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EVALUATION OF PASSENGER COUNTER SYSTEM FOR AN AVM EXPERIMENT
Volume I: Technical Report

A. Balaram
G. Gruver
H. Thomas

Gould Information Identification, Inc.
2908 Cullen Street
Fort Worth, TX 76107

DEPARTMENT OF
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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Bus and Paratransit Technology
Washington DC 20590

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16. Abstract

An evaluation of three commercial passenger counter systems was conducted to assess the potential performance of these systems for use as part of the Multi-User AVM System. Tests were structured to assess the counting accuracy of each counter under identical situations of passenger boardings and alightings. This was accomplished through the use of a laboratory test stand and also through ten days of testing all three counters on an operating transit bus. Environmental tests were also conducted on the sensor elements of all three counters. One counter incorporated treadle mats at each door step. The other two counters incorporated infrared beams established across each doorway. Test data indicated that the counter which incorporated treadle mats exhibited superior counting performance over the other two counters.

This report is comprised of two volumes: Volume I Technical Report and Volume II Test Data.

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PREFACE

During the spring of 1978, as part of the Multi-User Automatic Vehicle Monitoring (AVM) Program, Contract DOT-TSC-1237, Gould Information Identification Inc. of Fort Worth, Texas, conducted an evaluation of three commercially supplied passenger counters. This evaluation involved environmental and laboratory testing, as well as field testing on a City Transit of Fort Worth (CITRAN) bus. The purpose of this evaluation was to assess the potential performance of each counter for use as passenger sensors in an AVM system on six selected routes of the Southern California Rapid Transit District (SCRTD). Experiments with AVM are slated to begin in the fall of 1979. The AVM system is being developed for the Urban Mass Transportation Administration by Gould under Contract DOT-TSC-1237 to the U. S. Department of Transportation, Research and Special Programs Administration, the Transportation Systems Center.

A large number of Gould personnel contributed to the success of this program in the roles of simulated passengers and in conducting the tests. Particular acknowledgement is given to D. Brown, J. McKinney, and B. Roper for their aid in installation and testing of the counters. A. Balaram and G. Mayfield provided needed support in the data analyses and G. Gruver, Gould's Program Manager, assured that the evaluation was compatible with the overall program goals.

Special acknowledgement is accorded to Messrs. L. Heil and J. Bertosiwicze of CITRAN and their staff of operators and maintenance personnel without whose full support this program could not have been accomplished. The support of Mr. B. Blood, the Transportation System Center's Project Monitor and Project Engineers B. Kliem and J. Herlihy is also gratefully acknowledged.

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

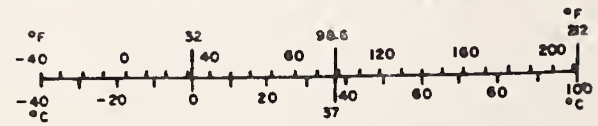


TABLE OF CONTENTS

Section		Page

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

This report contains the results of an evaluation of Passenger Counter Sensors (PCS) for use in transit buses. The work was performed by Gould Information Identification, Inc., under Contract DOT-TSC-1237 from the U. S. Department of Transportation's Research and Special Programs Administration, Transportation Systems Center. Funding was provided by the Urban Mass Transportation Administration.

The work effort reported herein represents a small part of the overall contract effort whose sole primary objective is the evaluation of Multi-User Vehicle Monitoring (AVM) for transit and paratransit users. As part of that overall effort, an AVM system is to be deployed on six test routes and 200 buses of the Southern California Rapid Transit District (SCRTD) and evaluated over a one-year period. An important requirement of AVM is that accurate knowledge of the transit rider load factors on each AVM-equipped bus be available, both in real time to facilitate closed-loop bus control tactics and off-line for transit management information. The transit rider count for each vehicle will be obtained using available passenger counters as sensors.

The process by which candidate passenger counters were selected for counting accuracy evaluation and the results of that process are reported herein. The criteria used for this evaluation were developed to fulfill the requirements set for the AVM experiment and evaluation program, the goal of which is to determine, through closely controlled experimental environment, the potential benefits that AVM may yield to both transit operators and passengers.

The PCS evaluation program involved three primary steps. The first step was to survey the literature and the marketplace to determine what PCS evaluation work had previously been performed and to ascertain what equipment was currently available. The results of this step are reported in Section 3. The second step was to acquire available equipment from selected manufacturers and to test this equipment in accordance with a test plan that was previously approved by the Transportation Systems Center. A description of the selection process, selected equipment and test program is contained in Section 4. The third step was the comparative analysis of the results obtained. These results are presented in Section 5. Section 6 presents the conclusions of this report. Volume II contains the reduced and raw data results.

2. SUMMARY

This report contains the results of an evaluation of three candidate transit-line passenger counter systems relative to their potential use as part of a Multi-User AVM experiment being conducted by Gould Information Identification Inc. for the U.S. Department of Transportation under a Transportation Systems Center contract. The evaluation involved three phases: (1) controlled testing of each candidate's counting accuracy under laboratory conditions, (2) simultaneous field testing of all three candidates on a transit bus during normal in-service operation, and (3) simultaneous environmental testing of the three candidates' sensors.

The laboratory tests were conducted using a test stand which accurately simulated the doorways of a transit bus. Field testing involved installing the three passenger counter systems on a CITRAN bus and comparing the counting results monitored by each counter with the actual passenger transactions which were carefully monitored by test personnel on the bus. Environmental tests were accomplished by an independent test laboratory.

The results of this evaluation indicated that the passenger counter system manufactured by Dynamic Controls, Inc., which incorporated treadle mats operated by the pressure of passengers' feet, exhibited slightly superior counting performance under virtually all test conditions and considerably superior performance during field tests.

3. PASSENGER COUNTER SENSORS

3.1 GENERAL

Passenger count information is needed by transportation planners and transit management (as well as required by UMTA under Section 15, Uniform Systems of Accounts and Records and Reporting Systems) to determine total transportation system requirements based on projected passenger movement throughout the transit network. Accurate information for transit planning will ensure that the level of service provided will meet the expected demand.

The present method used in the transit industry for obtaining passenger count information is to use "checkers" to manually count passengers on/off a bus at selected points in addition to determining Time of Arrival/Time of Departure information. Substantial cost is incurred in obtaining and processing data manually. These data are essential to a transit scheduler in establishing headway requirements.

The use of passenger counter sensors as part of the Automatic Vehicle Monitoring system to be installed on SCRTD buses during the AVM program will provide a heretofore unavailable means of observing, in real time, the passenger load characteristics of a large segment of a metropolitan transit system. A total of six (6) SCRTD routes and 200 buses will be equipped with AVM. The availability of passenger load data, in real time, in conjunction with bus location and time of passage data as required in the UMTA Multi-User AVM specification will allow the dispatcher to implement control strategies which are difficult to effect without the aid of passenger counters.

3.2 BACKGROUND

Automated passenger counting has been of interest to the transit industry since the nineteenth century. A patent for "Ringing-Fare Registers" was applied for as early as 1888. A more recent analysis of automatic passenger counting needs in the transit industry has led to the conclusion that the most effective and efficient technique was a mechanical turnstile with a counter attached. The advantages offered by such a device were that the passengers were forced to queue on or off the bus one at a time, thus generating a very accurate count. In addition, entry and exit points were forced to be different due to the nonreversible interlock feature of the turnstile mechanics.

This "perfect" passenger counter system has subsequently been rejected by modern day transit authorities as a result of certain inconsistencies with present day operational and safety requirements. In particular, the access of public transit by elderly and handicapped people precludes the use of such devices.

The design goal is, therefore, to create an "invisible turnstile" which will be truly automatic in operation yet as accurate and reliable as the mechanical units of yesterday.

3.3 PASSENGER COUNTER PROGRAMS

A multi-volume report[1] produced by the MITRE Corporation in 1973-1975 surveys the state-of-the-art at that time and provides a review of the applications of passenger counters. International Pro-Data Corporation of Hamburg, West Germany, evaluated by MITRE in 1973, still actively produces passenger counters.

In 1977, the New York Port Authority conducted a program[2] in which the objective was the development of a low-cost reliable passenger counter. That program involved the evaluation of five different passenger counters which were individually field tested on buses of the New York Transit Authority and Transport of New Jersey. None of the units tested were able to meet the pre-program goals of 95 percent accuracy.

The Southern California Rapid Transit District has been evaluating on-board data collection systems which record passenger transactions. SCRTD awarded contracts, under competitive bid, for five test systems each to Dyniman, Inc. of Costa Mesa, California and to Dynamic Controls, Inc., of Windsor Locks, Connecticut. SCRTD has recently received approval from the California Transportation Department (CALTRANS) for funds to purchase 65 Passenger Counting Sensors (PCSs) for a twelve-month demonstration. SCRTD has already accepted bids on their procurement specification and expects to award a contract for the 65 units in the near future. The design goal set for those counters is 95 percent accuracy.

The Metropolitan Transit Commission of St. Paul, Minnesota, recently awarded a contract for 44 on-board data collection systems to International Pro-Data Corporation. The accuracy specification on all types of passenger counts was 90 percent.

The accuracy specification for that competitive procurement was that the recorded count for both boarding and alighting passengers should be within 5 percent of the actual counts for each 100 consecutive passengers. For 90 percent of the stops, the boarding and alighting counts are required to be within ± 1 of actual boarding and alighting counts. For 99 percent of all stops, the recorded counts of boardings and alightings are required to be within ± 2 counts of the actual passenger flow.

The Urban Transportation Laboratory (UTL) is a cooperative program involving the city of Cincinnati, Southwest Ohio Regional Transit Authority (SORTA) and the General Motors Transportation Systems Division. In 1977, an AVM computer was installed in the UTL control room followed by the installation of communications equipment and passenger counter sensors and counting logic in 30 Queen City Metro buses. The passenger counting sensors and counting logic are manufactured by International Pro-Data Corporation. This is the only known system in the United States that currently provides passenger count data over a communication link. The interface to the communication link was provided by General Motors. This system is being used to conduct experiments on innovative transit operations. No specific accuracy data on the passenger counter has been released.

3.4 TEST PCS CANDIDATES

3.4.1 General

It was not the intent of this contract effort to develop or necessarily advance the current state-of-the-art in passenger counting. Rather, this effort was directed toward selecting a currently available passenger counter sensor (PCS) suitable for use in the AVM system to be deployed at the SCRTD.

To this end, only those PCSs in current production or in sufficiently advanced prototype stages were considered. When used in this context, PCS refers to only the sensors and counting logic and does not imply a full on-board data collection system.

The following subsections identify the manufacturers located by this survey whose products meet the above criteria. Included is a brief description of the particular vendor's system.

3.4.2 Dynamic Controls, Inc

The PCS available from Dynamic Controls, Inc. was specified as being a prototype unit. This PCS incorporates four treadle mats, two of which are mounted on the two steps at each door of the bus. The outputs of the switch sensors are provided to a logic processor which is designed to output a count of one whenever two steps are sequentially activated.

3.4.3 Dyniman, Inc.

The PCS available from Dyniman, Inc. was also specified as a prototype with the sensors being a production item. This PCS utilizes multiple beams of infrared light projected across the bus doorways. When the light beams are interrupted, the data are sent to the electronic control unit which invokes an algorithm to logically identify the occurrence and direction of a passage.

3.4.4 International Pro-Data Corporation

Pro-Data identified its PCS as a production unit. This unit incorporates a pair of infrared beams which are reflected across the passenger pathway. When the beams are broken in proper sequence, the logic unit counts. The sequence and time allow the direction to be sensed as well as aid in discriminating between one or more passengers.

3.4.5 Almex Corporation

Almex, a Swedish firm, is represented in the United States by Vapor Corporation. Vapor Corporation responded with a brochure on the Almex F05000 unit control system for vehicle fleets. The F05000 incorporates multiple infrared beams across each entryway for sensing passenger boardings and alightings. A quote was provided for an Almex passenger counter system without a recorder.

3.4.6 Keene Corporation

Keene Corporation responded to the solicitation released during this program with a quote for their on-board passenger counting system. This system is understood to operate through the use of an overhead sensor which senses changes in the ambient light level produced by passing passengers. The unit is identified as a prototype unit.

4. PASSENGER COUNTER SELECTION AND TEST DESCRIPTION

4.1 VENDOR SELECTION

A survey of companies which are currently involved in the development or manufacture of passenger counter systems yielded the five candidates identified in the previous section. As a result of limitations of the funding for this survey, it was decided to select three units for testing.

Each of the manufacturers was contacted and asked to provide cost and delivery quotes for quantities of 1 and 220 units. One manufacturer, Keene, quoted an eleven-month delivery for a prototype unit and was rejected on the basis that this schedule was incompatible with the contract schedule. Of the remaining four responding vendors, three utilized optical technology and one utilized pressure mats. In order to gain experience with the greatest range of technologies, it was decided to evaluate the pressure mat and two optical sensors. Pro-Data was selected on the strength of MITRE's evaluation of their PCS. Finally, Dyniman was selected because they appeared to have developed the most advanced IR sensor.

Therefore, the following three passenger counter systems were selected for evaluation:

- Dynamic Controls, Inc., Model # 0008-07148-11133-3
- Dynamin, Inc., (No designated number)
- International Pro-Data Corporation, Model # PR-44

4.2 DESCRIPTION OF SELECTED UNITS

Each system selected for evaluation is briefly described in the following paragraphs:

Dynamic Controls Incorporated

The PCS supplied by Dynamic Controls Incorporated is specified as being a prototype unit. This PCS incorporates four treadle mats, two of which are mounted on the two steps at each door of a bus as illustrated in Figure 4-1. Within each mat are a set of pressure-sensitive switches which are activated when a design weight of at least 25 pounds is applied to the treadle, causing an electrical contact to be made. Production mats are sealed to protect the switches from moisture, dust, and other contaminants. The outputs of the switch sensors are provided to a logic processor which is designed to output a count of one whenever two steps are sequentially activated. The PCS is designed to count passengers boarding and/or alighting depending on the order in which the steps are activated. Logic processing is incorporated to inhibit the counting of successive operations of the same treadle, i.e., a person walking in place on one step. Dynamic Controls Incorporated provided two prototype mat sets, a logic unit, and a display.

Dynamin, Incorporated

The PCS supplied by Dyniman, Incorporated is also specified as a prototype, but with the sensors being a production item. This PCS utilizes multiple beams of infrared light projected across the bus doorways. When the light beams are interrupted, the information is sent to an electronic control unit which contains logic to identify passage and the direction of passage of a person. The use of multiple beams (10) is intended to allow individual persons to be resolved during mass boardings, yet prevent the counting of extraneous objects such as purses, grocery sacks, parcels, etc. Figure 4-2

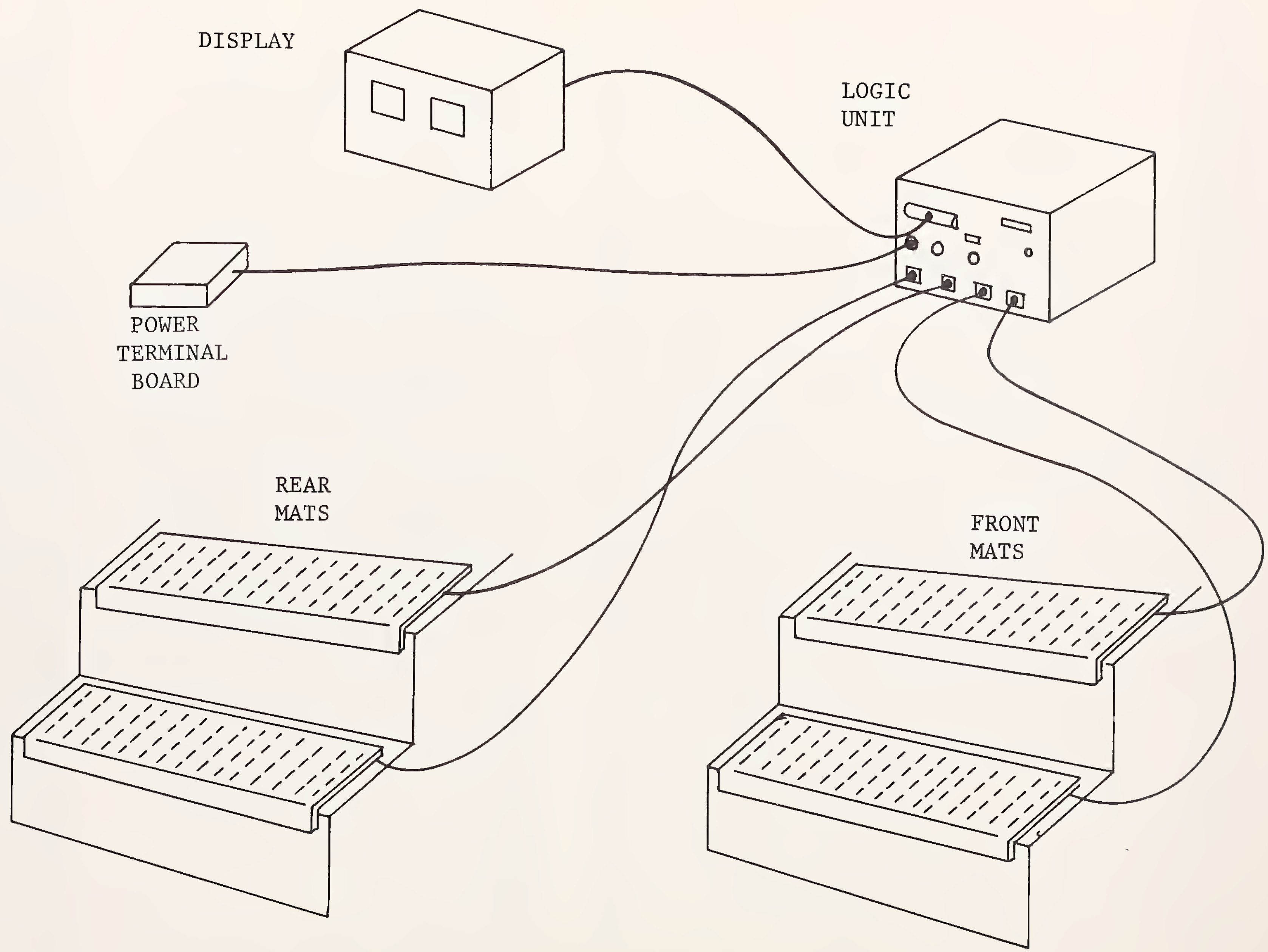


FIGURE 4-1. DYNAMIC CONTROL, INC.'S TEST PASSENGER COUNTER SYSTEM

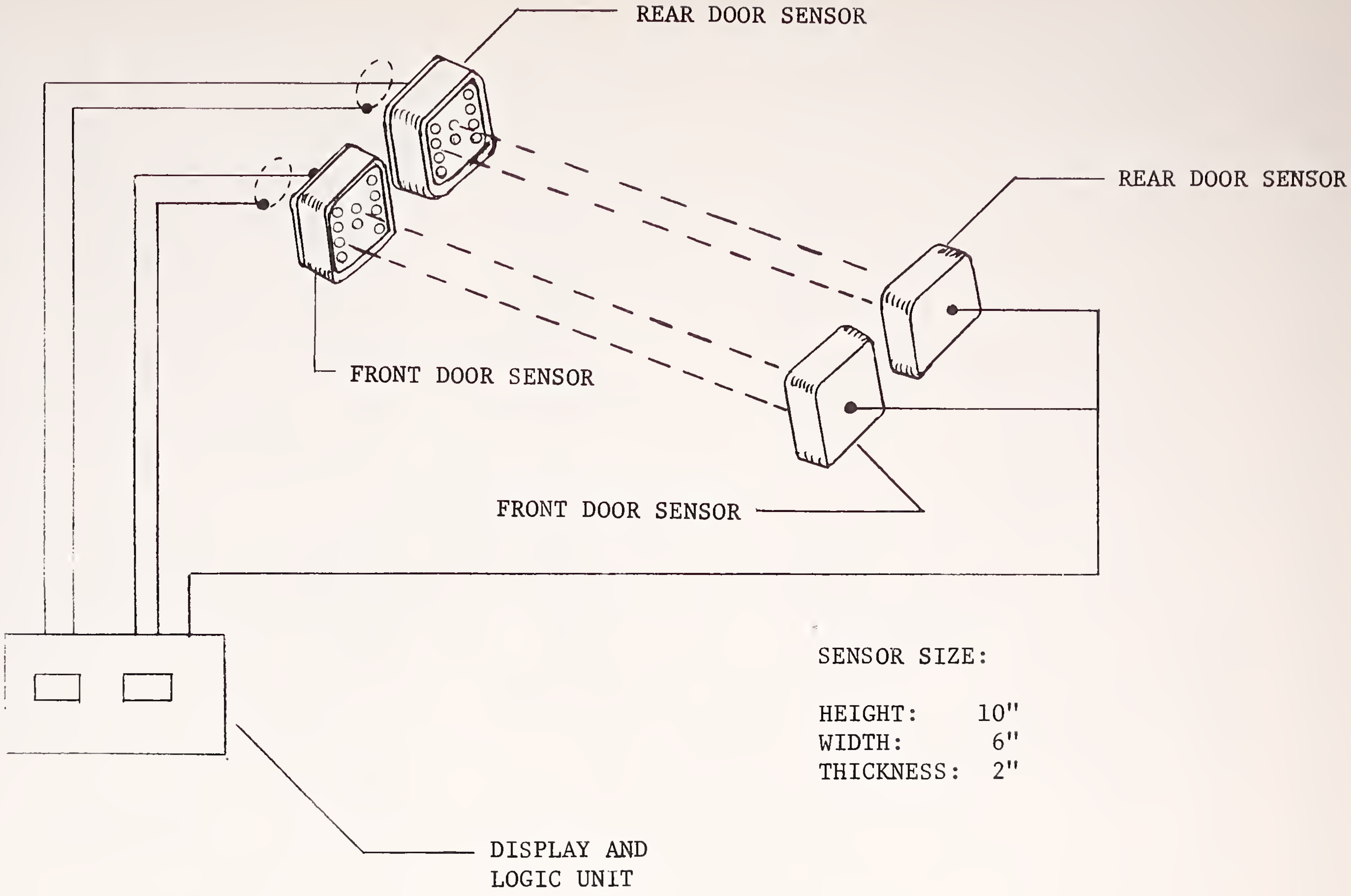


FIGURE 4-2. DYNIMAN, INC.'S TEST PASSENGER COUNTER SYSTEM

contains an illustration of this test PCS. Dyniman Incorporated provided two sets of light sources, two sets of light sensors, and a combined logic and display unit.

International Pro-Data Corporation

International Pro-Data Corporation supplied a PCS which was specified as being a production unit. This system utilizes a two-beam, photo-electric device which transmits and receives the infrared light beams. At each bus door, two beams of light are established across the doorway of the bus and reflectors mounted on the opposite side of the doorway to reflect the two light beams back to sensors which are located within the same unit as the light source. The light source, the reflectors, and sensors are located in each doorway as illustrated in Figure 4-3. The measurement of passenger movement on and off a bus requires two things: the detection of a passenger in the doorway and the determination of the direction of movement. The detection of the presence of a passenger in the doorway is accomplished as soon as one beam is interrupted. The sequence in which the beams are broken determines the direction of the passenger movement. For example, a boarding passenger will interrupt the outer beam first (the one closest to the door), then both beams simultaneously, then only the inner beam, and finally neither beam will be interrupted. The passenger count is not recorded until this sequence is completed. Pro-Data provided two light source sensors, two reflectors, and a combined display and logic unit.

For this evaluation all three PCSs were supplied by the manufacturers with displays that indicated the total number of passengers boarding and the total number alighting from the bus since last being reset. Although not required for the AVM system, these displays facilitated testing. The displays were combined into a test console which provided a means of directly reading the total number of passengers boarding and the total was recorded by each of the three passenger counter systems. This console is described in subsection 4.3.

4.3 TEST PROGRAM DESCRIPTION

The test program was designed to assess the capability of each passenger counter sensor and associated logic to reliably and accurately record bus passenger boarding and alighting activities through a uniform and objective comparison of each of the three selected PCSs. Two of the three PCSs that were selected for testing incorporated prototype electronic packaging although all three manufacturers have indicated that they have the capability to manufacture production hardware. In each case, the complete PCS went through both laboratory tests and field operational tests, but only the sensor elements underwent environmental testing since in the AVM application no displays are required and the logic would be packed with other on-vehicle AVM equipment in an environmentally protected enclosure.

The tests performed were designed to provide both absolute and comparative data regarding each PCS with regard to:

- accuracy in counting boarding passengers,
- accuracy in counting alighting passengers,
- susceptibility to error for particular types of boarding/alighting configurations,
- ease of installation on a bus,
- susceptibility to the environmental conditions associated with operation on a bus in an urban environment, and
- susceptibility to vandalism.

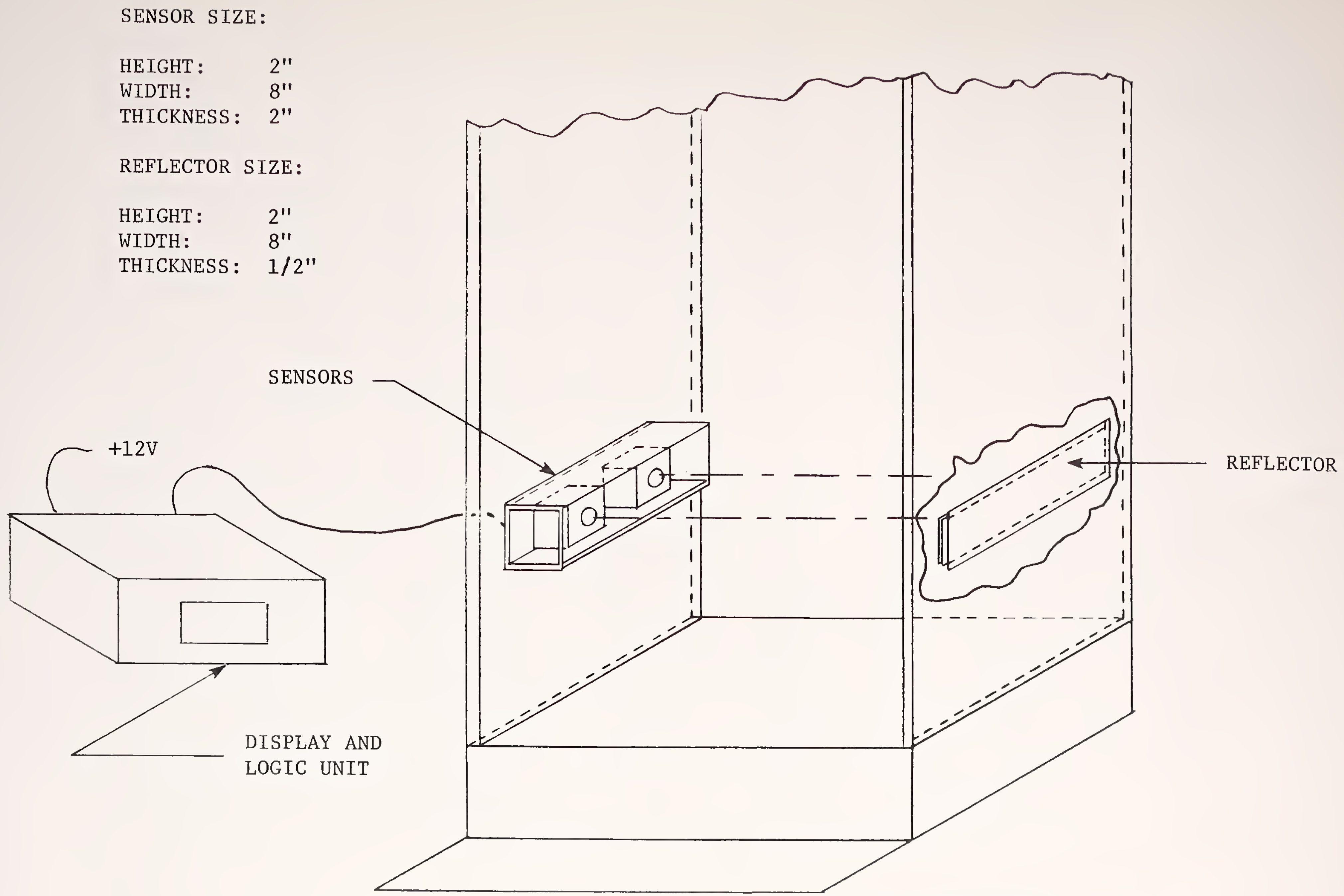


FIGURE 4-3. PRO-DATA CORPORATION'S TEST PASSENGER COUNTER SYSTEM

Tests were conducted in three parts as follows:

- Simultaneous testing of the three units in a laboratory mockup of a bus passageway as a means of identifying the basic counting capabilities of each PCS under controlled conditions.
- Simultaneous testing on a City Transit of Fort Worth (CITRAN) bus. During these tests, all three counters were subjected to exactly the same operational conditions in order to obtain a set of PCS data which can be authentically used as a basis for comparing the counting accuracies of three different PCSs.
- Environmental testing of the sensor elements of each PCS to determine their ability to function within the environment which may be expected in transit operating conditions and the extent to which the environment produces degraded performances.

These tests were conducted in the order shown. Laboratory and field tests as well as some environmental tests were conducted by GI^3 personnel. Selected environmental tests were subcontracted to a firm having the necessary facilities to perform the tests. The flow chart in Figure 4-4 illustrates the applicable test procedures and the sequence in which they were implemented during the test program.

4.3.1 Laboratory Tests

4.3.1.1 Laboratory Test Configuration. Laboratory testing was conducted through the use of a special test stand which was constructed at the Gould (GI^3) facility. This test stand includes a replica of both the front and rear doors of a Flxible Model 7200 Series bus. As shown in Figure 4-5, the test stand incorporates actual commercial bus doors which were purchased from the Flxible Corporation. In order to replicate the boarding/alighting areas of an actual bus, the test stand included the following:

- Doors which could be opened and closed remotely,
- A rear door which could be opened by a passenger pushing on the door,
- Step heights which were based on specifications provided by the Flxible Corporation,
- Sensors which were installed in the manner suggested by the appropriate PCS manufacturer,
- A test stand front door which was of a fan-fold type. (This was in contrast to the slide-type door found on the CITRAN bus. The test stand front door is also wider by six inches than the CITRAN bus front door.)

All three PCSs were installed in the test stand, in accordance with the applicable manufacturer's specifications, and were tested simultaneously. Therefore, passengers passing through either door of the test stand provided a common baseline for each test.

Laboratory testing served to verify the fundamental characteristics of each individual PCS in terms of its counting properties under controlled conditions. Also, since the passenger sensing mechanisms used (particularly the IR and treadle types) are basically different, these tests served to identify problems which result in degraded performance of each type of counter. Particular problems which were expected relative to the two technologies are as follows:

IR	TREADLE
• passenger size or carrying parcels	• passenger weight
• passengers boarding/alighting simultaneously	• type of boarding, e.g., both feet on one step simultaneously

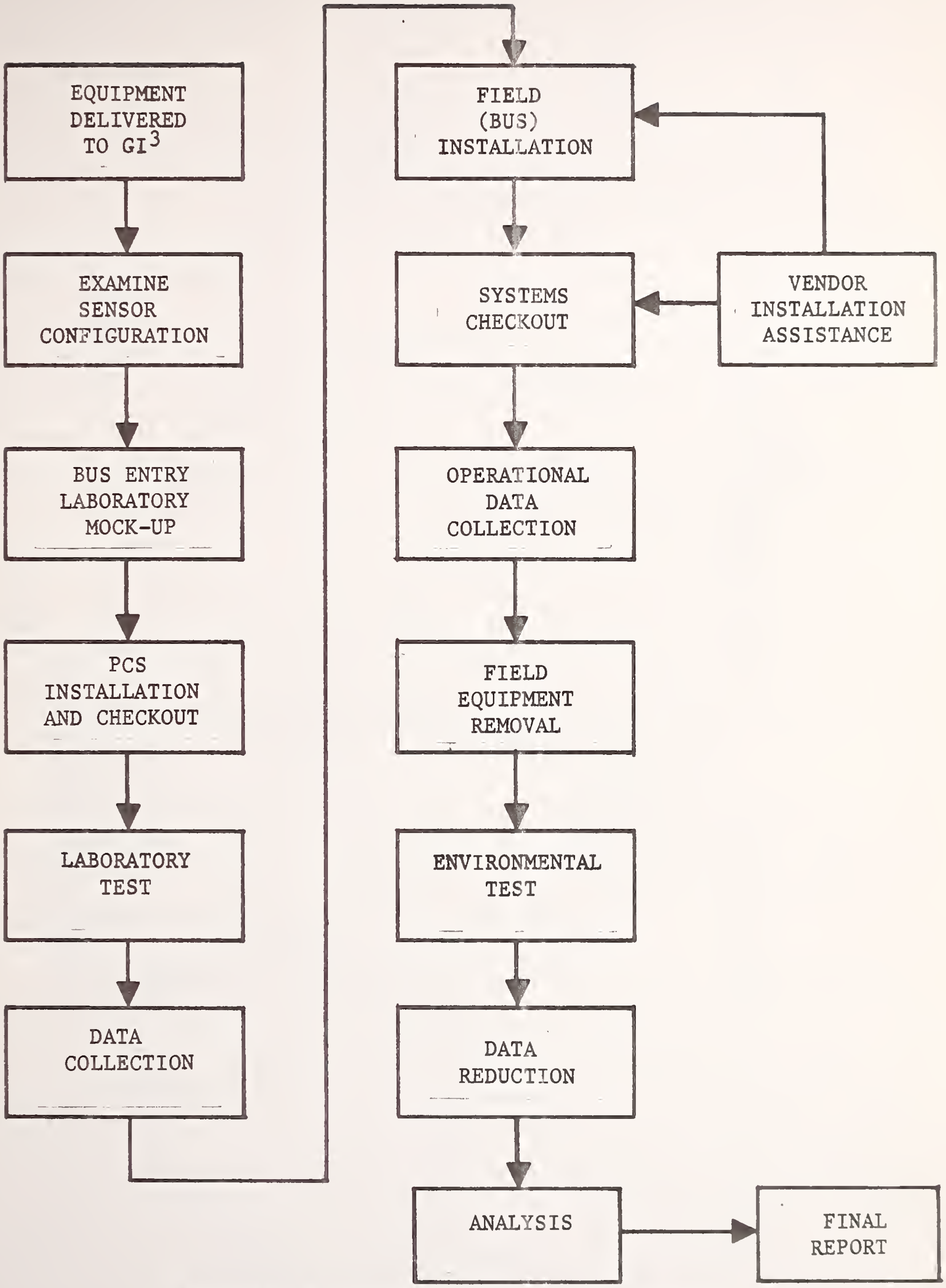


FIGURE 4-4. PASSENGER COUNTER TEST PROGRAM

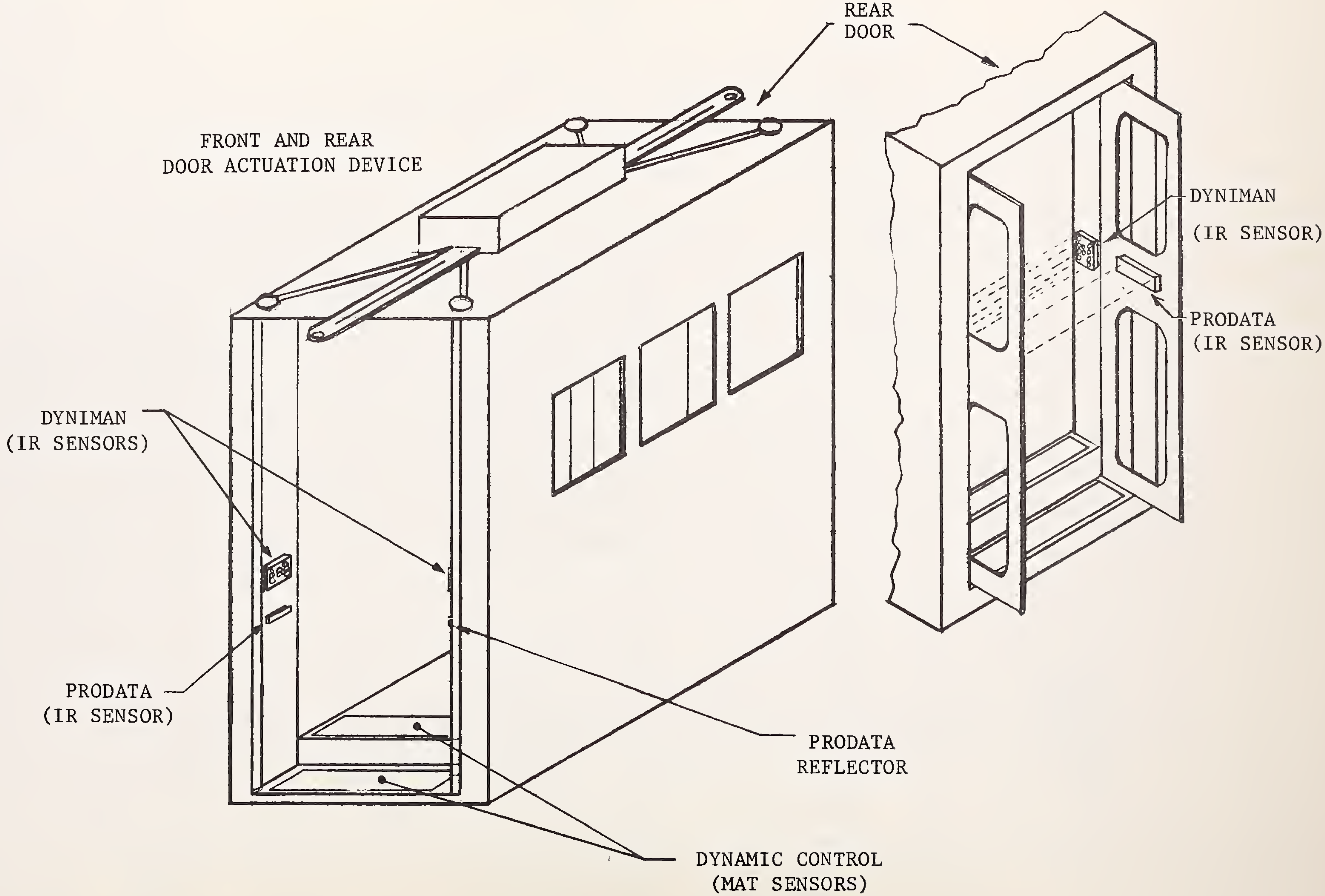


FIGURE 4-5. PASSENGER COUNTER TEST STAND

- whether or not passenger's hands touch the door or sensors
- position of foot on treadle
- door alignment after each closing
- curb height

Each of these items is discussed with regard to specific tests.

4.3.1.2 Laboratory Test Description. Laboratory tests were conducted through the use of personnel simulating the boarding/alighting of passengers from the test stand. Table 4-1 contains a description of each specific test that was conducted, the number of samples involved, and the conditions under which each test was performed. As noted in this table, both single boardings and mass boardings of passengers were simulated. Each test is briefly described in the following paragraphs.

Test 1. This test provided data for characterizing each individual PCS under conditions of single passenger, separate transactions with all doors open. In this manner, the effect of repeated door open/close events was not included, thus allowing the inherent counting accuracy of each PCS sensor to be assessed in both directions. Passengers weighing between 80 and 240 pounds were utilized during these tests.

Test 2. A passenger boarded at the front door and a passenger alighted at the rear door simultaneously. This test evaluated the ability of each PCS's logic to perform the simultaneous counting function.

Test 3. Two passengers alighted and boarded simultaneously at the front door and at the rear door.

Test 4. Same as 1 except passengers carried (a) briefcases, (b) grocery sacks, and (c) umbrellas.

Test 5. Same as 2 except passengers carried parcels identified in Test 4.

Test 6. Same as 2 except passengers were forced to dwell in the sensor area by planting both feet on each step.

Test 7. A steady stream of passengers were continuously crowded on and off the test stand. Some carried parcels as noted in Test 4.

4.3.1.3 Test Procedures. Laboratory tests were conducted with pre-planned boarding and alighting of passengers through the test stand. All tests were structured so as to involve sets of exactly 100 passenger boardings and a like number of passenger alightings in order to facilitate date recording and analysis. During all tests, a manual record was kept of all passenger transactions and the conditions of the test.

4.3.1.4 Sample Size. A passenger boarding event (P_B) was considered to be one (1) observation. An alighting passenger (P_A) was one (1) observation. A total of 600 observations was taken during each test.

The sample size analysis, which is documented in Reference 3, serves as the basis for the selection of 600 observations. A non-parametric analysis was performed to determine a cost-effective sample size which could be used to evaluate whether a system error rate was within the desired AVM specification. The approach was to analyze the Type II (β) statistical error probability as a function of sample size, while holding the Type I (α) statistical error probability at approximately 4 to 5 percent. (Table 41 of Reference 3 is reproduced herein as Table 4-2). The table shows, for different sample sizes, the Type I and Type II probabilities associated with conducting a pass/fail test on a system with a failure rate of 5 percent. In this test a failure is an erroneous passenger count reading. The null hypothesis for that test

TABLE 4-1. LABORATORY TEST DESCRIPTION

TEST NO.	OBSERVATIONS P_A	P_B	DESCRIPTION OF TEST	CONDITIONS
1	600	600	Passage through each door separately, board front/ alight rear	1. Both Doors Open 2. No Parcels
2	600	600	Simultaneous board at front door/alight at rear door	Same as 1
3	600	600	Simultaneously two passengers board/alight at front and rear doors	Same as 1
4	600	600	Passage through each door separately, board front/ alight rear	Passengers Carry Parcels *
5	600	600	Simultaneous board at front door/alight at rear door	Passengers Carry Parcels *
6	600	600	Same as 2 with both feet planted on each step at each transaction	No Parcels
7	600	600	Steady stream of passengers board at front door, alight at rear door	Passengers Carry Parcels *

P_A = number of passengers alighting

P_B = number of passengers boarding

*Parcels included briefcases, grocery sacks and umbrellas.

is that the failure rate (po) is less than or equal to 5 percent. For example, if the number of observations is 600, the null hypothesis is considered true if the number of erroneous passenger counter readings (r) is less than 40.

The probability of Type A error (that a 95 percent accurate PCS would fail the test) is only 4.2 percent. Table 4-2 also indicates the probability of the associated Type II error, i.e., the probability that a PCS of lesser accuracy (p1 greater than 5 percent error) would pass the test. A major objective in selecting the sample is to minimize Type II errors. The analysis in reference 3 indicates that a sample size of 600 reduces the probability of a Type II error to a reasonable value. For example, if 600 observations were taken and less than 40 counting errors were observed, the probability that the PCS under test may have an error rate of 10 percent, yet pass the 5 percent test is only 0.2 percent.

4.3.1.5 Data Recording. An example of the recording format used for the data taken during each test described in paragraph 4.3.1.2 is shown in Table 4-3. After each 100 observations, the test director recorded the displayed values of P_A and P_B corresponding to each of the three PCSs and then reset each display to zero.

4.3.1.6 Data Reduction. The data recorded during the laboratory test were analyzed with the objectives of

- identifying particular error-inducing conditions associated with each type PCS,
- characterizing the basic sensing ability of each PCS under the controlled conditions of each test,
- establishing incidence of boarding errors, and
- establishing incidence of alighting errors.

4.3.1.7 Data Analysis. For each PCS and for each test, the following data were computed from the recorded raw data:

- Percent correct boarding counts = $\dfrac{600 - \text{absolute no. of errors}}{600} \times 100\%$
- Percent correct alighting counts = $\dfrac{600 - \text{absolute no. of errors}}{600} \times 100\%$
- Percent overcounts/errors = $\dfrac{\text{no. of overcounts}}{\text{no. of errors}} \times 100\%$.

The number of counting errors in P_A and P_B observed for each PCS during each 600 observation test was compared with the number of failures (40) which would result in the PCS failing the test. For example, if the number of measured errors in P_A is less than 40, then there would be no more than a 4.2 percent probability that a PCS with a 5 percent error rate would have failed and no more than a 0.2 percent probability that the PCS actually had an error rate greater than or equal to 10 percent.

The absolute number of errors is defined to be the total number of errors (overcount and undercount) observed during each test. An overcount occurs when the display indicates more passengers boarded/alighted than actually boarded/alighted. An undercount occurs when the display indicates fewer passengers boarded/alighted than actually boarded/alighted.

TABLE 4-2 TYPE I (α) AND TYPE II (β) ERRORS FOR VARIOUS SAMPLE SIZES

No. of Samples n	No. of Failures r	Type I Error α p_o* = .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.

TABLE 4-3. LABORATORY TEST DATA SHEET

TEST NO. ___________

RUN NO.	NO. SAMPLES		TEST RESULTS					
			DYNAMIC CONTROLS		DYNIMAN		PRO-DATA	
	P_B	P_A	P_B	P_A	P_B	P_A	P_B	P_A
1	100	100						
2	100	100						
3	100	100						
4	100	100						
5	100	100						
6	100	100						
TOTAL	600	600						
NO. ERRORS ($\pm$)								
PERCENT ERRORS								
$\lvert \Sigma P_A - \Sigma P_B \rvert$	0	0						

4.3.2 Field Operational Tests

4.3.2.1 Field Test Methodology. Field testing of all three PCSs was accomplished through tests on a CITRAN bus in Fort Worth. All three PCSs were installed and tested simultaneously in order to ensure that the test results were based on exactly the same set of passenger transactions. All passenger transactions and, therefore, all observations consisted of boardings and alightings as they occurred during the day-to-day operation of the bus on a selected CITRAN bus route.

CITRAN operations personnel recommended that the Hemphill (B) line, shown in Figure 4-6, be utilized for the test route. This line was identified by CITRAN as one of their more heavily traveled routes. CITRAN data indicate that a bus on the "B" line typically handles 400 passengers per day which is considerably less than a typical SCRTD bus run. Consequently, special runs to schools, local aerospace contractor facilities, and a park-and-ride arrangement were also conducted to allow mass boarding data to be obtained.

Figure 4-7 is a plan view of the CITRAN bus which served as the operational test bed. A 7200 Series Flxible bus of the same series available at SCRTD was selected. Figure 4-7 also identifies the location at which the IR sensor equipment was installed on the bus as well as the location of test personnel. Figure 4-8 illustrates the installation of the treadle sensors.

4.3.2.2 Operational Test Procedure. Attempting to correlate passenger transactions at specific bus stops from run-to-run or day-to-day was not the goal of these tests. The primary goal was the determination of counting accuracy. Therefore, data were recorded at each bus stop in sequential order without reference, except through special comments, to the specific location.

The three PCS displays were mounted on a single console as shown in Figure 4-9. During the operational tests, the test conductor read and reset the PCSs after each stop. Other members of the test team manually counted the passenger transactions at the front and rear doors, leaving the test conductor free to coordinate the activities and record the data after each stop.

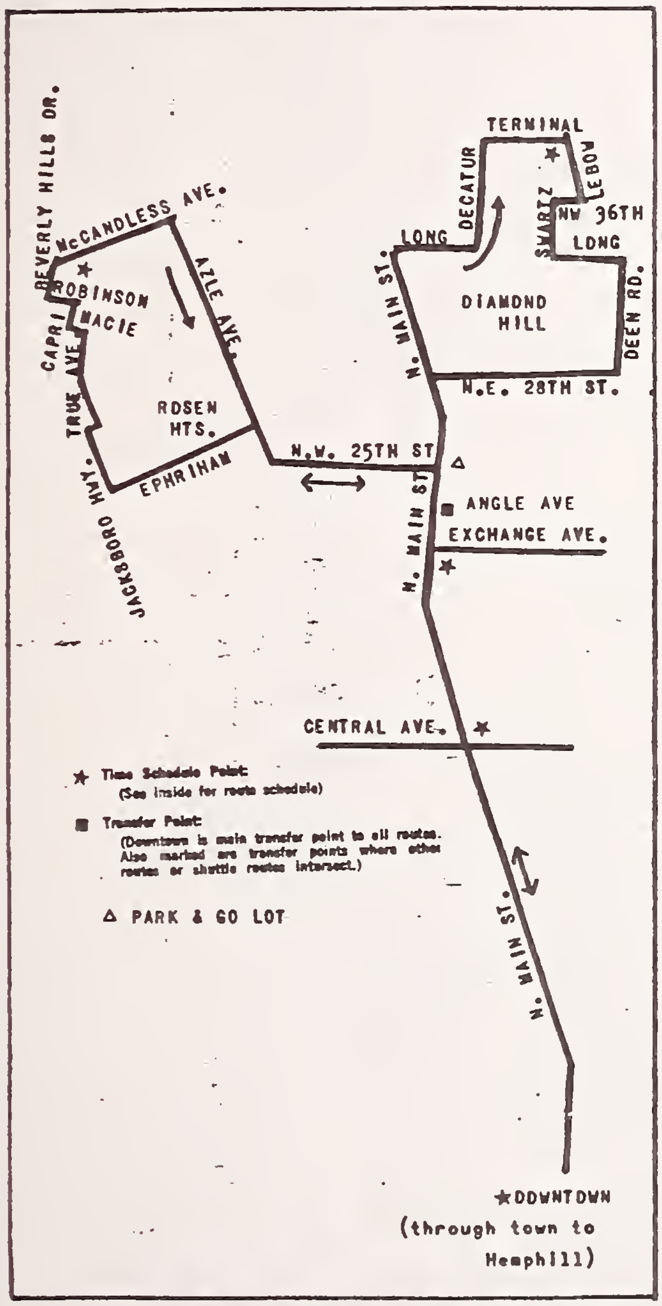
At each location at which the bus stopped, the following data were recorded:

1. P_B the actual number of passengers boarding.
2. P_A the actual number of passengers alighting.
3. $P_B(i)$ the number of passengers boarding as counted by the PCS designated as i = DC, D, or P (with DC corresponding to the Dynamic Controls PCS, D corresponding to the Dyniman PCS, and P corresponding to the Pro-Data PCS.)
4. $P_A(i)$ the number of passengers alighting as counted by the PCS designated as i = DC, D, or P.
5. T the elapsed time at each stop between the time the first door opens and the time the last door closes
6. Remarks as necessary, e.g., 7 of 9 passengers boarding were school children, mass boarding, etc.

The data identified above were obtained in accordance with the flowchart in Figure 4-10. Actual boarding and alighting data were obtained by two test personnel (situated front and rear) manually counting boardings and alightings on handheld mechanical counters, one in each hand. During actual passenger transactions, the test personnel devoted their full attention to obtaining accurate counts of P_A and P_B. A few instances of manual errors were detected during the test program; these were noted on the test log and the associated data deleted from consideration.

B-2 ROSEN HEIGHTS/ B-3 DIAMOND HILL

EFFECTIVE JUNE 4, 1978

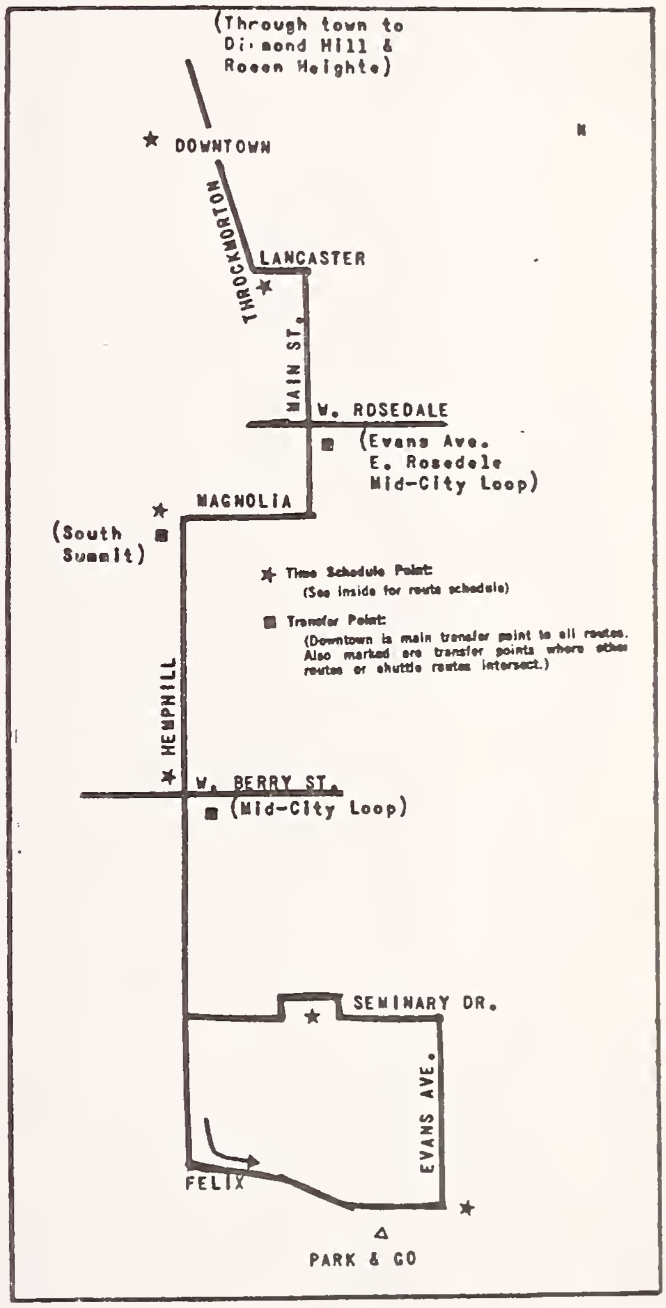


BUS SCHEDULE

FOR INFORMATION CALL 870-6200

B-1 HEMPHILL

EFFECTIVE JUNE 4, 1978



BUS SCHEDULE

FOR INFORMATION CALL 870-6200

FIGURE 4-6 HEMPHILL LINE

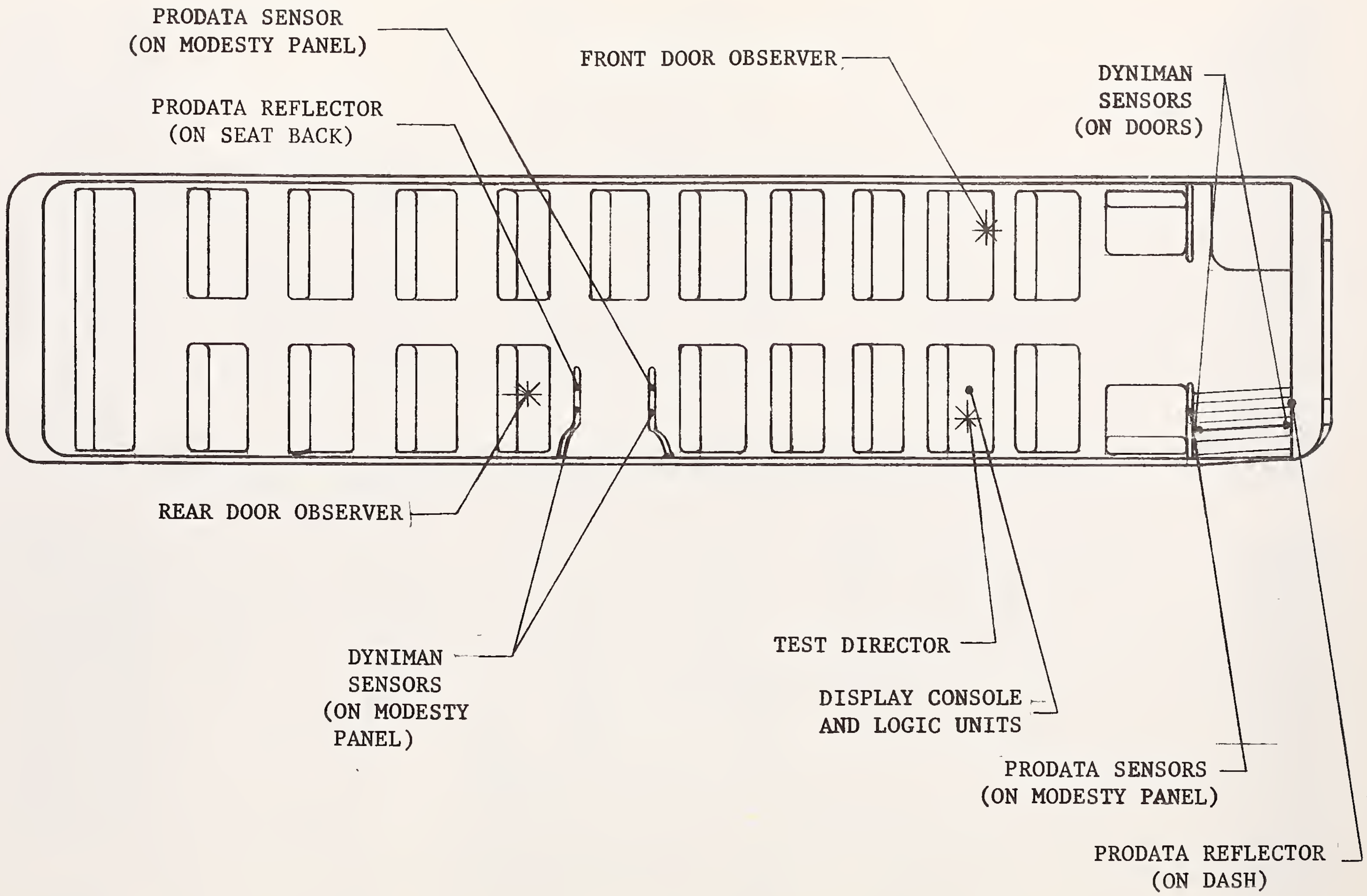


FIGURE 4-7. TEST LAYOUT OF IR SENSORS, DISPLAY CONSOLE, AND OBSERVERS ON CITRAN BUS

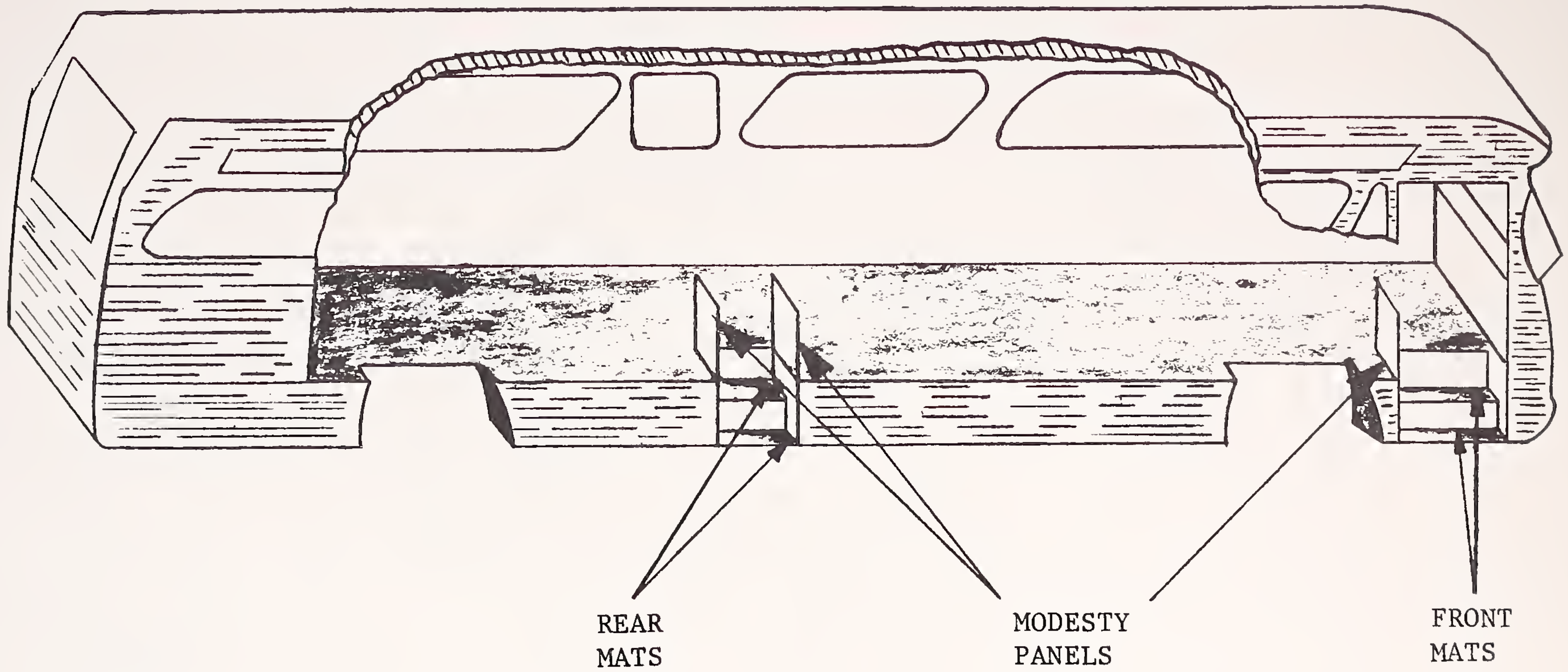


FIGURE 4-8. CUTAWAY VIEW OF CITRAN BUS WITH MAT SENSORS INSTALLED

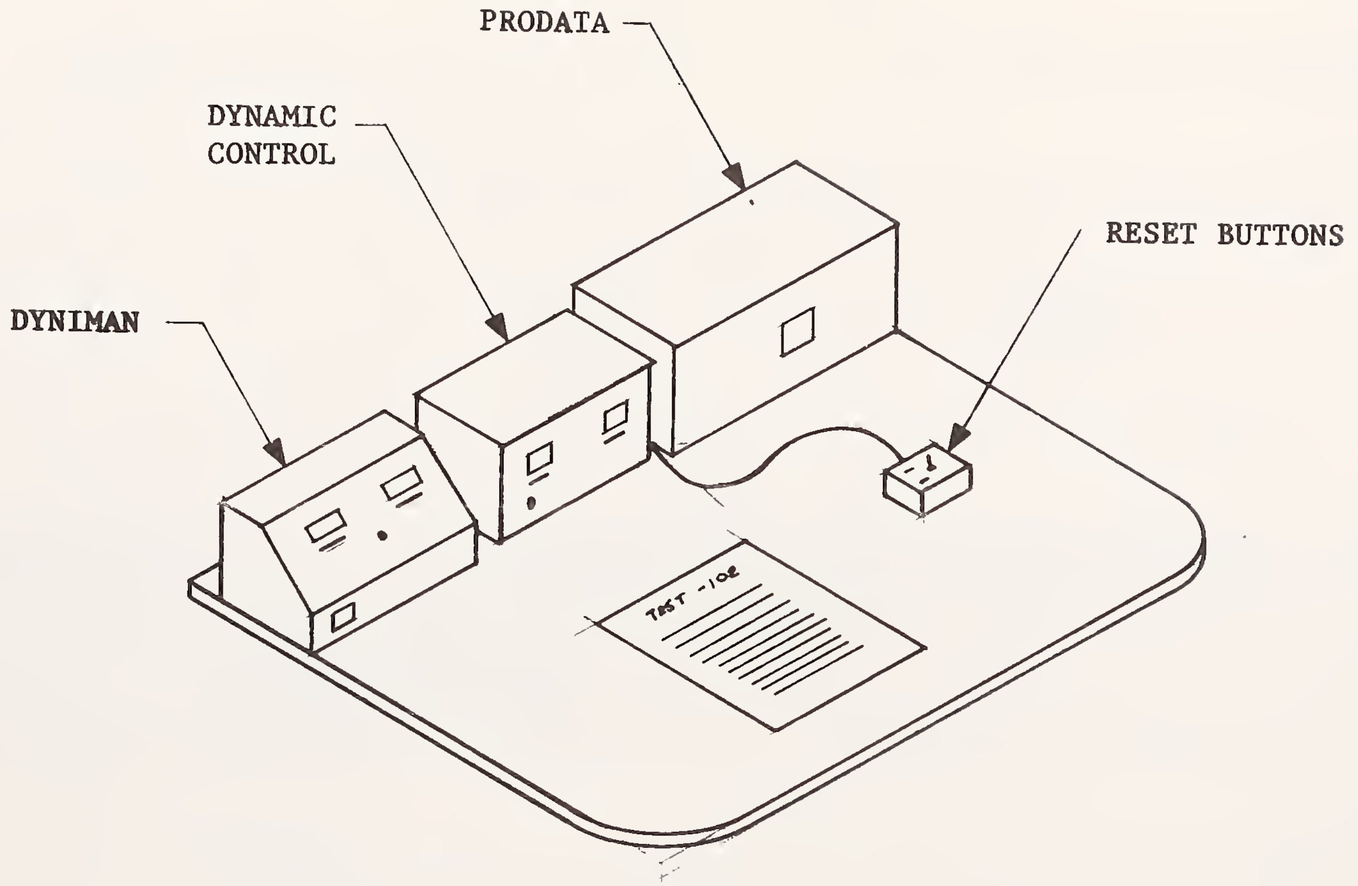


FIGURE 4-9. TEST CONSOLE SHOWING PCS DISPLAYS

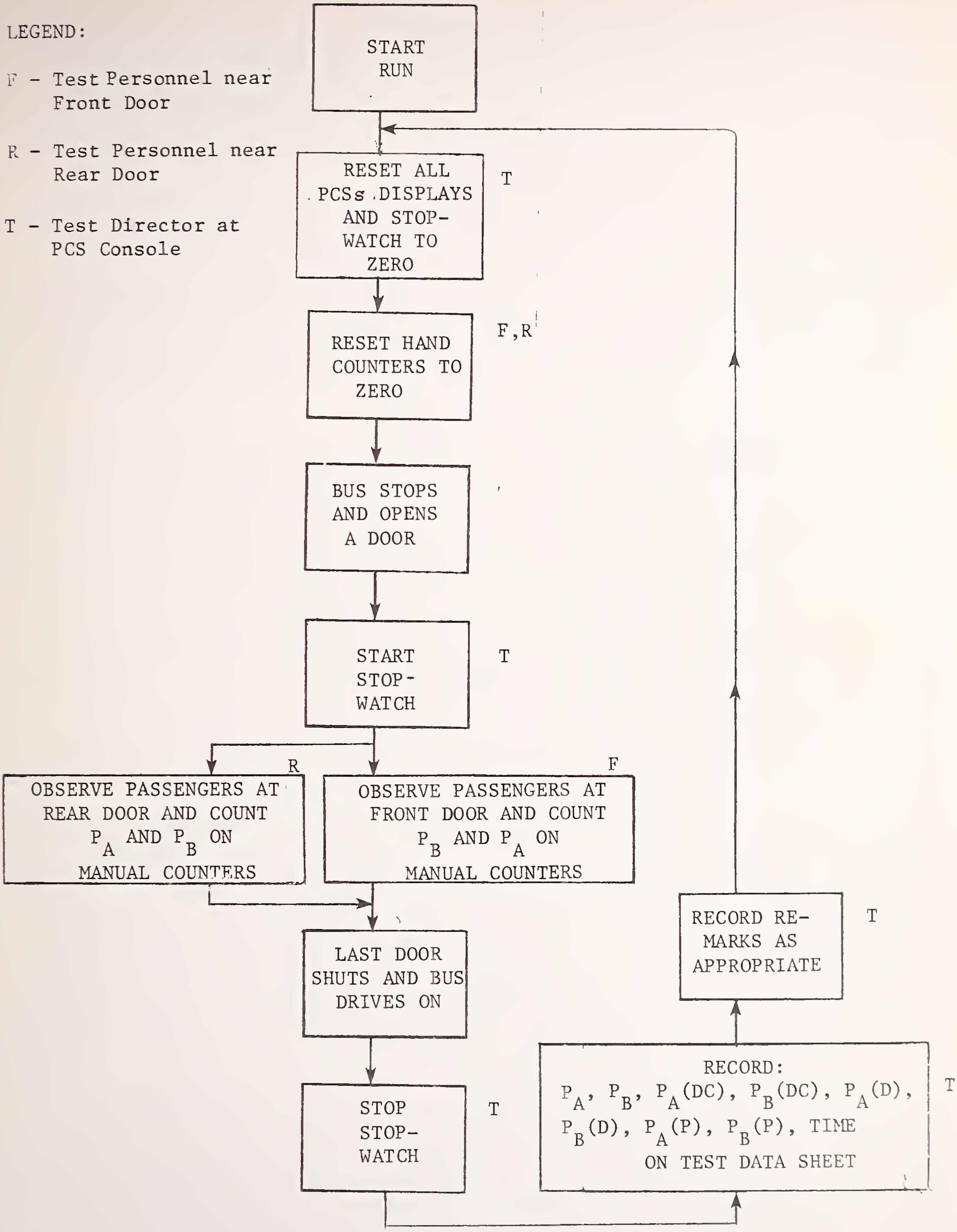


FIGURE 4-10. OPERATIONAL TEST PROCEDURES

After the bus ceased passenger transactions, the test director had ample time to (1) record the actual transactions as values recorded on the four mechanical counters (two values supplied by the reardoor observer and two by the frontdoor observer), (2) record and reset the three PCS displays, and (3) read the stop watch prior to reaching the next bus stop. Operational test data were recorded on test data sheets in the format shown in Figure 4-11.

CITRAN scheduled the bus as requested by GI^3. The tests were conducted on weekdays and Saturdays. Each test day began at the CITRAN garage with GI^3 personnel installing the display console and power connection to the PCSs and having test personnel board the bus for its initial scheduled run, which began during the 6-7 A.M. time block. Tests were then conducted continuously with a separate test run number being designated for each round trip. At least three test personnel participated in all test runs. During each test, a log of all extraordinary occurrences was kept to facilitate subsequent analysis.

4.3.2.3 Sample Size. Passenger transactions at each individual bus stop were considered to be independent of other transactions. This assumption allowed all operational field test data to be considered as part of a single test.

In terms of the required sample size, the analysis described in Paragraph 4.3.1.4 also applied to the field tests, implying that 600 P_A and P_B observations would be sufficient to characterize each PCS.

Data supplied by CITRAN indicated that a single bus on the Diamond Hill/ Hemphill run would handle an average of about 400 passengers per day, a day consisting of seven (7) round trips between a shopping center on the south and either the Diamond Hill or Rosen Heights areas to the north. Seven would be the maximum number of runs a bus could make on this route in one day. If only five runs were considered, by eliminating the first and last runs of each day, then one might expect 285-300 passenger transactions per day on one bus. Thus, approximately two days were required to acquire 600 observations.

It was also of interest to obtain PCS accuracy data which could be correlated with the total number of actual boarding/alighting observations occurring per stop. For example, if a "sample" were considered to be "the boarding of five or more passengers at a single stop," then one would want to observe a number of these "samples" in order to assess the performance of each PCS in accurately counting "five or more" passengers. Based on operational data supplied by CITRAN, the raw data required to perform this experiment could be collected in the course of approximately 50 test runs, each run consisting of a round trip on the Rosen Heights/Diamond Hill/Hemphill run. Acquisition of this data required 10 test days of approximately 10 hours each and consisted of approximately 3,000 observations.

4.3.2.4 PCS Installation. The three PCSs and the display console were installed on the CITRAN bus at the locations shown in Figures 4-7 and 4-8. Installation was in accordance with each PCS manufacturer's recommendation. Personnel from Dynamin Incorporated and Dynamic Controls Incorporated assisted in the installation of their respective PCS sensors. Provisions were made to power the three PCSs through a direct connection into the bus's 12 VDC supply; however, as a backup, all three systems could have been powered through use of a rechargeable battery. The connection to the bus's electrical system was in accordance with the wiring diagram supplied by CITRAN.

PASSENGER COUNTER FIELD TEST

PAGE 1

TEST NO. __________ DATE __________

BUS ROUTE __________ TEST DIRECTOR ____________________ START TIME __________

START LOCATION __________ BUS NO. __________ END TIME __________

BUS STOP	COUNTER A		COUNTER B		COUNTER C		ACTUAL		ELAPSED TIME	REMARKS
	ON	OFF	ON	OFF	ON	OFF	ON	OFF		
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
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19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										

FIGURE 4-11. FIELD TEST DATA RECORDING SHEETS

During installation, safety was emphasized. This included assuring that the IR sensors did not impede passenger movements or exhibit protrusions which could be snagged by handbags, clothes, etc. All wiring was completely covered by tape. The display console was mounted securely so as not to offer any hazard if the bus accelerated or decelerated rapidly. When tests were not being conducted, the display console was disconnected resulting in all power being removed from the sensors.

Installation of the sensor mats on the steps at the front and rear doors required removal of the existing mats. When tests were completed, new mats were installed, and the bus was restored to its original condition.

4.3.2.5 Data Reduction. The second step in the data reduction process involved segregating the test data into sets of data which were identifiable with a specific PCS. This involved reducing the data collected on test sheets shown in Figure 4-11 to the formats illustrated in Tables 4-4 and 4-5. The data shown in Tables 4-4 and 4-5 were selected at random for illustration.

4.3.3 Environmental Testing

4.3.3.1 Environmental Testing Objective. The environmental tests described in this section were designed as a means of simulating the most severe environmental conditions of the Los Angeles area. Environmental tests were conducted in Fort Worth by GI[3] in conjunction with a subcontractor, Southwest Test Laboratories, after field operational tests were completed.

4.3.3.2 Environmental Test Description. The sensors (IR transmitters/receivers, and treadle mats) from all three PCSs were environmentally tested for their ability to perform under real-world environmental conditions. Tests involved exposure of the sensors to

- fluctuations in primary power as might be produced by power transients, engine cranking, converters, etc.,
- temperature extremes,
- sand and dust,
- humidity,
- salt spray,
- water leakage,
- vibration, and
- shock.

Power fluctuations and shock testing wereconducted by GI[3] personnel. The remaining tests were conducted by Southwest Test Laboratories with GI[3] personnel in attendance. The test sequence was selected to minimize the probability of catastrophic failure of a sensor prior to completion of the majority of the environmental tests.

4.3.3.3 Test Procedures. The procedures followed during each environmental test are described in the following paragraphs. Specific test logs pertinent to each type of test were generated and used to record status and dynamic data during environmental tests.

Each test was conducted in accordance with a specific test procedure with the parameters of each test and the pertinent results of the test being recorded in appropriate test logs.

TABLE 4-4. FIELD DATA ANALYSIS, REDUCED DATA FORMAT

FIELD DATA ANALYSIS: PCS DC

ROUTE GD TEST RUN #7 DATE 02/03/8 START TIME 6:35 END TIME 8:05

BUS STOP	ACTUAL COUNT		PCS COUNT		ERROR COUNT (ACTUAL-PCS)		ON BOARD COUNT		
	ON	OFF	ON	OFF	ON	OFF	ACTUAL	PCS	ERROR
1	3	0	3	0	0	0	3	3	0
2	1	0	1	0	0	0	4	4	0
3	20	0	20	0	0	0	24	24	0
4	1	0	1	0	0	0	25	25	0
5	5	0	5	0	0	0	30	30	0
6	3	0	3	0	0	0	33	33	0
7	2	0	2	0	0	0	35	35	0
8	1	0	1	0	0	0	36	36	0
9	0	36	0	36	0	0	0	0	0
10									
11									
12									
13									
14									

TABLE 4-5. FORMAT OF REDUCED DATA, ALL TESTS, COUNTER D AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_B	NO. OF OCCURRENCES OF BOARDING ERRORS																							
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16	
654	1	628	21	4		1																			
201	2	173	17	4	6	1																			
104	3	91	10	2		1																			
59	4	52	2	3		1	1																		
25	5	20	3	1	1																				
31	6	23	4		1	1	1				1														
10	7	8	2																						
7	8	2		4									1												
3	9	2		1																					
4	10	2	2																						
4	11	2									2														
1	12	1																							
1	13	1																							
1	14		1																						
2	15	1	1																						
2	16			1			1																		
1	17										1														
3	20	1																	1					1	
	23																								
1	28	1																							
	36																								
1	37	1																							
850	0	843		7																					
1965		1852	63	27	8	5	3				4		1						1					1	

Primary Power

Each PCS was subjected to the following tests to determine the effects of prime power fluctuations on system operation. The sensors were activated during each test, and display information was recorded. Primary power was supplied from a 12-volt vehicle battery with 25 foot long leads to the test stand. Tests were conducted in the following sequence:

- During normal operation with the alternator running, the voltage regulator in the line, and engine speed at approximately 1500 RPM,
- During starting of the engine,
- With the engine not running, and
- Under voltage conditions of from 12 to 4 volts in 1 volt steps.

Temperature

Each sensor was subjected to a controlled temperature range from 0° to 140° F in a test chamber. Only the sensors were placed inside the chamber with the logic units and displays being mounted externally. Each sensor was "temperature soaked" for 30 minutes at temperatures of first 70° F, then 140° F, and then 0° F. After each cycle, the sensors were visually inspected and exercised ten times to simulate passenger transactions and verify their operation.

Sand and Dust

Each sensor was subjected to a sand and dust environment in order to determine if those elements could penetrate the sensor encapsulations, cables, or connectors, etc. The environmental conditions were as follows:

Sand--Air Temperature: 89° F; Wind: Approximately 10 MPH
Dust--Air Temperature: 89° F; Wind: Approximately 10 MPH

The exposure time was 20 minutes on each side of the sensor. At the end of the test, a visual inspection was performed, and each PCS was exercised to verify its operation.

Relative Humidity

The sensor portion of each PCS was placed in a humidity chamber for a period of 48 hours. The sensors were exercised through simulated passenger transactions every 12 hours to assess any degradation due to humidity. Relative humidity was 90 $\pm$ 5 percent, and the temperature range was 72° to 86° F. (This is due to the limitation of the test chamber.) At the conclusion of this test, each sensor was inspected for moisture penetration and corrosion and then each PCS was exercised to verify its operation.

Water Leakage

Each sensor was subjected to water penetration by spraying each with a 68° F water mist from all directions at a rate equivalent to 0.25 inch per hour and a velocity of approximately 25 feet per second for a maximum of 15 minutes. Each PSC was then exercised to verify its operation.

Salt Spray

Each sensor was subjected to a 5 percent solution of salt water in a mist spray from all directions for a 30-minute period and visually inspected for corrosion buildup. Each PCS was then exercised to verify its operation.

Vibration

The PCS sensors were subjected to a force of approximately 5 g at an RMS amplitude of 0.025 inches. The sensors were then repositioned in the test stand and exercised to verify their operation.

Handling Shock

Each sensor was subjected to flush drops and pivot drops onto hard, level concrete surfaces from the heights of 1 to 4 inches in 1 inch increments.

The displays were monitored after each of these tests to determine if there were any changes in PCS performance. After each drop, the sensors were visually inspected and exercised to see if they functioned properly.

4.3.3.4 Environmental Test Results. Environmental test results are described in this subsection. Results and analyses of laboratory and field test data are presented in Section 5.

Primary Power

Results of the Primary Power Test were as follows:

- Dyniman - PCS activation was normal in all phases of tests until the voltage was reduced to 5 volts. The Dyniman PCS would not operate correctly at a voltage of less than 5 volts.
- Pro-Data and Dynamic Controls - PCS operation was normal through all phases of the Primary Power Test.

Temperature

Visual inspection and activation of all three PCSs after soaking at 70° F and at 140° F revealed no physical damage. After each test, all sensors were activated ten times, and no errors were observed.

After a 30-minute soak at 0° F, visual inspection and sensor activation revealed no physical damage to any of the sensors. Sensors did frost over when subsequently subjected to ambient temperature. With frost on the IR sensors, passenger transactions could not be accurately recorded. However, once the frost was removed, sensors operated normally.

Sand and Dust

No penetration of either sand or dust was observed in any of the PCS sensors. Sensor activation produced normal operation in each case.

Relative Humidity

Visual inspection and sensor activation after 12 hours of testing revealed the following:

- Dyniman Water had penetrated the sensor. Corrosion had begun on face plate cover screws. However, sensor activation was normal.
- Pro-Data No water damage was observed. There was no indication of corrosion. Sensor activation was normal.
- Dynamic Controls No apparent water damage was observed. Some corrosion was observed on metal strips that were used to bind the prototype mats. Sensor activation was normal.

At the end of 24 hours of testing, there was no apparent change from the first 12 hours in the test chamber. All three PCS sensors were exercised, and no failures were observed.

At the end of the 36th hour of testing, there were no apparent changes in PCS sensors' conditions. All three systems were still operational.

Final visual inspection and system activation after 48 hours testing revealed the following:

- Dyniman Water had penetrated the sensor. Corrosion (rust) had begun to streak from the face plate cover screws. When activated, however, no errors were observed.

- Pro-Data There was no apparent damage from the water or corrosion. No errors were recorded when the sensors were activated.
- Dynamic Controls There was no apparent damage to sensors other than corrosion on the metal strips used to bind the mats together. However, when the sensors were exercised, they would not record any passenger transactions.
  Note: The mats became operational after 72 hours of drying out.

Water Leakage

At the conclusion of the water leakage test, the following results were observed:

- Dyniman There was evidence of condensation under the plexiglass cover over the IR sensors (about 50 percent coverage). Leakage of a large volume of water occurred at connectors.
- Pro-Data There appeared to be no physical damage.
- Dynamic Controls There appeared to be a breakdown of bonding of the rubber matting.

After this test, the PCSs were exercised to determine if internal water leakage had affected their operation. The PCSs were subjected to three simulated passenger transactions each, and all operated satisfactorily.

Salt Spray

At the conclusion of the salt spray tests, the following results were observed:

- Dyniman All four sensors showed signs of salt build-up on plexiglass covers.
- Pro-Data Salt build-up was evident on the cover over the light source.
- Dynamic Controls The metal rim around the mats showed salt build-up. There was no apparent damage to the rubber mats.

The following results were observed when the sensors were activated through three simulated boardings and alightings:

- Dyniman The displays recorded four boardings and four alightings.
- Pro-Data and Dynamic Controls The displays recorded three boardings and three alightings.

Vibration

There was no apparent damage to any PCS sensor when subjected to the specified g forces. Sensor activation was normal in all cases.

Handling Shock

Visual inspection and activation of sensors after this test revealed no apparent physical damage to any PCS.

5. LABORATORY AND FIELD TEST RESULTS AND ANALYSIS

5.1 LABORATORY TEST DATA

Each of the three passenger counters was subjected to the series of tests described in paragraph 4.3.1.2. The original series included two tests which were subsequently deleted. The first of these two tests was similar to Test Number 1, except that the rear doors were closed after each alighting and required the alighting passenger to push the door open. The other test was a repeat of Test Number 3 except that in this test, both doors were closed after each transaction, and the rear door was opened by pushing against it. During these two tests it was discovered that the passenger counters were affected by EMI generated by the electric motors used to open the test stand doors. Since these motors were not normally part of the bus environment, the tests were deleted from consideration.

Data collected from all other tests were analyzed separately, and each counter was evaluated in terms of counting performance, as described in the following subsections.

5.1.1 Test Number 1

This test involved one passenger at a time boarding at the front door and then alighting at the rear door. This test was designed to assess the basic counting performance of each PCS when presented with solitary boarding and alighting passengers. It was expected that each PCS would exhibit its highest accuracy during this test. The detailed test data are contained in Volume II and are summarized here in Tables 5-1 and 5-2.

For each test conducted in the test stand, the percentage of correct counts is given by

$$\frac{(600 - \text{Total number of errors})}{600} \times 100 \text{ percent}$$

As indicated in Tables 5-1 and 5-2 for both boardings and alightings, counter DC exhibited a higher percentage of correct counts. Counter DC exhibited only one (1) counting error, an overcount, whereas counters D and P exhibited 10 and 26 counting errors respectively, a higher percentage of these errors being undercounts. However, the development of any conclusions regarding biases would be premature based on the small number of occurrences of errors during this test.

In Tables 5-1 through 5-18, the percentage of errors which were overcounts (undercounts) is computed as

$$\frac{\text{Number of overcounts/undercounts}}{\text{Number of errors}} \times 100 \text{ percent}$$

In each figure, the range of errors corresponds to the largest overcount and undercount error observed during each of the six sets of 100 observations. As was expected, all three PCSs exhibited their best counting performance during Test Number 1.

5.1.2 Test Number 2

During the test, a passenger boarded at the front door, and a passenger alighted at the rear door simultaneously, with both doors remaining open and no parcels being carried by the passengers.

This test was designed to test the individual sensors and the counting logic of each PCS under simultaneous door transactions. The test results are summarized in Tables 5-3 and 5-4. As in Test Number 1, the data on boardings

TABLE 5-1. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 1

Parameter	PCS		
	DC	D	P
ERRORS	1	10	26
OVERCOUNTS	1	2	12
UNDERCOUNTS	0	8	14
RANGE OF ERRORS	0 to +1	-4 to +1	-6 to +10
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	20	46.15
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	80	53.85
PERCENTAGE CORRECT COUNTS	99.84	98.33	96.67

TABLE 5-2. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 1

Parameter	PCS		
	DC	D	P
ERRORS	0	7	15
OVERCOUNTS	0	0	3
UNDERCOUNTS	0	7	12
RANGE OF ERRORS	0	-2 to 0	-6 to +2
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	0	0	20
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	100	80
PERCENTAGE CORRECT COUNTS	100	98.83	97.5

TABLE 5-3. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 2

Parameter	PCS		
	DC	D	P
ERRORS	11	24	53
OVERCOUNTS	11	24	53
UNDERCOUNTS	0	0	0
RANGE OF ERRORS	0 to +4	0 to +8	+1 to +26
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	100	100
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	0	0
PERCENTAGE CORRECT COUNTS	98.17	96	91.17

TABLE 5-4. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 2

Parameter	PCS		
	DC	D	P
ERRORS	21	10	37
OVERCOUNTS	20	6	37
UNDERCOUNTS	1	4	0
RANGE OF ERRORS	-1 to +8	-2 to +4	+1 to +11
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	95.24	60	100
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	4.76	40	0
PERCENTAGE CORRECT COUNTS	96.5	98.33	93.83

indicate that the percentage of correct counts is highest in the case of counter DC, followed in order by counter D and counter P. All boarding errors were overcounts in the case of all three PCSs.

Counter D exhibited the highest percentage of correct alighting counts followed by counters DC and P respectively. All three counters were biased towards overcounting, with Counter D being the least biased. Overcounting, in the case of the IR counters, may be due to sensing of the swinging arm of the passenger. In Test 2, the 3 sensors experienced a greater number of overcount errors than in Test 1. This may imply a logic problem in simultaneous transactions.

5.1.3 Test Number 3

This test involved four passengers, two passengers simultaneously boarding and alighting at the front door, and the other two boarding and alighting at the same time at the rear door, with both doors remaining open and with no parcels carried by the passengers.

The test required that two passengers board the test stand prior to the counters being initially reset. Then two passengers boarded one at each door, and the two already on board alighted, one at each door. The sequence was repeated 25 times for a set of 100 transactions, and the set of transactions was repeated six times for a total of 600 observations. The results are summarized in Tables 5-5 and 5-6.

Counter DC exhibited the highest percentage of correct boarding counts, followed in order by counters D and P.

Counters DC and D exhibited the same percentage of correct alighting counts with that of counter P being only marginally less than the other two counters.

In the case of IR counters, one might expect the timing and sequence of the beam interruptions to produce more serious errors than were observed during this test. Intuitively, a trend to undercount might have been expected as a result. This was not the case, however, as the IR counters were biased towards overcounting both on boardings and alightings. Therefore, sensing of the passengers' arms offers a more meaningful explanation and supports the results observed during Test Number 2.

The number of errors exhibited by the treadle counter, counter DC, was too small to make a conclusive analysis of its biases.

5.1.4 Test Number 4

5.1.4.1 Test Number 4(a). This test involved one passenger carrying a briefcase entering at the front door and alighting at the rear door. The test results are summarized in Tables 5-5 and 5-8.

Counter DC exhibited the highest percentage of correct boarding counts followed in order by counters D and P.

Counters DC and D exhibited the same percentage of correct alighting counts with counter P showing a lower percentage of correct counts.

In the case of both boardings and alightings, the IR counters were biased towards overcounting (especially counter P). This may have resulted from the IR sensors being falsely energized by the briefcases. In the case of counter DC, the number of errors was small, and, therefore, no analysis of bias could be made.

5.1.4.2 Test Number 4(b). This test was similar to Test Number 4(a) with the exception that each passenger carried a full grocery sack instead

TABLE 5-5. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 3

Parameter	PCS		
	DC	D	P
ERRORS	4	12	42
OVERCOUNTS	2	11	42
UNDERCOUNTS	2	1	0
RANGE OF ERRORS	-1 to +1	-1 to +5	+1 to +11
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	50	91.67	100
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	50	8.33	0
PERCENTAGE CORRECT COUNTS	99.33	98	93

TABLE 5-6. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 3

Parameter	PCS		
	DC	D	P
ERRORS	7	7	15
OVERCOUNTS	4	6	13
UNDERCOUNTS	3	1	2
RANGE OF ERRORS	-2 to +2	-1 to +2	-2 to +5
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	57.14	85.71	86.67
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	42.86	14.29	13.33
PERCENTAGE CORRECT COUNTS	98.83	98.83	97.5

TABLE 5-7. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 4a

Parameter	PCS		
	DC	D	P
ERRORS	3	8	27
OVERCOUNTS	0	5	18
UNDERCOUNTS	3	3	9
RANGE OF ERRORS	-1 to 0	-2 to +3	-5 to +14
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	0	62.5	66.67
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	100	37.5	33.33
PERCENTAGE CORRECT COUNTS	99.5	98.67	95.5

TABLE 5-8. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 4a

Parameter	PCS		
	DC	D	P
ERRORS	4	4	18
OVERCOUNTS	4	2	16
UNDERCOUNTS	0	2	2
RANGE OF ERRORS	0 to +2	-2 to +1	-1 to +6
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	50	88.89
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	50	11.11
PERCENTAGE CORRECT COUNTS	99.33	99.33	97

of a briefcase. The results are summarized in Tables 5-9 and 5-10. Again, counter DC exhibited the highest percentage of correct boarding counts, followed in order by counters D and P.

On alightings, counter P exhibited the highest percentage of correct counts followed closely by counters DC and D.

The performance of counter P on alighting may be attributed to the fact that, by carrying the grocery sack, the combined spread of the passenger and sack offered a more positive sequential triggering of the IR beams.

The two IR counters showed different degrees of bias. Where counter D shows a tendency to be biased towards undercounting, counter P is biased towards overcounting, but only on boardings. Overcounting can probably be attributed to the counter erroneously counting grocery sacks as passengers. There does not appear to be any logical explanation for undercounting except that the counting logic may not always be capable of dealing with all possible timing sequences.

5.1.4.3 Test Number 4(c). This test was similar to Test Numbers 4(a) and 4(b); the only difference was that all passengers carried umbrellas.

The results are summarized in Tables 5-11 and 5-12.

Again, counter DC exhibited the highest percentage of correct boarding counts followed in order by counter D and counter P. There is an inconsistency in the bias displayed by the two IR counters. Counter D exhibited a 100 percent bias toward undercounting whereas counter P exhibited a 100 percent overcount. This might imply that counter D was not "fooled" by the umbrella, in that it was not mistaken for a person. However, the umbrella may have caused timing errors, depending on its actual direction of travel as carried past the sensors.

On alightings, counter DC exhibited the highest percentage of correct counts followed in order by counter P and counter D. While counter D again showed a 100 percent undercount, counter P maintained a fairly even split between over and undercounts. Fewer errors may have occurred on alighting as a result of the more compact manner in which an umbrella may be carried when passing through this, the narrower of the two doors.

One might have speculated that counter DC would have had difficulty in this test due to passengers pressing down on the mats with the umbrellas and thereby triggering overcounts. However, the overcounting did not occur.

Overcounting in the IR counters may be due to "mistaking" the umbrella for a passenger, but undercounting again appears predominantly the bias in the case of counter D, just as it was in Test Number 4(b).

5.1.5 Test Number 5

This test involved two passengers, one boarding at the front door and the other alighting at the rear door simultaneously, with both carrying parcels.

The results are summarized in Tables 5-13 and 5-14.

Counter DC exhibited the highest percentage of correct boarding counts, followed by counters D and P. Counter DC exhibited a 100 percent overcount in both cases of boardings and alightings. However, the results were generally poorer than for any previous tests. Both the IR counters exhibited a 100 percent undercount in both cases.

In the case of passengers carrying parcels, the IR counters may be expected to overcount, but the results of this test again proves otherwise. The analysis associated with Test Number 4 supports this conclusion.

Overcounting by counter DC appears to result from logic error in the sensor mechanism. Note that counter DC should be uneffected by the presence

TABLE 5-9. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 4b

Parameter	PCS		
	DC	D	P
ERRORS	2	17	42
OVERCOUNTS	1	0	37
UNDERCOUNTS	1	17	5
RANGE OF ERRORS	-1 to +1	-15 to 0	-3 to +19
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	50	0	88.08
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	50	100	11.92
PERCENTAGE CORRECT COUNTS	99.67	97.16	93

TABLE 5-10. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 4b

Parameter	PCS		
	DC	D	P
ERRORS	8	25	1
OVERCOUNTS	7	0	0
UNDERCOUNTS	1	25	1
RANGE OF ERRORS	-1 to +4	-10 to -2	-1 to 0
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	87.5	0	0
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	12.5	100	100
PERCENTAGE CORRECT COUNTS	98.67	95.83	99.84

TABLE 5-11. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 4c

Parameter	PCS		
	DC	D	P
ERRORS	5	35	54
OVERCOUNTS	0	0	54
UNDERCOUNTS	5	35	0
RANGE OF ERRORS	-3 to 0	-17 to 0	+3 to -15
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	0	0	100
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	100	100	0
PERCENTAGE CORRECT COUNTS	99.17	94.17	91

TABLE 5-12. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 4c

Parameter	PCS		
	DC	D	P
ERRORS	4	18	15
OVERCOUNTS	4	0	8
UNDERCOUNTS	0	18	7
RANGE OF ERRORS	0 to +1	-5 to 0	-4 to +3
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	0	53.33
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	100	46.67
PERCENTAGE CORRECT COUNTS	99.33	97	97.5

TABLE 5-13. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 5

Parameter	PCS		
	DC	D	P
ERRORS	40	72	134
OVERCOUNTS	40	0	0
UNDERCOUNTS	0	72	134
RANGE OF ERRORS	+1 to +15	-15 to -9	-29 to -18
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	0	0
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	100	100
PERCENTAGE CORRECT COUNTS	93.33	88	77.67

TABLE 5-14. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 5

Parameter	PCS		
	DC	D	P
ERRORS	21	74	101
OVERCOUNTS	21	0	0
UNDERCOUNTS	0	74	101
RANGE OF ERRORS	+1 to +10	-18 to -9	-22 to -9
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	0	0
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	100	100
PERCENTAGE CORRECT COUNTS	96.5	87.67	83.16

of the parcels; in fact, the results of Test Numbers 1 and 5 should have been virtually identical for counter DC.

5.1.6 Test Number 6

This test involved two passengers, one boarding at the front door, the other alighting at the rear door simultaneously, with each passenger briefly planting both feet on each step during boarding and alighting. No parcels were carried.

The results are summarized in Tables 5-15 and 5-16.

Counter DC exhibited the highest percentage of correct counts on both boardings and alightings, followed in order by counters D and P.

The two IR counters exhibited a bias towards undercounting in both instances of boarding and alighting.

One might have expected this test to adversely affect the performance of the treadle type of counter, however, just the opposite occurred. The two IR counters showed a tendency to be biased towards undercountering. This may be due to the passenger who stood with both feet planted on the same step, hence, confusing the counters by disordering the timing in which beams were interrupted.

5.1.7. Test Number 7

This test involved a steady stream of passengers carrying parcels passing through the front door and alighting at the rear door. The results are summarized in Tables 5-17 and 5-18.

Counter DC again exhibited the highest percentage of correct boarding counts followed closely by counter D with counter P close behind it. All three counters were biased towards undercounting. Undercounting in counter DC may have resulted from the phenomenon of having a passenger dwell too long in the stairwell, tending to confuse the counting logic. In mass boardings/alightings, passengers skipping steps may also have led to undercounting by counter DC. In the case of the IR counters undercounting may be due to the lack of definite gaps between passengers, resulting in a blurring effect.

Counter D exhibited the highest percentage of correct alighting counts followed by counters P and DC respectively. While counters DC and P continued to display a bias towards undercounting, counter D was biased towards overcounting during alightings. This may be because of the trailing arm phenomenon discussed earlier.

5.2 ANALYSIS OF FIELD TEST DATA

Raw data recorded during tests conducted on the CITRAN bus are presented in Volume II. Reduced data are described and analyzed in this subsection.

5.2.1 Boarding Counting Accuracy

The accuracy of boarding counting can be studied by observing the number of boarding errors generated by each counter.

5.2.1.1 Boardings, Counter DC. Reduced boarding data corresponding to that recorded through the use of the Dynamic Controls, Inc., PCS is shown in Table 5-19. The total number of boarding errors generated by this PCS is 176. This number is the sum of all boarding errors observed during all tests conducted on the bus. A total of 2395 boardings occurred during these tests. Therefore, the percentage of boardings in which no boarding error occurred for counter DC is given by

$$\frac{(2395 - 176)}{2395} \times 100 = 93.27 \text{ percent.}$$

TABLE 5-15. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 6

Parameter	PCS		
	DC	D	P
ERRORS	1	10	26
OVERCOUNTS	1	2	12
UNDERCOUNTS	0	8	14
RANGE OF ERRORS	0 to +1	-4 to +1	-6 to +10
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	100	20	46.15
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	80	53.85
PERCENTAGE CORRECT COUNTS	99.84	98.33	95.67

TABLE 5-16. LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 6

Parameter	PCS		
	DC	D	P
ERRORS	0	8	15
OVERCOUNTS	0	0	3
UNDERCOUNTS	0	8	12
RANGE OF ERRORS	0	-2 to 0	-6 to +2
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	0	0	20
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	0	100	80
PERCENTAGE CORRECT COUNTS	100	98.67	97.5

TABLE 5-17. LAB TEST RESULTS, BOARDINGS, TEST NUMBER 7

Parameter	PCS		
	DC	D	P
ERRORS	29**	25*	43
OVERCOUNTS	0	5	0
UNDERCOUNTS	29	20	43
RANGE OF ERRORS	-8 to -1	-13 to +5	-14 to -3
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	0	20	0
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	100	80	100
PERCENTAGE CORRECT COUNTS	95.17	95	92.83

* Only 500 observations were considered in the case of counter DC as a result of it being reset through cycling of the door during realignment.

** Only 500 observations were considered in the case of counter D due to realignment resulting in the logic being reset.

TABLE 5-18 LAB TEST RESULTS, ALIGHTINGS, TEST NUMBER 7

Parameter	PCS		
	DC	D	P
ERRORS	21	12	16
OVERCOUNTS	4	10	7
UNDERCOUNTS	17	2	9
RANGE OF ERRORS	-6 to +4	-2 to +6	-4 to +7
PERCENTAGE OF ERRORS THAT ARE OVERCOUNTS	19.05	83.33	43.75
PERCENTAGE OF ERRORS THAT ARE UNDERCOUNTS	80.95	16.67	66.25
PERCENTAGE CORRECT COUNTS	96.5	98	97.33

TABLE 5-19. PCS DC BOARDING OCCURRENCES AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_B	NO. OF OCCURRENCES OF BOARDING ERRORS																							
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16	
654	1	628	21	4		1																			
201	2	173	17	4	6	1																			
104	3	91	10	2		1																			
59	4	52	2	3		1	1																		
25	5	20	3	1	1																				
31	6	23	4		1	1	1				1														
10	7	8	2																						
7	8	2		4									1												
3	9	2		1																					
4	10	2	2																						
4	11	2									2														
1	12	1																							
1	13	1																							
1	14		1																						
2	15	1	1																						
2	16			1			1																		
1	17										1														
3	20	1																	1					1	
	23																								
1	28	1																							
	36																								
1	37	1																							
850	0	843		7																					
1965		1852	63	27	8	5	3				4		1						1					1	

Of these errors, 37, corresponding to 21.02 percent of the errors, were overcounts and 139 or 79.98 percent were undercounts.

5.2.1.2 Boardings, Counter D. Reduced data corresponding to the Dyniman, Inc., PCS are shown in Table 5-20. The total number of boarding errors observed during the 2395 boardings was 215. Therefore, the percentage of correct boarding counts for counter D was

$$\frac{(2395 - 215)}{2395} \times 100 = 91.02 \text{ percent.}$$

Of these, 67 errors were overcounts, corresponding to 31.16 percent of the errors. The remaining 148 errors, corresponding to 68.84 percent were, therefore, undercounts.

5.2.1.3 Boardings, Counter P. Reduced data for the Pro-Data PCS are shown in Table 5-21. A total of 507 boarding errors were observed. Therefore, the percentage of boardings at which no errors occurred was

$$\frac{(2395 - 507)}{2395} \times 100 = 78.83 \text{ percent.}$$

Of the boarding errors for counter P, 117 or 23.08 percent were overcounts and 390 or 76.92 percent were undercounts.

5.2.1.4 Boarding Summary. The results corresponding to boardings for all three PCSs are summarized in Table 5-22.

The results in Table 5-22 show counter DC to have the highest percentage of correct boarding counts (or highest percentage of zero errors), followed by counters D and P in order. All three PCSs were biased towards undercounting, i.e., having a higher probability (at least 2 to 1) of missing a count than of adding a count. Counter D exhibited the least bias.

5.2.2 Alighting Counting Accuracy

Reduced alighting data corresponding to that recorded during the bus tests are shown in Tables 5-23 through 5-25 for counters DC, D and P respectively.

5.2.2.1 Alightings, Counter DC. A total of 2388 alightings were observed during the tests. Considering counter DC, a total of 237 alighting errors were observed. Therefore, the percentage of correct alighting counts was

$$\frac{(2388 - 237)}{2388} \times 100 - 90.08 \text{ percent.}$$

Of the 237 alighting errors, 109 or 45.99 percent were overcounts, and 128 or 54.01 percent were undercounts.

5.2.2.2 Alightings, Counter D. The results for Counter D showed a total of 441 alighting errors. Therefore, the percentage of correct alighting counts for Counter D was

$$\frac{(2388 - 441)}{2388} \times 100 = 81.53 \text{ percent.}$$

Of these, 139 or 31.52 percent were overcounts, and 302 or 66.48 percent were undercounts.

5.2.2.3 Alightings, Counter P. The results for Counter P showed a total of 488 alighting errors. Therefore, the percentage of correct alighting counts for counter P was

$$\frac{(2388 - 488)}{2388} \times 100 = 79.56 \text{ percent.}$$

TABLE 5-20. PCS D BOARDING OCCURRENCES AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_B	NO. OF OCCURRENCES OF BOARDING ERRORS																							
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16	
654	1	608	31	14		1																			
201	2	165	24	10	1	1																			
104	3	85	13	4	2																				
59	4	48	4	3	1	1	1		1																
25	5	14	7	2		1	1																		
31	6	21	8	2																					
10	7	3	3	2	2																				
7	8	5	2																						
3	9	3																							
4	10	1	1			1											1								
4	11	1	2		1																				
1	12	1																							
1	13	1																							
1	14						1																		
2	15														1				1						
2	16	1	1																						
1	17	1																							
3	20	3																							
	23																								
1	28	1																							
	36																								
1	37	1																							
850	0	833		14		3																			
1965		1795	97	51	7	8	3		1						1		1		1						

TABLE 5-21. PCS P BOARDING OCCURRENCES AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_B	NO. OF OCCURRENCES OF BOARDING ERRORS																						
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16	
654	1	523	103	25		3																			
201	2	131	59	7	3			1																	
104	3	56	34	6	7	1																			
59	4	33	11	5	7		2					1													
25	5	11	6	1	6						1														
31	6	7	10	2	8	1	3																		
10	7	4	1		4		1																		
7	8	3	4																						
3	9	1	1						1																
4	10		3				1																		
4	11	1		1	1						1														
1	12								1																
1	13						1																		
1	14										1														
2	15						1		1																
2	16						2																		
1	17		1																						
3	20		1						2																
	23																								
1	28																		1						
	36																								
1	37														1										
850	0	801		46		3																			
1965		1571	234	93	36	8	11	1	5		3	1			1				1						

TABLE 5-22 SUMMARY OF BOARDING ERRORS

	DESIGNATED PCS		
MEASURE OF ACCURACY	DYNAMIC CONTROLS	DYNIMAN	PRO-DATA
PERCENTAGE OF ERRORS THAT WERE OVERCOUNTS	21.02	31.16	23.08
PERCENTAGE OF ERRORS THAT WERE UNDERCOUNTS	78.98	68.84	76.92
PERCENT CORRECT COUNTS	92.65	91.02	78.83

TABLE 5-23. PCS DC ALIGHTING OCCURRENCES AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_A	NO. OF OCCURRENCES OF ALIGHTING ERRORS																						
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16	
753	1	699	36	17		1																			
232	2	194	21	11	5	1																			
108	3	79	9	12	5	1	1			1															
60	4	39	14	3	2	1	1																		
26	5	18	2	3	1	2																			
20	6	13	4	1		2																			
11	7	8	2	1																					
5	8	4							1																
5	9	5																							
4	10	1	1	1				1																	
2	11	1	1																						
5	12	3		1	1																				
	13																								
1	14	1																							
	15																								
	16																								
	17																								
	20																								
1	23			1																					
	28																								
1	36	1																							
	37																								
731	0	708		19		3																1			
1965		1774	90	70	14	11	2	1	1	1												1			

TABLE 5-24. PCS D ALIGHTING OCCURRENCES AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_A	NO. OF OCCURRENCES OF ALIGHTING ERRORS																							
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16	
735	1	631	77	42		2		1																	
232	2	169	31	18	12	2																			
108	3	69	13	15	7	2	2																		
60	4	34	15	7	3		1																		
26	5	13	5	3	1	1	2		1																
20	6	8	9	1	1		1																		
11	7	3	2	1	1		2				1		1												
5	8	3		1							1														
5	9	2	1	1															1						
4	10		1	1	1							1													
2	11		1												1										
5	12		1				1		1								1						1		
	13																								
1	14								1																
	15																								
	16																								
	17																								
	20																								
1	23						1																		
	28																								
1	36			1																					
	37																								
731	0	711		14		6																			
1965		1643	156	105	26	13	10	1	3		2	1	1		1		1		1				1		

TABLE 5-25. PCS P ALIGHTING OCCURRENCES AND ERRORS

NO. OF OCCURRENCES	ACTUAL P_A	NO. OF OCCURRENCES OF ALIGHTING ERRORS																						
		0	1	-1	2	-2	3	-3	4	-4	5	-5	6	-6	7	-7	8	-8	9	-9	10	-10	12	16
753	1	597	87	65		4																		
232	2	151	44	28	5	4																		
108	3	66	18	17	3	2	2																	
60	4	30	14	5	8	1	1	1																
26	5	11	6	3	5						1													
20	6	9	2	2	3	2	1		1															
11	7	3	3	3	1		1																	
5	8	2	2						1															
5	9	2	1		2																			
4	10		1	1		1		1																
2	11			1					1															
5	12	3		1					1															
	13																							
1	14		1																					
	15																							
	16																							
	17																							
	20																							
1	23		1																					
	28																							
1	36	1																						
	37																							
731	0	681		44		5				1														
1965		1556	180	170	27	19	5	2	4	1	1													

TABLE 5-26. SUMMARY OF ALIGHTING ERRORS

MEASURE OF ACCURACY	DESIGNATED PCS		
	DYNAMIC CONTROLS	DYNIMAN	PRO-DATA
PERCENTAGE OF ERRORS THAT WERE OVERCOUNTS	45.99	31.52	44.67
PERCENTAGE OF ERRORS THAT WERE UNDERCOUNTS	54.01	68.48	56.32
PERCENT CORRECT COUNTS	90.08	81.53	79.56

Of these 488 alighting errors, 218 or 44.67 percent were overcounts, and 270 or 55.32 percent were undercounts.

5.2.2.4 Alighting Summary. The results of this analysis of alighting errors are summarized in Table 5-26. As in the case of boardings, the Dynamic Controls PCS (Counter DC) was observed to have the highest percentage of correct counts, followed by counters D and P in order. All three counters were biased towards undercounting with counter DC being the least biased for alightings.

5.2.3 Accuracy Relative to the Number of Passenger Boardings/Alightings

The relationship between the number of passengers boarding/alighting and the frequency of occurrence of zero errors was studied in order to assess the differences in the counting performance of the three PCSs. The available data were first reduced to convert the frequency of occurrences of errors to percentages. The curves in Figures 5-1 and 5-2 illustrate the performance of each PCS during different boarding and alighting situations.

It is noted that in the case of boardings, 98.42 percent of the occurrences of boarding involved fewer than seven boarding passengers. Therefore, for a critical appraisal of the data shown in Figure 5-1, the region identified by the values of the abscissa between 0 and 7 would be the region of primary interest. Within this region it is evident that counter DC exhibited the highest counting accuracy for all numbers of boarding passengers, followed by counter D and finally by counter P. Outside this region, the number of occurrences of an abscissa value was so small as to make any statistical inference meaningless.

During alightings 99.3 percent of the occurrences of alightings involved fewer than ten passengers. Therefore, the region of primary interest in the case of alightings would be that portion of the abcissa between 0 and 10 in Figure 5-2. In this case as well, counter DC exhibited the highest counting accuracy for all numbers of passenger alightings, followed again by counter D and counter P in order; except at the occurrence of 6 passenger alightings, counter P exhibited fewer errors than counter D. As in the case of the boarding of 7 or more passengers, the alighting of 9 or more passengers occurred so few times to allow no statistically significant statements to be made.

Thus, these results reveal that the Dynamic Controls, Inc., PCS (counter DC) exhibited the overall highest counting accuracy of the PCSs evaluated in the case of both boardings and alightings.

5.2.4 Analysis of Probability of Errors

This analysis is directed toward an examination of field data in an effort to characterize each PCS in terms of its probability of error at stops at which passenger transactions occur. The first step in this process involved reducing the field test data to the forms shown in Tables 5-19 through 5-21 and 5-23 through 5-25. These data were compiled directly from the raw field data which are contained in Volume II. Each table contains all boarding/alighting data recorded for a specific PCS. Table 5-19, for example, identifies the number of occurences of each value of P_B (the number of passengers board) and the number of occurrences of each value of undercounts (positive errors) and overcounts (negative on errors) for PCS counter DC. For example, out of a total of 1965 stops, two persons boarded (P_B = 2) exactly 201 times. Exactly

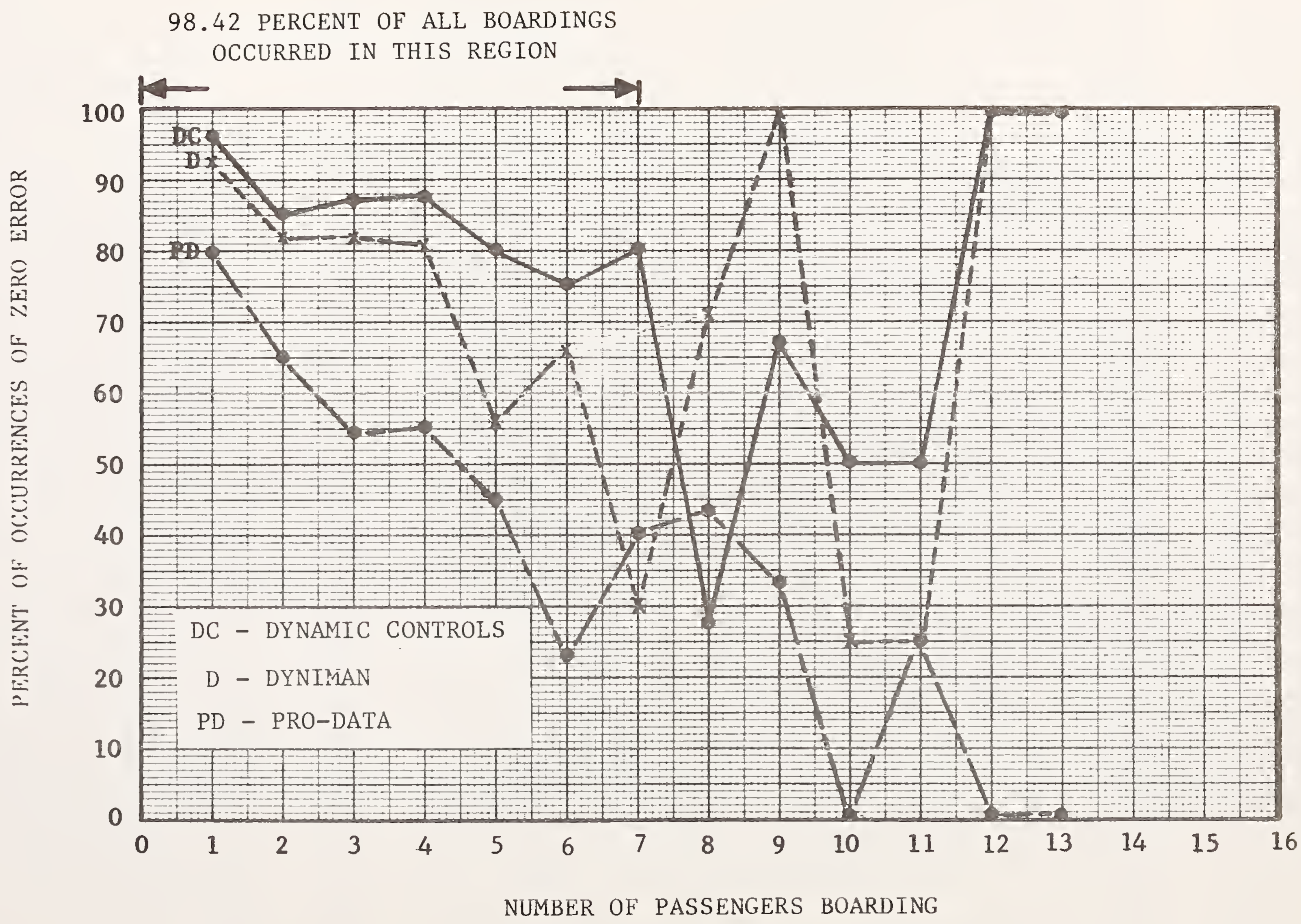

FIGURE 5-1. PERCENT OF OCCURRENCES THAT RESULT IN NO ERRORS VERSUS NUMBER OF PASSENGERS BOARDING

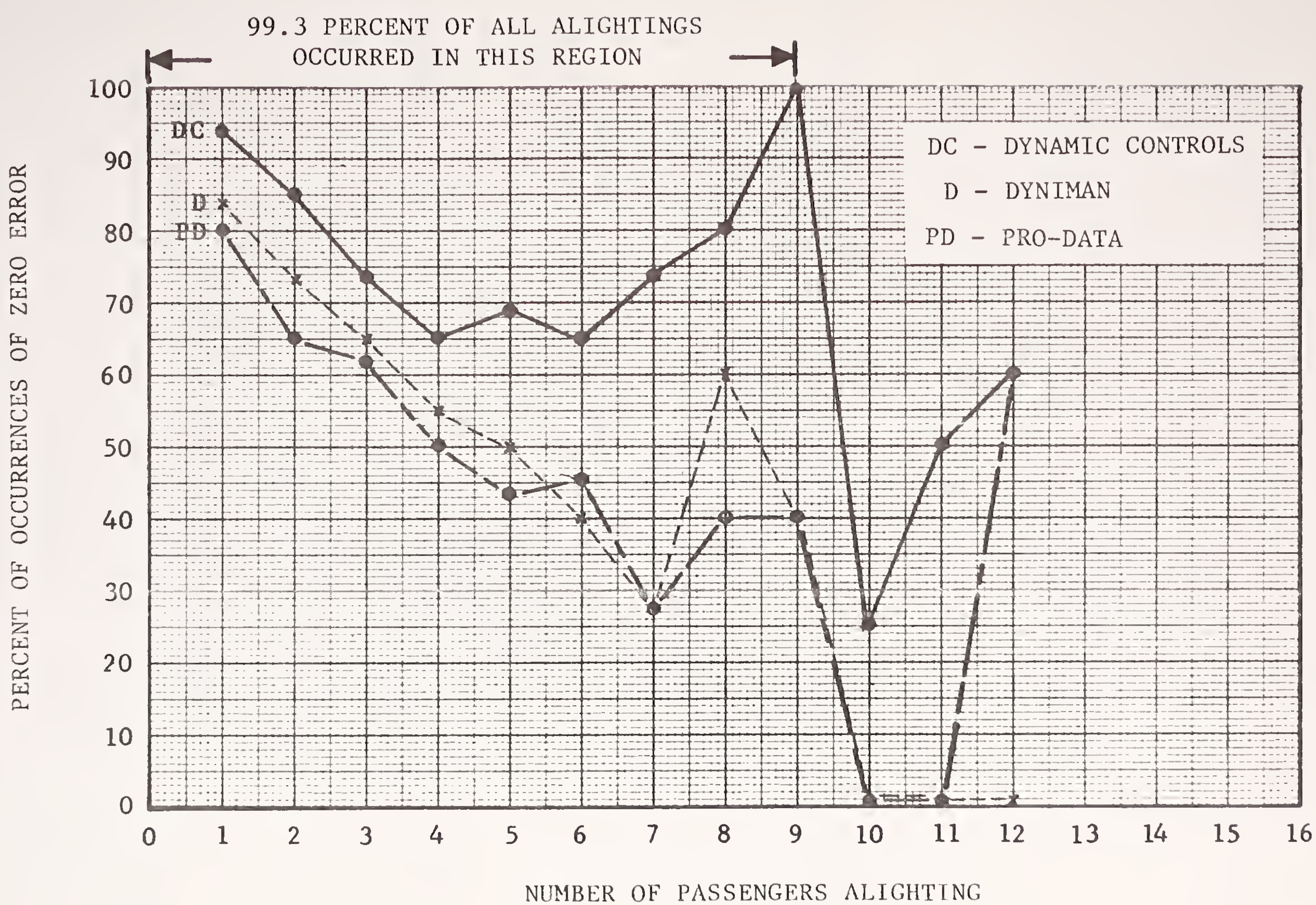

FIGURE 5-2. PERCENT OF OCCURRENCES THAT RESULT IN NO ERRORS VERSUS NUMBER OF PASSENGERS ALIGHTING

zero errors occurred at 173 of those 201 stops, an undercount of 1 (+1) occurred at 17 stops, an overcount of 1 (-1) occurred at 4 stops, an undercount of 2 (+2) occurred 6 times and an overcount of 2 (-2) occurred 1 time.

This analysis required that the frequency of occurrence of errors in the field of data be interpreted in terms of probabilities. In this instance, the probability space is taken as the total number of stops at which boarding and/or alighting transactions occurred plus the number of stops at which no transactions occurred, but which transactions were falsely recorded. Within this space, a set of error events of size 0, 1, 2, etc may occur. The probability of an error of sixe "x" is interpreted as the frequency of occurrence, n, of errors of size x divided by the total number of observations, N. For example, if the number of stops at which boardings occurred is 1115, and a counter recorded boardings at 7 stops at which no boardings occurred, then N = 1115 + 7. If at 1009 of these stops, exactly 0 errors occurred, then the probability that exactly 0 boarding errors will occur at a stop in which at least one passenger boards may be interpreted as

$$P[\text{Exactly Zero Errors}] = \frac{n}{N} = \frac{1009}{1115+7} = \frac{1009}{1122} = 0.899$$

The cumulative probability of error, i.e., the probability that the error will be less than a specified value, say "ε", is then given by

$$P[\text{Error} < \varepsilon] = \sum_{i=o}^{\varepsilon-1} P[\text{Error} = i] = \sum_{i=0}^{\varepsilon-1} \frac{n_i}{}$$

where n_i is the number of occurrences of errors of size i=0, 1, 2, etc. . .

Based on this interpretation, the boarding data in Table 5-19 can be reduced to provide the following values:

$$P[\text{Error} = 0] = \frac{\text{Number of Occurrences of Zero Errors}}{\text{Number of Stops at Which Boarding Occurred or Were Erroneously Recorded as Having Occurred}}$$

$$= \frac{1852 - 843}{1965 - 850+7} = \frac{1009}{1115+7} = \frac{1009}{1112} = 0.899$$

Note that at 850 of the 1965 stops, no passengers boarded, for errors of size 1.

$$P[\text{Error} = 1] = \frac{\text{Number of Occurrences of Undercounts of Size 1}}{1122}$$

$$+ \frac{\text{Number of Occurrences of Overcounts of Size 1}}{1122}$$

$$= \frac{63 - 0}{1122} + \frac{27}{1122} = \frac{90}{1122} = .080$$

Here, there were 63 occurrences of undercounts of size 1, all of which occurred at stops where passengers were boarded. There were also 27 occurrences of overcounts of size 1 (shown as 1 in Table 5-19), seven of which occurred at stops at which no passengers were boarded. These later values, also represent errors, and therefore have been included in this construction of cumulative probabilities, otherwise the probability of all possible events in the space would not be unity.

The data contained in Tables 5-19 through 5-21 and 5-23 through 5-25 were reduced in the preceding manner to determine the cumulative probability that the counting error was less than a specified value. These data were then plotted on linear paper such that the boarding data on all three PCS's could be plotted on one graph and the alighting data on another graph. These data are presented in Figures 5-3 and 5-4. The combined results for both boarding and alighting are summarized in Table 5-27 in terms of the absolute value of counting errors.

The data shown in Figures 5-3 and 5-4 and Table 5-27 indicate that the overall counting performance of the Dynamic Controls PCS was superior to the other PCSs, particularly in terms of having a higher probability of generating no counting errors at all. In terms of generating no more than one error (corresponding to the column labeled $\varepsilon = 2$ in Table 5-27) all three PCSs could be classified as exhibiting a 95 percent accurate count. It should be pointed out that 87 percent of the data collected on the CITRAN bus involved the boarding or alighting of no more than three passengers. Consequently, very little data was available upon which to base an analysis of larger counting errors. For this reason, the counting performance of all three PCSs was essentially equal when counting errors of more than 2 or 3 were concerned.

It is, however, significant that Dynamic Control's PCS exhibited a 10 percent advantage (0.873 versus 0.794) over the Dyniman PCS in terms of the probability of generating no errors. The Dyniman PCS exhibited an 18 percent (0.794 versus 0.672) advantage over the Pro-Data PCS.

5.2.5 <u>On-Board Count</u>

The number of passengers on board a bus at any time can be derived from the boarding and alighting data accumulated at each stop. Assuming that the bus begins a trip with no passengers on board, then the actual on-board count (OBC) after N stops is given by

$$OBC = \sum_{i=1}^{N} P_{Bi} - \sum_{i=1}^{N} P_{Ai} = \sum_{i=1}^{N} (P_{Bi} - P_{Ai})$$

where:

i is the stop number,

P_{Bi} is the number of passengers boarding at stop i, and

P_{Ai} is the number of passengers alighting at stop i.

The error in on-board count is given by the difference between the actual OBC and the OBC computed as the accumulated difference between the boarding and alighting passengers indicated by the PCS. Therefore, any errors in boarding or alighting will reflect in the value of the on-board count. In this respect, the on-board count is a derived statistic. Therefore, the performance of the counters in boarding and alighting accuracy tests will likewise be a pointer or predictor of their performance in the on-board counts.

One measure of PCS performance is its ability to accurately indicate the on-board count or load factor on a bus. The load factor is computed as the ratio of the on-board count to the seating capacity of the bus. One method of gaining insight into this PCS performance measure is to examine the maximum error in the on-board count during a normal trip. Table 5-28 contains the results of examining the data obtained during each field test run. Shown are the actual total number of passengers which boarded during the test run and the maximum deviation in the on-board count as computed by each PCS. For example, in Test Run Number 2, a total of 421 passengers boarded (and alighted) during the run. At each of the 370 stops made during that run, the value of actual OBC was computed and compared to the value of OBC computed from each PCSs accumulated boarding and alighting errors. During that run it was found that counter DC exhibited a maximum deviation in OBC of 15. Counter D and P exhibited maximum OBC errors of 13 and 35 during that same run.

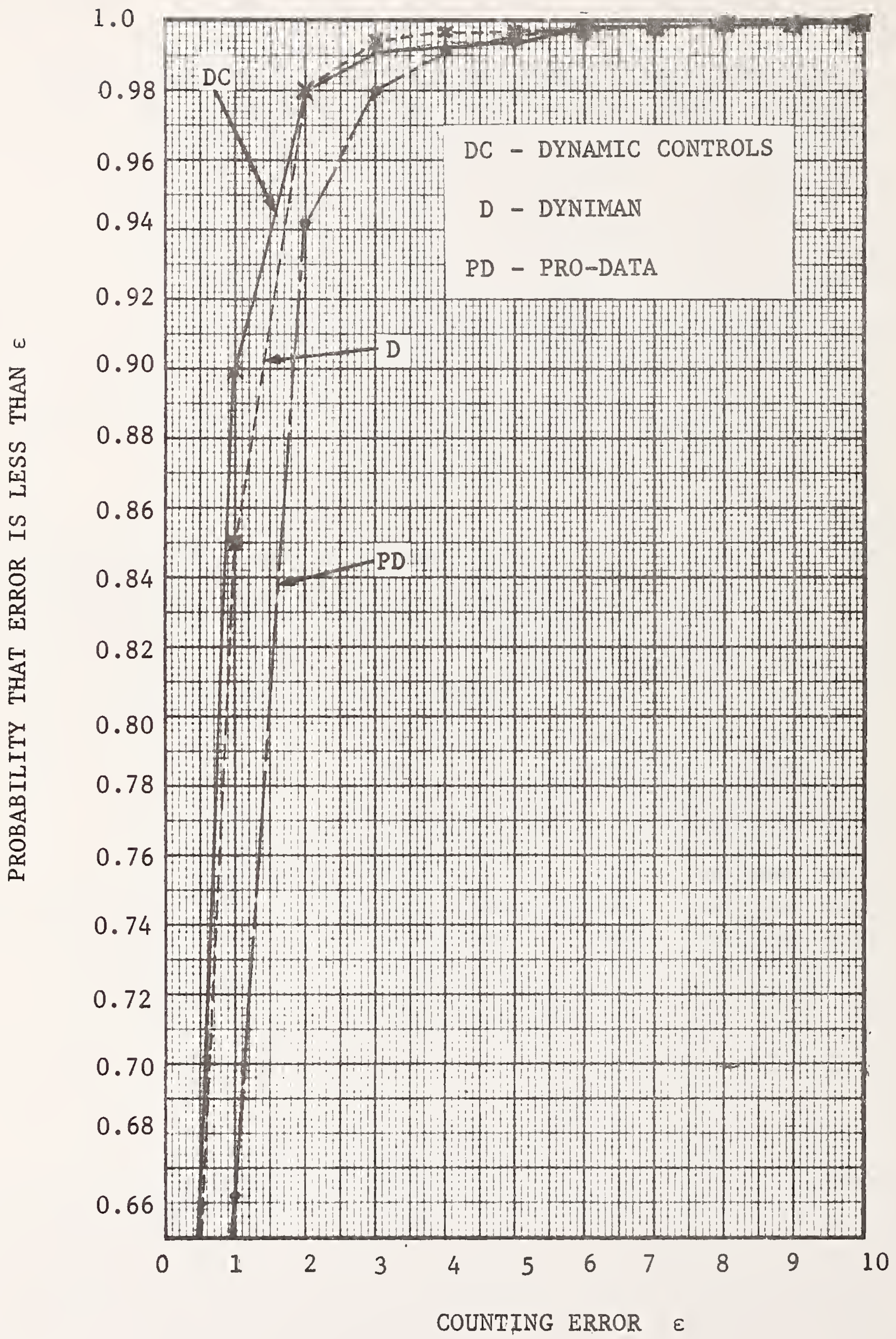

FIGURE 5-3 CUMULATIVE PROBABILITY OF BOARDING ERROR ON CITRAN BUSES

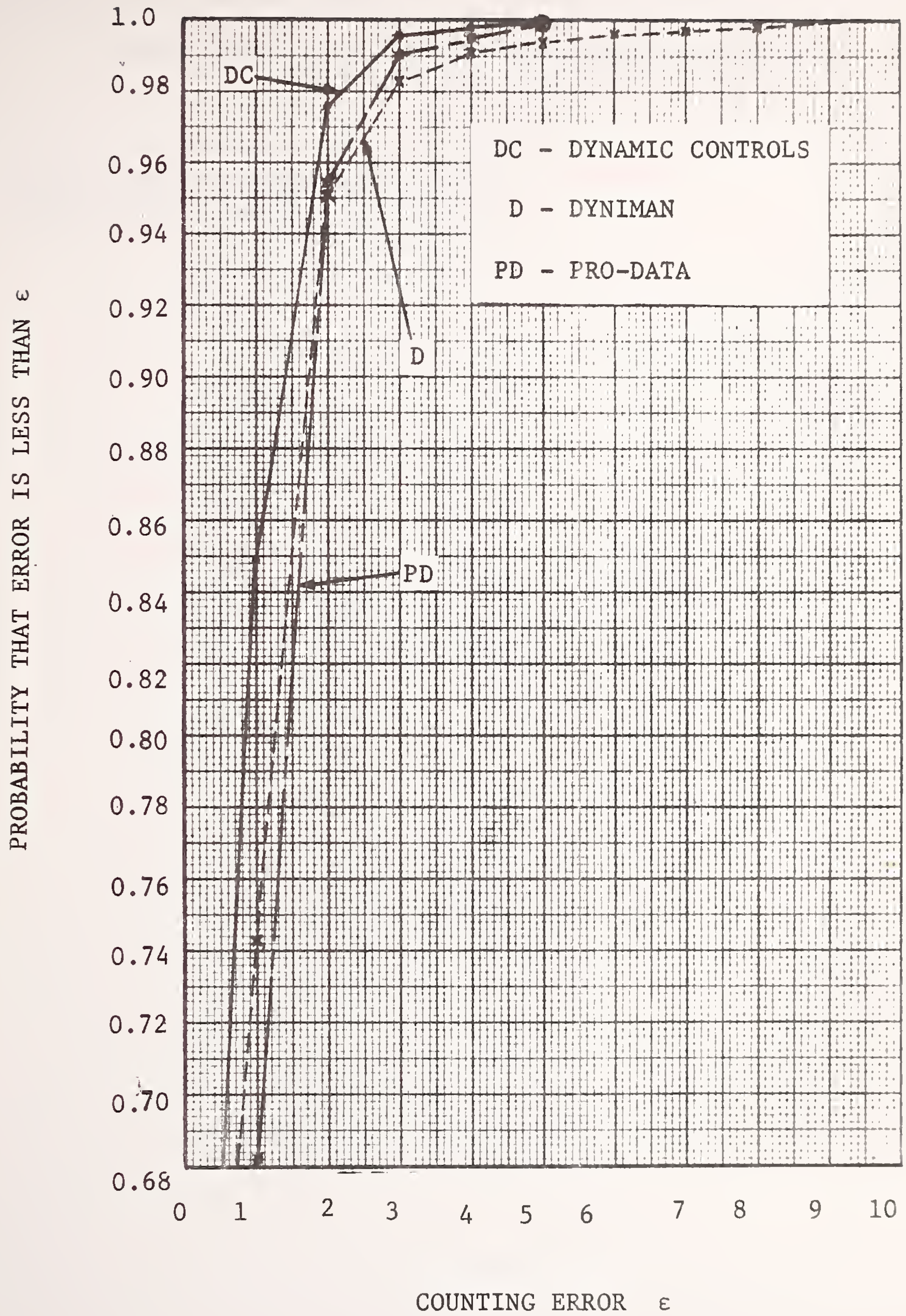

FIGURE 5-4 CUMULATIVE PROBABILITY OF ALIGHTING ERRORS ON CITRAN BUSES

TABLE 5-27. RELATIVE COUNTING ERROR PROBABILITIES

PASSENGER COUNTER	PROBABILITY THAT THE ABSOLUTE VALUE OF COUNTING ERROR IS LESS THAN ε		
	ε = 1	ε = 2	ε = 3
DYNAMIC CONTROLS	.883	.979	.994
DYNIMAN	.806	.968	.988
PRO-DATA	.700	.950	.985

The average maximum error in OBC for all test runs and for each PCS is also shown in Table 5-28. Individual test run data, as well as the average date, reinforce the results obtained on individual PCS counting performance as described in preceding paragraphs in this section.

TABLE 5-28. MAXIMUM ON-BOARD ERROR COUNT

Test No.	No. of Passengers Observed Per Run	DESIGNATED PCS		
		DC |Max Error|	D |Max Error|	P |Max Error|
1	109	8	5	12
2	421	15	13	35
3	437	38	15	9
4	74	2	14	16
5	416	19	41	36
6	377	10	17	30
7	36	0	2	7
8	523	5	15	54
Average |Max Error|		3.7	6.6	11.1

6. CONCLUSIONS

The PCS manufactured by Dynamic Controls, Inc., (counter DC) exhibited slightly superior counting performance under virtually all test conditions. In the laboratory tests conducted in the test stand, counter DC exhibited the highest counting accuracy during all 9 tests of 600 boardings and in 6 out of 9 of the tests involving 600 alightings. Counter D exhibited the second best performance in 8 out of 9 of the boarding tests and was either best or second best in 7 out of 9 of the alighting tests.

Both IR counters exhibited their poorest performance during Test Number 5 which involved simultaneous boardings and alightings of passengers that were carrying parcels. This was true for both boardings and alightings, more errors being exhibited during alightings. This may result from the fact that the width of the rear doorway on the test stand (and on the bus) is narrower than the front doorway, thus, the light beams are slightly narrower at the receiver sensors. This may result in the rear door sensors being more sensitive to door alignment. Alignment is somewhat more difficult to maintain when passengers carry parcels due to physical contact with the IR sensors.

It was noted that the only difference between Test Numbers 2 and 5 was the inclusion of parcels in Test Number 5. The results obtained during Test Number 5 were, however, poorer for all three counters. Since the treadle counter should not be effected by the carrying of parcels, this may indicate that all three counters were somewhat sensitive to the manner in which different personnel boarded and alighted. It is noted that Test Number 2 was conducted by two people, whereas Test Number 5 involved at least six different people.

It should be recalled also that the lab tests did not involve door openings and closings. Therefore, the influence of the door actuators in maintaining or degrading alignment of the IR sensors was not a factor.

Although the treadle PCS (counter DC) exhibited its worst performance during Test Number 5, the worst-case error observed for counter DC was over 5 percentage points better than the worst-case error observed for counter D and over 15 percentage points better than the worst-case error observed for counter P.

In general, the laboratory tests indicated that under controlled conditions, the Dynamic Controls' PCS is capable of providing superior counting performance over the other two counters.

As discussed in Section 5, the results of the field testing on the CITRAN bus were even more conclusive in identifying the Dynamic Controls PCS as capable of providing more accurate counting performance under operational contitions. The fact that all three counters were simultaneously tested through use of the same passengers and same boarding/alighting patterns, makes these results even more significant. This approach, coupled with the fact that all three sets of sensors were installed and calibrated in accordance with each PCS manufacturer's suggestions (and in two cases, with their direct involvement) makes these tests unique.

The results of the environmental testing indicated that all three PCSs should be capable of satisfactory operation in the Los Angeles environment.

7. REFERENCES

1. O'Sullivan, Denis F., "Passenger Counters, Volume I, State of the Art," The MITRE Corporation, October 1973.

2. The Port Authority of NY and NJ, "Bus Passenger Monitering Technical Study," Final Project Report, Urban Mass Transportation Technical Study, February 1977.

3. Gruver, George W., "A Comprehensive Field Test and Evaluation of an Electronic Signpost AVM System," Volume I. National Technical Information Service, Springfield, VA, Report Number MUTA-MA-06-0041-77-9, March 1977.

APPENDIX

REPORT OF INVENTIONS

The work performed under this contract during the evaluation reported herein has led to no new inventions. In terms of test procedures, however, it is believed that this evaluation represents the first time that three different transit-bus passenger counter systems were simultaneously tested on a single bus during regular service so as to provide a base line set of stimuli which was common to all three units being tested.

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