PERFORMANCE OF AUTOMATIC PASSENGER COUNTERS IN THE VENTURA/LOMPOC SMART CARD DEMONSTRATION PROJECT

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Automatic Passenger Counters (APCs) were deployed as part of a Field Operational Test (FOT) of a Fare Transaction and Vehicle Management/Monitoring System (Faretrans VMS). The test took place across several transit

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operators in Ventura County, California between May 1995 and June 1997. The automatic passenger counters relied on laser sensors installed on buses to count passenger boardings and alightings. The APC data was intended to help the operators meet Federal Section 15 reporting requirements. There were several major technical problems with the APCs. Some of these problems, such as incompatibility with other hardware and software components of the system, were overcome during the course of the FOT. However, data processing problems were not surmounted, and the test revealed significant differences between APC passenger counts and manual passenger counts. The authors conclude that, while APC technology may eventually be a useful means of gathering ridership data, the technology did not perform successfully in this test.

**Keywords:** Automatic Passenger Counters; Automatic Identification Systems; buses; transit systems; field operational tests; public transportation

**INTRODUCTION**

Section 15 of the Federal Transit Act, 49 USC Sec. 5335, requires the U.S. Department of Transportation (USDOT), with the help of many of its grant recipients, to maintain a reporting system using uniform categories to accumulate mass transportation financial and operating information, and employing a uniform system of accounts. The purpose of this reporting system is to help meet the needs of individual mass transportation systems, of Federal, State, and local government agencies, and the general public for information on which to base mass transportation service planning, and to help any level of government make public sector investment decisions. Pursuant to 49 USC Sec. 5307, the USDOT can only make an Urbanized Area Formula Grant if the grant applicant and beneficiaries are subject to these reporting and uniform accounting requirements.

Meeting Section 15 requirements has traditionally been a labor-intensive effort for transit properties, which normally meet these reporting requirements by collecting sample data consisting of manual counts of passenger boardings and alightings. Automatic passenger counter (APC) technology offers the prospect of more data, lower data costs, and greater accuracy. APCs were first deployed in the mid-1970s as stand alone systems that combined passenger counts with vehicle location
information from sources such as odometers or radio beacons affixed to signposts. More recently, APC deployments have been designed to rely on data from automatic vehicle location (AVL) systems. This has meant both deployment of integrated AVL/APC systems, and attempts to integrate AVL systems into existing APC deployments.

There are several incentives for combining AVL and APC functions. Global positioning systems (GPS) in public transit offer the possibility of vehicle tracking and monitoring schedule adherence. If coupled with GPS for logging locations, APCs provide the opportunity to track ridership in time and space, counting boardings and alightings by stop, and thus providing detailed information on transit demand patterns and vehicle load factors. This data supports the creation, evaluation, and improvement of schedules; and informs route change decisions (Boyle, 1998; Baltes and Rey, 1999). If coupled with smart card technology for processing fares, APCs also make it possible to construct spatially tagged customer databases. Such data would provide a range of system management and service innovation opportunities not currently available to transit agencies.

Interest in these advanced APC applications seems to have driven considerable growth in APC installations. In 1998, APCs were in use or scheduled for deployment on 31 fixed-route bus systems nationwide (Casey et al., 1998). By September 2001, APCs were installed or planned at 154 transit agencies nationwide (Yermak, 2001).

Given the level of interest in this technology, the empirical literature on APC performance is surprisingly sparse (Baltes and Rey, 1999). This deficit is partially a function of the relatively recent and rapid growth in intelligent transportation system (ITS) applications. Standard assessment procedures have been in place since at least the late 1980s (Strathman and Hopper, 1991), but the evaluation of advanced transportation technology tests, including APC deployments, did not being in earnest until the mid-1990s. In 1997, the USDOT evaluated the 84 field operational tests (FOTs) that it had funded since 1991 (USDOT, 1997). However, data was still incomplete or nonexistent for some of these tests. As a result, the USDOT study focused more on the development of systematic ITS benefits measures than on field measurements of these benefits. In 2000, the USDOT estimated the benefits of previously deployed, technology-based fleet management systems, and projected future benefits (Goeddel, 2000). In an analysis of a total of 111 fleet management systems either already operational, under implementation, or planned for deployment on fixed route buses nationwide, USDOT estimated that these systems would generate over $1.7 billion in benefits through 2009 in constant year 2000 dollars. The analysis did not isolate APC benefits from the
benefits accruing from other control technologies designed to improve transit operations (Goeddel, 2000).

The Washington Metropolitan Area Transit Authority (WMATA) provides the most documented, prominent APC success story to date. Following a six-week test, WMATA (1991) reported 99% boarding count accuracy and 98% alighting count accuracy for infrared APCs relative to manual counts. This early test system relied on mid- and late-1980s technology. The system was somewhat distinguished by reliance on high-energy sensors for passenger detection rather than treadle mats. The system required radio signals beamed from signposts for location information, and was not integrated with an AVL system.

More recent deployments have been less encouraging, particularly with respect to APC/AVL integration. WMATA has shifted its automatic passenger counting focus from APCs to fare cards. Built on an earlier fare technology test (WMATA, 1996), the SmarTrip card is a permanent, rechargeable smart card system designed for use on the agency’s subways and in transit facility park-and-ride lots. The cards can be used to pre-purchase simplified fares for the agency’s buses, but WMATA buses are not yet smart card ready.

The Chicago Regional Transportation Authority (RTA), which includes the Chicago Transit Authority (CTA), the suburban PACE bus system, and the Metra commuter rail lines, completed a smart card test in 2001 on the CTA and PACE lines using the same technology as WMATA. However, the existing CTA and PACE APC systems will not be integrated with the AVL component of this new smart card system.

In Atlanta, an ambitious ITS deployment including both an AVL system and APCs has not been fully fielded. The Metropolitan Atlanta Regional Transit Authority (MARTA) had hoped to coordinate the deployment with the 1996 summer Olympics. The expedited schedule proved to be an obstacle to the project’s success, and only one-third of the system’s buses had been equipped with AVL systems by the time the Games began (Monahan, Schweiger, and Buffkin, 2000). The APC element of the system was delayed. However, both AVL and APCs remain part of an integrated ITS effort in Atlanta, and deployment of both is ongoing.

In Los Angeles, an early APC demonstration project that relied on treadle mats for passenger detection was in place on Southern California Rapid Transit District (SCRTD) buses from 1977 to 1985. A 1997 Los Angeles County Metropolitan Transportation Authority (LACMTA) effort to redeploys APCs using high-energy sensors was redefined in 1999 to integrate the APC function into a new vehicle Advanced Transportation Management System (ATMS), rather than as stand alone system. The contract for ATMS was placed out to bid in 2001.
The most successful U.S. deployment of an integrated AVL/APC system is probably provided by the Tri-County Metropolitan Transportation District of Oregon (Tri-Met). Tri-Met has a long-standing involvement with APC systems, originally making relatively unique use of odometer data, timestamps, and layovers to identify the locations of boardings and alightings (Boyle, 1998). Tri-Met seems to have successfully integrated APCs into an ongoing AVL deployment. As of 1998, 15% of the fleet was equipped with APCs, with an intent to expand this share to 100% within a few years (Boyle, 1998). Tri-Met’s system has not yet been subjected to an independent evaluation.

This paper measures the effectiveness of automatic passenger counters in the form of laser sensors installed on buses as part of an electronic Fare Transaction and Vehicle Management/Monitoring System (Faretrans VMS) deployed across several transit operators in Ventura County, California, between May 1995 and June 1997. This multi-agency deployment appears to be the first formal, independent evaluation of an integrated AVL/APC system. The FOT deployment produced very few usable boarding and alighting estimates. A careful review of the test results suggests that this kind of APC system could eventually be used to support Section 15 reporting efforts, but not unless numerous technical problems are overcome first.

PHASE III OF THE VENTURA/LOMPOC SMART CARD DEMONSTRATION PROJECT

Phase III Ventura/Lompoc Smart Card Field Demonstration took place in Ventura County, California, from May 1995 to June 1997. The test was sponsored by the Federal Transit Administration (FTA) and the California Department of Transportation (Caltrans). The demonstration was the final phase of a larger field operational test evaluation of the effectiveness of smart cards and related technology as an alternative to traditional fare collection methods (Moorell and Giuliano, 1998). Phase I of the demonstration consisted of a survey that assessed agency needs and defined functions to be delivered by a smart card system. Phase II tested the technical feasibility of smart cards in service on lines operated by three fixed-route transit properties operating in Los Angeles County. Phase II involved neither APCs nor service integration across operators. Phase III sought to demonstrate the feasibility of using smart cards and related technology, including APCs, to provide an integrated fare medium and improved management information across several transit operations.

Phase III had two parts. The first was development of a multi-agency FareTrans VMS to be demonstrated among several transit operators. The
second part involved development of an automated system for demand-responsive services (Giuliano, Moore, and Golob, 1999). The Partnership for Advanced Transit and Highways (PATH) evaluated Phases II and III of the FOT (Chira-Chavala and Coifman, 1996; Giuliano and Moore, II, 1998; Moore, II and Giuliano, 1998; Giuliano et al., 1999; Giuliano, Moore, II, and Golob, 2000).

FOT Participants

A private technology vendor developed the smart card system, APC system, and related technology used in the demonstration. The system was implemented by the technology vendor with the cooperation of Caltrans, the Ventura County Transportation Commission (VCTC), and seven small transit operators on whose buses the Faretrans VMS was deployed. These operators were South Coast Area Transit (SCAT); the Ventura Inter-City Service Transit Authority (VISTA); Simi Valley Transit; Thousand Oaks Transit; Camarillo Area Transit; Moorpark City Bus; and the Ojai Trolley Service.

Fare Transaction and Vehicle Management/Monitoring System

The FareTrans VMS was designed to accommodate integrated fare transactions among the seven participating transit operators, generate data and reports necessary for multi-agency operation, and produce ridership statistics meeting Section 15 reporting requirements (Giuliano et al., 1999). To achieve these objectives, such a system must have a means for reading and writing to fare cards, for exchanging card status information among all transit operators on a daily basis, and for counting passengers and transmitting the ridership data to a common database.

The main system elements of the standard FareTrans VMS deployed in the FOT are summarized in Figure 1. These include the following.

1. **Passenger Transaction Controller (PTC):** The PTC is an on-board controller that receives, modifies, stores, and transmits data from and to a variety of sources.
2. **Driver Interface Unit (DIU):** The DIU provides the system and driver with information needed to accommodate passengers and to effectively process transaction data files.
3. **Passenger Transaction Unit (PTU):** The PTU reads and writes data to the fare cards.
FIGURE 1. Standard configuration for a full function FareTransaction and Vehicle Management/Monitoring System (FareTrans VMS). Arrows indicate data flows.

4. A Geo-Positioning System (GPS): The GPS provides the vehicle’s geographic location data. The PTC polls the GPS, providing location data for card transactions, boardings, and alightings.

5. Automatic Passenger Counters (APCs): The APCs are laser sensors installed near the front and rear doors. Boardings and alightings are
counted by passengers breaking the sensor beam. Passenger counts are then written to the PTC.

6. **Garage Computers**: Garage computers receive data from the PTCs via local area radios operating at garage sites.

7. **The Spread Spectrum Radio Networks**: These consist of PTCs located on buses communicating with garage computers over a short-range radio system installed at each garage.

8. **Mobility Manager**: The Mobility Manager serves as the central data bank or as the central node of communications between entities selling fare cards and the transit agencies.

9. **Other Communication Links**: In addition to communication links between garages and vehicles, communication links are required between card sales outlets and the central data bank, and between garages and the central data bank.

The FareTrans VMS ultimately deployed in Phase III of the FOT did not include stop announcements, but did combine three technologies: smart cards, GPS, and APCs. The APCs used in the FOT were intended to provide the FareTrans VMS with the capability of producing ridership data for Section 15 reporting requirements. Whether investment in such a system is warranted depends on its costs relative to the cost of collecting the data required for Section 15 reporting by conventional means.

Large transit systems would likely benefit more than small systems, because the cost of Section 15 data collection is higher for large systems. Further, ridership patterns are more transparent in small systems. Long-term managers or drivers have considerable informal knowledge of ridership patterns, so more extensive data collection may have limited use. In contrast, large systems may benefit greatly from the opportunity to gather ridership data in a systematic way, and the APCs provide the possibility of regular random sampling.

The smart card is required if individual trips are of interest. The propensity to use smart cards is related to characteristics of the riders (Giuliano et al., 2000). Consequently, smart card trip data will not be representative of the general ridership. Thus, smart cards cannot be justified on grounds of data collection or operations planning, though they may be of value from a management information perspective as an adjunct to a combined GPS/APC system.

Most operators associated with the test instrumented all of their vehicles to some degree. A total of 80 vehicles were equipped with card readers. Of these, 18 vehicles from 4 of the 7 transit operators participating in the test were also equipped with automatic passenger counters. One of these APC vehicles was retired from service during the test.
Role of the Automatic Passenger Counters

Contemporary automatic passenger counters usually rely on laser, infrared, or other high-energy sensors outfitted on the front and rear doors of buses. These sensors and the control system processing their signals must be discriminating enough to identify individuals breaking their sensor beams, even when the individuals are boarding in a dense queue. This can only be accomplished with the redundancy provided by multiple sensors operating simultaneously. Multiple sensor arrays also permit differentiation between boardings and alightings.

Automatic passenger counts are accumulated by the counter and written to the passenger transaction controller at 10- to 15-second intervals, depending on the level of competing data processing requirements imposed by fare transactions. Fare transactions are processed first by the PTC to avoid communication conflicts between signals from the APCs and the PTU. The PTC provides the set of boardings and alightings written by the APC with a time stamp, polls the GPS for location, and adds this information to the boardings and alightings record written to the passenger transaction controller.

PROBLEMS WITH THE AUTOMATIC PASSENGER COUNTERS

The FOT revealed several major problems with the operation of the APCs.

Poor Initial APC/Fare Card Integration

The technology vendor experienced initial difficulties integrating the APCs with the other FareTrans VMS components. Installation of the APCs began in late April of 1996. After the installation of five APC units, the technology vendor discovered that APC operation periodically interfered with fare card transactions. Buses with passenger counters incorrectly recorded as transactions all boardings and alightings following use of a fare card. When a card user crossed a passenger counter, the card ID was replicated for following passengers crossing the counter. Thus, some fare card transactions were recorded when in fact no cards were involved. Also, conflicts between the APC and the PTU caused five to seven percent of cash passengers to be missed by the system (Giuliano et al., 1999).

Federal standard SAEJ1708 defines how bus companies should interface computers on buses. Unfortunately, the standards for
communication speeds (9600 baud) and priorities proved inconsistent with the needs for the FOT. The APC and fare card transactions are measured in milliseconds, and they cannot be written to the passenger transaction control unit continuously. Writing APC data continuously interferes with fare transactions.

In June 1996, both the APCs and the PTCs were redesigned to address communication conflicts with the operation of the fare card system. The technology vendor redesigned the FareTrans VMS hardware and software to store passenger count data in a buffer so that the passenger transaction unit and the APC never write to the control unit simultaneously. The APCs continue to monitor passenger counts continuously, but the APC computer writes counts to the main computer only every 10 to 15 seconds (Giulano et al., 1999). This problem was resolved as of July 1996, at which point the technology vendor reported that relatively few boardings were fare card transactions. Most users boarded without cards.

Drivers, supervisors, and smart card sales outlet staff had to be retrained as a result of this redesign. Buses had to be taken out of service to be made available for equipment changes, and thus these changes could only be executed incrementally. As a result, work on the APCs continued through December of 1996.

APC Counts Differed from Field Counts

The FOT evaluation team requested counts of boardings and alightings generated by the technology vendor from APC data. Eleven buses were monitored both by the Faretrans VMS and by the evaluation team during May 1997 field tests. The team compared manual counts for these buses with the APC counts. In addition, the team requested counts for some buses they had not monitored, and for some that did not have APC equipment. Historical ridership data is available for all of the routes involved. If the technology vendor had provided APC counts for buses that have no APC equipment, these counts would necessarily have been fabricated, and the other APC counts would become suspect.

Of the 11 buses tracked by the evaluation team, 8 were equipped with APCs and a FareTrans VMS that appeared to be working during field test periods. The other three buses had passenger transaction units that appeared to be working, but no APC equipment. The technology vendor correctly identified the three buses with no APC equipment, but was able to provide the evaluation team with an estimated number of boardings and alightings by bus stop for only two of the remaining eight buses. These were SCAT bus 3511 (six runs) and Thousand Oaks bus 25 (three runs). A review of the raw data furnished by the technology vendor showed
that no data at all was collected from two of the eight APC-equipped buses tracked by the evaluation team, and that only data related to fare card transactions was collected on the remaining four APC buses. The technology vendor’s inability to provide automatic passenger data for most buses strongly suggests that this data was not being consistently collected or transmitted to the system’s master database during the test.

A comparison of the automatic and manual passenger counts appears in Figure 2. Ideally, the automatic and manual counts should be identical. This is not possible in practice. Some differences between observed and estimated counts would be expected even if the APC equipment was working correctly, and the technology vendor was using the best achievable algorithm available for converting raw APC counts into boarding

Note: Logically, passenger and driver alightings – passenger and driver boardings – passengers
already onboard when observations begin + passengers remaining onboard when
observations end = 0 for each run. Field observations are off by a count of 172 – 155 – 28 +

12 = 1

FIGURE 2. Boardings and alightings derived from APC counts versus observed values. Results are available for only two of eight APC-equipped buses.
and alighting estimates. For example, some of the passenger activity recorded by the evaluation team on Thousand Oaks bus 24 has no corresponding record in technology vendor’s data. This includes one boarding and two alightings between 4:40 PM and 5:00 PM. This discrepancy is an example of a Type I error: Activity that was intended to be measured by the APCs went unaccounted for.

Conversely, automatic equipment sometimes overcounts. These are events that should not be treated as passenger activity, but are. This is a Type II error. For example, the APCs record boardings and alightings that occur between runs and at the end of the day. These boardings and alightings do not appear in corresponding field counts completed by the evaluation team. Field observations indicate that this additional interim activity can be significant, amounting in this case to a total of six extra boardings and three extra alightings. The technology vendor reported that the counts based on the APCs were adjusted to account for such extraneous activity on the parts of drivers and others.

The technology vendor also provided the evaluation team with the cumulative APC counts in addition to the processed estimates of boardings and alightings by bus stop. The objective for requesting this raw data was to try and recreate the technology vendor’s estimates. Unfortunately, this was not possible. The method the technology vendor used to convert the APC data to passenger counts remains undocumented and thus unknown. The cumulative APC counts in the technology vendor’s raw data appear to be incrementing correctly. The automatic passenger counters take readings at frequent intervals, as often as every second. These readings do not necessarily correspond to passenger or bus activity.

Similarly, an analysis of transactions by fare type was not feasible. The technology vendor reports that the fare type fields in the transaction records were present for experimental purposes, and had not been successfully integrated with APC data collection.

Still, a few inferences can be drawn concerning the unknown algorithm the technology vendor used to process APC data into estimated passenger counts. The limited data available in Figure 2 suggests that the algorithm tends to underestimate the largest values of boardings and alightings. Simple regressions of the observed and APC boarding and alighting data for bus 3511 produced positive intercept terms and slopes of less than one, suggesting a tendency for estimates of larger values to include increasing deterministic error. The number of boardings and alightings associated with Thousand Oaks bus 25 are smaller than for SCAT bus 3511. The regressions for bus 25 demonstrate greater accuracy in the estimated values for this bus, but the sample is too small
to draw statistical conclusions about the process generating the APC estimates.

The APC data accounts for most of the riders on the Thousand Oaks bus, but some riders are clearly missing from the automatic SCAT counts. The evaluation team recorded 172 alightings compared with the technology vendor’s 141. Boardings also appear to be underestimated, on one run by as much as 36%. Some of the missing boardings might be attributed to passengers who boarded previously (12, including the driver). These riders may have boarded before the bus power was turned on and the system was initialized. However, total alightings from the SCAT bus, which the technology vendor reports are the most accurate means of measuring ridership, are still 18% lower than the field count.

This apparent undercount is surprising. Undercounts suggest Type I errors. For example, five babies carried by adults were observed in the field, and we presume the APCs cannot recognize these children as boarding passengers. However, field observations suggested that there are more ways for Type II errors to occur than for Type I errors to occur. For example, on two occasions, the evaluation team observed a significant amount of activity in front of the APC equipment during the operation of wheelchair lifts. Thus, the evaluation team expected the technology vendor’s APC data to overestimate ridership by capturing driver and passenger activity between runs, yet this was not the case.

**Other APC Problems**

The APCs were also associated with a number of the FOT’s other technical and operational problems, not all of which were resolved.

1. **Installation Delays:** It took the technology vendor over seven weeks to install equipment used to complete circuits in buses not equipped with APCs, and which inform the PTU control unit that no APC sensor is available. This delay was caused by transit agencies restricting the technology vendor’s access to their buses. Access improved during the course of the test.

2. **New Maintenance Requirements:** APC lenses and reflectors were sometimes covered or otherwise obscured, preventing them from operating. To avoid this problem, transit services using APCs must define routine maintenance checks to ensure that line-of-sight communication between APC sensors is unimpeded. The test agencies did so.

3. **Bus Practices:** The technology vendor required that buses equipped with APCs be assigned to specific routes, but standard bus practices on the part of the FOT participants made this difficult. Further, although
buses are rotated across routes, it is difficult for transit operators to modify their vehicle scheduling procedures to support sampling schemes by rotating APC-equipped buses across routes in a systematic way. This problem remained unresolved during the course of the test, greatly complicating the technology vendor’s efforts to convert raw APC counts to ridership estimates.

4. **Vehicle Configurations**: Neither smaller buses nor vans could be equipped with APCs. This problem was not resolved; but operators with small vehicles often have small fleets, which means that equipping even a single van with an APC provides substantial information about their ridership.

**OTHER PROBLEMS ASSOCIATED WITH THE FIELD OPERATIONAL TEST**

The APCs were not the only problematic part of the demonstration (Guiliano et al., 2000). This was a very complex test, and the system was beset by other technical, user, and institutional problems, some of which certainly contributed to the APCs’ loss of function. These included the following.

1. **Technical Problems**:

   - **FOT Logistics**: Several of the technical problems related to the field logistics of the demonstration. These included rushed deployment of untested equipment and software; delays in component deliveries; unexpected changes imposed by participating agencies; different bus fleets requiring different hardware installation procedures; and operator delays in reporting problems.

   - **Operator Performance**: Other technical problems related to operator performance. These were problems such as the technology vendor’s failure to explain the firm’s equipment-testing policies to the operators; wiring difficulties during installation; voltage incompatibilities between some vehicles and the FareTrans VMS; card initialization troubles; a number of poor human–machine interfaces; and problems with data management.

2. **Institutional Problems**: Transit operators were often given only limited information about the project, and were not thoroughly trained regarding the nature, installation, use, or repair of the equipment. No written contract or policies specified the role each agency and participant was to play, explained who was responsible for what activities, or provided the participating transit operators with a clear economic stake in the demonstration’s success.
RESULTS

The automatic passenger counting system did not function reliably during the FOT. Although the APC equipment appeared to be working, the technology vendor could not provide most of the corresponding passenger count data, nor could the evaluation team make use of the data in the vendor’s transaction data file. In the two of eight cases for which the technology vendor could provide the automatic passenger counts, there was considerable variance between the field counts and the APC estimates.

This is unfortunate. Without the ability to use the automated data for passenger counts, transit agencies must resort to manual counts for collection of Section 15 data and data on ridership patterns. None of the participating transit agencies received passenger count data during the FOT that was sufficient for Section 15 reporting purposes, although VCTC reports that SCAT used ridership data subsequently collected with the test APC equipment as the basis for a Section 15 report in Fiscal Year 1997 (Giuliano et al., 1999). The technology vendor provided some sample data of boardings and alightings for Carillo (1 route) and Simi Valley (4 routes). Data for operations as small and as lightly utilized as these, however, provides only limited evidence of the potential of the system. Further, these smallest operators have no Section 15 reporting requirements.

The real test for APCs is how they operate on heavily patronized routes, where many people are boarding and alighting at the same time. The FOT was a relatively large test, but was a much smaller exercise than most system-wide revenue service deployments, yet included problems both with lost data and with the accuracy of the counts. Until additional empirical field studies are undertaken and the results published, there is no fully objective evidence that APCs can provide adequate data for Section 15 reports to operators in Ventura County, or anywhere else. The FOT evaluation and associated literature search provides very little evidence from the field at large indicating that this technology is mature enough for transit properties to make low-risk installation decisions.

We can verify that the APC sensor equipment operates reliably, though the FareTrans VMS was in service less frequently than we expected. During the course of the FOT, service on individual vehicles was sometimes interrupted due to voltage fluctuations, failure of the BIOS battery, or because the PTC might have been removed for service. In addition, some Faretrans VMS units remained out of service for longer than would otherwise have been necessary because of the difficulty the technology vendor had in making on-site repairs at SCAT, the largest operator.
<table>
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<tr>
<th></th>
<th>No data present</th>
<th>Test card data present: No APC data</th>
<th>Both test card and APC data present</th>
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<td>82.8% of total</td>
<td></td>
<td>100.0%</td>
</tr>
</tbody>
</table>

**TABLE 1.** Cross Tabulation of Test Card and APC Data in Electronic Records Expected to Include These Data
Results are further summarized in Table 1. Test card transaction data were successfully transmitted from the bus to the technology vendor's master database 83% of the time across all buses. Test card data for buses without automatic passenger counters appeared relatively more frequently (87%) than test card data for APC-equipped buses (77%), though this difference is not statistically significant. APC buses tended to collect test card data even when the APC equipment was not working. Passenger count data was missing from records for APC-equipped buses 54% of the time, or more often than not.

These results describe the performance of an integrated APC/AVL system, not the APC sensors. There is no question about whether sensors operate on buses. They do work (Baltes and Rey, 1999; WMATA, 1991), and there are a variety of equivalent sensor technologies available. All such sensors require a degree of maintenance, with high-energy sensors requiring less maintenance than treadle mats.

CONCLUSIONS

The missing APC data is more likely the result of communications failures than failures in the APC systems. Even if the Farerans VMS is operating, there are many ways APC data recorded by the system might not be transmitted to the central data bank maintained by the technology vendor. Communications between vehicles and the garage computers could be interrupted due to spread spectrum radio antennae problems, excessively large files, or drivers proceeding too quickly past the antennae connected to the garage computers. The garage computer might not be operating due to voltage fluctuations or other interference. Communication between the garage computers and the technology vendor's central data bank might have been interrupted or prevented by a modem connection fault, or (very rarely) a file transfer fault after a modem connection was established. Even if APC data is successfully transferred from vehicles to the central data bank, some data might still be lost in automated data cleaning procedures. All of these failures occurred individually or in combination during the course of the FOT. As of August 1997, one bus had not successfully communicated with its garage computer since March 20, 1997. If no automatic accounting method is in place to check for missing data, outcomes such as this can go undetected for long periods of time.

The technology integrator was able to identify and overcome most of the communications problems encountered during the FOT. This was largely a matter of trial and error, of identifying missing or unusual vehicle and transaction information in the project's central data bank,
and working backwards to identify where the communication failure was occurring. Despite many simultaneous problems, continuous improvement was a consistent theme within the test. Consequently it is likely that the missing APC data ultimately could have been and likely was collected on subsequent trials.

It is less clear that the technology vendor could ever have developed the means to convert the raw APC data into reliable measures of boardings and alightings. Other agencies with APC field experience indicate that the software used to process raw APC data is critical to the quality of passenger count data (Casey et al., 1996; Boyle, 1998; Baltes and Rey, 1999), and that this step is most often the bottleneck in using APC data to support other planning and scheduling objectives.

The technology vendor provided the evaluation team with open access to its APC records, but not to the algorithm used to convert this raw data to report values. Even when this raw APC data seemed to have been successfully collected, the technology vendor was usually unable to provide automatic passenger counts to compare against the evaluation team’s field observations. Without knowledge of the technology vendor’s algorithm, there is no way to convert raw APC data into additional count estimates, no way to replicate the few estimates the technology vendor was able to provide, nor any way to try and improve the technology vendor’s algorithm.

Boarding and alighting data collected from stand-alone APC systems have been successfully post-processed to provide accurate ridership counts (WMATA, 1991). Such stand-alone APC systems differ from the APC element in the FareTrans VMS only in that location information is provided by means other than an AVL system. Making use of this information to estimate boardings and alightings is an algorithmic challenge in any event. Unfortunately, the technology integrator appears to have not had the resources to develop an adequate algorithm for post-processing boarding and alighting data into acceptable ridership estimates. The technology integrator might well have succeeded in doing so, had the test been less complicated in any of several dimensions. In this case, however, the project resources that might have otherwise been devoted to more advanced data processing were consumed resolving problems that a better structured FOT would have avoided.

Our overall assessment of APC technology is that it has worked (WMATA, 1991; Casey et al., 1996; Boyle, 1998; Baltes and Rey, 1999), though it is troubling that most of these results are self-reported by the transit agencies involved rather than independently observed. The FOT was successfully evaluated, but the evaluation could not provide independent verification of an integrated APC/AVL success. Still, the potential
for success was clear. Integrated APC/AVL technology has many potential transit applications of considerable importance, and we expect that the technology ultimately will work reliably on a routine basis. Combining APC and GPS data with changes in bus practices and advanced pattern recognition programs are likely to eventually provide the cross-referencing and inference opportunities needed to construct high-quality APC estimates.

A more sophisticated system may be more expensive, but if the objective is to support Section 15 data collection requirements, it is important to remember that not every bus need be equipped with working APCs (Strathman and Hopper, 1991; Boyle, 1998). Regular random sampling can be accomplished even if only a relatively small portion of the fleet is APC-equipped and these buses are rotated systematically across routes. These sorts of changes in bus practices were not part of the FOT, but achieving them is likely to be a necessary step for successful commercial deployment and for compliance with Section 15 reporting requirements.

REFERENCES


