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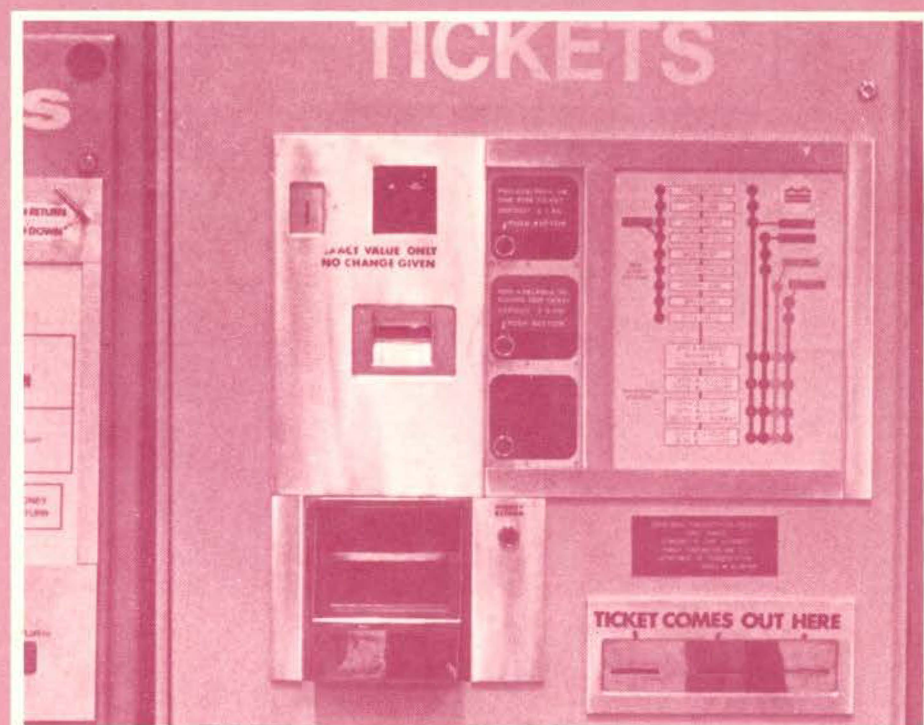
Urban Mass Transportation Administration

Assessment of High Reliability Ticket Vendor Developed by PATCO

Dynatrend, Inc.
21 Cabot Rd.
Woburn MA 01801

Final Report
September 1983



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16. Abstract

This report presents a description and preliminary evaluation of the High Reliability Ticket Vendor (HRTV) developed by the Port Authority Transit Corporation (PATCO) of Pennsylvania and New Jersey. Vendor development was supported in part by funds appropriated by PATCO and by an UMTA R&D Section 6 Grant. The HRTV was developed in response to the need for high reliability vendor performance required by PATCO's automatic fare collection policy, and the need to reduce maintenance costs. All the subsystems except for the bill acceptor (a Rowe Model BA-5) were designed by PATCO; these subsystems include: bill escrow, bill vault, coin acceptor, coin escrow, coin vault, ticket dispenser, command/control, and cabinet. A five month test program was initiated to collect reliability and maintainability data for the HRTV and from the Advanced Data System vendors located at the Lindenwold Station test site. Results indicated that the reliability of the HRTV in issuing tickets was determined to be 2724.86 mean cycle between failures (MCBF) and the composite reliability of the other vendors was determined to be 492.55 MCBF. The mean time to repair the HRTV was found to be comparable with the other vendors in the test group. Service time, or the time for the vendor to issue a ticket after deposit of money begins, was evaluated as part of a three day test program. It was found that the HRTV is slower than the other vendors when about eight or less deposits are made and faster when more than nine are made. It is concluded that the improvement in reliability performance of the HRTV warrants further development of this vendor, and consideration should be given to deployment of HRTV's in one or more stations to develop (1) a performance data base, and (2) an acquisition and operational cost data base.

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PREFACE

This Final Report describes the systems and subsystems characteristics, and reports on initial testing of a ticket vendor, the High Reliability Ticket Vendor (HRTV) developed by the Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO). The performing organization accomplished their work under sponsorship of the Technical Assistance Program of UMTA through the Transportation Systems Center, U.S. Department of Transportation, Contract No. DTRS-57-80-C-00081. Messrs. John E. Cadigan and Joseph S. Koziol, Code DTS-65 of the Office of Systems Assessment, Safety and Security Division were the Technical Monitors.

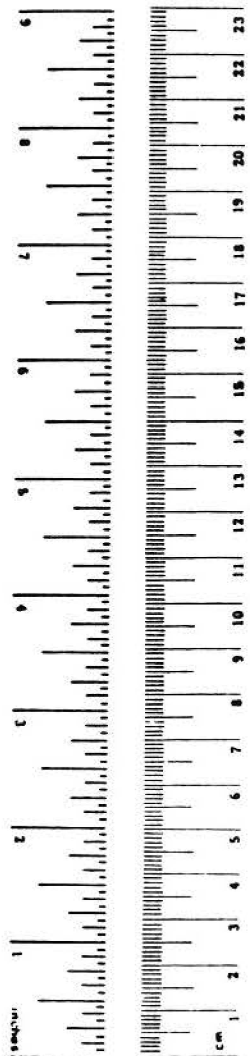
The work presented was drawn from data furnished by PATCO, interviews with PATCO personnel, and test data collected during visits to PATCO's Lindenwold Station. Dynatrend acknowledges PATCO's cooperation and in particular the assistance of Messrs. J. William Vigrass, Clayton E.Yost, and George C. Paxson.

The objective of this study was to describe and evaluate PATCO's newly developed ticket vendor to enable the managers of other transportation properties to assess the applicability of PATCO's vendor to their fare collection needs. This effort was initiated in December 1980 at which time the HRTV subsystems were being assembled. Descriptive data was obtained at that time, and the effort was then halted until the vendor was ready for installation at a station and its performance could be assessed. In June 1982, th investigation was resumed when the field test demonstration was initiated.

METRIC CONVERSION FACTORS

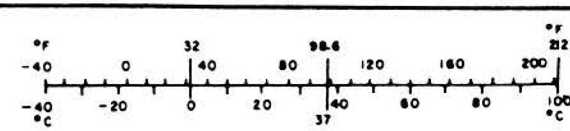
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



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EXECUTIVE SUMMARY

The objective of the study was to describe and evaluate a ticket vendor recently developed by the Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO) to enable managers of transportation properties to assess the applicability of PATCO's vendor to their fare collection needs.

PATCO is a relatively small transit system that provides rail service between downtown Philadelphia and suburban Lindenwold, New Jersey, a distance of 14 miles with a total of 13 stations from end to end, for about 40,000 passengers per weekday and about 11 million passengers per year. The system which began operation in 1969 is characterized by Automatic Train Operation wherein each train has a crew of one person, and by Automatic Fare Collection (AFC) wherein the stations are unattended for long periods during each day. Ticket sales are made directly to the patrons by vending machines which are monitored by closed circuit television (CCTV) cameras, and the turnstiles, which subtract rides from the tendered magnetically encoded tickets and capture exhausted tickets, are also monitored by CCTV. PATCO's experience has demonstrated that AFC is workable, but it was found that the station equipment had high failure rates which resulted in patron inconvenience and high maintenance costs. Following acquisition of new turnstile gates and some modifications, the gates now provide excellent service. Over the years there has been several programs to upgrade reliability of ticket vendors, but these programs have not achieved their design goals.

In 1977, a decision was made to initiate an in-house design of a High Reliability Ticket Vendor (HRTV). This effort was supported by an UMTA R&D Section 6 Grant (1980). A prototype HRTV was developed and installed at the Lindenwold Station on May 9, 1982. This report provides a first look at the description of operation and performance of this new vendor.

PATCO's HRTV is an <u>exact-value</u> ticket dispensing vending machine (no change given) which can issue as many as three tickets of different value. It has been designed to accept large fares for issue of a single ticket, and can

accommodate any combination of nickels, dimes, quarters, Susan B. Anthony one dollar coins, and one dollar bills which add up to the exact fare. (Fifty cent pieces can also be accepted, but current policy prohibits acceptance of this coin.)

HRTV design goals included: (1) high reliability, (2) easy maintenance, (3) low cost equipment operations and maintenance costs, (4) greater use of electronic solid state techniques and minimization of mechanical operations, (5) allowance for continued use of existing magnetically encoded tickets, (6) vending of recycled tickets which may be slightly deformed and irregularly stacked, (7) use of presorted stacks of different ticket values, (8) design of subsystems to adjust to known problems of worn coins and bills and coin jams, (9) automatic issuance of tickets, (10) operation based on exact change (addition of a change maker, if desirable, is a minor retrofit), (11) operation in a outdoor environment, (12) no bill stacking, (13) no money counting in equipment, (14) acceptance of high value escrow, (15) prevention of and defeat of fraud, and (16) vandal-proofing.

Vendor design has utilized the availability of CCTV surveillance. If a stack is jammed or out of tickets, then one of three lights located on top of the cabinet are turned on, when the internal logic detects the fault; if one of the other vendor subsystems fails then all three lights turn on. Appropriate maintenance action is requested by the person monitoring the CCTV. The CCTV is also used to monitor the external physical security of the vendor. Internal security is maintained via separate locked coin and bill vaults, and counters which allow for determination of cash deposited and tickets sold.

A ticket can only be vended if the exact amount of money is deposited. At any point during the transaction up to depressing the ticket selection button after the correct amount of money has been deposited, the money return button can be pushed and all the money being held in escrow will be returned. Light Emitting Diodes (LED) display the sum of money deposited following insertion of each coin and bill.

There are 11 major HRTV subsystems which include a: bill acceptor, bill escrow, bill vault, coin acceptor, coin escrow, coin vault, ticket dispensers(3), command/control, transaction/ticket counters(9) power supply, and cabinet. The Rowe Model BA-5 is the dollar bill acceptor; the bills, which if accepted, fall onto a belt in the bill escrow subsystem designed by PATCO. If a ticket is issued, the belt moves so as to deposit the bills into the vault, and if the money return button is pushed, the belt moves so as to deposit the bills into the till where they can be retrieved by the patron. The coin acceptor and coin escrow subsystems were also designed by PATCO. If a coin is accepted, it is held in escrow till the decision is made to make a ticket selection, at which time the container holding the coins pivots to allow the coins to fall into the vault; if a slug or one cent coin is deposited or the money return button is pushed, then all the coins (and bills) will be returned through the till. The most innovative feature of the HRTV is PATCO's design of the vend picker unit which on command pushes a ticket from the stack into the exit throat of the vendor where it can be extracted by the patron. In previous designs of power vend units, the picker - a unit with small raised surfaces that pushes against the ticket - is fixed relative to the direction of the picker arm stroke. It is necessary in this type of design for the relative dimensions between the picker surface and ticket be held within a relatively small tolerance to insure that only one ticket will be issued. The use of three gimballed joints in the HRTV allows for some relative motion between the picker surface and picker arm, and this greatly increases the acceptable tolerances in ticket shape and quality of stacking which in turn improves reliability and reduces maintenance problems. Complementary Metal Oxide Surface (CMOS) logic was used by PATCO in the design of the HRTV's command/control (c/c) subsystem. The c/c system is distributed among five plug-in boards. An important design feature of the boards has been to locate in-line test points which normally read zero voltage along the outside edge; to trouble-shoot the vendor, the leads of a voltmeter are run along the test points in search of the fault, a non-zero reading.

Reliability and maintainability data were collected, during a five month test period beginning on June 9, 1982 and running through November 11, for the HRTV as well as the four Advanced Data System ticket vendors located at Lindenwold Station. The HRTV reliability performance over this period was estimated as 2724.86 mean cycle between failures (MCBF) whereas the composite performance for the other four vendors was determined to be 492.55 MCBF. (The composite performance of data, related to eight IBM and nine cubic vendors operated by BART, was found to be 140.80 MCBF). Significance testing of the MCBF for the HRTV and the other four vendors at Lindenwold indicated that there was only a 0.1% chance that the observed results could be due to chance.

It was determined that the mean time to repair the HRTV is 0.3375 hours and that this time is comparable to the repair time for the other vendors at Lindenwold. Repair time is the time to trouble-shoot and replace vendor sub-systems on-site; it was not possible to include shop time because the HRTV is a one-of-a-kind. Based on this evaluation, it appears that the field service repair time has not been improved. The HRTV has the same level of complexity as the other vendors and turnstiles being maintained by PATCO personnel, so there should be no requirement for additional personnel or equipment resources other than a short training program.

Data was collected over a three day period to assess the service time of the vendors at Lindenwold Station; service time is the time from initiation of currency deposit by the patron till a ticket is dispensed. It was found that the HRTV is much slower than the other four vendors when about nine or less deposits are made to acquire a ticket. If nine deposits are made, then the service time of the HRTV is comparable to the other vendors, and for a greater number of deposits the HRTV is faster.

It was concluded that the design of the HRTV prototype vendor represents a substantial improvement in reliability. Consideration should be given to acquisition of sufficient number of these vendors to provide all the fare collection equipment at one or more stations with the goal of collecting data for establishing vendor system performance, and acquisition and operating costs to assess whether the HRTV should be added to the inventory of equipment available to the owners of rail transit properties.

1.0 INTRODUCTION

This section provides a brief description of the transit system operated by the Port Authority Transit Corporation of Pennsylvania and New Jersey, and the factors that have led to their development of a high reliability ticket vendor. The objectives of this assessment of the prototype development model of PATCO's vendor, and the approach taken to this collection, analysis, and evaluation program are presented.

1.1 DEVELOPMENT OF A HIGH RELIABILITY TICKET VENDOR

The PATCO Hi-Speed Line is owned and operated by the Port Authority Transit Corporation (PATCO) of Pennsylvania and New Jersey, with headquarters in Camden, New Jersey. PATCO is a relatively, small rail transit system which does not receive Federal or State operating subsidies. Total route length is 14 miles, and the line extends from downtown Philadelphia to suburban Lindenwold, New Jersey with a total of 13 stations. PATCO carries on the average 40,000 passengers per weekday and about 11 million passengers per annum.

This rail line which began operations in February 1969 was the first modern high performance automated rapid transit facility in the United States. The area presently served by PATCO is shown in Figure 1. Automatic Train Operation, a system introduced by PATCO, is used to control of each train which vary in size from one car to a maximum of eight cars. Every PATCO train has a crew of one person, the Train Operator. PATCO also introduced an Automatic Fare Collection (AFC) system wherein the stations are unattended,[1] i.e., there are no attendants or cashiers. Ticket sales are made directly to the patrons by ticket vending machines which are monitored by closed circuit television (CCTV) cameras. Assistance to patrons is available if needed from Call-For-Aid telephones located in each station. An arrangement of a typical suburban station is presented in Figure 2. The top photograph presents an external photograph of the entrance structure. Note the glass block wall and

[1] Sixty percent of the passengers purchase tickets from vendors. Three stations have cashiers during rush hours.

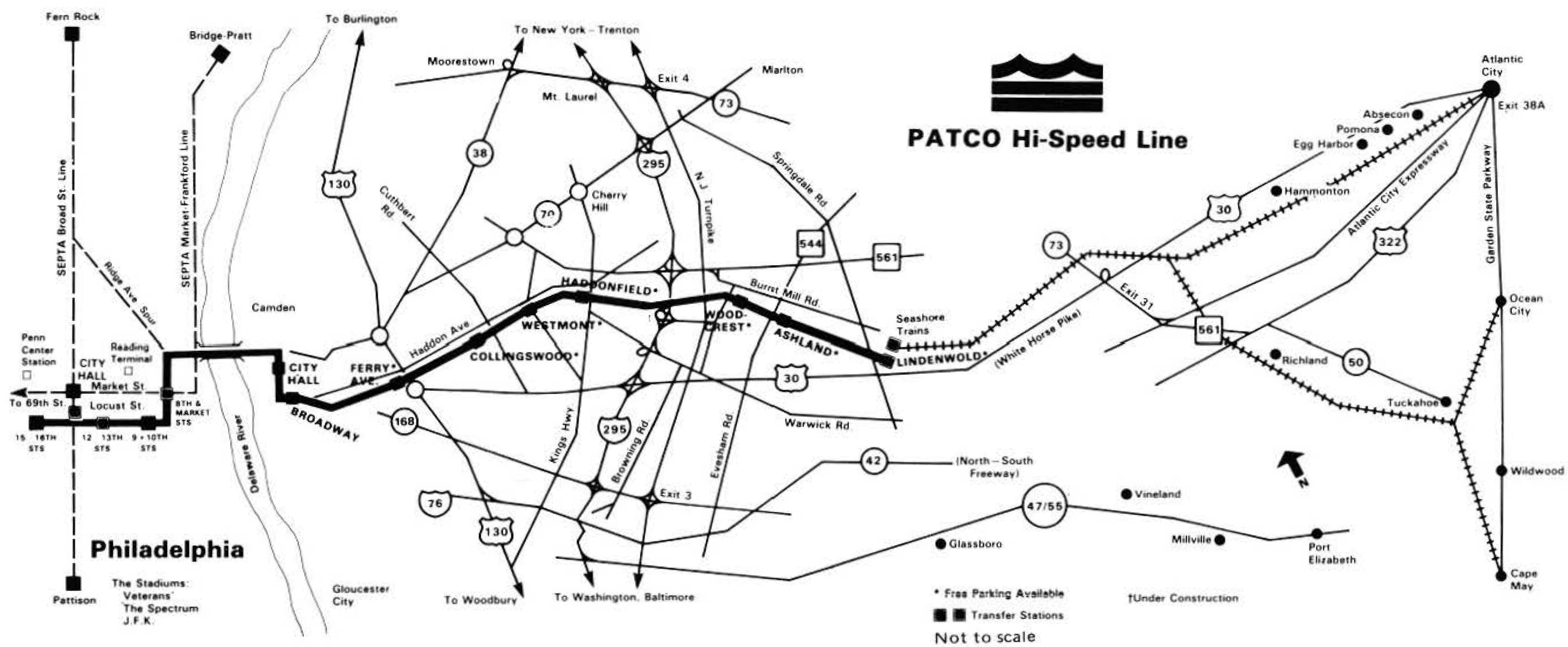

FIGURE 1. AREA SERVED BY PATCO

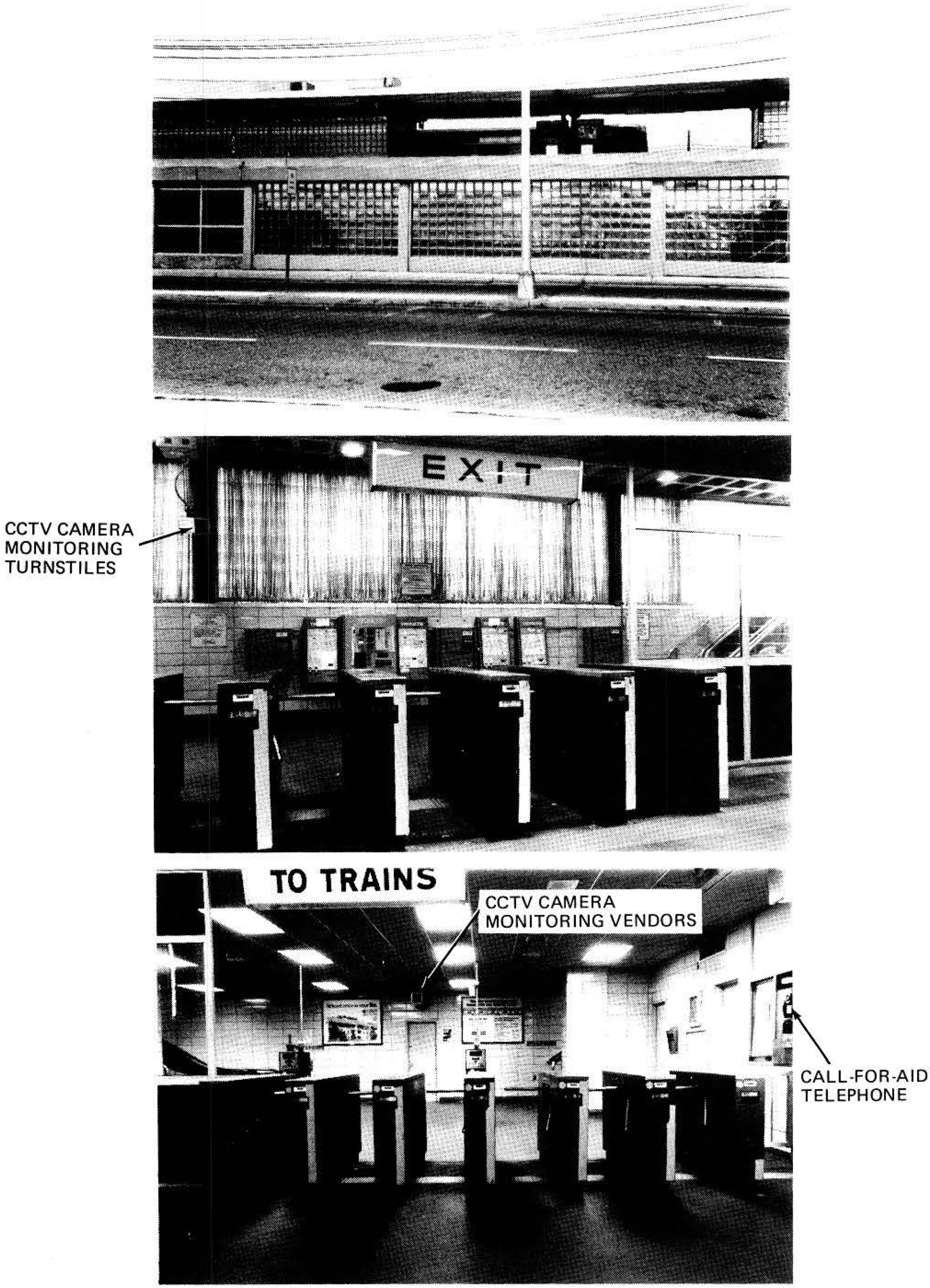

FIGURE 2. ARRANGEMENT OF LINDENWOLD STATION

the handrails at the top of this staircases at both ends of the entrance structure. The middle photo presented in Figure 2 shows the array of all of the automatic vendors in the station and some of the money changing equipment. For orientation purposes, the glass block wall can be seen through the curtains located above the vendors and changers, and also the bottom of the two staircases can also be seen. The top left of the middle photo shows the CCTV camera used to monitor the turnstiles. After purchase of tickets from the vendors, the patrons turn around and walk toward the turnstiles shown in the bottom photograph of Figure 2. The CCTV camera which monitors the vendors and changers can be seen in the top center of the bottom photograph of this figure. Also shown on the right side of the photo is the Call-For-Aid telephone, available to the patron from either side of the turnstiles, provided for those needing assistance, and immediately to the left of the phone (but not shown) is a ticket window which is opened during the morning and evening rush hours where multiple ride tickets are sold and change is provided. Multiple ride tickets can also be purchased at the newsstand (not shown) to the left of the turnstiles. To the right of the ticket window and not shown are two dollar bill changers.

Electronically controlled gates allow passage to the trains upon insertion of a magnetically encoded ticket. This ticket is returned to the passenger after passage through the gate, and the same ticket must be used to allow exit from the station through the turnstile at the destination station. After the ticket has been exhausted, that is when the number of available rides have been used up, the ticket is captured and recycled.

PATCO's experience [2] has demonstrated that AFC and unattended stations is workable, but it was found that the station equipment had high failure rates which resulted in customer inconvenience and high maintenance expenses. The original power-operated, four door, hydraulic gates used for the turnstiles had a high failure rate, and it was determined that a reliability improvement program would not significantly improve performance. New turnstile type gates were ordered and installation was completed by 1976. Following some modifi-

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[2] This historical description was extracted from PATCO's application for R&D Grant for Development of a High Reliability Ticket Vendor Under Section 6 of UMTA Act of 1964, dated April 3, 1980.

cations, these new gates achieved a high level of reliability, and now provide excellent service. Over the years, there have been several programs to upgrade the reliability of ticket vendors, but these programs have not achieved their design goals.

The original ticket vendors supplied to PATCO were manually operated, and the coin count mechanism was of a type similar to those used in beverage vending machines. PATCO found that heavy usage rapidly wore out the coin count mechanisms and opened up tolerances in the ticket release mechanism which resulted in ticket vendor failures. A design deficiency in the ticket release mechanism made it necessary for the patron to extract the ticket in one continuous motion, otherwise the ticket engagement mechanism would move to the next ticket while the first ticket was still blocking the path. The patron could not extract the first ticket although his/her money had been accepted, and the vendor would continue to accept additional money from other patrons with a high likelihood that no ticket would be dispensed and the money retained. By 1973, 15 ticket vendors were modified to (1) surmount the ticket extraction problem, (2) allow a money count to $1.95, and (3) provide a dollar bill acceptance mechanism. It was found that the power vend mechanism gave good service at first, but with usage and attendant wear, the reliability of the mechanism dropped drastically. The ticket engagement mechanism was not easy to repair, nor was it simple to fabricate replacement parts. By 1974, a redesigned adjustable ticket engagement mechanism was added. Performance was improved, but required a scheduled maintenance program to insure that critical mechanical alignments stayed within tolerance. By 1976, the coin acceptor mechanisms were found to be badly worn, and it was not feasible to fabricate new parts necessary for repair. This resulted in the design of a new coin sizing mechanism which incorporated photo-sensors and electronic logic circuits. These coin acceptors have proven to be highly reliable, with only a few failures per year.

Although ticket vendor reliability programs improved certain problems, the overall performance was not satisfactory since maintenance costs were still high, and failures resulted in inconvenience to the public. In 1977, an assessment was made of the necessary modifications to the existing vendors for improvement of their performance. It was decided that a modification program to upgrade existing equipment would probably not provide the desired results. A review of available equipment, including evaluation of potential improvements to existing hardware would not yield the desired level of reliability and maintainability, so the decision was made to initiate the in-house design of a high reliability ticket vendor (HRTV). A prototype HRTV was developed and installed at the Lindenwold Station near PATCO's Lindenwold Shop on May 9, 1982. This report provides a first look at the description of operation and performance of this new vendor.

1.2 OBJECTIVES OF ASSESSMENT

The goal of this assessment is to evaluate the high reliability ticket vendor (HRTV) developed by PATCO in part under an UMTA R&D Section 6 Grant (1980), and to prepare a report which provides sufficient detail about HRTV operation and performance to enable managers of said properties to determine its application to their fare collection needs.

The specific outputs of this investigation are:

(1) a description of the HRTV system and subsystems,
(2) determination of the reliability and maintainability of the HRTV in its operational environment, and comparison of performance with other ticket vendors located within the same station,
(3) determination of waiting and service times to procure tickets from the HRTV and from other nearby vendors, and
(4) assessment of the utilization of the HRTV by the passengers.

1.3 APPROACH TO ASSESSMENT

This assessment of PATCO's HRTV was conducted through:

(1) discussions with the development engineer, head of maintenance and repair, and supervisor of equipment,

(2) review of maintenance and repair records of the HRTV and other vendors,

(3) observation and data collection of patron interaction with HRTV and nearby vendors,

(4) statistical analysis of data and extraction of inferential comparisons regarding reliability, maintainability, and time to acquire a ticket.

2.0 SYSTEM DESCRIPTION

PATCO's High Reliability Ticket Vendor (HRTV) is an exact-value ticket dispensing vending machine (no change given) which can issue tickets with as many as three different fare values. It has been designed to accept large fares for issue of any single ticket, and can accept any combination of dollars or coins which add up to the exact fare value. The upper limit of fare value that could be held in escrow during the ticket purchase process were tested up to a deposit of over 30 bills, and over 100 coins. This high escrow design feature allows for changes in fare structure without regard to vendor limitations. Currency acceptable to the HRTV includes:

- nickel
- dime
- quarter
- half-dollar [3]
- one dollar Susan B. Anthony (SBA) coin
- one dollar bill

The vendor has been designed to be (1) resistant to vandalism, which is aided by constant monitoring by a closed circuit television camera (CCTV), (2) intolerant to acceptance of counterfeit currency, (3) simple to use by the patrons, (4) highly reliable, and (5) rapidly repaired and placed back-on line. At the time of a vending malfunction, either one or more ticket stacks are shutdown or the entire vendor is removed from service. When a vendor failure occurs one or more lights turn on, and these lights can be seen and interpreted at the CCTV monitor located at central control.

2.1 PATCO'S FARE COLLECTION REQUIREMENTS

At the time of preparation of this report, the array of PATCO vendors were dispensing five different value one-way tickets. Fare structure policy requires (1) four different fare values between Philadelphia stations and New Jersey stations, and (2) a single fare for rides between New Jersey stations.

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[3] The equipment can be programmed to accept a half-dollar, but the present policy requires that this coin not be accepted.

Only one-way tickets can be purchased in Philadelphia, but round trip tickets can be purchased at all New Jersey stations. Round trip tickets cost two times the one-way fare, and there are a total of ten different fare value tickets dispensed from vendors. (Ten ride tickets can be purchased at newsstands located at the stations or by mail.) Ticket booths staffed by a cashier during the two rush hour periods are located at three stations. PATCO has five different fare types:

(a) all Philadelphia stations to Broadway in Camden	$0.70
(b) all Philadelphia stations to Ferry Ave. in Camden	.95
(c) all Philadelphia stations to Haddonfield, New Jersey	1.25
(d) all Philadelphia stations to Lindenwold, New Jersey	1.45
(e) all New Jersey stations	0.75

Vendors located in Philadelphia dispense four types of tickets: (a), (b), (c), (d), and vendors located in New Jersey dispense two types of tickets: (a) or (b) or (c) or (d), and (e). Of course, no single vendor at a given station has to dispense all required tickets, but the array of vendors at a given station provide for all the combinations.

2.2 VENDOR DESIGN GOALS

The major system design requirements set forth for the design of the HRTV included:

(1) high reliability,
(2) easy maintenance,
(3) low cost equipment operations and maintenance costs,
(4) greater use of electronic solid state technique and minimization of mechanical operations,
(5) allowance for continued use of existing magnetically encoded tickets,
(6) vending of recycled tickets which may be slightly deformed and irregularly stacked,
(7) use of presorted stacks of different value tickets,

(8) design of subsystems to adjust to known problems of worn coins and bills, and coin jams.

(9) automatic issuance of tickets,

(10) operation based on exact change,[4]

(11) operation in an outdoor environment,

(12) no bill stacking,

(13) no money counting in equipment,

(14) acceptance of a high value escrow,

(15) prevention of and defeat of fraud, and

(16) vandal-proofing.

2.3 OVERALL CONFIGURATION OF VENDOR

The HRTV is shown in Figure 3, and has been designed to be hung from the wall. Some physical characteristics include:

- overall cabinet dimension

  53 3/4 in. high
  36 in. high
  20 1/2 in. deep

- weight

  325 lb (approx.)

- line input current at 110V. AC (transit power)

  0.6A stand by
  2.0A ticket vend
  1.9A major fault (all lights on, and vendor removed from service)

The top of the steel cabinet shown in Figure 3 is 69 in. above the floor.

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[4]This was a policy decision. Change is available at dollar bill changers located near the vendor. Addition of a change maker to the HRTV is considered to be a minor retrofit.

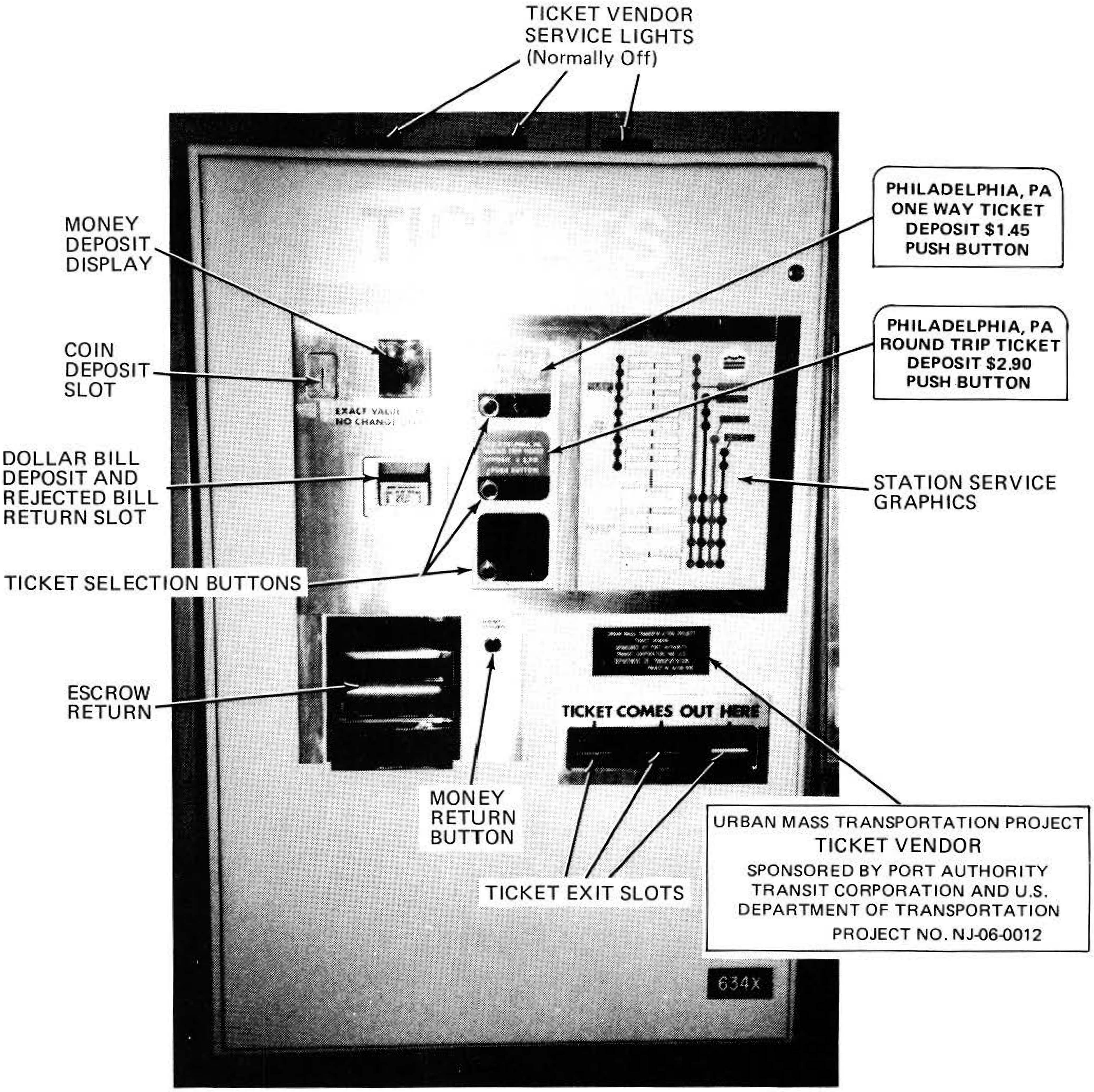

FIGURE 3. HIGH RELIABILITY TICKET VENDOR-OPERATIONAL CONFIGURATION

Provision has been made for the placement of a Braille plaque in the area presently covered by the station service graphics. A plaque was prepared, but its installation has been delayed and awaits confirmation of its helpfulness to the visually impaired.

2.4 INTERFACES WITH THE PUBLIC

Figure 4 presents a flow chart of the sequence of patron inputs and vendor responses that take place during the process of ticket sale. The HRTV is an exact change machine, and a ticket will only be vended if the money deposited equals the value of the ticket. A ticket will not be dispensed if overpayment is made.

On the top left of Figure 4, the process of ticket purchase begins with START followed by DEPOSIT MONEY. [5] The HRTV accepts dollar bills, Susan B. Anthony (SBA) dollar coins, quarters, dimes, and nickels. The HRTV currently dispenses tickets valued at $ 1.45 and $2.90, and any combination of bills and coins that add up to these values can be deposited in any order; it is possible to use two one dollar bills for the higher priced ticket. When a bill is deposited, the vendor assesses whether a VALID BILL? has been deposited. If the bill is inserted into the bill slot with the incorrect orientation, relative to the required input orientation, or has a value greater than one dollar or is badly worn or counterfeit, then the bill will be rejected (REJECT BILL). Rejection takes place at the bill deposit slot, shown in Figure 3. If the bill is accepted, then the BILL GOES TO ESCROW within the vendor, and the AMOUNT DEPOSITED IS DISPLAYED. Vendor logic determines whether each coin deposited is a VALID COIN? If a one cent coin is deposited, or a slug is deposited, then the state VALID COIN? NO, exists and all coins and bills deposited will RETURN (from) ESCROW. If a VALID COIN? YES state exists, then the COIN GOES TO ESCROW and the AMOUNT DEPOSITED is displayed. The next step in the sequence is TICKET BUTTON IS PUSHED.

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[5] Capitalized words refer to flow chart of Figure 4.

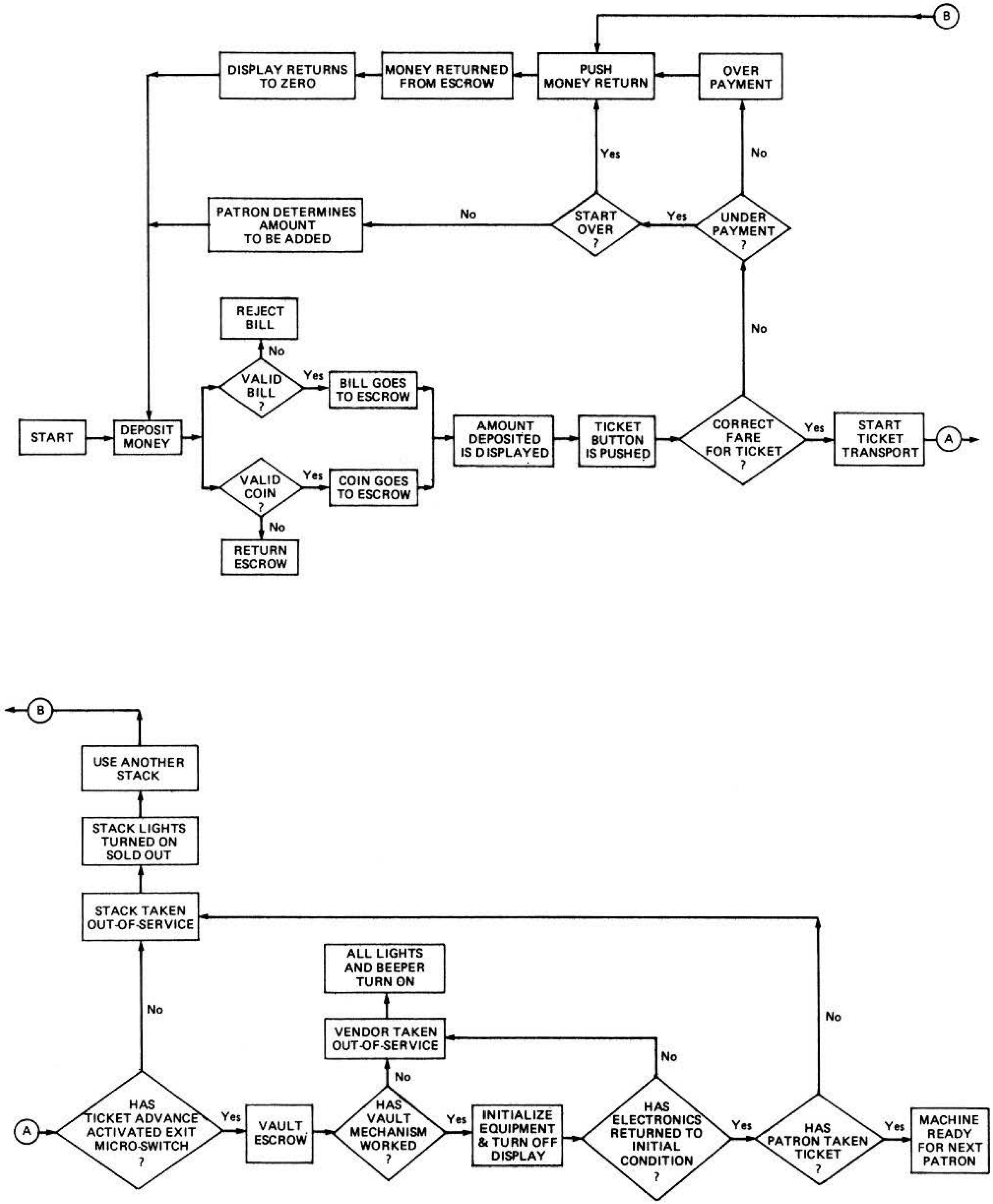


FIGURE 4. HIGH RELIABILITY TICKET VENDOR OPERATIONS FLOW CHART

If the CORRECT FARE FOR TICKET? NO is determined by the vendor logic, then either an underpayment or overpayment has been made. For UNDERPAYMENT? YES, the next step is to START OVER? If the NO branch of start over is followed, the PATRON DETERMINES AMOUNT TO BE ADDED and DEPOSIT(s) MONEY, and the initial phase of DEPOSIT MONEY is repeated. If the YES branch of start over is followed, then it is necessary to PUSH MONEY RETURN, immediately after which the MONEY (is) RETURNED FROM ESCROW, followed by DISPLAY RETURNS TO ZERO. The patron must then DEPOSIT MONEY and repeat the process. If the UNDERPAYMENT ? NO branch is followed, then an OVERPAYMENT has been made, and the patron must PUSH MONEY RETURN and follow the sequence shown in Figure 4 which will lead to return at all money and require the patron to start over, i.e., DEPOSIT MONEY.

If the correct fare is deposited then the CORRECT FARE? YES branch is followed, and the START TICKET TRANSPORT process begins. A sensor determines HAS TICKET ADVANCE ACTUATED EXIT MICRO-SWITCH? If the response is NO, then the STACK (is) TAKEN OUT OF SERVICE, and STACK LIGHTS (are) TURNED ON. The patron must USE ANOTHER STACK, PUSH MONEY RETURN, and repeat the process at DEPOSIT MONEY.

The purpose of the exit micro-switch is to ensure that if the ticket is not dispensed, the patron can get his/her money back. If the HAS TICKET ADVANCE ACTUATED EXIT MICRO-SWITCH ? YES, then the next step is for the vendor to VAULT ESCROW and capture the money. Another sensor determines HAS VAULT MECHANISM WORKED ? If NO, then the VENDOR (is) TAKEN OUT-OF-SERVICE and ALL LIGHTS AND BEEPER TURN ON. If HAS VAULT MECHANISM WORKED? YES, then the vendor INITIALIZE(s) EQUIPMENT AND TURN(s) OFF DISPLAY. The vendor then performs a self-test to determine HAS ELECTRONICS RETURNED TO INITIAL CONDITION? If NO, then the VENDOR (is) TAKEN OUT-OF-SERVICE, and if YES it is next determined HAS PATRON TAKEN TICKET? If the answer is NO, then the STACK (is) TAKEN OUT-OF-SERVICE and if YES, then the MACHINE (is) READY FOR NEXT PATRON.

During the ticket transaction process, the only read-time process information provided by the HRTV to the patron is (1) the amount of money that has been deposited, and (2) appearance of stack light(s) and beeper in the event of equipment failure.

Figure 5 shows the HRTV, after it is removed from service. The three lights on top are lit; the place where the amount of money deposited is normally displayed is lit to read OUT OF ORDER, and the displays which are in line with the ticket buttons and normally dark show the words SOLD OUT. A low volume beeper is also turned on to discourage further usage. Lights atop the vendor are viewed by a continuously monitoring CCTV camera located within the station (see bottom photo in Figure 2), and can be interpreted by an operator at PATCO's control center located in Camden, New Jersey who then dispatches a service person to correct the problem. When a single stack is OUT-OF-ORDER (or out of tickets), one light atop the vendor as well as the SOLD OUT light for the particular ticket dispenser turns on.

If the patron needs assistance in using the vendor, there is a Call-For-Aid telephone (see bottom photo of Figure 2) which puts him/her in direct contact with PATCO's control center. The phone and turnstiles are also under surveillance by a CCTV camera (see bottom photo of Figure 2). If the proper funds have been deposited and a vendor does not deliver a ticket, the control center, after telephone notification, can unlatch the turnstile and allow the patron to enter the system; since the patron entered without a ticket, it is necessary for him/her to call the control center at the destination station so the turnstile can be unlatched to permit exit.

2.5 VENDOR SECURITY

Vendor security refers to the protection of the HRTV against (1) overt and covert attack by the public, and (2) theft of revenue by employees.

2.5.1 External Security

The vendor and its contents are protected from overt attack through design of a steel cabinet which provide penetration delay time, and the presence of a CCTV monitoring system which allows for early detection. When an attack is

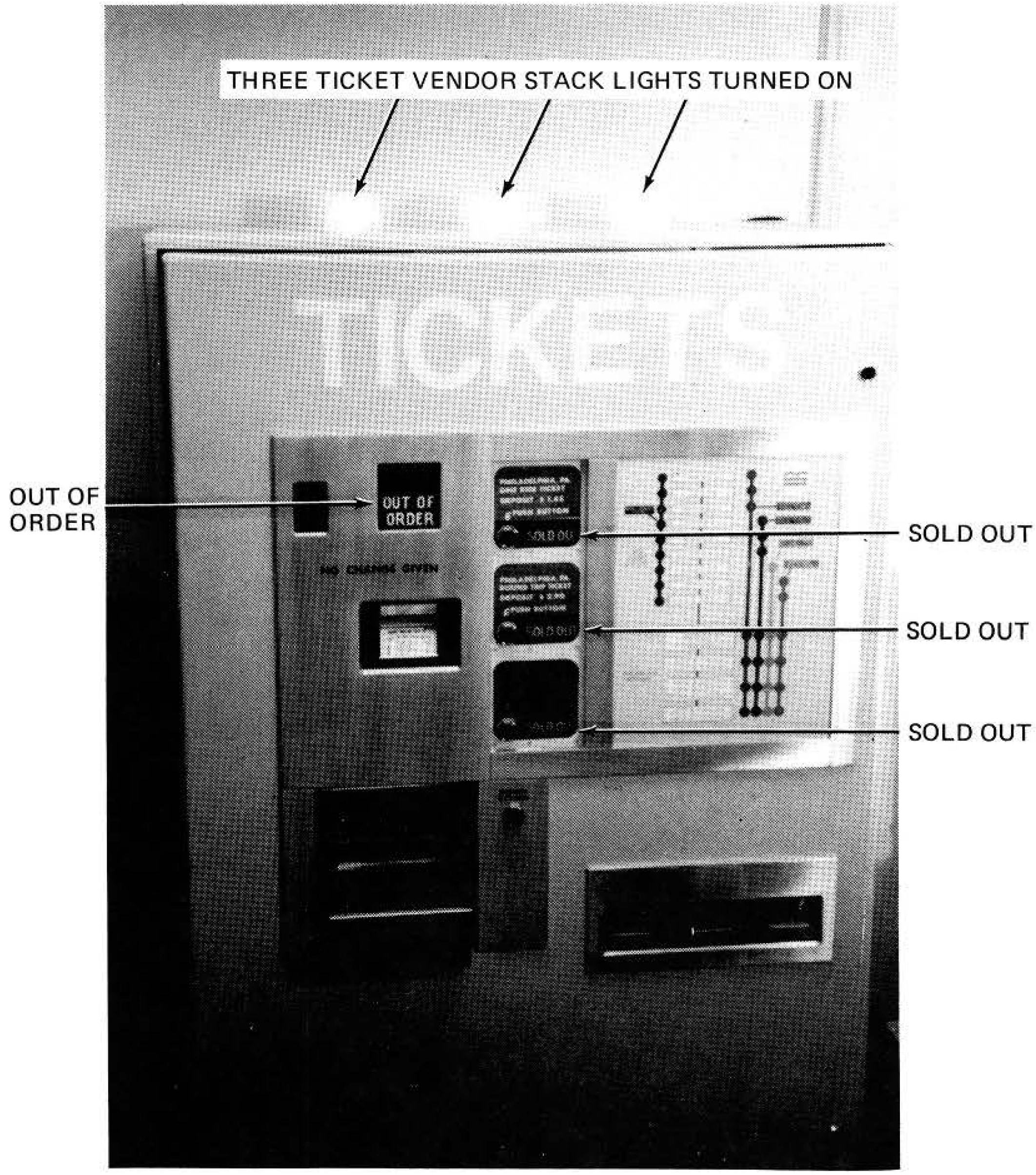


FIGURE 5. HIGH RELIABILITY TICKET VENDOR - REMOVED FROM SERVICE CONFIGURATION

observed, the PATCO security person would notify the police, and through a loud speaker located in the station could also at his/her option notify the attacker that the police are on the way.

If the attacker could manage to open the vendor door, it would then be necessary to defeat a padlock to get at the dollar bills stored in the bill vault and another padlock to get at the coins stored in the coin vault. The tickets are not secured.

The principal mode of covert attack would be through the deposition of counterfeit bills and slugs. As a result of the multiple tests that can be performed on paper money by the bill acceptor, collection of counterfeit money by the HRTV is negligible. Like other transit properties, PATCO acknowledges revenue losses resulting from the use of slugs and tolerates it to a limit. When the rate of slug deposits becomes unacceptable, an integrated police/revenue department procedure is instituted to help capture the offending person(s). First, the revenue department determines the time of day the slugs are being deposited. This is accomplished via more frequent revenue collections about the time the slugs are being deposited, to help pinpoint a time pattern. After a pattern of slug passing has been formulated, a police officer in plain clothes observes the patrons conducting transactions with the vendors with the intention of apprehending the cheat.

It is not possible for the vendor to issue a ticket and return the monies held in escrow if for example a patron should push both buttons. Once the advancing ticket activates the exit micro-switch, the monies are vaulted and a ticket is issued. In the event the exit micro-switch is not activated by the ticket, then the monies will be returned from escrow. If the ticket advance micro-switch does not work, the stack is taken out of service and the stack light(s) is turned on; and if the vault mechanism does not work, the vendor is taken out of service and all the stack lights turn on. These lights alert the security person located at the control center to request that maintenance action be taken.

2.5.2 Internal Security

Both revenue personnel and maintenance personnel can gain access to the interior of the cabinet, but only the revenue personnel have keys to unlock the padlocks on the bill vault and the coin vault. Accountability for the tickets is maintained by a pair of electromechanical counters one of which indicates when a ticket is vended and the other when a ticket is taken. The monies deposited can be accounted for by the mechanical counter attached to the picker arm of each ticket stack; the arm can only be commanded to move forward, if the exact amount money required for the ticket has been deposited.

3.0 SUBSYSTEM DESCRIPTION

The major subsystems that comprise the HRTV include:

(1) bill acceptor,
(2) bill escrow,
(3) bill vault,
(4) coin acceptor,
(5) coin escrow,
(6) coin vault,
(7) ticket dispenser(3),
(8) command/control,
(9) transaction/ticket counter(9),
(10) power supply, and
(11) cabinet.

Photographs of the HRTV were taken with the cabinet door open, and are presented in Figures 6 and 7. Figure 6 shows the subsystems that are attached to the door, and Figure 7 shows the subsystems attached to the frame.

3.1 BILL ACCEPTOR SUBSYSTEM

The HRTV utilizes a Rowe model BA-5 dollar bill acceptor. PATCO's experience with this device in their other vendors has proven satisfactory. Technical and operational data pertaining to this bill acceptor is available from the manufacturer and is not reproduced here. This subsystem is composed of two units; the transport mechanism show in Figure 8 is located on the door, and the verifier is located in this electrical locker at the top of the frame (see Figure 7). The function of the transport mechanism is to receive the bill oriented in manner indicated at insert slot, and scan the bill to determine that it is an authentic one dollar bill. The scanning data is transmitted to the bill verifier via hard wire, and the verifier has the capability to accept reasonably worn dollar bills and so minimize customer annoyance with regard to rejection. Bills that are of a value other than one dollar or inserted with the improper orientation or are too worn for positive identi-

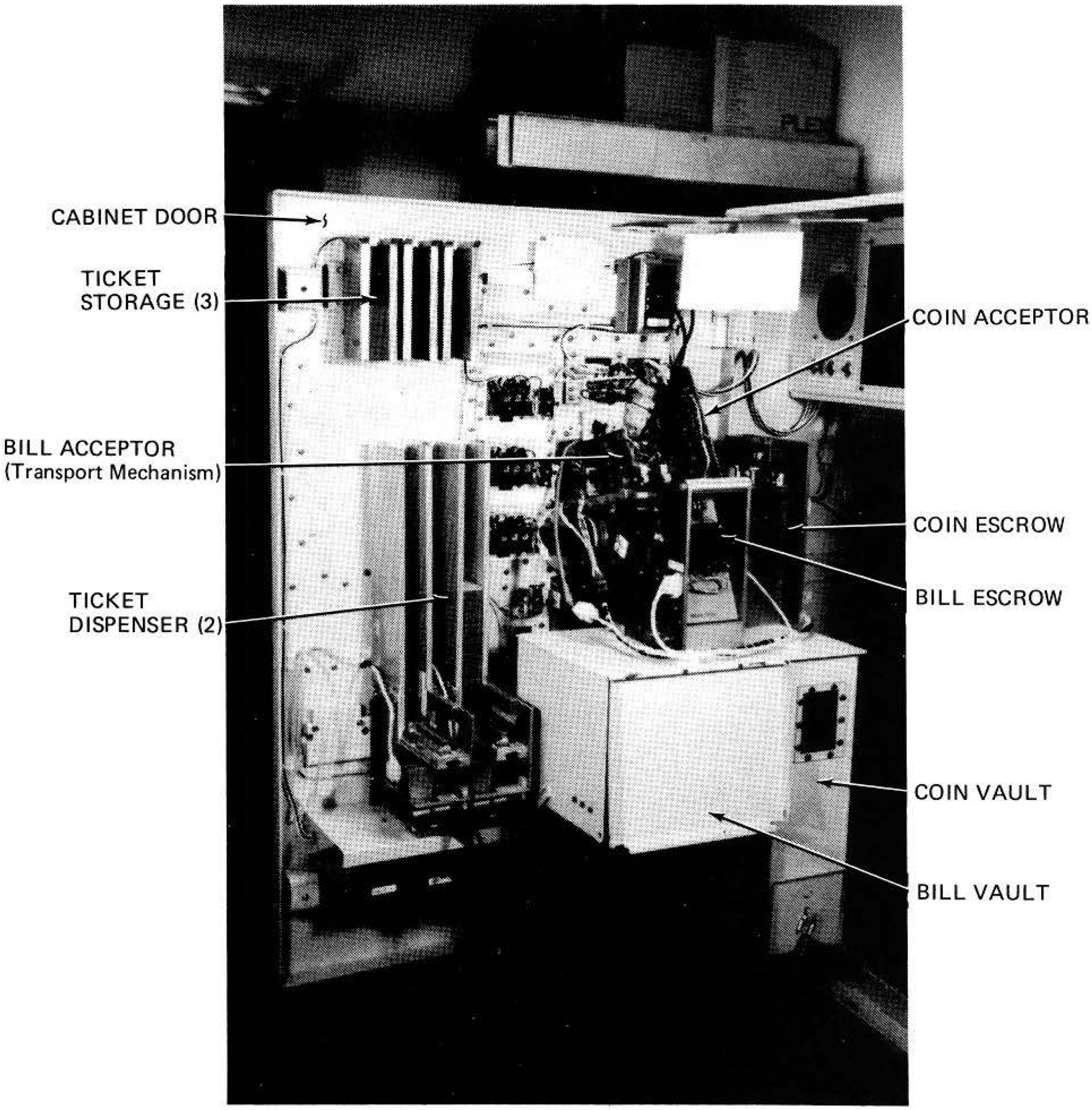


FIGURE 6. HRTV SUBSYSTEMS ATTACHED TO DOOR

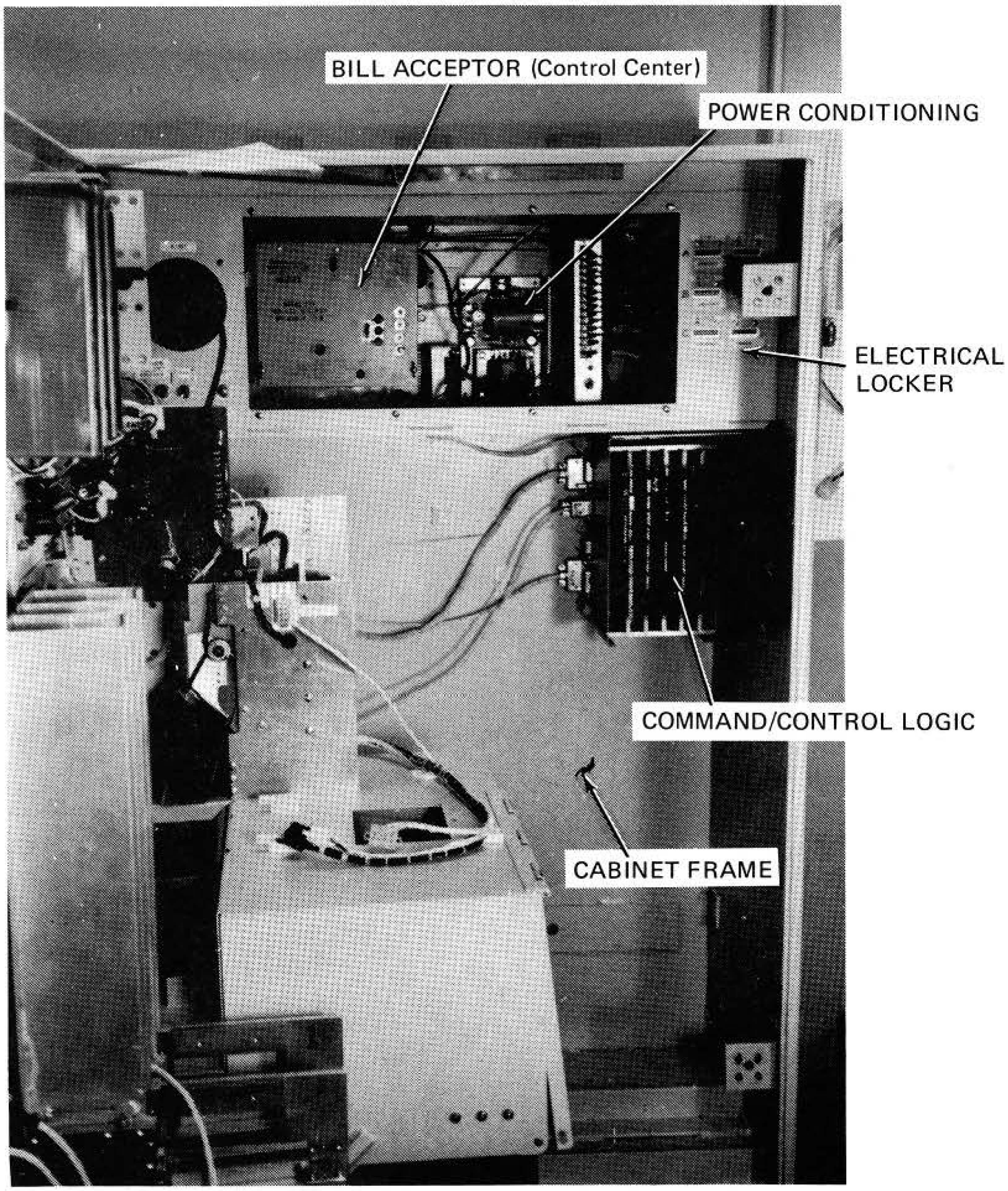


FIGURE 7. HRTV SUBSYSTEMS ATTACHED TO FRAME

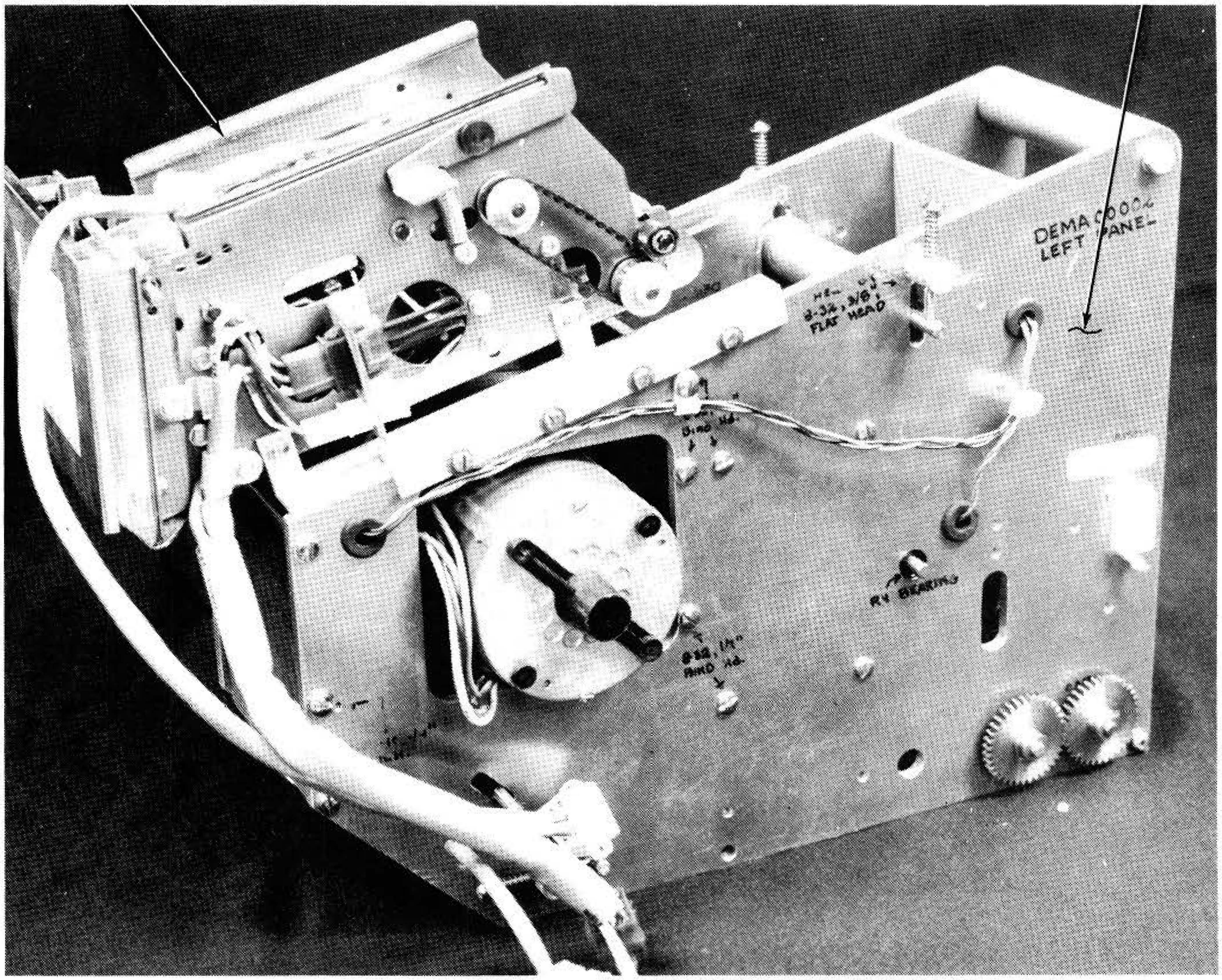


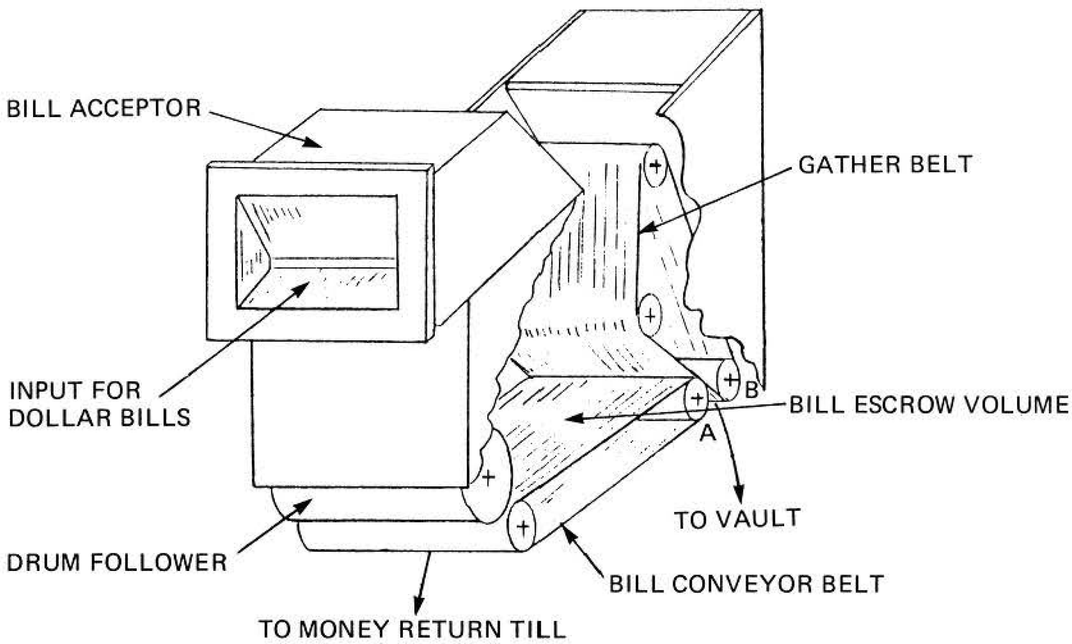
FIGURE 8. BILL ACCEPTOR (Transport Mechanism) AND BILL ESCROW SUBSYSTEM

fication or counterfeit are returned to the patron. The validator measures three properties to determine whether a bill is valid; these include (1) frequency generated by the magnetic ink lines on the bill in two fixed locations as the bill moves at a fixed speed and direction, (2) and optical measure of bill size, and (3) magnetic properties of the bill. If the bill is accepted, it is deposited in the bill escrow subsystem, the amount of the deposit is recorded in the control logic, and the amount of one dollar is added to the LED display readout on the front of the cabinet door as shown in Figure 3.

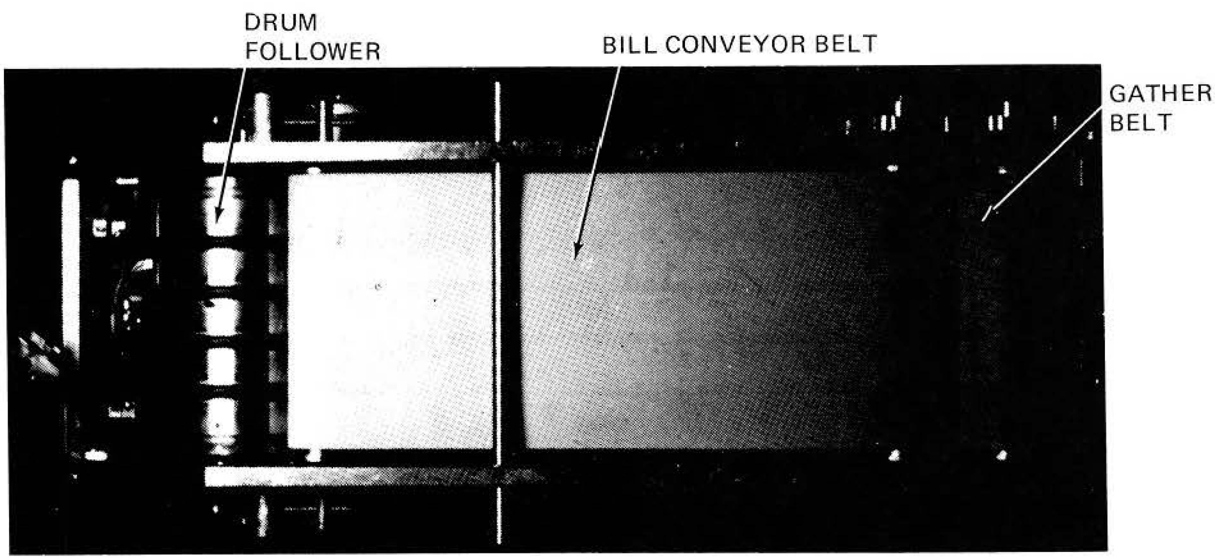
Bill jamming and acceptance are the biggest problems associated with bill validators; acceptance is the ability of the unit to identify a valid bill presented in a proper manner in a single trial. It is to be noted that the Rowe BA-15 unit has superseded the BA-5. Also, the Illinois Central Gulf Railroad is developing a bill validator under a UMTA grant.

3.2 BILL ESCROW SUBSYSTEM

The bill escrow subsystem developed by PATCO is also shown in Figure 8. As the bill falls from the bill acceptor transport mechanism, it lands on a conveyor belt which can move in either of two directions. This volume (shown in Figure 9) above the belt can accept a large quantity of bills. Each subsequent bill deposited by the patron is dropped onto the conveyor belt. The bills are stored until the patron makes his/her selection. If the money return button is pushed, the bill escrow motor drives the conveyor belt shaft A (see Figure 9) in a counterclockwise direction that moves the belt and with it the bills towards the drum where the bills are forced through the interface between the belt and drum, and drop into the return till. The patron gains access to the bills through he opening in the door to the right of the money return bottom (see Figure 3). If a ticket selection is made, and the correct sum of money has been deposited, the conveyor belt which is turned in a clockwise direction by shaft A and the gather belt which is turned in a counterclockwise direction by shaft B, together force the bills to squeeze through these belts after which they fall into the vault.



ARRANGEMENT OF BILL ESCROW VOLUME AND BILL MOVEMENT MECHANISMS



BOTTOM VIEW OF BILL ESCROW SUBSYSTEM

FIGURE 9. INTERNAL CONFIGURATION OF BILL ESCROW SUBSYSTEM

Operation in either direction is for two seconds. This has been determined as the maximum time needed to move all bills from escrow and deposit them in the return till or vault. A signal generated during rotation of the conveyor belt shaft (both clockwise and counterclockwise) is used during processing as a triggering mechanism in the control logic to keep account of the stage of the transaction.

Belt and housing angles are designed to permit smooth flow paths in both directions. Standard components have been used throughout the design of the subsystem to ease maintenance. The component that is expected to have the shortest life are the belts. It is expected that the roller bearings which are operated at low speed and with reduced loading should provide long-lived service.

3.3 BILL VAULT

After the ticket button is pushed following deposit of the exact fare value, the belt rotates so as to allow the bills to drop from escrow and they fall freely into the bill vault, presented in Figure 10 which was designed by PATCO. To gain access to the vault, the revenue person uses a key to open a padlock which secures the vault. After the door is swung up to provide access to the vault, the vault is then pulled out on glides. A sheet metal transition cone which rests on top of the vault, used to constrain the motion of the bills during their full from escrow, is removed to allow for easier bill removal. The bills are scooped out by hand.

3.4 COIN ACCEPTOR SUBSYSTEM

Coins which are deposited by the patron must be assessed for value and authenticity. The PATCO developed coin acceptor employs electro-optics to perform this function rather than mechanical methods conventionally used. The coin acceptor is shown in Figure 11.

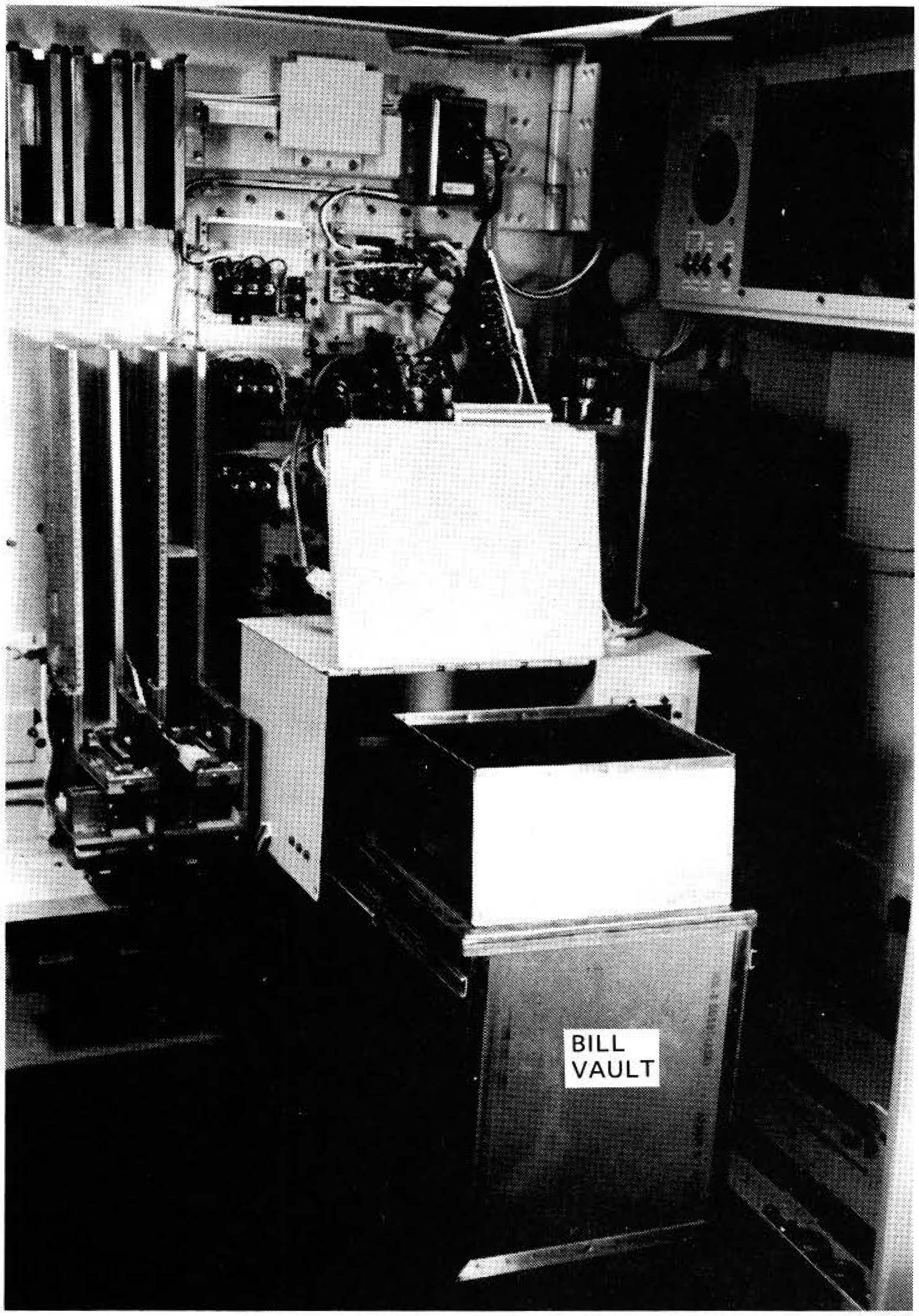


FIGURE 10. BILL VAULT SUBSYSTEM

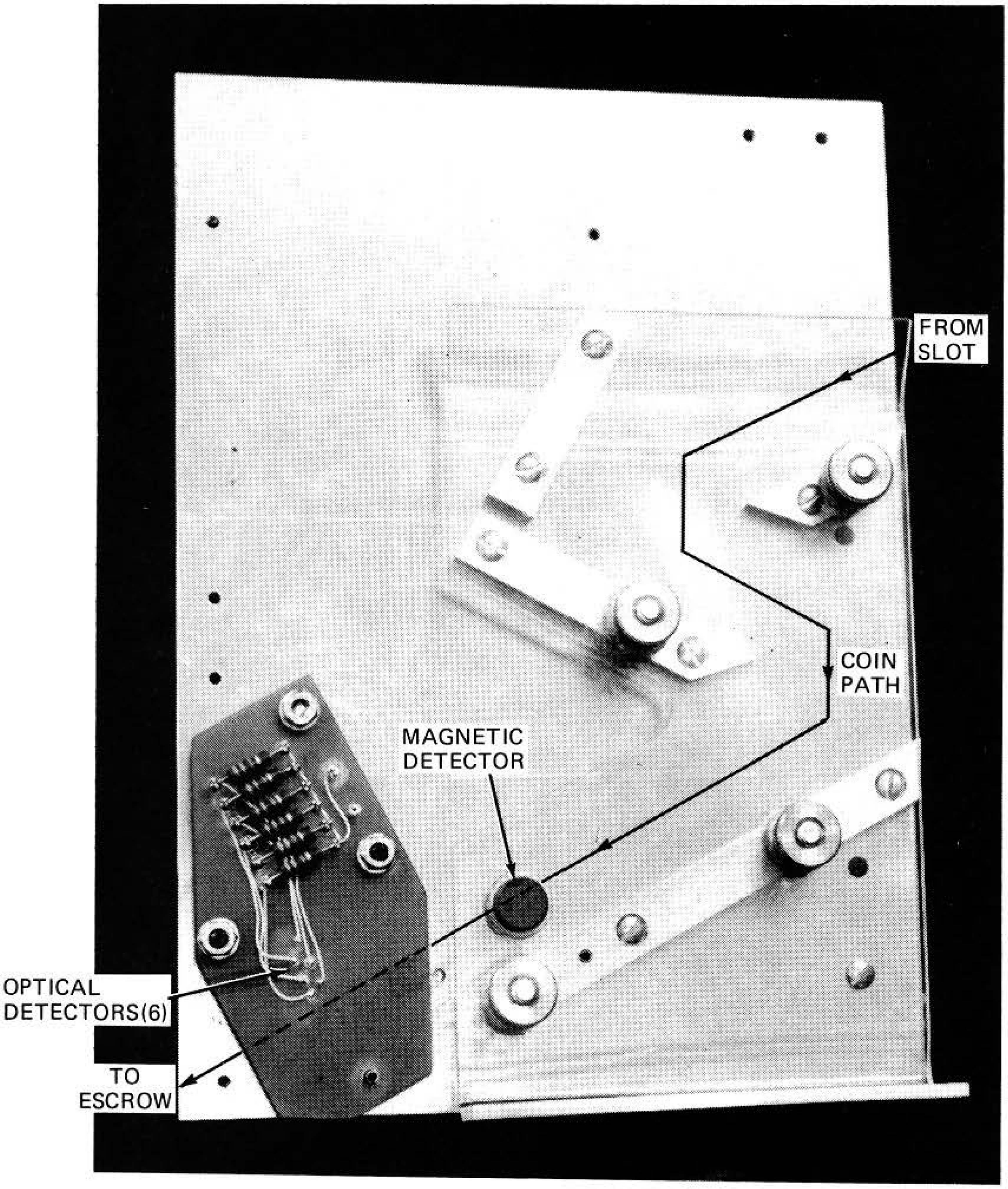
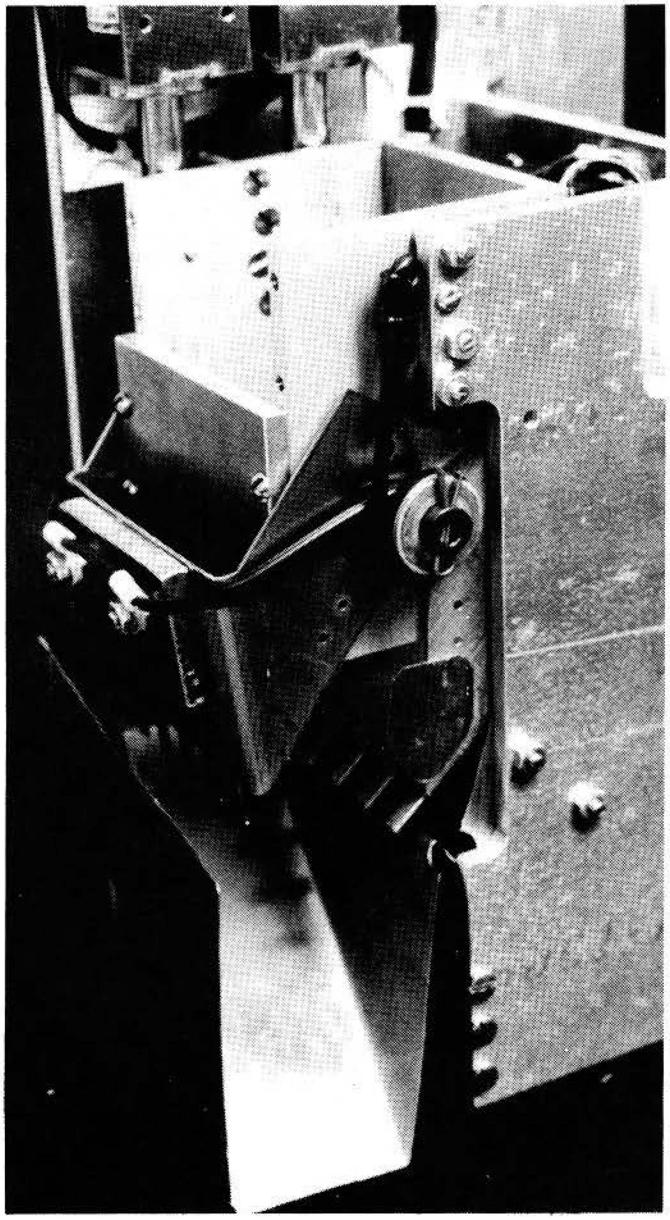


FIGURE 11. COIN ACCEPTOR (BOARD) SUBSYSTEM

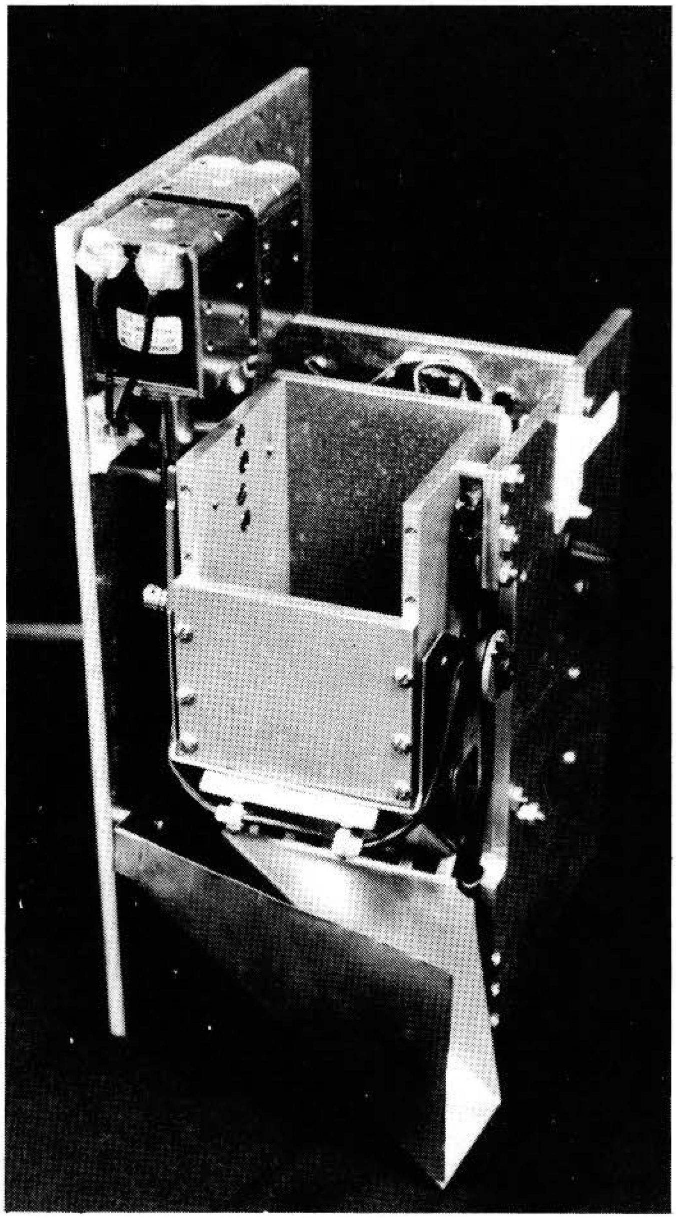
The entering coin follows a multi-directional path through the detection apparatus. Ultimately, the coin ends up on the coin slide and on a path which in turn breaks an optical circuit which in turn provides the signal for validation and value. An amplifier is provided to boost the electrical output from the optical sensor. This amplified signal is sent via cable to the control logic for coin counting. The optical network is set up in a pattern which tests for the size of coins: nickel, dime, quarter, and SBA dollar. This hole pattern is arranged to measure coin diameter. In addition to validation by size, the coin must pass a ferro-magnetic detector. If the coin is accepted by both tests it is held in escrow and if the coin is rejected by either one of the two tests, it is rejected along with all valid coins and bills that are being held in escrow. If a cent is deposited, the coin acceptor will treat it as if it were a slug, and all coins and bills being held in escrow including the cent would be rejected. Provision has been made by PATCO for the addition of a slug detector to the HRTV's coin acceptance logic.

3.5 COIN ESCROW SUBSYSTEM

The coin escrow subsystem developed by PATCO accepts all validated coins that have passed through the coin acceptor. Each validated coin deposited during the transaction is stored in the escrow volume. The coin escrow as shown in Figure 12 is a metal hopper that is split into two halves and pivoted about a central location. Each half of the hopper jaws is attached to a solenoid which, when activated, pulls on that half of the hopper, separating it from the other and allowing the coins to fall out. The hopper operates in a manner which prevents the coins from lodging or from jamming the hopper during storage or dumping. Each solenoid is electrically connected to the control logic. Upon patron request to return his/her deposit, the proper solenoid is activated and money released to the till (see photo on left in Figure 12). When the ticket selection is made, the money is directed to the coin vault which is separate from the bill vault (see photo on right in Figure 12). The hopper opening is interconnected with the bill escrow return mechanism to provide two seconds of solenoid activation. The hopper is situated above chutes that meet directly below the hopper opening centerline. Upon the



COIN ESCROW RETURN MONEY CONFIGURATION



COIN ESCROW VAULT MONEY CONFIGURATION

FIGURE 12. COIN ESCROW SUBSYSTEM

activation of either solenoid, the attached hopper section opens over the proper chute. This opening action assures that the coins are delivered to the correct chute. The coin return chute opens into the same till area as the bill returns, while the vault chute directs the coins to the coin vault.

The unit has been designed with security features should faults occur. Particularly, should a coin be jammed and the hopper jaw halves remain open, a micro-switch has been so arranged that if it is not closed the entire vendor unit is shut down.

3.6 COIN VAULT SUBSYSTEM

PATCO designed this subsystem shown in Figure 13 which stores the coins in a locked container. Figure 13 shows the bottom of the coin vault in an open position for extraction of collected funds. To gain access, the revenue person places a bucket under the vault, uses a key to unlock the padlock, and when the shackle of the lock is pulled out of the hasp, the door to the vault swings open, and the coins drop out.

3.7 TICKET DISPENSER SUBSYSTEM

The PATCO developed ticket dispenser is shown in Figure 14. This unit uses a stack loader which is compatible with the existing tickets. The stack is sized to hold up to 1,500 tickets. The primary concerns identified prior to design were issuance of bent and split tickets (since PATCO tickets are recycled), issuance of only one ticket, prevention of jamming, and ease of adjustment. A typical PATCO ticket is show in Figure 15. The magnetically enclosed plastic tickets are about half the thickness of a credit card.

At the command to dispense a ticket a rod powered by a rack and pinion drive moves forward. Located at the front of the rod there is a three-point gimballed jig supporting two blocks and on the top of each of the blocks there is a raised surface 0.0075 ± 0.0005 in. above the block plane. These raised surfaces, called pickers, (see Figure 16) make contact with the ticket and pushes it out through the exit throat. Use of three-point gimbals in the

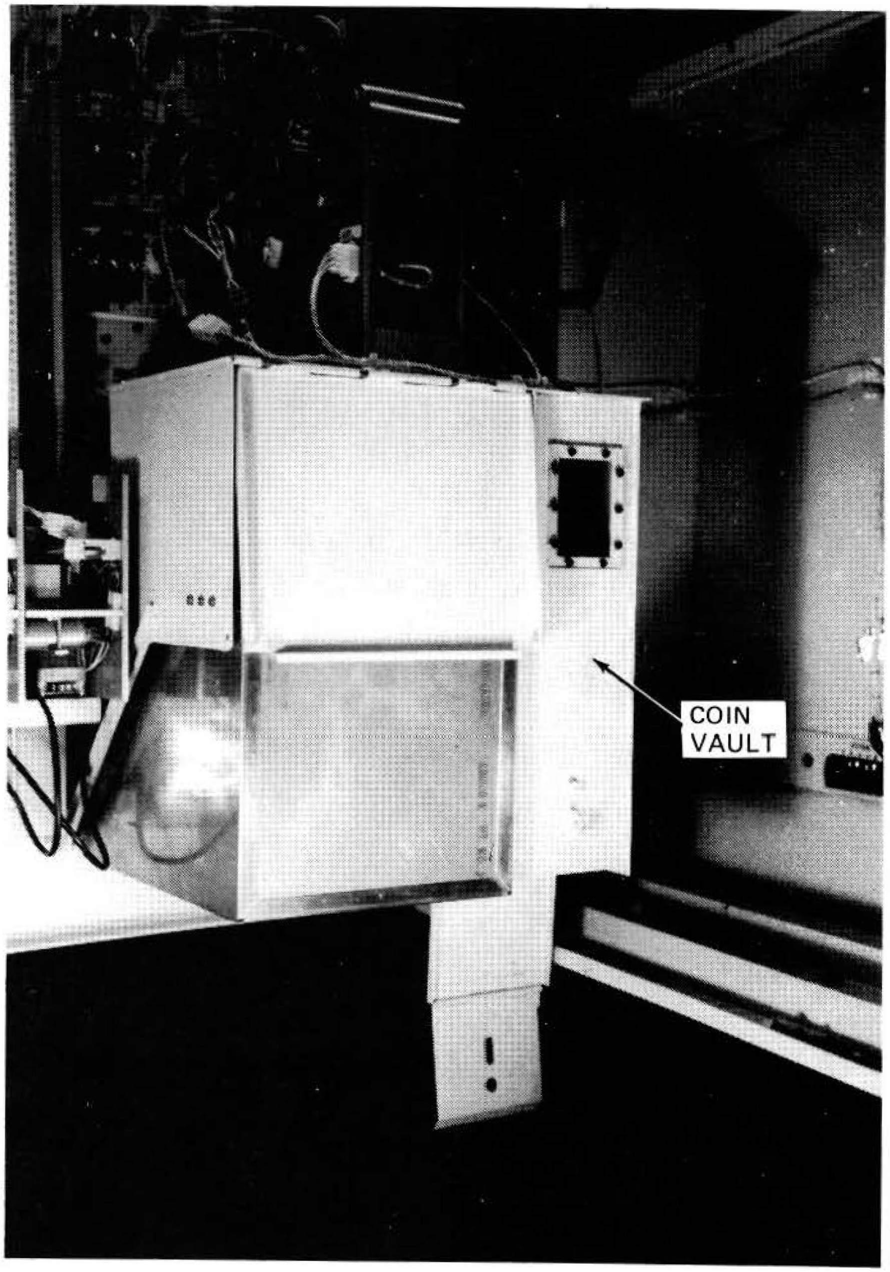


FIGURE 13. COIN VAULT SUBSYSTEM

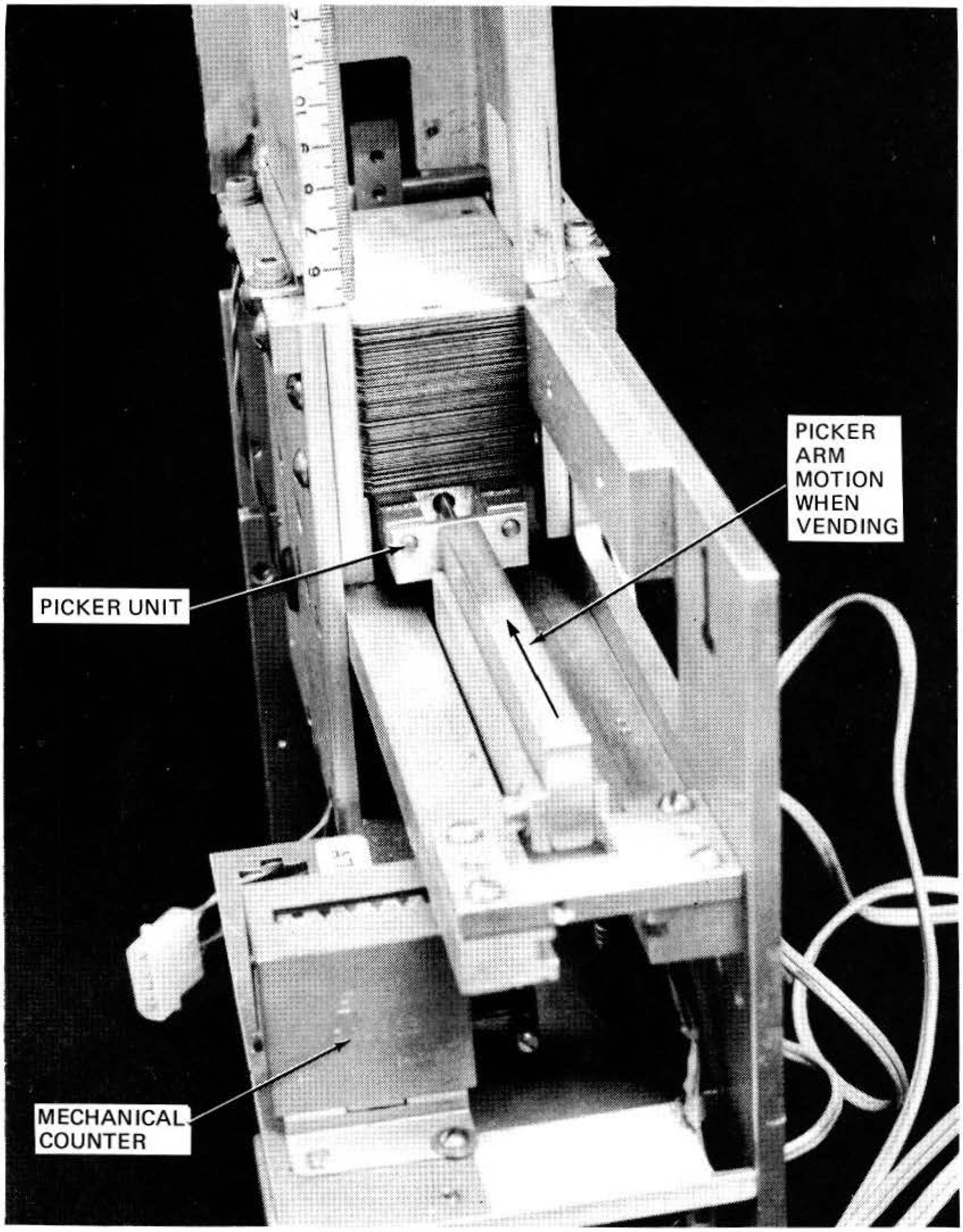


FIGURE 14. TICKET DISPENSER SUBSYSTEM.

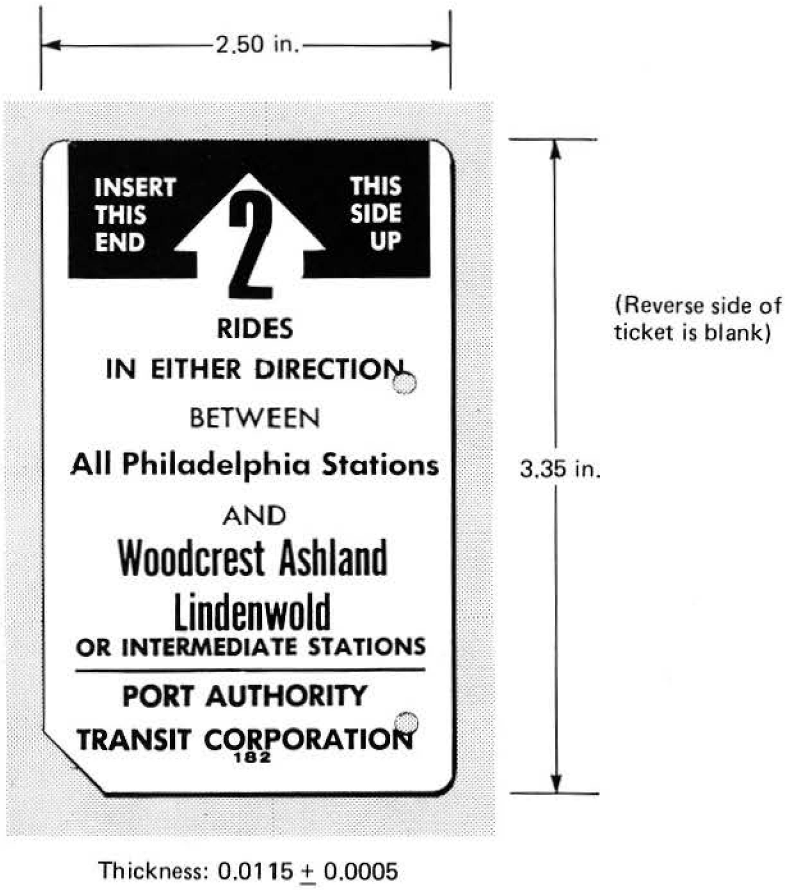


FIGURE 15. PATCO'S MAGNETICALLY ENCODED TICKET

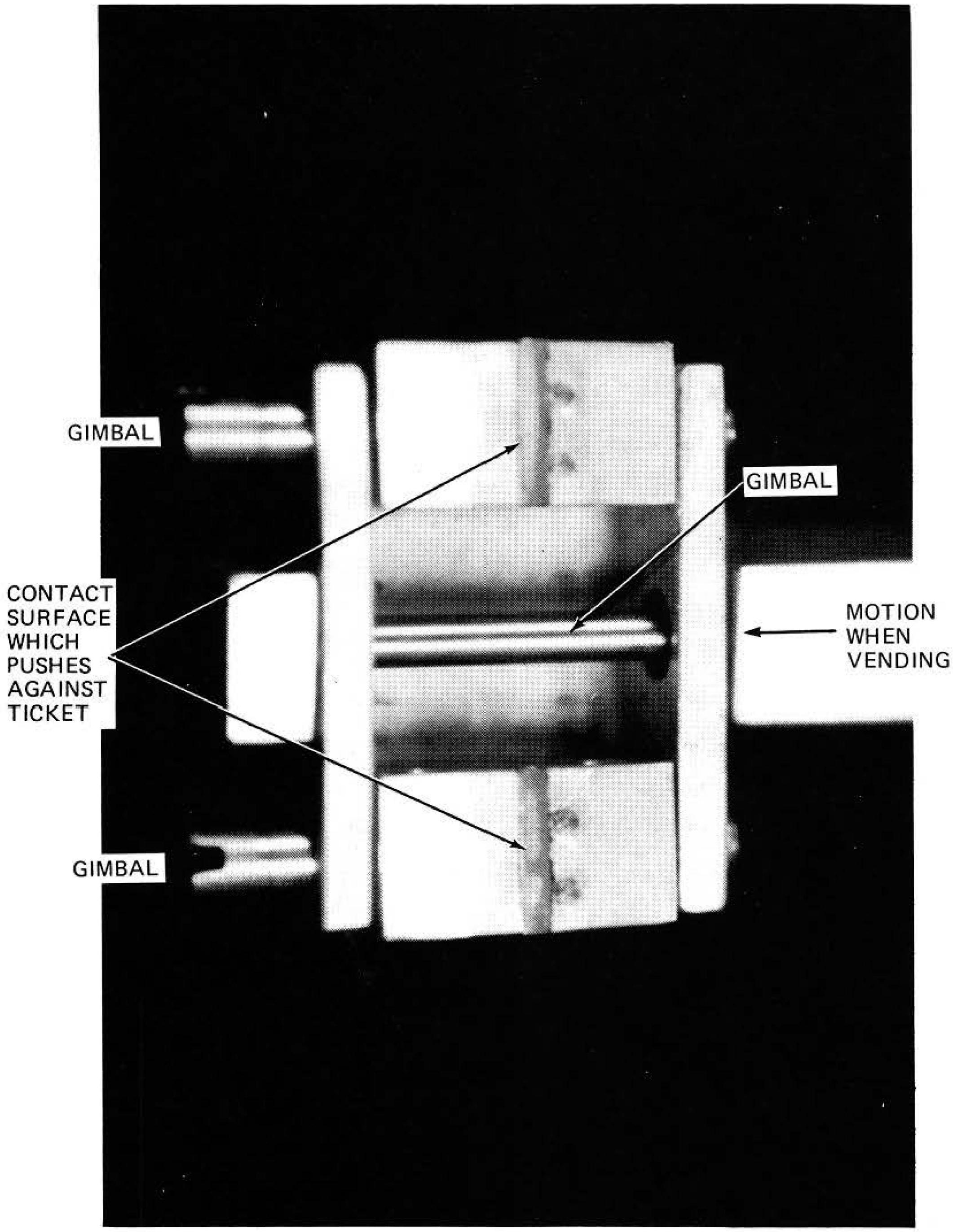


FIGURE 16. TICKET DISPENSER PICKER UNIT

picker provides the necessary degrees of freedom to allow the contact surface to conform to the variations in ticket shape and stacking irregularities. The ratio of picker height to ticket thickness is 0.65, and was based on the requirement to dispense only one ticket at a time and the need to have sufficient contact surface over which to exert the force with which to push the ticket out.

The three-point gimbal joint allows for movement of the picker to accommodate variations in ticket position caused by ticket warpage. Since the system can respond to warpage, there is no necessity to add a dead weight to the top of the ticket stack to remove the effect of warpage. The penalty for the dead weight is a reduction in height of tickets so as to keep the force required to overcome sliding friction between tickets compatible with other mechanical adjustments. A large stack of tickets reduces the number of refills by revenue personnel.

3.8 COMMAND/CONTROL SUBSYSTEM

The operational logic presented in the flow chart of Figure 4 is controlled by the command/control subsystem designed and built by PATCO using CMOS logic. This subsystem is located below the electrical locker as shown in Figure 17. All signal transmission within the HRTV is via hard wire. There are five plug-in boards that have been wire wrapped for the prototype model; the production model will use printed circuits where possible.

Within the control boards there are a series of in-line test points for convenient trouble-shooting of the various logic/control circuits. The voltage level at these points is normally zero. To find the circuit which has failed the repair technician runs his/her voltmeter leads along the test points located along the outside edge of the five boards; a non-zero reading indicates a fault.

3.9 TRANSACTION/TICKET COUNTER

There are three transaction/ticket counters for each of the three ticket stacks. These counters are non-resettable, i.e, can only be advanced) and

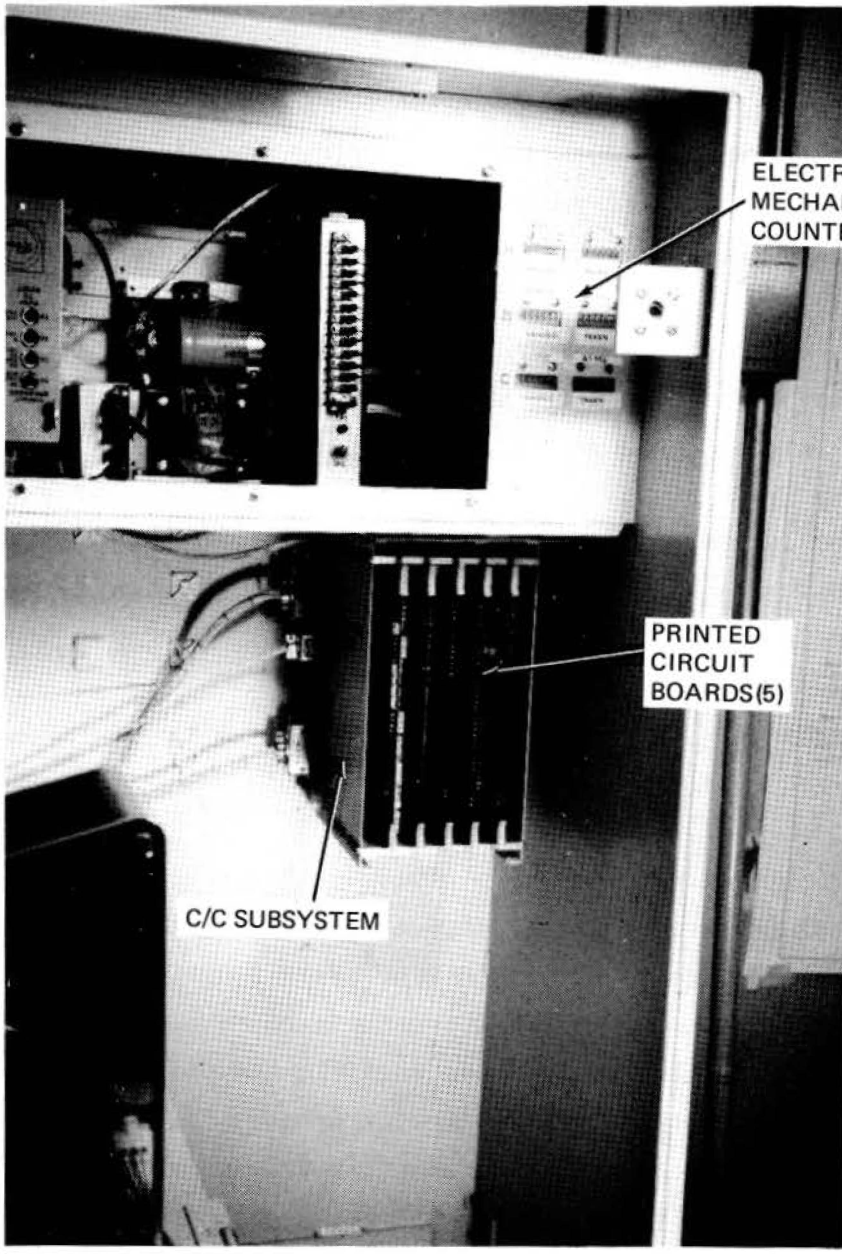


FIGURE 17. COMMAND/CONTROL SUBSYSTEM

used to reconcile the money deposited with the number of tickets sold. The counters include:

(1) a mechanical counter (see Figure 14) which changes by one unit every time the picker arm moves forward,

(2) a ticket-vend electromechanical counter (see Figure 17) which changes by one unit every time a ticket enters the throat of the exit plate and closes a micro-switch, and

(3) a ticket-taken electromechanical counter (see Figure 17) which changes by one unit every time a patron takes a ticket which allows a micro-switch to open.

The ticket-taken counter provides the accountability for the number of tickets sold; the ticket-vend counter is used to provide accountability for the total money deposited; and the mechanical counter on the picker unit provides back-up should an electromechanical counter fail.

3.10 POWER SUPPLY SUBSYSTEM

The input power to the vendor is 110v. AC. All power-conditioning equipment is located in the electrical locker shown in Figure 7. Power is supplied at 110v. after filtering, to the bill verifier and the drive motors for the bill transport mechanism, the escrow unit, and the vendors. Filtered 110v. power is dropped to 12v., and after full wave rectification is used to power the lamps. The power used for the control electronics is 12v. DC that has been massively conditioned through the use of an LC filter, varactor, and a switching voltage regulator.

3.11 CABINET SUBSYSTEM

The cabinet designed by PATCO to house all the subsystems is built of 3/16 in. welded steel plate to provide maximum security. It is attached to the lobby wall by a system of bolts that are accessible only after the vendor door is opened. The door is secured by two locks, and the vendor is continuously monitored by a CCTV.

4.0 TEST AND EVALUATION

This section presents the results of a test program designed to compare the High Reliability Ticket Vendor (HRTV) with the other ticket vendors to the extent possible and the three objectives/purposes of the test program were to:

(1) evaluate and compare the reliability and maintainability of the HRTV and the other ticket vendors within the station,

(2) evaluate patron service time, i.e, the time from initiation of money deposit to receipt of a ticket for the HRTV and the other ticket vendor, and

(3) utilization of the HRTV and other vendors by the patrons.

Data are also presented for (1) operational performance of the HRTV at low temperature and at low voltage, and (2) the accuracy of reconciliation of the tickets dispensed and currency deposited into the HRTV as well as other ticket vendors.

4.1 STATION CONFIGURATION

Figure 2 presents the configuration of the Lindenwold (New Jersey) Station where the tests were conducted. A close-up of the ticket vendors is shown in Figure 18 and the vendor equipment located at the station is described in Table 1. Vendor B which was similar in operation to Vendor D was removed to make a space available for the High Reliability Ticket Vendor (HRTV) also referred to as Vendor X.

4.2 EVALUATION OF RELIABILITY AND MAINTAINABILITY

In the development of a test plan, it was assumed that if the failure rate of the HRTV was one-half that of the Advanced Data System ticket vendor, then it would be necessary to collect data over a five month period to have a 95% confidence that the performance being observed was due in fact to improvements in

FIGURE 18. ARRAY OF TICKET VENDORS AT LINDENWOLD STATION

TABLE 1
VENDING EQUIPMENT AT LINDENWOLD STATION

TICKET VENDORS

PATCO EQUIPMENT NO.	MANUFACTURER	MONIES ACCEPTED [3]	CHANGE GIVEN OR EXACT VALUE	TICKETS SOLD	STACK CODE [4]
634 A	Advanced Data Systems [1]	Coins	Change Given	$1.45 Phil. One-Way 1.50 N.J. Round Trip	A B
634 X	PATCO[2]	$1 Bill and Coins	Exact Value	$1.45 Phil. One-Way 2.90 Phil. Round Trip	A B
634 D	Advanced Data Systems [1,2]	$1 Bill and Coins	Exact Value	$0.75 N.J. One-Way 1.45 Phil. One-Way	A B
634 C	Advanced Data Systems [1]	Coins	Change Given	$0.75 N.J. One-Way 2.90 Phil. Round Trip	A B
634 E	Advanced Data Systems [1]	Coins	Change Given	$0.75 N.J. One-Way 2.90 Phil. Round-Trip	A B

[1] Vendors A, C, and E have been equipped with the Mars Coin Acceptor, and vendor D has been equipped with the Sesko Coin Acceptor.
[2] Vendor uses Rowe Dollar Bill Acceptor.
[3] Coins include SBA dollars, quarters, dimes, and nickels.
[4] Refers to stack code of Appendix A.

MONEY EXCHANGER/CHANGERS

EQUIPMENT NO.	INPUT	OUTPUT
934 Y	$5 Bill	4 SBA dollars and 4 quarters
434 D	$1 Bill	1 SBA dollar
434 E	$1 Bill	1 SBA dollar
434 A	$1 Bill	3 quarters, 2 dimes, and 1 nickel
434 B	$1 Bill	3 quarters, 2 dimes, and 1 nickel

hardware and not the happenstance of mere chance. The HRTV was installed at Lindenwold Station on May 9, 1982. After a five week shake-down period, it was agreed that the data collection and comparison would begin on June 9, 1982 and last for a period of time of not less than five months; the last piece of test data collected by PATCO and used in the evaluation was dated November 11, 1982. The data acquired and reported by PATCO relating to reliability and maintainability is presented in Appendix A.

4.2.1 Reliability

A summary of the results for reliability performance is presented in Table 2. The table shows the trials or the total number of times each vendor was used during the test period. The trials are equal to the sum of successes or the number of tickets issued, and failures are the number of times the vendor was unable to provide a ticket after the proper funds were deposited. Failure rate is equal to the total number of failures the vendor experienced divided by the total number of trials. Mean cycles between failure (MCBF) is the reciprocal of the failure rate where:

$$MCBF = \frac{1}{n} \sum_{i=1}^{n} Y_i$$

n is the number of failures, and

Y_i is the number of successful transactions between failures, and

The standard deviation, σ, in MCBF is computed via

$$\sigma^2(MCBF) = \frac{1}{n-1}\left[\sum_{i=1}^{n} Y_i^2 - n(\overline{Y})^2\right]$$

where $\overline{Y}$ is the MCBF.

It can be seen from Table 2 that for all vendors except the X-vendor (which is the High Reliability Ticket Vendor), the MCBF is nearly equal to the σ(MCBF). The mean and standard deviation of an exponential distribution are equal which indicates that these vendors are failing according to an exponential model.

TABLE 2

VENDOR RELIABILITY AND REPAIR PERFORMANCE

EQUIPMENT NO.	FAILURES	TRIALS	FAILURE RATE	MCBF [1]	σ(MCBF)	MTTR [2]	σ(MTTR)
634 A	48	35,626	0.001347	742.21	784.15	0.3265	0.1816
X	7	19,074	0.000367	2724.86	1874.74	0.3375	0.1867
C	104	39,544	0.002630	380.23	318.25	0.3333	0.1208
D	55	33,186	0.001657	603.38	602.21	0.3018	0.1094
E	93	39,408	0.002630	423.74	379.37	0.3375	0.1867

[1]Mean Cycles Between Failure
[2]Mean Time To Repair in hours

It can also be seen from Table 2 that the failure rate of the X-vendor (HRTV) as determined from the test data is the lowest among the five ticket vendors in service at Lindenwold. It is necessary to perform a comparison test among the vendors to provide assurance the the favorable estimated performance of the X-vendor is indeed due to its superior reliability and not the result of chance.

The test statistic, Z, which is of the form

$$Z = \frac{\hat{p}_1 - \hat{p}_x}{\sqrt{\hat{p}\hat{q}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where: Y_x = no. of X-vendors successes

Y_1 = no. of comparison vendor successes

n_1 = no. of X-vendor trials

n_x = no. of comparison vendor trials

$$\hat{p} = \frac{Y_1 + Y_x}{n_1 + n_x}$$

$$\hat{q} = 1 - \hat{p}$$

subscript 1 = A,C,D, and E

was used to test the null hypothesis that the failure rate of the X-vendor is equal to the failure rate of the other vendors. The alternative hypothesis is that failure rates of the other vendors are greater than the X-vendor. Table 3 shows the Z values calculated from the above equation. If a 5% level of significance is assumed for the test, and if

$$Z > 1.64$$

the null hypothesis of equality should be rejected, and the alternative hypothesis be accepted. From Table 3, it can be seen that the Z values are all greater than 1.64. Therefore, there is a 95% confidence that the estimated failure rate of the X-vendor is lower than that of the other vendors.

TABLE 3

HYPOTHESIS TESTING OF X-VENDOR FAILURE RATE

Vendor No.	Failure Rate	Test Statistic, Z	$Z^*_{0.05}$
X	0.000367	---	---
A	0.001347	3.45	1.64
D	0.001657	4.13	1.64
E	0.002360	5.47	1.64
C	0.002630	5.90	1.64

*from normal distribution

If a 0.1% level of significance had been assumed, then the null hypothesis would not be accepted if

$$Z > 3.10$$

From Table 3, it can be seen that even at this more exacting test level, there exists an intrinsic difference in performance between the X-vendor and the other vendors.

A Chi-square distribution was used to compute the confidence interval in the MCBF, i.e., the reciprocal of the failure rate. Table 4 shows the estimated values (repeated for Table 1) and the upper and lower 95% confidence interval bounds. The relative excursion between the upper and lower bounds for the X-vendor shown in Table 4 is greatest for the X-vendor because of the smaller data base; the vendor did not fail as frequently as the other vendors. The indicated performance of the X-vendor is so far superior than the other vendors that there exists no overlap in 95% bounds between the X-vendor lower bound MCBF, and the upper MCBF bounds of the other vendors.

The MCBF of the X-vendor and other vendors at Lindenwold Station can be compared with the MCBF for other ticket vendors. There is reported[6] a composite MCBF for nine IBM and eight Cubic ticket vendors operated by Bay Area Rapid Transit District (BART):

Class	MCBF
All Failures	140.8
Soft Failures	160.2
Hard Failures	1,401.4

Soft failures are defined as those failures normally serviced by the attendants in the station, and hard failures are defined as those serviced by maintenance personnel.

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[6] Automatic Fare Collection Equipment Reliability and Maintainability Assessment Plan for Urban Rail Transit Properties, UMTA-MA-06-0025-81-8, prepared by Automated Services, Inc., McLean, VA, March 1981.

TABLE 4

VENDOR MEAN CYCLES BETWEEN FAILURES*

Vendor	Estimated Value	Lower Bound	Upper Bound
X	2727.86	1461.61	6775.84
A	742.21	572.27	1013.07
D	603.38	472.65	805.33
E	423.74	110.60	526.60
C	380.23	317.18	466.62

*95% confidence level.

The data collected by PATCO for the non X-vendors were for all failures, and they stated that if a revenue person arrived to collect money and the vendor was jammed, the jam would be corrected and not reported. Special care was taken with the reporting of X-vendor failures and of the seven failure, only one was considered to be a jam. It can be seen from Table 4 that the 2727.86 MCBF of the X-vendor far exceeds the 140.8 MCBF for all failures of the BART vendors. Note the composite MCBF of the other four vendors at Lindenwold Station is determined to be 492.55. A hard failure MCBF can be calculated for the X-vendor by scaling the 2727.86 value by 7/6 which results in a X-vendor hard failure MCBF or 3182.50, a value in excess of the BART hard failure MCBF of 1,401.4. A comparison of the other PATCO vendors at Lindenwold Station with the BART vendors cannot be as conclusive due to the possible exclusion of some soft failure data. If some soft failure data was not reported for the other PATCO vendors, then there exists the possibility that the MCBF of these vendors is lower than the values reported, which would result in a greater difference in MCBF between these other PATCO vendors and the X-vendor.

If the data were available, a comparison would have been made of X-vendor subsystems with the subsystems of the other vendors at Lindenwold. Since there were only seven failures, a comparison of vendor subsystems, i.e., acceptor, escrow, vend, etc., would not be meaningful.

It is concluded based on the data that the X-vendor has displayed a significantly greater reliability than the comparison vendors. It should be pointed out that the X-vendor has been assembled as a one-of-a-kind with new hardware and the other vendors are units that have been in service for a long period of time, and manufactured using mass assembly techniques.

4.2.2 Maintainability

Maintainability is the quality of the combined features of equipment design and installation which facilitates the accomplishment of inspection, test, checkout, servicing, repair, and overhaul with a minimum of time, skill, and resources in the planned maintenance environments. Since the X-vendor is a one-of-a-kind, it was not possible to assess the time required to complete a maintenance action following a disruption in service. Only one element of the maintenance cycle, the servicing time, which is the time to repair-in-place, was investigated. The ground rules set for repair-in-place were as follows: the repair-in-place clock was started when the maintenance person opened the vendor and the repair time included fault location, removal of parts, correction or adjustment, replacement of parts, checkout, and the repair-in-place clock was stopped after the vendor was repaired and closed up. If the part(s) could not be corrected or adjusted on site, then the clock was stopped; it was started up again when the maintenance person returned to complete the repair cycle, and stopped after the vendor was closed up and returned to service. The shop repair time was not considered since the X-vendor development engineer repaired the X-vendor in his lab and the maintenance personnel repaired the other vendors in their shop.

The last two entries in Table 2 are the mean time to repair (MTTR) and the standard deviation, σ(MTTR). MTTR is computed by summing the repair time and dividing by the number of failures, and σ(MTTR) is calculated according to the preceding equation for σ(MCBF) wherein Y_i is defined as the time to repair for each failure, and $\bar{Y}$ is the MTTR.

It can be seen from Table 2 that the D vendor was calculated to have the shortest mean time to repair (MTTR). A test was made to determine whether the difference in MTTR between the X-vendor and the other vendors was due to design or chance. The test statistic T was used:

$$T = \frac{(\bar{Y}_1 - \bar{Y}_x)}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_x^2}{n_x}}} \quad \text{, where:} \quad \nu = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_x^2}{n_x}\right)^2}{\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{S_x^2}{n_x}\right)^2}{n_x - 1}}$$

and the variances of the populations are unknown and unequal.

ν = no. of degrees of freedom
$\overline{Y}_x$ = MTTR of X - vendor
$\overline{Y}_1$ = MTTR of comparison vendors
n_x = no. of X - vendor samples
n_1 = no. of comparison vendor samples
S_x = σ(MTTR) of X - vendors
S_1 = σ(MTTR) of comparison vendors
subscript 1 = A,C,D, and E

The null hypothesis is

$$\overline{Y}_1 = \overline{Y}_x$$

where $\overline{Y}$ is defined as MTTR.

A 5% level of significance was assumed, and the alternative hypothesis

$\overline{Y}_1 > \overline{Y}_x$ is accepted if $T > t_{0.05}$.

Table 5 shows that the T-statistic is less than $t_{0.05}$ for all the vendors tested in comparison with the X-vendor, so it is concluded that the null hypothesis cannot be rejected at the 5% level. Therefore, it is concluded that the MTTR of the X-vendor is comparable with the MTTR of the other vendors at Lindenwold Station.

During the test period, the X-vendor was maintained by its development engineer. Therefore, it is not possible to directly assess the level of technical skills that are required by the maintenance department to keep the vendor in a state-of-repair. Through an understanding of the design complexity of the X-vendor and the maintenance of existing PATCO STATION hardware, it is possible to draw some inferences about the impact of maintenance of the X-vendor on the existing organization. First, it is to be expected that trouble-shooting the vendor after it breaks down should be simplified as result of the

TABLE 5

HYPOTHESIS TESTING OF X-VENDOR MTTR

Equipment No.	MTTR, hr.	Test Statistic, T	Degrees of Freedom, ν	t*
A	0.3265	0.146	7.75	1.869
X	0.3375	---	--	---
C	0.3333	0.059	6.34	1.927
D	0.3018	0.495	6.53	1.918
E	0.2926	0.631	6.20	1.933

*t distribution at the 0.05 level of significance.

attention given to provision of test points on the printed circuit boards. Any point that gives a high reading indicates a fault. Once a fault is identified, the circuit or component carrying the problem can be readily identified. Second, most of the X-vendor hardware is similar to hardware used in the other ticket vendors with the main difference being the extensive use of CMOS integrated circuits. PATCO maintenance personnel are responsible for all station equipment and the turnstiles use the same series of CMOS integrated circuits as are used in the X-vendor. Maintenance of X-vendor(s) should not create any special problems require special resources other than a brief training program.

4.3 EVALUATION OF SERVICE TIME

Operation of the ticket vendors at Lindenwold Station was observed during the three day period beginning January 11, 1983 and ending January 13, 1983. Data was acquired at intervals throughout the day and included morning rush hour, mid-morning, late morning, early afternoon, mid-afternoon, and evening rush-hour. During the three day period of data acquisition the weather was mild, i.e., temperatures were in the low 40's (deg F.) and there was no precipitation; garments did not hinder the locating of money, and the moderate ambient temperature allowed for nimble handling of money.

It was observed that:

(1) No queue formed in front of any of the vendors during the morning rush hour when the passenger arrival rates at the ticket vendor was the greatest. The absence of a queue is due to the presence of five automatic ticket vendors, and a ticket window with attendant which is open during the rush hours. Ten ride tickets could also be purchased at the newsstand located nearby on the vendor/turnstile level. It appears that PATCO has provided sufficient paths for ticket acquisition so as to avoid the build up of a queue in front of the ticket vendors. A queue did, however, form from time to time in front of the ticket window.

(2) The vast majority of the people who used the ticket vendors knew what they were doing and needed no help. A small number of people did need some help, and this assistance was gained from other passengers or the PATCO station attendant when present. The biggest problem with the HRTV (X-vendor) was associated with the fact that it does not give change. Some people seemed to believe that it accepted overpayment and were willing to pay $3.00 for a $2.90 round trip ticket to Philadelphia. These people did not understand that the HRTV would only except exact change.

(3) It is not possible to draw any conclusions about the use of the HRTV by elderly and handicapped persons. To gain entrance to the ticket vendors and turnstile lobby, it is necessary to descend a flight of steps. The presence of this architectural barrier would certainly screen out all non-ambulatory persons, feeble persons, and persons with medical orders that require they do not exert themselves (as they must when they exit the lobby at the conclusion of a round trip). Two blind persons with guide dogs were noted, but both of these persons had multiple ride tickets and went directly to the turnstiles.

(4) On occasion the non-HRTV ticket vendors would reject a coin. The patron would then reinsert the coin and the non-HRTV vendor would ultimately accept the coin. All coins deposited into the HRTV were accepted.

The quantitative data collected are associated with the service time at each vendor. Service time refers to the elapsed time that starts when the patron first drops a coin or starts to insert a dollar bill into a ticket vendor and is concluded when the patron removes the ticket from the vendor. By starting the clock at the time the first coin was deposited, the searching and fumbling time was nearly eliminated.

A stop watch was used to time the ticket issuance events. The number of coins/bills deposited were counted by watching the LED display of monies deposited and/or by counting the number of hand motions. The data collected by this process are contained in Appendix B.

The data were then processed to extract information about the service time for each vendor. It was assumed that the service time was proportional to the number of coin/bills deposited. This assumption led to a linear regression analysis for the data collected for each vendor. The mean value and standard deviation of the slope and intercept based on one insertion are presented in Table 6. It can be seen from Table 6 that the mean value of the slopes for all the vendors is roughly similar. The data of Table 6 are also plotted in Figure 19. The slope parameter is related to the manner in which the patrons locate, select, orient, and deposit coins, and this process should be the same, independent of vendor type. The intercept provides some insight into the time required for vendor to process the coin and if the coin is accepted to light the display. It is to be noted that the intercept data presented in Table 6 is for one coin deposited. The processed data indicates that the service time for the HRTV to vend one ticket with the deposit of one coin is 8.03 seconds. It can be seen that vendors A, C, and E are roughly similar in their time to process one coin, and are all faster than the X-vendor. These other vendors which are Advanced Data System ticket vendors have been modified to incorporate a Mars coin acceptor. The one coin intercept value of the D-vendor is 0.85; the D-vendor which is also an Advanced Data System ticket vendor had been modified to incorporate a modified Sesko coin acceptor. Therefore, it is not surprising that there appears to be three distinct groupings of service time for the X-vendor, the A-, C-, E-vendors, and the D-vendor each of which reflect a different coin acceptor design.

A statistical test was performed to assess whether the difference in the time to service one coin is due to differences in design of the X-vendor or the result of chance. This test was performed by calculation of the confidence interval of each of the vendors and by comparison of the interval with that of the X-vendor. It was determined that in only 8% of similar tests would the differences in the service time between the X-vendor and A-vendor be due to

TABLE 6

COMPARISON OF VENDOR SLOPES AND
INTERCEPTS ASSUMING A LINEAR SERVICE TIME

VENDOR NO.	INTERCEPT *(sec)		SLOPE (sec/deposit)	
	MEAN	STD. DEV.	MEAN	STD. DEV.
X	8.03	2.02	1.91	0.28
A	2.90	0.67	2.62	0.22
C	2.47	0.69	2.50	0.14
D	0.85	0.66	2.66	0.16
E	2.30	0.45	2.11	0.08

*The intercept is based on a single deposit.

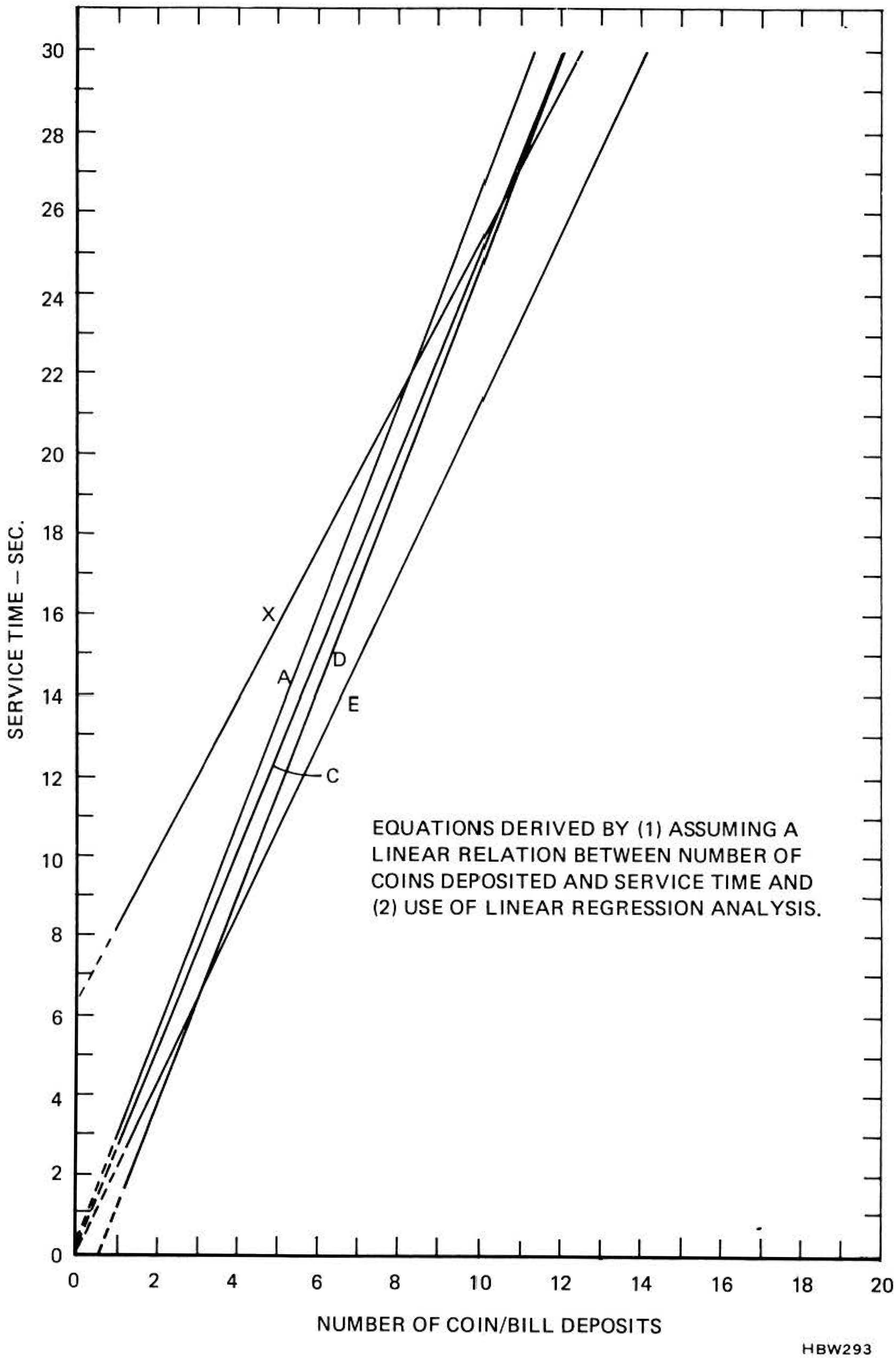

FIGURE 19. COMPARISON OF VENDOR SERVICE TIME

chance, and that for the C-, D-, and E-vendors the differences in performance with the X-vendor would occur in less than 5% of similar tests as a result of chance. Based on the statistical test, it is concluded that for one coin, the service time of the HRTV is significantly longer than that of the other vendors in Lindenwold Station.

Longer service time may be due in part to the longer path that the coin must follow in the X-vendor as it travels through the coin acceptor on the way to the coin escrow. This large path provides for greater separation between coins and greater time for sensing, which may be the reason the HRTV (1) does not tend to reject valid coins as was observed for the other vendors, and (2) has better accounting accuracy, i.e., value of tickets sold equals monies deposited; this accounting aspect of performance is discussed in the next section.

Figure 19 also shows a cross-over in service time between the X-Vendor and the other vendors. When the number of coins is small, less than about nine, the machine process time dominates the total service time. As the number of coins being deposited increases, the influence of the patron's rate of deposit becomes more important. The vast majority of the currency deposited into the HRTV was in the form of coins. For example, the minimum number of deposits to purchase a $1.45 ticket is four (one dollar bill or an SBA dollar plus one quarter and two dimes) and the minimum number of deposits to purchase a $2.90 ticket is seven (one combination of bills and SBA dollars that add to two plus three quarters, one dime, and one nickel). It was found that an average of about seven deposits were made per ticket transaction.

For the case where no queue forms, it is expected that the observed difference in service time should not be important. For the case where queues form, then the impact of number of pieces of currency deposited must be considered. As the number of deposits increase, the differences in service time between the X-vendor and other comparison vendors becomes less important.

4.4 PATRON UTILIZATION

Part of the test and evaluation was to assess the utilization of the X-vendor by the patrons. This comparison of patron utilization has to be made with the total number of trials recorded by each vendor[7]. Table 1 indicates the X-vendor dispenses the $1.45 and $2.90 ticket, the A-vendor dispenses the $1.45 ticket, the D-vendor dispenses the $1.45 ticket, and the C- and E-vendors dispense the $2.90 ticket.

The comparison must be made with this smaller set of data in contrast with the reliability and maintainability comparison which is based on the total number of trials regardless of ticket value.

Table 7 compares the number of trials of the X-vendor with the number of trials experienced by vendors dispensing similarly valued tickets. It can be seen that the trials associated with the X-vendor is lower than that of the other vendors during the five month test period.

This evaluation of patron utilization is not considered to be fair because the X-vendor (1) is significantly different than the other vendors; it is much larger and is painted a light blue whereas the other vendors are smaller and painted brown, (2) is a one-of-a-kind and therefore if a patron knows how to use the other vendors which are to be found throughout the PATCO system, there is little incentive to learn to use a seemingly different device, (3) is located adjacent to another and more familiar exact change, bill accepting vendor (4) does not give change, and (5) is not near a coin changer.

The low utilization demonstrates the difficulty of introduction of a one-of-a-kind vendor, if older more familiar equipment is still available. Favorable reliability and maintainability are characteristics important to PATCO, but the X-vendor does not offer any obvious characteristics that would be advantageous to the patron so as to encourage its utilization. Testing has

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[7] Trials include the sum of the number of tickets vended plus the number of vendor failures.

TABLE 7

COMPARISON OF VENDOR UTILIZATION

VENDOR	A	X	X	D	C	E
TICKET VALUE ($)	1.45	1.45	2.90	1.45	2.90	2.90
TRIALS	21,547	9,053	10,021	20,576	14,860	14,390

demonstrated the X-vendor has a greater availability (ratio of up time to total time) than each of the other vendors, but this advantage is lost since there are four other vendors most of which are usually working because of excellent established maintenance practice. Higher utilization of the X-vendor would definitely be achieved if there were fewer of the other vendors available, and might be achieved if the period of observation was extended.

4.5 ADDITIONAL TEST DATA

PATCO furnished additional test data which are included because of their value in overall assessment of vendor performance.

4.5.1 Low Temperature Testing

The HRTV (X-vendor) was operated at low temperature by placing it outdoors at the time a cold front moved through Lindenwold, New Jersey. As the temperature dropped, the following subsystems were observed to fail:

Subsystem	Failure Mode	Temperature in deg F. at which Failure Occurred
Dollar Escrow	Belt stiffened and would not turn	20 ± 3
Rowe Dollar Transport	Motor torque was insufficient to move bill at proper speed for verification.	11 ± 3

The coin acceptor, coin escrow, ticket dispenser, and electronics continued to operate satisfactorily when the temperature was reduced to 5 deg F. at which point the test was concluded. No heat, other than that dissipated internally by electrical components, was available during the testing. The application of heaters located in close proximity to the low temperature sensitive components could be expected to overcome the observed problems.

4.5.2 Voltage Variation Testing

Although the nominal operating line voltage is 110 V. AC, the HRTV was fully operational when the line input voltage was lowered to 85 V. AC during a controlled test. This extended operating range is attributed to the use of a switching power supply and the relatively light loading of that power supply.

4.5.3 Reconciliation of Receipts Testing

Data were collected and evaluated to compare the absolute errors between the sales and receipts for the ticket vendors at the Ferry Avenue station and the HRTV located at Lindenwold Station.

Table 8 shows qualitatively the reconciliation performance. The HRTV was reconciled for almost 50% (10 reconciliations out of 21 revenue collections) of collection, whereas the other vendors as a group were reconciled a little more than three-quarters of 1% of their collections.

Table 8 also shows quantitatively the absolute average revenue error between sales and receipts, where the error is defined as the percent of sales. Use of averaging absolute values avoids the minimization of error that would result from averaging positive and negative quantities. The absolute error made by the HRTV is about ten fold lower than that of the other vendors.

TABLE 8

COMPARISON OF RECONCILIATION
BETWEEN VENDOR SALES AND RECEIPTS

Equipment No.	No. of Revenue Collections	Receipts Equal To Sales	Receipts Less Than Sales	Receipts More Than Sales	Abs. Revenue Error, Percent
HRTV (634A)	21	10	7	4	0.035
628A	64	0	22	42	0.433
628B	64	1	55	8	0.549
628C	64	0	21	43	0.472
628D	65	1	27	37	0.512

5.0 FINDINGS

PATCO set out to design and build a ticket vendor with a significantly superior reliability and maintainability compared with the ticket vendors now in service. This need for improvement in vendor performance was brought about by PATCO's operating policy of automatic fare collection, i.e., collection of fares without the presence of station personnel. It is important to PATCO that their vending equipment have a high availability (or low downtime) to provide smooth and unbroken demand service to the patrons and to reduce the costs of maintenance. The test and evaluation of the high reliability ticket vendor included investigation of reliability and maintainability as well as the service time.

The results of a five month test and evaluation indicated the following:

(1) The reliability of the High Reliability Ticket Vendor (HRTV) is significantly superior in comparison to the reliability of the other ticket vendors, at Lindenwold Station. It was determined that at the 95% confidence level, the mean cycles between failures (MCBF) for the HRTV were

$$1462.0 < \text{MCBF} < 6775.0.$$

(2) The mean time to repair (MTTR) is 0.3375 hours, and that this performance following a significance test is comparable to the MTTR of the other ticket vendors in the test group. It was determined that the skill levels needed to maintain the HRTV were consistent with the skill levels required to maintain existing equipment.

(3) The service time, or the time for the vendor to process the currency deposited by the patron for the issuance of a ticket, was higher for the HRTV than for the other ticket vendors at Lindenwold station. This difference was greatest for the hypothetical case of one deposit and diminished as the number of deposits increased.

(4) It was not possible to evaluate the ability of the elderly and handicapped to use the HRTV in comparison with the other ticket vendors. To reach the ticket vendor/turnstile lobby at the test station, it is necessary to descend a flight of steps. This architectural barrier served to screen out the feeble and non-ambulatory.

(5) During the five month test period, the rate of usage of the HRTV was about one-third the rate of usage of the other vending machines. Since only one HRTV was tested and the test time was only five months, it is difficult to draw any definite conclusions regarding the utilization of the HRTV by the patrons.

6.0 CONCLUSIONS

PATCO set out to design and manufacture a ticket vendor with improved (1) reliability to meet the performance needs of operation within unattended stations, and (2) maintainability to reduce the costs associated with vendor operation. Based on this test and evaluation, it has been demonstrated that the reliability is significantly superior to the other vendors in the test group as well as superior to to the vendors reported in the literature. Based on the test results, it was determined that the maintainability should be comparable to the other PATCO vendors, and there should be no additional resources beyond those that exist at PATCO for performance of needed maintenance.

Consideration should be given to (1) assessment of expected reduction in reliability of a mass produced X-vendor in comparison with the prototype X-vendor, (2) the addition of a money changer, (3) redesign to allow for large scale production, (4) a buy of a sufficient number of vendors and spare parts to provide all automatic ticket vending at one or more stations, and (5) development of a acquisition cost data base to permit scaling of vendor acquisition for different size orders. The vendors would be used in a demonstration to acquire (1) a vendor reliability and maintainability data base, (2) an operating cost data base, (3) a passenger utilization data base, and (4) service time data to permit definition of number of vendors and money changers to accommodate various rates of passenger traffic.

APPENDIX A

RELIABILITY AND MAINTAINABILITY TEST DATA

The following test data pertaining to vendor performance at Lindenwold Station were collected and reported by PATCO during the test period beginning May 12, 1982 and ending Nov. 11, 1982. Table data are to be interpreted as follows:

VND - vendors A,X,C,D, and E

MD - month of year in which failure is reported

DAY - day of month in which failure is reported

TIME - time of day in which failure is reported in hours and minutes

STACK A - stack which issues the lower priced ticket (see Table 1)

STACK B - stack which issue the higher priced ticket (see Table 1)

CODE - type of failure where:

A = A stack
B = B stack
C = coin acceptor
D = dollar acceptor or validator
E = ticket vendor

REP. TIME (hrs) - repair time in hours

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982

VMC	MO.	DAY	TIME	STACK A	STACK B	CODE	REP.TIME
A	5	12	1200.	61889	155595	A	0.20
D	6	9	1015.	459652	524424	C	0.40
A	6	10	823.	47311	27594	C	0.40
E	6	10	1335.	39470	15831	A	0.30
E	6	11	1115.	39623	15892	A	0.30
E	6	12	1316.	39753	16010	B	0.30
D	6	12	1950.	459863	524893	C	0.40
C	6	15	1830.	36443	62683	A	0.30
A	6	16	1315.	48179	28056	B	0.30
C	6	16	1335.	36563	62729	E	0.30
C	6	17	740.	36677	62800	E	0.30
A	6	17	1040.	48284	28159	E	0.20
A	6	17	1732.	48339	28194	E	0.20
E	6	17	1840.	40717	16428	E	0.20
C	6	17	1953.	36798	62870	A	0.20
A	6	18	620.	48410	28230	A	0.10
C	6	18	748.	36844	62909	A	0.30
A	6	19	1605.	48474	28258	A	0.20
E	6	19	630.	40946	16647	A	0.30
D	6	20	1000.	460403	526034	C	0.40
C	6	21	615.	37153	63200	F	0.50
C	6	21	950.	37184	63207	B	0.50
E	6	22	605.	41366	17075	F	0.50
D	6	23	1305.	460660	526580	B	0.10
D	6	24	1034.	460730	526747	C	0.50
C	6	24	2055.	37883	63621	A	0.40
D	6	24	2135.	460797	526829	C	0.20
E	6	25	1305.	42029	17412	E	0.30
C	6	27	1230.	38238	63846	B	0.40
E	6	27	1255.	42201	17610	F	0.30
A	6	28	1612.	50166	29094	C	0.20
D	6	29	840.	461124	527475	B	0.30
A	6	25	1330.	50281	29162	A	0.30
A	6	29	1602.	50316	29173	C	0.20
C	6	29	1625.	38711	64141	C	0.20
A	6	30	1610.	50458	29304	C	0.20
C	6	30	1708.	38872	64251	B	0.40
E	7	1	1310.	42809	18010	B	0.30
D	7	1	1100.	461345	527894	A	0.30
C	7	1	1115.	38990	64309	C	0.30
C	7	1	1350.	39004	64329	C	0.50
A	7	2	700.	50698	29476	C	0.40
A	7	2	1755.	50891	29543	C	0.20
D	7	2	1745.	461451	527972	B	0.50
E	7	4	1623.	43168	18289	B	0.20
C	7	4	2110.	39432	64738	B	0.20
E	7	4	2113.	43193	18327	F	0.20

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982 (Cont.)

VND	MO.	DAY	TIME	STACK A	STACK B	CODE	REP. TIME
D	7	5	1010.	461567	528218	C	0.20
C	7	6	1335.	39697	64927	B	0.30
D	7	7	725.	461700	528515	C	0.30
A	7	7	900.	51595	29831	B	0.30
C	7	7	1648.	39969	65051	B	0.20
E	7	8	715.	43731	18670	B	0.30
C	7	8	1055.	40133	65069	A	0.30
C	7	8	1355.	40158	65118	A	0.20
E	7	8	2210.	43885	18752	A	0.20
X	7	9	2135.	64680	158648	B	0.10
E	7	9	805.	43954	18767	A	0.30
C	7	9	825.	40295	65191	C	0.90
C	7	10	1745.	40456	65305	B	0.30
X	7	12	1040.	64844	158824	D	0.50
D	7	12	1245.	462103	529174	C	0.60
D	7	13	2202.	462226	529360	C	0.20
E	7	14	705.	44714	19244	C	0.20
A	7	14	725.	52638	30444	C	0.60
C	7	15	1052.	41378	65761	A	0.50
D	7	18	1445.	462619	530031	A	0.40
C	7	19	601.	41846	66004	B	0.30
E	7	19	708.	45371	19682	B	0.20
E	7	19	1616.	45435	19704	C	0.20
E	7	21	627.	45644	19809	B	0.20
C	7	22	800.	42559	66375	A	0.50
C	7	23	849.	42738	66488	A	0.50
E	7	24	540.	46221	20143	B	0.30
C	7	24	1010.	42885	66592	C	0.20
C	7	24	1600.	42887	66598	B	0.40
A	7	25	1245.	54308	744	A	0.40
E	7	26	1105.	46372	20302	B	0.50
X	7	26	1610.	65578	159628	C	0.30
D	7	27	2128.	463429	531366	C	0.30
A	7	28	1620.	54876	1143	C	0.20
C	7	28	1630.	43578	67065	B	0.30
D	7	28	815.	463441	531402	A	0.40
D	7	28	1640.	463532	531469	C	0.20
E	7	28	1322.	46746	20497	A	0.40
E	7	28	1645.	46755	20513	B	0.30
C	7	28	2215.	43600	67069	A	0.30
D	7	28	2220.	463559	531486	C	0.30
C	7	29	839.	43674	67105	A	0.40
C	7	29	1540.	43755	67209	A	0.30
E	7	30	1540.	47039	20654	A	0.30
C	7	31	610.	44016	67369	A	0.30
E	7	31	1250.	47110	20722	B	0.30
C	7	31	2005.	44091	67470	B	0.40
D	8	1	1105.	463880	531962	C	0.40
E	8	3	1620.	47586	21008	A	0.40
D	8	3	2140.	464071	532302	C	0.50

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982 (Cont.)

VND	MO.	DAY	TIME	STACK A	STACK B	CODE	REP. TIME
C	8	4	705.	44569	67805	A	0.30
D	8	4	1045.	464132	533260	C	0.30
A	8	5	1355.	56142	1960	B	0.30
E	8	5	720.	47866	21148	A	0.30
E	8	5	1711.	47959	21214	A	0.20
D	8	6	715.	464302	532608	C	0.30
D	8	6	910.	464313	532636	C	0.20
E	8	7	1140.	48153	21346	B	0.30
C	8	7	1530.	45297	67883	E	0.30
D	8	7	1835.	464404	532825	C	0.30
A	8	8	1620.	56586	2129	A	0.30
C	8	8	1635.	45879	68322	A	0.40
C	8	11	804.	45914	68602	B	0.40
D	8	12	725.	464721	533387	C	0.40
D	8	12	1405.	464749	533462	B	0.40
A	8	12	1410.	57199	2661	A	0.40
C	8	12	2030.	46242	68835	C	0.30
A	8	12	2113.	57254	2678	A	0.30
D	8	13	730.	464788	533543	E	0.50
E	8	13	1243.	48996	21845	A	0.50
A	8	13	1325.	57339	2738	C	1.10
C	8	13	2137	46472	68953	A	0.20
E	8	14	1320.	49124	21982	B	0.30
C	8	14	1346.	46556	69066	B	0.30
D	8	13	1529.	464834	533649	B	0.30
D	8	14	1840.	464919	533823	C	0.20
C	8	16	1630.	46830	69175	B	0.40
C	8	16	2125.	46883	69194	C	0.30
C	8	17	1315.	47030	69254	C	0.30
C	8	17	1600.	47056	69270	A	0.30
E	8	17	1610.	49573	22239	A	0.40
C	8	18	1135.	47215	69312	C	0.20
E	8	18	1730.	49748	22324	A	0.40
A	8	19	1100.	58152	3212	A	0.30
X	8	20	1600.	66973	161091	C	0.50
E	8	21	835.	50108	22504	A	0.30
A	8	21	1510.	58430	3361	A	0.40
C	8	23	1115.	47994	69754	A	0.40
C	8	23	1800.	48021	69788	A	0.30
C	8	24	1602.	48195	69904	A	0.20
E	8	24	1608.	50532	22758	B	0.20
A	8	25	1053.	58923	3685	C	0.20
E	8	25	1805.	50679	22822	A	0.30
C	8	26	2030.	48687	70113	A	0.20
E	8	28	730.	51026	23002	A	0.30
C	8	28	1650.	48946	70301	B	0.40
A	8	30	722.	59573	3996	B	0.30
E	8	30	854.	51224	23199	A	0.30
C	8	30	1128.	49201	70431	E	0.30
D	8	30	1148.	466127	535858	C	0.20

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982 (Cont.)

VND	MO.	DAY	TIME	STACK A	STACK B	CODE	REP. TIME
A	8	31	753.	59688	4117	C	0.40
E	8	31	758.	51392	23304	A	0.30
C	8	31	1600.	49467	70592	A	0.40
A	8	31	2125.	59797	4222	A	0.40
C	9	1	842.	49584	70619	B	0.30
D	9	1	855.	466297	536171	B	0.30
E	9	1	1300.	51636	23434	A	0.30
E	9	1	1510.	51645	23462	B	0.40
C	9	1	1505.	49631	70693	B	0.40
A	9	3	730.	60143	4497	A	0.40
D	9	3	1137.	466506	536486	C	0.40
E	9	3	1340.	52009	23587	A	0.30
E	9	3	1615.	52068	23608	B	0.30
C	9	3	1630.	50112	70991	B	0.40
D	9	4	930.	466623	536611	C	0.30
E	9	4	1855.	52166	23733	B	0.30
C	9	4	1906.	50265	71061	B	0.30
C	9	6	1300.	50380	71230	A	0.30
C	9	7	2130.	50719	71372	B	0.20
A	9	7	1702.	60841	4804	B	0.20
A	9	8	800.	60900	4848	B	0.30
A	9	8	1035.	60902	4851	B	0.30
D	9	8	1810.	466970	537202	B	0.20
E	9	8	1820.	52841	24069	A	0.20
C	9	9	822.	51006	71537	A	0.30
E	9	9	830.	52921	24096	A	0.30
A	9	10	830.	61160	5127	B	0.30
D	9	10	832.	467139	537399	C	0.30
D	9	10	1335.	467171	537435	B	0.30
A	9	10	1832.	61234	5188	A	0.20
E	9	10	2050.	53347	24253	A	0.20
A	9	10	2055.	61237	5190	B	0.20
A	9	11	1520.	61318	5245	B	0.40
C	9	12	1215.	51674	71895	A	0.40
A	9	12	1230.	61411	5288	A	0.30
A	9	13	755.	61490	5362	C	0.30
A	9	13	835.	61492	5371	C	0.50
C	9	13	805.	51848	71957	B	0.30
C	9	13	1345.	51930	72003	B	0.40
E	9	14	835.	53905	24564	A	0.30
E	9	14	1315.	53937	24578	B	0.50
D	9	14	850.	467551	538068	C	0.20
C	9	16	750.	52569	72302	A	0.40
C	9	16	1555.	52637	72370	B	0.40
E	9	16	1915.	54492	24812	A	0.40
C	9	17	1900.	52840	72457	A	0.50
E	9	17	2059.	54732	24911	B	0.20
C	9	18	800.	52912	72492	C	0.30
E	9	18	1620.	54790	25012	B	0.30
A	9	19	1750.	62350	6155	A	0.30

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982 (Cont.)

VND	MO.	DAY	TIME	STACK A	STACK B	CODE	REP. TIME
C	9	20	900.	53158	72687	B	0.50
E	9	20	1315.	55027	25134	B	0.30
D	9	21	800.	468081	538949	C	0.50
C	9	21	1030.	53369	72788	B	0.30
C	9	21	1325.	53384	72809	B	0.30
D	9	21	1640.	468166	539021	C	0.20
E	9	21	1650.	55328	25299	A	0.20
D	9	21	1655.	468168	539023	C	0.20
D	9	22	1630.	468250	539155	C	0.20
C	9	22	1945.	53706	72967	A	0.20
E	9	23	1100.	55728	25495	B	0.30
C	9	24	1015.	53999	73098	A	0.50
E	9	24	1625.	55968	25609	A	0.20
C	9	25	1115.	54262	73293	B	0.40
E	9	25	1515.	56037	25679	A	0.40
A	9	27	1300.	63643	6956	B	0.30
E	9	27	1310.	56234	25789	A	0.30
C	9	28	1130.	54735	73535	B	0.30
A	9	29	730.	63899	7214	A	0.30
D	9	29	1058.	468886	540058	C	0.20
C	9	29	1335.	54943	73682	E	0.30
C	9	30	730.	55053	73733	C	0.50
A	9	30	1055.	64089	7428	A	0.30
C	9	30	1110.	55087	73741	A	0.30
E	9	30	1140.	56882	26067	C	0.50
X	9	30	1210.	69292	163610	C	0.50
C	10	1	710.	55218	73840	A	0.40
A	10	2	1015.	64402	7671	A	0.50
C	10	2	1035.	55450	73984	C	0.50
C	10	2	2200.	55534	74069	A	0.40
C	10	3	1000.	55547	74074	A	0.30
D	10	4	1020.	469299	540767	A	0.30
A	10	4	1100.	64721	7771	C	0.80
C	10	5	720.	55883	74238	A	0.30
C	10	5	1615.	55915	74271	C	0.20
D	10	6	835.	469508	541055	C	0.20
A	10	6	1320.	65015	8123	C	0.20
E	10	7	1315.	58364	26811	A	0.30
A	10	8	800.	65290	8324	A	0.80
C	10	8	1535.	56496	74612	A	0.20
E	10	9	1125.	58744	27044	B	0.30
E	10	11	1310.	58929	27158	A	0.30
D	10	11	1320.	469935	541789	D	0.30
C	10	11	1540.	56880	75029	E	0.30
D	10	11	1540.	469948	541815	E	0.30
C	10	12	810.	56968	75076	B	0.30
C	10	12	2005.	57081	75145	A	0.30
A	10	13	1010.	66112	8747	B	0.30
E	10	13	1740.	59511	27400	B	0.40
C	10	14	1025.	57448	75289	A	0.30

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982 (Cont.)

VND	MO.	DAY	TIME	STACK A	STACK B	CODE	REP.TIME
E	10	14	1320.	59666	27483	B	0.30
C	10	14	1338.	57469	75375	A	0.30
D	10	14	1705.	470220	542259	C	0.30
D	10	14	2000.	470223	542262	C	0.30
E	10	16	1120.	60024	27688	B	0.30
C	10	16	1145.	57786	75524	A	0.30
C	10	16	1700.	57805	75589	B	0.40
C	10	18	1302.	58008	75690	A	0.30
E	10	18	1312.	60241	27856	E	0.30
E	10	19	1120.	60490	27939	B	0.30
C	10	19	1125.	58133	75757	B	0.30
C	10	19	1322.	58149	75786	B	0.30
E	10	19	1710.	60561	27959	E	0.20
D	10	20	1010.	470742	542884	C	0.30
E	10	20	1135.	60658	28037	A	0.30
A	10	20	1600.	67321	9637	B	0.20
E	10	20	1608.	60760	28081	A	0.20
E	10	21	732.	60828	28110	A	0.20
E	10	21	1630.	60979	28117	A	0.20
D	10	21	1850.	470865	543078	B	0.20
E	10	22	1052.	61035	28213	A	0.30
D	10	22	1505.	470959	543197	C	0.20
E	10	22	1512.	61077	28275	A	0.20
C	10	22	1521.	58884	76229	B	0.20
E	10	23	925.	61164	28335	E	0.30
C	10	23	945.	58976	76301	E	0.30
C	10	23	1215.	58997	76331	C	0.20
D	10	23	1620.	471000	543288	D	0.30
X	10	25	725.	70509	165139	B	0.30
E	10	25	1320.	61401	28584	E	0.10
C	10	25	1335.	59268	76526	B	0.30
C	10	25	1810.	59314	76552	C	0.30
E	10	25	2110.	61478	28616	C	0.30
E	10	26	1410.	61644	28685	C	0.30
E	10	27	715.	61721	28712	C	0.30
C	10	27	825.	59609	76675	A	0.30
C	10	27	1110.	59645	76687	B	0.30
A	10	27	1535.	68450	10441	C	0.30
D	10	27	1555.	471282	543725	D	0.30
C	10	28	935.	59786	76763	A	0.90
E	10	28	1600.	62081	28874	A	0.40
D	10	29	855.	471442	543949	C	0.40
E	10	29	1345.	62268	28927	E	0.30
E	10	29	1620.	62370	28944	E	0.50
C	10	30	1015.	60129	76951	C	0.30
D	11	1	700.	471588	544263	A	0.30
E	11	1	1030.	62619	29231	A	0.30
E	11	1	1540.	62715	29291	A	0.20
C	11	1	1550.	60488	77200	B	0.20
E	11	2	1340.	62845	29338	A	0.30

TABLE A-1. TICKET VENDING MACHINE FAILURES IN 1982 (Concl'd)

VND	MO.	DAY	TIME	STACK A	STACK B	CODE	REP. TIME
X	11	3	1035.	70942	165616	D	0.50
E	11	3	2130.	63187	29459	A	0.20
C	11	3	2140.	60831	77456	A	0.20
E	11	4	1302.	63334	29518	B	0.30
C	11	4	1310.	60910	77480	B	0.30
E	11	4	1715.	63407	29539	A	0.20
E	11	5	1030.	63462	29555	A	0.30
C	11	5	1042.	61127	77543	A	0.30
E	11	5	1630.	63525	29623	A	0.20
E	11	6	815.	63591	29645	B	0.30
D	11	6	835.	472262	545000	D	0.30
E	11	6	1100.	63600	29654	B	0.30
E	11	7	1435.	63667	29773	B	0.40
E	11	8	710.	63699	29791	E	0.30
A	11	9	1650.	70528	11973	A	0.30
E	11	11	1520.	64468	30221	B	0.30

APPENDIX B

SERVICE TIME TEST DATA

The following test data pertain to service time - the time which begins when the patron first starts to deposit currency into the vendor to the time the patron extracts the ticket. These data were collected by DYNATREND at the Lindenwold Station during the time period beginning January 11, 1983 and ending January 13, 1983. Table data are to be interpreted as follows:

VND - vendors A, X, C, D, and E

T - service time in seconds

C - no. of pieces of currency deposited

TABLE B-1. VENDOR SERVICE TIME

VND	T	C	VND	T	C	VND	T	C	VND	T	C
A	5.0	2.	E	7.2	3.	C	16.0	5.	E	4.8	3.
C	11.8	3.	X	25.0	6.	A	4.5	3.	C	4.8	1.
A	12.5	6.	E	13.0	7.	C	2.0	1.	A	4.8	2.
A	18.8	6.	A	10.4	3.	A	8.0	4.	A	7.0	3.
D	7.0	3.	A	12.6	5.	X	58.0	26.	D	5.0	3.
C	7.6	4.	X	17.2	7.	C	3.0	1.	D	7.8	4.
D	11.3	6.	A	17.4	4.	E	13.2	8.	A	8.6	4.
A	13.4	3.	C	4.6	1.	C	7.5	3.	E	9.0	3.
C	5.4	3.	X	16.8	8.	D	4.2	3.	X	20.0	6.
C	5.8	3.	X	16.0	5.	A	8.8	3.	D	9.5	3.
A	20.4	7.	X	24.5	7.	X	15.0	7.	D	4.2	3.
D	14.6	5.	X	10.0	7.	A	5.4	2.	A	11.8	3.
A	12.2	6.	C	52.2	17.	X	12.6	5.	E	2.0	1.
X	22.0	4.	D	6.3	3.	C	8.0	3.	A	4.0	2.
A	6.8	3.	C	12.5	3.	X	10.0	7.	D	4.0	3.
A	12.8	3.	E	1.0	1.	X	11.2	4.	D	11.0	5.
D	17.2	8.	A	20.8	6.	C	3.6	3.	X	29.0	6.
D	4.8	3.	A	10.6	4.	D	9.6	4.	A	10.0	3.
A	7.6	3.	E	6.8	3.	C	5.4	3.	E	3.0	1.
A	2.6	2.	D	6.0	3.	D	8.6	4.	A	13.0	6.
D	16.2	7.	D	11.0	5.	A	6.0	2.	A	8.2	3.
C	7.0	3.	X	23.4	7.	A	9.0	3.	D	40.0	15.
A	7.0	3.	A	5.6	4.	A	22.0	9.	E	1.0	1.
A	21.0	8.	C	6.0	3.	D	12.7	7.	A	5.2	2.
D	14.2	7.	A	6.6	3.	E	3.0	1.	A	3.2	2.
D	4.2	3.	D	21.5	7.	C	34.0	13.	X	6.0	5.
A	11.4	4.	X	18.0	7.	A	5.0	2.	A	16.0	6.
X	18.2	4.	E	2.2	1.	A	11.6	3.	A	10.0	3.
C	9.4	5.	C	2.0	1.	C	4.0	1.	D	5.4	3.
X	25.4	7.	X	30.0	12.	A	15.0	3.	A	17.4	4.
C	1.6	2.	E	18.2	7.	D	12.0	7.	A	5.4	3.
C	29.8	14.	X	9.8	5.	A	5.0	3.	D	12.8	5.
C	5.6	1.	C	16.2	7.	A	3.0	1.	D	11.8	4.
X	9.0	5.	D	8.0	3.	X	5.6	4.	E	4.8	3.
A	4.0	2.	X	30.0	5.	E	5.0	1.	A	14.1	4.
A	10.2	4.	D	9.0	3.	A	8.2	3.	C	5.0	3.
A	9.6	3.	A	5.0	3.	E	3.0	3.	A	3.8	2.
A	10.4	2.	D	12.0	3.	D	6.5	3.	A	9.8	4.
E	7.0	3.	A	4.0	2.	D	7.0	3.	C	2.5	1.
X	12.0	4.	A	12.4	7.	A	4.0	3.	C	20.0	10.
X	13.0	4.	X	17.3	7.	E	1.8	1.	X	31.0	15.
E	18.6	6.	A	24.0	8.	C	2.2	1.	A	3.8	2.
E	4.0	3.	A	7.0	3.	E	13.0	5.	D	3.6	3.
A	17.6	4.	D	6.0	3.	C	4.0	1.	E	6.0	3.
E	6.2	3.	X	33.0	7.	E	7.0	3.	A	8.2	3.
C	6.6	3.	C	5.6	3.	D	4.2	3.	A	2.8	2.
X	20.0	7.	C	9.0	3.	X	11.5	5.	D	8.6	3.
C	12.6	7.	E	7.0	3.	D	6.0	3.	C	13.0	5.
E	2.0	1.	D	5.5	3.	E	59.0	28.	X	14.0	7.
C	15.2	3.	X	18.4	7.	D	22.8	8.	C	22.2	10.
									X	26.8	5.
									A	4.0	2.

APPENDIX C

REPORT OF NEW TECHNOLOGY

This report presents for the first time a detailed description and assessment of PATCO's High Reliability Ticket Vendor (HRTV) in an operating environment. There is presented sufficient information to allow operators of transportation properties to assess the appropriateness of this ticket vendor to their system's needs and requirements. The HRTV developed by PATCO under an UMTA R&D Section 6 Grant grew out of their need for a vendor with superior reliability and maintainability to support their automatic fare collection policy. Innovative features of the HRTV were included in the design of the following subsystems: coin acceptor, coin escrow bill escrow, ticket vend, command/control using CMOS integrated circuits, coin vault, and bill vault.

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