Integration of Fareboxes with Other Electronic Devices on Transit Vehicles

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The data that a farebox-based system can provide—boardings by route, direction, time of day, trip, stop, and fare category for day of the year—can be of immense value for planning, scheduling, marketing, and operations monitoring. For the most part, boarding information is being captured by an electronic device (the farebox), but for various reasons, much of that information is lost, and the data quality is often suspect. Integration with other on-board devices could enhance the quality and value of farebox data. For good-quality data segmentation, integration with the head-sign is important. For verification, integration with the speedometer (to get an odometer stamp) is valuable. In a farebox system using a transactional data base, integration with the door sensor and speedometer enables the system to add an odometer stamp to each record. Integration with a vehicle-location system and a vehicle-logic unit offer still more advantages. To move the industry toward data integration, use of open specifications using industry standards is important. Model specifications were developed for direct links between fareboxes and head-signs, speedometers, and door sensors, and for linking fareboxes to a vehicle area network that comply with the SAE J1708 standard.

Since the 1980s, use of electronic fareboxes has become prevalent in the U.S. transit industry. For most transit agencies, the primary reasons for introducing fareboxes were improved dollar-bill handling, reduction of fare disputes, and better revenue accounting. But with the fareboxes came, almost as a fringe benefit, a data system capable of counting and accounting for passenger boardings. Some transit agencies have made good use of these data, but for many agencies, particularly the larger ones, various problems have kept farebox data from attaining their potential value to the agencies (*1*). One means of overcoming some of these problems is integrating fareboxes with other on-board devices. In addition to overcoming problems with current farebox data, integration offers new opportunities that will be of interest to many transit agencies.

Although electronic fareboxes were developed as stand-alone systems, they can be integrated with other devices. The pace of integration has been slow, however. This paper examines benefits of integrating fareboxes with other on-board devices, and practical integration schemes are for a variety of situations identified. Additional details are available in the project final report (*2*). A diagram of the integration schemes explored is shown in Figure 1.

FAREBOX DATA SYSTEMS

The farebox keypad can be used both to indicate fare category for a boarding passenger and to enter, via a programmed menu, *identifiers* such as operator, route, and run or trip number. Initially, an operator enters the identifiers when logging onto the system. As each passenger boards, there is a transaction in which information is captured about the fare category, the payment medium (e.g., cash, card, or transfer), and the amount of revenue received. How the information is stored determines whether there is a *transactional data base* or a *summary data base*. In a transactional data base, a *transactional record* is created and stored for each transaction. This record includes fare category, payment medium, current identifiers (i.e., operator, route, and run number), and a time stamp. In a summary data base, the information from each transaction is not saved, but is used to update cumulative data registers that count, for example, the number of boardings in each fare category and coin revenue. The cumulative registers keep summing until the operator enters an identifier change in response to a change in direction, route, run, or operator. When an identifier change is entered, the farebox is programmed to create and store a *summary record* containing the amounts accumulated in each register, the identifiers, and a time stamp. The act of creating a summary record is called segmenting the data.

In a summary data base, the frequency with which the data are segmented determines the level of detail. The finest level of detail commonly seen in a summary data base is the trip level, in which a summary record is created for every trip. This will occur if the operator enters a new route or run identifier with each change in direction. Trip level data are the most useful for scheduling, planning, and other purposes. A good data system should be capable of aggregating records to produce reports at a coarser level of detail (e.g., combining trips to produce reports at the route-direction-period level, or the route-period level, or the route level). Therefore, trip-level segmentation results in the most useful data. Even with trip-level segmentation, it is unusual for each trip to have its own identifier; instead, the identifier identifies the route and direction (e.g., the code '460' indicates Route 46 outbound, and '461' indicates Route 46 inbound), and the time stamp is used to identify the particular trip. This arrangement is fine for most purposes, although trip matching is less precise.

If the operator enters an identifier change only when changing routes, the finest level of detail available will be route level. If there is an identifier change only when changing operators, the finest level of detail available will be the run level. If the data are not segmented at all, the only record created will be a daily summary for that vehicle, and no level of detail beyond systemwide will be achievable. Fareboxes can also be programmed to create summary records at specified times: for example, every hour or at designated period boundaries. This way, period-level summaries data can be obtained without operator intervention.

Until recently, all electronic fareboxes used summary data bases. However, transactional data offer the greatest flexibility in analysis. For example, these data make it possible to track the use of promotional-fare media, fare media issued by different agencies (e.g., for revenue allocation), or of individual farecards (e.g., to find linked-trip patterns). If transactional records are also stamped with

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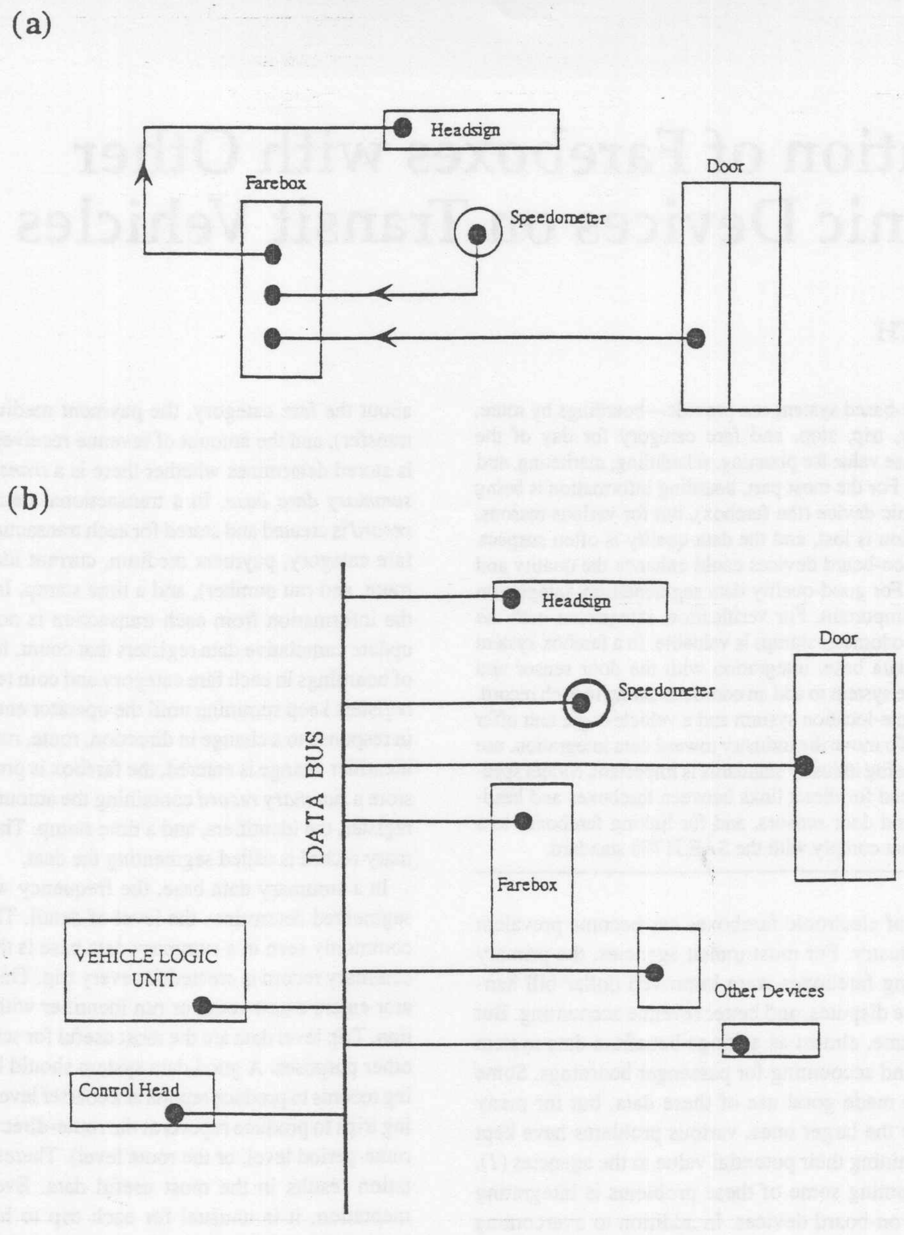

FIGURE 1 Communication options: (*a*) direct links; (*b*) VAN.

vehicle location, boardings can be counted by stop, by route segment, or by political jurisdiction. Naturally, the amount of data stored in a transactional system is greater than that in a summary system, although it is still not much by modern standards. With each transactional record taking 10 to 16 bytes, 3 days' worth of transactional records will require only about 50 to 80 kilobytes, depending on the number of stamps and identifiers attached to each record, assuming 100 boardings each hour for 16 hr a day. In contrast, summary records with 32 fare categories would require about 4 kilobytes.

With data storage as inexpensive as it currently is, there is a move toward transactional data bases. One farebox manufacturer has developed a transactional system that is now in pilot testing with three small agencies in Los Angeles County. These three agencies sell a common stored-value card and use the transactional data to allocate revenue from the card sales to the agencies according to actual use. In such an application, integrity of the data is a great concern because, when it comes to allocating card-sales revenue, data equal money. For this reason the system was built to include extensive redundancy and backup capability. Other transit agencies foresee third-party transactional data bases being compiled on an on-board computer, called a *vehicle-logic unit* (VLU), with inputs from the farebox at each transaction.

Farebox data systems include their own software for editing and reporting. For many transit agencies, the software is adequate. For others, particularly large agencies, its capabilities are limited, and because the software is proprietary, modifying it is impractical. The solution is to export the data to a general-purpose data base and develop software as needed. However, the effort required for software development can be prohibitive, especially when the software is customized to a single agency. In the future the development of farebox data analysis software is likely to be applicable to many agencies, it will be written on a platform from which agencies can query and to which they can add analysis and report capability as needed.

CHALLENGE AND BENEFITS OF CLEAN DATA

Effective transit management requires good data. All too often, practices are not changed because the data necessary to indicate the need for change are too expensive to collect. Meanwhile, in many cities, reams of farebox data, gathered every day from every bus, are virtually ignored because farebox counts are not trusted. Obtaining clean farebox data is worth the effort, which must be expended on two fronts: reducing errors and verifying the data.

The primary source of errors in farebox data is operator error. These errors can be summarized into three categories. First, the operator can incorrectly enter identifiers (or even fail to enter identifiers) at the beginning of a run. Incorrect or missing operator identifiers are a particular nuisance because they make it difficult to provide the operator with feedback about other errors. Farebox systems can be programmed to require an operator identifier before they will accept fares, but it is not common for there to be any validation of the identifier. Even then, operators who begin their days on buses already in service can fail to enter their identifiers unless the previous operators have electronically checked out.

Second, operators do not always key in correct fare type. Simplifying fare policies and farebox codes and installing card readers can go a long way toward reducing this problem. Further improvement requires operator training and discipline, again requiring a means of verification and feedback. A certain amount of verification can only be conducted by on-board observation; however, much can be automated, such as comparing records from day to day or operator to operator. Some agencies accept a small amount of undercount (free passengers, and young children in particular) and misclassification. Some agencies sample trips using on-board observers to estimate correction factors for undercount and misclassification (*3*).

Third, operators sometimes fail to segment the data properly by entering the new route or trip code when changing route or direction. This problem is widespread, and for many agencies is the main impediment to effective use of farebox data. Many transit agencies find that they cannot use their farebox data to determine route-level boardings or revenue (much less boardings at the route-direction-period level), only system-level totals. Route-level totals are a vital input for service monitoring and performance evaluation at any level more detailed than the system as a whole. The first input needed for any effectiveness indicator and for many service-quality measures is passenger boardings by route or route-period. With clean, segmented farebox data, the supply of data on boardings at the route-period level is unlimited; without, the managers must rely on estimates made from small and often old samples, sometimes using systemwide average-fare factors that ignore differences in fare category distribution between routes. Having route-level totals also enables passenger-miles to be estimated (a measure required annually by the Federal Transit Act, Section 15) far more efficiently because they permit stratification by route or groups of routes with similar average trip lengths. Without route-level totals, a factor for a single average trip length (or average of passenger-miles per dollar of revenue) must be estimated from an on-board sample (*4*). If route-level totals are available, factors can be estimated and then expanded for many different strata, requiring a smaller sample size if the strata are internally homogeneous. The availability of route-level boarding totals can reduce the necessary Section 15 ride-check sample size by a factor of between 2 and 4. Segmentation by trip or route-direction-period is vital if the data are to be useful for scheduling, operations monitoring, or detailed service-quality assessment.

Any effort to reduce operator errors requires strong verification and feedback capabilities. The experience of many transit agencies has shown that it is vital that the data be verified and that feedback be given right away to operators and their supervisors. Without this kind of feedback, it is not uncommon for passengers to be undercounted by 10 percent and for 20 percent of the data to have invalid or incorrect route codes. With strong supervision, it is not unusual for these rates to drop to 2 percent. Of course, even with a vigorous program of supervision, there will still be faulty data. However, because fareboxes provide such a large sample, once the general quality of the data is good, the agency can afford to discard questionable passenger data, again pointing to the need for strong verification checks.

With the standard farebox software, only a limited degree of verification is carried out automatically, such as testing for invalid identifiers or out-of-range values. Visual inspection of daily or monthly reports, and responses to inconsistencies, are tedious and expensive. It is difficult for larger systems to provide this level of attention. Stronger verification tests, daily verification/exception reports, and a streamlined treatment of suspect data in summary reports are needed. Many potentially valuable verification tests depend on effectively integrating the farebox data with other data. They include testing the actual itinerary against the dispatch or payroll system; comparing the data segmentation with the scheduled itinerary; comparing the time or distance elapsed between records, or the recorded location at record creation, against the scheduled itinerary; and comparing counts against route-specific historical averages.

In addition to improving the chances of getting clean farebox data, integrating fareboxes with other devices presents the opportunity to enhance the value of farebox data by correlating them with other data, as described in the following sections.

DATA COMMUNICATION ON TRANSIT VEHICLES

Some integration of the farebox and other devices can be accomplished on a small scale, by direct links between devices. Direct links are commonly used in a variety of applications on transit buses and other highway vehicles. For example, cruise control involves a (usually nondigital) link from the speedometer to the fuel delivery system. Interlocks involving a link from the door sensor to brake have been used on buses to force the brake to remain applied while a door is open.

A broader scale for communication involves a vehicle area network (VAN). With a VAN, there is a central data link, known as the data bus, to which all devices are connected. Messages transmitted to a VAN can be received by any other device connected to the VAN. The VAN needs standards for electrical parameters (e.g., voltages) and communications protocol. The protocol includes organization of the bitstream; a scheme for resolving contention (when two devices try to broadcast a message at the same time); a standard set of device identifiers; and formats for a standard set of message types. Devices can then be programmed to transmit messages according to the protocol. To receive messages, a device must also be programmed to recognize the source and type of each message and whether a particular message pertains to that device. If so, the device must be able to interpret the message contents and respond accordingly.

SAE has a set of standards, originally developed for trucks, for VANs. Known as the J1708 family of standards, they include the standards J1708 (electrical parameters and basic protocol), J1587 (message content and format), and J1455 (operating environment). Through a joint effort sponsored by FTA, the American Public Transportation Association, transit device manufacturers, and companies specializing in systems integration, the J1587 standard was revised in 1994 to accommodate devices found on transit vehicles, resulting in the first-ever industry standard for a transit VAN. Bill Kronenburger of Houston Metro was instrumental in this development and has authored several documents describing the VAN concept (*5*, materials available from the author). The J1708 standards call for connection between devices and the VAN via a modified RS 485 port, but beyond that do not fully specify the physical connection. RS 485 is a standard of the Electronics Industries Association, widely used in highway-vehicle applications because it can take a harsher environment than, for example, the RS 232 port commonly used with desktop computers.

If a VAN is used for compiling passenger and related data, it will almost certainly be connected to an on-board computer, known as a vehicle logic unit (VLU), that is programmed to manage the data. In the topology of the VLU is just another node on the VAN. However, it usually plays a special role, managing data communications (e.g., initializing other devices at log-on, requesting diagnostic and other data, providing software and data uploads) and storing data accumulated from the network over the day. Although the VLU conceivably could be a computer designed specifically for this purpose, it is almost certain to be a computer procured as part of an automatic vehicle location (AVL) system or an annunciator system configured to serve as a VLU. It is also conceivable that farebox manufacturers will increase the computing power of their systems and market them as VLUs, but they do not appear inclined to do so.

Working in conjunction with the VLU is the operator control head (keypad or console). It is not uncommon for buses to have three different keypads: one each for the farebox, head-sign, and radio. At one level of integration, a VLU could be programmed to receive information entered from all three keypads: at a further level of integration, the operator could control all devices through a single control head that could include both a keypad and a display. The German transit industry association (VDV) has established standards for a control head, and VDV-standard control heads are now common on European buses. For various reasons, among them the lack of fareboxes on European buses and the high-voltage needs of VDV standards, which are more geared to trams, U.S. and Canadian transit agencies have not adopted the VDV standard. The SAE standards mention little about the control head, specifying only the way in which it, as another device, is to transmit and receive messages.

Although the J1708 standards for transit were published in 1994 through a cooperative effort of parties throughout the transit industry, their adoption is entirely voluntary. Some agencies have required J1708 compliance in their bid specifications. For some devices, among them fareboxes, simply specifying "J1708 compliance" is insufficient because the SAE standards do not always make it clear which messages a device is expected to send and receive. A good example of incorporating SAE standards into bid documents is in the specifications developed by Houston Metro for its recent farebox procurement. It specifies which messages the farebox is expected to transmit and receive, and defines characters that, in the SAE standards, are to be "agency defined."

Some device manufacturers have developed and are actively marketing J1708 communications capability. Others are taking a wait-and-see approach. Before there are other devices with which to communicate and a VLU to manage the data, of what value to a buyer is J1708 communications capability? For example, one speedometer manufacturer has developed J1708 capability for truck speedometers, because trucking companies want it for their data systems, but has not developed it for their bus speedometers because, so far, no transit agency has wanted to pay for a capability it cannot yet use.

Another important obstacle to the development of VANs is the cost of wiring vehicles. Wiring is easy during manufacture, but retrofitting buses is quite expensive. Some see this as a barrier to a full implementation until a whole new generation of prewired buses replaces the existing fleet.

FAREBOX COMMUNICATIONS CAPABILITY

Fareboxes, although developed as self-contained systems, use digital serial communication links between components and have RS 232 and RS 485 ports that can be used for serial communication with other devices. For example, one farebox manufacturer produces a magnetic ticket reader that can operate on its own or in conjunction with the farebox; in the latter case, the devices communicate through a serial port. Farebox manufacturers take a cautious approach to integration with other devices because of concern for the security of cash and accounting records. Manufacturers are more amenable to transmitting data (say, a record of a passenger boarding) to other devices than to receiving data that might have an unexpected effect on their systems. If a farebox is to receive data through a data link, it is important that it be able to discern which messages are intended for it, to recognize the message formats it supports, and to ignore all other signals. The J1708 protocols have been designed expressly for this purpose.

DESIRABLE INTEGRATION LINKS

Whether through a VAN or through simple direct links, there are several devices whose integration with the farebox could increase the value of farebox data.

Integration with Head-Sign

Several transit systems have recognized that the key to getting the correct route and direction information into the farebox is the head-sign (also called destination sign). Vehicle operators are more conscientious about changing the head-sign than the farebox route or run identifier, because the head-sign is visible to all, affording operators immediate feedback. At least one agency, the suburban bus division of Chicago's Regional Transportation Authority (PACE), has linked head-signs to fareboxes so that, in effect, the head-sign is controlled by the farebox keypad. Every route and direction change registered with the head-sign will also be registered with the farebox. This very promising approach is being pursued by other agencies as they procure head-signs, fareboxes, or both. Aside from improving the reliability of data segmentation and the quality of identifiers in the farebox data, it simplifies the operator's job and reduces the risk of injury to the operator who might otherwise have to stretch or stand up to use an overhead head-sign keypad. However, integrating the farebox and head-sign can require adjustments to an agency's information systems. It is not uncommon for a different set of route, branch, and direction codes to be used by the farebox, the head-sign, the scheduling system, and publications. For example, Boston's Massachusetts Bay Transit Authority recently changed its farebox route codes to match the codes used in the head-signs to simplify the operators' job and, it is hoped, increase the chance that operators will key changes in route or direction into the farebox keypad when they key them into the head-sign keypad. However, both operators and managers agree that it would be far preferable to enter the code into a single keypad.

Newer models of head-signs have microprocessors and use digital communication between components. They are able to connect with other devices using RS 232 or RS 485 serial ports. For PACE, the farebox and head-sign suppliers jointly developed a proprietary communications protocol using an RS 485 link. The same is being done for the New York City Transit Authority, albeit with different farebox and head-sign suppliers. However, because the protocols are equipment-specific and proprietary, they cannot be used if there is a change in equipment, nor can they be freely distributed among transit agencies. Head-sign manufacturers are also developing J1708 communications capability.

Integration with Speedometer or Transmission

Location or odometer stamps on farebox records, similar to the time stamps that are already standard, are desirable for several reasons. In systems with summary records, a location or odometer stamp provides an excellent means of verifying that the data were segmented at the correct location. Agencies with AVL are in the best position to provide location stamps. However, for agencies without AVL, location information can be obtained by connecting the farebox with the speedometer (which includes the odometer) and then programming the farebox to include an odometer stamp with each record. Some extra effort to calibrate speedometers may be needed, as it is not unusual for them to be off by a few percent; on the other hand, miscalibrated speedometers are consistent in their errors, and the verification software can be programmed to recognize and correct for each particular bus's miscalibration.

But transmissions typically produce an output signal the frequency of which is proportional to the frequency at which the transmission output shaft rotates, which in turn is proportional to road speed. Speedometers receive this signal and use it to calculate speed and to drive a mechanical odometer. Speedometers have, when needed, produced an enhanced version of this transmission signal (sometimes buffered, sometimes converted to a square signal) to serve as input to cruise control and to AVL systems using dead reckoning. Fareboxes could be modified to receive the same type of signal. Then by accumulating cycles in a counter, the farebox would have an odometer reading with which it could stamp records. It is also possible to get the same information directly from the bus transmission signal, but it is preferable to get the signal from the speedometer because the speedometer will have already filtered and improved it.

Integration with Speedometer and Door Sensor

To stamp transactional farebox records with location data, it is necessary to have information from the front-door sensor. By the time passengers pay their fares, the bus is often under way. The location stamp should therefore reflect the location at which the bus last opened its doors. Location or distance stamping of transactional records makes it possible to compile boardings by stop or by route segment. A method for estimating passenger-miles and passenger loads from distance-stamped boardings transaction data has recently been developed and is described elsewhere (*2*).

If the location stamp is simply an odometer stamp, stop-matching can be a problem. Positive experience with stop matching using dead reckoning on simple routes has been reported (*6*); however, other AVL system users report that, without signposts to establish precise location, errors and uncertainty tend to accumulate. However, integrating the farebox with the head-sign may be almost as good as providing a signpost at the beginning and end of every route, if head-signs are reliably changed at close to the same location every trip. As long as the beginning and end of each trip can be established, adequate estimates of passenger-miles, load, and boardings by segment can still be made, even if stop-level resolution is not perfect.

Integration with Radio

Typically, AVL systems have been connected to the radio system and transmit location information in real time, with each bus being polled every 1 to 3 min. It is impractical to have the radio transmit routine boarding information to the central computer for several reasons. First, many boardings can take place between polls, so boardings data would have to be accumulated between polls. The question is what level of detail will be accumulated and transmitted: simply the total number of boardings, or the number in each fare category, or the number by stop (i.e., odometer reading)? The greater the detail, the greater the number of bits that must be added to the radio message at each poll, increasing the time needed for each poll. The number of radio channels a transit system is licensed to use is strictly limited, especially in large urban areas. For a fixed number of channels and buses, the longer each poll takes, the longer the interval between polls will be, compromising the timeliness of the data and rendering the entire AVL system almost useless. Only the most summarized farebox data, if any, should be sent by radio. Accumulated boardings, if sent modulo 128 (since it is highly unlikely that more than 128 boardings would occur between polls), would require 7 bits. Probably the only worthwhile integration between the radio and the farebox is for the radio to transmit farebox alarms (e.g., alerts of mechanical malfunction, or estimated overload), because these only require 1 bit each. Further detail about farebox transactions is of no value to real-time control anyway; it is meant for off-line analysis related to planning, scheduling, service evaluation, and marketing. The full detail of farebox data should be stored on-vehicle and uploaded at the end of the day.

Integration with AVL and Annunciator Systems

High-quality location information for stamping farebox records can be readily obtained if an on-board computer is continuously calculating location. This is the case in modern AVL systems and annunciator systems (which are not tied to the radio system, but calculate location nevertheless). In older AVL systems, raw inputs (e.g., signpost identifiers, odometer readings) are transmitted off-vehicle to a central computer, which then calculates location. It would be impractical to have the radio transmit back the calculated location, because of channel limitations and the relatively long time between polls. Therefore, older AVL systems are not suitable for location-stamping transactional records.

Both AVL and annunciator suppliers have marketed their systems' computers as VLUs for VANs. Because a VLU will be considerably more powerful than a farebox computer, it is far more practical for a VLU to receive and store transaction data from a farebox than for a farebox computer to receive location data from a VLU-AVL system to put a location stamp on its records. Thus, although fareboxes could continue to store their own data (and probably will, because farebox manufacturers do not want to compromise product integrity by forcing them to rely on a VAN and a VLU), data would be integrated by the farebox's transmission of a message to the VLU by concerning each transaction. The VLU would be programmed to then create a full transactional record—including appropriate identifiers, a time stamp, and a location stamp—and to store the data over the course of the day and provide a means for off-loading it at the end of the day.

Because of the considerable storage requirements of voice messages, one annunciator system's VLU uses Personal Computer Memory Card Industry Association (PCMCIA) cards for transferring data: one card to bring itinerary and annunciator data onto the vehicle, another to store data collected throughout the day for off-loading at the end of the day. PCMCIA cards can hold several megabytes of data and offer quick data access. A less costly alternative, certainly adequate for uploading itinerary data and storing and off-loading transactional data, is a floppy disk. As operators are dispatched, their PCMCIA cards or floppy disks, holding data about themselves and their runs, would effectively become their "keys" to their buses. As needed, software and data updates to VLU could be put on the cards or disks, making it unnecessary for an individual to go from bus to bus loading software. Data could also be stored in any standard medium on the vehicle and transferred by infrared (as is currently done by farebox systems) or high-capacity radio-frequency link. These nonphysical transfer systems are amenable to data transfer at end of the day at a central service bay while farebox vaults are being pulled, both for downloading a day's data and uploading software updates, but they would be likely to lead to congestion and complications if used for loading data at the beginning of the day.

When transactional data becomes available through a medium other than the farebox system, software will be needed to process the data. Because of the great expense and complication associated with software development, it is in the transit industry's best interest to develop software that can be used at many transit agencies, much as the software that was developed by the farebox manufacturers is used all over the country. As long as a general-purpose data base platform is used, and transactional records created by different agencies' VLUs all use a format that mirrors the J1708 formats, this should not be a problem.

What About Automatic Passenger Counters?

Automatic passenger counters are devices that, using either infrared beams or pressure sensitive mats, detect passenger boardings and alightings. They include a system for locating a bus based on dead reckoning or a modern system such as global positioning, and usually resolve the location to a stop location, enabling them to record ons and offs by stop. Such a system is superior to the farebox-based system this paper describes, primarily because it counts offs as well as ons. In addition, although automatic passenger counter (APC) counts are not perfect (error rates of 3 to 5 percent are common), they are not subject to human errors that can give farebox counts far higher error rates. A transit agency with an APC system has no need for location-stamped farebox data. However, few agencies have APC systems. They are expensive to procure, expensive to maintain, and the market for them is so small that no manufacturer can be relied on to stay in business for long. As long as this situation persists, a farebox-based passenger-counting system is the most economical and reliable alternative for most agencies. As was previously mentioned, a method has been developed for estimating offs by stop using farebox data, and tests of the method have given promising results. With this method, there is little advantage that APCs can offer over a well-configured farebox-based counting system.

SPECIFYING CONNECTIONS

Although integrating various devices discussed is technologically simple, for integration to be possible economically it is important that communication specifications be based on an open standard instead of a proprietary standard, so that the system can be modular and expandable. Proprietary protocols can benefit their owners in the short run, but in the long run open standards are best for the industry as a whole, and probably for the manufacturers as well, because they can reuse their products in agency after agency. Agencies will have the benefit of modularity and more open market competition.

VAN Specifications

A transit agency with an on-vehicle VLS (either radio- or annunciator-based) that wishes to integrate farebox data with other data will want to use a VAN. The vehicle-location computer should be configured as the VLU. There is only one open standard for VAN, SAE's J1708 standard. Three alternative levels of integration can be considered. In Level A the farebox only transmits data to the network. This level is least intrusive to the farebox system and is adequate for data needs. Because it poses less risk and complication to farebox manufacturers than more advanced levels of integration, it should be less costly as well.

In Level B, the farebox also receives and responds to messages from the network, enabling the VLU to exercise some control over the farebox. One advantage of Level B is enabling the operator to log on once to a single control head. Level B also gives VLU some control over the farebox in case of malfunctions, allowing it to request diagnostics or a restart. At Level C, the farebox keypad is never used; the VLU control head is used to operate the farebox even for boardings transactions. For example, using touch-screen technology, the control head could make itself look like a farebox keypad whenever the door opens. Level C is not envisaged for the near future.

Agencies will have to express precisely in their bid specifications their expectations of a J1708-compliant farebox. Specifications for VAN integration at Levels A and B are reported elsewhere (2). The J1708 modules and messages that the farebox is expected to support for each level of integration are also specified. Farebox manufacturers have demonstrated the ability to transmit data in J1708 protocol. Therefore they seem prepared to provide Level A VAN integration. At least one major manufacturer is still resisting Level B VAN integration because of the costs and risks involved, and because the extra benefits of Level B do not appear to be very large. However, if a paying customer demands a farebox with full Level B J1708 capability, it is almost certain to get it, and farebox manufacturers will probably then begin marketing the J1708 capability that they have developed for that customer.

Direct Connections with Farebox

Transit agencies not in a position to procure an AVL or annunciator system will have to rely primarily on the computing power of the farebox. The vastly smaller scope of such a system makes the VAN overhead unnecessary. Transit agencies will instead want direct connections between devices and the farebox. Their implementation will depend on the willingness of farebox manufacturers to make necessary hardware and software modifications to enable these links. Model specifications are given elsewhere (*2*) for direct connections with the head-sign, the speedometer, and the door sensor. They were guided by two main principles: first, to use what is commonly available; and second, to make any necessary new protocols as similar as possible to J1708 because manufacturers must develop J1708 capability for VAN applications anyway.

Direct Connection to Head-Sign

The model specification for connecting the farebox to the head-sign calls for the farebox to transmit a message that updates the head-sign every 10 sec, far more transmissions than are needed. The frequent transmissions eliminate the need for handshaking and verification. An RS 485 port is specified because it is more electrically isolated than an RS 232 port. The message transmitted by the farebox uses the J1708 protocol and the J1587 head-sign message format, including route and destination information. In this way, route and destination changes to the head-sign are entered through the farebox keypad. The head-sign keypad would only be used for special messages or other nonstandard head-sign operations. The farebox would determine the proper route and destination to transmit to the head-sign in one of two ways. In the simplest scheme, there are no trip-level identifiers, only route and direction (destination) codes common to the farebox and the head-sign, directly keyed into the farebox (or selected from a menu). It would also be valuable for the farebox to enable toggling between the last two sets of codes entered to simplify the operator's job when going back and forth on the same route. In the more complex scheme, operators key in more complex trip codes (to get trip-level data), from which the head-sign codes are determined by the farebox computer by means of a look-up table.

Direct Connection to Speedometer

Two model specifications were developed for direct connections to the speedometer. The first applies to a nondigital speedometer. The speedometer should supply an output signal to the farebox, the frequency of which is proportional to ground speed. The output signal has been specified to be in transistor-transistor logic (TTL) format, a common format for a clock signal. Modular microprocessor boards that can receive a TTL signal, accumulate the number of cycles in a counter, and communicate the counter's value to the farebox computer are readily available. The scale factors to convert number of cycles to distance traveled should be easily adjustable, either at the speedometer or at the farebox. For example, there might be dip switches for different standard tire sizes. A digital speedometer should transmit total distance traveled approximately every 10 sec via through an RS 485 port. The J1708/J1587 protocol and format are specified.

Direct Connection to Door Sensor

For the purpose of identifying the location at which people are boarding, connection will typically be needed only to the front-door sensor. A pair of simple microswitch signals indicating whether the door is fully open, fully closed, or neither is sent to the farebox, which will use a standard board to receive this signal and inform the farebox computer when the door opens or closes.

CONCLUSIONS

The data that a farebox-based system can provide—boardings by route, direction, trip, time of day, stop, and fare category for every day of the year, can be of immense value for planning, scheduling, marketing, and operations monitoring. For the most part, these boardings transactions are being captured by fareboxes, but, for reasons outlined, some of the information is lost and the data quality is sometimes suspect. Several methods have been described by which integration with other on-board devices could enhance the quality and value of farebox data. For good-quality data segmentation, integration with the head-sign is important. For verification, integration with the speedometer into get an odometer stamp is valuable. In a transactional–data base farebox system, integration with the door sensor and speedometer will enable the system to add an odometer stamp to each record. Integration with an annunciator- or AVL-based vehicle-location system, with the vehicle-location computer serving as a VLU, offers still more advantages. To move the industry toward data integration, open specifications using industry standards are important. Model specifications have been developed for direct links between fareboxes and head-signs, speedometers, and door sensors, and for linking fareboxes to a J1708 vehicle-area network.

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REFERENCES

1. Dawson, T. C., and D. Ryan. *Integrating Electronic Fareboxes at the CTA*. Presented at American Public Transit Association Operations and Service Planning Symposium, 1993.
2. Furth, P. G. *Management Information Benefits of Integrating Fareboxes with Other On-Board Devices*. Transit-IDEA Investigation No. 4, Final Report. TRB, National Research Council, Washington, D.C., (submitted).
3. Martin, M. K. *Using Farebox Data to Accurately Account for SCCTA Bus Ridership*. Santa Clara County Transportation Authority, 1993.
4. Furth, P. G., and B. McCollom. Using Conversion Factors To Lower Transit Data Collection Costs. In *Transportation Research Record 1144*, TRB, National Research Council, Washington, D.C., 1987, pp. 1–6.
5. Kronenburger, W. An Overview of the IVHS/FHWA/SAE Standard for a Vehicle Area Network. Draft release. Vehicle Area Network Subcommittee, FTA, 1994.
6. Hobeika, A. G., C. E. Nunnally, S. Raju, and P. Anderson. Data Processing Software for an Automatic Data Acquisition System in Mass Transit. In *Transportation Research Record 1165*, TRB, National Research Council, Washington, D.C., 1988, pp. 86–93.

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Direct Connections with Farebox

Transit agencies not in a position to procure an AVL or annunciator system will have to rely primarily on the computing power of the farebox. The vastly smaller scope of such a system makes the VAN overhead unnecessary. Transit agencies will instead want direct connections between devices and the farebox. Their implementation will depend on the willingness of farebox manufacturers to make necessary hardware and software modifications to enable these links. Model specifications are given elsewhere (3) for direct connections with the head-sign, the speedometer, and the door sensor. They were guided by two main principles: first, to use what is commonly available; and second, to make any necessary new protocols as similar as possible to J1708 because manufacturers must develop J1708 capability for VAN applications anyway.

Direct Connection to Head-Sign

The model specification for connecting the farebox to the head-sign calls for the farebox to transmit a message that updates the head-sign every 10 sec, far more transmissions than are needed. The frequent transmissions eliminate the need for handshaking and verification. An RS 485 port is specified because it is more electrically isolated than an RS 232 port. The message transmitted by the farebox uses the J1708 protocol and the J1587 head-sign message format, including route and destination information. In this way, route and destination changes to the head-sign are entered through the farebox keypad. The head-sign keypad would only be used for special messages or other nonstandard head-sign operations. The farebox would determine the proper route and destination to transmit to the head-sign in one of two ways. In the simplest scheme, there are no trip-level identifiers, only route and direction (destination) codes common to the farebox and the head-sign, directly keyed into the farebox (or selected from a menu). It would also be valuable for the farebox to enable toggling between the last two sets of codes entered to simplify the operator's job when going back and forth on the same route. In the more complex scheme, operators key in more comprehensive codes (to get trip-level data), from which the head-sign codes are determined by the farebox computer by means of a look-up table.

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Two model specifications were developed for direct connections to the speedometer. The first applies to a nondigital speedometer. The speedometer should supply an output signal to the farebox, the frequency of which is proportional to ground speed. The output signal has been specified to be in transistor-transistor logic (TTL) format, a common format for a clock signal. Modular microprocessor boards that can receive a TTL signal, accumulate the number of cycles in a counter, and communicate the counter's value to the farebox computer are readily available. The scale factors to convert number of cycles to distance traveled should be easily adjustable, either at the speedometer or at the farebox. For example, there might be dip switches for different standard tire sizes. A digital speedometer should transmit total distance traveled approximately every 10 sec via through an RS 485 port. The J1708/J1587 protocol and format are specified.

Direct Connection to Door Sensor

For the purpose of identifying the location at which people are boarding, connection will typically be needed only to the front-door sensor. A pair of simple relays with signals indicating whether the door is fully open, fully closed, or neither is sent to the farebox, which will use a standard board to receive this signal and inform the farebox computer when the door opens or closes.

CONCLUSIONS

The data that a farebox-based system can provide—boardings by route, direction, trip, time of day, stop, and fare category for every day of the year—can be of immense value for planning, scheduling, marketing, and operations monitoring. For the most part, these boardings transactions are being captured by fareboxes, but, for reasons outlined, some of the information is lost and the data quality is sometimes suspect. Several methods have been described by which integration with other on-board devices could enhance the quality and value of farebox data. For good-quality data segmentation, integration with the head-sign is important. For verification, integration with the speedometer (to get an odometer stamp) is valuable. In a transactional-data base farebox system, integration with the door sensor and speedometer will enable the system to add an odometer stamp to each record. Integration with an annunciator or AVL-based vehicle-location system, with the vehicle-location computer serving as a VLC, offers still more advantages. To move the industry toward data integration, open specifications using industry standards are important. Model specifications have been developed for direct links between fareboxes and head-signs, speedometers, and door sensors, and for linking fareboxes to a J1708 vehicle-area network.

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REFERENCES

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2. Furth, P. G. *Management Information Benefits of Integrating Fareboxes with Other On-Board Devices.* Transit-IDEA Investigation No. 4, Final Report. TRB, National Research Council, Washington, D.C. (unpublished).
3. Martin, M. R. *Using Farebox Data to Accumulate Section 15 for SCCTA* [illegible]. Santa Clara County Transportation Authority, 1993.
4. Furth, P. G., and B. McCollom. Using Conversion Factors To Lower Transit Data Collection Costs. In *Transportation Research Record 1144,* TRB, National Research Council, Washington, D.C., 1987, pp. 1–8.
5. [illegible], W. *An Overview of the TVIS/PTIS/SAE Standard for a Vehicle Area Network.* Draft report. Vehicle Area Network Subcommittee, FTA, 1994.
6. [illegible], A. G., C. S. [illegible], S. Bate, and P. Andreas. Data Processing Software for an Automatic Data Acquisition System in Mass Transit. In *Transportation Research Record 1266,* TRB, National Research Council, Washington, D.C., 1990, pp. 86–93.

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