ANALYZING DATA FROM AVL/APC SYSTEM FOR IMPROVING TRANSIT MANAGEMENT
Theory and Practice

Yun Ye
Nanjing Radio and TV University, No.46, YouFuXi Street, Nanjing, 210002, China

Jie Li
Transportation College, Southeast University, No.2, Sipailou Street, Nanjing, 210096, China

Keywords: AVL, APC transit, Data analysis.

Abstract: AVL (Automatic vehicle location) and APC (Automatic passenger counter) systems are capable of gathering an enormous quantity and variety of operational, spatial and temporal data that—if captured, archived, and analyzed properly—hold substantial promise for improving transit performance. Historically, however, such data has not been used to its full potential. This paper discussed how to use this type of data to supporting transit service planning, scheduling, and service quality monitoring. First, AVL/APV system was introduced. Then the actual use and potential uses were reviewed and data requirements for each use are analyzed. Finally the distribution-based data method was proposed and associated analysis software tool were developed.

1 INTRODUCTION

The transit industry is in the midst of a revolution from being data poor to data rich. Traditional analysis and decision support tools required little data, not because data has little value, but because traditional management methods had to accommodate a scarcity of data. Automatic data gathering systems do more than meet traditional data needs; they open the door for new analysis methods that can be used to improve monitoring, planning, performance, and management (Furth, 2005).

At first**,** transit agencies may look to an automatic data collection system only to provide the data needed for traditional analyses. But, once they have the larger and richer data stream that AVL and APCs offer, they think of new ways to analyze it, and they want more. Eventually, their whole mode of operation changes as they become data driven.

This paper proposes a framework for analyzing AVL and APC data and designed the associated software tool. It is organized as follow: Section 2 reviews AVL/ APC system to collect data. Section 3 points out the five trends of potential transit data use. Section 4 describes the analyzing for each use the kind of AVL-APC data it requires. Section 5 designs the software tool that facilities analyzing running time and passenger demand. Section 6 gives the conclusions.

2 AVL/APC SYSTEM AND DATA TYPES

2.1 AVL System

In the last decade, global positioning system (GPS) has become the preferred location technology. GPS receivers on vehicles determine their location by triangulation based on signals received from orbiting satellites. Location accuracy for buses is generally better than 10 m, depending on the accuracy of clocks in the GPS receivers and on whether differential corrections are used.

Because GPS requires a line of sight to the satellites, GPS signals can be lost as buses pass through canyons, including man-made canyons caused by tall buildings. Tall buildings also reflect

Ye Y. and Li J..
ANALYZING DATA FROM AVL/APC SYSTEM FOR IMPROVING TRANSIT MANAGEMENT - Theory and Practice.
DOI: 10.5220/0003602402670274
In *Proceedings of the 13th International Conference on Enterprise Information Systems* (BIS-2011), pages 267-274
ISBN: 978-989-8425-54-6

GPS signals, causing a phenomenon called multipath that can lead to erroneous location estimation. Older AVL-APC systems use a combination of beacons, which serve as fixed-point location devices, and dead reckoning for determining location between beacons, using the assumption that the bus is following a (known) route. All transit coaches have electronic odometers, making it easy to integrate odometers into a location system. Route deviations present a problem for odometer-based dead reckoning, which is one of the reasons GPS is preferred. Some AVL systems include a gyroscope, which makes it possible to track a bus off-route using dead reckoning. Many GPS-based systems often use dead reckoning as a backup. When GPS signals indicate a change in location inconsistent with the odometer, dead reckoning takes over from the last reliable GPS measurement, until GPS and odometer measurements come back into harmony .Odometers require calibration against known distances measured using signposts or GPS, because the relationship between axle rotations (what is actually measured) and distance covered depends on changeable factors such as tire inflation and wear. Therefore，location technologies have been based on GPS while integrating with other measurements to improve the accuracy.

2.2 Integrating APC with AVL

Valuable reviews of the history of APCs are found in reports by Levy and Lawrence (1991), and Friedman (1993). APCs use a variety of technologies for counting passengers, including pressure-sensitive mats, horizontal beams, and overhead infrared sensing. Automatic passenger counting has not yet seen widespread adoption primarily because of its cost and the maintenance burden it adds. Where adopted, APCs are typically installed on 10% to 15% of the fleet. Equipped buses are rotated around the system to provide data on every route. However, technological advances may soon make APCs far more common.

The term “APC” can refer to a full data collection system or to simply the passenger counter as a device within a larger data collection system. Historically, APCs were implemented as full, independent systems that included location measurement and stop matching. In spite of the emphasis their name gives to passenger use data, they not only counted passengers but also provided valuable operation data that supported analysis of running time and schedule adherence; in effect, they doubled as (non-real-time) AVL systems. Canadian transit agencies have been particularly active in exploiting APC data.

2.3 Data Type

AVL and APC systems provide four types of data:

2.3.1 Polling Records

Most real-time AVL systems use round-robin polling to track their vehicles. The polling interval depends on the number of vehicles being tracked per radio channel; 40 to 120 s is typical. Within each polling cycle, every vehicle is polled in turn, and the vehicle responds with a message in a standard format. Round-robin polling is an effective protocol for avoiding message collisions; however, the need to transmit messages in both directions, with a time lag at either end for processing and responding, means that a significant amount of time—on the order of 0.5 s—is needed to poll each bus. The polling cycle is therefore limited by the number of buses being monitored per radio channel. A polling message includes ID codes (for the vehicle, its run or block, and perhaps its route) and various fields for location data. Location fields depend on the location system used. For a beacon-based system, they include ID of the most recently passed beacon and odometer reading.

2.3.2 Event Records

In addition to round-robin polling, WANs also support messages initiated at the vehicle, generically called “event messages.” Each event record has a code and specified format. Modern AVL systems can have 100 or more different types of event records. Messages initiated by on-board computers are likely to collide—that is, one bus will try to send a message while the channel is busy with another message. WANs manage this kind of network traffic problem in various ways, such as by having messages automatically re-sent until a receipt message is received. This need to manage traffic limits the practical capacity of radio-based communication, because, with randomly arising messages, the channel has to be unoccupied a relatively high fraction of the time (unlike with round-robin polling) to provide an acceptable level of service. In the face of limited channel capacity, then, radio-based systems have to be designed in a way that limits the frequency and length of messages sent.

2.3.3 Timepoint Records

In most AVL systems, the timepoint event, indicating a bus's arrival or departure from a timepoint, is the most frequent event record used for archived data analysis. The event can be defined in various ways, depending on the location system.

Where GPS is used and door switches are not, it is common to report when the bus first reaches a circular zone (typically a 10-m radius) around the stop. The timepoint record may also include the time the bus left that zone. In principle, timepoint records could also include fields indicating when doors first opened and last closed; however, the researchers are not aware of any radio-based systems incorporating door information. The level of detail of timepoint records affects their accuracy and value for off-line analysis. For example, some running time and schedule adherence measures are defined in terms of departure times, others in terms of arrival times, and others involve a difference between arrival time at one point and departure time at a previous timepoint. Off-line analysis therefore benefits from having both arrival and departure times recorded, particularly if operators hold at timepoints. Records of when buses enter and depart a stop zone are only approximations of when buses arrive and depart the stop itself. Errors can be significant in congested areas where traffic blocks buses from reaching or pulling out of a stop. Detail on door opening and closing, and on when the wheels stop and start rolling, can help resolve ambiguities and make arrival and departure time determination more accurate.

2.3.4 Stop Records

Stop events are much more frequent than timepoint events, and therefore, far more demanding of radio channel capacity if transmitted over the air. Therefore, most AVL/APC systems collecting data at the stop-level store stop records in the on-board computer, uploading them overnight. The data items typically included in a stop record—in addition to the usual time stamp, location stamp, vehicle IDs, and door switches—are door opening and closing times and (if available) on and off counts. If routes are tracked by the on-board computer, as is the case with stop announcement systems, the stop record will include stop ID in addition to generic location information; otherwise, the data is matched in later processing.

3 TRENDS IN DATA USE: BECOMING DATA RICH

Five trends in data use have emerged from the paradigm shift from data poor to data rich:

3.1 Focus on Extreme Values

Traditional methods of scheduling and customer service monitoring generally use mean values of measured quantities, because mean values can be estimated using small samples. However, many management and planning functions are oriented around extreme values and are, therefore, better served by direct analysis of extreme values such as 90th- or 95th-percentile values. These extreme values now can be estimated reliably because of the large sample sizes afforded by automatic data collection. Three examples are as follow:

- ✓ Recovery time is put into the schedule to limit the probability that a bus finishes one trip so late that its next trip starts late. Therefore, logically, scheduled half-cycle times (scheduled running time plus recovery time) should be based on an extreme value such as the 95th-percentile running time. However, without enough data to estimate the 95th-percentile running time, traditional practice sets it equal to a fixed percentage (e.g., 15% or 20%) of scheduled running time. Yet, some route-period combinations need more than this standard, and others less, because they do not have the same running time variability. AVL data allows an agency to actually measure 95th-percentile running times and use that to set recovery times.
- ✓ Passenger waiting time is an important measure of service quality. Studies show that customers are more affected by their 95th-percentile waiting time—for a daily traveler, roughly the largest amount they had to wait in the previous month—than their mean waiting time, because 95thpercentile waiting time is what passengers have to budget in their travel plans to be reasonably certain of arriving on time.
- ✓ Passenger crowding is also a measure in which extreme values are more important than mean values. Although traditional planning uses mean load at the peak point to set headways and monitor crowding,

planners understand that what matters for both passengers and smooth operations is not mean load but how often buses are overcrowded. Therefore, design standards for average peak load are set a considerable margin below the overcrowding threshold. However, load variability is not the same on every route. With a large sample of load measurements, headways can be designed and passenger crowding measured based on 90th-percentile loads, or a similar extreme value, rather than mean loads.

3.2 Customer-oriented Service Standards and Schedules

AVL-APC data allows customer-oriented service quality measures to replace (or supplement) operations-oriented service standards. For example, on high-frequency routes, a traditional operations-oriented standard of service quality is the coefficient of variation (cv) in headway. Although such a standard may mean something to service analysts, it means nothing to passengers, and it resists being given a value to passengers. With a large sample size of headway data, one can instead measure the percentage of passengers waiting longer than x minutes, where x is a threshold of unacceptability. Similarly, in place of average load factor as a crowding standard, one could use a standard such as "no more than 5% of our customers should experience a bus whose load exceeds x passengers." As these examples show, a shift toward customer-oriented measures goes hand-in-hand with the ability to measure extreme values.

3.3 Planning for Operational Control

One of the questions posed by the explosion of information technology is how best to use information in real time to control operations, for example, by taking actions such as holding a bus to protect a connection or having a bus turn back early or run express. As agencies experiment with, or use, such actions, they need off-line tools to study the impacts of these control actions in order to improve control practices.

For example, AVL-APC data were used to determine the impacts of a Tri-Met experiment in which buses were short turned to regularize headways during the afternoon peak in the downtown area (Lehtonen, 2002).

3.4 Solutions to Roadway Congestion

Transit agencies are more actively seeking solutions to traffic congestion, such as signal priority and various traffic management schemes. They need tools to monitor whether countermeasures are effective. In this particular study, only the overall effect on rather long segments was analyzed by comparing before and after running times, making the results hard to correlate with particular intersections. For better diagnosis and fine-tuning of countermeasures, agencies need tools to analyze delays on stop-to-stop, or shorter, segments.

3.5 Discovery of Hidden Trends

Behind a lot of the randomness in transit operations may be some systematic trends that can be discovered only with large data samples. For example, by comparing operators with others running the same routes in the same periods of the day, Tri-Met found that much of the observed variability in running time and schedule deviation is in fact systematic: some operators are slower and some faster. Exploratory analysis might also reveal relationships that can lead to better end-of-line identification, or to better understanding of terminal circulation needs.

4 DATA NEEDS FOR SPECIFIC ANALYSIS

4.1 Running Time

Analyzing and scheduling running time is one of the richest application areas for archived AVL-APC data. Without AVL data, agencies must set running times based on small manual samples, which simply cannot account for the running time variability that comes with traffic congestion.

Buses are scheduled at the timepoint level; therefore, scheduling demands timepoint data. Because schedules sometimes refer to arrivals as well as departures, it is helpful if timepoint records include both arrival and departure times.

Running time analyses that require only estimation of mean values, or that involve only occasional studies (e.g., delay and dwell time analysis), can be conducted with only a sample of the fleet equipped with AVL. However, routine scheduling applications based on extreme values need the entire fleet equipped.

4.2 Headway Regularity and Short-headway Waiting

On routes with short headways, headway regularity is important to passengers because of its impact on waiting time and crowding. It is also important to the service provider because crowding tends to slow operations and because much of operations control is focused on keeping headways regular.

To measure headways, data has to be captured on successive trips, making headway analysis particularly sensitive to the rate of data recovery, as one lost trip means two lost headways.Analyzing headway when only part of the bus fleet is instrumented poses the logistical challenge of getting all the buses operating on a route to be instrumented; because of this challenge,

Headways matter all along the route, not only at timepoints; therefore, stop records are best suited to headway analysis. (In fact, headways matter most at stops with high boarding rates.) However, because headways at neighboring stops are strongly correlated, timepoints can be thought of as a representative sample of stops, making it possible, although not ideal, to estimate headway-related measures of operational quality from timepoint data.

4.3 Schedule Adherence, Long-headway Waiting, and Connection Protection

Monitoring schedule adherence is a valuable management tool, because good schedule adherence demands both realistic schedules and good operational control. It is probably the most common analysis performed with AVL-APC data. Schedule adherence can be measured in a summary fashion as simply the percentage of departures that were in a defined on-time window, or perhaps as the percentage that were early, on time, and late. Standard deviation of schedule deviation is an indicator of how unpredictable and out of control an operation is. A distribution of schedule deviations provides full detail. Such a distribution allows analysts to vary the "early" and "late" threshold depending on the application, or to determine the percentage of trips with different degrees of lateness.

Because schedules are written at the timepoint level, timepoint data will support schedule adherence analysis. And because schedule adherence involves estimating proportions and extremes (detecting the percentage of early and late trips),the full fleet should be equipped. Finally, because schedules sometimes refer to arrival time as well as departure time, a data collection system that captures both is preferred.

Passenger waiting time on routes with long headways is closely related to schedule adherence. It is possible to determine excess waiting time from the spread between the 2nd-percentile and 95th-percentile schedule deviation.

Passengers are particularly interested in whether they can make their connections. Arriving 4 min late is not a problem if the time allowed for the transfer is 5 min, but it could be a big problem if the allowed time is only 3 min. However, if the departing trip is held—again, the convergence of schedule planning and operations control—other issues arise. AVL data is ideal for determining whether specific connections were met.

To analyze connection protection an agency must define the particular connections it wishes to protect or at least analyze.

Integrating control message data, which might include requests for holding to help passenger make a connection, would permit a deeper analysis of operational control. Incorporating demand data, ideally transfer volumes, would make the analysis richer still.

5 RUNNING TIME AND DEMAND ANALYSIS TOOL

First it is necessary to define the basic input data collected by AVL/APC, which is served as the basis for running time and demand analysis.

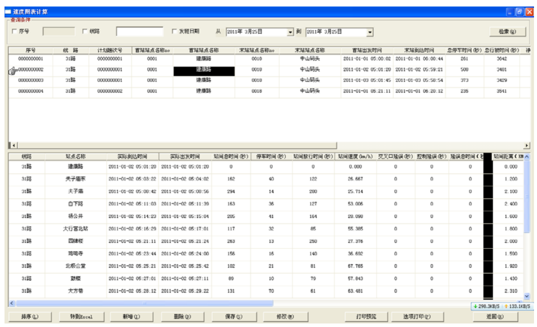

Figure 1: Daily trip records.

Figure 1 shows the basic input data items including route and trip number, stop name, actual arrival and departure for each stop for each daily trip, stop-to-stop distance, etc. Route and stops along it are created and maintained by a route manger as shown by Figure 2 .This setting-up facilities input process and avoid typos by eliminating typing in these items for each trip. Every time a trip is created, only the name or number of the route on which this trip is made needs to be selected from a drop-down list. The route manager can update the stop name and location.

Figure 2: Route and stop manager.

5.1 Scheduled Running Time and Recovery Time

A common analysis examines the distribution of observed running time for scheduled trips across the day. An example is given by Figure 3, the maximum and minimum observed running time ,mean observed running time, percentile value for observed running time was calculated .

Based on the observed distribution of running time for either a single scheduled trip or a set of contiguous trips in a period that will be scheduled as a group, schedule makers can choose a value for allowed time according to their preferred scheduling philosophy. Some schedule makers prefer to base schedules on mean running time. An alternative approach, aimed at improving schedule adherence, is to intentionally put slack into the schedule; this approach has to be coupled with an operating practice of holding at timepoints. With such a schedule, a high percentage of trips depart almost exactly on schedule, and the low percentages of trips that run late are not far behind schedule. The amount of slack put into a schedule is often a simple fraction of mean running time, with ad hoc adjustments based on experience. A more scientific, data-driven approach is to use a percentile value, or “feasibility criterion.” To illustrate, a feasibility criterion of 85% means setting allowed time (scheduled running time) equal to 85th-percentile observed running time; such a schedule can be completed on time 85% of the time.

Analysis of running time is also pertinent for determining how much recovery time to schedule at the end of the line. The time from a bus’s departure

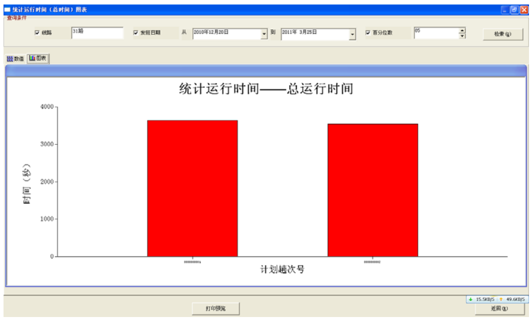

Figure 3: Observed running time distribution for one single trip.

at one terminal to its next departure in the reverse direction has been called the “half cycle time”; it is the sum of running time and recovery time .Because the purpose of recovery time is to limit the likelihood that delays encountered in one trip will propagate to the next, half-cycle time is based logically on a high-percentile value of running time. For example, if scheduled recovery time is set to be the difference between 95th-percentile running times and allowed time, there will be only a 5% chance that a bus will arrive so late that it starts the next trip late.

5.2 Speed and Delay Analysis

Speed, delay, and dwell time studies are analyses that help support a transit agency’s efforts to improve commercial speed, something that benefits both operations and passengers. “Speed” in this context is average speed over a segment, not instantaneous or peak speed. A display such as given in Figure 4 showing delay by segment (or, alternatively, average speed by segment) helps a transit agency to identify problem locations, to monitor the impacts of actions that affect speed, and to monitor and document historic trends in operating speed (Barry et al., 2003).

In that figure, it allows analysts to obtain percentile value of delay, maximum and minimum delay and mean delay. Analysts will be interested not only in average delay, but also in how variable it is, and in the likelihood of extreme values. A report showing delays or speeds between stops offers a richer, more geographically detailed view than one using timepoint segments. Another reason to prefer stop records as the basis of delay analysis is that it allows dwell time and control time (which almost always occur at stops) to be removed, which puts a clearer focus on the effects of the roadway and traffic on bus speed and delay.

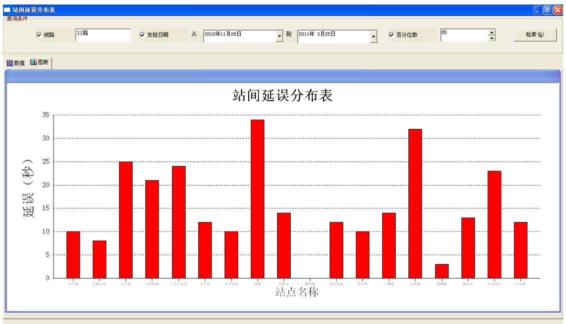

Figure 4: Stop-level observed delay distribution.

5.3 Dwell Time Analysis

Transit agencies also try to improve commercial speed by reducing dwell time, using such measures as low-floor buses or changes to fare collection equipment and practices. Stop records with door open and close times allow agencies to analyze dwell time to determine impacts and trends. Such an analysis should preferably be aided by passenger counts, in order to separate out the impact of the number of boardings and alightings and to identify whether any on-vehicle congestion impact arises when vehicles are crowded. On-off counts, farebox transactions, and incident codes that reveal wheelchair and bicycle use are all useful for giving analysts an understanding of dwell time (Navick and Fruth, 2002).

Figure 5 shows dwell time distribution for each stop along a route.

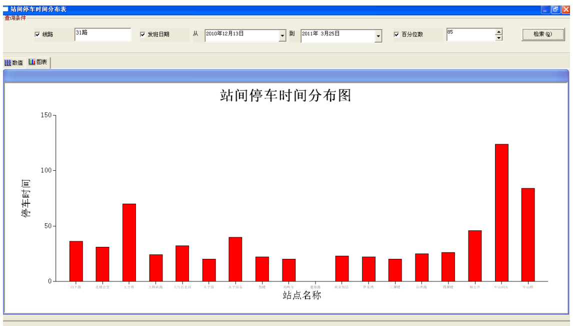

Figure 5.

5.4 Demand Along a Route

The shows not only mean segment loads, but also mean offs, ons, and through load at each stop in a single profile. This paper has already pointed out the importance of extreme values of load for both passenger service qualities monitoring and scheduling.

Analysis of demand along a route is necessary for understanding where along the route high loads occur. It supports decisions about stop relocation and installing stop amenities, and routing and scheduling actions that affect some parts of a route differently from others, such as short turning, zonal service, and limited stop service.

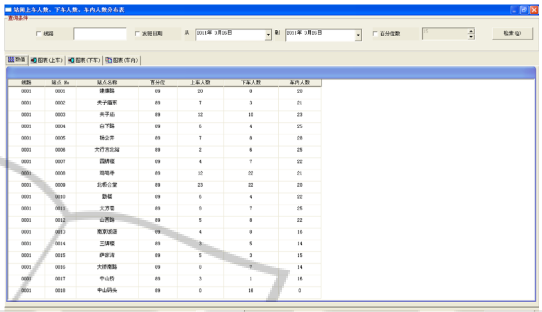

Figure 6: Passenger on-off counts and load.

6 CONCLUSIONS

Automatic data collection can revolutionize schedule planning and operations quality monitoring as agencies shift from methods constrained by data scarcity to methods that take advantage of data abundance. The large sample sizes afforded by automatic data collection allow analyses that focus on extreme values, which matter for schedule planning (e.g., how much running time and recovery time are needed, what headway is needed to prevent overloads) and service quality monitoring (e.g., how long must passengers budget for waiting, how often do they experience overcrowding). Stop-level data recording provides a basis for stop-level scheduling, a practice with potential for improved customer information and better operational control. With AVL-APC data, trends can be found that might otherwise be hidden, such as operator-specific tendencies and sources of delay en route. Regularly analyzing AVL data gives a transit agency a tool for taking greater control of its running times by offering a means of detecting causes of delay and evaluating the effectiveness of countermeasures.

REFERENCES

Furth, P. G., J. P. Attanucci, I. Burns, and N. H. Wilson, 2005. *Transit Data Collection Design Manual.* Report DOT-I-85-38. U.S.DOT.

Levy, D. and L. Lawrence, 1991. *The Use of Automatic Vehicle Location for Planning and Management*

Information. STRP Report 4, Canadian Urban Transit Association.

Friedman, T. W.,1993. "The Evolution of Automatic Passenger Counters."In *Proceedings, Transit Planning Applications Conference*

Navick, D. S. and P. G. Furth, 2002. "Estimating Passenger Miles, Origin-Destination Patterns, and Loads with Location-Stamped Farebox Data."*Transportation Research Record: Journal of the Transportation Research Board, No. 1799,* Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 107–113.

Barry, J. J., R. Newhouser, A. Rahbee, and S. Sayeda. 2003. "Origin and Destination Estimation in New York City with Automated Fare System Data." *Transportation Research Record: Journal of the Transportation Research Board,No. 1817,* Transportation Research Board of the National Academies, Washington, D.C., , pp. 183–187.

Lehtonen, M. and R. Kulmala. "Benefits of Pilot Implementation of Public Transport Signal Priorities and Real-Time Passenger Information." *Transportation Research Record: Journal of the Transportation Research Board, No. 1799,* Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 18–25.