

AUTOMATICALLY IDENTIFYING THE CAUSES OF BUS TRANSIT SCHEDULE
ADHERENCE PERFORMANCE ISSUES USING AVL/APC ARCHIVED DATA

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ABSTRACT

Automatic Vehicle Location (AVL) and Automatic Passenger Counting (APC) systems can provide rich archived databases for analysis. Previous work has focused on using APC/AVL data to evaluate system performance using various quantitative performance measures and data visualization methods. Given the large volume of data, there is a benefit to automating the creation of performance measures and data visualizations and “pushing” interesting information to the user, rather than requiring the user to create the performance measures and figures and sift through them on their own. This paper presents a methodology for identifying bus stops that are not meeting schedule adherence performance standards, and the factors causing inadequate performance. The methodology is designed to be automated and therefore can be applied efficiently to AVL/APC data for an entire transit network. Use of this proposed method will enable transit agencies to more efficiently identify service quality issues and the root causes of these issues.

INTRODUCTION

The types and amount of data available to many transit agencies is currently undergoing a dramatic shift. Historically, the significant cost and complexity of manually collecting data on transit system performance has forced many agencies to make do with limited datasets for planning and evaluating their networks (1). Automated transit data collection, including Automatic Vehicle Location (AVL) systems and Automatic Passenger Counting (APC) systems, has the potential to create rich operational and passenger activity databases (2) and is revolutionizing the quality and quantity of data available to transit agencies.

These large datasets provide the opportunity for new planning and analysis methods that were previously impractical, however they also present new challenges (3). Typically, transit agencies have used ad hoc manual methods of manipulating and visualizing data. Though these methods are adequate for relatively small datasets they are generally impractical for identifying and extracting meaningful results from the much larger datasets obtained from AVL/APC systems. Consequently, it is necessary to compile and summarize the data in a way that facilitates effective decision making and assists in focusing resources. The usage of performance measures and figures to aggregate and highlight key areas has been a focus of much recent research (1, 4, 2, 5, 3, 6).

Automatic creation of performance measures and/or figures would benefit transit agencies since it would allow the entire network to be continuously monitored using the most recent data, while minimizing resource requirements. Performance measures of particular interest to the transit agency should be “pushed” to agency staff. This takes advantage of their automatic creation by alerting the agency as to where attention is needed, rather than requiring a planner to sift through tables and figures to identify areas are not performing acceptably. Furthermore, the efficiency and effectiveness of transit planning operations can be improved through the automatic identification of the likely causes leading to unacceptable quality of service.

This paper focuses on a using archived data available from a typical AVL/APC installation and evaluates a single performance measure, schedule adherence. A methodology is developed to identify bus stops failing to meet service standards, highlight those stops, and then identify causes of not meeting service standards at a given stop. The methodology can be automated and applied to an entire transit network.

The methodology is demonstrated through an application to Grand River Transit Route 3 in the Region of Waterloo, Ontario, Canada.

LITERATURE REVIEW

Previous work has highlighted the rich databases made available to transit agencies through automated data collection systems such as AVL and APC. AVL systems were originally designed with real-time monitoring in mind (7), but more recent installations have been moving towards archiving the collected data and providing a sampling frequency suitable for offline analysis (4). APC systems have generally been installed for off-line data analysis and typically provide a high sampling frequency, however low deployment and recovery rates had limited the amount of data made available through these systems (7). However, deployment of APC systems is increasing (8) and newer systems are showing better recovery rates (7).

1 Bertini and El-Geneidy (1) noted that the large AVL/APC datasets provide an opportunity to
2 calculate and utilize previously infeasible performance measures to assist transit agencies in
3 improving the quality and reliability of their service. Many performance measures were suggested
4 and presented, including a schedule adherence measure which plotted the difference between
5 scheduled and actual departure time for each stop on a route over the course of a day. An analysis
6 presented the percent of time that buses were late, early, and on-time over the route.

7
8 TCRP Web Document 23 (4) suggests that a graph of schedule deviation along a route can be created
9 using AVL/APC data and is a common tool to improve scheduling, since patterns become easy to
10 spot. More advanced measures are also proposed that combine schedule deviation with on/off
11 counts. It is suggested that the analysis should recognize, for example, that arriving early is not a
12 problem for passengers departing the transit vehicle, but departing early can be a significant problem
13 for passengers wishing to board.

14
15 The Transit Capacity and Quality of Service Manual (TCQSM) (9) suggests a performance measure
16 for *on-time performance* to evaluate transit schedule adherence. A bus is considered to be “on-time”
17 when it is between zero and five minutes late. The specific level of service (LOS) is determined by
18 the percent of time that a bus is “on-time”.

19
20 Furth et. al. (2) suggest that at a minimum AVL systems should be capable of reporting and storing
21 timepoint level records in order to be used for quality of service analysis. Additional analysis
22 capabilities are available with higher levels of detail such as stop records. To create time-at-location
23 records at a timepoint level or higher, the bus must be able to determine its current location and
24 match it against known timepoints and/or bus stops. Furth et. al. note the challenge of moving from
25 well-entrenched methodologies designed for a data-poor environment to new methods to utilize the
26 rich-data provided by AVL/APC systems.

27
28 Hammerle et. al. (5) used data from a Chicago Transit Authority AVL/APC implementation to
29 compute various service reliability indicators. Schedule adherence was investigated by finding the
30 deviation from the scheduled time at each timepoint for each trip. This was used to plot the
31 percentile deviation at each stop and also to calculate the LOS for the route as a whole using the
32 TCQSM methodology.

33
34 TCRP Report 113 (3) notes that schedule adherence is one of the most common analyses performed
35 with AVL/APC data. A recommended analysis tool involves a profile showing the schedule
36 deviation along the line, including 15th and 85th percentile deviations. Information that can be
37 interpreted from this form of plot include whether the scheduled running time is realistic (sudden
38 jumps in the mean of the deviation indicate unrealistic scheduled running time) and the quality of
39 operational control (a large spread in deviation, especially if increases along the line, indicate poor
40 operational control). A sample of the profile recommended in this report is presented in Figure 1,
41 showing a poorly scheduled and poorly controlled route.

42

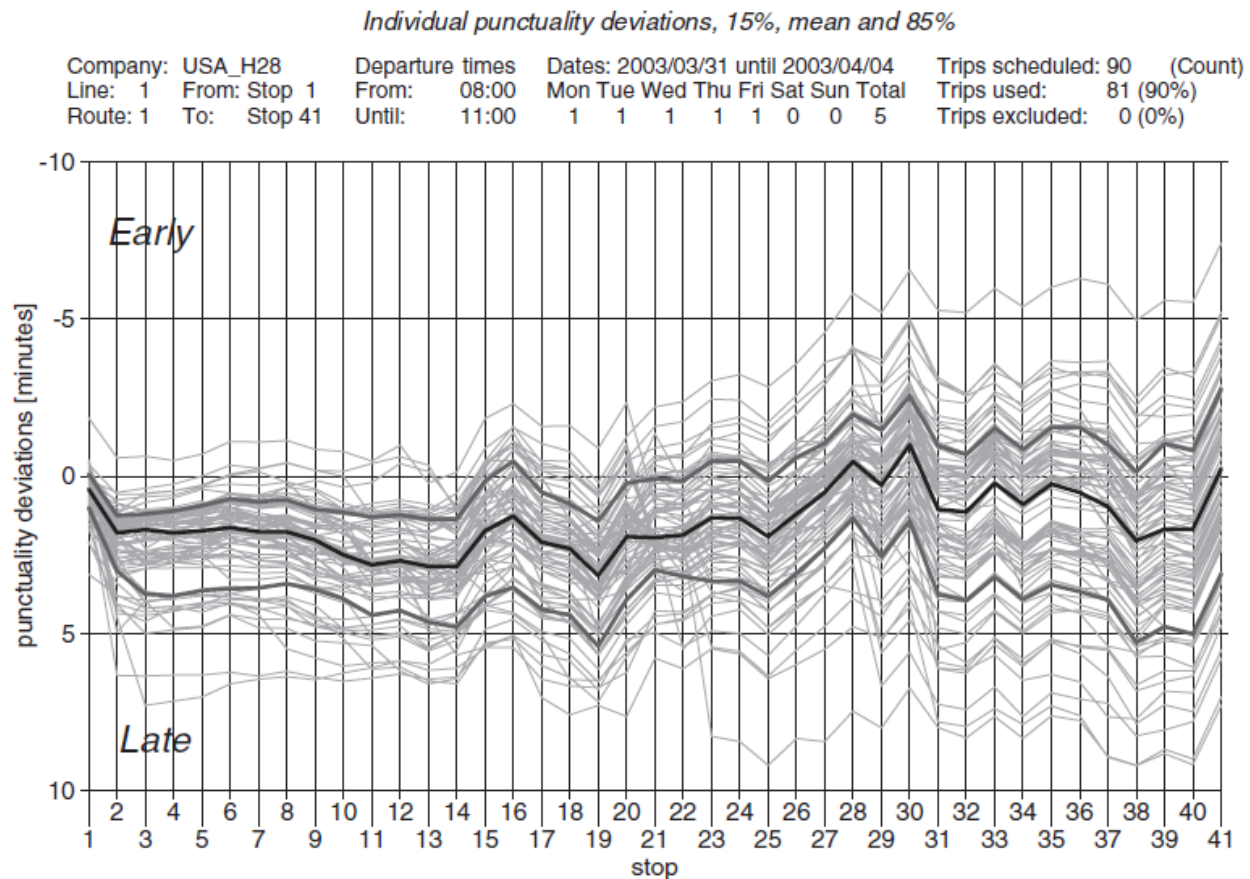


FIGURE 1 Schedule deviation along a line, showing strong random and systematic deviation (source: TCRP Report 113).

Kimpel et. al. (10) reviewed a variety of historical literature and highlighted innovated uses of AVL/APC data from TriMet in Portland, Oregon. A variety of tabular reports are presented that can be used to aggregate and summarize AVL/APC data such that various aspects of system performance can be analyzed. Kimpel et. al. also present a figure that shows median and scheduled run times as well as a proposed optimal run time for a given timepoint pair, however the methodology used to calculate the optimal run time is unclear.

Berkow et. al. (6) suggested that the quantity of data being archived is too much for an analyst to understand and use without summarization or visualization aids. Data from TriMet was used to present various aids. A “drill-down” methodology was used which started with system level summaries before moving down to route, segment, and point level analysis.

Much of the current work has focused on how to present the vast quantities of data made available by AVL/APC systems such that it can be understood and used. For schedule adherence, data is often used to calculate performance measures similar to those presented in the TCQSM or to plot schedule adherence by stop or route. These methods have been performed by preselecting a specific route and conducting a detailed analysis. However, the methods could be applied in an automated fashion that can alert a transit agency when schedule adherence at a route or stop is not meeting performance goals, rather than requiring a conscious effort to check each route on a regular basis. Furthermore,

once performance issues at a stop have been identified, there has been only limited work to identify the causes of these issues.

By implementing a system that automatically alerts transit agencies when timepoints/stops are not meeting performance standards, as well as automatically providing guidance on the reasons behind the problems, transit agencies will be better positioned to make decisions to improve the quality and reliability of their network.

PROPOSED METHODOLOGY

The proposed methodology consists of two main components. In the first component, bus stops that are not exhibiting acceptable schedule adherence are identified and “flagged”. The flag also identifies whether schedule adherence performance measures are not being met due to early departures (“early”), late arrivals (“late”), or both. In the second component, flagged stops are further analyzed to calculate “cause statistics” which identify the likely causes of the poor schedule adherence. The methodology is illustrated in Figure 2 and described in more detail in the following sections.

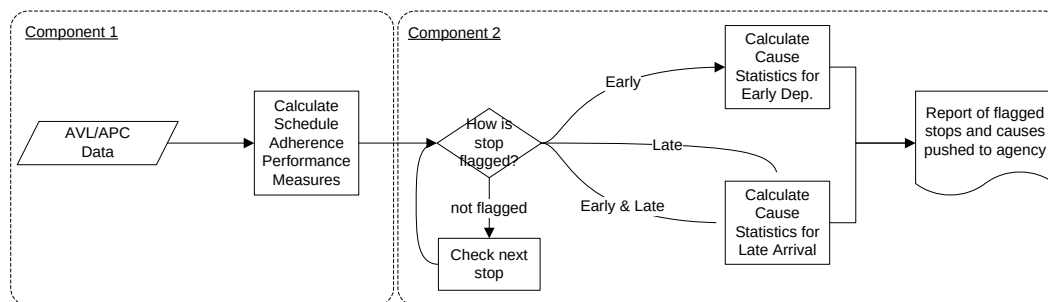


FIGURE 2 Proposed methodology framework.

1. Identify Stops with Poor Schedule Adherence

The archived AVL/APC data is divided into time periods, each of which is then further subdivided by route, direction, and stops. This forms the basic unit of analysis for the methodology. At each stop, the percentage of time that buses are ‘early’ and ‘late’ are each calculated and compared with a service threshold. The stop is flagged if the threshold is exceeded.

The TCQSM defines a bus as late if it arrives more than 5 minutes late and early if it departs before its scheduled departure time. The TCQSM also specifies a LOS based on the percentage a time that a bus is late or early. However, the TCQSM methodology lumps all late and early buses together as “not on-time”. This definition is not sufficient for the purposes of the proposed methodology, because factors causing buses to be early are typically different from those causing buses to be late. Therefore, in the proposed methodology a separate service performance threshold must be specified for late or early arrivals. The process of flagging stops that do not meet service standards for schedule adherence is illustrated in Figure 3.

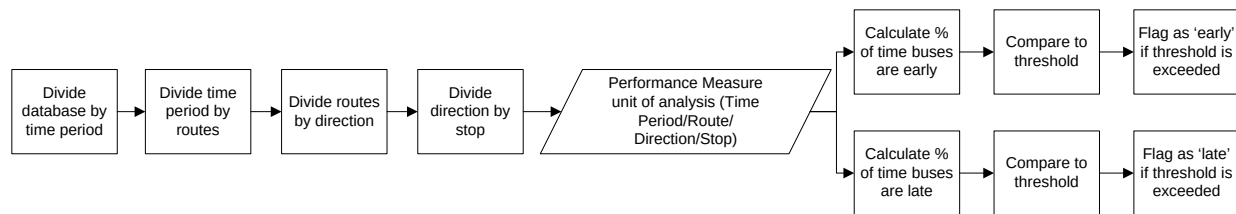


FIGURE 3 Method to calculate schedule adherence performance measures.

2. Determine Causes of Poor Schedule Adherence

The second component of the proposed methodology identifies causes of poor schedule adherence. Three categories of factors that cause a bus to be late at a stop can be identified, namely:

- Travel time from the previous timepoint to the current timepoint exceeded the scheduled time (travel time causes)
- The bus dwell time at the previous timepoint was longer than scheduled (dwell time causes)
- The bus arrived late at the previous timepoint as a result of problems upstream (upstream causes)

Three categories of causes can also be identified for buses departing early, namely:

- The bus dwell time at the current timepoint was less than scheduled (dwell time causes)
- Travel time from the previous timepoint to the current timepoint was less than scheduled (travel time causes)
- The bus departed the previous timepoint early (upstream causes)

Table 1 lists these categories and identifies a number of specific causal events associated with each category. The categories can be identified from the archived AVL/APC data.

TABLE 1 Cause Categories for Late Arrivals and Early Departures

Problem	Category	Potential Causes
Late Arrival	Travel time from previous stop took longer than scheduled	• Traffic reasons (congestion, inclement weather, signal timing, etc.) • High demand for intermediate (non-timepoint) stops • Unscheduled stops • Etc.
	Dwell time at previous stop was longer than scheduled	• High passenger activity (on/off) • Difficulty rejoining traffic stream • Lift use • Etc.
	Arrived at previous stop late	• Upstream causes
Early Departure	Dwell time at current stop was less than scheduled	• Low passenger activity (on/off)
	Travel time from previous stop was lower than scheduled	• Traffic reasons (lower than expected congestion, etc.) • Low demand at intermediate (non-timepoint stops) • Etc.
	Departed previous stop early	• Upstream causes

The process for calculating cause statistics for late arrivals at a given stop is illustrated in Figure 4. The final result is the percent of time that being late can be attributable to travel time issues, the percent of time that being late can be attributable to dwell time at the previous stop, and the percent of time that being late can be attributable to issues upstream of the previous stop segment. The total percentages can add up to greater than 100% since it is possible for multiple causes to combine and result in a late bus.

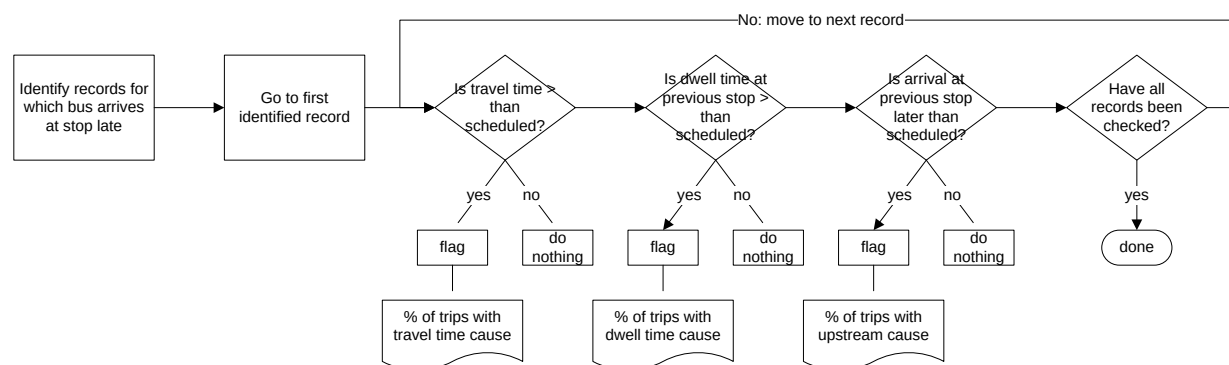


FIGURE 4 Method to calculate late arrival cause statistics.

The process for calculating the cause statistics for early buses is similar and is presented in Figure 5.

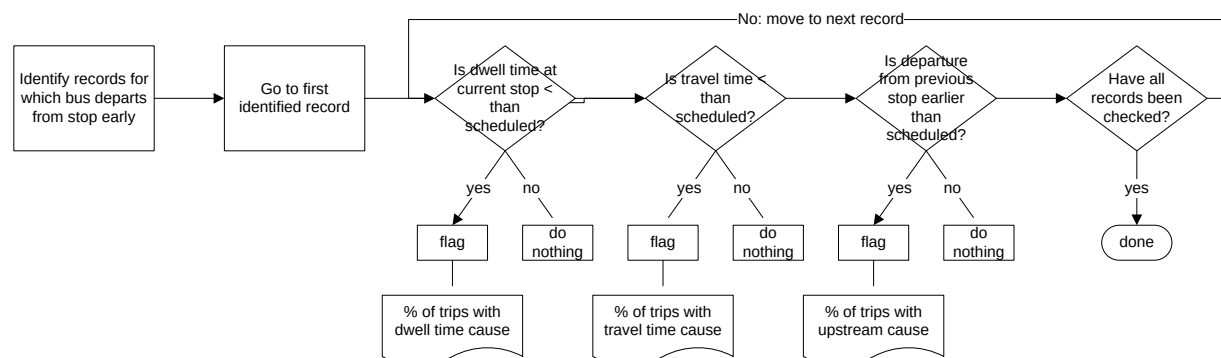


FIGURE 5 Method to calculate early departure cause statistics.

Applying the Methodology

The methodology calculates performance measures for each stop and generates a report that highlights stops where schedule adherence is not meeting identified thresholds. For each of these stops, cause statistics are calculated in order to assist in choosing an appropriate strategy to address the issue. These reports and causes statistics will be used in conjunction with other visualization and summarization aids to decide on an action.

SAMPLE APPLICATION

Grand River Transit (GRT) is a public transit service serving the cities of Waterloo, Kitchener, and Cambridge in Ontario, Canada. GRT serves approximately 15.8 million annual trips on over 60 routes, with a fleet of 208 buses. Ridership has grown by 53% over the past 8 years.

1 A total of 34 buses are outfitted with an AVL/APC system. Fifteen of these buses are permanently
2 assigned to GRT's iXpress route, which is a high-frequency, limited-stop express bus service running
3 through much of GRT's service area. The other 19 buses are rotated among the remaining bus
4 routes.

5
6 The AVL/APC system records stop level records consisting of information on arrival/departure
7 times, passenger on/off counts, odometer readings, and more. When the outfitted bus returns to the
8 garage at the end of its run, the recorded data is downloaded via a Wi-Fi link, matched with the
9 associated schedule data, and stored in a database for later analysis. For the purposes of
10 implementing this methodology, only timepoint level records from the database are used.

11
12 A four-month sample (September 1, 2008 to December 31, 2008) of data from a single GRT route is
13 used to demonstrate application of the methodology. The route is approximately 10.5 km in length
14 (one-way) and consists of thirty-six stops, of which six are timepoints (Figure 6). The schedule is
15 built at the timepoint level and dwell time is scheduled only at selected timepoints. Only one
16 direction (from Charles Street Terminal to Forest Glen Plaza) and time period (weekday p.m. period,
17 2:30 p.m. – 6:00 p.m.) is analyzed. There were approximately 50 observations at each timepoint
18 during the above period.
19

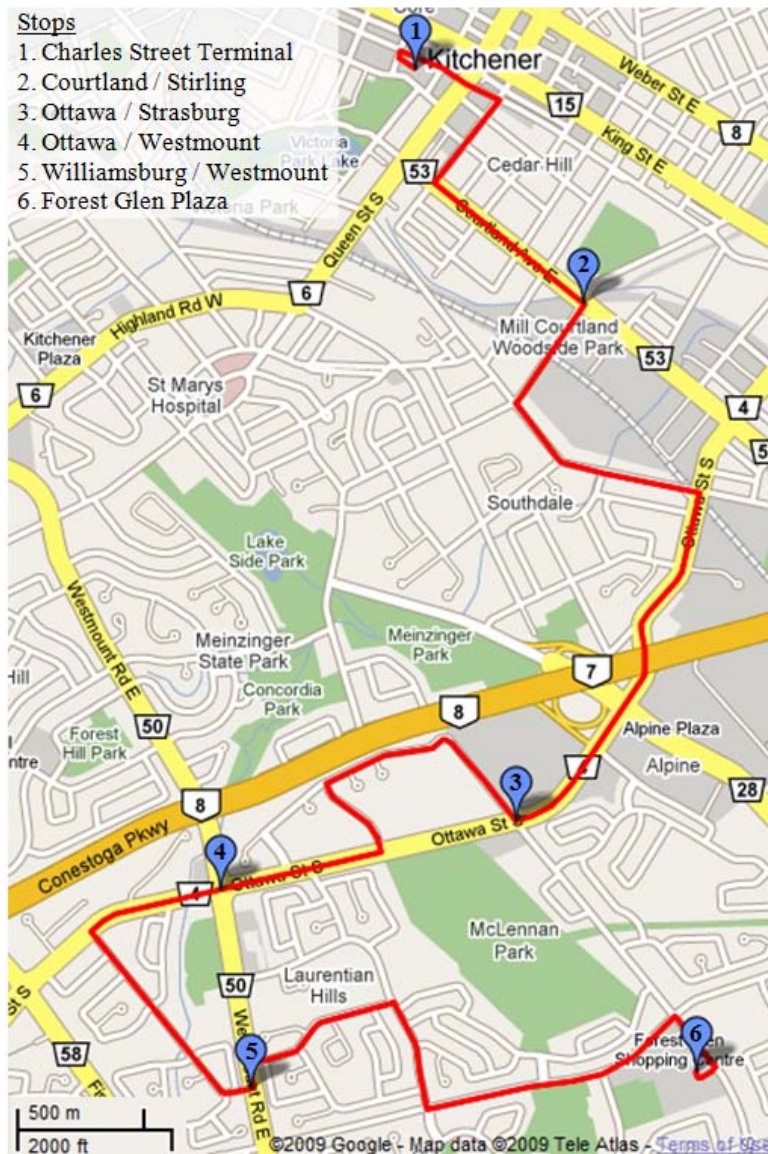


FIGURE 6 Grand River Transit, Route 3 (source: Google Maps, 2009).

The first step is to calculate performance measures at each stop. The TCQSM “on-time” definition was used, such that a bus must depart a stop early or leave a stop more than 5 minutes late to be considered early or late, respectively. However, the TCQSM suggests that leaving even one second early counts as early. Although this makes sense in a data-poor environment, AVL/APC systems record events to the nearest second, and this definition would count even small early departures (such as those caused by minor differences between the operators watch and the AVL/APC system time) as early. Given the precision of the data, it was felt that an early departure definition of “more than 30 seconds early” was more reasonable, and was used in this analysis. The TCQSM suggests that to maintain a LOS ‘C’ or better, no more than 15% of buses should be not “on-time”. Since early and late schedule adherence performance measures are being calculated separately, the recommended not “on-time” threshold has been split and a value of 7.5% is used for early and late. LOS is calculated at each stop based on half the TCQSM recommended not “on-time” percentages for late and early, respectively. The results are presented in Table 2.

TABLE 2 Schedule Adherence Performance Measure (Percent Late and Early)

<i>Stop Name</i>	<i>Late (LOS)</i>	<i>Early (LOS)</i>
<i>Charles Street Terminal</i>		0.0% (A)
<i>Courtland / Stirling</i>	6.4% (C)	0.0% (A)
<i>Ottawa / Strasbourg</i>	10.2% (E)	0.0% (A)
<i>Ottawa / Westmount</i>	4.0% (B)	14.0% (F)
<i>Williamsburg / Westmount</i>	16.0% (F)	6.0% (C)
<i>Forest Glen Plaza</i>	10.0% (D)	
Total	9.3% (D)	4.1% (B)

The performance measures presented in Table 2 indicate that two-thirds of the stops fail to meet the desired service standards due to departing early or arriving late too frequently. This implies schedule adherence is not meeting performance standards along the majority of the route, but could also hint at unreasonably high performance thresholds.

Cause statistics are calculated for each stop and presented in Table 3. Note that if a stop had been flagged for being both too frequently early and late, late cause statistics are recommended to be calculated since intervention strategies in this case should focus on fixing the late arrival problems – the problem of an early departure can be dealt with by (a) requiring the bus driver to hold for longer before departing the stop, or by (b) investigating strategies to reduce variation in the run time such that the stop is only flagged for a single performance measure.

TABLE 3 Cause Statistics at Flagged Stops

<i>Cause Statistics</i>	<i>Charles Street Terminal</i>	<i>Courtland / Stirling</i>	<i>Ottawa / Strasbourg</i>	<i>Ottawa / Westmount</i>	<i>Williamsburg / Westmount</i>	<i>Forest Glen Plaza</i>
Late Arrival						
<i>Travel time in prior segment longer than scheduled</i>			60%		88%	20%
<i>Dwell time at previous stop longer than scheduled</i>			0%		25%	0%
<i>Late arrival at previous stop</i>			100%		100%	100%
Early Departure						
<i>Dwell time at current stop shorter than scheduled</i>				0%		
<i>Travel time in prior segment less than scheduled</i>				100%		
<i>Early departure from previous stop</i>				25%		

We can begin by looking at the terminal at the end of the route, Forest Glen Plaza, which has been flagged for having late bus arrivals more than 7.5% of the time. The cause statistics reveal that when a bus is late, 20% of the time the travel time in the preceding segment is longer than scheduled. This means that in the other 80% of times that a bus is late, the scheduled travel time is sufficient. We also find that buses arriving late at Forest Glen Plaza arrived behind schedule at the previous stop in 100% of cases. Clearly, improving schedule adherence at this stop requires changes upstream.

Moving upstream to Williamsburg/Westmount, we find that this stop is also flagged for being too frequently late. Cause statistics are calculated to explain the late arrivals. The statistics indicate that late arrivals at this stop are a combination of insufficient travel time in the preceding section and arriving behind schedule at the previous stop, Ottawa/Westmount. Dwell time at the preceding stop is not generally a cause of late arrival at this stop. This suggests that some additional time added to the schedule in the preceding segment may be appropriate, however it is the combination of delay accrued in the preceding segment and delay accrued earlier in the route that is resulting in a late bus.

At Ottawa/Westmount, the bus is not flagged for arriving late. However, it is departing early 14% of the time. In all cases where the bus departs early, it has a quicker than scheduled travel time in the previous segment. The bus is not dwelling for less than scheduled at this stop (in fact, no dwell time is scheduled at this stop).

At Ottawa/Strasbourg, the bus is flagged for being too frequently late. The cause statistics indicate that when a bus is late, the scheduled travel time in the previous section is insufficient in slightly over half the cases. However, all buses that are late at Ottawa/Strasbourg also arrived behind schedule at the previous stop, Courtland/Stirling. As at Forest Glen Plaza and Williamsburg/Westmount, this indicates that the schedule upstream may need to be adjusted.

The Courtland/Stirling stop was found to meet performance standards.

The Charles Street Terminal was also found to meet performance standards. This is not surprising since there is little reason for schedule deviation at the beginning of the route.

The flagged stops in the above analysis indicate stops that are failing to meet performance standards, and the cause statistics point to where to look when developing a solution. This information will be used in conjunction with other visualization and summarization aids to determine an appropriate action.

Actions to be investigated could include schedule adjustments in the latter half of the route and/or options to decrease route variability (such as bus priority systems, a more consistent selection of bus drivers, or other strategies).

CONCLUSIONS

The above analysis can ultimately be conducted automatically for an entire network. However, the high number of stops that are being flagged for not meeting performance measures illustrate a challenge that will need to be addressed by transit agencies: The large volumes of data provided by AVL/APC systems really shines a magnifying glass on the transit network, and performance measures that appeared satisfactory when used in a data-poor environment may require adjustment to be useful in this new reality.

The proposed methodology will work best when failing to meet performance measures is the exception rather than the rule. Pushing a list of nearly every stop to a user is not particularly useful for highlighting problem areas and focusing attention on them. Several suggestions that can work in tandem to improve the situation include:

1. Re-evaluate existing performance standards to select thresholds that are more reasonable.
2. Begin the analysis at a route level. This will organize the data and present it more intuitively to transit agencies. It can begin with a list of routes that require attention. Specific routes can be “drilled-down” to find stops along the route that are not meeting performance standards. The stop can be “drilled-down” to find the cause statistics.
3. Develop measures to prioritize the routes and stops that fail to meet performance standards. Due to the rich datasets provided by AVL/APC data, it is possible to move beyond a measure of just the percentage of time a stop fails and also include factors such as the amount of customers affected by the failure. This should recognize that being late at a stop is not nearly

as much of a problem if no passenger is getting off the bus, and departing early is not a problem when it's from a bus stop where passengers aren't boarding.

The flagged stops and cause statistics provided by this methodology can be "pushed" to transit agencies and provide useful guidance. The information calculated by the methodology may not be used by planners to make decisions on its own, but will be used in conjunction with other visualization and summarization aids to make effective decisions with reduced effort and cost.

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