Assessment of Operational Effectiveness, Accuracy, and Costs of Automatic Passenger Counters

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The research results of an assessment of the operational effectiveness, accuracy, and costs of various bus transit automatic passenger counter (APC) technologies are presented. The primary objective of automated passenger counters is to efficiently acquire accurate data on passenger activity and transit travel times. These data, which are essential for ongoing planning and scheduling activities, may include boardings, alightings, passenger loads, and vehicle running times. Automated techniques enable the reporting and analysis of these data in varying levels of detail. The current applications of APC technology in 12 North American transit properties are assessed on the basis of four technological factors: accuracy, equipment reliability, data turnaround time, and cost. Findings indicate that APC technology and its creative use may not be the magical solution to the bus transit monitoring dilemma; however, APC technology does offer a reasonable cost-effective option that operators can seriously consider to satisfy their data-collection needs.

The change in planning emphasis from capital-intensive transit improvements to short-range transit efficiency actions, plus growing fiscal pressures, have increased the importance of transit system surveillance. It is important to design a data-collection program to obtain reliable data at a reasonable cost. To do this transit managers need answers to questions such as how much data should be collected (i.e., what size sample should be obtained), which data-collection techniques are most appropriate, and how often data should be collected (e.g., once a year or at every schedule change).

The objective of a current UMTA-sponsored research study (known as the Bus Transit Monitoring Study) is to provide transit operators with the information they need to design their own comprehensive, statistically based data-collection programs. In the first phase of this study a technical manual was prepared for use by operators in the design of a data-collection plan consisting of manually collected data (1). As part of that effort, several observations were made.

1. The costs of manual data-collection activities and subsequent processing requirements are significant. For example, based on typical industry data requirements and property characteristics, a manually performed monitoring program would require 1 to 2 full-time checkers for a 50-bus property and 10 to 19 traffic checkers for a 1,000-bus property. In addition to relatively high costs, several properties that use manual techniques report difficulty in obtaining reliable data, and they experience long turnaround times between data collection and reporting.
2. A growing interest in automated surveillance techniques has been expressed by transit properties. The shift to automated methods is in response to the relatively high costs and operational problems associated with manual data-collection programs (such as the introduction of tinted window buses, which hinder wayside point checks).

Previous investigations of automated surveillance techniques suggest that they can be used successfully on a regular basis. Nevertheless, there has been no comprehensive assessment of how automated surveillance techniques have been and can be used in ongoing data-collection programs. Recent research attempted to synthesize available information about automated surveillance technologies and to report on their operational characteristics, overall cost-effectiveness, and current use in more than a dozen North American transit properties (2). One part of this research is reported in this paper--the assessment of the operational effectiveness, accuracy, and costs of various automatic passenger counter (APC) technologies.

HOW AUTOMATED PASSENGER COUNTERS WORK

Automated data-collection techniques count the number of passengers boarding and alighting a vehicle at each bus stop. Passenger activity is detected either by infrared beams or ultrasonic rays projected across the front and rear doors of the bus or by pressure-sensitive mats placed on the steps. Most of the experiments to date have involved devices that record the number of passengers boarding and alighting, the time of day, and an odometer mileage reading every time the bus stops and the doors open.

Most of the early research and applications focused on the use of APCs as components within an automatic vehicle monitoring (AVM) system (3-15). AVM systems are designed to provide continuous information on vehicle locations, emergency status, and schedule adherence. Automated passenger data are periodically transmitted through a radio or another communication network to a central processing location. This information is used by transit controllers to modify bus schedules as conditions warrant on a real-time, instantaneous basis. This information is also used off-line to perform operational analyses.

Recently, there has been considerable interest in using APCs as separate surveillance tools. The difference between this approach and AVM systems is that data are not transmitted instantly, but are stored on board the bus on either magnetic tape or solid-state memory. At a later time the data are transferred to a central processing location for validation and analysis.

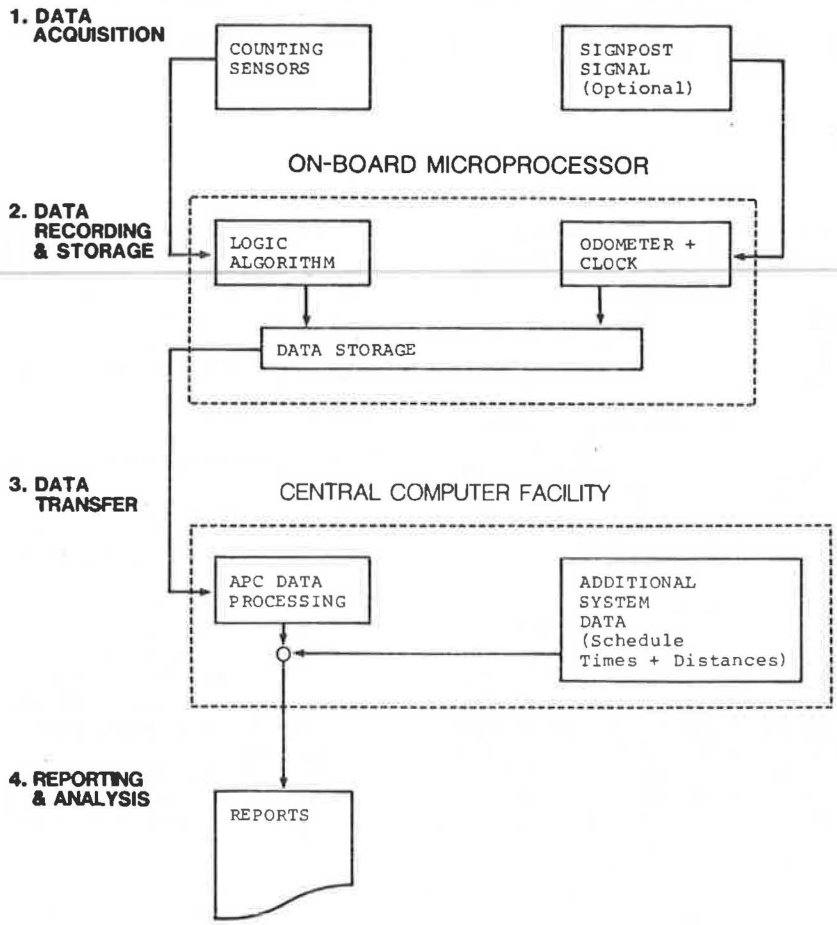
The primary objective of automated passenger counters is to efficiently acquire accurate data on passenger activity and transit travel times. These data, which are essential for ongoing planning and scheduling activities, may include boardings, alightings, passenger loads, and vehicle running times. Automated techniques enable the reporting and analysis of these data in varying levels of detail (i.e., route, trip, route segment, or bus stop).

There are four basic steps in collecting and analyzing APC data that are common to all APCs (see Figure 1):

1. Data acquisition,
2. Data recording and storage (on board),
3. Data transfer to a central computing facility, and
4. Reporting and analysis.

Several hardware and software components are used in these steps. Counting sensors located at each

Figure 1. Basic steps and components of APC techniques.



doorway of the bus detect passenger activity. A data-processing unit located on board the bus uses a logic algorithm to translate the counts into boardings and alightings. Generally, these boardings and alightings are then stored in a way that permits easy stop referencing of the counts. This is done through the recording of time or distance measurements, or from signposts (located at designated intervals along the route) that transmit coded signals to the bus. After the data have been stored for a period of time (usually several days), some mechanism is used to transfer the information from the on-board processing unit to a central computing facility. Finally, the data are input to software packages and the desired reports are generated.

CHARACTERISTICS OF CURRENT APC SYSTEMS

Twelve North American properties are now operating or are about to implement APC systems (Table 1). These properties can be grouped into three categories:

1. AVM systems (three properties),
2. Operational APC systems (non-AVM) (two properties), and
3. New APC systems (seven properties).

Three types of counting-sensor technologies have been used (i.e., dual infrared beam, multiple infrared beam, and treadle mats), although currently the dual-beam counters have proven most popular with eight systems in use (or proposed). Half (six) of the current systems use or plan to use signpost location referencing technology.

The earliest applications of APC techniques were in coordination with comprehensive AVM systems. In Cincinnati, the General Motors Transportation Systems Division experimented with an AVM system that used infrared-beam counters. Signposts located at scheduled time points transmitted location code signals to passing buses. At frequent intervals the raw data collected on the bus were sent over the radio to the computer for processing. (The full Cincinnati system has been moved recently to Windsor, Ontario, Canada.) In 1976 the Toronto Transit Commission designed and installed 100 dual-beam counter units and 16 signposts as a part of its overall AVM surveillance program. They have also been experimenting with treadle mats due to dissatisfaction with the accuracy of the beam-counting logic. Finally, an UMTA-sponsored demonstration in Los Angeles has implemented a broad-beam signpost AVM system that uses pressure-sensitive treadle mats for passenger counting. The 200 units have been used exclusively on four heavily patronized bus lines.

Two transit properties have extensive experience with APCs, which are used to collect passenger data and store it for later processing. The Seattle Metro installed a treadle-mat system on 56 buses in early 1978, and it has installed signpost identification systems in 1982. OC Transpo in Ottawa, Ontario, Canada, installed 49 dual-beam counters in 1978-1979 and acquired 16 more units in 1982.

Three U.S. systems have more recently installed,

Table 1. APC systems in North America.

Property	No. of Units	Type of Counter	Implementation Date
AVM systems			
Windsor (formerly Cincinnati)	27 counters, 37 signposts	Pro-Data dual beam	1981 (1977-1981)
Los Angeles	200 counters, 500 signposts	Dynamic Control treadle mats	1980
Toronto	100 counters, 16 signposts	Dual beam (self-designed)	1976
Operational APC systems			
Ottawa	49 counters (16 new units anticipated)	Pro-Data dual beam (Paul Isaacs infrared beam)	1978-1979; 1982 (new systems)
Seattle	56 counters (acquiring 250 signposts)	Dynamic Control treadle mats	1978
New APC systems			
Calgary	5 counters (demonstration)	Paul Isaacs infrared beam	1982
California Department of Transportation (Caltrans)	25 counters (obtaining 65 units from Los Angeles)	Dynamic multiple beam	1979 (purchase); 1982 (implementation)
Columbus	6 counters, 8 signposts	Pro-Data dual beam	1982
Kalamazoo	20 counters, 30 signposts	Honeywell dual beam	1982
Minneapolis-St. Paul	44 counters	Pro-Data dual beam	1979 (purchase)
Portland	50 counters	Paul Isaacs infrared beam	1982
Quebec City	3 counters (10 new units)	Pro-Data dual beam (Paul Isaacs infrared beam)	1980; 1982 (new systems)

or are planning to acquire, automated counter units. Michigan is sponsoring a demonstration in Kalamazoo. Twenty buses have been equipped with dual-beam counters, and 30 signposts have been installed for stop referencing. The purpose of the demonstration is to examine the applicability of APC techniques in the service monitoring programs of a small transit system within the state. Tri-Met in Portland, Oregon, implemented 50 dual-beam units in 1982. Tri-Met made the decision to initiate an operational program after 2 years of experience with two prototype units. The Central Ohio Transportation Authority (COTA) in Columbus has made a rather unique arrangement. A consultant has been contracted for a 14-month period to provide 6 dual-beam counters and 8 portable signposts, collect data on all routes and bus runs, and generate detailed reports appropriate for route planning activities.

The Metropolitan Transit Commission (MTC) in Minneapolis-St. Paul purchased 44 dual-beam systems in 1979. However, due to contractual difficulties with the manufacturer (and the resultant nondelivery of on-board storage units), use of these systems has been limited. Although the existing units display a cumulative count of boardings and alightings on board the bus, no mechanism for data storage is available. Drivers are required to record count readings at designated points in order to use the counters. Because these problems have not been resolved, MTC does not currently use the counters as part of their ongoing data-collection program.

In 1979 Caltrans began a demonstration program with 6 small transit systems in the state (Bakersfield, Golden Gate Transit, Montebello, Monterey, Sacramento, and Santa Cruz) by acquiring 25 multiple-beam counters. Caltrans is currently also negotiating for the acquisition of 65 units originally purchased for Los Angeles. The purpose of the test is to determine whether the APC technique is practical for small properties. Currently, all hardware (i.e., 25 units) has been installed, and processing software is being developed in Sacramento.

Four other Canadian cities have some experience with the implementation of APC systems. In Calgary five infrared-beam counter units are currently being installed on a demonstration basis. In Quebec City 13 units are being used in a systemwide monitoring program to identify problem routes that may require more detailed manual data collection to identify appropriate service changes. One APC unit is currently being tested by the London, Ontario, transit system to determine if a full-scale program should be developed. In Edmonton, Alberta, two prototype APC units were developed in 1977-1978, but after testing the program was discontinued primarily because of high development and implementation costs.

ACCURACY OF APC TECHNOLOGIES

Most assessment of automated counter techniques have concentrated almost exclusively on the issue of counter accuracy. As with manual data-collection techniques, the implications of selecting desired accuracy levels must be carefully considered. The use of the data and the increased cost of obtaining more accurate data must be weighed in selecting appropriate accuracy levels and, consequently, data-collection methods (1).

The results from accuracy tests presented in the research literature are addressed in the following sections. Findings from tests performed by several transit properties operating APC units are then discussed.

Research

In 1979 an evaluation of three commercial passenger-counter systems (one treadle-mat system and two infrared-beam systems) was conducted to assess their potential performance for the Los Angeles AVM system (15). Accuracy and environmental tests were conducted in the laboratory and on board an operating transit bus. Test data indicated that the counter that incorporated treadle mats exhibited superior counting performance over the two infrared-beam systems. The mat APC system yielded correct (100 percent accuracy) boarding counts 93 percent of the time and correct alighting counts on 90 percent of the observations. In general, all three counter systems were more accurate on boarding counts as compared to alighting counts. Also, all three systems tended to undercount rather than overcount passenger activity.

In March 1982 UMTA, through the Transportation Systems Center, sponsored research to conduct a limited-scale accuracy field test to provide an indication of the relative performance of APCs and on-board, manually taken ride checks. The test covered a range of boarding conditions on routes exhibiting from 1 to 12 passengers boarding at any given stop. The field test was conducted on five properties: Seattle, Minneapolis-St. Paul, Columbus, Kalamazoo, and Los Angeles. The counter technology used on three of the five properties was a dual-infrared beam; on the remaining two properties, pressure-sensitive treadles (mats) were tested.

The results of the field test did not indicate a significant difference in performance between the APCs and the on-board ride checkers. A summary analysis of a composite sample of approximately 8,600 transactions yielded the following results. The APCs were in absolute agreement with truth for 78 percent of the transactions compared with 86 percent for conventional on-board ride checkers; with a variance of ±1, the performance of the APC was 95 percent compared with 96.5 percent for the ride checkers. In terms of total passenger counts for a sample size in excess of 20,000, the data acquired by using APCs was 94 percent of the truth compared with 96 percent for the on-board ride checkers.

Operator Experience

Most APC transit properties have undertaken loose accuracy checks and concluded that counters appear to be accurate enough for their purposes. Yet few properties have implemented extensive accuracy testing through comparisons of APC-generated counts with manual counts.

In the winter of 1978-1979, Seattle Metro undertook a series of accuracy tests on both standard and articulated buses equipped with automatic counters. In general, the treadle-mat counters were extremely accurate. For example, standard bus accuracy is 98 percent for boardings and almost 94 percent for alightings. These accuracy measures are even higher when examined on the basis of stop records being within ±1 or ±2 of manual counts. These findings are somewhat consistent with the 1979 Los Angeles AVM study, which indicated that the treadle-mat counters were highly accurate. Test results on standard buses also confirm previous findings that counters are more accurate for boarding measurements than for alightings. It is interesting to note that the articulated test results do not agree with this finding. Although there is a slight tendency toward more accurate measurement of alightings, accuracy levels are generally identical. In ongoing operation, Seattle Metro has found that about 80 percent of the boarding and alighting totals for a full-day bus operation are within 10 percent of each other (the standard established for retention use of the APC data in Seattle).

The London Transit Commission in London, Ontario, has been experimenting with one APC-equipped bus that uses pressure-sensitive treadle mats. A series of accuracy tests were performed during the winter and spring of 1982. In March 1982, peak hours were surveyed for 1 week by two checkers who manually recorded passengers boarding and alighting at each stop and recorded the count from the APC equipment. Accuracy was compared on the basis of number of passengers boarding at the front door, alighting at the front door, and alighting at the rear door. Tests concluded that APC counts for front-door boardings and rear-door alightings were extremely accurate in comparison with manual checks (93.9 and 97.6 percent, respectively), whereas front-door alighting counts exhibited 84.8 percent accuracy. The APC units tended to overcount on rear-door alightings. The test results present accuracy data separately for stops with relatively low passenger activity (1 to 5 boardings or alightings) and high passenger activity (6 to 10 boardings or alightings). Findings indicate that, at stops with high passenger activity, APC counts are 100 percent accurate within ±1 of the manual count. At stops with low passenger activity, APC counts were 98 to 100 percent accurate within ±2 of the manual counts.

Accuracy tests were also performed in Cincinnati as part of the evaluation of the transit information system. The Cincinnati results differed from previous findings in that alighting counts were more accurate than boardings. The Cincinnati results are consistent, however, in that the APCs tended to undercount.

During the winter of 1980-1981, the MTC in Minneapolis-St. Paul performed accuracy tests on its APC-equipped buses. Because MTC did not have a complete set of APC equipment on their buses (no on-board memory), the automated count data was tabulated by drivers reading off the counter at the end of each trip. These numbers were then compared with the manual count data on a trip and run basis. As a result of this methodology, no stop-level analyses were possible. The MTC tests indicated that the accuracy of APC boarding counts was extremely high (i.e., 95 percent). On the other hand, the accuracy of alighting counts was somewhat lower (i.e., 85 percent). The difference is particularly evident when the percentage of runs and trips that are within ±15 percent accuracy (90 percent for boardings and 54 percent for alightings) are examined. As with previous test results, the MTC data indicate that the automated counters tend to undercount rather than overcount passenger activity.

In the MTC test results, the fact that the accuracy of boarding counts is so high appears to indicate that the counting sensors are performing extremely well. Nevertheless, the significant difference between boarding and alighting accuracy may be due to the location of the sensor in the rear stepwell or some other minor flaw. Experiences in other APC properties have revealed that sensor location for infrared-beam counters is a major determinant in count accuracy. Even a slight movement of the light-beam sensor (also referred to as light-head) toward the skin of the bus can yield substantial improvements in count accuracy.

In addition to altering the location of counting sensors, there are other measures that can be taken to compensate for differences in boarding and alighting accuracies. In cases like the MTC, where there is a systematic error resulting in undercounts of alighting activity, these data can be factored by the boarding count on a trip or run basis in order to yield matching and consistent counts. For example, OC Transpo calculates and applies such a factor within their analysis and reporting software. For individual APC-equipped vehicles, the software calculates the systematic undercount of alightings (from the previous day's data) and computes a factor that is then applied to the count.

Generally, the available data have indicated that APC data obtained from properly installed and cared for units are reasonably accurate, especially when boarding counts alone are considered.

EQUIPMENT RELIABILITY

An issue of special concern that transit operators frequently raise when discussing APC technology is the reliability and durability of counting-sensor hardware, on-board microprocessing units, and electrical connections. Transit properties are not able to use 100 percent of the data potentially collected with APC equipment. Operators report that only 85 to 90 percent of the APC units are in working order at any given time and, of these, only about 80 percent produce acceptably accurate readings on specific bus runs. In some cases there have been mechanical problems that have hampered the effective use of the counting technology. Most properties have been able to overcome these technical difficulties; however, there remains skepticism regarding the reliability of the APC equipment.

Only one operational system (Seattle Metro) was able to provide an estimate of continuing equipment availability. In Seattle Metro's case, 35 to 36 (90 percent) of their 40 operating units are generally in working order on any given day. For those in working order, Seattle Metro generally has to discard about 20 percent of the individual vehicle trip readings because of unsatisfactory or inconsistent data.

The reliability issue is addressed in the following sections by examining typical mechanical malfunctions and the various actions taken to solve them. In general, problems of equipment reliability experienced by North American transit properties that have implemented APC programs can be grouped into the following categories: sensor malfunction or nonalignment, electrical disconnections, odometer readings, and environmental factors.

Sensor Malfunction

In Los Angeles the treadle mats with counting sensors were originally installed on the first and second steps of the stairwell at both the front and rear doors of the bus. The mat on the first step was often damaged or destroyed when buses turned close corners and hit the curb. To minimize damage, the installation procedures were changed and the mats were moved to the second step and the platform. This alteration successfully minimized the problem. In addition, Los Angeles experienced difficulty when mats tended to set on the stairwell; that is, after some time the mats occasionally settle in over the treadle pins, with the result that pins are no longer activated and counts are not registered. This malfunction can be corrected by replacing the mat and resetting the treadle pins.

One major difficulty with infrared-beam counting sensors concerns maintaining the proper alignment of the paired units of lightheads at each doorway. Improper alignment of the two lightheads means that the light source is being emitted, but it is never received; therefore, no counts are registered. Front-end collisions may damage or change the alignment of the lighthead sensors. The location of the sensor units within the doorway also makes them highly susceptible to general abuse and movement by crowded passengers. In addition, counting units may be vandalized on board the bus. To minimize these problems, the counting sensors require frequent monitoring and inspection to identify and correct problem units.

Electrical Disconnections

Buses have an extensive series of electrical connections weaved throughout the frame of the vehicle. The electrical wiring complicates APC installation procedures and often requires special body work to insert the wires and connectors for the APCs. Electrical disconnections or other malfunctions occasionally occur. For example, Seattle Metro experienced difficulty when its data dump operation would unexpectedly hang up. Maintenance personnel originally thought it was a noise spike from the bus electrical system. After examination, it was discovered that one of the electrical sockets merely had a bad connection. As a result, what was originally feared as a major electrical problem turned out to only require a few dollars for a new connecting socket. Clearly, there have been other instances where APC applications have experienced more extensive electrical malfunctions. One interesting note concerns the Los Angeles automated counter units. At one time Los Angeles was having difficulty on chair-lift installations because cables running under the mats on the floor were being guillotined by wheelchairs.

Odometer Readings

Another equipment problem is inaccurate odometer readings. Odometer readings are required to stop reference count data. Inaccuracies of the odometer readings can produce distance-calibration errors. Odometers are extremely sensitive measuring devices. Several properties mentioned problems experienced with distance calibration. For example, Caltrans and OC Transpo have both observed variation in odometer readings. OC Transpo keeps a record of distance-calibration accuracy for each APC-equipped bus and introduces a correcting factor that is applied to the distance measurement in the software processing.

Environmental Factors

Environmental factors can affect the accuracy and reliability of counting sensors. For example, Seattle Metro has problems with their treadle mats because of leaking and water penetration. Although the mats have been redesigned, there are still some linkage problems, particularly on the lower mats. Seattle operating personnel believe that the major defect is the design of the mats, in that they do not hold strongly in place on the step.

Infrared-beam sensors are also susceptible to environmental factors, particularly cold weather, ice, and snow. OC Transpo experienced malfunction problems with sensors, particularly lightheads located closest to the skin (exterior) of the vehicle, as a result of ice produced by the extreme cold weather. The problem was solved by redirecting the flow of warm air from a nearby heater vent toward the lighthead. The added warmth has been extremely helpful in minimizing the problem.

Another environmental problem is light reflections. OC Transpo observed that boarding and alighting counts are extremely inaccurate when APC buses are traveling directly into the sun, particularly in early morning and late afternoon periods. On the other hand, passenger counts are excellent when the vehicle is moving away from the sun. They have observed that vinyl clothing (e.g., raincoats, parkas) or other shiny objects reflect light and interrupt the operation of the light-beam counting sensors.

There are a number of specific actions that can be taken to minimize problems with equipment reliability. Preliminary testing of the equipment can help avoid potential technical difficulties. Many of the successful automated passenger counter programs started with a few prototype units before they introduced the total system. For example, Portland, Ottawa, Quebec City, and Calgary all gained experience with prototype units and worked out the technical bugs before defining desired equipment and performance specifications. In addition, these properties shared information and were able to learn from the mistakes of others.

Proper installation techniques can also minimize reliability problems regarding beam alignment. For example, the appropriate location of the sensor, protective brackets, hidden wiring, and secure doors can protect the lightheads from vandalism and general abuse.

Finally, monitoring of the equipment and its performance can be critical to the effective use of APC technology. Several transit operating personnel stated that it is important to develop a close working relationship among APC supervision personnel and maintenance, body shop, and electrical staffs. Although it is clear that APC equipment needs a degree of special attention that other vehicle subsystems generally do not require, the properties that use APC systems believe that equipment reliability and maintenance needs do not pose major obstacles to the successful operation of an APC system. Yet greater industry acceptance of APC technology appears to hinge on an improvement (and solid documentation of this improvement) in the operational reliability of such systems.

DATA TURNAROUND TIME

One of the major concerns regarding the collection of transit operating data is the turnaround time between observation and analysis. The automated passenger counter technique appears to be superior to manual data-collection turnaround time. APC data are read directly from on-board storage into the central computing facility. Software is then used to generate the desired reports and analyses. Manually collected data, on the other hand, requires assembling all ride and load count sheets, keypunching, and finally reading the data into software packages. A significant amount of time can be saved by using an APC system. In fact, several properties that currently use manual data-collection programs have experienced excessively long turnaround times (e.g., up to 1 year) between observation and data reporting and analysis. The Southern California Rapid Transit District (SCRTD) in Los Angeles is currently experiencing this problem. The longest delay in the typical process includes the time for data validation, editing, and keypunching.

Specific information on data turnaround times for APC applications is limited. Little information was discovered on direct comparisons between turnaround times of APC and manual data-collection programs. Nevertheless, interviews with operating personnel from properties that implemented APC techniques did provide insights on turnaround time.

The average turnaround time at Seattle Metro is between 5 and 6 days. A portion of this time includes a day or two during which the data are stored on board the bus in solid-state memory. Because of personnel and APC scheduling conflicts, it sometimes takes 2 to 3 weeks to provide the information requested from a transit manager and the generated analyses. Despite these minor time lags within the data-collection program, Seattle Metro personnel noted that this turnaround time represented a major improvement over the manual system previously used.

OC Transpo assembles all APC-generated data into a series of management reports at the end of each quarterly service period. OC Transpo also assembles data from APC-observed bus runs for spot analyses for purposes of short-term planning and scheduling. APC count and time data are transferred from onboard storage to the central computer facility on the day following data collection. A series of automated processing procedures then separate each bus run into individual trips and segments. Finally, stop-by-stop listings of APC count data are produced and become available for spot analyses 1 or 2 days after the initial observation.

Metro Transit in Kalamazoo specified within their contract with the APC vendor a maximum of a 1-week turnaround time from pulling the data tapes from onboard storage to generation of reports. Currently, all data processing is undertaken at the vendor's computing facility. Operating personnel at Metro Transit stated that turnaround time may be reduced significantly if the processing capability is maintained in-house rather than off-site. Nevertheless, the current 1-week turnaround represents a significant time savings over the manual system.

COSTS OF APCs

An obviously critical step in the assessment of automated passenger counters is to examine the costs of acquiring and operating such systems. Two major aspects of APC cost factors are considered in this discussion: (a) the actual costs experienced by North American APC applications, and (b) the costs of APC systems as compared with the costs of manual data-collection programs (on a hypothetical basis).

Ranges of Actual APC Costs

The costs of acquiring and operating APC systems have been disaggregated into discrete cost components. These major cost components, divided into expenditures for hardware and software, are given in Table 2 along with the range of (unit) costs encountered by the 12 properties that use APCs. As noted in the data in Table 2, the costs of acquiring and operating APC systems (for both hardware and software) vary significantly among transit properties. Several different types of systems have been implemented to serve a variety of data analysis and reporting functions. Consequently, the costs of these systems also differ, depending on the type of information desired and the accuracy required.

APC hardware costs cannot be easily estimated because the market for such equipment is so small. Manufacturers of APC components have come and gone over the past decade, and virtually every procurement has involved tailor-made specifications. As a result there are few, if any, off-the-shelf components currently on the market or in production. Although it is difficult to make meaningful comparisons of the component costs among systems because of the different specifications and dates of acquisition, a potential user of APC equipment would do well to review the specific experience of the systems currently in use (2,16-18).

Table 2. APC system costs.

Component	Unit Cost Range ($)
Equipment	
Counting sensors	500-750/bus
On board microprocessor	2,000-3,500/bus
Signposts	300-450/location
Transfer mechanisms	2,000-6,000 (1 or 2/garage)
Installation	350-750/bus and post
Maintenance	450-1,000/bus annually
Software	
Development	150,000-250,000 initially
Ongoing processing	50,000-70,000 annually

Comparison Between APC and Manual Data-Collection Costs

The conventional method of data collection used by most transit properties involves the use of traffic checkers to perform point (or load) checks, riding checks, or the collection of boarding counts by the bus operator. To make a valid assessment of automated counter techniques, it is necessary to compare APC costs with typical expenditures for manual data-collection programs. Few of the transit properties that have implemented APC techniques were able to provide detailed comparisons between the current budget and previous expenditures for manual data collection.

COTA in Columbus awarded a $31,000, 6-month contract to a consulting firm to collect, process, and report data for each run in the system. Although a direct comparison is not available, one COTA representative stated that a similar effort attempted manually in-house would cost in excess of $200,000, and most likely would not be completed within the same 6-month time period.

OC Transpo previously employed eight full-time traffic checkers, with an annual cost of $160,000 for the manual monitoring program. OC Transpo currently operates 49 APC-equipped buses, and it is in the process of equipping 16 more vehicles. The current staff consists of two people who are now responsible for other administrative duties, but do occasionally perform trailing checks or load counts. OC Transpo believes that the APC system paid for itself in its first 2 years of operation. In addition, they believe that much more useful data are being collected and reported than was possible with the manual program.

Because there have not been many direct comparisons, an analysis was made of typical expenditures for APC and manual programs. Major cost components within a budget for manual data-collection programs generally include the following:

1. Personnel needed to collect data on board buses or on the street,
2. Administrative or supervisory tasks (e.g., the detailed scheduling of checker work assignments),
3. Data preparation (coding and keypunching of completed forms), and
4. Data processing, editing, and reporting.

Costs for manual checkers and supervisory personnel were based on an estimated $23,000 annual salary (including benefits). Software costs for manual data-collection systems were obtained by using professional judgment and experience. For example, the study team is currently undertaking a comprehensive software development effort as part of the Bus Transit Monitoring Study. The study team is currently spending approximately $125,000 for software development to analyze both ride and point checks as well as driver boarding counts. The APC hardware and software costs use ranges of expenditures actually experienced by APC properties of that size (and documented in Table 2).

In general, the cost estimates used in the analysis can be considered conservative in favor of the manual technique; that is, lower estimated costs were applied to the manual system, whereas higher estimated costs were applied to the automated counter system. The comparison considers the costs accrued over a 5-year period. Consequently, manual costs incorporate checkers' salaries (and benefits) over the 5-year period, and APC costs incorporate the initial purchase expenditure and installation and maintenance costs (assuming a 5-year useful life); both manual and APC system costs include software development and ongoing processing costs.

Estimates were used to develop a cost comparison between manual and APC systems for properties of different sizes (Table 3). The number of APC units and checkers required for each size property was estimated based on statistical sampling requirements as identified in the Bus Transit Monitoring Study (1). Unit costs for manual personnel and APC hardware acquisition, installation, and maintenance are the same for different sized properties. Administrative and supervisory personnel requirements change proportionally with varying property size. However, the estimation of software costs for both manual and APC systems does not change in strict linear proportion with the size of the transit property or with the number of APC-equipped buses. There is a relatively high initial start-up cost for software development and file creation that is difficult to minimize, even with small properties and few APC units. In addition, large properties with many APC units experience significantly higher processing costs because the volume of data increases and the processing routines become more complex.

The comparison of costs for manual and APC data-collection programs (Table 3) indicates that, for most sized properties, APC systems can be less costly than manual techniques. When costs are accrued over a 5-year period, the high up-front costs for APC hardware and software development are lower than the ongoing costs for manual checker salaries and benefits. Nevertheless, the analysis indicates that for those transit properties below 100 to 200 peak-period buses (using less than seven checkers or APC units), the difference in costs between the two data-collection techniques is minimal. Note that many of the costs associated with APC systems (e.g., equipment, installation, initial software development) are eligible for reimbursement from federal capital grants, whereas the bulk of manual collection costs falls into a local operating budget.

In addition to the difference in costs between manual and APC techniques, note the decreasing cost per APC unit as the number of APC-equipped vehicles increases. The decreasing marginal cost is primarily because software development and processing costs make up the major expenditures, and these costs tend to increase at a decreasing rate for additional units. The significance of the marginal cost is illustrated by noting that the annual cost of using one additional checker equals approximately $23,000, whereas the annual cost of using (installing and monitoring) one additional APC-equipped bus equals approximately $6,000.

CONCLUSIONS

This assessment of current applications of APC technology has reviewed a number of issues that should be carefully considered by any bus transit property investigating the utility of APC systems. Perhaps the most important issue is the realization that the technology currently exists to adequately count passengers and record time-related bus performance data with little or no direct human interaction. Nevertheless, it should be noted that some technological improvements are still desirable. In particular, more attention needs to be given to making the APC equipment more reliable, perhaps by standardizing the design of several of the most troublesome components. Also, it is clear that operators contemplating the use of APC equipment should be aware of related software needs (i.e., broadly defined in terms of the potential use of APC techniques, as well as potential data processing requirements).

Transit managers should be extremely careful in

Table 3. Cost comparison for different sized transit properties.

Peak Buses	No. of Traffic Checkers Required[a]	No. of APC-Equipped Buses[a]	Annual Costs[b] ($) Manual Program	Annual Costs[b] ($) APC Program	Annual Costs per Unit[b] ($) Manual Program	Annual Costs per Unit[b] ($) APC Program
25	1	1	59,000	82,000	59,000	82,000
50	2	2	86,000	84,000	43,000	42,000
100	4	4	142,000	121,000	36,000	30,000
200	6	6	200,500	141,500	33,400	23,600
300	7	7	227,000	149,000	32,000	21,000
500	13	13	385,000	196,000	30,000	15,000
750	15	15	436,000	225,000	29,000	15,000
1,000	19	19	532,000	245,000	28,000	13,000
2,000	38	38	1,027,000	398,000	27,000	10,000

[a]Assumes the maximum number of units (checkers or APC buses) required, as estimated in the Bus Transit Monitoring Study (1).
[b]Assumes a useful life for APC equipment of 5 years, and all other costs are accrued over a 5-year period (discount rates were not applied to annualized costs).

defining just what might be expected from APC data-collection techniques so that equipment and data processing needs can be anticipated in advance of any decision to proceed with a new data-collection program. If nothing else has been learned to date, experience has revealed that a number of current APC users initially underestimated the time and effort required to implement and maintain automated data-collection systems. A general lack of prior information and the need to use unproven equipment sometimes resulted in the trial-and-error efforts in installing equipment and maintaining it, much higher-than-expected data editing and processing costs, and the underutilization of available equipment capabilities. Fortunately, much can be learned from the experiences of users of current APC technology. Any operator contemplating a move to APC data collection would do well to contact the properties discussed in this paper.

A number of specific considerations should be reviewed in planning for the initiation of an APC system.

1. Both of the major types of APC units currently in use (infrared beams and treadle mats) perform satisfactorily. In general, the treadle mats have been found to be slightly more accurate, but they appear to require more maintenance and may need to be replaced more frequently than comparable infrared units.
2. The accuracy of the APC units currently in use is adequate for most purposes to which the data are put. Data from a recent U.S. Department of Transportation test revealed that the APC units were remarkably close to counts taken by a human ride checker.
3. For medium to large-sized bus properties (those with more than about 100 buses), the cost of an APC system compares favorably to manual (ride check) data-collection costs over the long run; however, because different equipment and data-collection techniques will provide different types of data (and data detail), a property should perform a careful cost analysis before moving forward with any new program.
4. Although the use of APC signposts for location referencing may reduce the overall cost of the postprocessing needed to get the raw APC data into usable form, recent developments by Portland Tri-Met indicate that an odometer-linked referencing system may provide an equivalent level of accuracy in stop referencing.
5. It is extremely important for potential APC users to define in detail the potential uses of APC data. These uses will affect the design of the data recording and counting algorithm internal to the APC counter units, as well as the extent of the data processing development that will be necessary to produce fully usable reports. A careful anticipation of the full range of potential uses and required data reports will undoubtedly reduce the overall cost of implementing a new system.
6. Potential users of APC equipment should be aware of the need to carefully install and maintain the equipment. Preplanning should include the discussion and agreement on interdepartmental responsibilities, and all personnel involved should fully understand the need for the APC data and the importance of regular, careful attention to ensure that the system operates to its fullest capability.

In addition, more attention should be paid to sampling issues concerning planning and use of APC technology. Initially, the number of APC units to be ordered should be based on a detailed design of an ongoing data-collection program (1). Several pilot units might actually be purchased or leased to help monitor a number of routes before the major procurement in order to calculate route data variances to be used in estimating route and system sampling rates. Once the necessary units have been obtained, it is important to determine individual line sampling rates so that all line data obtained are of comparable accuracy levels (rather than only having equal sample sizes). APC equipment also offers the advantage of allowing an operator to determine seasonal variation in line performance during the first several years of use, thus allowing a better determination of the number of times a year an individual line should be monitored.

More can still be learned about the use and capabilities of APC technology. With the initiation of fully supported operational programs in Portland, Kalamazoo, and Seattle, the information available regarding the potential problems and opportunities related to automated surveillance techniques will grow significantly during the next several years. Although APC technology and its creative use may not be the magical solution to the bus transit monitoring dilemma, it offers one more option that operators can seriously consider to more effectively satisfy their data-collection needs.

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Potential of Graphical Information Support for Transit Decision Making and Performance Evaluation

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The objective of this paper is to examine the potential of the graphical information system (GIS) to increase transit operator control over performance by improving decision-making effectiveness. The GIS is based on the distinction between data and information; data are collected facts, but information is only that data useful for a particular purpose and perceived as such by the user. The GIS increases both relevant information and its perception. The GIS is effectively used in semistructured decisions where it enhances the ability of the user to apply creativity and judgment in solving novel problems. An example illustrates the potential of the GIS to convey patterns, trends, and relationships, thereby enhancing the ability of the user to filter relevant information from extraneous data. Several graphic profiles of a bus route are contrasted with the corresponding tabular summary. All are derived from the same data, but because of data format they convey significantly different information.

Inadequate information to support decision making is a fundamental problem in increasing the ability of the transit operator to control performance. Control is exercised through two types of decisions: (a) decisions that identify problems, and (b) decisions that specify problem correction. To increase control, the transit operator must be able to identify and correct problems effectively.

Effective decision making, however, is often constrained by a lack of information. Despite masses of collected data, little true information may be available to support decision making.

This paradox indicates the significant distinction between data and information. Data are a collection of facts, but information is that data subset that is useful for a particular purpose and perceived as such by the user. Information is knowledge for the purpose of taking effective action (1) and is context specific.

Graphical information systems (GISs) offer the transit operator a powerful tool to increase the information available for control decision making.