.0	33416.	22	CP35	18717	7051	18636	7044	81
115	33624.	38:31.0	33558.	23	CP35	18826	7013	18778	7039	54
116	33740.	38:51.0	33668.	23	TA16	18803	6899	18823	6974	77
117	34198.	39:11.0	34128.	24	TA16	18719	6469	18762	6518	65
118	34368.	39:31.0	34296.	24	TA16	18704	6299	18740	6352	64
119	34858.	39:51.0	34786.	24	TA16	18660	5812	18676	5866	56
120	35202.	40:11.0	35124.	25	TA17	18504	5625	18511	5626	7
121	35426.	40:31.0	35348.	25	CP36	18281	5653	18250	5663	32
122	35722.	40:51.0	35642.	25	CP36	17988	5691	17959	5703	31
123	35792.	41:11.0	35712.	25	CP36	17918	5700	17889	5712	31
124	35792.	41:31.0	35712.	25	CP36	17918	5700	17889	5712	31
125	35842.	41:51.0	35762.	25	CP36	17869	5706	17840	5719	31
126	35842.	42:11.0	35762.	25	CP36	17869	5706	17840	5719	31
127	35986.	42:31.0	35906.	25	CP37	17726	5724	17757	5730	31
128	36236.	42:51.0	36156.	25	CP37	17478	5756	17509	5762	31
129	36352.	43:11.0	36274.	25	CP37	17363	5771	17392	5777	29
130	36722.	43:31.0	36642.	25	CP37	16996	5818	17027	5824	31
131	36762.	43:51.0	36682.	25	CP37	16956	5823	16987	5829	31
132	37194.	44:11.0	37114.	25	CP38	16528	5877	16534	5884	9
133	37224.	44:31.0	37146.	25	CP38	16498	5881	16502	5888	8
134	37348.	44:51.0	37268.	25	CP39	16375	5897	16389	5902	14
135	37676.	45:11.0	37596.	25	CP39	16050	5938	16064	5946	16
136	37676.	45:31.0	37596.	25	CP39	16050	5938	16064	5946	16
137	37676.	45:51.0	37596.	25	CP39	16050	5938	16064	5946	16
138	37716.	46:11.0	37636.	25	CP39	16010	5943	16024	5951	16
139	37764.	46:31.0	37684.	25	CP39	15963	5949	15977	5957	16
140	38118.	46:51.0	38038.	25	CP40	15611	5994	15621	6005	14
141	38118.	47:11.0	38038.	25	CP40	15611	5994	15621	6005	14
142	38304.	47:31.0	38222.	25	CP40	15427	6018	15437	6023	11
143	38390.	47:51.0	38312.	25	CP40	15342	6029	15348	6031	6
144	38390.	48:11.0	38312.	25	CP40	15342	6029	15348	6031	6
145	38390.	48:31.0	38312.	25	CP40	15342	6029	15348	6031	6
146	38522.	48:51.0	38440.	26	TA18	15237	6065	15235	6056	9
147	38712.	49:11.0	38628.	26	TA18	15266	6253	15259	6243	12
148	38856.	49:31.0	38774.	28	TA19	15274	6380	15239	6385	35
149	39000.	49:51.0	38922.	28	TA19	15131	6401	15092	6406	39
150	39438.	50:11.0	39358.	28	TA19	14697	6464	14661	6469	36
151	39682.	50:31.0	39608.	29	TA20	14652	6241	14653	6252	11
152	39736.	50:51.0	39662.	29	TA20	14645	6188	14647	6199	11
153	40088.	51:11.0	40016.	29	TA21	14601	5838	14628	5785	59
154	40512.	51:31.0	40436.	31	TA22	14880	5682	14881	5694	12
155	40870.	51:51.0	40796.	31	TA22	14835	5327	14832	5337	10
156	41076.	52:11.0	41000.	31	CP43	14809	5122	14805	5116	7
157	41196.	52:31.0	41122.	31	CP43	14794	5003	14792	4995	8

TABLE 8-8 AVM SYSTEM TEST RESULTS, RUN 28 (CONT'D)

PCP	ODOM	TIME	FIFTH	STSEG	SSG5	AVM X	AVM Y	REF X	REF Y	ERROR
158	41540.	52:51.0	41460.	32	TA23	14497	4991	14505	4985	10
159	41572.	53:11.0	41494.	32	TA23	14465	4995	14472	4989	9
160	41718.	53:31.0	41640.	32	TA23	14321	5014	14327	5005	10
161	41946.	53:51.0	41864.	32	CP44	14094	5044	14029	5040	65
162	42070.	54:11.0	41990.	32	CP44	13972	5060	13904	5059	68
163	42070.	54:31.0	41990.	32	CP44	13972	5060	13904	5059	68
164	42150.	54:51.0	42070.	32	CP44	13892	5070	13825	5071	67
165	42666.	55:11.0	42586.	32	CP45	13381	5137	13314	5146	67
166	43206.	55:31.0	43124.	32	CP46	12845	5208	12808	5206	37
167	43708.	55:51.0	43628.	33	CP46	12305	5279	12308	5269	10
168	43850.	56:11.0	43768.	33	CP46	12164	5299	12169	5287	13
169	43860.	56:31.0	43780.	33	CP46	12154	5300	12157	5288	12
170	43916.	56:51.0	43836.	33	CP46	12099	5308	12101	5295	13
171	44044.	57:11.0	43962.	33	CP46	11972	5325	11976	5311	14
172	44428.	57:31.0	44350.	33	CP46	11592	5378	11592	5359	19
173	44454.	57:51.0	44376.	33	CP46	11566	5382	11566	5362	20
174	44526.	58:11.0	44448.	33	CP47	11495	5392	11480	5374	23
175	44894.	58:31.0	44814.	33	CP47	11130	5443	11117	5425	22
176	45288.	58:51.0	45210.	33	CP48	10740	5497	10699	5483	43
177	45780.	59:11.0	45702.	33	CP49	10253	5565	10262	5542	24
178	46334.	59:31.0	46256.	33	CP49	9704	5642	9714	5623	21
179	46624.	59:51.0	46546.	33	CP50	9417	5682	9456	5660	44
180	46830.	60:11.0	46752.	33	CP50	9213	5710	9252	5688	44
181	46850.	60:31.0	46772.	33	CP50	9193	5713	9232	5690	45
182	47366.	60:51.0	47290.	33	CP51	8682	5784	8648	5769	37
183	47938.	61:11.0	47862.	33	CP52	8116	5863	8133	5841	27
184	48462.	61:31.0	48386.	34	CP52	7578	5917	7613	5906	36
185	48864.	61:51.0	48782.	35	TA24	7518	6211	7504	6217	15
186	49040.	62:11.0	48960.	35	TA24	7548	6385	7526	6394	23
187	49092.	62:31.0	49012.	35	TA24	7557	6436	7532	6446	26
188	49558.	62:51.0	49478.	35	CP53	7636	6896	7643	6934	38
189	49748.	63:11.0	49662.	36	TA25	7708	7028	7778	7019	70
190	50168.	63:31.0	50084.	36	TA25	8124	6973	8197	6964	73
191	50628.	63:51.0	50544.	36	CP55	8580	6913	8653	6907	73
192	50722.	64:11.0	50638.	36	CP55	8674	6901	8746	6896	72
193	51150.	64:31.0	51066.	36	CP55	9098	6844	9171	6845	73
194	51626.	64:51.0	51542.	36	CP56	9570	6782	9638	6774	68
195	51906.	65:11.0	51822.	36	CP57	9847	6745	9911	6728	66
196	52484.	65:31.0	52404.	36	CP57	10420	6670	10489	6654	70
197	52990.	65:51.0	52908.	36	CP57	10922	6603	10989	6590	68
198	53226.	66:11.0	53146.	37	CP57	11156	6573	11225	6560	70
199	53268.	66:31.0	53186.	37	CP57	11197	6567	11264	6555	68
200	53316.	66:51.0	53234.	37	CP57	11245	6561	11312	6549	68
201	53734.	67:11.0	53650.	37	CP57	11660	6506	11725	6496	65
202	54236.	67:31.0	54154.	37	CP58	12157	6441	12179	6439	22
203	54724.	67:51.0	54640.	37	CP59	12641	6377	12693	6386	52
204	55202.	68:11.0	55118.	37	CP60	13115	6315	13136	6324	22
205	55618.	68:31.0	55534.	37	CP61	13528	6260	13568	6255	40
206	55990.	68:51.0	55902.	38	TA26	13519	5923	13493	5894	38
207	56110.	69:11.0	56024.	38	TA26	13503	5804	13470	5774	44
208	56378.	69:31.0	56290.	38	CP62	13468	5538	13427	5468	81
209	56618.	69:51.0	56530.	38	CP62	13436	5300	13399	5230	79
210	56990.	70:11.0	56900.	38	CP63	13387	4931	13374	4864	68
211	57238.	70:31.0	57154.	39	TA27	13378	4704	13461	4695	83

TABLE 8-8 AVM SYSTEM TEST RESULTS, RUN 28 (CONT'D)

PCP	ODOM	TIME	FIFTH	STSEG	SSG5	AVM X	AVM Y	REF X	REF Y	ERROR
212	57488.	70:51.0	57402.	39	TA27	13626	4669	13708	4674	82
213	57604.	71:11.0	57518.	39	CP65	13741	4653	13830	4660	89
214	57980.	71:31.0	57894.	39	CP65	14113	4601	14201	4600	88
215	58400.	71:51.0	58312.	40	CP66	14609	4535	14620	4541	12
216	58436.	72:11.0	58348.	40	CP66	14644	4531	14655	4536	12
217	58436.	72:31.0	58348.	40	CP66	14644	4531	14655	4536	12
218	58766.	72:51.0	58678.	40	CP66	14972	4489	14982	4490	10
219	59318.	73:11.0	59232.	40	CP66	15520	4419	15531	4414	12
220	59510.	73:31.0	59424.	40	CP66	15710	4395	15721	4387	13
221	59724.	73:51.0	59640.	40	CP67	15922	4368	15931	4366	9
222	60140.	74:11.0	60056.	40	CP68	16335	4316	16337	4319	3
223	60334.	74:31.0	60250.	40	CP68	16528	4291	16529	4290	1
224	60724.	74:51.0	60638.	40	CP68	16915	4242	16913	4233	9
225	60852.	75:11.0	60766.	40	CP68	17042	4226	17040	4214	12
226	60908.	75:31.0	60822.	40	CP69	17097	4219	17128	4201	35
227	61318.	75:51.0	61232.	40	CP69	17504	4168	17537	4163	33
228	61348.	76:11.0	61262.	40	CP69	17534	4164	17567	4160	33
229	61692.	76:31.0	61600.	41	TA28	17509	3847	17506	3833	14
230	61764.	76:51.0	61674.	41	TA28	17498	3775	17494	3760	15
231	62166.	77:11.0	62076.	42	CP70	17437	3332	17447	3372	41
232	62470.	77:31.0	62382.	43	TA29	17584	3173	17554	3177	30
233	62698.	77:51.0	62612.	43	TA29	17811	3152	17783	3155	28
234	63026.	78:11.0	62940.	43	TA29	18137	3121	18110	3125	27
235	63188.	78:31.0	63102.	43	TA29	18299	3106	18271	3110	28
236	63486.	78:51.0	63398.	43	TA29	18595	3078	18566	3083	29
237	63770.	79:11.0	63686.	44	TA30	18766	3190	18759	3181	11
238	63938.	79:31.0	63852.	44	TA30	18786	3356	18768	3347	20
239	64138.	79:51.0	64050.	44	TA30	18809	3555	18780	3545	30
240	64428.	80:11.0	64340.	44	CP72	18843	3843	18820	3816	35
241	64806.	80:31.0	64716.	44	CP72	18888	4218	18876	4187	33
242	65110.	80:51.0	65024.	45	TA31	18830	4446	18844	4443	14
243	65444.	81:11.0	65358.	45	TA31	18498	4485	18511	4474	17
244	65636.	81:31.0	65548.	45	CP73	18308	4507	18319	4499	13
245	65940.	81:51.0	65852.	45	CP73	18006	4543	18018	4541	12
246	66294.	82:11.0	66204.	45	CP73	17654	4584	17669	4590	16
247	66514.	82:31.0	66424.	45	CP74	17435	4610	17479	4613	44
248	66772.	82:51.0	66684.	45	CP74	17179	4640	17221	4644	42
249	66772.	83:11.0	66684.	45	CP74	17179	4640	17221	4644	42
250	66828.	83:31.0	66742.	45	CP74	17123	4646	17164	4650	41
251	67270.	83:51.0	67184.	45	CP75	16684	4698	16696	4706	14
252	67560.	84:11.0	67474.	45	CP75	16396	4731	16408	4746	19
253	67686.	84:31.0	67598.	45	CP75	16271	4746	16286	4763	22
254	67688.	84:51.0	67602.	45	CP75	16269	4746	16282	4764	22
255	67972.	85:11.0	67886.	46	CP75	16060	4771	16000	4803	68
256	68128.	85:31.0	68042.	46	CP75	15905	4793	15846	4824	66
257	68128.	85:51.0	68044.	46	CP75	15905	4793	15844	4825	68
258	68128.	86:11.0	68044.	46	CP75	15905	4793	15844	4825	68
259	68452.	86:31.0	68368.	46	CP76	15584	4839	15542	4860	46

Table 8-8 AVM SYSTEM TEST RESULTS, RUN 28(CONT'D)

NO COMMUNICATION ERRORS

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NO. SAMPLES	PERCENT OF SAMPLES
0- 10	20	7.72
10- 20	53	20.46
20- 30	35	13.51
30- 40	43	16.60
40- 50	27	10.42
50- 60	18	6.95
60- 70	32	12.36
70- 80	15	5.79
80- 90	7	2.70
90- 100	5	1.93
100- 110	2	0.77
110- 120	1	0.39
120- 130	1	0.39

CUMULATIVE ERRORS

ERROR	# SAMPLES LT ERROR	PERCENT SAMPLES LT ERROR
10	20	7.72
20	73	28.19
30	108	41.70
40	151	58.30
50	178	68.73
60	196	75.68
70	228	88.03
80	243	93.82
90	250	96.53
100	255	98.46
110	257	99.23
120	258	99.61
130	259	100.00

AVERAGE ERROR = 39.30
STANDARD DEVIATION = 25.12

5% COMMUNICATION ERRORS

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NO. SAMPLES	PERCENT OF SAMPLES
0- 10	20	7.72
10- 20	52	20.08
20- 30	34	13.13
30- 40	43	16.60
40- 50	26	10.04
50- 60	20	7.72
60- 70	33	12.74
70- 80	14	5.41
80- 90	7	2.70
90- 100	5	1.93
100- 110	2	0.77
110- 120	1	0.39
120- 130	2	0.77

CUMULATIVE ERRORS

ERROR	# SAMPLES LT ERROR	PERCENT SAMPLES LT ERROR
10	20	7.72
20	72	27.80
30	106	40.93
40	149	57.53
50	175	67.57
60	195	75.29
70	228	88.03
80	242	93.44
90	249	96.14
100	254	98.07
110	256	98.84
120	257	99.23
130	259	100.00

AVERAGE ERROR = 39.85
STANDARD DEVIATION = 25.60

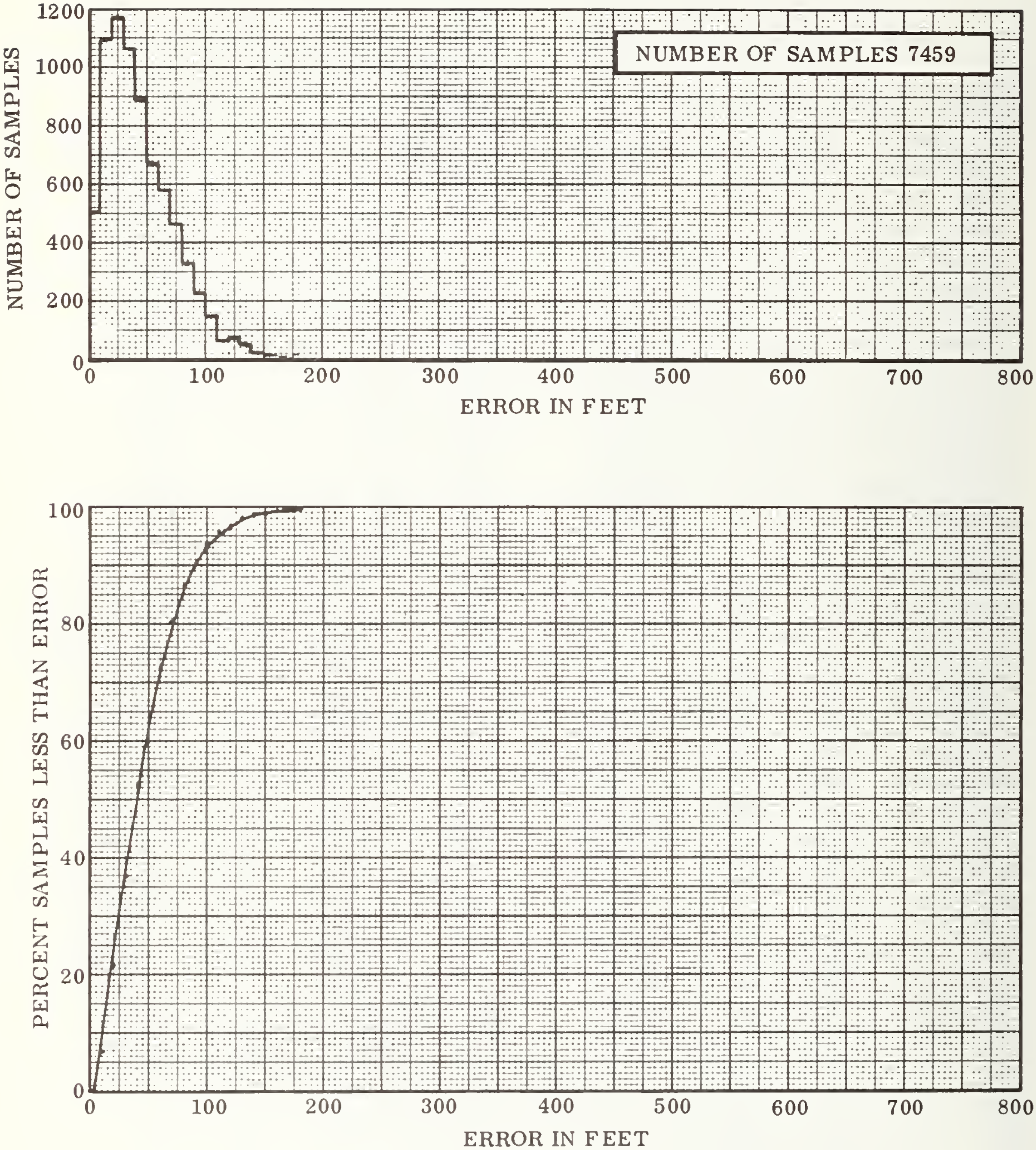


FIG. 8-33 FIXED ROUTE AVM SYSTEM ERRORS, ALL RUNS

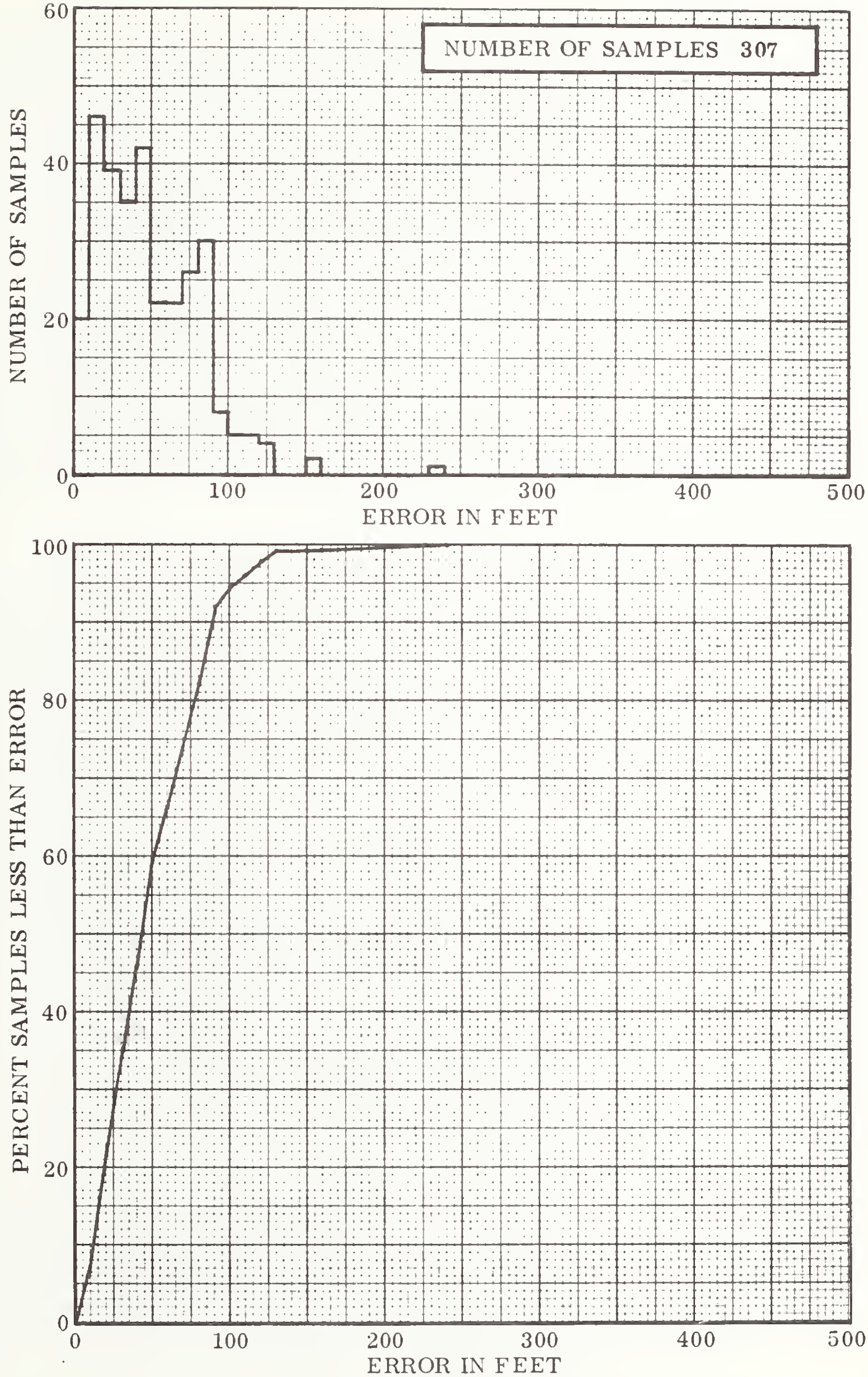


FIG. 8-34 FIXED ROUTE AVM SYSTEM ERRORS, RUN 11

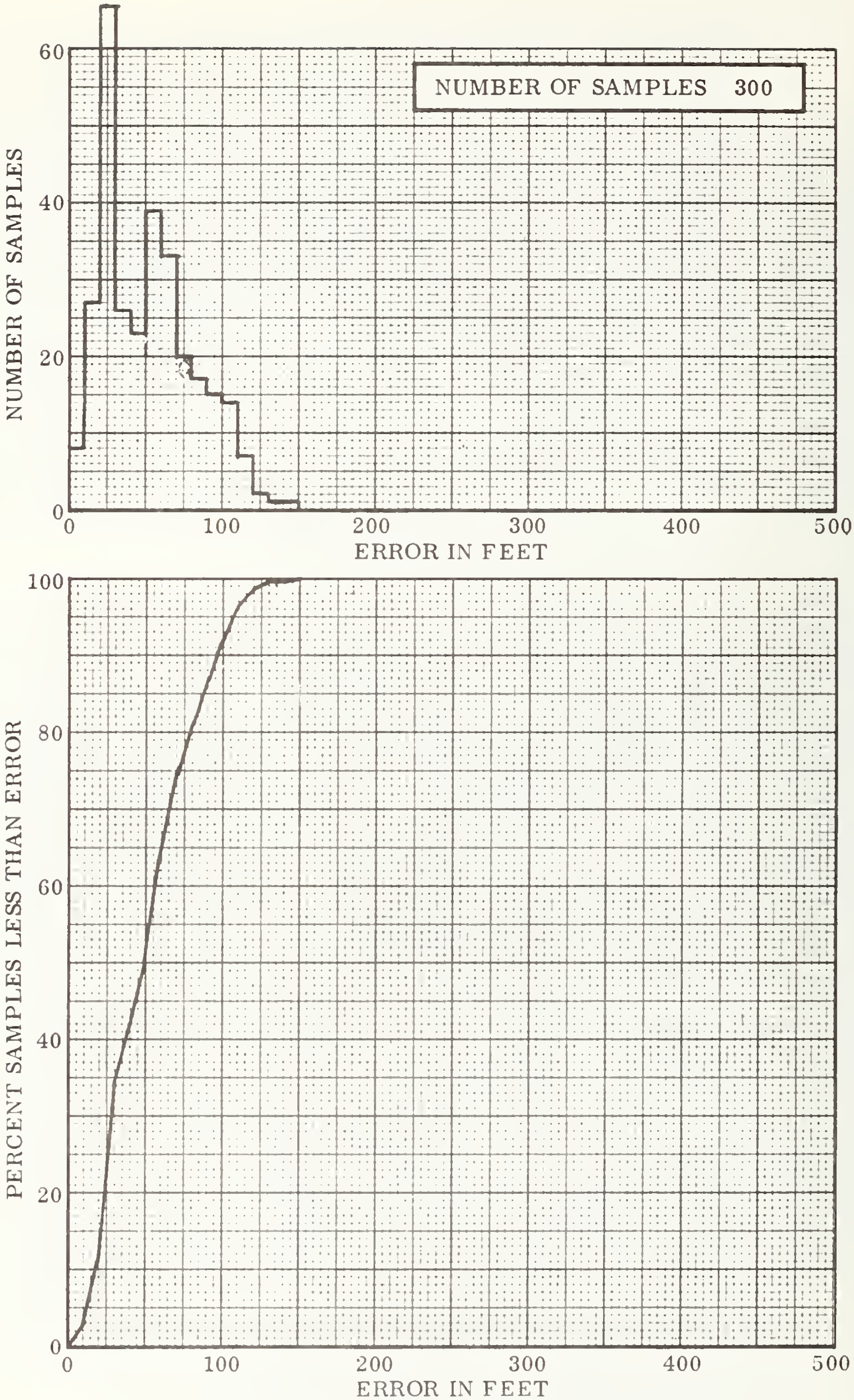


FIG. 8-35 FIXED ROUTE AVM SYSTEM ERRORS, RUN 12

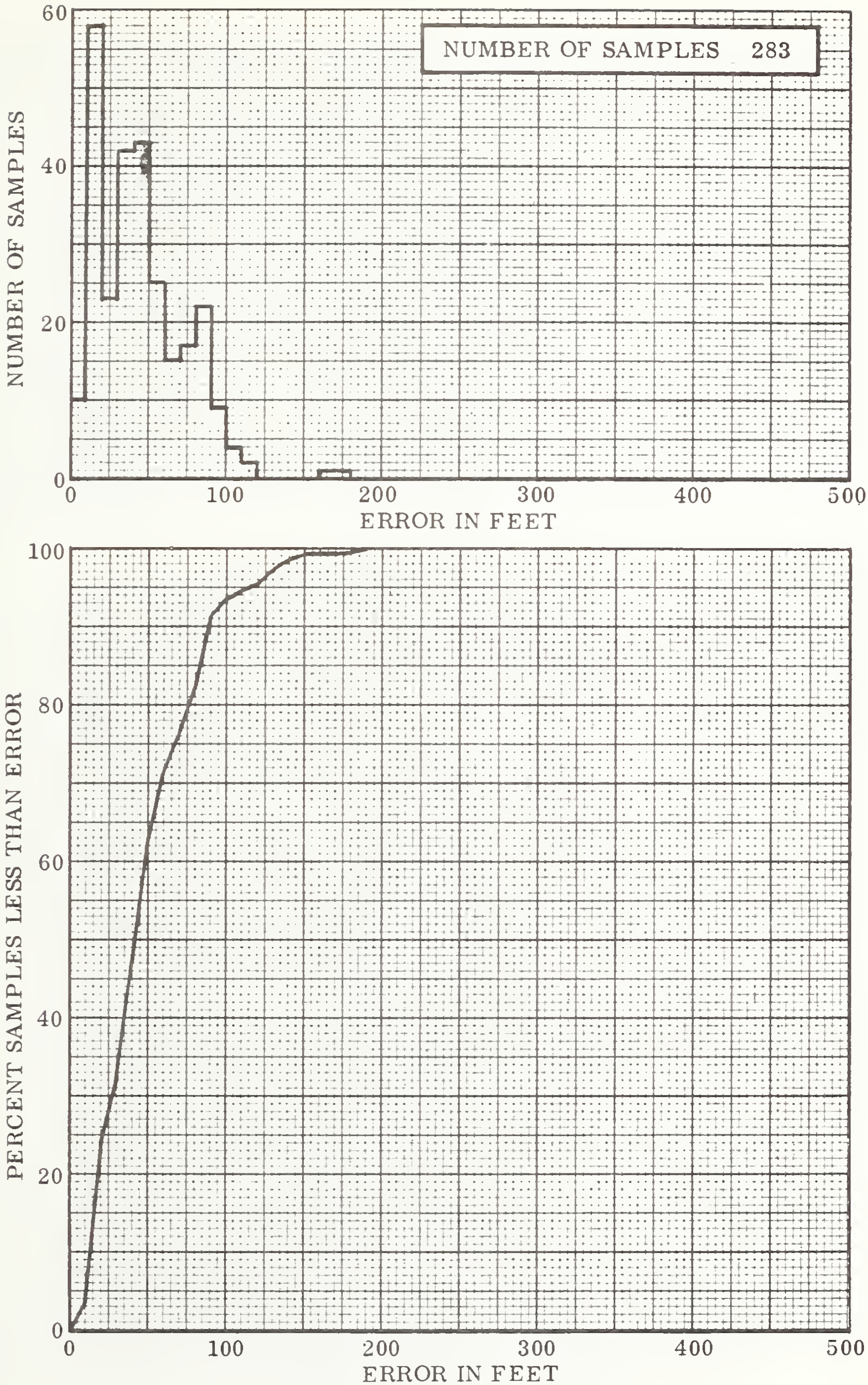


FIG. 8-36 FIXED ROUTE AVM SYSTEM ERRORS, RUN 13

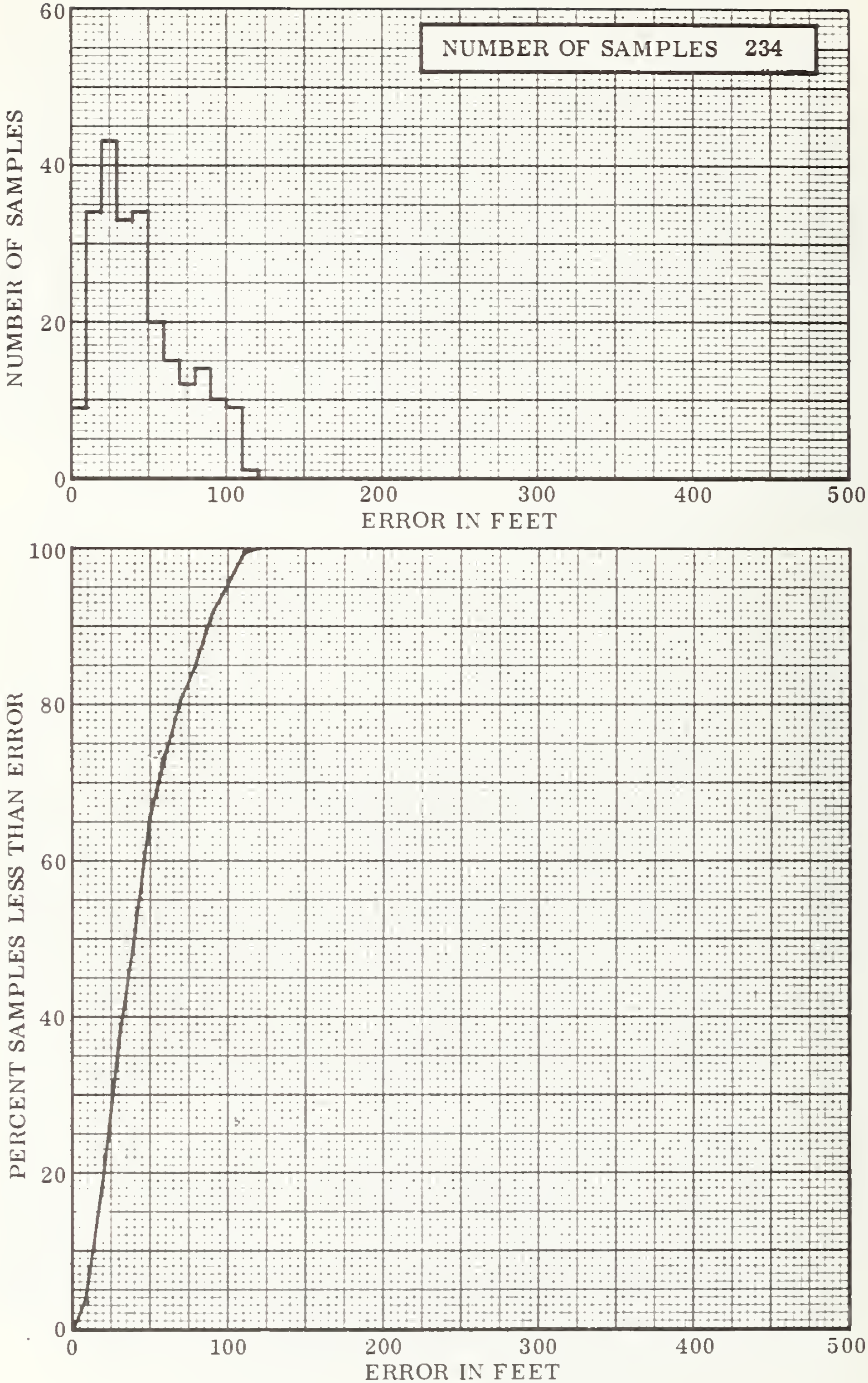


FIG. 8-37 FIXED ROUTE AVM SYSTEM ERRORS, RUN 14

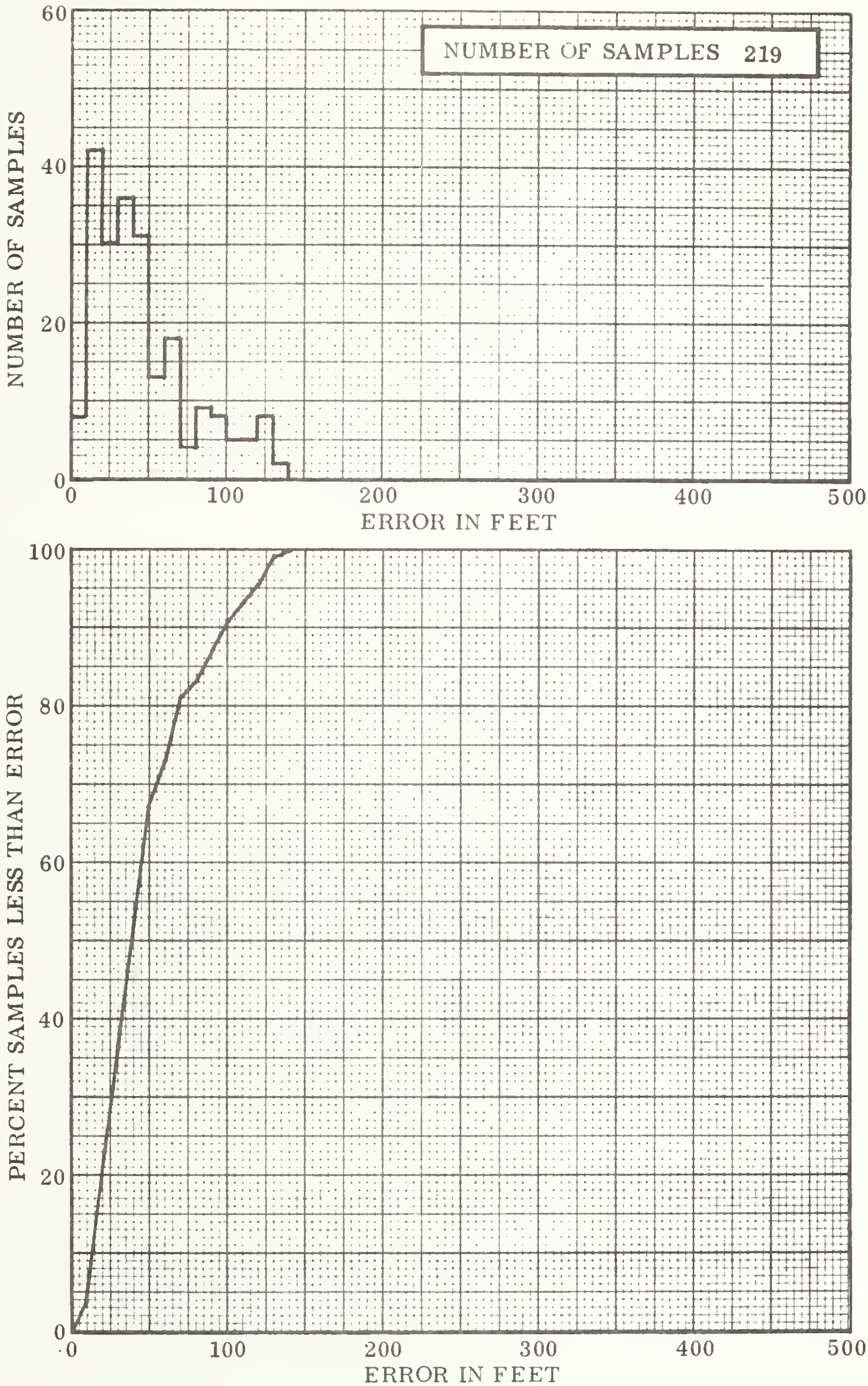


FIG. 8-38 FIXED ROUTE AVM SYSTEM ERRORS, RUN 15

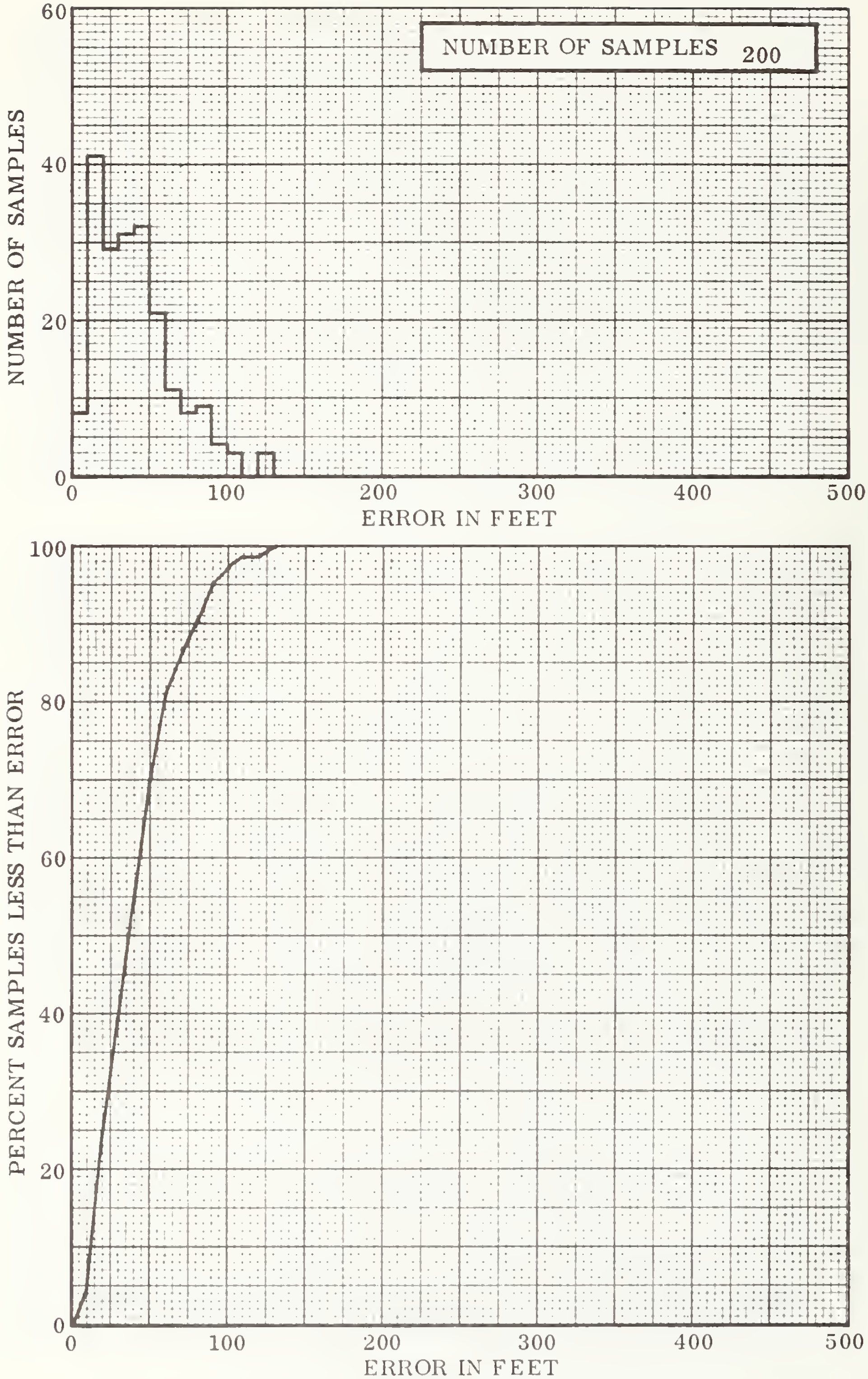
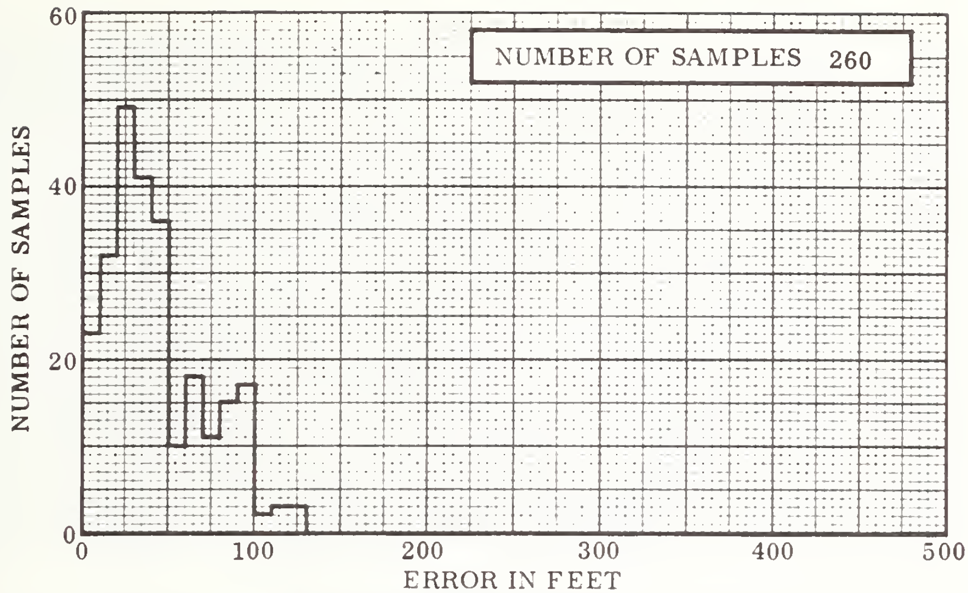


FIG. 8-39 FIXED ROUTE AVM SYSTEM ERRORS, RUN 16



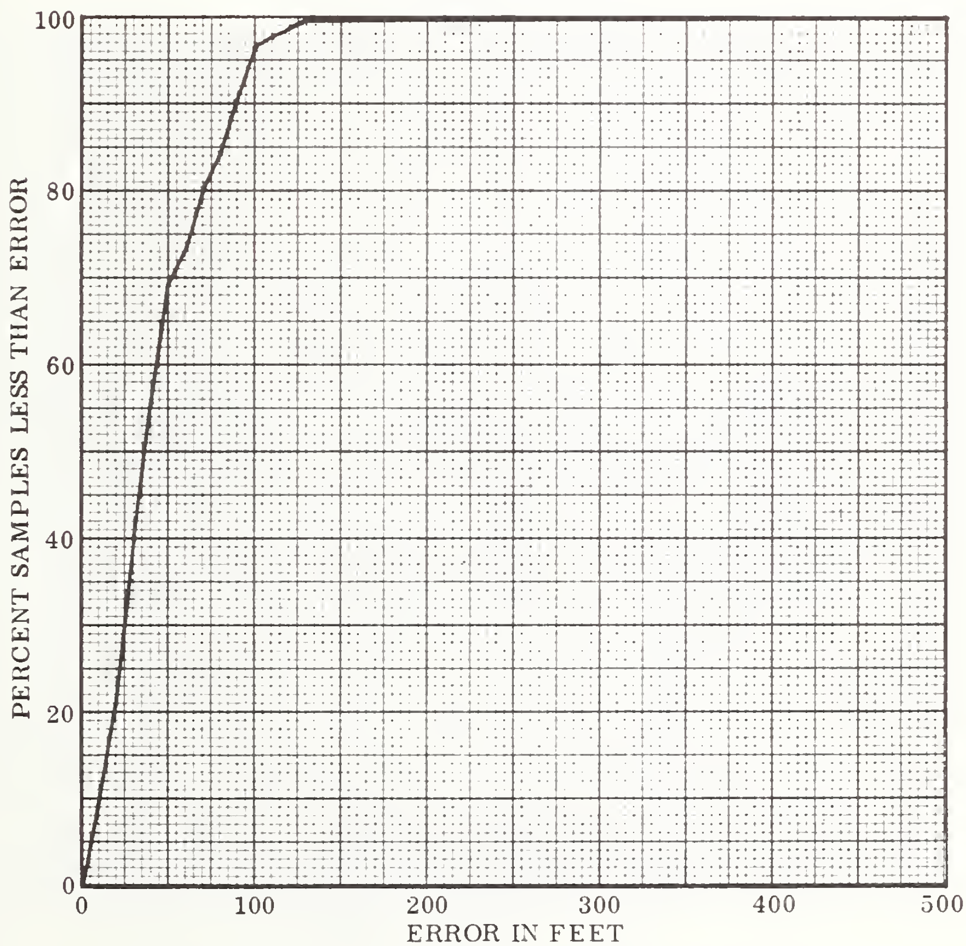
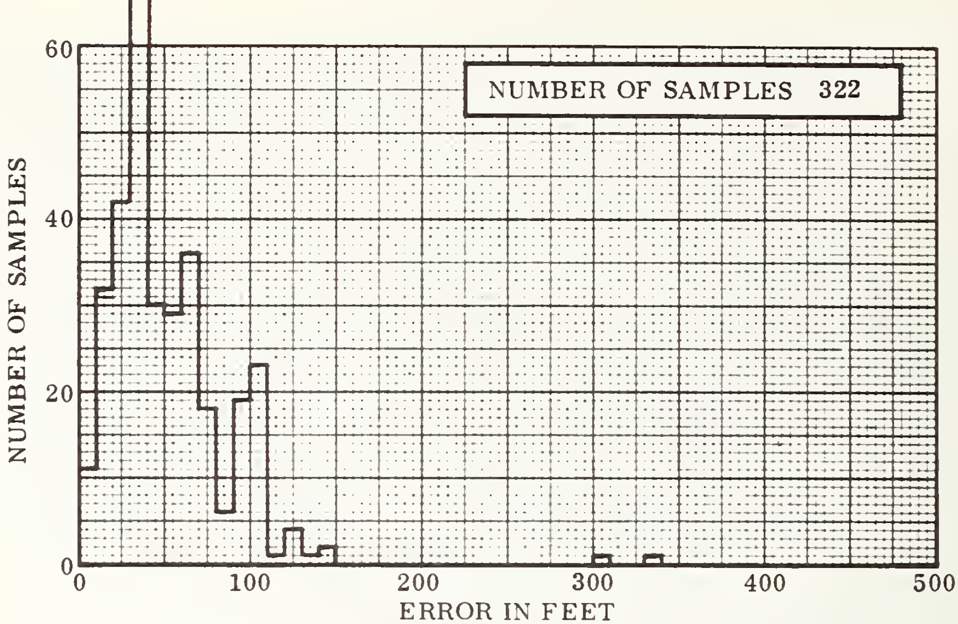


FIG. 8-40 FIXED ROUTE AVM SYSTEM ERRORS, RUN 17



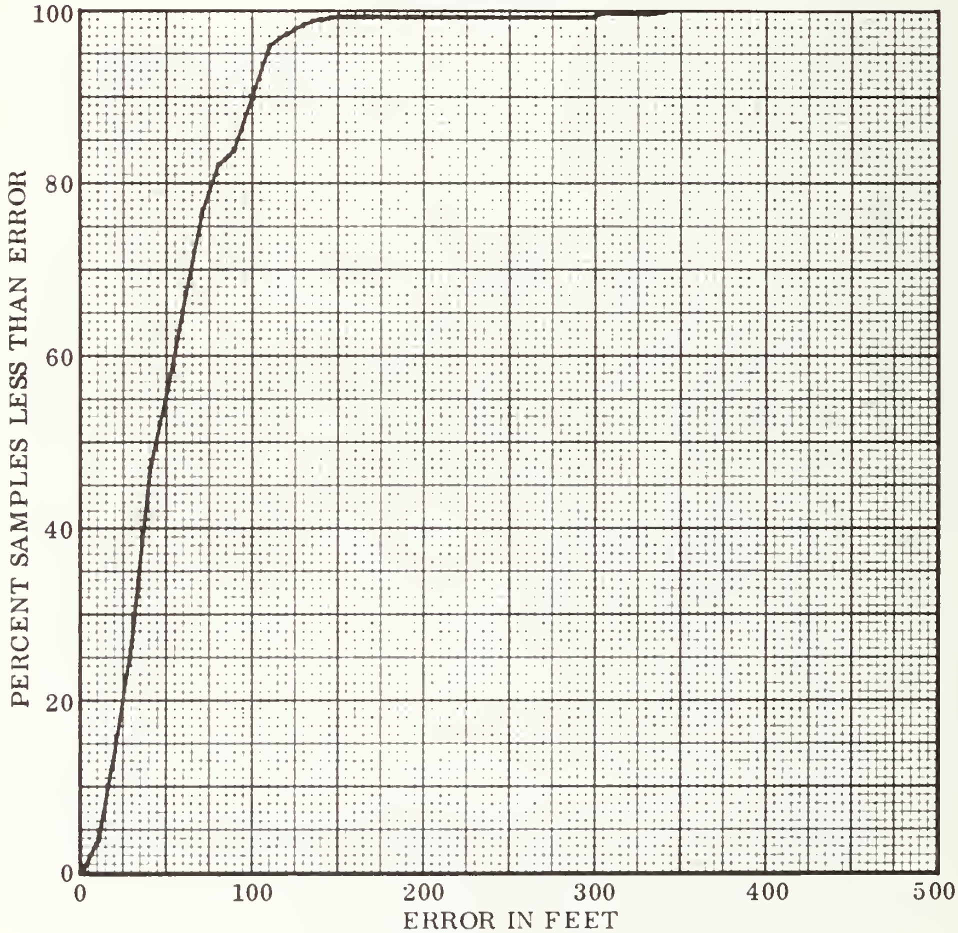
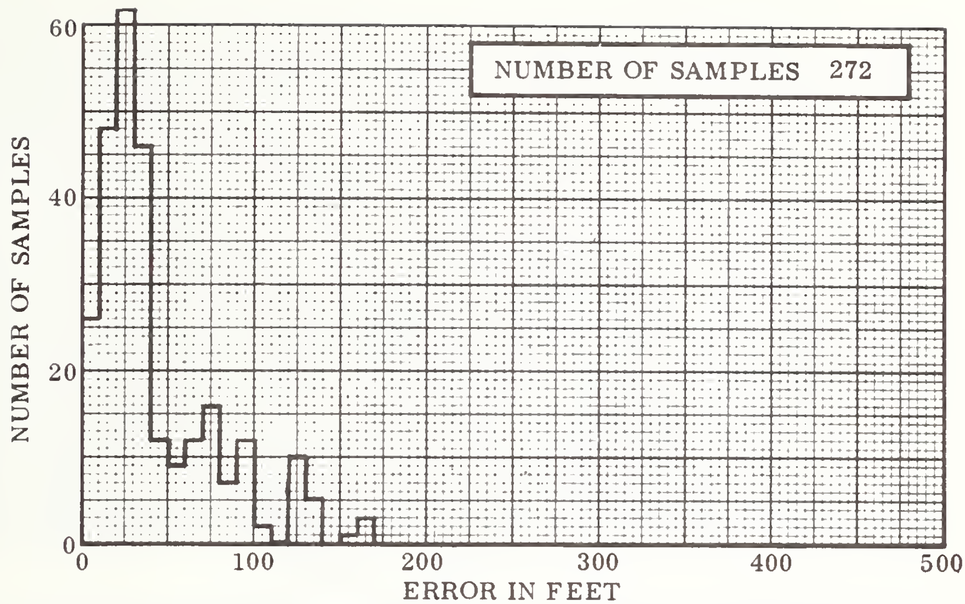


FIG. 8-41 FIXED ROUTE AVM SYSTEM ERRORS, RUN 18



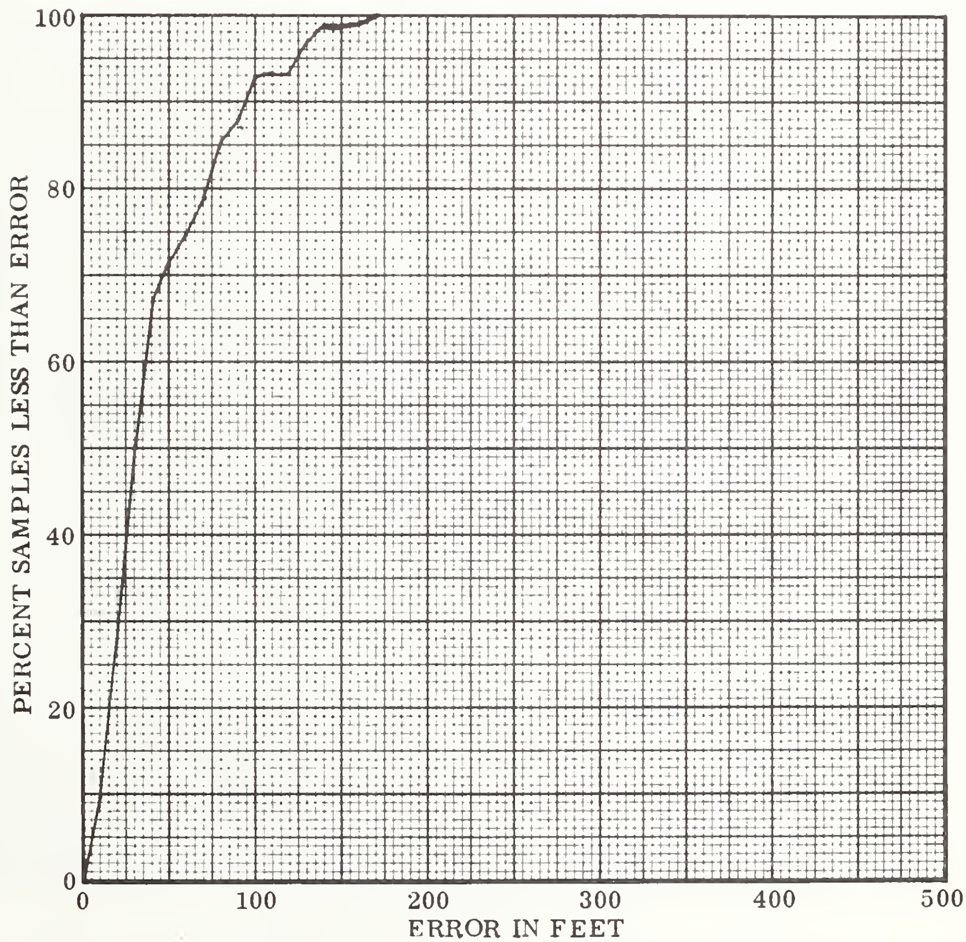


FIG. 8-42 FIXED ROUTE AVM SYSTEM ERRORS, RUN 21

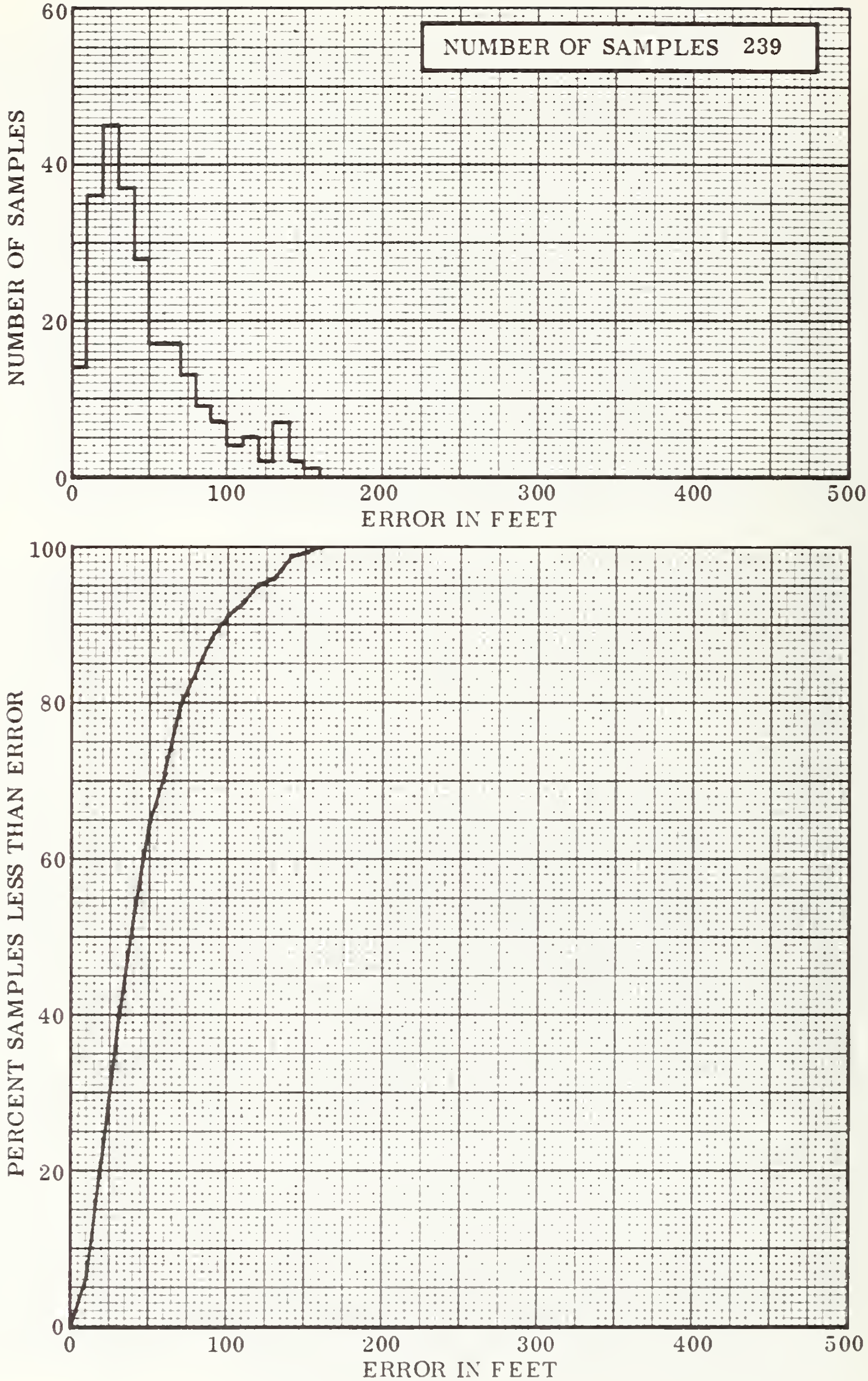


FIG. 8-43 FIXED ROUTE AVM SYSTEM ERRORS, RUN 22

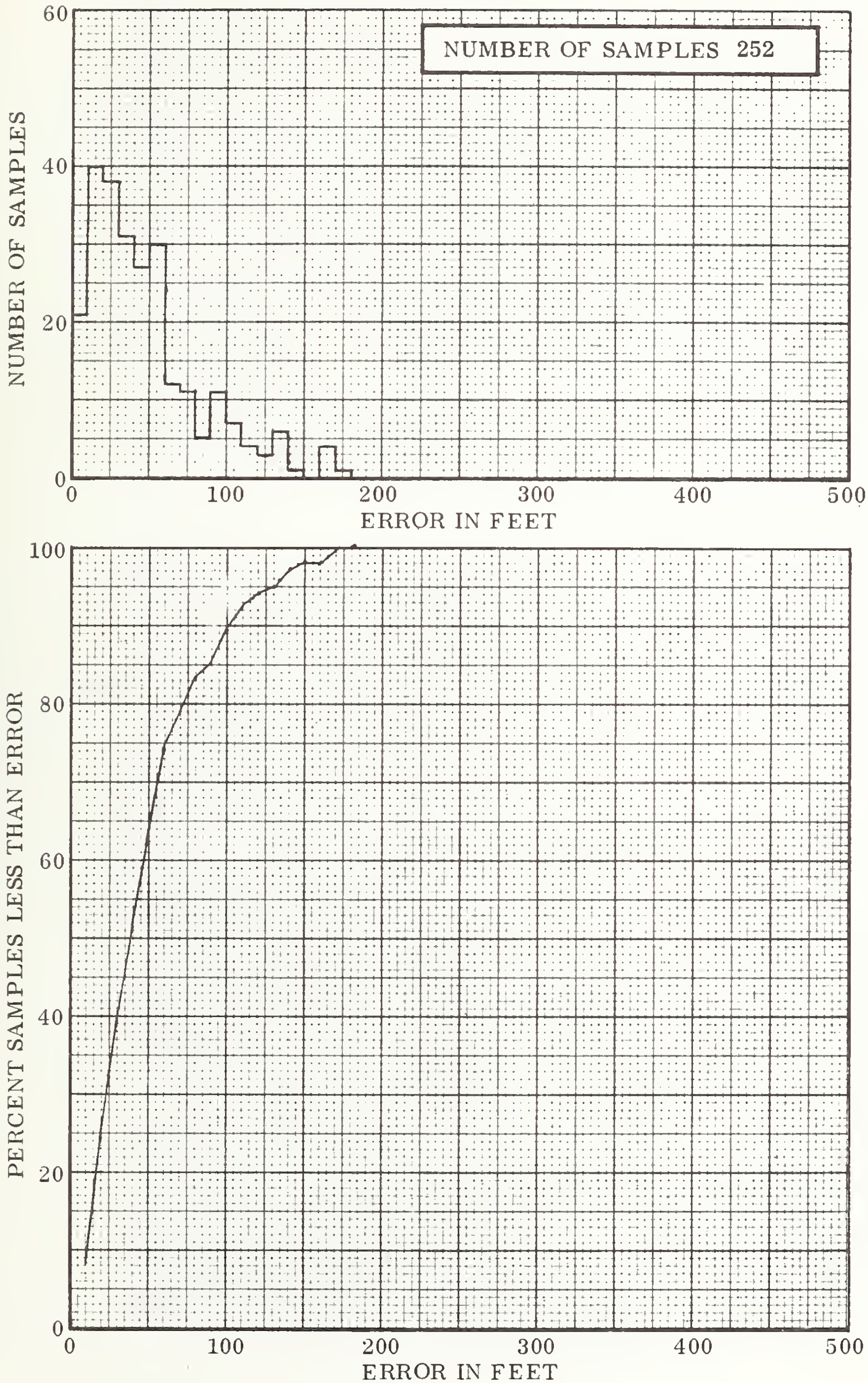


FIG. 8-44 FIXED ROUTE AVM SYSTEM ERRORS, RUN 23

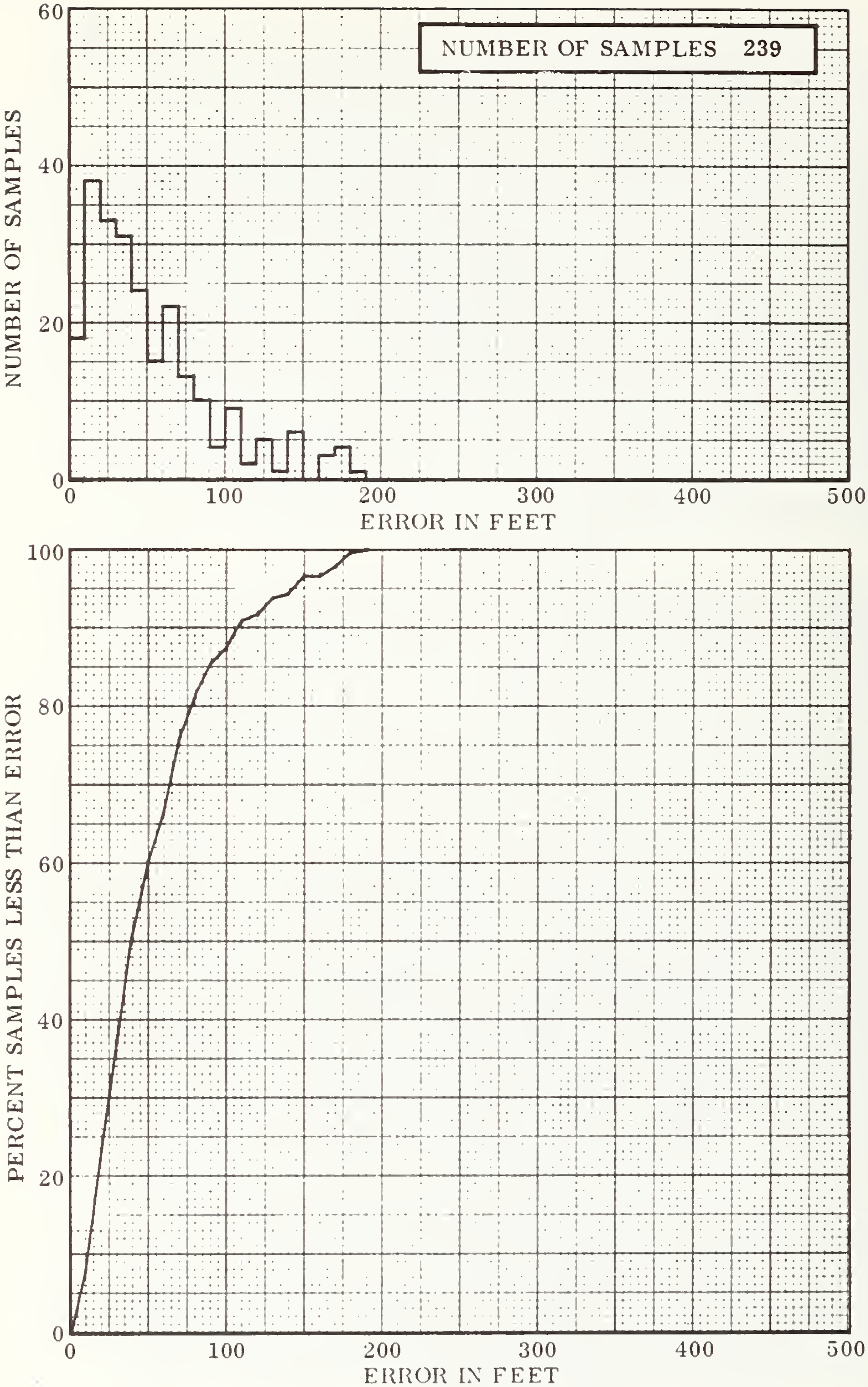


FIG. 8-45 FIXED ROUTE AVM SYSTEM ERRORS, RUN 24

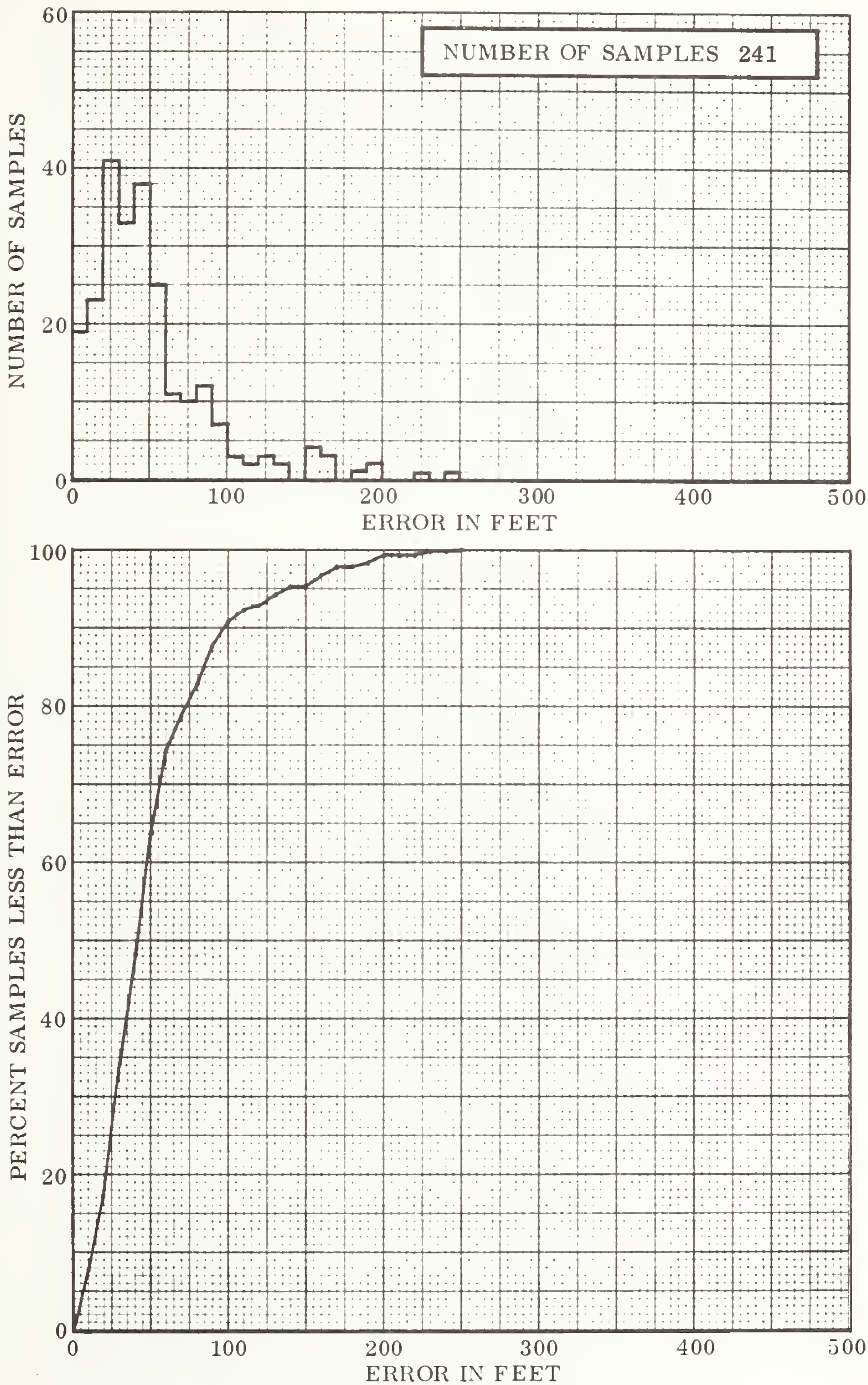


FIG. 8-46 FIXED ROUTE AVM SYSTEM ERRORS, RUN 25

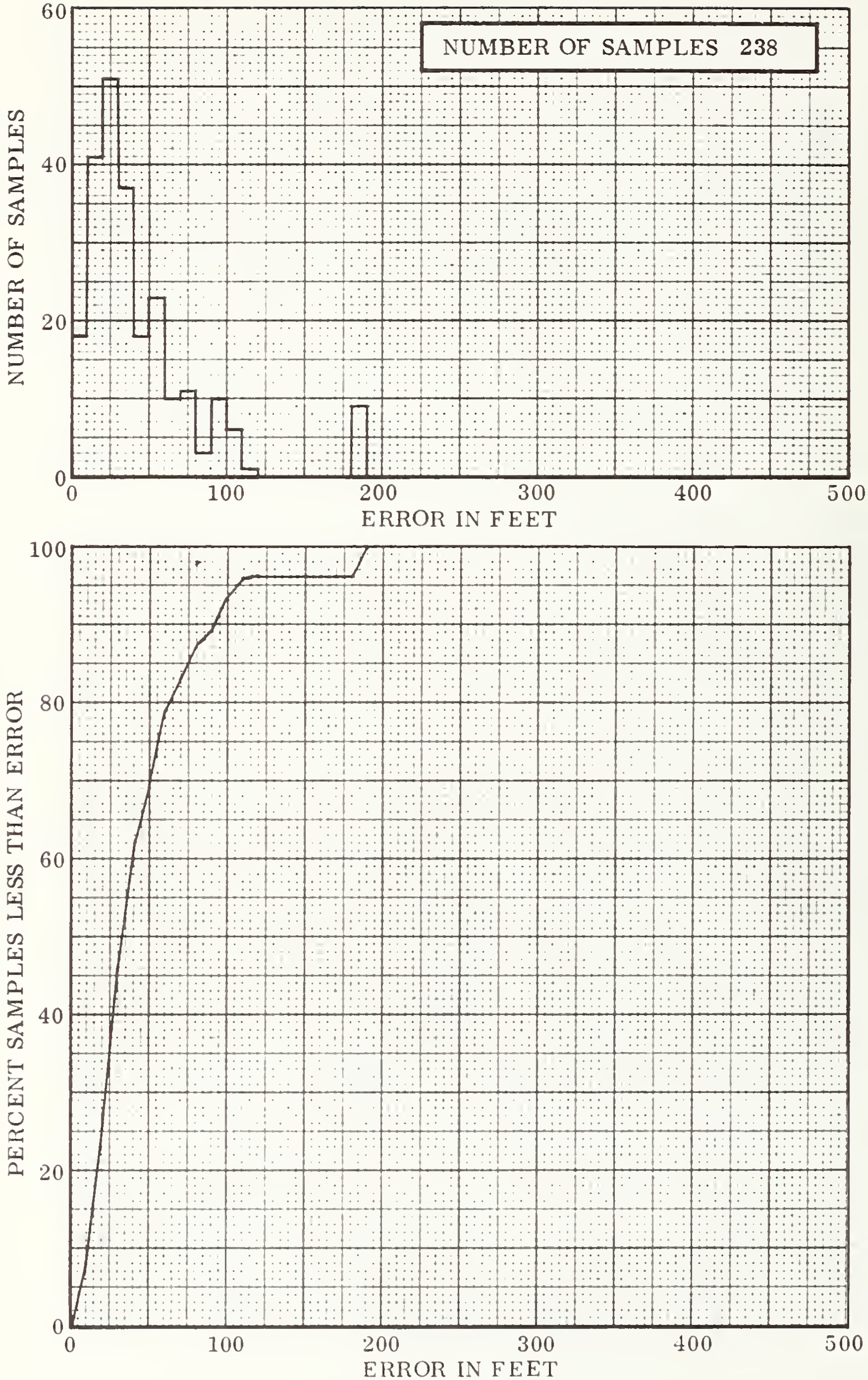


FIG. 8-47 FIXED ROUTE AVM SYSTEM ERRORS, RUN 26

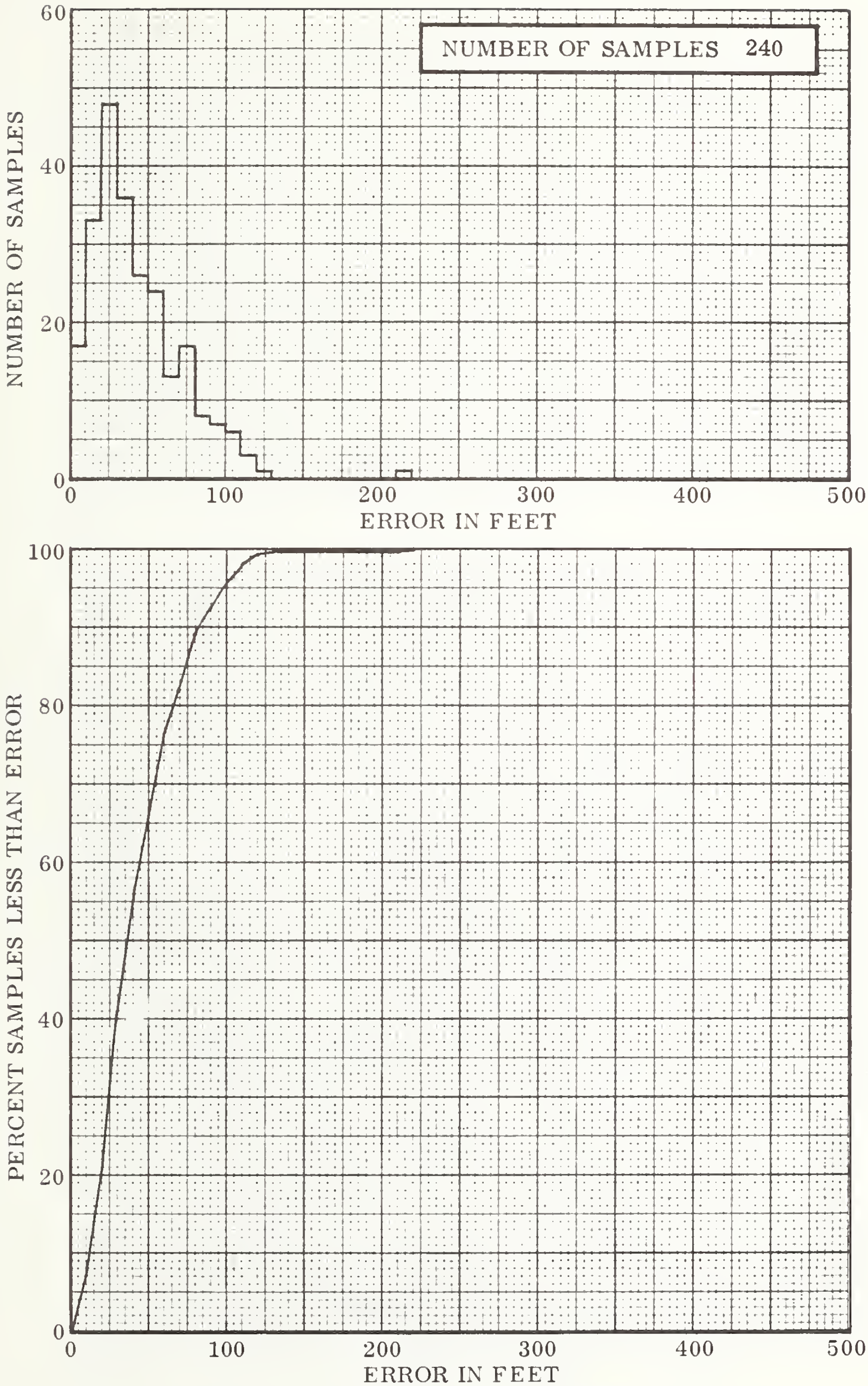


FIG. 8-48 FIXED ROUTE AVM SYSTEM ERRORS, RUN 27

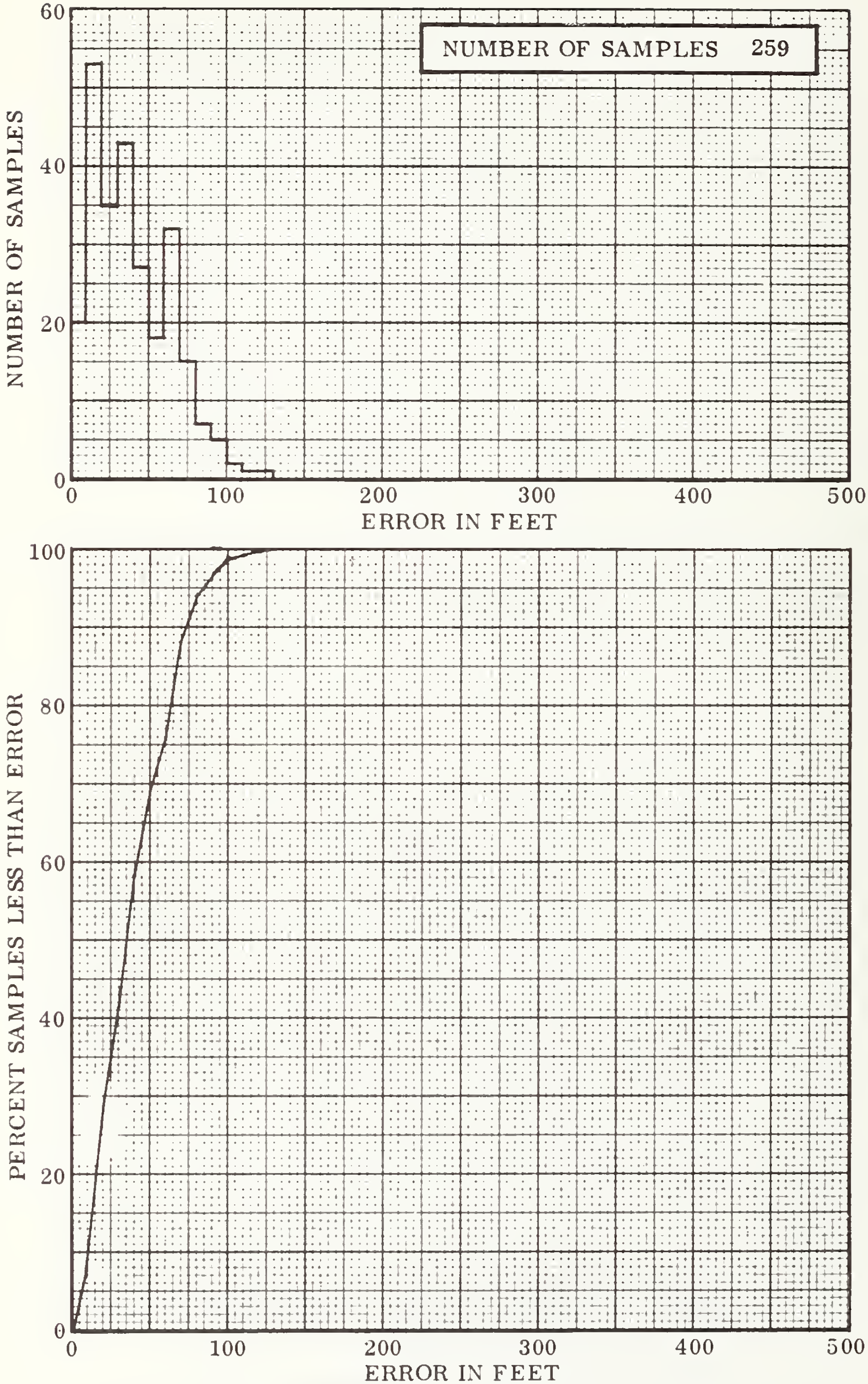


FIG. 8-49 FIXED ROUTE AVM SYSTEM ERRORS, RUN 28

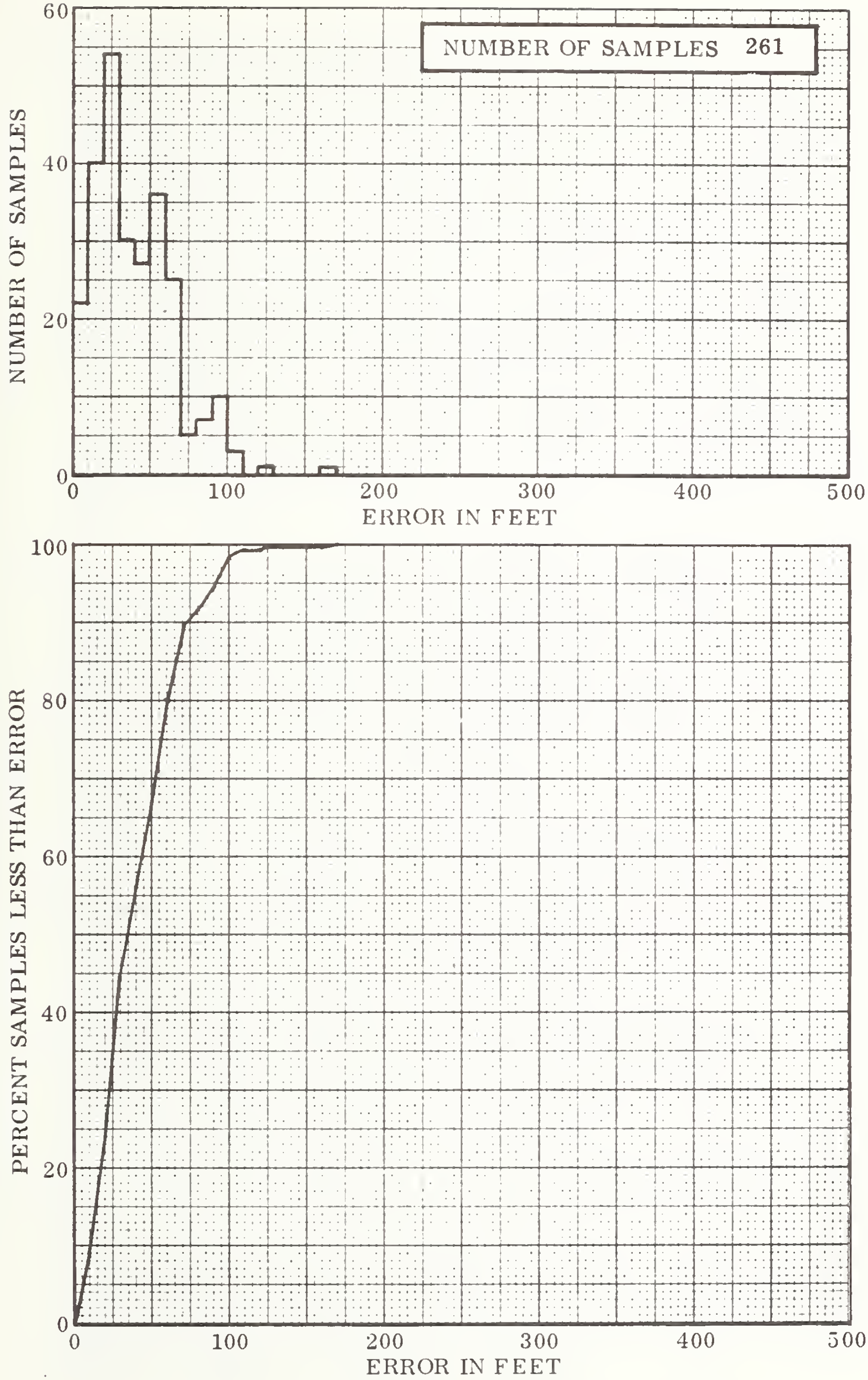


FIG. 8-50 FIXED ROUTE AVM SYSTEM ERRORS, RUN 29

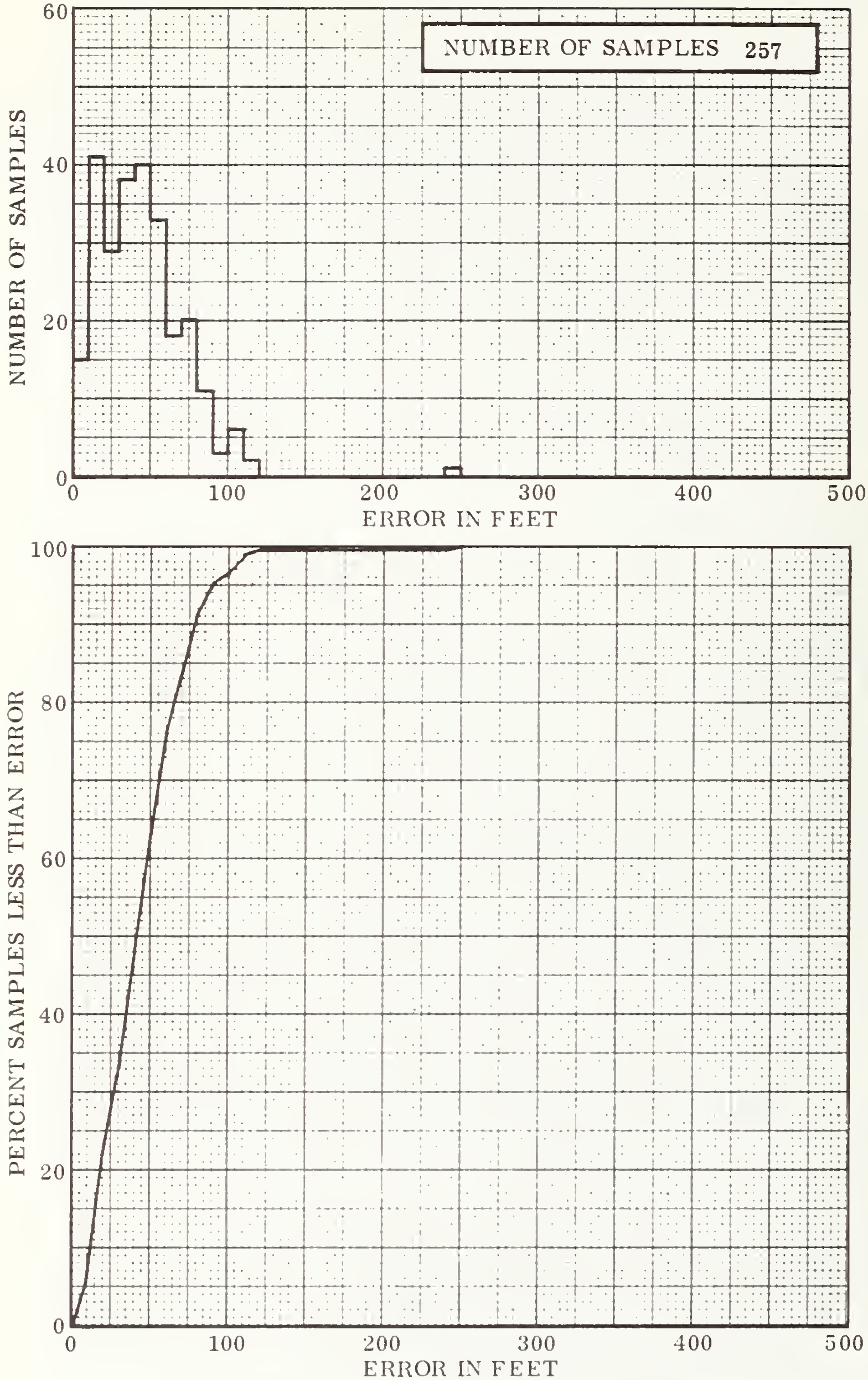


FIG. 8-51 FIXED ROUTE AVM SYSTEM ERRORS, RUN 30

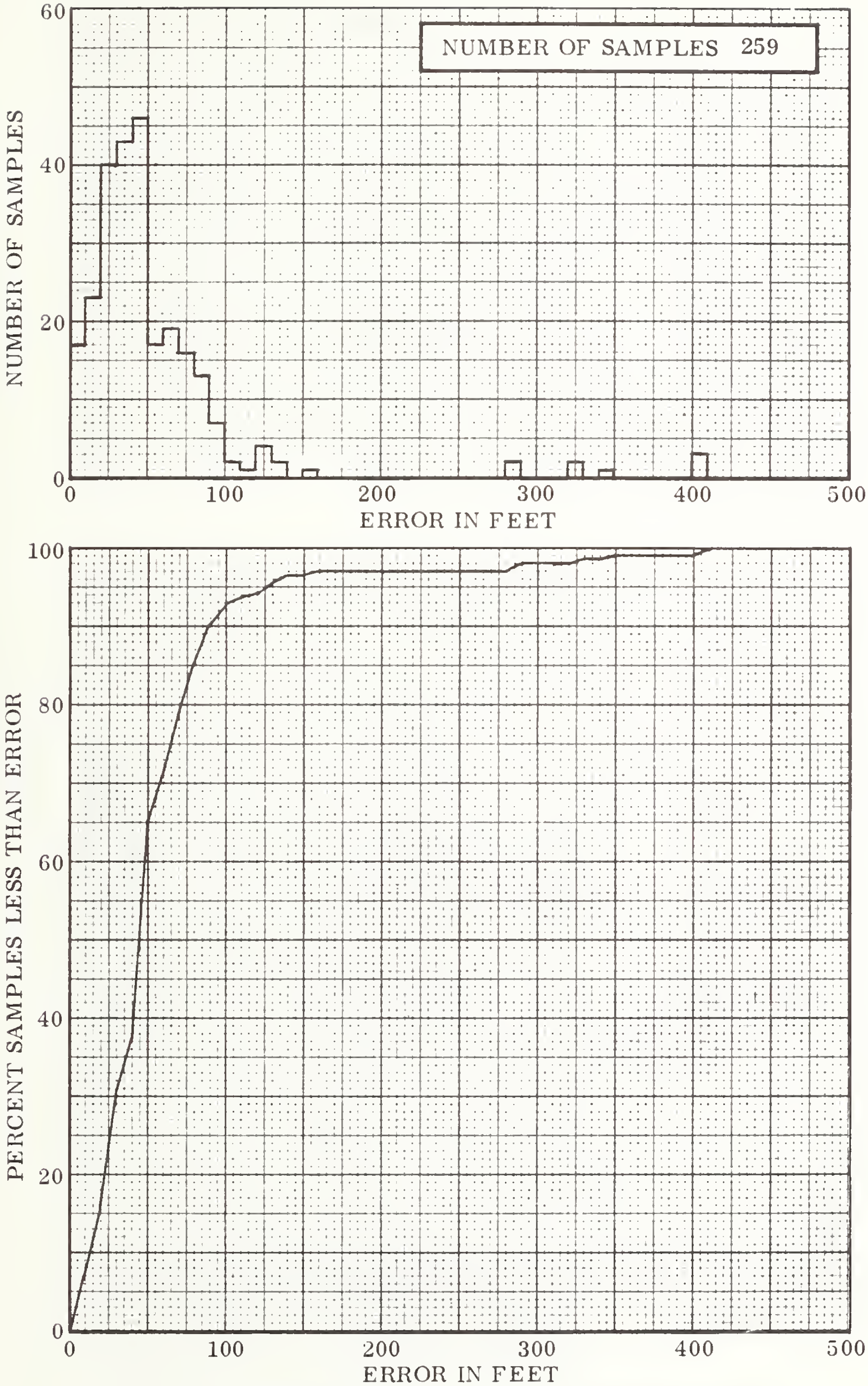


FIG. 8-52 FIXED ROUTE AVM SYSTEM ERRORS, RUN 31

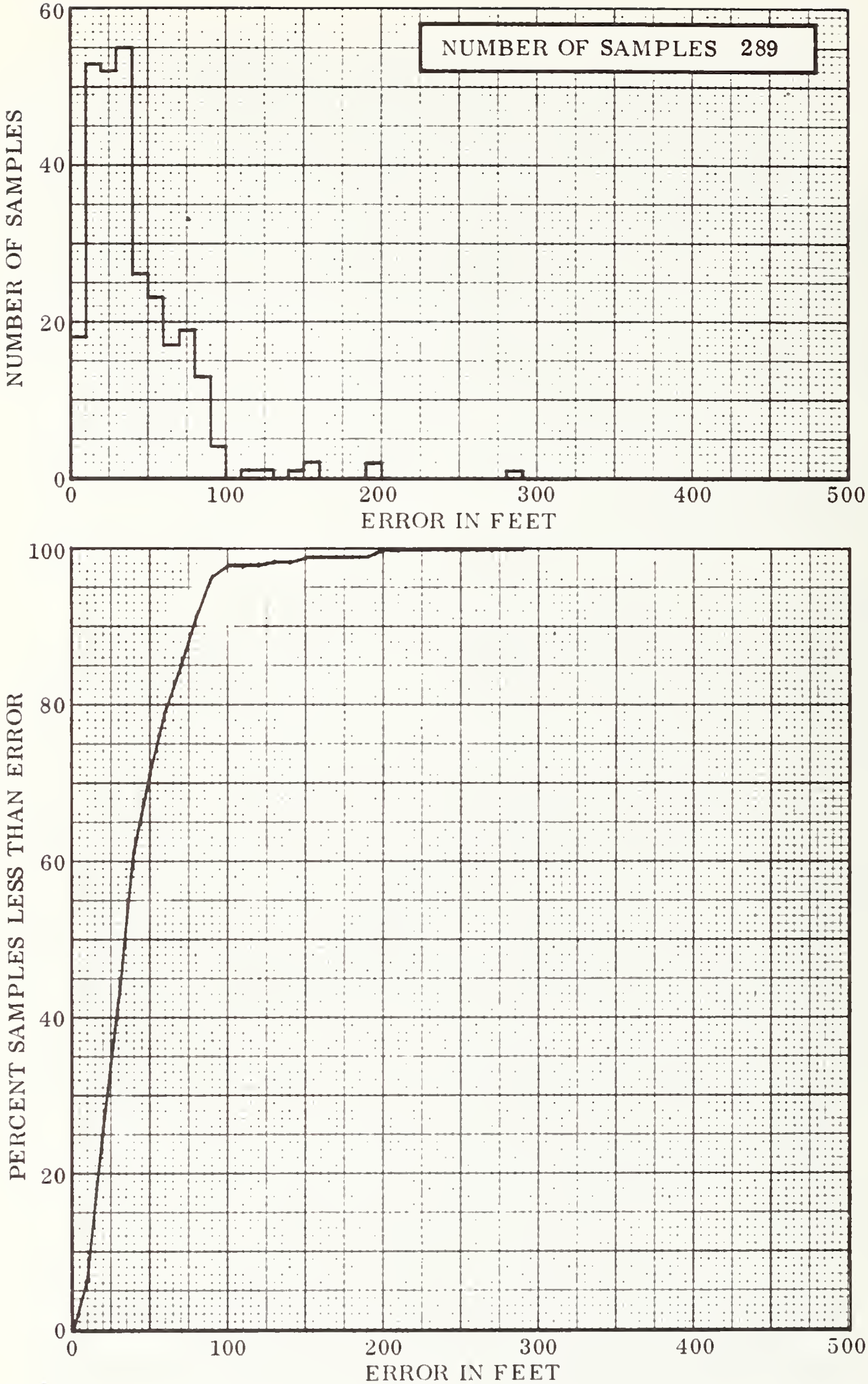


FIG. 8-53 FIXED ROUTE AVM SYSTEM ERRORS, RUN 34

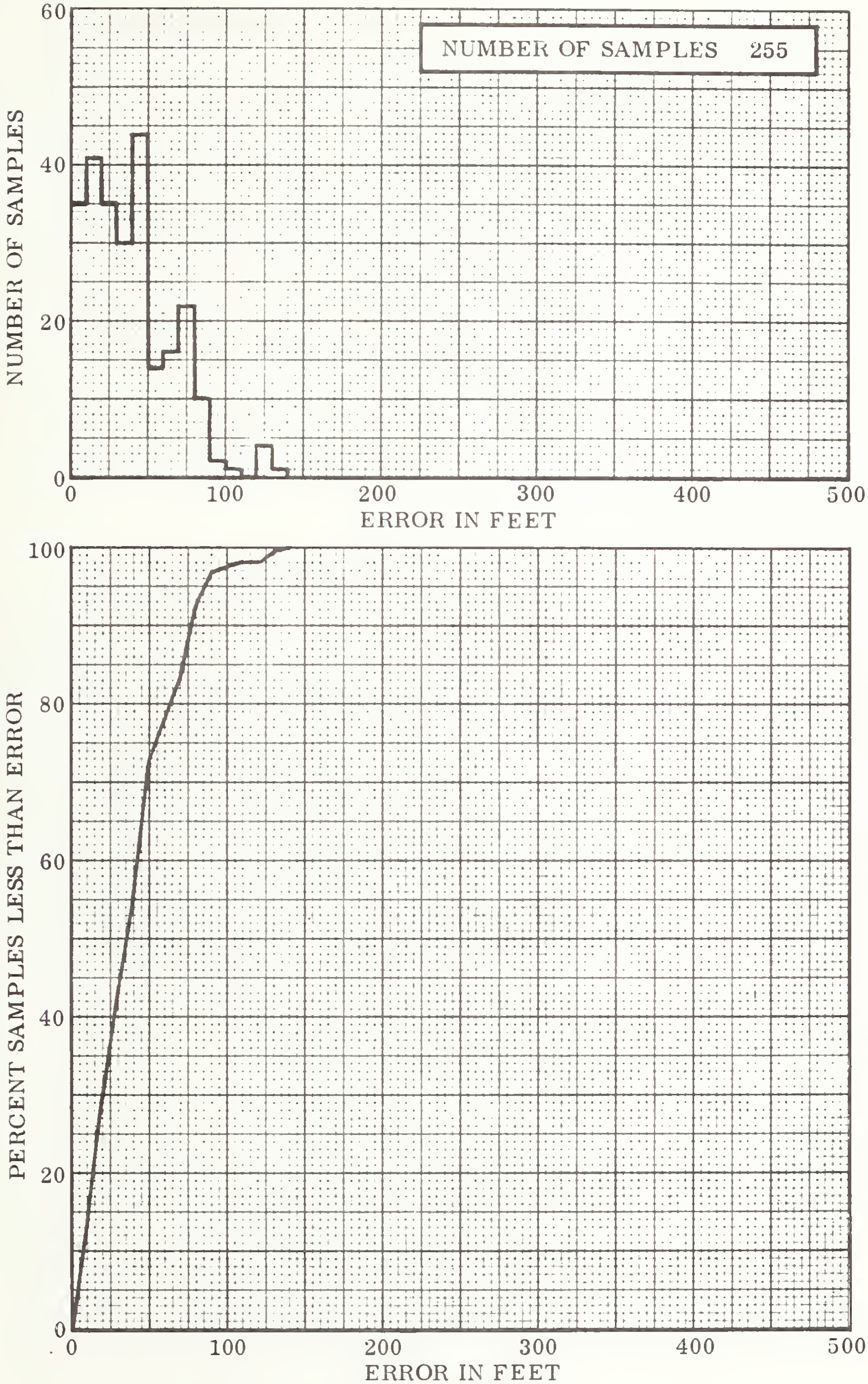


FIG. 8-54 FIXED ROUTE AVM SYSTEM ERRORS, RUN 35

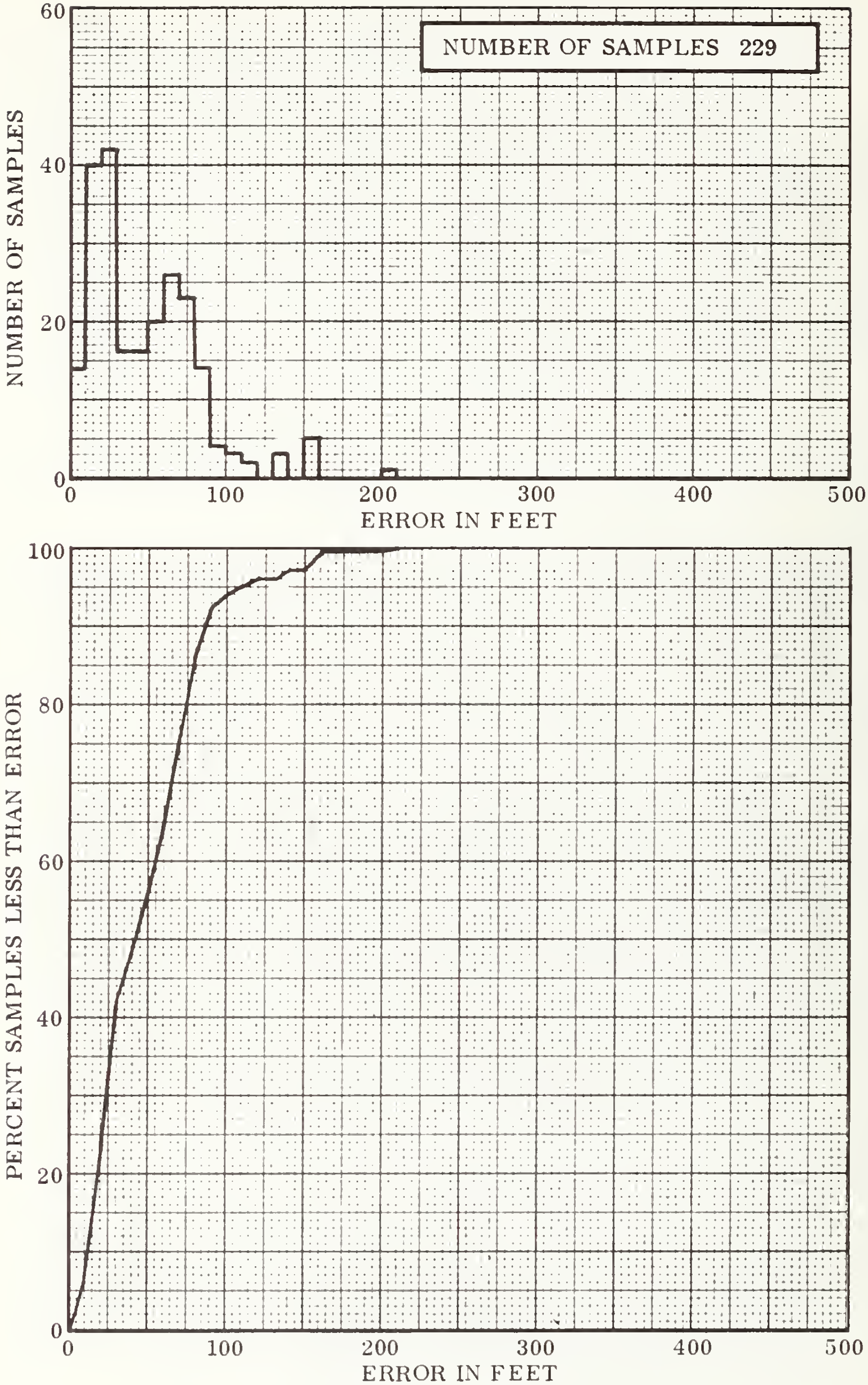


FIG. 8-55 FIXED ROUTE AVM SYSTEM ERRORS, RUN 36

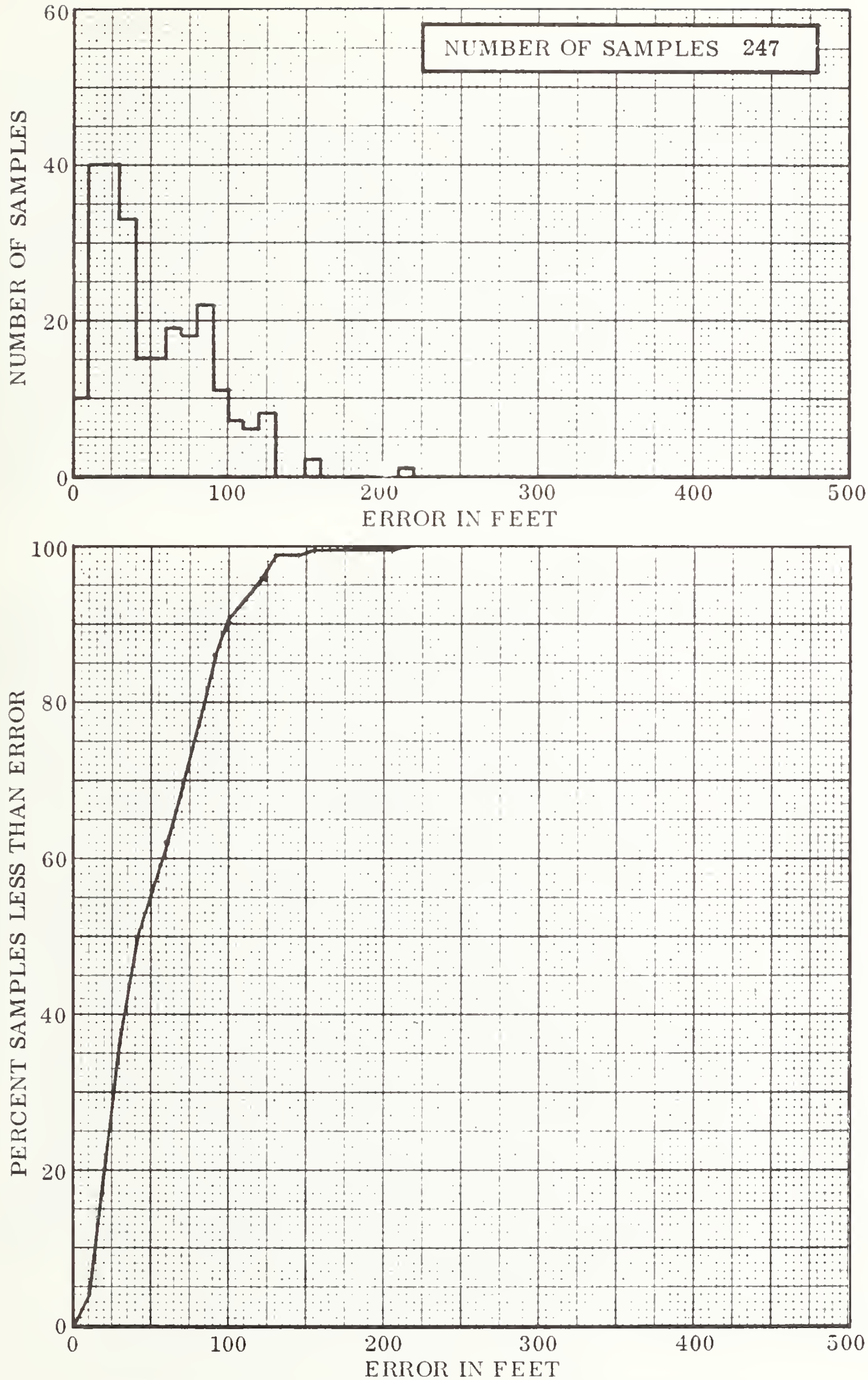
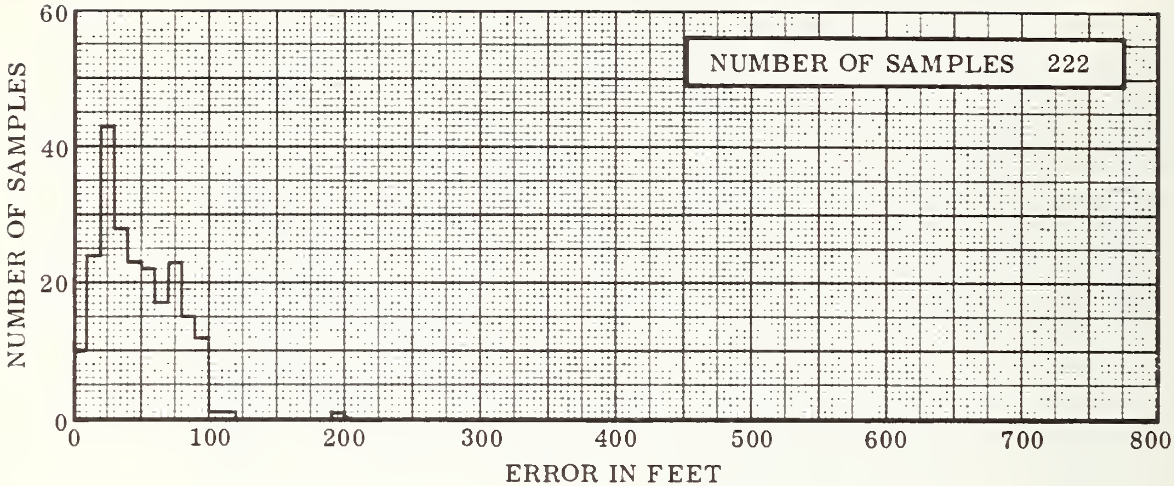


FIG. 8-56 FIXED ROUTE AVM SYSTEM ERRORS, RUN 37



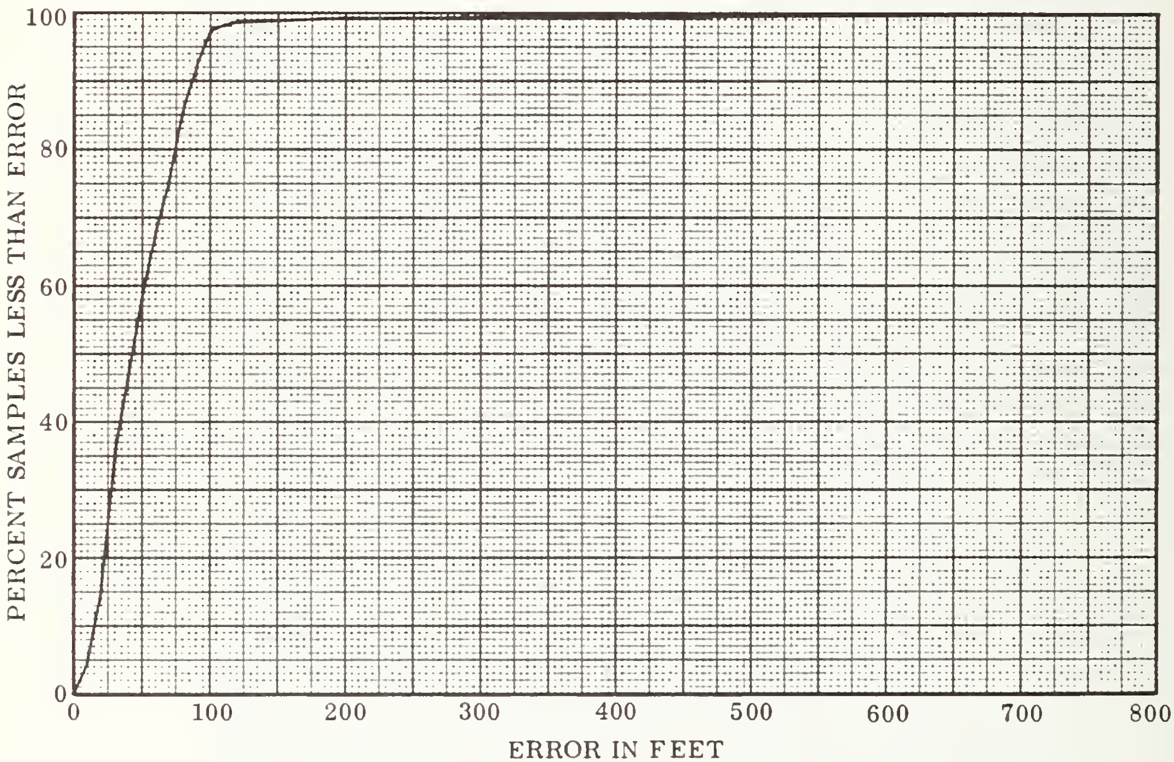


FIG. 8-57 FIXED ROUTE AVM SYSTEM ERRORS, RUN 38

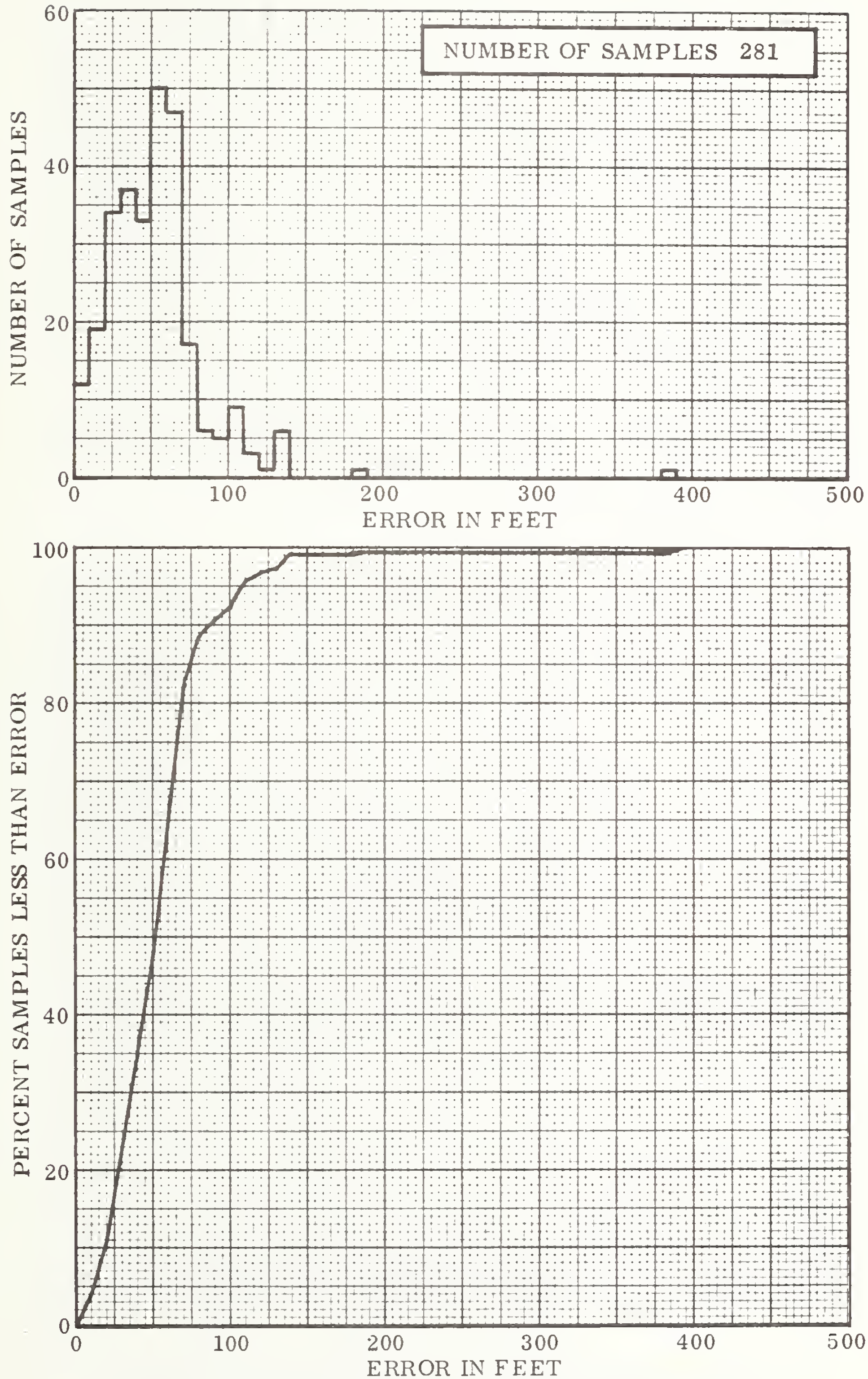


FIG. 8-58 FIXED ROUTE AVM SYSTEM ERRORS, RUN 39

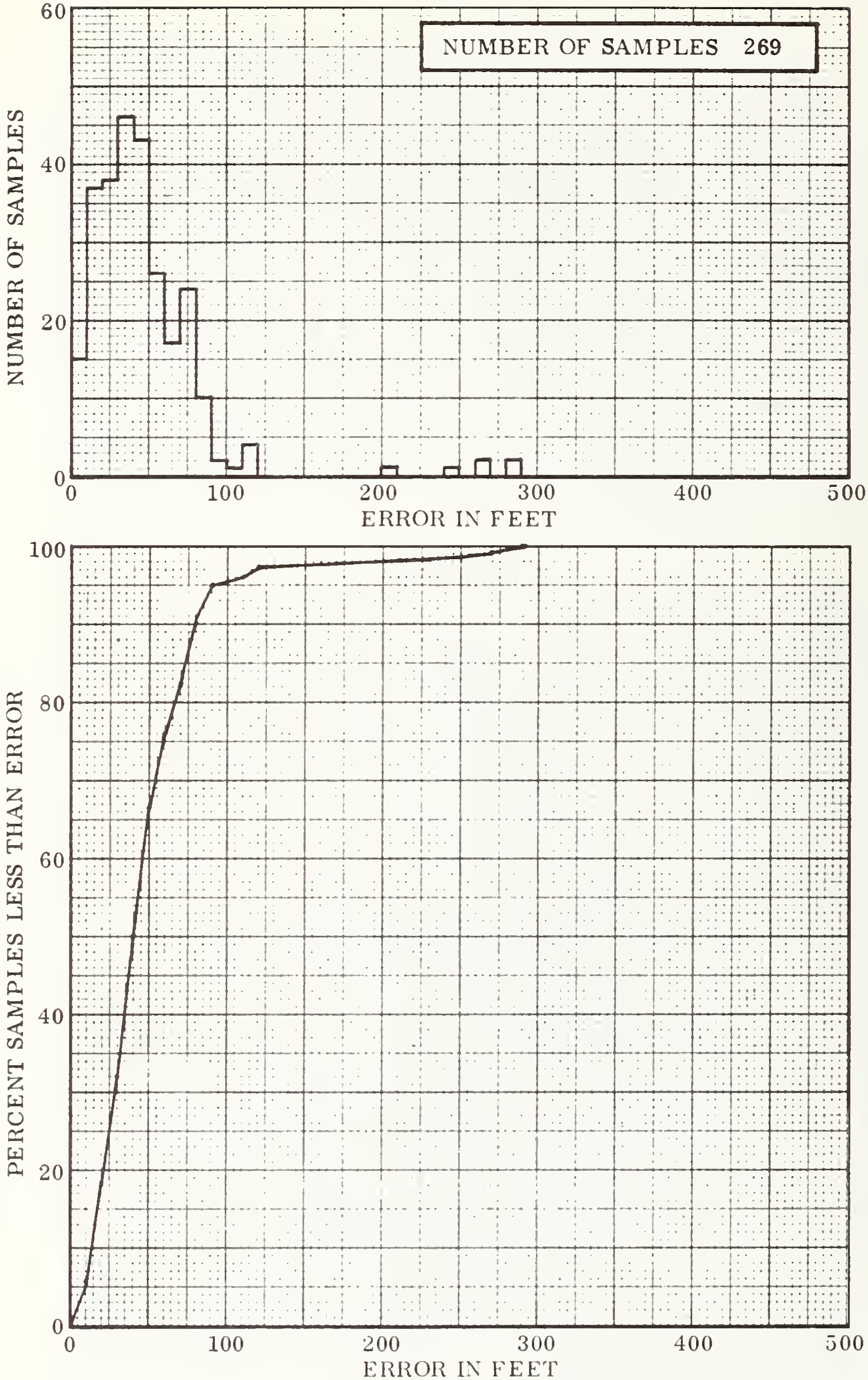


FIG. 8-59 FIXED ROUTE AVM SYSTEM ERRORS, RUN 40

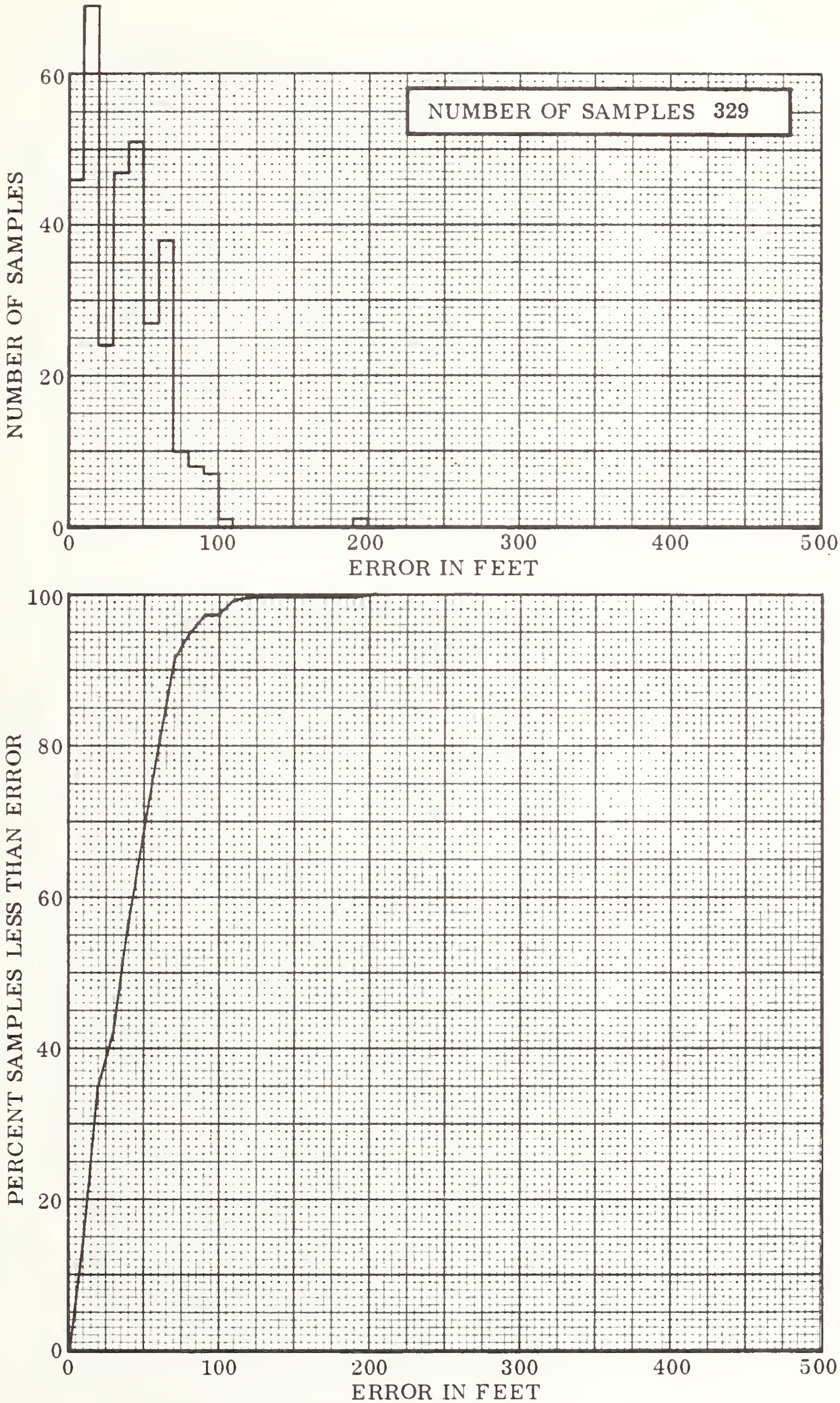


FIG. 8-60 FIXED ROUTE AVM SYSTEM ERRORS, RUN 41

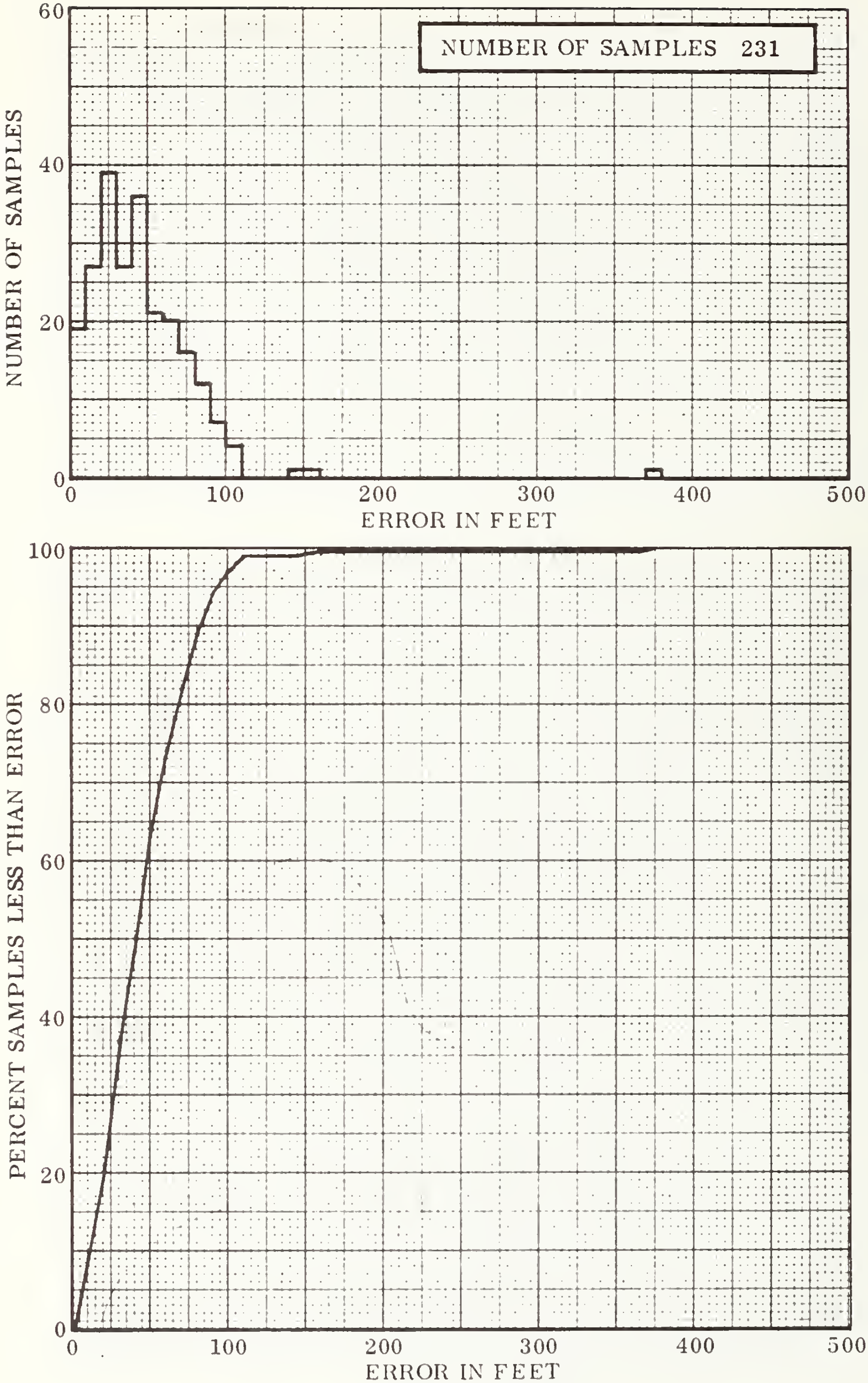


FIG. 8-61 FIXED ROUTE AVM SYSTEM ERRORS, RUN 42

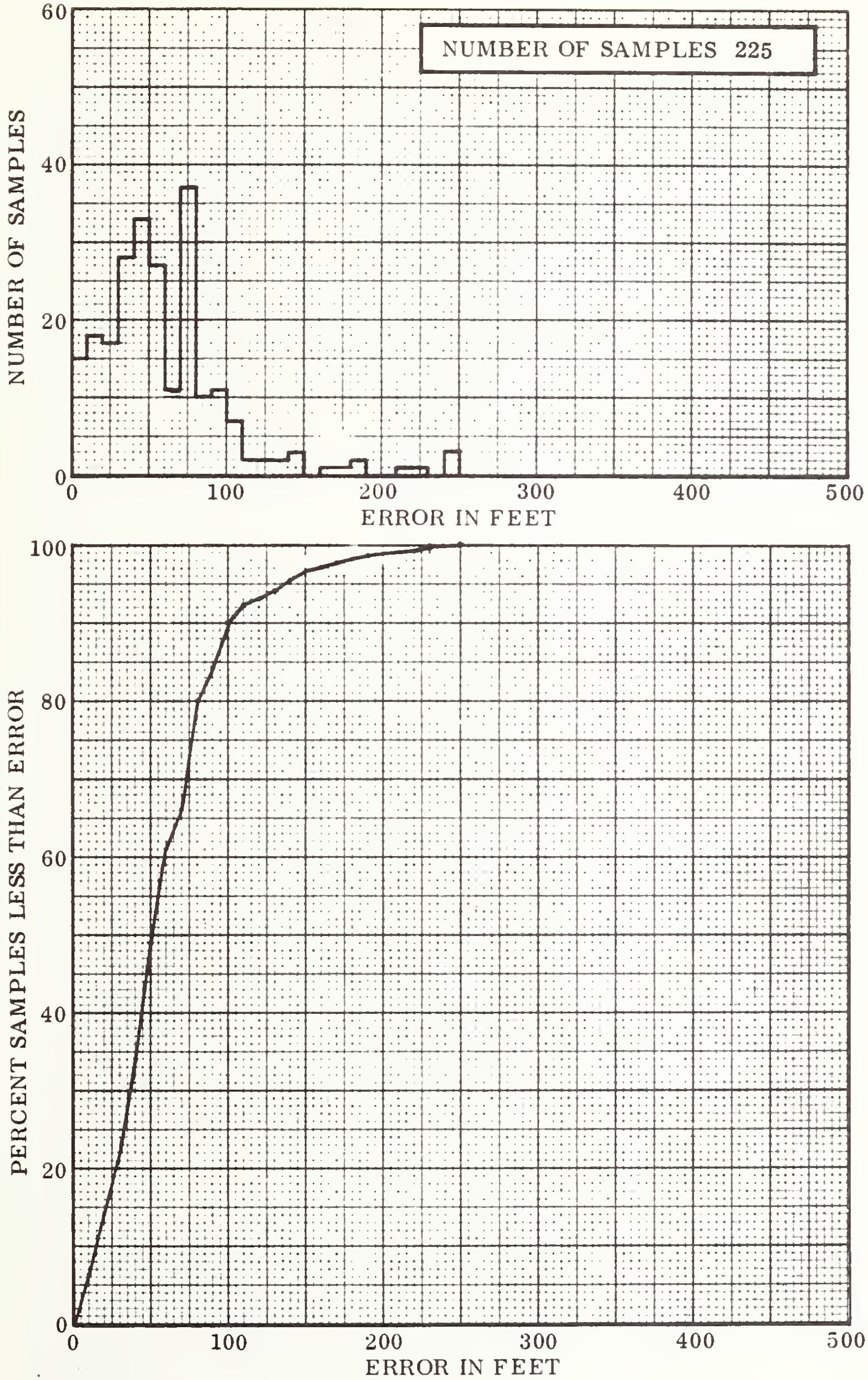


FIG. 8-62 FIXED ROUTE AVM SYSTEM ERRORS, RUN 43

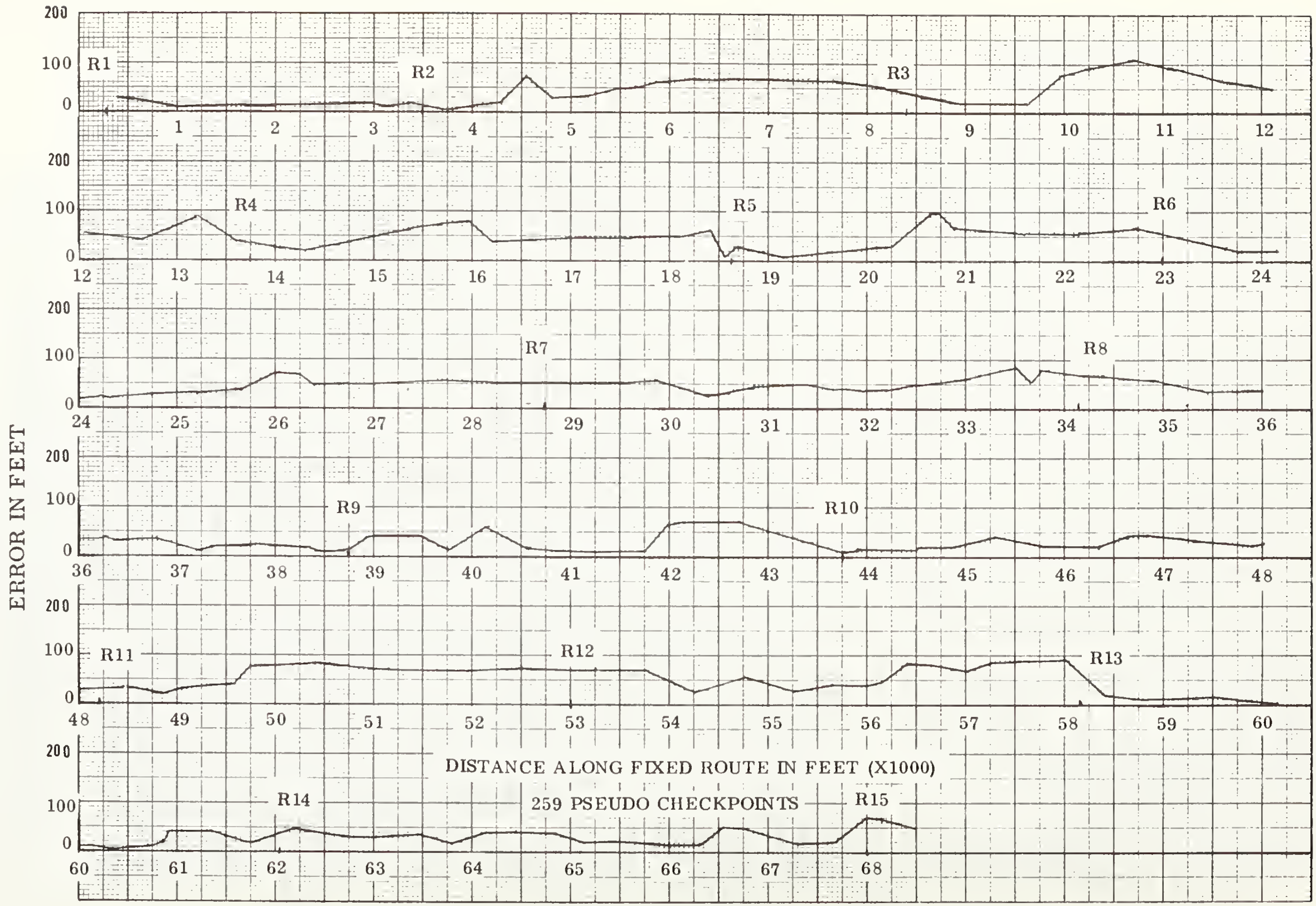


FIG. 8-63 AVM SYSTEM ERRORS PLOTTED VS. ROUTE DISTANCE, RUN 28

TABLE 8-9 TIMEPOINT PERFORMANCE OUTPUT DATA, RUN 27

RUN # 27 TIME POINT PERFORMANCE

TP#	OPEN MIN:SEC	CLOSE MIN:SEC	TOD MIN:SEC	TLR1D MIN:SEC	DELTAT SEC	ERROR SEC
1	0: 0.0	0: 0.0	0:37.5	0:46.0	7.0	1.5
2	4:52.0	0: 0.0	4:57.0	5: 3.0	7.0	-1.0
3	0: 0.0	0: 0.0	11: 5.0	11:11.5	7.0	-0.5
4	14:50.0	15: 7.5	15:16.5	15:20.0	5.0	-9.0
5	0: 0.0	0: 0.0	23: 2.0	23: 6.0	6.0	-2.0
6	26:40.0	26:43.0	26:29.0	26:31.0	2.0	14.0
7	0: 0.0	0: 0.0	32:30.5	32:29.5	-2.0	1.0
8	37:39.5	37:49.5	37:54.5	37:58.0	2.0	-5.0
9	47:55.5	48: 2.5	48: 6.0	48:12.0	9.0	-3.5
10	53:27.0	53:39.0	53:42.5	53:47.0	5.0	-3.5
11	57:12.0	57:16.5	57:20.0	57:23.5	5.0	-3.5
12	60:52.0	61: 5.5	61: 7.5	61: 6.5	1.0	-2.0
13	0: 0.0	0: 0.0	66:56.5	66:58.5	1.0	1.0
14	0: 0.0	0: 0.0	71:24.0	71:26.5	5.0	-2.5
15	0: 0.0	0: 0.0	80:16.0	80:20.5	5.0	-0.5

ERROR FREQUENCY DENSITY

ERROR INTERVAL	NO. OF SAMPLES	PERCENT OF SAMPLES
0- 1	2	13.33
1- 2	4	26.67
2- 3	3	20.00
3- 4	3	20.00
5- 6	1	6.67
9- 10	1	6.67
14- 15	1	6.67

CUMULATIVE ERRORS

ERROR	NO. OF SAMPLES LT ERROR	PERCENT OF SAMPLES LT ERROR
1	2	13.33
2	6	40.00
3	9	60.00
4	12	80.00
5	12	80.00
6	13	86.67
7	13	86.67
8	13	86.67
9	13	86.67
10	14	93.33
11	14	93.33
12	14	93.33
13	14	93.33
14	14	93.33
15	15	100.00

TABLE 8-10 TIMEPOINT PERFORMANCE ERRORS (SECONDS)

TP \ RUN	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26
1	1.5	1.5	1.5	2.5	-0.5	-6.0	0.0	3.5	1.0	3.0	-9.0	-6.0	-2.5	-9.5	3.0
2	1.5	2.0	-2.0	-7.0	-4.0	-4.0	-8.0	-1.5	1.0	-1.0	0.0	-0.5	-5.0	-3.0	-5.5
3	-5.5	-4.0	-0.5	-4.0	-1.0	-5.0	-7.0	-8.0	-5.5	-6.0	-6.0	-6.0	-3.5	-6.0	0.0
4	-10.0	-12.0	-13.5	-8.0	-0.5	-14.0	-2.5	-2.5	-4.5	-7.0	0.0	0.0	-5.0	-6.0	-3.5
5	23.5	-27.5	42.5	-3.0	-2.5	-2.5	-4.0	-3.5	-2.0	-1.0	-3.0	-1.5	-4.5	-1.5	-2.0
6	0.0	-8.0	-4.5	-0.5	-4.5	-1.5	9.5	-14.5	-4.5	0.5	-1.0	0.0	12.5	R1D	12.0
7	0.0	0.5	1.5	-0.5	1.0	1.0	1.0	1.5	-9.0	1.5	2.0	-3.5	1.0	0.0	1.0
8	1.0	-5.5	-15.0	-0.5	-5.0	1.0	-6.0	-5.5	-5.0	-10.0	0.0	-8.5	-1.0	-11.0	-5.5
9	-5.5	-2.0	-3.0	-2.0	-3.5	-3.0	-2.0	-3.0	-3.0	-3.5	-3.0	4.5	-4.5	1.0	1.5
10	-5.0	-2.0	-4.5	-2.5	-3.5	-1.5	-2.0	-1.0	P	-4.5	-3.0	-0.5	-1.0	-1.0	-2.0
11	-2.5	-2.5	-2.0	-4.5	-3.0	-7.5	TD	-3.5	P	-3.5	-2.0	-4.0	-4.5	-3.0	-3.5
12	1.0	-0.5	0.0	-2.0	-3.0	-2.5	0.0	0.0	P	-0.5	-3.0	-0.5	-1.5	-3.0	-0.5
13	-2.0	-4.0	-6.0	-2.0	0.0	-10.0	-6.5	-2.0	P	-6.0	-7.0	-7.5	0.0	0.0	0.0
14	-3.0	-2.0	-2.0	-1.0	-3.0	3.0	-4.5	-2.5	P	-4.0	-4.0	-2.0	-4.0	6.0	-1.5
15	-1.0	0.0	0.0	-1.0	-7.5	-1.0	-2.0	-0.5	P	-0.5	-1.0	-2.5	-1.0	-1.0	TD

R1D - Missed R1 Dropout
P - Auxiliary Power Generator Failure
TD - Missed Event Marker

TABLE 8-10 TIMEPOINT PERFORMANCE ERRORS (SECONDS) (CONT'D)

TP \ RUN	27	28	29	30	31	32	34	35	36	37	38	39	40	41	42	43
1	1.5	-5.5	1.5	-8.5	-5.0	-8.0	-9.0	1.5	2.0	4.0	- 4.0	1.0	3.5	-5.5	2.0	2.0
2	-1.0	-1.0	-6.5	-7.0	2.5	-2.5	-4.0	2.0	-4.5	-3.5	-4.5	-4.5	-6.0	-3.5	-4.5	-5.5
3	-0.5	0.5	-8.0	-8.5	-6.5	-9.0	-7.0	0.5	0.0	-8.0	-5.5	-11.0	-11.0	-9.0	-9.0	-0.5
4	-9.0	-2.5	-4.0	-5.5	-5.0	-6.0	-1.0	-6.5	-7.0	-0.5	-5.5	-2.5	-8.0	-1.5	-3.5	-5.5
5	-2.0	-2.0	-2.0	-2.0	-1.5	-2.0	17.0	-1.5	-2.0	-2.0	-2.0	-6.0	-6.5	-8.0	-1.5	-1.5
6	14.0	1.5	-0.5	13.5	0.0	-0.5	0.0	0.0	0.5	-0.5	19.0	11.0	-0.5	0.0	0.5	-10.5
7	1.0	0.5	1.5	1.0	0.5	2.0	8.5	2.0	1.0	0.5	0.5	1.5	0.5	1.5	1.5	1.0
8	-5.0	0.0	0.5	0.0	-10.5	TD	0.0	-6.5	-4.5	-8.0	-6.0	-5.5	0.5	0.5	2.0	-5.5
9	-3.5	-4.0	-5.5	-3.5	-3.0	0.5	-3.0	-5.5	-2.5	-4.0	-4.0	-4.0	T	-4.5	-4.0	-1.0
10	-3.5	-4.0	-11.0	0.5	-5.0	-12.0	-1.0	-9.5	-1.5	-7.0	-5.5	-1.0	8.0	-5.0	-6.0	-6.5
11	-3.5	0.0	-7.5	-5.5	-3.5	-1.0	-6.0	-5.5	-4.5	-0.5	-3.5	-6.0	4.0	1.0	-4.0	-4.0
12	-2.0	-5.0	-0.5	-0.5	0.0	-11.0	0.0	-9.5	-3.0	-5.5	R1D	R1D	-3.0	R1D	4.0	R1D
13	1.0	0.0	-3.5	1.0	0.0	-5.5	-5.0	-5.0	-4.0	-4.5	-10.0	-9.0	1.0	-7.0	-4.5	1.0
14	-2.5	-3.0	-6.5	-1.0	-4.0	-5.0	-9.0	-2.0	-4.5	-2.0	2.0	-1.5	-3.0	-3.5	-5.0	-4.0
15	-0.5	-9.0	-0.5	-1.0	0.5	-1.5	-8.0	-1.5	-1.0	-1.0	-0.5	0.5	-1.0	3.0	-0.5	-1.0

T - Time Error on Tape
R1D - R1D Not Received
TD - Missed Event Marker

All anomalies are explained in Table 8-11. Note that a signpost failure between Runs 37 and 38 resulted in no R1D data at Timepoint 12 on Runs 38 through 43. In the Phase II system, an absence of R1D information would result in no computation of timepoint performance at that timepoint unless the bus door were first opened and then closed at the timepoint. The Phase II procedure was followed to the letter in Phase I in that timepoint performance at Timepoint 12 was only computed during Runs 40, 41, and 42 when the door close event was utilized. Table 8-12 contains composite timepoint error statistics for all fixed route runs.

Figure 8-64 contains a histogram and cumulative distribution of the absolute time-of-departure errors resulting from processing Runs 11 through 43. Figure 8-65 contains an error frequency density of these errors, with the sign preserved.

By using the Door Open event as an indication of time of arrival, the following results were obtained:

Number of Door Open Samples:	221 Samples
95 percentile value of (TOA-TD):	37 Seconds
99.5 percentile value of (TOA-TD):	56 Seconds
Average (TOA-TD):	16 Seconds.

Note that use of the Time of Door Open to indicate TOA has a built in error if the stop is a near side stop since the time during which the door is open is included.

The speed of the test vehicle while passing timepoints was computed for each case in which the Door Open/Door Close events were not utilized. Table 8-13 shows the results obtained. Note that the maximum vehicle speed of passage was 23 mph, a constraint imposed by both traffic and legal speed limits. In order to determine if there was a correlation between vehicle speed of passage and time of passage errors, a plot was constructed showing the time of passage error versus vehicle velocity. This plot, shown in Figure 8-65, indicates that the errors were rather uniformly distributed over the interval between 5 and 18 miles per hour. In particular, there is no indication that high (or low) speeds tend to produce larger errors. Note that all data shown in Figure 8-66 resulted from the use of the Region 1 dropout, and therefore would also apply to the proposed Phase II system with the odometer eliminated as described in Subsection 10.2.

The application of the Door Close event to determine time of passage as presented herein has been in strict accordance with the AVM specification. However, it is of interest to note the results obtained if one assumed that the vehicle passes the timepoint at the exact <u>time of door closure</u>. This would produce zero error in each case in which the Door Close event was employed. The effect on the overall error statistics obtained during Phase I would be as follows:

(Text continued on 8-93)

TABLE 8-11 TIMEPOINT ANOMALIES

RUN NO.	PROBLEM	RESULT
14	Couldn't process second cassette	4 TP's computed manually
17	Missed TD 11	14 TP's
19, 33	Couldn't process	No Results
20	Auxiliary power failure at CP 46	9 TP's
24	Couldn't process all tapes	3 TP's computed manually
24	First TD 12 entered early	Deleted with EE 12
25	Couldn't process all of tape	9 TP's computed manually
25	No R1D from TP 6 due to 0.5 second sampling interval	14 TP's
26	Missed TD 15	14 TP's
27	First TD 10 should be TA 10	Card input change
34	Couldn't process all of tape	7 TP's computed manually
34	DP 15 and DC 15 entered early	Deleted with EE 15
38, 39, 41, 43	No R1D from TP 12 due to signpost failure	Missed TP 12
40	Time record error at TD 6	Missed TP 6
40	Couldn't process all of second cassette	6 TP's computed manually
42	TD 15 entered early	Deleted with EE 15
43	Couldn't process all of second cassette	3 TP's computed manually

TABLE 8-12 COMPOSITE TIMEPOINT PERFORMANCE ERROR STATISTICS

ERROR FREQUENCY DENSITY		
Error* Interval	No. Samples	Percent Samples
0- 1	80	17.74
1- 2	79	17.52
2- 3	58	12.86
3- 4	49	10.86
4- 5	49	10.86
5- 6	39	8.65
6- 7	27	5.99
7- 8	13	2.88
8- 9	16	3.55
9-10	14	3.10
10-11	7	1.55
11-12	5	1.11
12-13	4	.89
13-14	2	.44
14-15	3	.67
15-16	1	.22
17-18	1	.22
19-20	1	.22
23-24	1	.22
27-28	1	.22
42-43	1	.22

CUMULATIVE ERRORS		
Error*	No. Samples LT Error	% Sample LT Error
1	80	17.74
2	159	35.25
3	217	48.12
4	266	58.98
5	315	69.84
6	354	78.49
7	381	84.48
8	394	87.36
9	410	90.91
10	424	94.01
11	431	95.57
12	436	96.67
13	440	97.56
14	442	98.00
15	445	98.67
16	446	98.89
18	447	99.11
20	448	99.33
24	449	99.56
28	450	99.78
43	451	100.00

* Error in Seconds

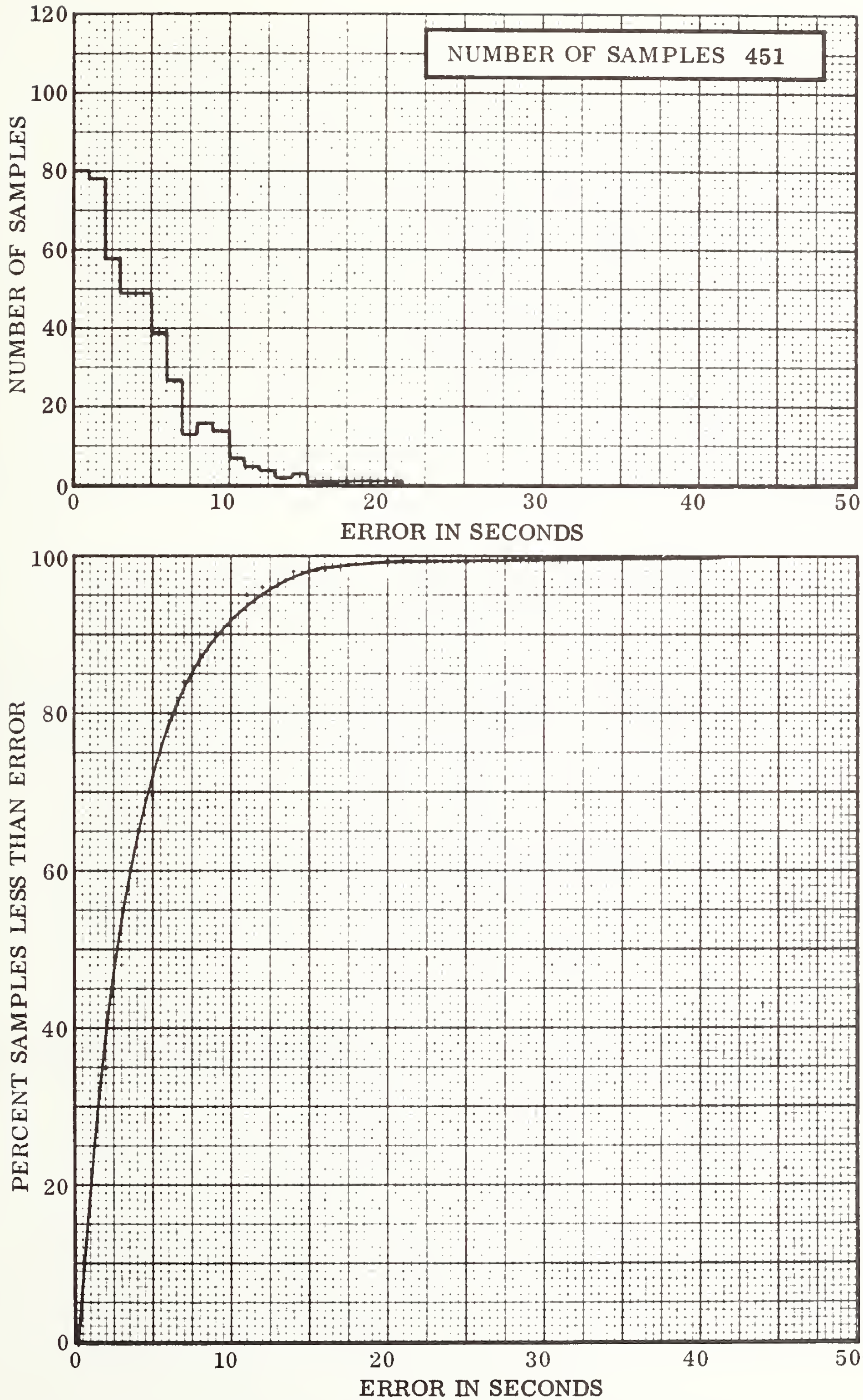


FIG. 8-64 FIXED ROUTE AVM SYSTEM TIMEPOINT PERFORMANCE

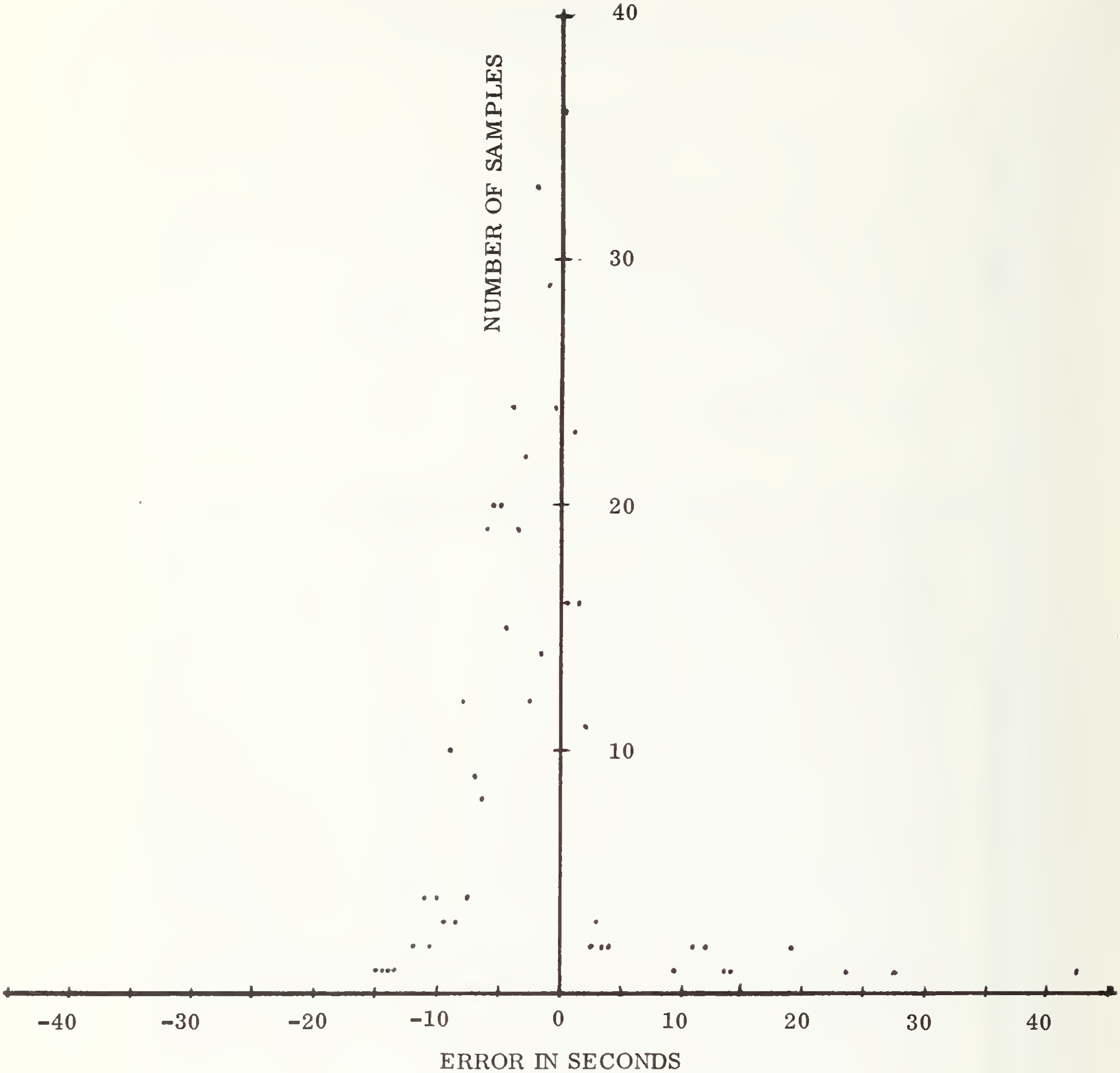


FIG. 8-65 TIMEPOINT ERROR FREQUENCY DENSITY

TABLE 8-13 AVERAGE SPEED OF TRAVEL PAST TIMEPOINTS

RUN	TIMEPOINT 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
11	9.4	9.0				15.8	3.4	6.7				5.5		14.7	16.6
12	14.2	6.7					7.4		7.4			4.1		9.2	
13	6.9		8.3		4.0		8.9		5.5			17.8		7.5	15.2
14	7.5				17.1	16.2	12.6	8.2						6.7	13.5
15	18.2		17.1	12.5	17.4		7.9		9.8				6.1		
16		12.1			17.1	21.6	16.1	18.2		20.2	15.8				16.0
17	19.4				20.3		7.2			12.8		19.5			2.9
18	13.0	7.6			18.9		8.1			15.7		16.9		11.5	3.4
20	6.9	9.6			3.1										
21	11.1	11.1			12.2	12.7	8.0					18.5			13.2
22		9.8		8.1	13.9	15.1	13.7	16.2			9.5				15.1
23		12.2		11.4	14.3	12.5			5.3	9.4		22.7		8.3	
24	20.0						10.9	16.8	5.6	5.6		17.2	16.7		15.2
25		12.6			13.2		15.1		5.2	12.9			15.5		15.2
26	12.5		16.9		14.4	15.3	9.4		9.0	17.1		18.5	16.5	5.9	
27	16.9		15.4		15.7		7.6						15.9	9.1	20.4
28		6.1	18.2		15.4	12.2	10.6	7.6			15.2			10.5	
29	11.5				17.5	15.8	7.6	13.1				15.1			14.5
30					13.6	16.8	7.6	16.5		13.6		4.4	14.8	5.4	14.2
31		8.6			13.9	17.4	7.9					16.4	14.3		8.3
32		9.6			15.4	17.1	14.7	10.2	6.3		9.4				11.9
34		7.5		3.8		16.2		16.2	10.0	14.2		15.0			
35	14.7	8.8	14.9			16.6	12.6							10.1	15.6
36	14.0		9.0		14.6	13.8	7.7			17.5					15.3
37	10.5			14.3	15.8	13.2	7.7				8.8			9.2	15.1
38	13.3	11.8			13.5	12.9	10.4					18.4		7.1	15.5
39	12.8						7.4		10.0	11.3		8.6		6.3	3.4
40	13.7					15.5	7.9	10.1					7.5	6.4	13.0
41				4.4		4.0	7.6	18.0	8.8		2.8				11.7
42	15.8	11.3			14.8	12.5	8.4	15.5							16.8
43	16.4	11.6	7.3		16.1		11.0		8.5			17.7	13.4		15.0

AVERAGE SPEED IN MILES PER HOUR

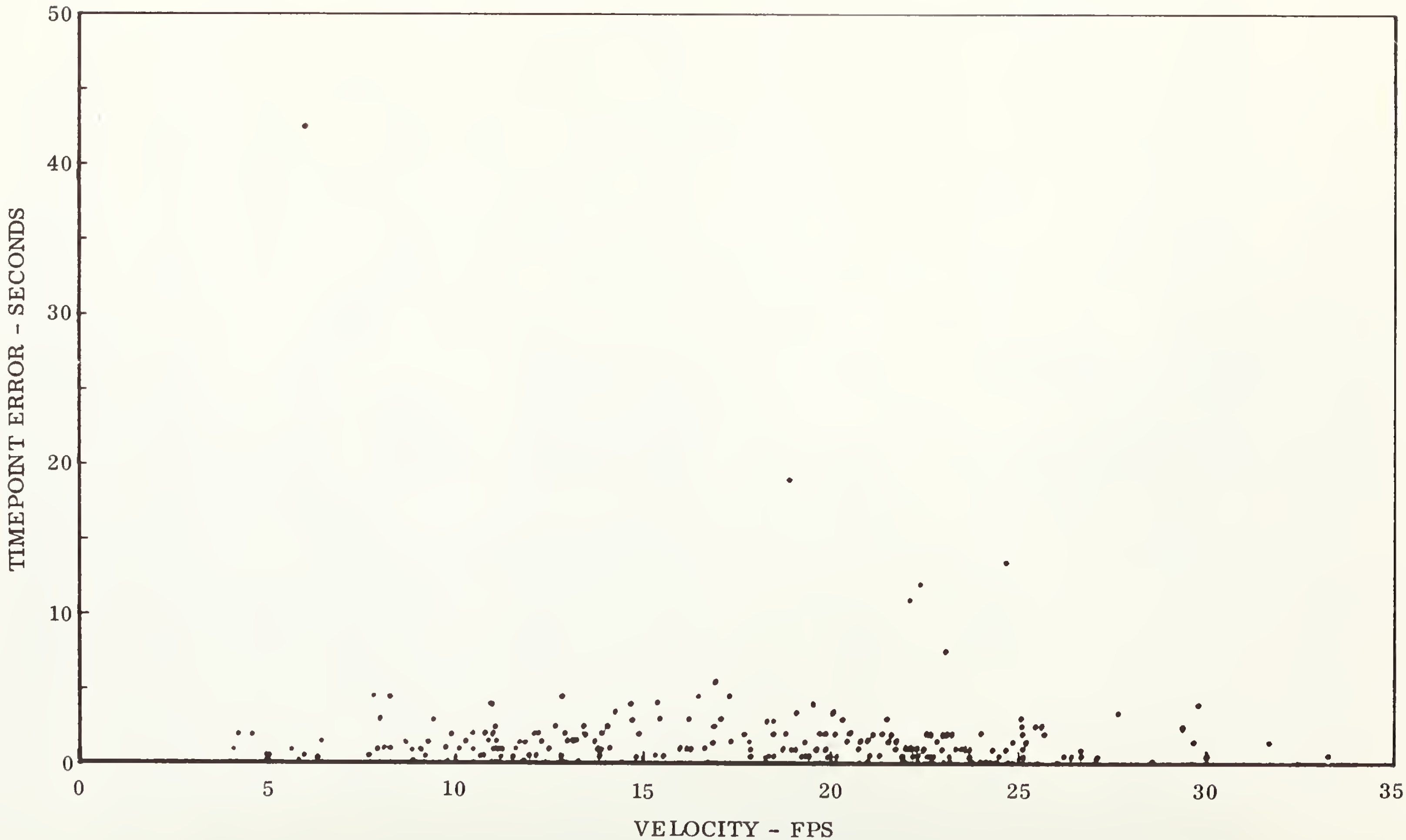


FIG. 8-66 FIXED ROUTE AVM SYSTEM ERRORS, RUN 25

Assuming use of DC event results in zero TOD error, then for 451 samples:

95 percent value of TOD error: 3.5 seconds
99.5 percent value of TOD error: 24 seconds

The error statistics obtained for the 225 samples in which the R1 dropout algorithm was used resulted in the following time-of-departure error statistics:

95 percent value of TOD error: 5 seconds
99.5 percent value of TOD error: 8 seconds.

8.3 FIXED ROUTE DATA PROCESSING ANOMALIES AND CORRECTIONS

Tables 8-2 and 8-7 summarized the problems encountered in processing fixed route data. The details of these problems and the procedures through which these data were ultimately processed are addressed in this subsection. Specific instances in which erroneous results were obtained by processing contaminated data records are also addressed.

8.3.1 Location Subsystem Data Processing

Five tapes, Runs 14, 24, 34, 40, and 43, could not be processed to completion as a result of the inability of the RT-11 operating system to read past erroneous data records. Figure 8-67 shows a typical record dump of the data between checkpoints CP37 and CP38 on Run 34. The eight data records beginning at time 56:04 and ending with the record having signpost code (68,01) are not valid data. This is evident since (1) the event codes 54 099, 204, 205, etc. are meaningless; (2) the signpost codes are non-existent; (3) the odometer and fifth wheel values are obviously meaningless; and (4) the time does not change. Subsequently, the correct signpost code and incremented odometer and fifth wheel values are read from the tape.

The exact source of the bad data is unknown; however it obviously affects each word of the data record and is definitely not related to the location subsystem signposts or vehicle unit. The source is probably a transient induced by the 115 volt auxiliary AC power generator and it affected the transfer of data from the computer to the cassette. This is evident from the data since the correct signpost code and odometer and fifth wheel values are maintained in the ICU and correctly transferred to the cassette subsequent to the end of the erroneous data.

Figure 8-68 contains similar records from Runs 24, 40, and 43. In each instance, the event code entry is non-existent and time is incremented erroneously. In the cases of Runs 24 and 40, the signpost code are also non-existent. The fact that time is altered indicates that these are indeed data recording anomalies since time ticks are recorded on the cassette directly from the computer and are completely independent of the AVM system and the ICU.

	000	12	10	R1		0 01857	F 01699	T 55 49	
	000	12	10	R1		0 01861	F 01702	T 55 50	
	000	12	10	R1		0 01864	F 01706	T 55 50	
—	000	12	10	R1		0 01868	F 01709	T 55 51	← PCP#167
	000	12	10	R1		0 01872	F 01713	T 55 51	
	000	12	10	P1		0 01876	F 01718	T 55 52	
	000	12	10	R1		0 01880	F 01722	T 55 52	
	000	12	10	R1		0 01885	F 01726	T 55 53	
	000	12	10	R1		0 01889	F 01731	T 55 53	
	000	12	10	P1		0 01893	F 01735	T 55 54	
	000	12	10	R1		0 01898	F 01740	T 55 54	
	000	12	10	R1		0 01903	F 01744	T 55 55	
	000	12	10	R1		0 01907	F 01749	T 55 55	
	000	12	10	R1		0 01912	F 01753	T 55 56	
	000	12	10	R1		0 01917	F 01758	T 55 56	
	000	12	10	R1		0 01922	F 01763	T 55 57	
	000	12	10	R1		0 01927	F 01768	T 55 57	
	000	12	10	R1		0 01932	F 01773	T 55 58	
	000	12	10	R1		0 01937	F 01778	T 55 58	
	000	12	10	R1		0 01942	F 01783	T 55 59	
	000	12	10	R1		0 01947	F 01788	T 55 59	
	000	12	10	R1		0 01953	F 01793	T 56 00	
	000	12	10	R1		0 01958	F 01798	T 56 00	
	000	12	10	R1		0 01963	F 01804	T 56 01	
	000	12	10	R1		0 01968	F 01809	T 56 01	
	000	12	10	R1		0 01974	F 01814	T 56 02	
	000	12	10	R1		0 01979	F 01819	T 56 02	
	000	12	10	R1		0 01984	F 01825	T 56 03	
	000	12	10	R1		0 01989	F 01830	T 56 03	
54	099	74	24	R2	S	0 04042	F 22525	T 56 04	BAD RECORDS
	204	20	01	R1		0 00641	F 24440	T 56 04	
	205	20	01	R1		0 00641	F 26369	T 56 04	
	206	20	01	R1		0 00641	F 28289	T 56 04	
	208	20	01	R1		0 00641	F 30209	T 56 04	
	209	20	01	R1		0 00641	F 32129	T 56 04	
	210	20	01	R1		0 00641	F 34048	T 56 04	
	000	68	01	R1		0 00641	F 01871	T 56 04	
	000	12	10	R1		0 02036	F 01876	T 56 25	
	000	12	10	R1		0 02041	F 01881	T 56 25	
	000	12	10	R1		0 02045	F 01886	T 56 26	
	000	12	10	R1		0 02050	F 01890	T 56 26	
	[illegible]	[illegible]	[illegible]	R1		0 02055	01895	[illegible]	
	000	12	10	R1		0 02059	F 01899	[illegible]	
	000	12	10	R1		0 02063	F 01903	[illegible]	— PCP#168
	000	12	10	R1		0 02067	F 01907	T 56 28	
	000	12	10	R1		0 02071	F 01911	T 56 29	
	000	12	10	R1		0 02074	F 01914	T 56 30	
	000	12	10	R1		0 02077	F 01917	T 56 30	
	000	12	10	R1		0 02079	F 01920	T 56 30	
	000	12	10	R1		0 02082	F 01922	T 56 31	
CP	038	12	10	R1		0 02084	F 01924	T 56 31	
	004	12	10	R1		C 02086	F 01926	T 56 32	
	000	12	10	R1		0 02087	F 01927	T 56 32	

FIG. 8-67 PARTIAL LISTING SHOWING BAD RECORDS, RUN 34

000	16	11	R1	0 03930	F 11661	T 67 16	
000	16	11	R1	0 03935	F 11666	T 67 17	
045	01	12	R* A	0 02059	F 00466	T 67 17	
045	01	12	R2 W	0 02059	F 00496	T 68 08	
045	01	12	R* H	0 02059	F 00526	T 68 08	
045	01	12	R* A	0 02059	F 00556	T 68 08	Run #24
045	01	12	R2 W	0 02059	F 00586	T 68 08	
045	01	12	R3 N	0 02059	F 00616	T 68 08	
045	01	12	R1 D	0 02059	F 00646	T 68 08	
000	01	12	R1	0 02059	F 11707	T 68 08	
000	16	11	R1	0 03982	F 11713	T 68 08	
000	16	11	R1	0 03987	F 11718	T 68 08	

	000	15	16	R2 S	0 02892	F 02800	T 50 22	
	000	15	16	R2 S	0 02892	F 02800	T 50 22	
EE	120	13	37	R1	0 03823	F 43780	T 50 22	
	120	13	03	R1	0 02053	F 47620	T 50 22	
	120	13	03	R1	0 02053	F 51460	T 50 22	
	120	13	03	R1	0 02053	F 55300	T 50 22	
	120	13	03	R1	0 02053	F 59140	T 50 22	PCP #151
	120	13	03	R1	0 02053	F 62980	T 50 22	
	120	13	03	R1	0 02053	F 01285	T 50 22	
	120	13	03	R1	0 02053	F 05125	T 50 22	Run #40
	120	13	03	R1	0 02053	F 08965	T 50 22	
	120	13	03	R1	0 02053	F 12805	T 50 22	
	140	13	03	R1	0 02053	F 02800	T 50 22	
	000	15	16	R2 S	0 02892	F 02800	T 53 02	

000	19	13	R1	0 03765	F 11843	T 62 40	
000	19	13	R1	0 03771	F 11850	T 62 40	
000	19	13	R1	0 03777	F 11856	T 62 41	
000	19	13	R1	0 03783	F 11862	T 62 41	
063	19	13	R1	0 03789	F 11937	T 62 42	
000	19	13	R1	0 03864	F 11942	T 62 48	Run #43
000	19	13	R1	0 03869	F 11947	T 62 49	
000	19	13	R1	0 03874	F 11952	T 62 49	

FIG. 8-68 PARTIAL LISTINGS SHOWING BAD RECORDS, RUNS 24, 40, and 43

As a result of being able to read these cassettes with a different operating system, a complete record dump was made of each tape on which processing problems were experienced. The required data were then extracted manually from those listings (such as those shown in Figure 8-67 and 68) and the location error data recorded manually. Tables 8-14, -15, -16, -17 and 18 contain location subsystem results which were obtained by manual processing of data from Runs 14, 24, 34, 40 and 43. These results have been incorporated in Table 8-1.

Data processing errors were also experienced on run 25. These were traced to bad data records as shown in Figure 8-69. However, although the computer was able to read this tape, the location errors computed for checkpoints 26 through 30 were incorrect, as a result of the erroneous records beginning just after TD006. Recalling that the HI^3 Phase I system determines fixed route location based on elapsed odometer distance from a reset signpost, one notes from Figure 8-69 that signpost (6, 6) R1 was initially received at time 26:08.00. This was the correct reset point. However, due to the erroneous interjection of the code (6, 8)R1 for five records beginning at time 26:17:05, the data processing routine uses the record at time 26:36:05 (re-occurrence of (6, 6)R1) as the reset point for computation of checkpoint 26 through 30.

Table 8-19 contains the correct values of the errors corresponding to CP26-CP30. When corrected, the location subsystem results for run 25 should be as follows:

Corrected Results for Run 25, FRLS: 76 Samples

	Corrected Results	Incorrect Results
Average Error:	50.18 Feet	62.84 Feet
95% Error:	135 Feet	244 Feet
99.5% Error:	216 Feet	309 Feet

As noted previously, checkpoints 37, 38, 39 and 40 were not processed by FRLS during Runs 39, 40, 41, 42 and 43 as a result of the simulation of an off-route condition during the passage of those checkpoints. These checkpoints were processed manually and the results are shown in Table 8-20. The 306 foot error at CP40 on Run 42 resulted from entering CP40 late after initially entering it early and subsequently entering on EE40. As a result, the last CP40 entry was delayed. This action was recorded on the Test Data Log in the presence of the TSC monitor.

With the inclusion of all location subsystem data (including those having all tape errors corrected, the data in Table 8-20 and the correct value for CP3).

(Text continued on 8-104)

TABLE 8-14 FIXED ROUTE LOCATION SUBSYSTEM ERROR STATISTICS, RUN 14

ERROR FREQUENCY DENSITY RUN 14a

Error Interval	No. Samples	Percent of Samples
0- 10	5	6.57
10- 20	8	10.52
20- 30	11	14.47
30- 40	14	18.42
40- 50	4	5.26
50- 60	9	11.24
60- 70	5	6.57
70- 80	5	6.57
80- 90	7	9.21
90-100	3	3.94
100-110	3	3.94
110-120	2	2.63

CUMULATIVE ERRORS RUN 14a

Error	Samples LT Error	Percent Samples LT Error
10	5	6.57
20	13	17.10
30	24	31.57
40	38	50.00
50	42	55.26
60	51	67.10
70	56	73.68
80	61	80.26
90	68	89.47
100	71	93.42
110	74	97.36
120	76	100.00

TABLE 8-15 FIXED ROUTE LOCATION SUBSYSTEM ERROR STATISTICS, RUN 24

ERROR FREQUENCY DENSITY RUN 24a

Error Interval	No. Samples	Percent of Samples
0- 10	1	1.61
10- 20	13	17.33
20- 30	14	18.66
30- 40	14	18.66
40- 50	5	8.06
50- 60	10	13.33
60- 70	4	6.45
70- 80	2	3.23
80- 90	2	3.23
90-100	1	1.61
100-110	2	3.23
120-130	1	1.61
130-140	2	3.23
140-150	2	3.23
170-180	1	1.61
1500-1510	1	1.61

Cumulative Errors Run 24a

Error	Samples LT Error	Percent Samples LT Error
10	1	1.61
20	14	17.33
30	28	37.33
40	42	56.00
50	47	62.66
60	57	76.00
70	61	81.33
80	63	84.00
90	65	86.66
100	66	88.00
110	68	90.66
120	68	90.66
130	69	92.00
140	71	94.66
150	73	97.33
160	73	97.33
170	73	97.33
180	74	98.66
1510	75	100.00

TABLE 8-16 FIXED ROUTE LOCATION SUBSYSTEM ERROR STATISTICS, RUN 34a

ERROR FREQUENCY DENSITY RUN 34a

Error Interval	No. Samples	Percent of Samples
0- 10	1	1.33
10- 20	11	14.66
20- 30	14	18.66
30- 40	12	16.00
40- 50	11	14.66
50- 60	5	6.66
60- 70	6	8.0
70- 80	5	6.66
80- 90	3	4.0
90-100	4	5.33
110-120	2	2.66
130-140	1	1.33

Cumulative Errors Run 34a

Error	Samples LT Error	Percent Samples LT Error
10	1	1.33
20	12	16.00
30	26	34.66
40	38	50.66
50	49	65.33
60	54	72.00
70	60	80.00
80	65	86.66
90	68	90.66
100	72	96.00
110	72	96.00
120	74	98.66
130	74	98.66
140	75	100.00

TABLE 8-17 FIXED ROUTE LOCATION SUBSYSTEM ERROR STATISTICS, RUN 40a

ERROR FREQUENCY DENSITY RUN 40a

Error Interval	No. Samples	Percent of Samples
0- 10	4	5.26
10- 20	6	7.89
20- 30	12	15.78
30- 40	12	15.78
40- 50	11	14.47
50- 60	11	14.47
60- 70	4	5.26
70- 80	7	9.21
80- 90	4	5.26
90-100	1	1.31
100-110	1	1.31
110-120	2	2.63
170-180	1	1.31

Cumulative Errors Run 40a

Error	Samples LT Error	Percent Samples LT Error
10	4	5.26
20	10	13.15
30	22	28.94
40	34	44.73
50	45	59.21
60	56	73.68
70	60	78.94
80	67	88.15
90	71	93.42
100	72	94.73
110	73	96.05
120	75	98.65
180	76	100.00

TABLE 8-18 FIXED ROUTE LOCATION SUBSYSTEM
ERROR STATISTICS, RUN 43a

ERROR FREQUENCY DENSITY RUN 43a

Error Interval	No. Samples	Percent of Samples
0- 10	3	4.0
10- 20	3	4.0
20- 30	6	8.0
30- 40	8	10.66
40- 50	14	18.66
50- 60	9	12.0
60- 70	2	2.66
70- 80	12	16.00
80- 90	3	4.0
90-100	5	6.66
100-110	5	6.66
110-120	1	1.33
120-130	1	1.33
130-140	1	1.33
140-150	1	1.33
180-190	1	1.33

CUMULATIVE ERRORS RUN 43a

Error	Samples LT Error	Percent Samples LT Error
10	3	4.00
20	6	8.00
30	12	16.00
40	20	26.66
50	34	45.33
60	43	57.33
70	45	60.00
80	57	76.00
90	60	80.00
100	65	86.66
110	70	93.33
120	71	94.66
130	72	96.00
140	73	97.33
150	74	98.66
190	75	100.00

	000	06	06	R3	E	0 03357	F 11389	T 26 07	
	000	06	06	R3	E	0 03362	F 11394	T 26 07	
	000	06	06	R1		0 03368	F 11399	T 26 08	
	000	06	06	R1		0 03374	F 11405	T 26 08	
	000	06	06	R1		0 03379	F 11410	T 26 09	
	000	06	06	R1		0 03385	F 11416	T 26 09	
	000	06	06	R1		0 03391	F 11422	T 26 10	
	000	06	06	R1		0 03396	F 11427	T 26 10	
	000	06	06	R1		0 03402	F 11433	T 26 11	
	000	06	06	R1		0 03408	F 11439	T 26 11	
	000	06	06	R1		0 03413	F 11444	T 26 12	
	000	06	06	R1		0 03419	F 11450	T 26 12	
	000	06	06	R1		0 03425	F 11456	T 26 13	
	000	06	06	R1		0 03431	F 11461	T 26 13	
	000	06	06	R1		0 03436	F 11467	T 26 14	
	000	06	06	R1		0 03442	F 11472	T 26 14	
	000	06	06	R1		0 03447	F 11478	T 26 15	
	000	06	06	R1		0 03453	F 11483	T 26 15	
	000	06	06	R1		0 03458	F 11488	T 26 16	
	000	06	06	R1		0 03463	F 11493	T 26 16	
TD	006	06	06	R1		0 03468	F 11498	T 26 17	
	000	06	08	R1		0 03473	F 10196	T 26 17	ERROR RECORDS
	000	06	08	R1		0 02158	F 10201	T 26 34	
	000	06	08	R1		0 02163	F 10206	T 26 35	
	000	06	08	R1		0 02169	F 10211	T 26 35	
	000	06	08	R1		0 02174	F 10217	T 26 36	
	000	06	06	R1		0 03497	F 11526	T 26 36	
	000	06	06	R1		0 03501	F 11531	T 26 38	
	000	06	06	R1		0 03506	F 11535	T 26 38	
	000	06	06	R1		0 03511	F 11539	T 26 39	
	000	06	06	R1		0 03515	F 11544	T 26 39	
	000	06	06	R1		0 03520	F 11549	T 26 40	
TA	012	06	06	R1		0 03524	F 11553	T 26 40	
	000	06	06	R1		0 03529	F 11557	T 26 41	
	000	06	06	R1		0 03533	F 11562	T 26 41	
	000	06	06	R1		0 03538	F 11566	T 26 42	
	000	06	06	R1		0 03543	F 11571	T 26 42	
	000	06	06	R1		0 03547	F 11576	T 26 43	
	000	06	06	R1		0 03552	F 11580	T 26 43	
	000	06	06	R1		0 03557	F 11585	T 26 44	
	000	06	06	R1		0 03562	F 11590	T 26 44	
	000	06	06	R1		0 03568	F 11595	T 26 45	
	000	06	06	R1		0 03572	F 11600	T 26 45	
	000	06	06	R1		0 03578	F 11605	T 26 46	

FIG. 8-69 RECORDING ERRORS, RUN 25

TABLE 8-19 CORRECTED CHECKPOINT ERRORS, RUN 25

Checkpoint	ODOM (CP) (Count)	ODOM (R6) (Count)	SP	SEG	INCREM (feet)	Comp X	Comp Y	Error
26	3997	3368	6	18	979	12206	10192	19
27	373	3368	6	18	1923	13141	10068	34
28	630	3368	6	19	460	13124	9606	52
29	903	3368	6	19	1006	13040	9067	30
30	2026	3368	6	21	955	13833	7645	135

On Run 24, the following overall location subsystem results were obtained:

Number of Samples: 2313 of a possible 2326 (99.44% of recorded data)
95 Percent of Errors Less than: 106 feet
99.5 Percent of Errors Less than: 146 feet.

TABLE 8-20 LOCATION SUBSYSTEM ERRORS FOR CHECKPOINTS 37-40 ON RUNS 39-43 WHILE "OFF ROUTE" CONDITION WAS SIMULATED

Run \ Checkpoint	Location Error in Feet			
	37	38	39	40
39	24	26	16	17
40	22	28	18	27
41	10	26	11	15
42	36	60	41	306
43	13	26	6	12

8.3.2 AVM System Data Processing

As in the case of FRLS, Runs 24, 34, 40 and 43 could not be processed to completion through the use of FRSYS. However, the data which could not be processed via the use of FRSYS was processed manually using the exact same algorithm. The results obtained are contained in Tables 8-21 through 8-24. These results have been incorporated in Table 8-6.

An anomaly was also detected in the results obtained for Run 18. FRSYS produced an error of 12321 feet at PCP'(2). Manual processing of these data resulted in an error of 18 feet. In processing the cassette data, the value of AVM y only was in error with all other values correct. The 18 foot value was incorporated in Table 8-6.

When Run 25 was processed by use of FRSYS, the bad records noted in Figure 8-69 resulted in erroneous results for PCP 77 through PCP 97. As discussed in subsection 8.3.1, the use of the later reset value of R8 was partially at fault. The erroneous record also made it appear as if the odometer had rolled over an additional 4096 (2^{12}) counts. This was offset to some extent by the use of the later reset point. Table 8-25 contains the correct results for these pseudo checkpoints as computed manually using the correct reset point and the correct odometer values. Details of these computations are included in the appendix.

TABLE 8-21 FIXED ROUTE AVM SYSTEM ERRORS, RUN 24

ERROR FREQUENCY DENSITY RUN 24

Error Interval	No. Samples	Percent of Samples
0- 10	18	7.53
10- 20	38	15.90
20- 30	33	13.81
30- 40	31	12.97
40- 50	24	10.04
50- 60	15	6.28
60- 70	22	9.21
70- 80	13	5.44
80- 90	10	4.18
90-100	4	1.67
100-110	9	3.77
110-120	2	8.37
120-130	5	2.09
130-140	1	0.42
140-150	6	2.51
160-170	3	1.26
170-180	4	1.67
180-190	1	0.42

Cumulative Errors Run 24

Error	Samples LT Error	Percent Samples LT Error
10	18	7.53
20	56	23.43
30	89	37.24
40	120	50.21
50	144	60.25
60	159	66.53
70	181	75.73
80	194	81.17
90	204	85.36
100	208	87.03
110	217	90.79
120	219	91.63
130	224	93.72
140	225	94.14
150	231	96.65
170	234	97.91
180	238	99.58
180-190	239	100.00

TABLE 8-22 FIXED ROUTE AVM SYSTEM ERRORS, RUN 34

ERROR FREQUENCY DENSITY RUN 34

Error Interval	No. Samples	Percent of Samples
0- 10	19	6.59
10- 20	52	18.05
20- 30	52	18.05
30- 40	55	19.09
40- 50	27	9.37
50- 60	23	7.98
60- 70	17	5.90
70- 80	19	6.59
80- 90	13	4.51
90-100	4	1.38
110-120	1	.34
120-130	1	.34
140-150	1	.34
150-160	2	.69
190-200	2	.69
280-290	1	.34

Cumulative Errors Run 34

Error	Samples LT Error	Percent Samples LT Error
10	19	6.59
20	71	24.65
30	123	42.70
40	178	61.80
50	205	71.18
60	228	79.16
70	245	85.06
80	264	91.66
90	277	96.18
100	281	97.56
120	282	97.91
130	283	98.26
150	284	98.61
160	286	99.30
200	288	100.00
280-290	289	

TABLE 8-23 AVM SYSTEM ERRORS, RUN 40

ERROR FREQUENCY DENSITY RUN 40

Error Interval	No. Samples	Percent of Samples
0- 10	14	5.2
10- 20	37	13.75
20- 30	37	13.75
30- 40	48	17.84
40- 50	43	15.98
50- 60	26	9.66
60- 70	17	6.31
70- 80	24	8.92
80- 90	10	3.71
90-100	2	.74
100-110	1	.37
110-120	4	1.48
200-210	1	.37
240-250	1	.37
260-270	2	.74
280-290	2	.74

Cumulative Errors Run 40

Error	Samples LT Error	Percent Samples LT Error
10	14	5.2
20	51	18.95
30	88	32.7
40	136	50.5
50	179	66.54
60	205	76.2
70	222	82.5
80	246	91.44
90	256	95.16
100	258	95.91
110	259	96.28
120	263	97.76
210	264	98.14
250	265	98.51
270	267	99.25
290	269	100.00

TABLE 8-24 FIXED ROUTE AVM SYSTEM ERRORS, RUN 43

ERROR FREQUENCY DENSITY RUN 43

Error Interval	No. Samples	Percent of Samples
0- 10	15	6.66
10- 20	18	8.0
20- 30	17	7.5
30- 40	28	12.44
40- 50	33	14.66
50- 60	27	12.0
60- 70	11	4.8
70- 80	32	14.22
80- 90	11	4.88
90-100	10	4.44
100-110	7	3.11
110-120	2	.88
120-130	2	.88
130-140	2	.88
140-150	3	1.33
180-190	2	.88
220-230	1	.44
210-220	1	.44
240-250	3	1.33

Cumulative Errors Run 43

Error	Samples LT Error	Percent Samples LT Error
10	15	6.66
20	33	14.66
30	50	22.22
40	78	34.66
50	111	49.33
60	138	61.33
70	149	66.22
80	181	80.44
90	192	85.33
100	202	89.77
110	209	92.88
120	211	93.77
130	213	94.66
140	215	95.55
150	218	96.88
190	220	97.77
220	221	98.22
230	222	98.66
250	225	100.00

TABLE 8-25 MANUALLY CORRECTED AVM SYSTEM ERROR RESULTS, RUN 25

ERROR FREQUENCY DENSITY

Error Interval	No. Samples	Percent Samples	Error	No. Samples LT Error	% Samples LT Error
0- 10	18	7.46	10	18	7.46
10- 20	23	9.54	20	41	17.01
20- 30	42	17.43	30	83	34.43
30- 40	33	13.69	40	116	48.13
40- 50	39	16.18	50	155	64.31
50- 60	24	9.95	60	171	74.27
60- 70	11	4.56	70	190	78.83
70- 80	10	4.14	80	200	82.98
80- 90	12	4.98	90	212	87.96
90-100	8	3.32	100	220	91.28
100-110	2	0.83	110	222	92.16
110-120	2	0.83	120	224	92.85
120-130	3	1.24	130	227	94.19
130-140	3	1.24	140	230	95.43
150-160	3	1.24	160	233	96.68
160-170	3	1.24	170	236	97.92
180-190	1	0.41	190	237	98.34
190-200	2	0.83	200	239	99.17
210-220	1	0.41	220	240	99.59
220-230	1	0.41	230	241	100.0

9. SPECIAL CASE TESTS

The HI^3 location subsystem was subjected to a large number of special case tests, both in Fort Worth and in Philadelphia, in order to assess its performance under the most stringent urban conditions. These tests provided results which supplement the data obtained during random- and fixed-route testing. Special Case Tests have been grouped into three generic categories:

Special Urban Conditions
Special Environmental Conditions
Special Vehicle Related Conditions.

9.1 SPECIAL URBAN CONDITIONS

The random route area assigned to HI^3 in Philadelphia included a full spectrum of conditions which provided a comprehensive test of the location subsystem technique used by HI^3. The area, shown in Figure 3-12, included the Reading Railroad terminal and eight elevated steel railroad crossings, two of which were over 250 feet long. At two separate locations, the entire roadway was covered by portions of parking garages, one for a distance of 297 feet. Electric trolleys operated on both 11th and 12th streets through the entire random route area. Reference to Figure 3-13 will show the building structures in the area which included many miles of highrise "canyons". The area also included narrow streets (Wood Street is only 18 feet wide curb-to-curb), wide boulevards (Vine Street is eight lanes wide (134 feet) with three separate medians); Market Street is 63 feet wide, curb-to-curb, with numerous metal traffic standards extending completely across the roadway. Although most available utility poles were metal, a wide variety of poles and configurations were used. On Wood Street, three wooden poles with overhead wires were used. Street patterns in the area varied, all North-South streets were one-way, and only Vine and Market streets were two-way. Since the HI^3 location system operates independent of the direction of vehicle travel, this traffic engineering pattern offered no problems.

Special tests categories under Special Urban Conditions were designed to determine the effects of the following items:

1. Large metallic structures
2. Freeway overpasses and tunnels
3. Buildings extending over roadways
4. Narrow streets and deep canyons
5. Wide boulevards, open areas, parks, and malls

6. Trolley and other overhead wires

7. Signpost mounting conditions.

9.1.1 Large Metallic Structures

All ten (10) Random Route tests included tests under the Reading Railroad Terminal on Filbert Street, under the steel reinforced parking garage on 8th Street, and under railroad tunnels on Cherry, Race, and Vine Streets. Table 9-1 contains a list of the location errors associated with TSC checkpoints which were located near these elevated metal structures. Not only are there no errors exceeding 179 feet at these locations, but the repeatability of the location region is demonstrated by the extremely low variance in the errors incurred at each checkpoint. Additional data relating to large metallic structures are discussed in subsequent paragraphs in this section.

9.1.2 Freeway Overpasses and Tunnels

The data presented in Table 9-1 is also applicable to demonstrate the fact that the HI^3 location subsystem performed within specification in the vicinity of overpasses and tunnels. In addition, special tests were performed to demonstrate the ability of the HI^3 location subsystem to generate location regions within tunnels and for signposts to propagate energy through tunnels and under overpasses. Figure 9-1 contains data taken during Random Route Test 10 during travel West on Filbert Street beneath the Reading Railroad Terminal. As shown in the figure, signposts were installed on street light poles near each end of the tunnel. Three different location regions were received by the vehicle while moving through the tunnel at the locations shown (to scale) in the figure.

A similar test involved installation of a signpost in the center of the 297-foot long covered roadway on 8th Street between Filbert and Arch. The signpost was installed, as shown in Figure 9-2, by simply setting the signpost on 2 by 12-inch wooden walkway with the antenna extended downward between two 2- by 12-inch boards. This signpost (15, 16) created a Region 1 location region within the tunnel and produced overlap regions in conjunction with signposts (16, 16) to the North and (13, 16) to the South. Data obtained during Random Route Test Run 8 are also shown in Figure 9-3. The vehicle was traveling South on 8th after passing signpost (16, 16) at 8th and Cherry. At the intersection of 8th and Arch, the vehicle received a Level 3 from signpost (15, 16) in the tunnel and declared a new location region (16, 16) R3S, 230 feet from signpost (15, 16). While the vehicle stopped, the location toggled to a (16, 16) R2S and a (15, 16) R3N. Just under the tunnel entrance, a Region 1 from signpost (15, 16) was declared. 144 feet from signpost (15, 16), a (15, 16) R3N was declared followed by a (15, 16) R1 at a distance of 128 feet from signpost (15, 16). This code was stored throughout the remainder of the tunnel until a (15, 16) R2S was declared 194 feet south of signpost (15, 16). The location error incurred during this run is shown plotted in Figure 9-3.

TABLE 9-1 RANDOM ROUTE LOCATION ERRORS NEAR LARGE METALLIC STRUCTURES

Run No. / *Checkpoint	Under 8th St. Tunnel		At Edge of Reading Terminal Tunnel on Filbert		Near Railroad Overpass on Cherry		Near Railroad Overpass on Race			Near Railroad Overpass on Vine	
	P2	S16	P35	S24	S49	S50	P9	P52	S13	P23	P31
1	145		22				40	7		71	86
2	145		22				40	7		71	86
3	145		22				40	7		71	86
4	145		22				40	7		71	86
5	145		22				40	120		71	179
6		10		20	0	40			8		
7		10		20	0	71			8		
8		10		20	0	40			8		
9		10		20	0	40			8		
10		10		20	0	160			8		

* Primary Checkpoints are denoted Pnn

Secondary Checkpoints are denoted Snn

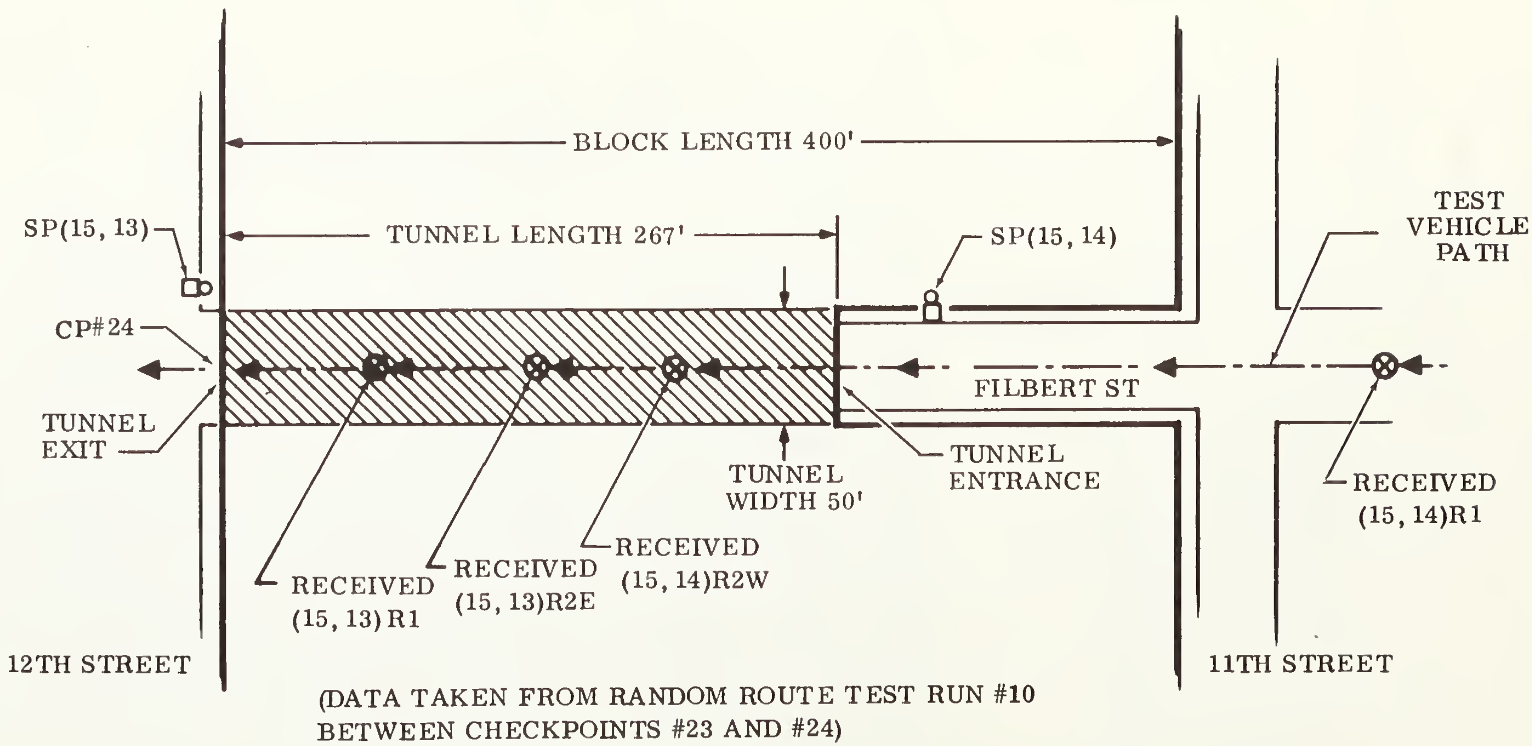


FIG. 9-1 FILBERT STREET TUNNEL TESTS

FIG. 9-2 SIGNPOST INSTALLATION IN 8TH STREET TUNNEL

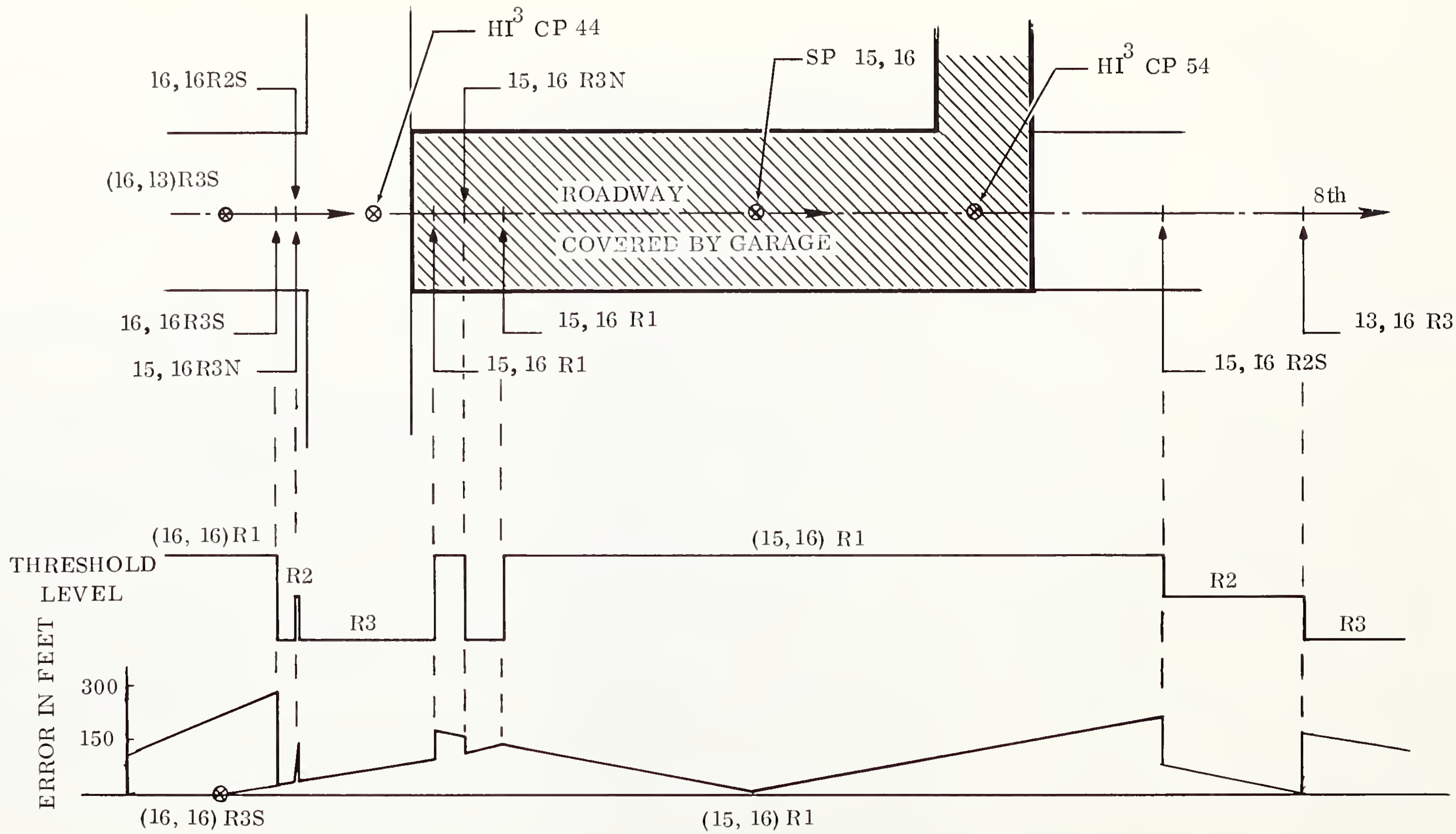


FIG. 9-3 8TH STREET TUNNEL TESTS

The effect of the tunnel in this latter case was to slightly reduce the distance from the signpost at which the specified signal level was received. For this reason, the signpost within the tunnel was located closer (520 feet) to the adjacent signpost than the average for the remainder of the random route area. However, this simple procedure still allowed the location subsystem error specification to be met in the confines of so restrictive a situation. It is noted that there were no poles available for mounting a signpost within the 8th Street tunnel. The adaptability of HI^3 signposts to virtually any mounting environment was demonstrated in this case.

9.1.3 Buildings Extending Over Roadways

The ability of the HI^3 location subsystem to meet the multi-user AVM performance specifications in the presence of buildings which extend over roadways was adequately demonstrated in the two preceding special case tests. Additional data pertinent to this situation are discussed in subsequent paragraphs in terms of parking garages.

9.1.4 Narrow Streets and Deep "High Rise" Canyons

The ability of the HI^3 location subsystem to meet multi-user AVM performance specifications on narrow streets and in deep canyons formed by high-rise buildings was repeatedly demonstrated during Random Route tests. Many TSC checkpoints were located along narrow streets which were framed by high-rise buildings. Notable among these were secondary checkpoints 8, 11, 23, 24, 25, 37, and 55, which were located on streets 27-, 26-, 50-, 5-, 26-, and 25-feet wide respectively, and framed on each side by multistory buildings which were constructed 10 to 20 feet from the curb line. Table 9-2 is a summary of the location errors recorded at these checkpoints during all five secondary random route test runs.

Table 9-2 HI^3 LOCATION SUBSYSTEM PERFORMANCE ON NARROW STREETS IN HIGH-RISE AREA

	Secondary Checkpoint						
Run No.	S8	S11	S23	S24	S25	S37	S55
6	153	0	77	20	61	89	0
7	153	0	77	20	61	89	0
8	153	225	226	20	61	89	0
9	153	0	77	20	139	89	0
10	153	225	77	20	139	89	0
	Location Error in Feet						

Figure 9-4 contains a plot of location error as a function of vehicle location recorded during Random Route Test Run 10 traveling East on Race Street through the heart of Philadelphia's Chinatown. Along this stretch of Race Street, the roadway is only 25 feet wide, and both sides of the street are wall-to-wall buildings at least three stories high. It is noted that, even in this extremely narrow canyon, the location error is less than 300 feet over 98 percent of this roadway.

9.1.5 Wide Boulevards, Open Areas, Parks, and Malls

The area on Vine Street between 9th and 11th Streets is representative of this type of area. Vine Street itself consists of eight traffic lanes separated into four separate roadways by three raised medians. The total curb-to-curb width is 134 feet. The 9th-Street end is totally open on all sides with no buildings. However, 10th Street, which crosses Vine perpendicularly, is only 27 feet wide, curb-to-curb, and is solidly framed by two- and three-story buildings, on both sides.

Figure 9-5 contains data obtained during Random Route Test Run 1 between 9th; and 11th Streets, eastbound on Vine. Signposts (12, 8) and (12, 10) were located on the center medians at 11th and 9th Streets, respectively, and were separated by 880 feet. Signposts (19, 15) and (17, 15) were located on 10th Street at Wood and Spring Streets, respectively, and separated by 700 feet. At only two locations along this stretch of Vine Street, corresponding to less than 6% of the roadway shown, did the location error exceed 300 feet.

These data show that the performance of the HI^3 location subsystem is not degraded in areas containing wide boulevards and open areas and that the use of signposts on narrow streets (10th Street) opening onto open areas (Vine Street) is effective in the formation of location regions. Additional data on this same area is discussed in paragraph 9.7 which is directed to a discussion of vehicles making U-Turns.

9.1.6 Trolley and Other Overhead Wires

Both 11th and 12th Streets had trolleys operating from overhead wires. Typical signpost installations near these wires, as well as near other overhead wires are shown in Figure 3-13. Secondary checkpoints 9, 17, 18, 19, 20, 24, 28, 29, 37, 38, 39, 40, 46, 52, 53, 57, and 60 were all on 11th and 12th Streets within 15 feet of overhead trolley wires. The data taken on Random Route Test Runs 6 through 10 for these 17 checkpoints is summarized as follows:

Total number of samples: 84
Number of samples with error $<$ 250 feet: 82(97.62%)
Maximum error among samples: 376 feet
Average location error: 81 feet
95% confidence error: 241 feet
Percent samples with less than 450 feet errors: 100

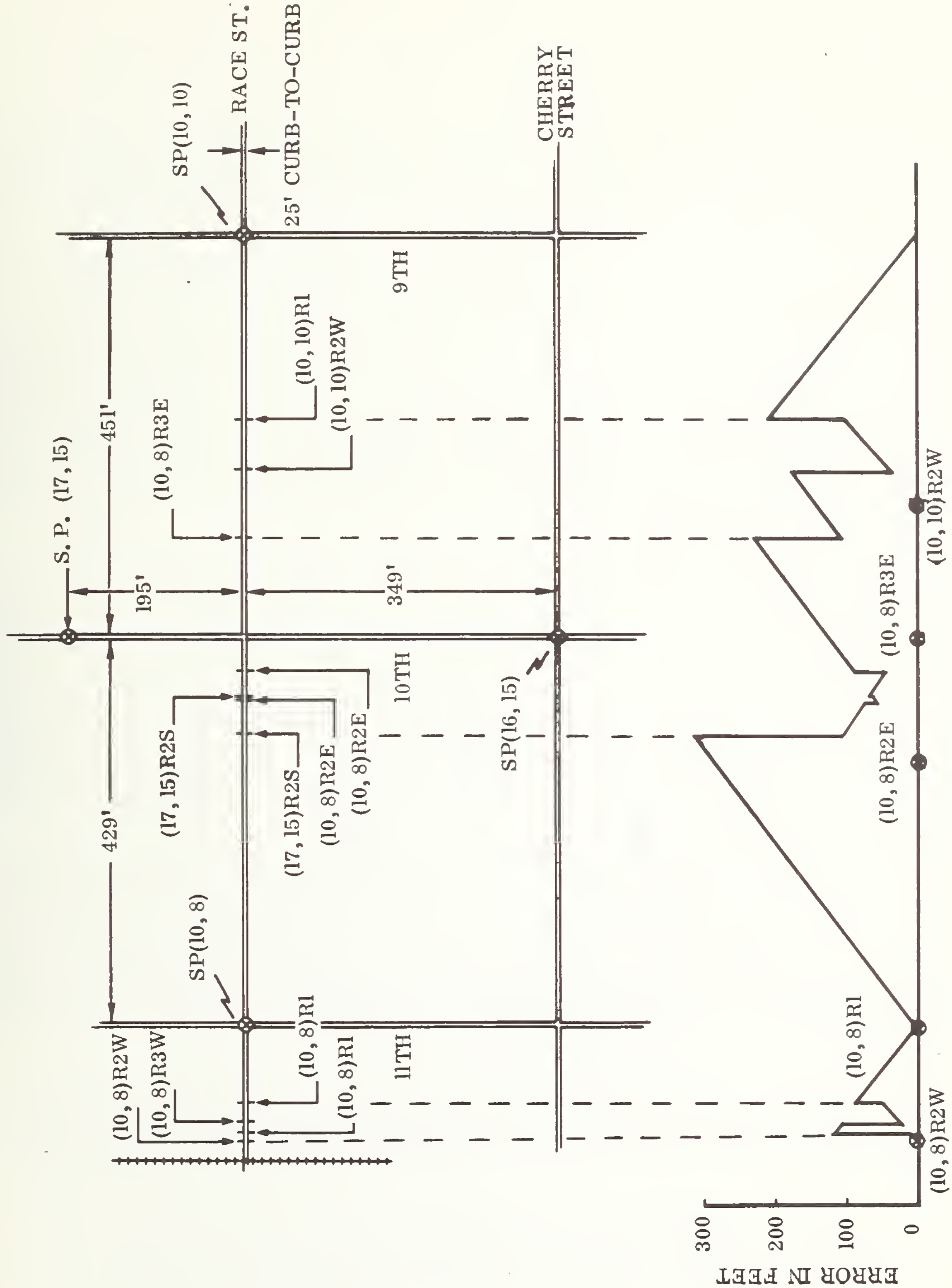
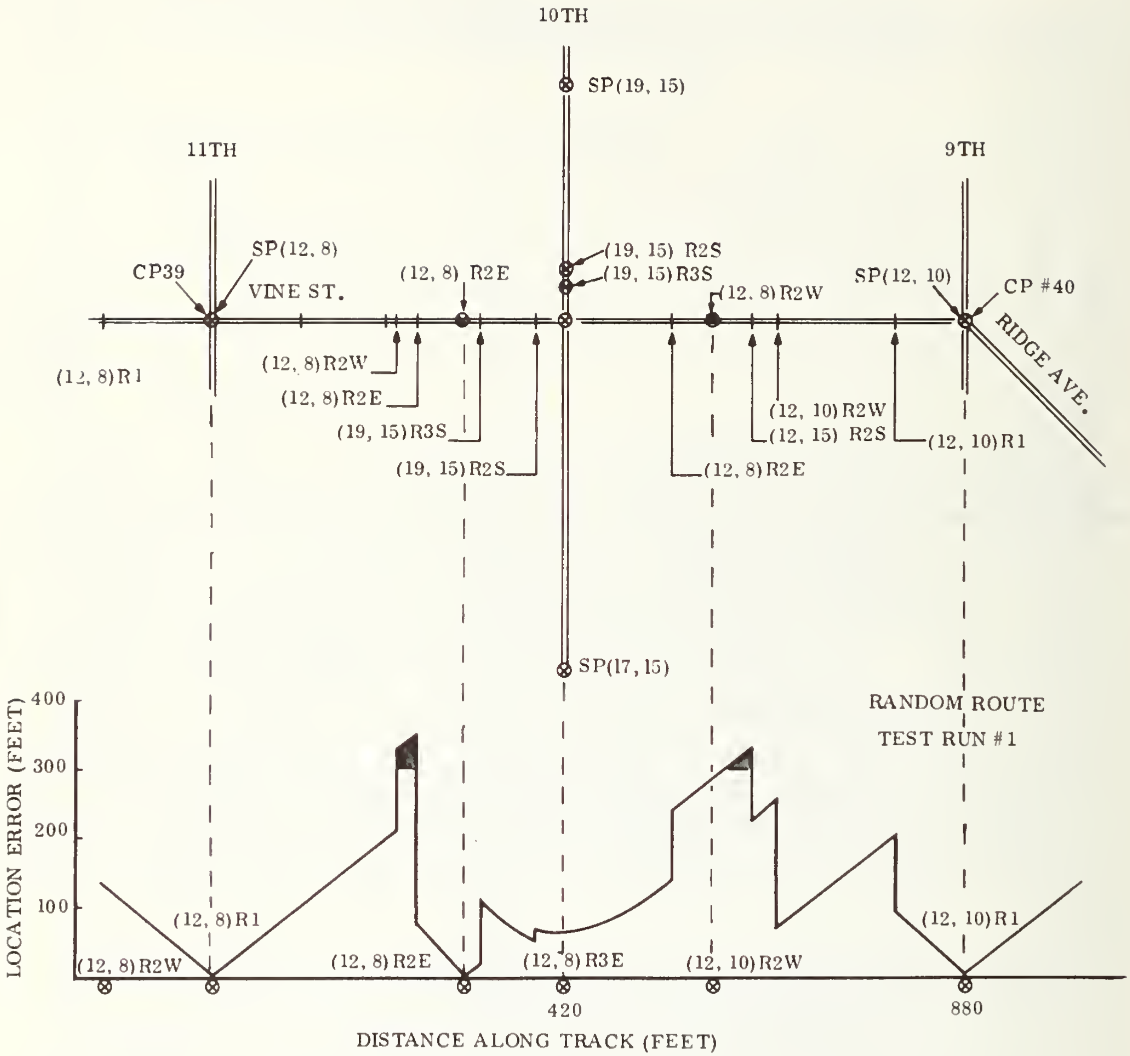


FIG. 9-4 NARROW ROADWAY TESTS



*(12, 8)R3E; (12, 8)R3W, (19, 15)R3S and (19, 15)R2S ARE OFFSET NORTH OF THE EAST BOUND LINE OF VINE.

FIG. 9-5 WIDE BOULEVARD TESTS

These results are consistent with the overall results obtained during random route tests and show that trolley wires and other overhead wires, e.g., those near Wood and Pearl Streets, had no effect on the performance of the HI^3 location subsystem.

9.1.7 Signpost Mounting Conditions

Figure 3-13 contains photographs of all HI^3 signpost installations in Philadelphia. In most instances, signposts were mounted 18 to 26 feet above the roadway. However, some signposts (19, 15), (19, 16), and (15, 13) were mounted less than 16 feet above the ground. Photographs of 12 different installations in Philadelphia are shown in Figure 9-6. These installations were simply dictated by the availability of permanently installed poles owned either by the City of Philadelphia or by the Philadelphia Electric Company. HI^3 contracted pole agreements with both of these organizations prior to installation.

At a given distance from a HI^3 signpost, the strength of the signal received from the signpost is relatively independent of the signpost height above the ground. This relationship is illustrated in Figure 9-7 which contains a plot of the distances, from a signpost, where a Region 1 was received for signpost heights of 20, 22.5, and 25 feet above the ground. The test vehicle was utilized during these tests, and the signpost was approached from two opposite directions. These data were taken in Fort Worth during Special Test Runs 19 through 36. The average and standard deviation of the R1 radius for all of 10 samples taken were 245 feet and 26 feet, respectively. This latter value is very close to the 18-foot standard deviation in R1 boundary location for all 15 fixed route signposts.

These tests show that the HI^3 location subsystem can be utilized in any type of installation without modification to any part of the location subsystem. Height is not critical, and the unit can be attached to any space available on the pole, preferably out of reach of passersby. And, on poles with overhead wires, flexible mounting specifications will permit the installation to adhere to OSHA safety requirements concerning the minimum space between power wires and items mounted on the pole.

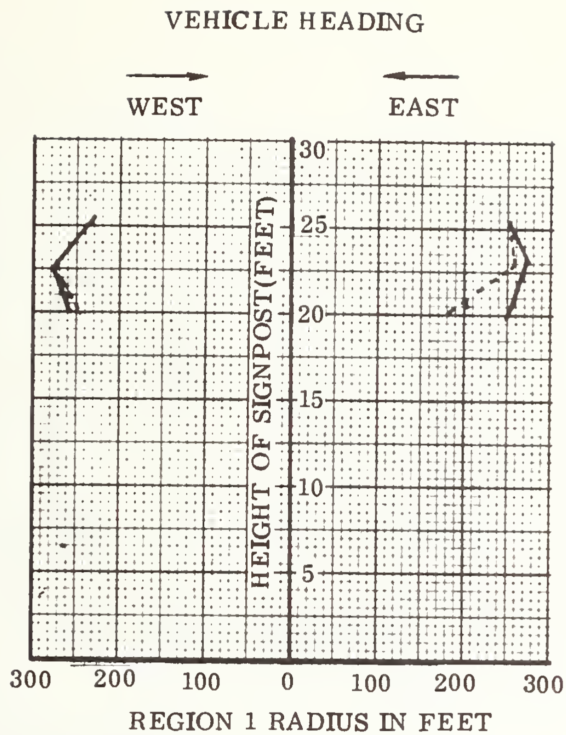
A second item of consideration is the effect of local structures near the signpost; in particular, buildings which are very close to the signpost. Figures 9-8 and 9-9 contain contour plots of data obtained during special tests in Philadelphia under the following conditions:

> Wide open streets with no buildings near the signpost
>
> Narrow streets with tall buildings on all sides and very close to the signpost.

The same signpost was utilized and antennas mounted at the same height, 23 feet, during both sets of measurements although the poles were quite different, as shown

(Text continued on 9-16)

FIG. 9-6 A VARIETY OF SIGNPOST INSTALLATIONS



Run #	Vehicle Heading	Signpost Height (feet)	R1 Radius (feet)
19	West	25	222
20	East	25	240
29	West	22.5	270
30	East	22.5	250
31	West	22.5	270
32	East	22.5	260
33	West	20	260
34	East	20	180
35	West	20	250
36	East	20	250

$\mu(R1_{West}) = 254'$	$\mu(R1_{East}) = 236'$	$\mu(R1) = 245'$
$\sigma_{R1_{West}}) = 18'$	$\sigma(R1_{East}) = 28'$	$\sigma(R1) = 26'$

FIG. 9-7 SIGNPOST HEIGHT TEST RESULTS

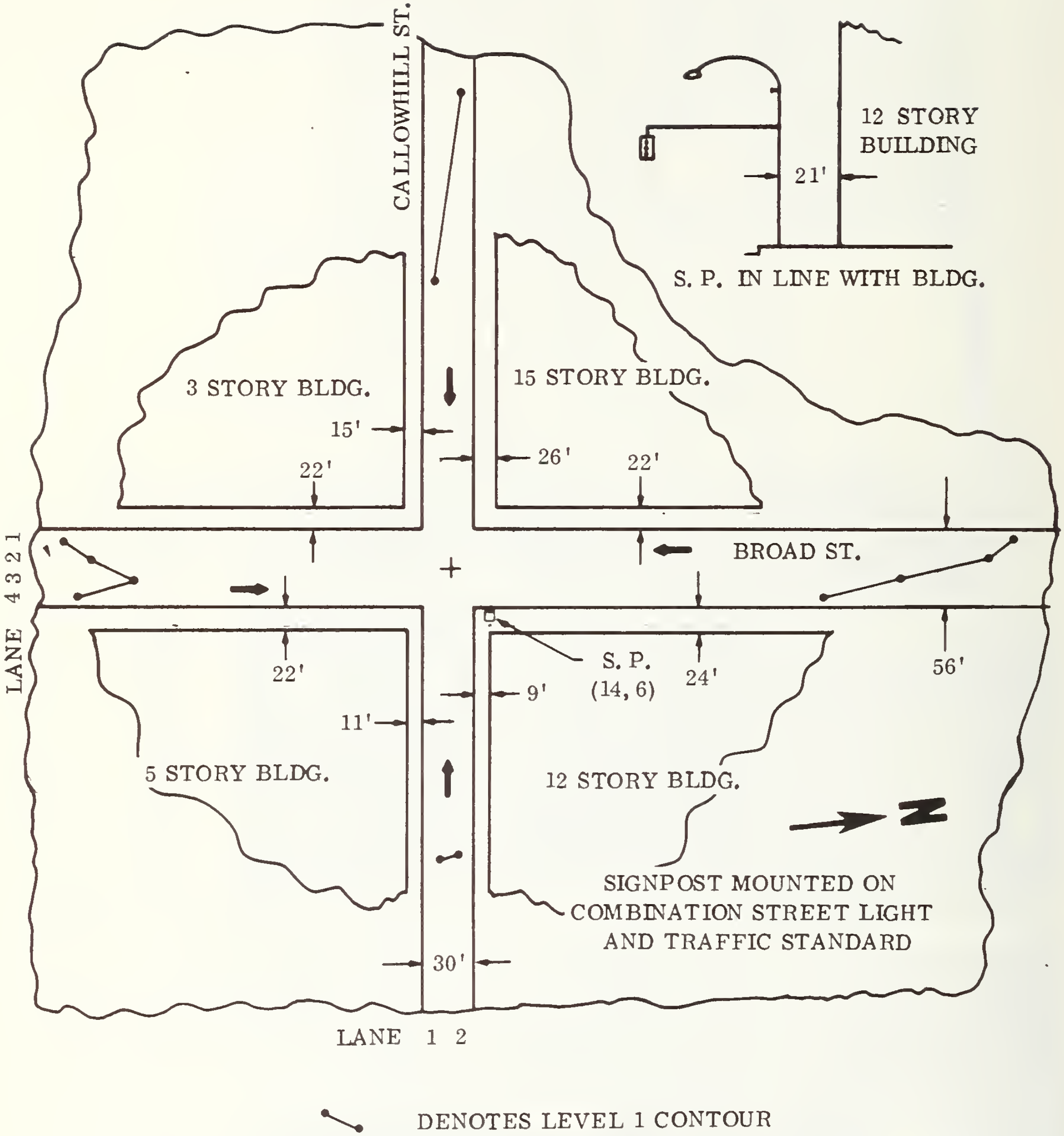


FIG. 9-8 SIGNPOST REGION 1 CONTOUR, NARROW STREETS

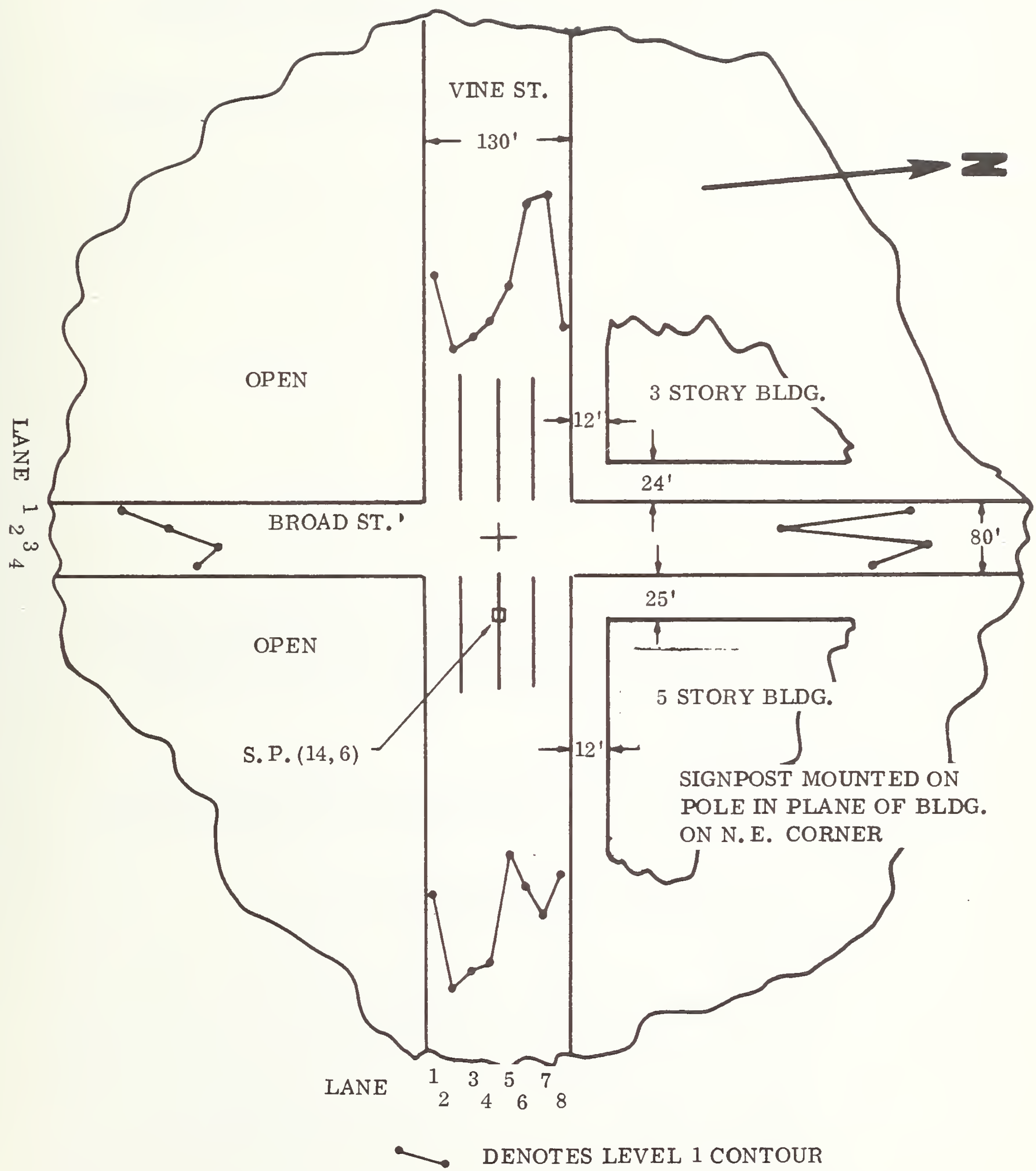


FIG. 9-9 SIGNPOST REGION 1 CONTOUR, WIDE STREETS

in Figure 9-6. Data were taken in all driving lanes heading in all possible directions, the latter being limited because Callowhill is one-way in both directions leading into Broad. There were no other crossing two-way streets in the Center City region of Philadelphia which included a narrow street.

Table 9-3 contains the data obtained during these tests. Where possible, both R1 and R1 dropout data were recorded. The mean and standard deviations of the two sets of data were as follows:

At Broad and Callowhill (Narrow Streets - Congested Structures)

μ = 179 feet
σ = 42 feet

At Broad and Vine (Wide Streets - No Large Structures)

μ = 206 feet
σ = 49 feet

Both Sets of Data Combined

μ = 224 feet
σ = 46 feet

These data show the consistency obtained from the HI^3 location subsystem under quite different installation conditions. In one case the signpost was only 21 feet from a 12-story building. In the other case, there were no structures within 77 feet of the signpost.

9.2 SPECIAL ENVIRONMENTAL CONDITIONS

Special tests categorized under Special Environmental Conditions included the following:

Power substations electromagnetic interference

RF survey

Electromagnetic interference from trolleys

Temperature environment

Traffic and weather

Signpost battery drain.

TABLE 9-3 SIGNPOST LEVEL 1 CONTOUR DATA

Broad and Vine St. 12-15-76 2025-2135 HRS

Temp = 46°

Dry

ODOMETER SETTING : 1 Foot Per Pulse

LANE	HEADING	Odometer Reading			ΔR in feet	ΔR out feet
		At R1	At Center of Intersection	At R1D		
1	South	0419	645	853	226	208
2	South	488	641	822	153	181
3	North	713	866	1101	153	234
4	North	602	767	973	165	206
1	East	1298	1442	1636	144	194
2	East	1509	1610	1856	101	246
3	East	408	517	755	109	238
4	East	1290	1409	1643	119	234
5	West	466	641	776	175	135
6	West	379	509	751	190	182
7	West	1793	2000	2188	207	188
8	West	658	843	956	185	113

BROAD & CALLOWHILL

ODOMETER SETTING : 2 Feet Per Pulse

1	West	401	477	-	152	-
2	West	128	189	-	150	-
1	East	341	416	-	150	-
2	East	698	823	-	250	-
1	South	15	163	264	296	202
2	South	198	340	434	284	188
3	North	107	190	310	166	240
4	North	70	168	268	196	200

NOTE : Odometer Calibration 0.2 Percent Low.

9.2.1 Power Substation EMI

These tests were conducted at the intersection of 11th and Noble. As shown in Figure 9-10, both the Southwest and Northwest corners of this intersection are covered by power substations. The tests were conducted by operating the test vehicle against signpost (15, 13) which was mounted on a street light on the Southwest corner. Table 9-4 contains the results obtained. The signpost was successfully received and decoded on each and every pass. When the test vehicle was located near the Reading Railroad crossing, on 11th Street, an overlap region between signpost (15, 13) and signpost (19, 13) was recorded. Signpost (19, 13) was located approximately 680 feet South on 11th Street. A strong 60 cycle hum could be distinctly heard emitting from the substation as far as 1 block away. The overall results obtained during this test document the fact that 60-cycle EMI has no perceptable effect on the HI^3 location subsystem.

9.2.2 RF Survey

A survey of in-band RF energy at 49.860 MHz was conducted in order to establish the background level of in-band radio frequency interference. Data were taken manually through use of a special RF signal strength meter and a calibrated attenuator. The test vehicle and test location subsystem antenna were used during the tests. The calibrated attenuator was adjusted so as to produce midscale on the meter which had previously been calibrated at -81.5 dBm. Tests were conducted at a number of locations throughout the random and fixed route test areas in downtown Philadelphia. Table 9-5 contains the results of this survey. Signal levels below -81.5 dBm were estimated from the meter by calibrating it with the attenuator and a calibrated signal source. The receiver in the RF survey meter was a standard vehicle unit signpost receiver.

With signposts installed, the indicated level of attenuation was required in order to produce midscale deflection of the meter. The attenuation required was, of course, dependent on the distance to the signpost.

In the vicinity of the power substation at 11th and Noble streets, the in-band energy was -88 dBm. No perceptable difference was observed when a train passed nearby. The most significant source of in-band energy was ignition noise; however, this was quite spurious and difficult to quantify. The RF noise produced by the test vehicle was approximately -80 dBm at the receiver at 49 MHz contrasted with -49 dBm at a similar 27-MHz receiver. In the few instances, automobiles passing directly by the test vehicle produced a transient signal as high as -76 dBm. However, in no case was the presence of ignition noise correlatable to any location error.

9.2.3 EMI From Trolleys

On a number of occasions, the test vehicle followed or was followed by trolleys operating from overhead wires. In these cases, visual observation of

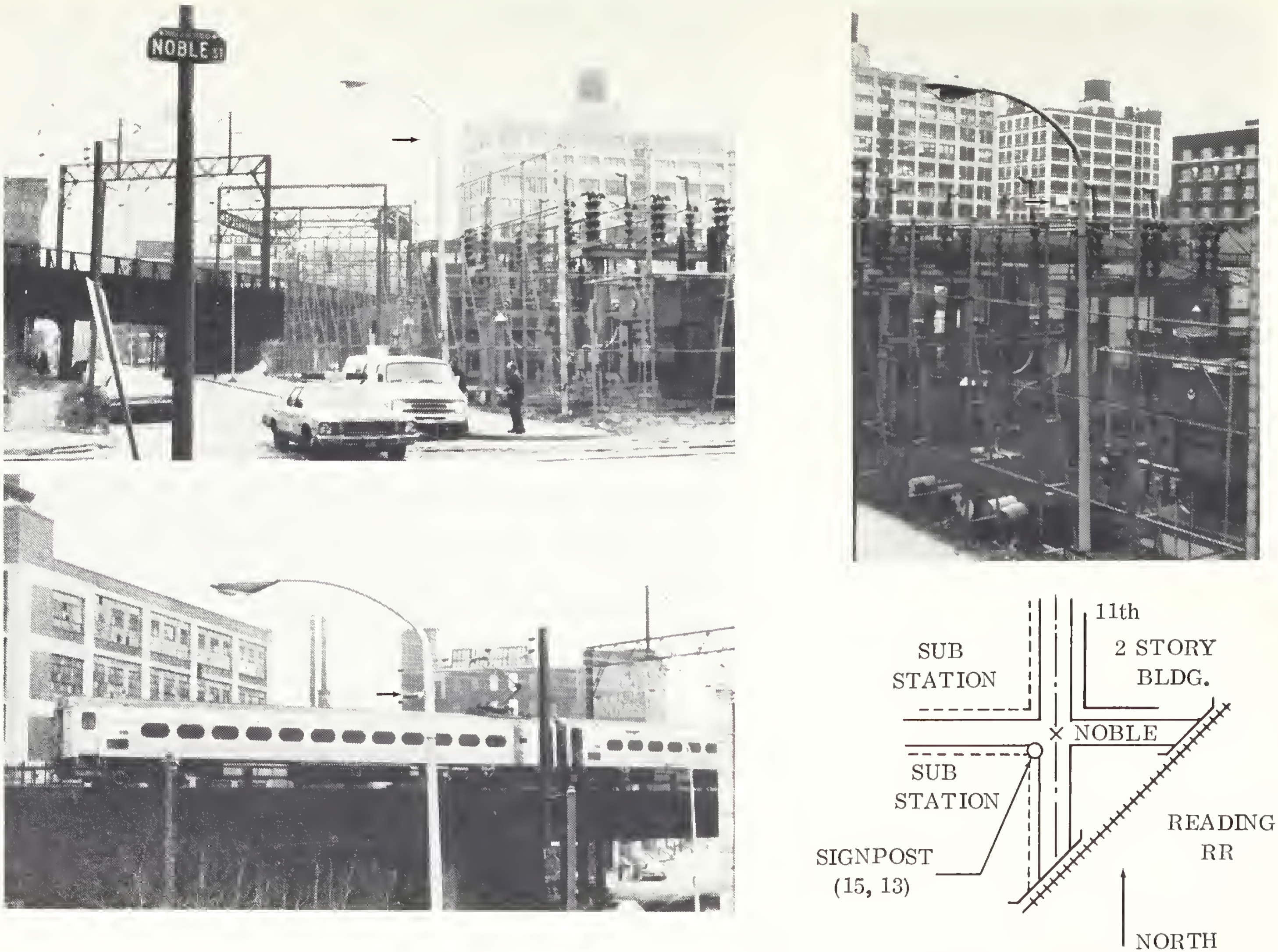


FIG. 9-10 POWER SUBSTATION TEST CONFIGURATION

TABLE 9-4 TEST DATA TAKEN NEAR POWER SUBSTATION

RUN #	HEADING	ODOM (R1) (feet)	ODOM (center of Inter-section) (feet)	R (feet)
1	E	126	224	98
2	E	274	376	102
3	E	302	374	72
4	N	102	214	112
5	N	363	493	130
6	S	100	193	98
7	W	160	402	242

TABLE 9-5 PHILADELPHIA RF SURVEY 12-15-76

FREQUENCY 49.860 MHz EXCEPT AS NOTED

TIME	LOCATION	REMARKS	SIGNAL LEVEL (dBm)
1940	Broad and Hamilton	Attenuator Removed	-83
1943	12th and Hamilton		-88
1952	9th and Spring Garden		-88
1955	11th and Noble 30 feet from signpost	Signpost Installed	* (34 dB atten for 0.5 ma)
1957	11th and Noble	Signpost Removed	-88
2006	Broad and Callowhill	Signpost Installed	* (55 dB for 0.5 ma)
2008	Broad and Callowhill	Signpost Removed	-88
2012	Broad and Spring Garden		-88
2015	15th and Ridge		-88
2035	16th and Vine		-88
2036	17th and Vine		-88
2038	18th and Hamilton		-88
2039	19th and Spring Garden		-88
2043	Ben Franklin Parkway Circle	Near Signpost 6,6	-80
2044	22nd and Ben Franklin P.W.		-88
2045	19th and Cherry		
2050	18th and Market	No cars within 1 block	-88 to -78
2051		Cars passing 150' away	-88
2052		Cars passing in next lane	-81.5 to -76
2053		Cars passing 2 lanes away	-88 to -87
2055		Many cars passing simultaneously	-83
2210	4th and Vine		
12-16-76			
1020	11th and Noble	Motor On	-80
1020	11th and Noble	at 27 MHz - Motor On	-49
1021	11th and Noble	Motor Off	-88
1022	11th and Noble	at 27 MHz - Motor Off	-80
0530	15th and Market	Heavy Traffic - Motor Off	-88 to -76

*With signpost installed, attenuation was increased to provide mid scale deflection of the meter corresponding to -81.5 d BM. The attenuation necessary depends on the distance to the signpost.

sparking at the trolley wire connection occurred. During Random Route Run 1, as noted in the test log, the test vehicle followed directly behind a trolley heading South on 12th Street from CP 45 to CP 46. Reference to Run 1 test data in Table 5-1 will indicate that the location errors associated with these two checkpoints were not influenced by the presence of the trolley since the error was the same for Runs 1, 2, 3, and 4 and no trolley was present during those latter runs. On Run 4, a trolley followed directly behind the test vehicle from CP 25 through CP 28. Again, reference to Table 5-1 will indicate that the presence of the trolley during Run 4 did not influence the location error since the errors incurred at CP 25, 26, 27, and 28 were exactly the same in 17 out of 20 cases. It is concluded from those tests that the HI^3 AVM system can operate without degradation in performance near, and most probably on, electric trolleys.

9.2.4 Temperature Environment

A series of tests were performed in order to establish the ability of the HI^3 signpost to operate over a wide variation in temperature. The results of these tests are presented in Table 9-6.

Each HI^3 signpost used in Phase I was checked for operation over the temperature range -25°C to +50°C in the environmental chamber. These tests were not part of the special case tests; however, the results are directly applicable to Phase I and Phase II. These tests were conducted by using the field strength meter which includes a built-in signpost decoder to monitor the signpost output while the signpost was in the chamber. During this test, the signal strength meter was at room temperature and the test was simply a go, no-go type test which was based on the ability to decode the signpost code over the temperature range. The purpose of the test was to assure that the signposts were operating over the expected temperature range. Note that the signal strength meter is normally battery operated.

Subsequent to these tests, during the process of adjusting the vehicle units for use in Phase I, the receiver in the signal strength meter was used as a reference; however, it was connected to a 12-volt power supply at the time the clock frequency was being determined. As a result, the clock frequency in both Vehicle Unit 1 and 2 were erroneously set a few kilohertz too high (204 KHz versus 198 KHz). This error caused no problem at normal temperatures; however, at lower temperatures, the signpost FSK frequencies change within a design tolerance. This design tolerance is within the capture bandwidths of the correctly adjusted vehicle unit. However, in this case, the capture bandwidth of the erroneously adjusted vehicle units was too narrow. Hence, during Runs 1 through 5, as the temperature decreased, some degradation in system performance resulted.

As noted in the random route data log in the Appendix, this error was discovered and corrected between Runs 5 and 6, with the highly significant results previously described in Section 5 of this volume.

TABLE 9-6 HOFFMAN SIGNPOST PARAMETERS VS. TEMPERATURE

Temperature °C	Source Voltage Volts	49.860 MHz Signpost SP-03				27.095 MHz Signpost SP-02			
		RF Freq. MHz	RF P-P Out Volts	% MOD	F_{low} KHz	RF Freq. MHz	RF P-P Out Volts	% MOD	F_{low} KHz
+20	11.6	49.860 437	1.80	.2	3.776	27.094 528	2.05	.24	3.275
+20	11.4	49.860 430	1.75	.2	3.249	27.094 520	1.95	.24	3.240
+20	11.2	49.860 411	1.70	.2	3.210	27.094 492	1.95	.24	3.205
+20	13.34	49.860 283	1.50	.25	2.981	27.094 397	1.80	.2	2.956
+20	9.86	49.860 743	2.10	.2	3.544	27.093 802	2.15	.3	3.563
0	11.6	49.861 280	1.75	.2	3.261	27.094 517	2.00	.24	3.272
0	11.4	49.861 133	1.70	.2	3.228	27.094 490	1.98	.24	3.229
0	11.2	49.861 122	1.60	.2	3.195	27.094 483	1.93	.24	3.195
-20	11.6	49.861 875	1.70	.25	3.259	27.094 486	1.90	.26	3.281
-20	11.4	49.861 876	1.66	.25	3.225	27.094 473	1.85	.26	3.728
-20	11.2	49.861 849	1.63	.25	3.193	27.094 427	1.70	.26	3.192
+50	11.6	49.859 001	1.78	.18	3.274	27.094 566	2.05	.26	3.270
+50	11.4	49.858 976	1.75	.18	3.241	27.094 553	2.00	.26	3.237
+50	11.2	49.858 965	1.70	.168	3.211	27.094 546	1.95	.24	3.203
+50						27.094 571	2.10	.26	3.302

Data taken with Textronix 485 Oscilloscope with signpost inside of Standard Environmental Systems, Inc. model TB/2 Environmental Chamber.

At first, it was believed that signpost failures produced the problems observed in Run 5 since the same type of problem was observed during preliminary calibration of the system. Isolation and correction of the vehicle frequency adjustment problem shed new light on this problem, and it is now documented that HI^3 experienced only one signpost failure during the 90 days in which the 41 signposts were installed in Philadelphia. That failure occurred during extremely cold weather when a mica capacitor failed in signpost (16, 11) on the night of 16 January between fixed route Runs 37 and 38. The failure was possibly due to a faulty capacitor which could not stand the thermal shock of the temperature dropping 11 degrees in less than three hours during the period in which the signpost failed. As a result of this failure and tests run on signposts to be installed in Labrador, these mica capacitors are being replaced with ceramic capacitors.

Table 9-7 contains data taken on a HI^3 vehicle unit during operation over the temperature range between -25°C and 65°C at source voltages between 11 and 14 volts DC. As in the case of the signpost, a standard environmental system, Model TB12 environmental chamber, was utilized. These data show that the Level 3 and Level 2 thresholds do not change with temperature over the -25°C to +65°C operating range and over a source voltage range from 11 to 14 volts. The Level 1 threshold varied a total of 1.5 dB over this same range. However, this change represents only a few feet since this level change is associated with the steepest portion of the RF field produced by the signpost.

9.2.5 Weather, Traffic, and Time of Day

A total of 10 random route, 33 fixed route, and approximately four full days of special case tests were performed in Philadelphia. At no time was any test delayed as a result of weather, traffic conditions, or the time of day. Table 9-8 reflects the weather and traffic conditions and the start and finish times of each formal test run. Figure 9-11 contains photographs taken during fixed route Runs 18, 19, and 34 and one taken when the "off-route" signposts were being installed during 5°F weather after completing Run 38.

The only problems created by the weather involved the 5th wheel. These included (1) a shorted connector caused by water on Run 26, (2) loss of a magnet during Run 32, probably because of roadway ice ruts, and (3) an accumulation of up to 1/4 inch of ice and slush on the 5th wheel as shown in Figure 9-11. An average accumulation of 1/8-inch increase in the radius of this 13-inch radius wheel produces an error since the wheel would turn 1 percent fewer revolutions per foot, or, on the basis of assuming a total distance traveled of 68,000 feet, a total of 100 fewer revolutions. This difference would produce an error (shorter indicated distance traveled by the 5th wheel) of 681 feet. A comparison of odometer and 5th wheel distances for the fixed route indicated that this buildup of snow and ice in conjunction with some sliding of the 5th wheel did indeed cause the 5th wheel to lose distance during those runs where the centers of streets were icy.

TABLE 9-7 HI^3 SIGNPOST RECEIVER TEMPERATURE CHARACTERISTICS

Temperature °C	Input Voltage Volts	Minimum Decode Level db	Maximum Decode Level db	Level #1 db	Level #2 db	Level #3 db	*Level #1 Drop Out db
+25	11.0	66	10	38	53	63	< 4
+25	12.5	66	7	38	53	63	< 4
+25	14.0	66	10	38	50	63	< 4
0	11.0	65	10	39	53	63	
0	12.5	65	10	39	53	63	
0	14.0	63	12	39	53	63	< 4
-25	11.0	62.5	21	39.5	53	63	
-25	12.5	62.5	19	39.5	53	63	< 4
-25	14.0	62.5	23	39.5	53	63	< 4
+50	11.0	65	19	37.5	53	63	< 4
+50	12.5	65	17	37.5	53	63	
+50	14.0	65	20	37.5	53	63	
+65	11.0	64	29	37	53	63	6
+65	11.5	65	24	37	53	63	6
+65	12.5	65	19	37	53	63	6
+65	14.0	63	24	37	53	63	6

*Note: Level #1 drop out occurs at high signal levels due to saturated mixer characteristics.

Test Configuration

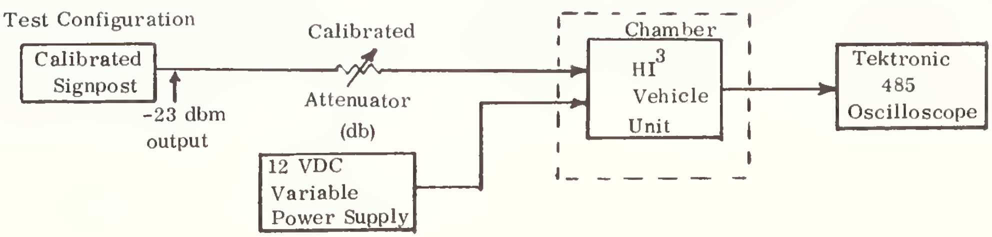


TABLE 9-8 HI^3 TEST DATA (WEATHER, TEMPERATURE, AND TIME)

Run #	Temperature °F	Weather	Traffic	Start Time Hrs. Min.	End Time Hrs. Min.
1	48	Wet Streets	Heavy	15:41	17:15
2	48	Wet Streets	Heavy	17:35	18:48
3	46	Wet Streets	Moderate	18:56	20:05
4	45	Wet Streets	Moderate	20:25	21:50
5	41	Wet Streets	Light	21:56	22:57
6	28	Dry	Moderate	09:45	10:55
7	34	Dry	Heavy	11:05	12:35
8	36	Dry	Heavy	12:40	14:09
9	38	Dry	Moderate	14:20	15:35
10	36	Dry	Heavy	17:05	18:18
11	24	Dry	Moderate	13:10	14:50
12	25	Dry	Moderate	15:00	16:37
13	24	Dry	Heavy	16:50	18:20
14	24	Dry	Moderate	20:25	21:40
15	23	Dry	Light	22:00	23:10
16	23	Dry	Light	23:20	00:30
17	30	Dry	Moderate	08:50	10:15
18	32	Snowing	Heavy	10:20	12:00
19	31	Snowing	Heavy	13:30	15:35
20	32	Snowing	Heavy	16:00	17:30
21	33	2" Slush	Moderate	18:00	19:30
22	33	2" Slush Freezing Rain	Light	20:40	21:55
23	32	Freezing Rain	Light	22:00	23:20
24	32	Freezing Rain	Light	23:30	00:45
25	32	Light Rain	Light	00:50	02:10
26	33	Slush	Moderate	10:35	12:00
27	34	Slush	Moderate	12:10	13:22
28	38	Slush	Moderate	13:30	14:55
29	37	Slush	Moderate	15:00	16:20
30	34	Slush	Heavy	17:15	18:38
31	34	Slush	Moderate	18:45	20:10
32	32	Slush	Light	20:25	21:50
33	26	Snow	Light	10:10	12:25
34	26	Snow	Moderate	12:35	14:05
35	26	Snow	Moderate	14:15	15:35
36	28	Snow	Heavy	15:50	17:05
37	26	Slush	Heavy	17:15	18:30
38	15	Slush	Moderate	20:40	21:50
39	8	Ice	Light	10:15	11:45
40	8	Ice	Light	12:15	13:40
41	12	Ice	Moderate	15:35	17:15
42	12	Ice	Moderate	18:55	20:10
43	12	Ice	Light	20:30	21:40

FIG. 9-11 INCLEMENT WEATHER TEST CONDITIONS

9.3 SPECIAL VEHICLE RELATED CONDITIONS

During the Phase I test program, a number of tests were conducted to assess the limitations, if any, and capabilities of the HI^3 AVM System in terms of special conditions which pertain to the AVM-equipped vehicle. HI^3 selected a large motor home for use as a test vehicle for two reasons: (1) it provided an ideal working space for the DAS and for observers during tests and demonstrations, and (2) it was an ideal simulation for a bus in terms of height, width, and maneuverability. The success achieved through use of the Phase I test vehicle makes it a logical choice for use during Phase II test program in Los Angeles as a test and calibration vehicle.

Special vehicle related tests were categorized as follows:

Vehicle velocity

U-Turns

Parking Garages.

9.3.1 Vehicle Velocity

During the random route and fixed route tests in Philadelphia, the test vehicle operated under prevailing traffic conditions and speed limits. As a result, the vehicle was rarely able to exceed a speed of 30 miles per hour during formal tests. In order to demonstrate the performance of the HI^3 LS at speeds much greater than 30 mph, a series of special tests were conducted in Fort Worth, Texas, on 27 October 1976. Two types of tests were conducted. The first involved making repeated passes at a constant speed by a signpost mounted on a street light and recording the distance from the signpost at which the R1 boundary was detected. These tests (Special Case Runs 17 through 28) covered speeds from 10 to 48 mph. Higher velocity tests were performed by attaching a signpost to the top of another vehicle and subsequently driving the two vehicles toward each other at constant speeds. By recording these speeds and the location, ODOM (R1), at which the R1 was received, and the location, ODOM(P), at which the vehicles passed, the actual R1 radius associated with the relative velocity between the test vehicle and the signpost could be computed. The value of the odometer at the occurrence of the R1 was automatically recorded by the data recording software. Passage of the two vehicles was recorded by use of a CP event code.

The geometry involved in the latter test is shown in Figure 9-12. If it is assumed that the test vehicle was traveling at a speed of V_{TV} and the signpost at a speed of V_{SP}, then the actual vehicle velocity relative to the signpost is

$$V_R = V_{TV} + V_{SP} \cdot$$

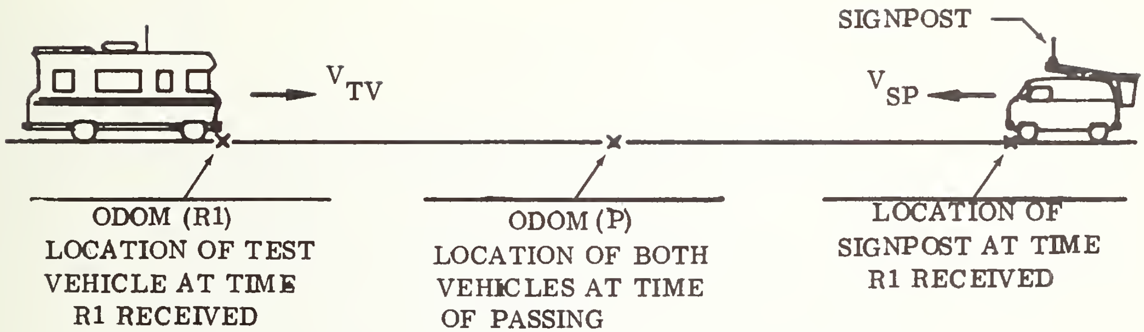


FIG. 9-12 VEHICLE VELOCITY TEST CONFIGURATION

During the period of time between receipt of the R1 by the test vehicle and the passing of the two vehicles, the test vehicle traveled a distance of

$$D_{TV} = ODOM(P) - ODOM(R1).$$

The time required to travel this distance is

$$R = \frac{D_{TV}}{V_{TV}}.$$

During the same time period, the signpost traveled a distance of $D_{SP} = T \times V_{SP}$. The actual R1 distance is given by

$$R1 = D_{TV} + D_{SP} = D_{TV} + T \times V_{SP} = D_{TV} + D_{TV} \frac{V_{SP}}{V_{TV}}$$

or

$$R1 = D_{TV} \quad 1 + V_{SP}/V_{TV}$$

$$R1 = \quad ODOM(P) - ODOM(R1) \quad (1 + V_{SP}/V_{TV}).$$

This last relationship was used to compute the R1 distances shown in Table 9-9 for the case of two vehicles. The slightly shorter R1 value that resulted during Runs 43 through 49 are primarily attributed to the manner in which the signpost was mounted on top of a van. The signpost height was only 9 feet above the ground. Note that the average R1 radius is 216 feet for the data in Figure 9-9 and the standard deviation is less than 54 feet, including the effect of both vehicle speed and the height difference of the vehicle-mounted signpost. The standard deviation of the pole-mounted signpost tests was 37 feet while that of the vehicle-mounted signpost tests was 22.8. The results show that the HI^3 AVM System performance is not degraded at any speed contemplated for either fixed or random route vehicles.

9.3.2 Vehicle Making U-Turns

The HI^3 AVM System is independent of the direction of travel of the vehicle. No dead-reckoning is performed, and no application of location history is made in computing subsequent locations. Each vehicle simply computes and stores its most current location as it determined by the 18-BIT location region code. The process of making a U-Turn in no way affects the performance of the HI^3 system. This fact was demonstrated during a special test conducted on Vine Street between 9th and 10th Streets. Figure 9-13 reflects the path of the vehicle on a scale drawing of the street, which is 134 feet wide. The small solid circles on the vehicle path indicate the occurrence of a new location region code. The locations of these HI^3 test and calibration checkpoints 14, 15, and 17 are also

TABLE 9-9 VEHICLE VELOCITY TESTS

Run #	Heading	V_{TV} mph	V_{SP} mph	V_R mph	R1 Radii Feet	Odometer CAL Feet per pulse
17	West	10	NA	10	280	10
18	East	10	NA	10	290	2
19	West	20	NA	20	272	2
20	East	20	NA	20	298	2
21	West	30	NA	30	*	10
22	East	30	NA	30	*	10
23	West	40	NA	40	240	10
24	East	40	NA	40	170	10
25	West	45	NA	45	240	10
26	East	45	NA	45	260	10
27	West	48	NA	48	210	10
28	East	40	NA	40	260	10
43	East	20	0	20	190	10
44	East	20	20	40	180	10
45	East	30	30	60	160	10
46	East	40	40	80	140	10
47	East	40	45	85	191	10
48	East	48	50	98	163	10
49	East	48	54	102	127	10

* Experienced problem recording output of odometer

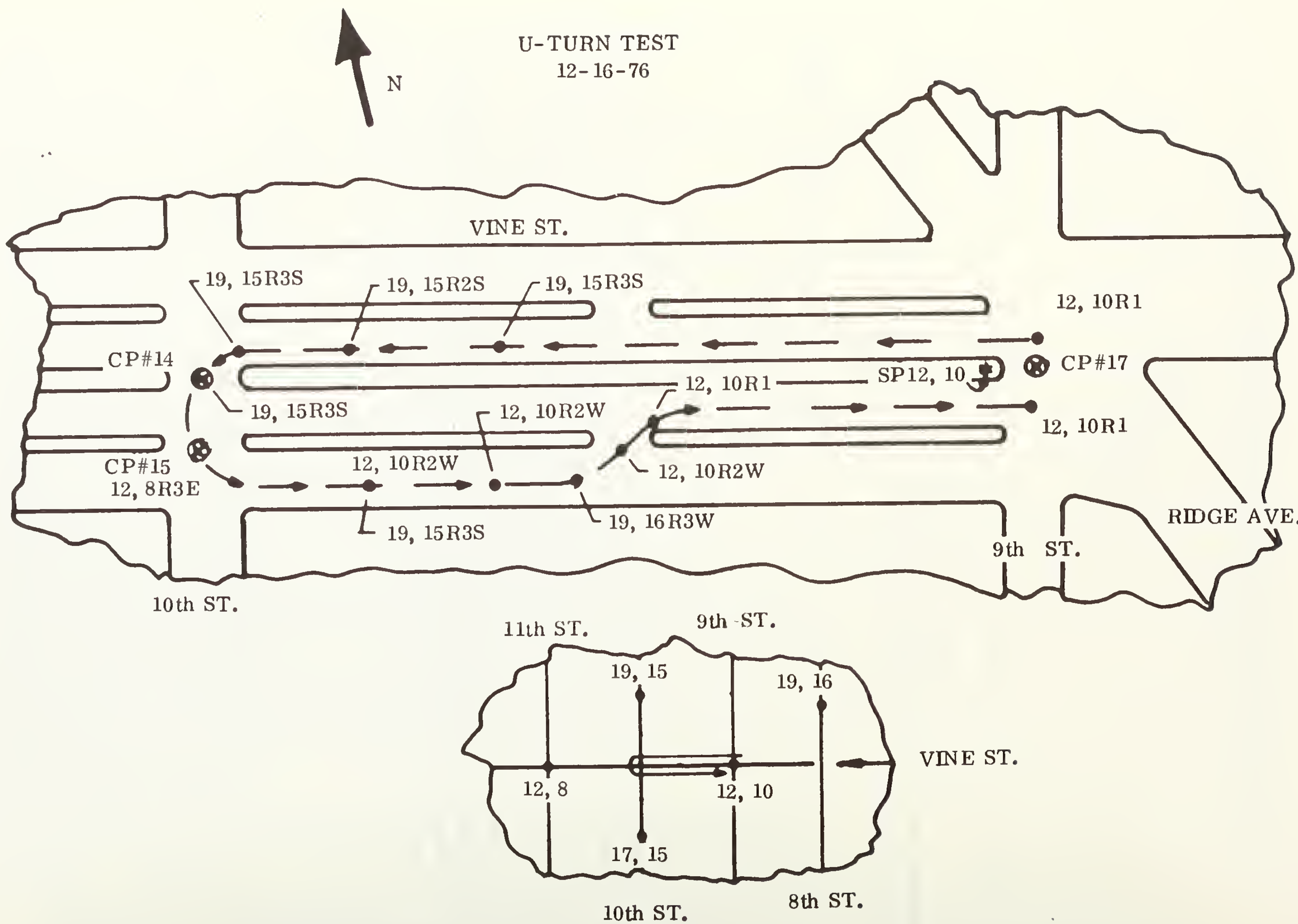


FIG. 9-13 VEHICLE U-TURN TESTS

indicated. The inset is the street geometry and the location of signposts and location region coordinates. Table 9-10 contains a listing of the U-Turn Test Data.

9.3.3 Parking Lots and Garages

During normal activities of a random route vehicle, particularly a police car, the vehicle may be required to enter parking lots and parking garages, pass through alleys, etc. The HI^3 random route location subsystem provides accurate location data on vehicles in these situations. Where an AVM-equipped vehicle enters a parking garage, the storage register in the vehicle maintains the last location region code until the unit is turned off. When it is turned back on and driven back onto the street, the vehicle unit picks up a new location region code as its current location. This fact was demonstrated by driving into the covered roadway area on Filbert Street near 8th Street shown in Figure 9-14. At the location designated CP 99, the vehicle was parked and the power to the vehicle unit was cycled, clearing the location storage register. The vehicle was then driven East. CP 98 was entered as the vehicle left the garage to record the odometer value. The odometer value at the occurrence of the first location region code was also recorded. The resulting data are shown in the figure. This data demonstrated the capability of detecting a valid location region code (in this case an overlap code), within less than 270 feet after leaving a completely covered garage. It is significant to note that the HI^3 AVM system does not require that the first location region be a Region 1. The system responds equally well to location region created by use of the overlap technique.

In paragraph 9.1.2, it was shown that coverage within a covered garage can be easily obtained by placing a HI^3 signpost within the covered area. This arrangement allows, for example, all cars leaving a fleet vehicle garage to be accurately located from the instant their systems are turned on.

9.3.4 Vehicle Unit Power Requirements

During special tests conducted in Fort Worth, the Phase I test vehicle unit was tested to determine its power drain. The source voltage was 12-5 volts DC and the total current drawn was 201-212 milliamps, with the vehicle unit operating under operational conditions. This resulted in a power drain of 2.59 watts.

TABLE 9-10 U-TURN TEST DATA

	000	12	10	R1		D	03394	F	00000	T	04	42
CP	017	12	10	R1		D	03434	F	00000	T	04	44
	000	19	15	R3	S	D	03726	F	00000	T	04	55
	000	19	15	R2	S	D	03812	F	00000	T	04	58
	000	19	15	R3	S	D	03885	F	00000	T	05	03
	000	19	15	R2	S	D	03880	F	00000	T	05	05
	000	19	15	R2	E	D	03880	F	00000	T	05	06
	000	19	15	R2	S	D	03880	F	00000	T	05	07
CP	014	19	15	R3	S	D	03880	F	00000	T	05	11
	000	19	15	R2	E	D	03880	F	00000	T	05	13
	000	12	10	R3	W	D	03880	F	00000	T	05	14
	000	19	15	R2	S	D	03880	F	00000	T	05	15
	000	12	08	R3	E	D	03880	F	00000	T	05	18
	000	19	15	R2	S	D	03880	F	00000	T	05	19
CP	015	12	08	R3	E	D	03913	F	00000	T	05	24
	000	12	10	R2	W	D	03999	F	00000	T	05	29
	000	19	15	R3	S	D	04002	F	00000	T	05	30
	000	12	10	R2	W	D	04064	F	00000	T	05	32
	000	19	16	R3	W	D	00033	F	00000	T	05	35
	000	12	10	R2	W	D	00091	F	00000	T	05	37
	000	12	10	R1		D	00117	F	00000	T	05	38
CP	017	12	10	R1		D	00332	F	00000	T	06	04

U-TURN TEST
12-16-76

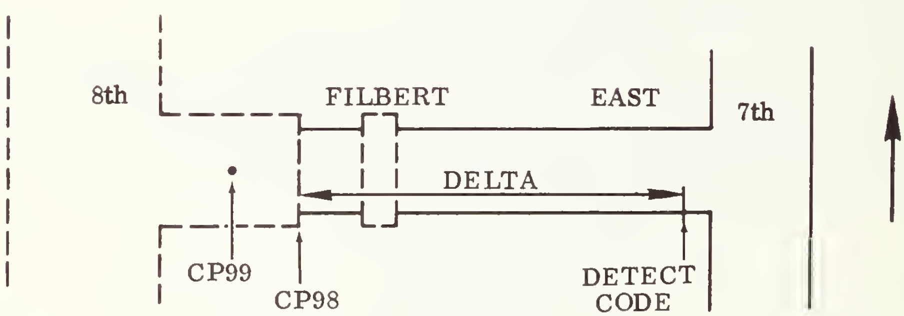


FIG. 9-14 PARKING GARAGE TEST CONFIGURATION

10. SPECIAL PHASE II CONSIDERATIONS

The HI^3 proposals for the Multi-User AVM System were submitted to TSC on 14 October 1975. Contract go-ahead was received on 2 September 1976. During this 11-month period and during the period in which Phase I was conducted, HI^3 was continuously involved in specific and general studies which may have a direct bearing on Phase II of the Multi-User AVM Program. A number of items considered are briefly discussed in this section.

10.1 RELATIONSHIP BETWEEN PHASE I AND PHASE II EQUIPMENT

The location subsystem equipment used during Phase I tests was functionally identical to that proposed for use in Phase II. Specific differences are discussed in this section.

10.1.1 Signposts

The signposts proposed in HI^3 proposal of 14 October 1975 were Model SP-02 which operated at 27.095 MHz. Phase I tests were conducted through the use of signpost Model SP-03 which operates at 49.860 MHz. Model SP-03 signposts are proposed for use in Phase II. Other than minor component replacement and new printed circuit board layout with an etched loading coil designed for use at 49.860 MHz, no signpost design changes are contemplated for Phase II. The loading coil used during Phase I was designed to operate at 27.095 MHz and was modified for operation at 49.860 MHz. HI^3 signposts were connected to batteries on 27 September 1976. Except for a two day period during which they were modified to operate at 49.860 MHz, these 41 signposts were operated continuously from that date through 31 March 1977, when this report went to press. During that 183 day period only one signpost failure occurred, as discussed in Subsection 8.2. That failure occurred on the 111th day of operation.

The design MTBF of the HI^3 signpost is 100,000 hours. Operation of 41 signposts for 183 days corresponds to 180,072 signpost hours of operation. If, as is commonly assumed, a second failure is assumed to have occurred on the 183rd day, one computes an observed failure rate of 2 signposts in 180,072 hours or 1 failure in 95,000 hours, very close to the design MTBF.

10.1.2 Vehicle Units

During Phase I, a separate Interface Controller Unit (ICU) was used to interface the vehicle unit to the computer. In Phase II, all functions incorporated in the ICU would be incorporated on a single communication interface board within the vehicle unit. The primary reason for use of the ICU was to accommodate the odometer and fifth wheel inputs. If the odometer is eliminated from the HI^3 AVM system, the communication interface becomes significantly simpler. Subsection 10.2 contains the rationale for elimination of the odometer. No vehicle unit failures occurred during Phase I. Between random route runs 5 and 6, both vehicle units were found to have erroneously set clock frequencies; however, this was not considered a failure.

10.1.3 Auxiliary Equipment

In Phase I, the CRT keyboard was used to simulate the opening and closing of the bus door. In Phase II, this function would be performed by use of a door position sensor and direct interface to the vehicle unit.

10.2 DESIRABILITY OF ELIMINATING ODOMETER

A number of AVM or AVL systems are currently installed in transit systems. These include the CTA in Chicago, and systems in Zurich, Paris, Hamburg, and London. In each of these systems, odometers are used to determine the distance of a bus along a route from a reference point. The reference points are determined either through (1) being manually reset (Paris' SECAMA system), (2) use of electronic signposts (CTA, Zurich's VBZ, and Hamburg's HVV) and (3) London's optical inverse proximity system. These systems are common to the extent that all use odometers and all are limited to fixed route vehicles. In all of these systems, one key cost element is the design, development, installation, and maintenance of the odometer system.

The development of a true random route AVM system has required a significant departure from the technology utilized in these fixed route systems. The HI^3 random route system, for example, can provide all of the information required of a fixed route system; however, the inverse is not true.

In the interest of making all vehicle units (for use in both random and fixed-route vehicles) identical, in terms of location processing, HI^3 has conducted a study into the cost-benefit of eliminating the odometer. The results of this study are summarized below.

In the Phase II system originally proposed, only fixed-route vehicles would incorporate the odometer. In those vehicles, the odometer would perform the following two functions:

a. Accumulate the elapsed distance along the route from the last signpost.

b. Set a flag when the vehicle has traveled 600 feet from the last R1. This flag signifies that the last R1 dropout has occurred.

Both of these functions can be eliminated by providing complete signpost coverage along the fixed route. The advantages associated with this are many, and they include

1. Timepoints may be moved without requiring movement of any signposts.
2. All multi-user vehicle unit location processors are identical.

3. Non-recurring design costs associated with the odometer system are eliminated.

4. Installation costs of odometer systems are eliminated.

5. Logistics and maintenance problems associated with the odometer are eliminated.

6. Maintenance and logistics are simplified with the multi-user system through increased commonality.

7. Costs of the additional required signposts are less than the cost of providing an odometer system in all fixed-route bases.

8. Software is simplified.

9. All signposts in the system are identical; i.e., there are no differences between "random route", "fixed route", or "timepoint" signposts.

10.2.1 Method of Computing Location and Timepoint Performance Without Using an Odometer

If overlapping signposts are installed along each fixed route, the location of fixed route vehicles is obtained in exactly the same manner as is that of the random route vehicles. Each location region along the route is assigned a pair of X, Y coordinates which are part of the base station data base. Thus, receipt of an 18-bit code location region at the base station allows the bus to be located to within the specified system accuracy.

In the all-signpost system, timepoint performance could be computed as often as each new signpost is received. The vehicle would sense a timepoint through the signpost code. One approach would be that signposts near timepoints would have a logical 1 in the most significant bit. Recall from subsection 3.2.1 that only the four least significant bits are utilized in determining overlap codes. After having sensed a level 1 (Region 1) from a timepoint signpost, a fixed route vehicle would record the time at which the next overlap code was received in the vehicle. This time would be used in exactly the same manner as the TLR1D was used during Phase I. This process is illustrated in Figure 10-1.

At the base station, predetermined values of ΔT_L would be stored for each timepoint and for each direction of bus travel that the timepoint must service. For example, if it is assumed that signpost (71, 8) is used as a "timepoint" signpost at timepoint 15, then a data base file (TPTABL) would provide two values of ΔT; $\Delta T(N)$ that corresponds to the average time required for a bus to travel from the timepoint to the TLR1D point when it is heading north and $\Delta T(S)$ that corresponds to the average time required for a bus to travel from the timepoint to the TLR1D point when it is heading south. Note that the bus must transmit only the single TLR1D time (or the time the door is closed), as in Phase I;

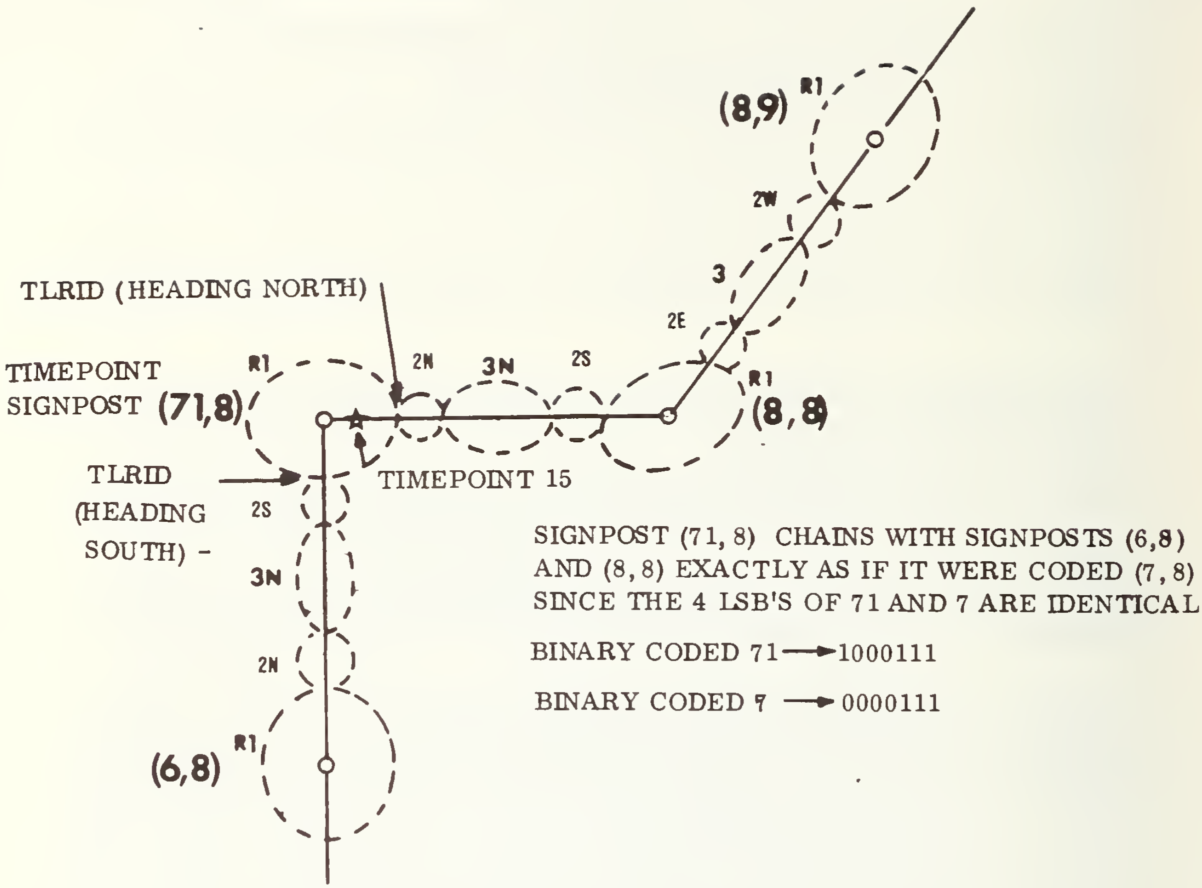


FIG. 10-1 USE OF HI^3 SIGNPOSTS TO PROVIDE FIXED ROUTE VEHICLE LOCATION AND TIMEPOINT PERFORMANCE

however, it need not store or transmit the 12-14 bit odometer code. Consequently, the odometer storage register and all associated odometer logic can be eliminated from the fixed-route vehicle units, and the communication technique is simplified. Furthermore, a significant gain in the flexibility of timepoint selection is achieved since timepoints may be selected without requiring movement of any signposts.

10.2.2 Cost Benefit of Eliminating Odometers

From an economic point of view, the elimination of the odometer from the fixed route system is beneficial, particularly as the number of vehicles is increased. An analysis of this cost benefit follows:

1. Non-recurring Costs - These costs are independent of the number of vehicles. They include engineering and development costs associated with the odometer system. No additional non-recurring costs are incurred by expanding the signpost system.

2. Recurring Costs - If a cost per vehicle of \$40 per installed odometer system is assumed and a cost of \$70 per installed signpost, one can establish the following relationship:

   $$\text{Delta Recurring Cost} = 70N_{SP} - 40N_V$$

   An analysis of the designated SCRTD lines 7, 21, 26, 29, 83, and 89 indicates a total of 70 miles would require signpost coverage. The total route miles of all these lines is 102.7 miles; from this distance was subtracted the 29.3 miles which occurs within the random route area and 3.7 miles which are common to more than one route. The installation of a signpost every 1000 feet along this 70 miles would require 370 signposts and meet the LS and system accuracy specification at all points along the routes. Thus, for Phase II

   $$N_V = 200 \text{ fixed route vehicles}$$

   and

   $$N_{SP} = 370 \text{ signposts}$$

   which results in a total Delta Recurring Cost of \$17,900.

3. Cost Saving - In order to compute the cost saving achieved by eliminating the odometer, the amount bid in the Phase II cost proposal for Fixed Route and Timepoint signposts must be subtracted from the recurring costs. Since 260 units were proposed, the net recurring saving is

   $$\$18,200 - 17,900 = \$300.$$

   To this value must be added the saving in non-recurring cost, \$10,000. The result is a total saving of \$10,300 that results from elimination of the odometer, without loss in performance.

4. Additional Cost Savings - Additional areas in which use of a signpost-only system (no odometers) would provide cost savings include:

   a) Training - Simpler system involves less training for maintenance.

   b) Maintenance - No in-vehicle maintenance, just replace vehicle units.

   c) Spares - Fewer required since all units are identical.

   d) Software - Simpler coding and simpler maintenance.

   e) Quantity buy - More signposts allow per-unit cost savings.

The inclusion of this change involves no design changes in the HI^3 vehicle unit used in Phase I since the odometer was accumulated within the ICU, not in the vehicle unit. Thus, use of a signpost-only system during Phase II allows the vehicle unit location region processor to be even more identical to the Phase I system than originally proposed.

10.3 FCC REQUIREMENTS AND STATUS OF HI^3 EQUIPMENT

Operation of HI^3 signposts Model SP-03 requires certification by the FCC pursuant to Subpart D of Part 15 of the current FCC Rules and Regulations. To be certified under Part 15 as a low-power device, the signpost must meet the specified technical requirements and be certified through the process set forth in Subpart B of Part 15.

Model SP-03 signposts certification requires that a set of simple measurements be taken; however, the calibrated equipment necessary to conduct these measurements is not available at HI^3. For this reason, HI^3 provided test units to Approved Test Engineering Laboratory of Chatsworth, California. That laboratory has provided the technical data necessary for certification by the FCC, which has been applied for.

HI^3 has held numerous meetings with FCC personnel with regard to AVM. The HI^3 AVM system installed at Huntington Beach, California, is certified by the FCC under Part 15 under the rules in force at the time of manufacture of that 27.095 MHz system. In the near future HI^3 intends to petition the FCC for a nationwide dedicated signpost frequency. We believe such a step would be beneficial to the government.

10.4 FEDERAL, STATE, AND LOCAL REQUIREMENTS FOR PHASE II

Installation of Phase II equipment will involve obtaining permits for the use of space on existing street light and/or utility poles in the cities of Los Angeles, Santa Monica, Culver City, and Beverly Hills, and the County of Los Angeles. Well over 90 percent of these poles will be in the City of Los Angeles.

HI^3 has initiated the process of obtaining pole agreements from the organizations and municipalities involved. Our success rate in obtaining similar agreements from the Cities of Huntington Beach, Los Angeles, Santa Monica, and Vernon, California, Palm Beach, Florida, Fort Worth, Texas, and Philadelphia, Pennsylvania has been 100 percent. We have provided engineering data to these organizations and demonstrated full compliance with state and Federal Occupational Safety Hazards Act in terms of both equipment and installation procedures.

10.5 NATIONWIDE MULTI-USER AVM

Within the confines of a given city or metropolis, the HI^3 Multi-User AVM System can provide AVM benefits to all potential users within the area, regardless of type. Since all users may simultaneously share the same signpost system, proliferation of users does not result in the requirement for additional signposts. Different users may or may not utilize a common communication link. Generally, users would utilize their own assigned mobile radio frequencies. Since the great majority of vehicle fleets operate in the VHF or higher bands, the spatial distance over which a particular vehicle can be located is limited by the achievable mobile radio coverage, generally line-of-sight. For example, frequencies assigned to vehicle fleets in the UHF band are generally limited to use over approximately a 35-mile radius.

As a result of these limitations imposed by mobile communications, there has been little emphasis on having different cities or metropolises having a common signpost frequency. For example, a PUD truck which normally operates in Los Angeles might be required to operate temporarily in San Diego. Unless the truck's mobile radio was initially equipped to operate at the frequency assigned to that fleet in San Diego, it would not be able to communicate directly with the San Diego fleet base station. Therefore, the primary reason for having signposts in Los Angeles and San Diego operate on the same frequency would be one of economics, i.e., common design and common parts allow reduced costs.

If, however, a vehicle fleet has the capability of operating inter-city or even nationwide, it would be highly advantageous, if not necessary, that all such cities be provided with a common-frequency signpost system. Assuming that communication with different base stations is available over long range (for example at HF), communication to a base station can be maintained, and a common signpost frequency would allow the location of such a vehicle to be known within each city. It is assumed that a vehicle operating in this mode would come under the control of a local base station upon entry into a coverage area. The attainment of this capability by use of a HI^3 AVM system operating at 49.860 MHz is currently achievable without design change to the location subsystem. Nationwide operation at 49.860 MHz is currently acceptable to the FCC. However, since operation at 49.860 MHz is on a suffrage basis, it seems reasonable that the expansion of a signpost AVM system to many cities would certainly be sufficient justification for licensing of a single narrow-band dedicated frequency.

However, provisions to obtain location subsystem coverage in non-urban areas, especially on long cross-country routes between cities can best be achieved through use of a hybrid system which would incorporate the proven economic and technical benefits of the HI^3 signpost approach with a wide-area AVM system such as Loran. Such a hybrid system would take advantage of the useable signal-to-noise ratios achievable through the use of Loran in non-urban areas and the proven signpost technology in urban areas.

Major drawbacks to an urban Loran system has always been (1) high vehicle unit costs and (2) costs associated with providing some type of augmentation of the Loran system to overcome the signal-to-noise problems associated with the urban environment. If Loran is only used for wide-area, non-urban coverage, then only those vehicles which are required to operate in non-urban areas would require the Loran portion of the system. As a result, the cost benefits and superior urban operation of the signpost system are provided to all urban vehicles as well as those which operate inter-city and use Loran during inter-city operation. Vehicles which operate only cross country or whose location, intra-city, is not of importance, might only incorporate the Loran portion of the system.

The development of a hybrid signpost-triangulation AVM system is not new to HI^3. In December of 1975, HI^3 (then Information Identification, Inc.) began the development of a hybrid signpost - AM Phase AVM System for the Justice Department, under contract to The Aerospace Corporation as part of a Cargo Security System for PUD trucks. This system involves the use of a triad of phase-locked AM stations as a basic source for a triangulation location system. Overlapping signposts were also used (1) as a reference for testing the AM Phase system and (2) as a means of augmenting the AM Phase system in fade zones. This system was successfully pilot tested in Los Angeles, Santa Monica, and Vernon, California in the Spring of 1976. A single base station provided control of the hybrid AVM system through the use of a shared voice communication link in the participating trucking company.

HI^3 is currently under contract to produce an operational Cargo Security System to be installed in 40 PUD trucks operating in a 400 square mile area of greater Los Angeles including 40 different municipalities in Los Angeles and Orange counties. Radio stations KFI, KNX, and KPOL provide the phase locked AM carriers and 331 signposts provide location updates and fade-zone augmentation. This system is scheduled to become operational in June of 1977 at which time an extensive 12-month evaluation period will commence.

The purpose of this discussion is to show that the development of a hybrid AVM system using signposts in the cities and Loran in the country is not just a concept, for the groundwork has already been carefully laid. Such a system can be developed without technical risk since wide-area, vehicle location in non-urban areas through use of Loran is proven and vehicle location in urban areas through use of the HI^3 signpost AVM is proven. The development of a hybrid vehicle unit consisting of plug-in optional modules and the use of modular software would allow the use of a considerable amount of existing hardware and algorithms and would culminate in a nation-wide system which would meet the technical specifications of both urban and non-urban AVM yet not impose the costs of non-urban AVM on the high percentage of users which operate only on a metropolitan basis.

10.6 HI^3 RANDOM ROUTE LOCATION SUBSYSTEM SUPPLEMENTARY ANALYSIS

In the interest of determining more explicitly the distribution of errors for the random route configuration of the HI^3 location subsystem, the program RRTEN was modified to print out the error statistics for all samples obtained during Run 6. This procedure resulted in the processing of 8304 samples with the following pertinent results:

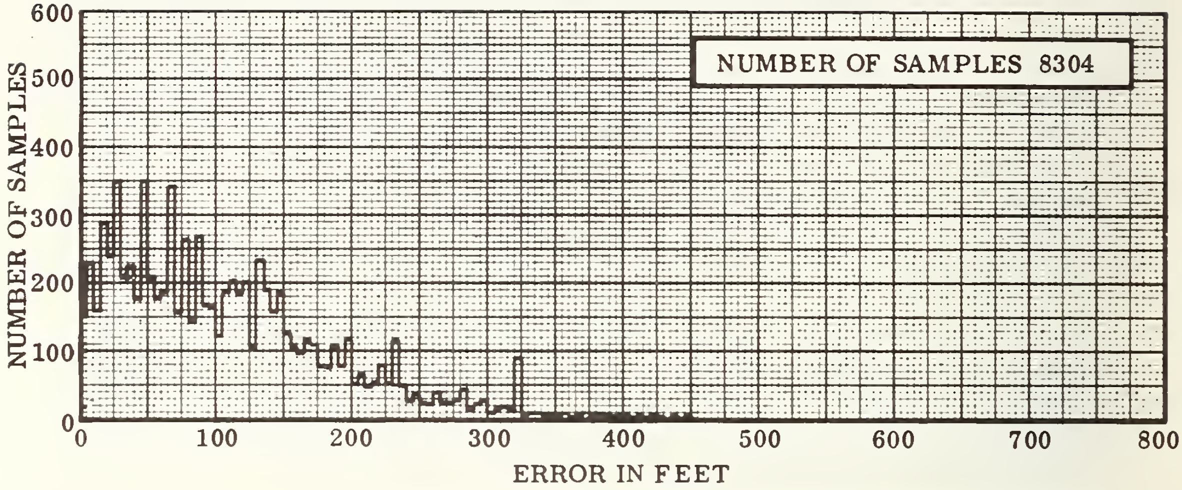
50 percent of samples less than: 94 feet.
95 percent of samples less than: 274 feet.
99.5 percent of samples less than: 389 feet.

The overall results are shown plotted in Figure 10-2. The distribution function is virtually identical to the composite error distribution obtained for 2235 pseudo checkpoint samples and shown in Figure 5-16. That curve is replotted in Figure 10-2 to illustrate their similarities. The density function which most closely approximates the error frequency density appears to be of the Raylergh form

$$f(x) = xe^{-\frac{x^2}{2\alpha^2}},$$

although a few errors having a value of zero are observed.

Other parameters of interest relative to the HI^3 location subsystem are the distribution of overlap region sizes. These parameters could not be explicitly determined from Phase I data because the passage of each signpost was not marked and the occurrence of cross-track overlaps partially obscured the occurrence of on-track overlaps. However, an approximation to these distributions was obtained by analyzing the listings of recorded data from Random Route Runs 6 through 10. The distances from the checkpoints which were located near signposts to the first occurrence of Region 2's and Region 3's was determined. Of the 5 runs analyzed, 116 such occurrences were observed. Of these, 91 occurrences involved receiving a region 2 after having passed through a Region 1 and 25 occurrences involved receiving a Region 3 after passing through a Region 1. 64 occurrences of Region 2 to Region 3 transitions (equivalent to Region 2 widths) were also analyzed. The distributions of these three distances



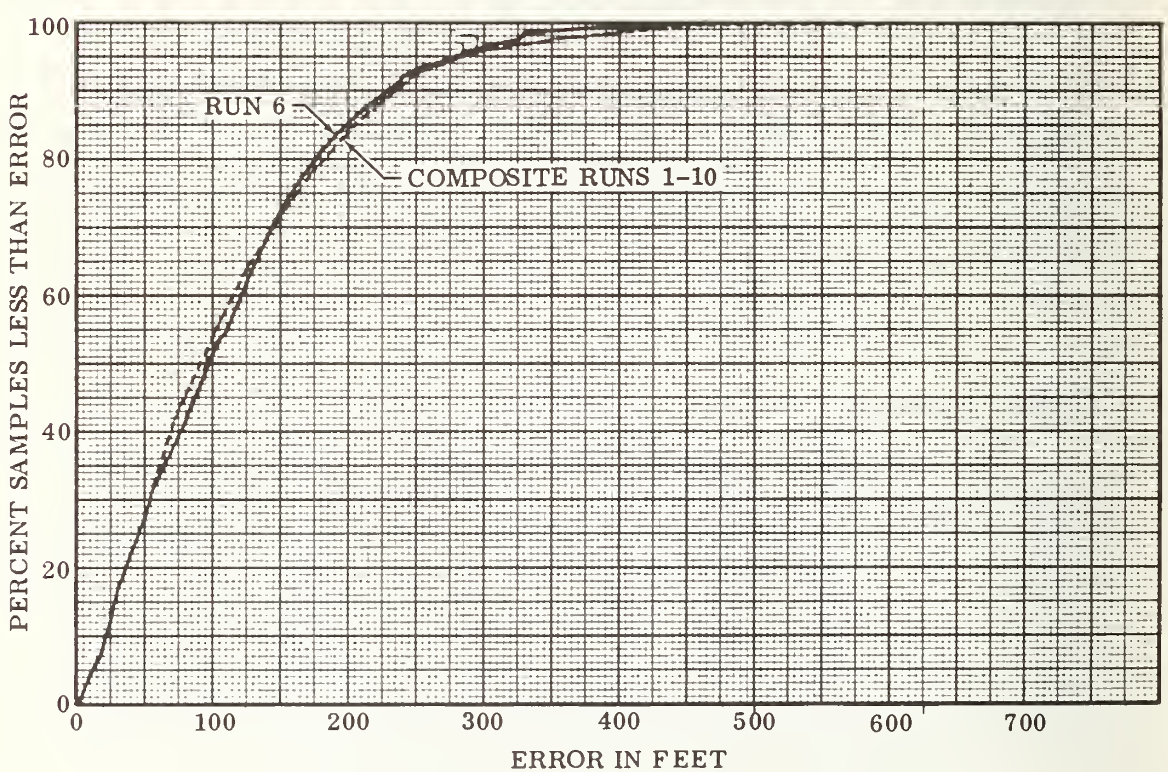


FIG. 10-2 HI^3 RANDOM ROUTE LOCATION SUBSYSTEM ERROR DISTRIBUTION are plotted in Figure 10-3. Note that the distance from signpost-to-Region 2 or Region 3 is half of a region width, since it is on one side of a signpost whereas the Region 2-to-Region 3 width represents the width of a full region. As a result of the presence of cross-track overlaps at intersections, it was impossible to determine widths of Region 3's.

10.7 SPECIAL PHASE II CONSIDERATIONS

HI^3 has initiated or completed a number of activities which relate directly to achieving all cost and schedule milestones on Phase II. For example, HI^3 has digitized every intersection in the entire Los Angeles basin and has these on file on diskettes at Fort Worth. Computer programs to print these X, Y coordinates and intersection names, delete and add intersections, etc. are currently available at HI^3. Digitization was accomplished in exactly the same manner used by MITRE to digitize the intersections in Philadelphia.

As mentioned in subsection 10.3, the HI^3 location subsystem requires no FCC license. HI^3 has recently applied for and received an experimental license for use of two UHF frequencies in the Los Angeles area for communication between AVM equipped vehicles and a base station. Thus, we understand the mechanism and timing necessary to obtain all necessary FCC permits.

As mentioned in subsection 10.4, HI^3 has extensive experience in obtaining pole agreements from municipalities and utility companies. We have already initiat the process in 40 municipalities in Los Angeles and Orange Counties in conjunction with the Cargo Security System. Installation of the signposts for that system will be accomplished in April and May of 1977 and although temporary (12 months) this will lay the groundwork necessary for proceeding directly with the Phase II pole agreements upon go-ahead. Hoffman's Corporate engineering and manufacturing facility in El Monte, California will be the base of these operations.

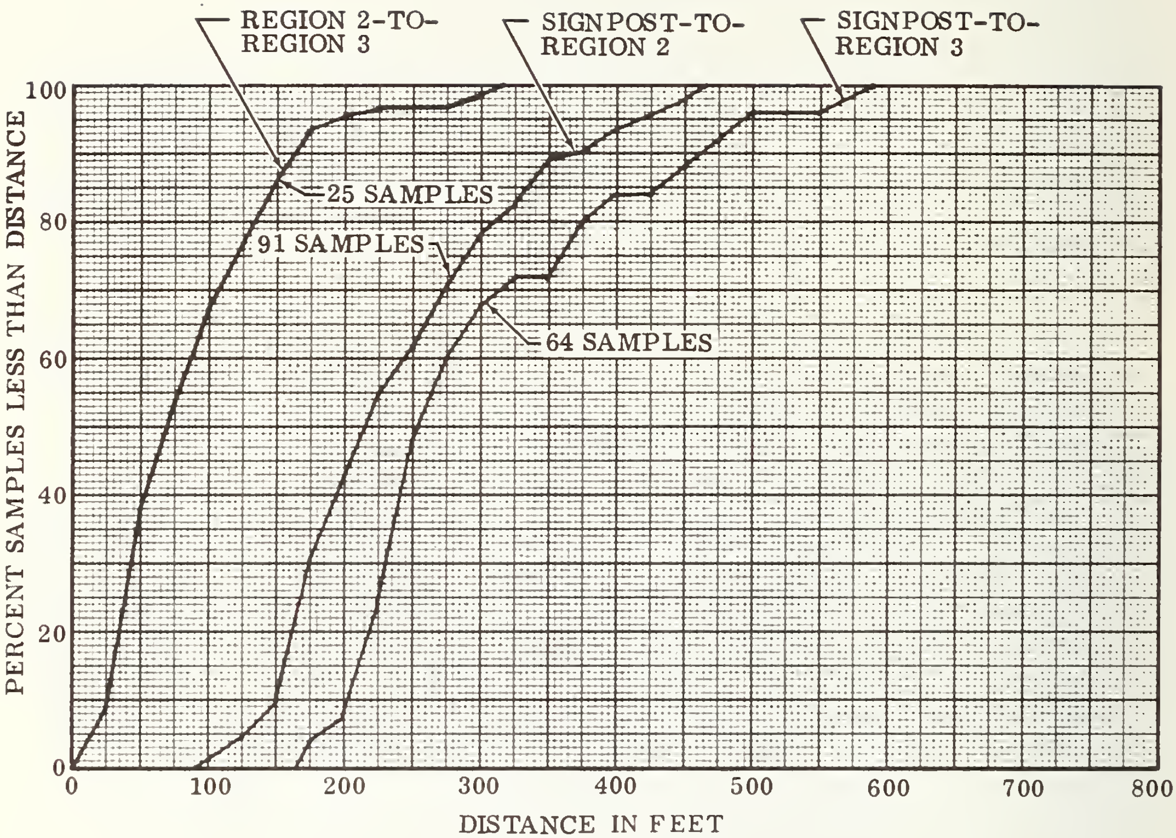


FIG. 10-3 HI^3 RANDOM ROUTE LOCATION SUBSYSTEM REGION WIDTH DATA SECONDARY RUNS 6 THROUGH 10

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