4. In systems serving cities with many known landmarks, verbal directional information can be reinforced and complemented by images of those landmarks, providing a link to the city above.

ACKNOWLEDGMENT

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Assessment of a High-Reliability Ticket Vendor Developed by PATCO

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ABSTRACT

A description and evaluation are given of a high-reliability ticket vendor (HRTV) developed by the Port Authority Transit Corporation (PATCO) of Pennsylvania and New Jersey. The ticket vendors are part of the automatic fare collection system used by PATCO in its rail operations. The HRTV evaluation has shown it to be superior in reliability and comparable in maintainability compared with other ticket vendors.

The objective of this paper is to describe and evaluate a ticket vendor recently developed by the Port Authority Transit Corporation (PATCO) of Pennsylvania and New Jersey 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 in which each train has a crew of one person and by automatic fare collection (AFC) in which the stations are unattended for long periods during each day. Ticket sales are made directly to the patrons by vending machines monitored by closed-circuit television (CCTV) cameras; 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 have 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 research and development grant financed by Section 6 funds. A prototype HRTV was developed and installed at the Lindenwold station on May 9, 1982. A first look at the operation and performance of this new vendor is provided in this paper.

HRTV DESCRIPTION

PATCO's HRTV, shown in Figure 1, is an exact-value ticket-dispensing vending machine (no change given) that can issue as many as three tickets of different values. It has been designed to accept large fares for issue of a single ticket and can accommodate any

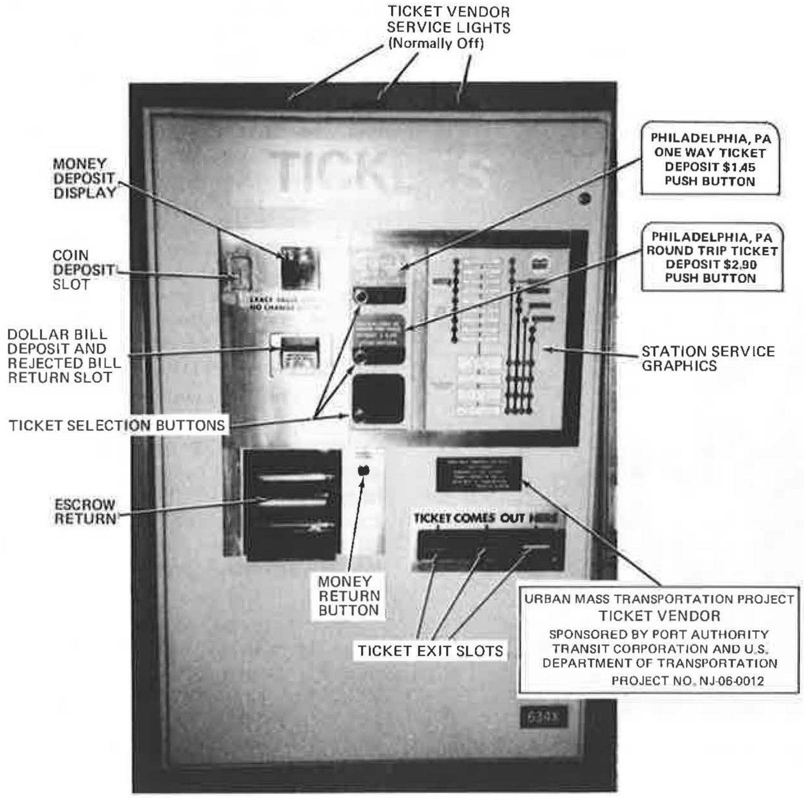

FIGURE 1 High-reliability ticket vendor (HRTV): operational configuration.

combination of nickels, dimes, quarters, Susan B. Anthony dollar coins, and one-dollar bills that 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 (a) high reliability; (b) easy maintenance; (c) low equipment operations and maintenance costs; (d) greater use of electronic solid-state techniques and minimization of mechanical operations; (e) allowance for continued use of existing magnetically encoded tickets; (f) vending of recycled tickets, which may be slightly deformed and irregularly stacked; (g) use of presorted stacks of different ticket values; (h) design of subsystems to adjust to known problems of worn coins and bills and coin jams; (i) automatic issuance of tickets; (j) operation based on exact change (addition of a change maker, if desirable, is a minor retrofit); (k) operation in an outdoor environment; (l) no bill stacking; (m) no money counting in equipment; (n) acceptance of high-value escrow; (o) prevention and defeat of fraud; and (p) vandalproofing.

Vendor design has utilized the availability of CCTV surveillance. If a stack is jammed or out of tickets, one of three lights located on top of the cabinet is turned on when the internal logic detects the fault; if one of the other vendor subsystems fails, all three lights and a beeper are turned on. Figure 2 shows the vendor in a removed-from-service mode. 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 electromechanical counters that allow for determination of cash deposited and tickets sold.

A ticket can be vended only if the exact amount of money is deposited. At any point during the transaction before the ticket selection button is pressed and 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 (LEDs) display the sum of money deposited following insertion of each coin and bill. Figure 3 is a flowchart that presents the HRTV operation.

On the top left in Figure 3, the process of ticket purchase begins with START followed by DEPOSIT MONEY (words in capital letters refer to steps on the flowchart). 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 it is valid (VALID BILL?). If the bill is inserted into the bill slot with the incorrect orientation or has a value greater than one dollar or is badly worn or counterfeit, the bill will be rejected (REJECT BILL). Rejection takes place at the bill deposit slot, shown in Figure 1. If the bill is accepted, it goes into escrow within the vendor, and the amount deposited is displayed. Vendor logic determines whether each coin deposited is valid (VALID COIN?). If a one-cent coin or a slug is deposited, the VALID COIN? NO state exists and all coins and bills deposited will return from escrow. If a VALID COIN? YES state exists, the coin goes to escrow and the amount deposited is displayed. The next step in the sequence is TICKET BUTTON IS PUSHED.

If it is determined by the vendor logic that the

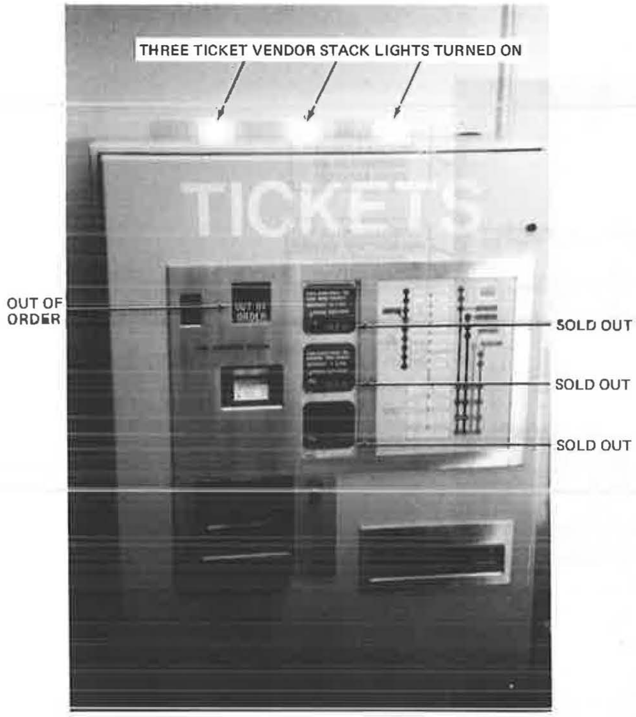

FIGURE 2 HRTV: removed-from-service configuration.

correct fare has not been paid, either an underpayment or an overpayment has been made. If there has been an underpayment, the next step is START OVER? If the patron decides not to start over, he determines the amount to be added and deposits the money, and the initial phase of DEPOSIT MONEY is repeated. If the patron decides to start over, he pushes the MONEY RETURN button, immediately after which the money is returned from escrow and the display returns to zero. The patron must then repeat the process, beginning with DEPOSIT MONEY. If there has not been an underpayment, an overpayment has been made, and the patron must push MONEY RETURN and follow the sequence shown in Figure 3, which will lead to a return of all money and require the patron to start over with the phase DEPOSIT MONEY.

If the correct fare has been deposited, the CORRECT FARE? YES branch is followed, and the START TICKET TRANSPORT process begins. A sensor determines whether the ticket advance has actuated the exit microswitch. If the response is no, the stack is taken out of service, and the 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 microswitch is to ensure that if the ticket is not dispensed, the patron can get his money back. If the ticket advance has actuated the exit microswitch, the next step is for the vendor to vault escrow and capture the money. Another sensor determines whether the vault mechanism

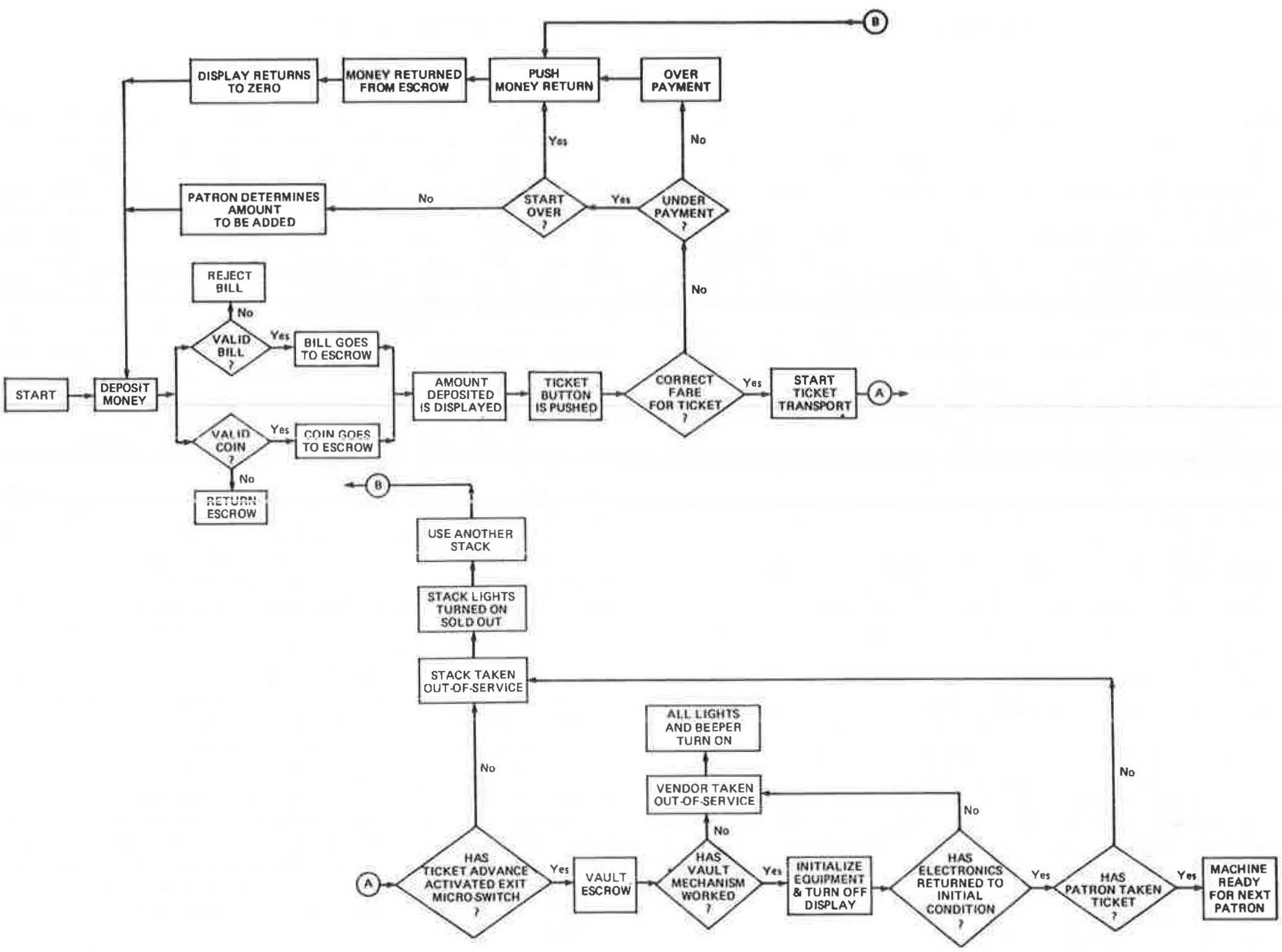

FIGURE 3 HRTV operations flowchart.

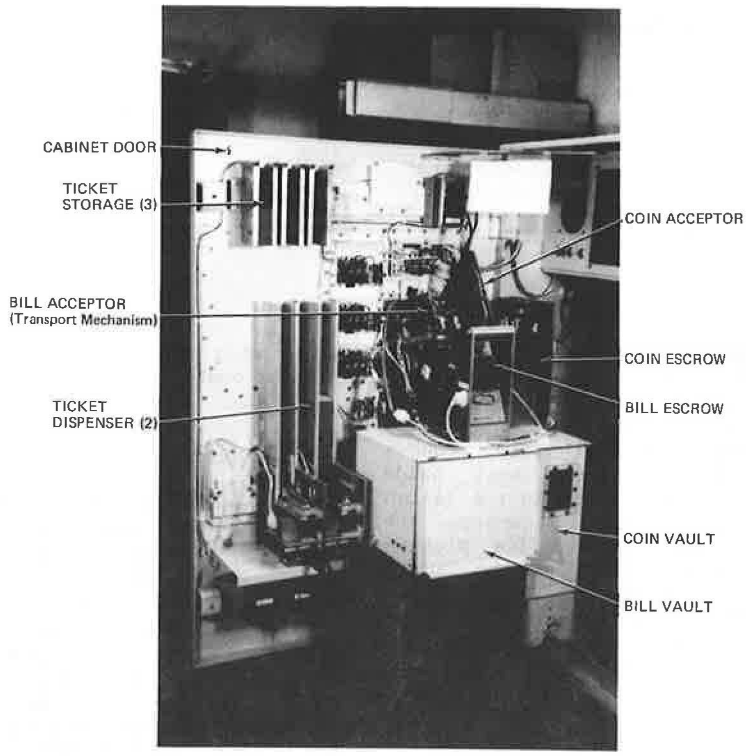

FIGURE 4 HRTV subsystems attached to door.

has worked. If not, the vendor is taken out of service and all lights and a beeper turn on. If the vault mechanism has worked, the vendor initializes the equipment and turns off the display. The vendor then performs a self-test to determine whether the electronics has returned to the initial condition. If not, the vendor is taken out of service, and if yes, it is next determined whether the patron has taken a ticket. If the answer is no, the stack is taken out of service and if yes, the machine is ready for the next patron.

There are 11 major HRTV subsystems, which include bill acceptor, bill escrow, bill vault, coin acceptor, coin escrow, coin vault, two ticket dispensers, command/control logic, nine transaction/ticket counters, power supply, and cabinet. Figure 4 shows the subsystems attached to the door, and Figure 5 shows the subsystems attached to the frame. The Rowe model BA-5 is the dollar-bill acceptor; the bills, 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 in the vault, and if the MONEY RETURN button is pushed, the belt moves so as to deposit the bills in 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 until 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, all the coins (and bills) will be returned through the till. The most innovative feature of the HRTV is PATCO's design of the vendor 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 vendor 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 that the relative dimensions between the picker surface and the ticket be held within a relatively small tolerance to ensure that only one ticket will be issued. The use of three

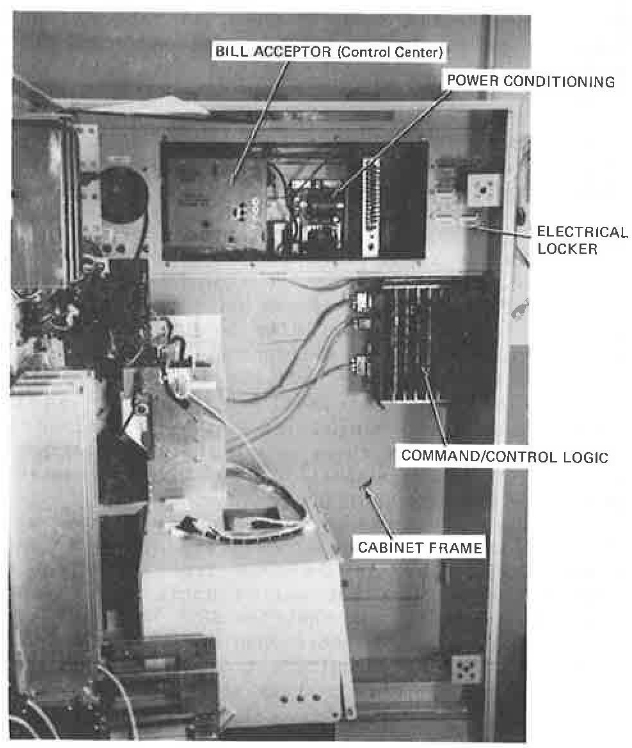

FIGURE 5 HRTV subsystems attached to frame.

TABLE 1 Vendor Reliability and Repair Performance

Equipment No.	Failures	Trials	Failure Rate	MCBF[a]	σ(MCBF)	MTTR[b]	σ(MTTR)
634 A	48	35,626	0.001347	742.21	784.15	0.3265	0.1816
X	7	19,074	0.000367	2,724.86	1,874.74	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

[a]Mean cycles between failures.
[b]Mean time to repair (in hours).

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 subsystem is distributed among five plug-in boards. An important design feature of the boards has been to locate in-line test points that 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 nonzero reading.

HRTV PERFORMANCE

Reliability and maintainability data were collected during a 5-month test period from June 9 through November 11, 1982, for the HRTV as well as for the four Advanced Data System ticket vendors located at the Lindenwold station. The HRTV reliability performance over this period was estimated as 2,724.86 mean cycles between failures (MCBF), whereas the composite performance for the other four vendors was determined to be 492.55 MCBF. The performance as measured by MCBF and the mean time to repair (MTTR) during the 5-month test is shown in Table 1. [The composite performance for eight IBM and nine Cubic Western vendors operated by the Bay Area Rapid Transit was found to be 140.80 MCBF (1).] Significance testing of the MCBF for the HRTV and the four other vendors at Lindenwold indicated that there was only a 0.1 percent probability that the observed results could be due to chance.

It was determined that the mean time to repair the HRTV is 0.3375 hr and that this time is comparable with the repair time for the other vendors at Lindenwold. Repair time is the time to trouble-shoot and replace vendor subsystems on site; it was not possible to include shop time because the HRTV is unique. 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 were collected over a 3-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 until a ticket is dispensed. It was found that the HRTV is much slower than the other four vendors when about nine deposits or less are made to acquire a ticket. If nine deposits are made, the service time of the HRTV is comparable with that of the other vendors, and for a greater number of deposits the HRTV is faster.

CONCLUSIONS

PATCO set out to design and manufacture a ticket vendor with improved reliability to meet the performance needs of operation within unattended stations and 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 that of the other vendors in the test group as well as superior to that of the vendors reported in the literature. Based on the test results, it was determined that the maintainability should be comparable with that of the other PATCO vendors and that no additional resources beyond those that exist at PATCO should be needed for performance of maintenance.

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

ACKNOWLEDGMENT

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