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Generating Transit Performance Measures with Archived Data

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Measuring the performance of a transit system is the first step toward efficient and proactive management. Since 1990, the use of performance measures for transportation planning and operations has gained a great deal of attention, particularly as transportation agencies are required to provide service with diminishing resources. In the past, it was very difficult and costly to collect comprehensive performance data. Thus, until recently, the transit industry has relied on limited, general, and aggregate measures for reporting performance to external funding and regulatory agencies. In Portland, Oregon, the local transit provider (TriMet) has developed a bus dispatch system (BDS) consisting of automatic vehicle location, communications, automatic passenger counters, and a central dispatch center. Most significantly, TriMet had the foresight to develop a system to archive all of its stop-level data, which are then available for conversion to performance indicators. It is demonstrated that there are powerful ways in which the data collected by the BDS can be converted into potentially valuable Transit Performance Measures (TPMs). These TPMs have been proposed in the past but were not implemented because of data limitations. It is envisioned that systematic use of TPMs can assist a transit agency in improving the quality and reliability of its service, leading to improvements for customers and operators alike.

The deployment of new surveillance, monitoring, and management systems as part of the nation's intelligent transportation systems (ITS) now enables us to monitor the performance of our transportation system in real time or in retrospect. Rather than relying on limited, aggregate measures with costly data collection efforts, we can now design, extract, and test specific, relevant, and dynamic measures of actual system performance. As a result, the use of performance measures for planning and operations management is gaining great attention nationwide.

Transit performance has a substantial impact on people's daily lives and on the cost of providing transit service. To quickly put the status of the U.S. transit industry in perspective, consider that in 1998 Americans made 5.4 billion passenger trips on buses. The total transit passenger volume remained essentially constant between 1960 and 1992, whereas operating costs nearly doubled during the same period. Transit ridership has been increasing since the mid-1990s, and this trend is expected to continue over the next 25 years (*1*). Currently, the U.S. public transportation fleet consists of 129,000 vehicles in active service, of which 58% are buses, 26% are demand-responsive vehicles, and the remaining 16% are light and heavy rail vehicles and other modes.

In the past, to measure transit performance, it was very difficult and costly to collect the necessary data. From the service planning perspective, a large number of people were initially needed to obtain a small amount of data. Today, a small number of people can obtain large amounts of data. There is a concern relating to how we can meaningfully analyze these data, creating information relevant for service planning and control (H. L. Levinson, personal communication, 2002).

Since 1990, the development and use of transit performance measures has gained increasing attention in the form of several key *Transit and Quality of Service Manual* (TCQSM) and the NCHRP *Performance-Based Planning Manual* (*2, 3*). The TCQSM provides transportation agencies with tools for measuring transit availability and quality of service from the passengers' point of view. The TCQSM contains a library of performance measures that will be used as a guide in this paper. The TCQSM provides the following definitions:

- Transit performance measure. A quantitative or qualitative factor used to evaluate a particular aspect of transit service.
- Quality of service. The overall measured or perceived performance of transit service from the passengers' point of view.
- Transit service measure. A quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. It is also known elsewhere as a measure of effectiveness.

The TCQSM emphasizes that the quality of transit service from the passengers' perspective depends on the availability and convenience of such service, which in turn depend on operating decisions made by transit agencies. As shown in Figure 1, Fielding (*4*) illustrated this by using a triangle with service input as the top and service output and service consumption as the base. In the mid-1980s, Fielding proposed the use of performance indicators for measuring an agency's progress toward meeting organizational objectives. Another point is relevant to the transit industry today. Fielding described the primary challenges to transit agencies as managerial ones. This still appears to be true more than 15 years later.

In the transit industry, transit performance measures (TPMs) are required at both the external and internal levels. For example, external TPMs are prepared by transit agencies as a condition of receiving federal funds. Transit agencies are required to report their performance annually in a standardized, aggregated format, including specific performance variables that are fed into federal reporting systems. These types of TPMs have been discussed at length in the literature over the past two decades. The objective of this paper is to describe how an archived database of bus dispatch system (BDS) data can be used to generate performance measures that should be prepared by transit agencies, to measure their own performance and help them to increase their service standards and effectiveness to the population they serve (*5*). This is a pilot research effort, and it is

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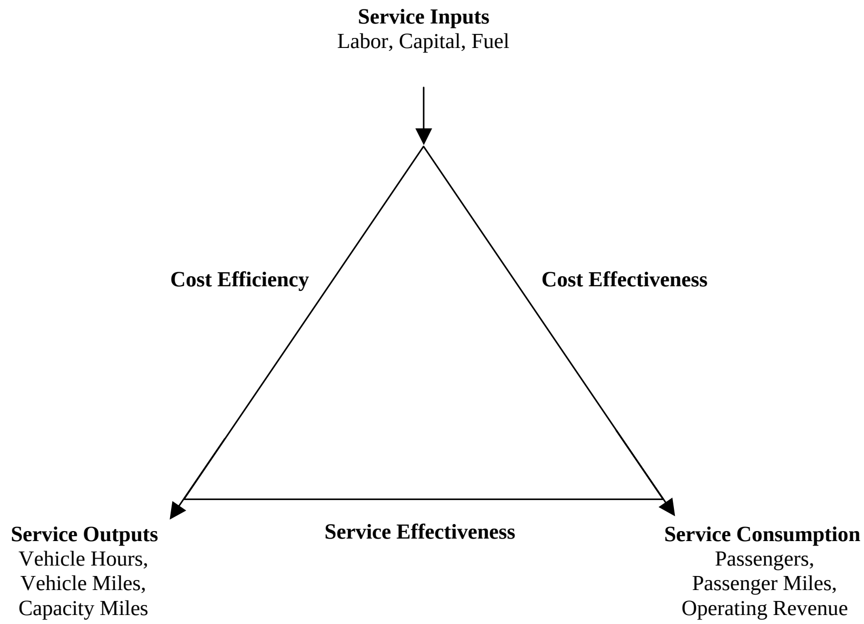


FIGURE 1 Framework for transit performance concepts.

hoped that these performance measures can be fed into the transit operations environment for use in revising schedules and operations strategies.

Provision of reliable service has been a basic transit service objective for more than a century (H. L. Levinson, personal communication, 2002). This highlights the importance of beginning a process for developing, testing, using, and incorporating performance measures into transit agencies' daily operations. Toward this end, this paper will concentrate on developing an experimental set of TPMs that can help transit operators understand and manage their systems more efficiently and effectively.

DATA

The Portland Tri-County Metropolitan Transportation District of Oregon (TriMet) is the local transit provider for the Portland, Oregon, metropolitan area. TriMet operates 62 million annual bus trips to serve an area of 592 mi^2 with a population of 1.2 million. TriMet operates approximately 700 vehicles on 98 routes with approximately 9,000 bus stops. TriMet has implemented a unique BDS that collects stop-level data as a part of its overall service control and management system. The main components of this system include

- Automatic vehicle location (AVL) using a satellite-based Global Positioning System;
- Voice and data communications via cellular and radio;
- Onboard computer and control head displaying schedule adherence to operators; detection and reporting of schedule and route deviations to dispatchers; and two-way, preprogrammed messaging between operator and dispatchers;
- Automatic passenger counters on most vehicles; and
- Dispatch center with computer-aided dispatch/AVL consoles (*6*).

The BDS records detailed operating information in real time and thereby enables the use of a variety of control actions. TriMet also archives stop-level BDS data that are available for later analysis on a systemwide basis. Each time the bus arrives at a stop, a new row of data is added to the database describing the particular stop. TriMet has geocoded each stop location, and using a geographic information system, a hypothetical 30-m (98-ft) circle is inscribed around each stop.

The BDS records the arrive time when the bus enters the stop circle and records the leave time when the bus departs the same circle. Table 1 shows a sample of the data obtained from TriMet BDS data for Route 72. When there is an unscheduled stop, an artificial 30-m stop circle is created. The type of stop is indicated in another field. If the door opens at the stop, this means that a dwell occurs, most likely to serve passengers boarding or alighting, or both. In these situations, the arrive time is overwritten by the actual time that the door opens, and the total dwell time (the time that the door remains open) is recorded in another field. Figure 2 shows the description of the stop circle and the distribution of different time intervals during a bus trip. All trips include a layover at the beginning and end of the trip, representing approximately 12% of the total service time. The nonlayover travel time (hatched area) will be separated from the layovers in this study.

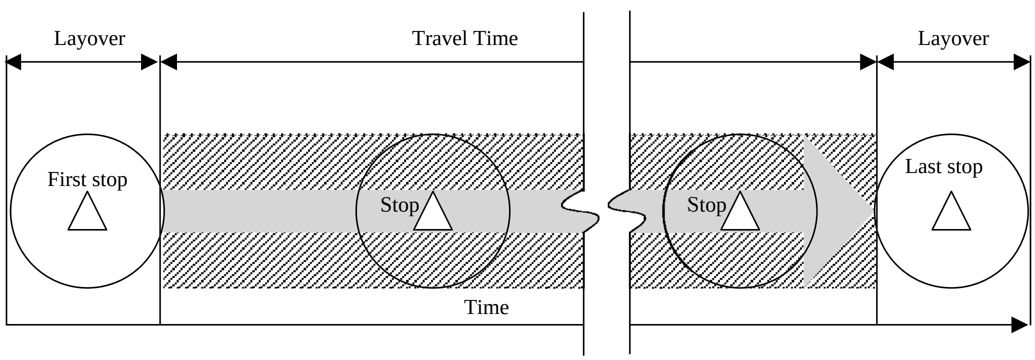
PERFORMANCE MEASURES

The *Performance-Based Planning Manual* recommends measures related to accessibility, mobility, and economic development across all modes. The recommended accessibility measures related to transit include the following (*3*):

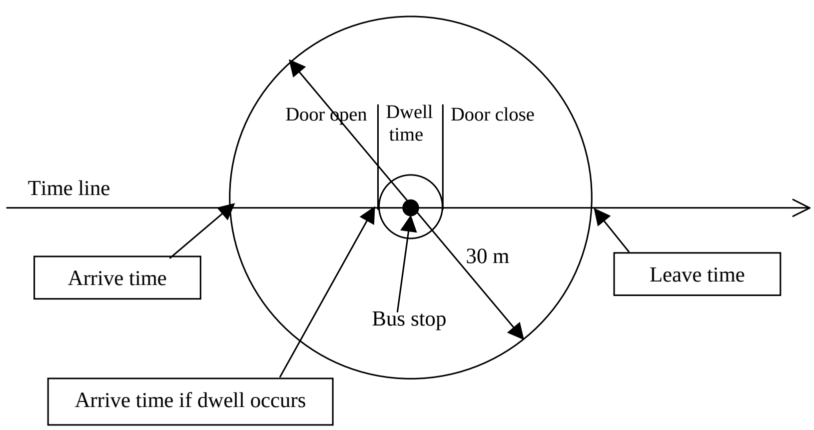
- Average travel time;
- Average trip length;
- Percentage of population within X miles of employment;
- Percentage of population that can reach services by transit, bicycle, or walking;

TABLE 1 Sample from TriMet Data for Route 72

Date	Train	Route	Leave_Time	Stop_Time	Arrive_Time	Dwell	Location_ID	Door	Lift	Ons	Offs
1-Apr-02	7244	72	6:34:40	6:32:00	6:32:54	53	8185	2	0	9	0
1-Apr-02	7244	72	6:35:12	6:32:25	6:34:48	12	4001	1	0	3	0
1-Apr-02	7244	72	6:35:20	6:32:39	6:35:16	0	11008	0	0	0	0
1-Apr-02	7244	72	6:36:04	6:33:30	6:35:58	0	7941	0	0	0	0
1-Apr-02	7244	72	6:36:44	6:34:04	6:36:18	12	7920	1	0	1	0
1-Apr-02	7244	72	6:37:10	6:34:47	6:37:06	0	7918	0	0	0	0
1-Apr-02	7244	72	6:37:20	6:35:10	6:37:16	0	7968	0	0	0	0
1-Apr-02	7244	72	6:37:34	6:35:33	6:37:28	0	8015	0	0	0	0
1-Apr-02	7244	72	6:38:44	6:36:12	6:38:26	4	8017	1	0	1	0
1-Apr-02	7244	72	6:38:48	6:36:12	6:38:46	0	8017	0	0	0	0
1-Apr-02	7244	72	6:39:26	6:36:49	6:39:14	0	7983	0	0	0	0
1-Apr-02	7244	72	6:39:42	6:37:02	6:39:16	10	7995	2	0	1	0
1-Apr-02	7244	72	6:39:52	6:37:16	6:39:46	0	7951	0	0	0	0
1-Apr-02	7244	72	6:40:04	6:37:38	6:40:02	0	7946	0	0	0	0
1-Apr-02	7244	72	6:40:50	6:38:04	6:40:14	17	7976	1	0	1	0
1-Apr-02	7244	72	6:40:56	6:38:12	6:40:56	0	7953	0	0	0	0
1-Apr-02	7244	72	6:41:22	6:38:41	6:41:14	0	7993	0	0	0	0
1-Apr-02	7244	72	6:41:52	6:39:00	6:41:24	15	7962	2	0	3	0
1-Apr-02	7244	72	6:42:36	6:39:41	6:42:08	8	7982	2	0	2	0
1-Apr-02	7244	72	6:43:16	6:40:26	6:42:58	6	7970	1	0	1	0
1-Apr-02	7244	72	6:43:52	6:40:57	6:43:30	9	7960	2	0	1	1
1-Apr-02	7244	72	6:44:06	6:41:26	6:44:02	0	8057	0	0	0	0
1-Apr-02	7244	72	6:44:42	6:41:56	6:44:16	9	8059	1	0	1	0
1-Apr-02	7244	72	6:44:54	6:42:23	6:44:52	0	8027	0	0	0	0



(a)



(b)

FIGURE 2 TriMet BDS System: (*a*) time distribution and (*b*) stop circle description.

- Percentage of transit-dependent population;
- Percentage of transfers between modes to be under X min and *n* ft;
- Transfer distance at passenger facility;
- Percentage of workforce that can reach worksite by transit within 1 h and with no more than two transfers;
- Percentage of population within access to transit service;
- Percentage of urban and rural areas with direct access to passenger rail and bus service;
- Access time to passenger facility;
- Route miles of transit service;
- Route spacing;
- Percentage of total transit trip time spent out of vehicle;
- Existence of information services and ticketing; and
- Availability of park and ride.

Mobility measures related to transit include the following (*2*):

- Percentage of on-time performance,
- Percentage of scheduled departures that do not leave within a specified time limit,
- Travel time contour,
- Minute variation in trip time,
- Fluctuations in traffic volumes,
- Average transfer time and delay,
- Dwell time at intermodal facilities,
- Proportion of persons delayed,
- In-vehicle travel time,
- Frequency of service,
- Average wait time to board transit, and
- Number of public transportation trips.

The one economic development measure related to transit includes the percentage of a region's unemployed or low-income citizens that cite transportation access as a principal barrier to seeking employment (*3*).

There are ideal transit performance measures for enhancing bus supervision strategies, to improve service reliability (*7*). In the past, it was more difficult to collect the necessary data. Now, however, it is relatively easy to use the BDS data already being collected to produce TPMs using the archived data. This paper demonstrates some of the TPMs that can be extracted from the BDS data at four different levels: system level, route level, segment level, and point level. These levels will be discussed in the following sections.

SYSTEM-LEVEL PERFORMANCE MEASURES

A system-level TPM can include all data reported in external reports pertaining to ridership, boardings, revenue, and expenditures for the overall system. In addition, route-level measures can be aggregated over the entire transit network. Therefore, we will not focus on system-level TPMs here.

ROUTE-LEVEL PERFORMANCE MEASURES

Figure 3 shows the time distribution between trip time and layover time for Route 12 during 1 selected weekday of service (January 24, 2002). Using archived BDS data, it is possible to create a daily report for each route. The control of layover time is crucial, for the operator and vehicle are not producing any revenue to the transit agency. As shown in the figure, for 1 day on Route 12, the layover time made up 9% of the total service time.

As shown in Table 2 for Route 14, some of the following information can be extracted readily (*2, 7*):

- Scheduled hours of service,
- Actual hours of service,
- Number of scheduled trips,
- Number of actual trips,
- Number of scheduled miles,
- Number of actual miles operated,
- Number of passengers carried,
- Total boardings and alightings,
- Average passenger load during each trip,
- Number of passengers per mile,

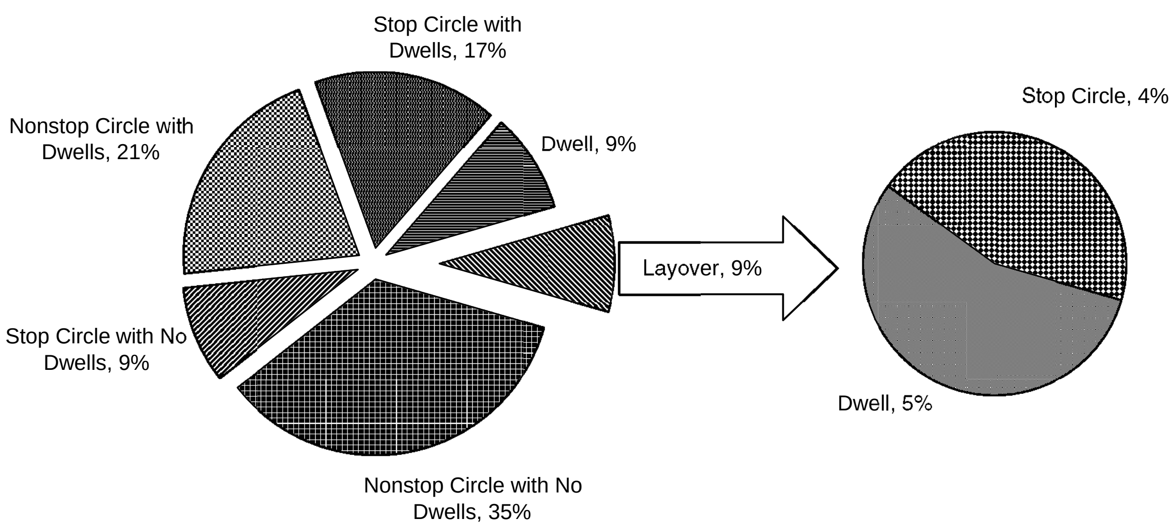


FIGURE 3 Time distribution for Route 12 during 1 weekday.

TABLE 2 Daily Report for Route 14

	Inbound			Outbound			Total		
	Hours	Minutes	Seconds	Hours	Minutes	Seconds	Hours	Minutes	Seconds
Hours of service	77	37	48	71	15	40	148	53	28
Scheduled hours of service	72	18	0	71	55	0	144	13	0
Number of scheduled trips		105			107			212	
Number of actual trips		103			104			207	
Number of scheduled miles		814.8			862.4			1,677.2	
Number of actual miles operated		843.6			806.8			1,650.3	
Number of passengers carried		3,772			4,165			7,937	
Total boardings and alightings		7,544			8,331			15,875	
Average passenger load during the trip		73.2			80.1			116.7	
Number of passengers per mile		8.9			10.3			14.8	
Average scheduled speed mile/hour		11.3			12.0			11.7	
Average speed mile/hour		10.9			11.3			11.1	
Number of operators		46			24			70	

- Average scheduled speed (mi/h),
- Average speed (mi/h), and
- Number of operators.

These data can also be compared for peak periods only, and from day to day, and, if archived systematically, they can be compared longitudinally over many years. As shown in Table 2, on Route 14 there were 103 inbound trips per day, and the average delay was 3 min per trip which resulted in total delay of approximately 5 h and 19 min. At the system level, TriMet operates approximately 98 routes in the Portland metropolitan area. A total of daily 531 h of lost time can be extrapolated from the data from the single route.

Table 3 shows a sample of a peak period analysis for Route 12, indicating the following variables:

- Actual trip time,
- Scheduled trip time,
- Actual layover time,
- Total dwell time,
- Total passenger boardings,
- Total passenger alightings, and
- Total number of trips.

Dwell time is another measure that can be analyzed at the system, route, or point level. Table 4 shows an example of route-level analysis of dwell time for Route 12 over 3 consecutive days, using the following measures:

- Total number of stops,
- Total dwell time and layovers,
- Total dwell time without layovers,
- Total layover time,
- Total number of dwells and layovers,
- Total number of dwells without layovers,
- Average dwell time,
- Total number of passengers served,
- Total number of passenger boardings,
- Total number of passenger alightings,
- Total number of lift use,
- Total dwell time with lift used,
- Total number of dwells with passenger movement,

TABLE 3 Peak Period Analysis for Route 12

	Measures	Hours	Minutes	Seconds
Inbound trips a.m. peak	Actual trip time	14	47	46
	Scheduled trip time	14	59	0
	Actual layover	3	10	12
	Total dwell time	1	55	24
	Total passenger boardings		747	
	Total passenger alightings		471	
	Total number of trips		18	
Outbound trips p.m. peak	Actual trip time	17	28	10
	Scheduled trip time	16	15	0
	Actual layover	0	24	14
	Total dwell time	4	2	28
	Total passenger boardings		712	
	Total passenger alightings		973	
	Total number of trips		16	

TABLE 4 Dwell Time Analysis for Route 12

	January 23, 2002	January 24, 2002	January 25, 2002	Average
Total number of stops	10,756	11,268	11,254	11,093
Total dwell time and layovers in seconds	115,664	112,384	118,229	115,426
Total dwell time without layovers in seconds	54,393	52,964	57,565	54,974
Total layover time	61,271	59,420	60,664	60,452
Total number of dwells and layovers	4,058	4,171	4,128	4,119
Total number of dwells without layovers	3,850	3,958	3,911	3,906
Average dwell time in seconds	14.1	13.4	14.7	14.1
Total number of passengers served	10,101	10,235	9,513	9,950
Total number of passenger boardings	5,186	5,268	4,960	5,138
Total number of passenger alightings	4,915	4,967	4,553	4,812
Total number of lift use	12.0	8.0	14.0	11.3
Total dwell time with lift used in seconds	1,217	609	1,214	1,013
Total number of dwells with passenger movement	3,327	3,368	3,065	3,253
Total dwell time with passenger movement in seconds	49,351	47,936	46,675	47,987
Average dwell time with passenger movement in seconds	14.8	14.2	15.2	14.8
Total number of dwells without passenger movement	523	590	846	653
Total dwell time without passenger movement in seconds	5,042	5,028	10,890	6,987
Average dwell time without passenger movement in seconds	9.6	8.5	12.9	10.7

- Total dwell time with passenger movement,
- Average dwell time with passenger movement,
- Total number of dwells without passenger movement,
- Total dwell time without passenger movement, and
- Average dwell time without passenger movement.

The TCQSM discusses transit availability as a primary means of measuring quality of service. As one example of assessing transit availability in a highly populated area, Figure 4 consists of a sample census tract (area of 1.5 mi^2, year 2000 population of 7,900) with a 1,300-ft (0.25-mi) buffer around each bus stop, representing a walking distance in the studied neighborhood. A simple area calculation indicates that only 38% of the area of the tract is within easy walking distance of the bus route. A systematic indication like this can be used to add more service to areas exhibiting population growth or demographic shifts. Characteristics such as household income (not yet available from the 2000 census) can also be used to determine accessibility across income strata, and they can be applied to the entire system when determining how to add appropriate service in poorly served areas.

Transit operating speed and travel time influence service attractiveness, costs, and efficiency. They also provide important descriptions of system performance for use in the transportation planning process (*7*). Average speed and travel time are critical measures from both the passenger and agency perspectives. It is possible to examine average speed in several ways. Figure 5 shows trajectories for 14 inbound trips on Route 14 on 1 day. The trajectories are plotted in a time-space plane where the *x*-axis is time and the *y*-axis is distance, so the slope of the trajectory at any point is the vehicle speed. It is possible to see how the speed of each vehicle varies with time and distance. Average speed can be examined across the entire day as well as by comparing the average peak hour transit speed with off-peak speed (*2, 7, 8*). Figure 6 shows the average speed for 1 day for both inbound and outbound Route 14.

As shown in Figure 6, the average speed on 1 day was 27.8 km/h (17.3 mph) for Route 14 inbound trips and 25.6 km/h (15.9 mph) for outbound trips. TriMet divides the service day into five periods: early morning (before 6:00 a.m.), morning peak (6:00 to 9:00 a.m.), midday (9:00 a.m. to 3:00 p.m.), evening peak (3:00 to 6:00 p.m.), and night (after 6:00 p.m.). Average speeds are shown for each of these periods. A similar plot can be developed at a higher aggregated level to include the entire transit system serving the entire metropolitan area or at lower levels for each individual route or key route segments.

Another valuable measure of transit reliability is schedule adherence. This measure translates to customer perception and is also useful for assessing operator performance and for identifying necessary schedule modifications. The use of the archived BDS data makes it possible to observe the relationship between scheduled and actual departure time at each stop. Figure 7 shows a sample of this analysis for 1 day on Route 14. An analysis of the data shown in Figure 7 reveals that the bus arrived on time 22.2% of the time, arrived late 50.6% of the time, and arrived early 27.2 % of the time.

Excess dwell time, surges in passenger movements, lift use, and traffic delays are the main reasons a bus would arrive late at the next stop. Figure 8 shows a graph of passenger movements and dwell time for 1 day on outbound Route 14, including passenger movements and dwell times according to location. In addition, the second part of the figure shows the total passenger movement at each

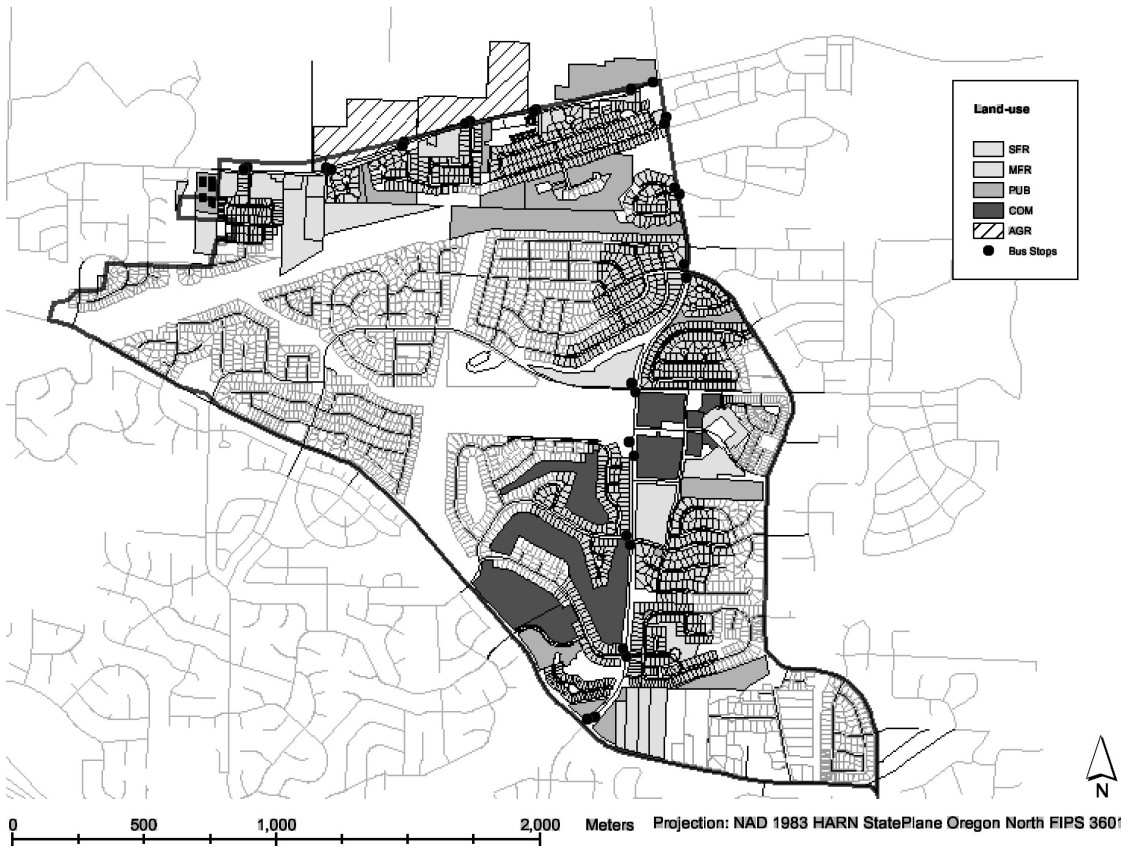


FIGURE 4 High population census tract with Route 67 service.

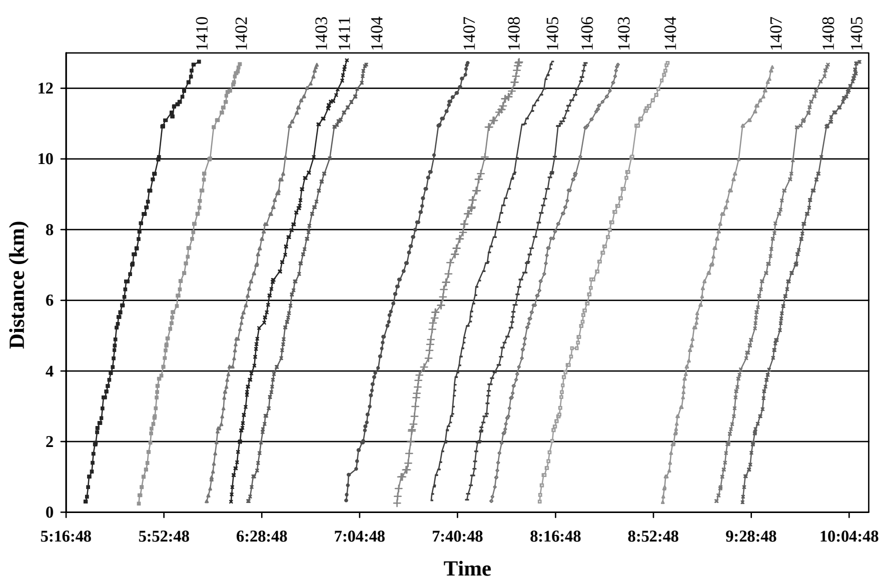


FIGURE 5 Cumulative distance versus time for 14 trips.

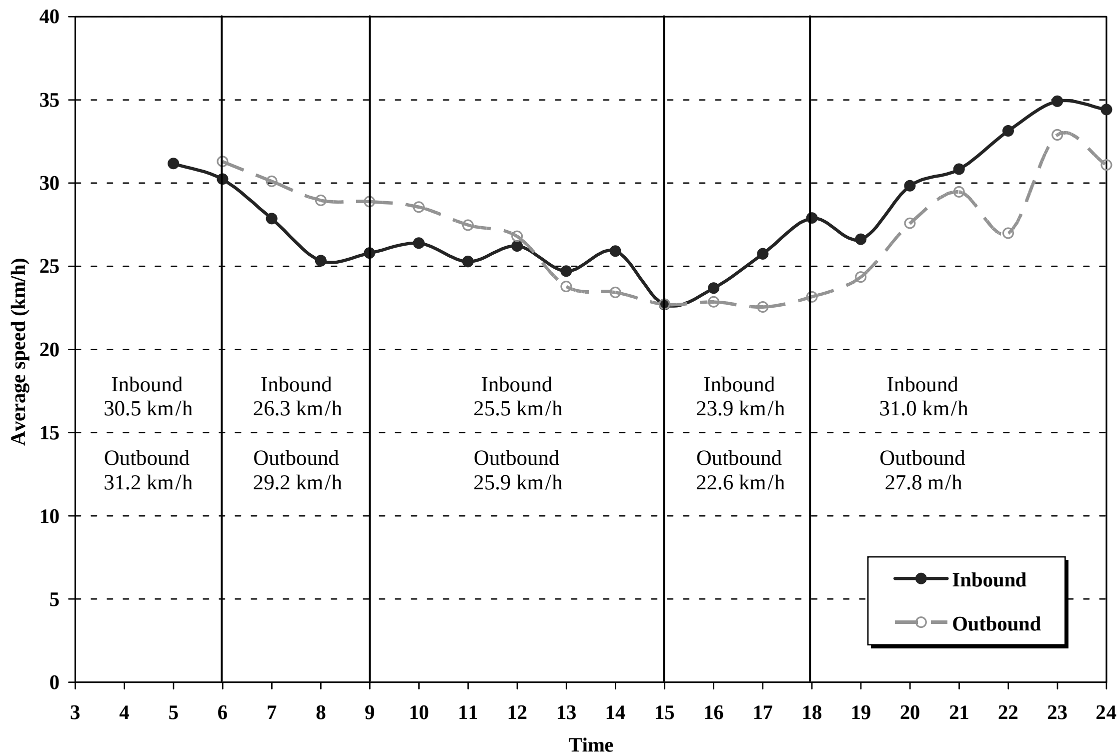


FIGURE 6 Average speed during 1 day of service on Route 14.

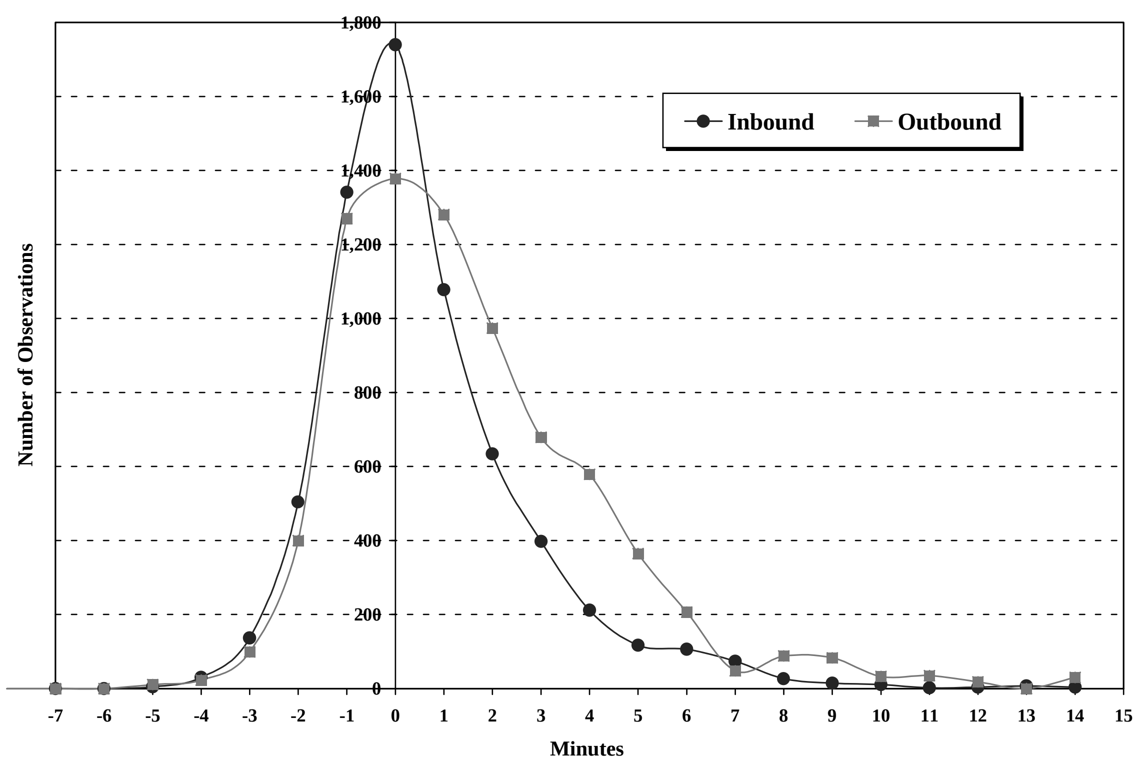


FIGURE 7 Schedule adherence during 1 day of service on Route 14.

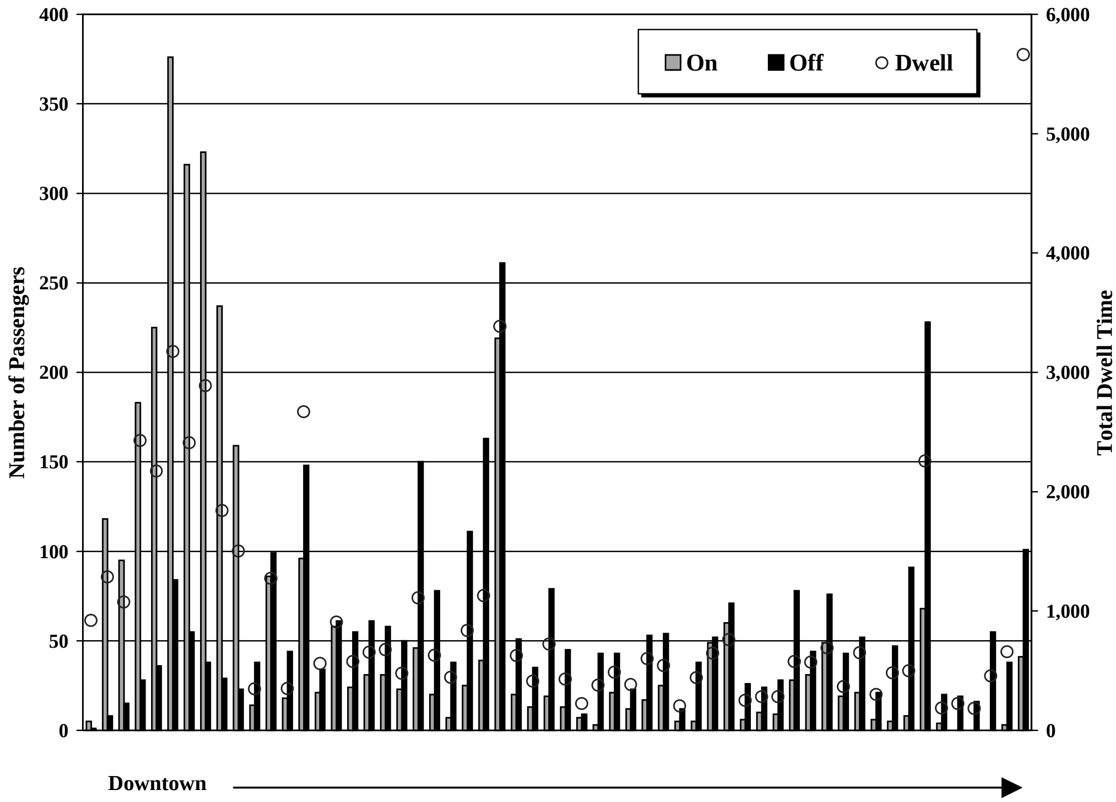


FIGURE 8 Total dwell time and passenger movement during 1 day of outbound trips on Route 14.

stop (*7*). Note that the layovers at the ends of the route were excluded from the graphs.

SEGMENT-LEVEL PERFORMANCE MEASURES

Many route-level TPMs can also be applied to key segments of important routes that may require analytical focus. As one example, a portion of Route 12 has been analyzed to investigate the population that is being served in a particular area. Figure 9 shows a route segment map accompanied by a histogram for the land use around this particular route segment, along with the characterization of passenger movement at each stop. From this analysis, it is shown that the highest passenger movement occurred around transfer points with the highest proportion of commercial land around them. These transfer points are locations that deserve additional attention, particularly if timed transfer policies are desired.

POINT-LEVEL PERFORMANCE MEASURES

From the customer's standpoint, it is often the point-level performance that is first perceived. If one takes a system perspective, it is also clear that small delays at individual stops are difficult to make up, particularly in congested traffic conditions. For any particular point on a bus route, it would be possible to report the following (*7*):

- Number of scheduled trips passing this point,
- Number of actual trips,
- Percentage of actual and scheduled trips,
- Number of passengers carried,
- For a maximum 30-min interval of loading time,
- Time interval,
- Average deviation,
- Standard deviation,
- Number of vehicles passing,
- Number of passengers moving, and
- Number of passengers per vehicle.

To examine on-time performance at a significant stop, one can see that Figure 10 shows a scheduled cumulative bus arrival function for the stop at Hawthorne and 39th (which is also a time point). The *x*-axis is time, and the *y*-axis records the vehicle number and its scheduled arrival time. Also shown is a cumulative arrival function for actual vehicle arrivals. The value of presenting the data in this fashion is that it is possible to *see* the vehicular delay as the difference between the two step-functions. Another benefit is that it is possible to see the scheduled and actual headways from the perspective of passengers at the particular stop. Also shown in the figure are the total passenger movements associated with each vehicle. From this figure, the effects of bus bunching are extremely clear—that when there are two buses with very short headways, the second bus serves almost no passengers.

From this type of analysis, it would be possible to determine the percentage of buses that arrived on time during an entire service day, as well as to compare overall on-time performance with that during the peak periods. Doing so could lead to better decision-making and prioritization capabilities for stop-level improvements such as stop consolidations, relocations, boarding area improvements, queue jump lanes, and traffic signal priority.

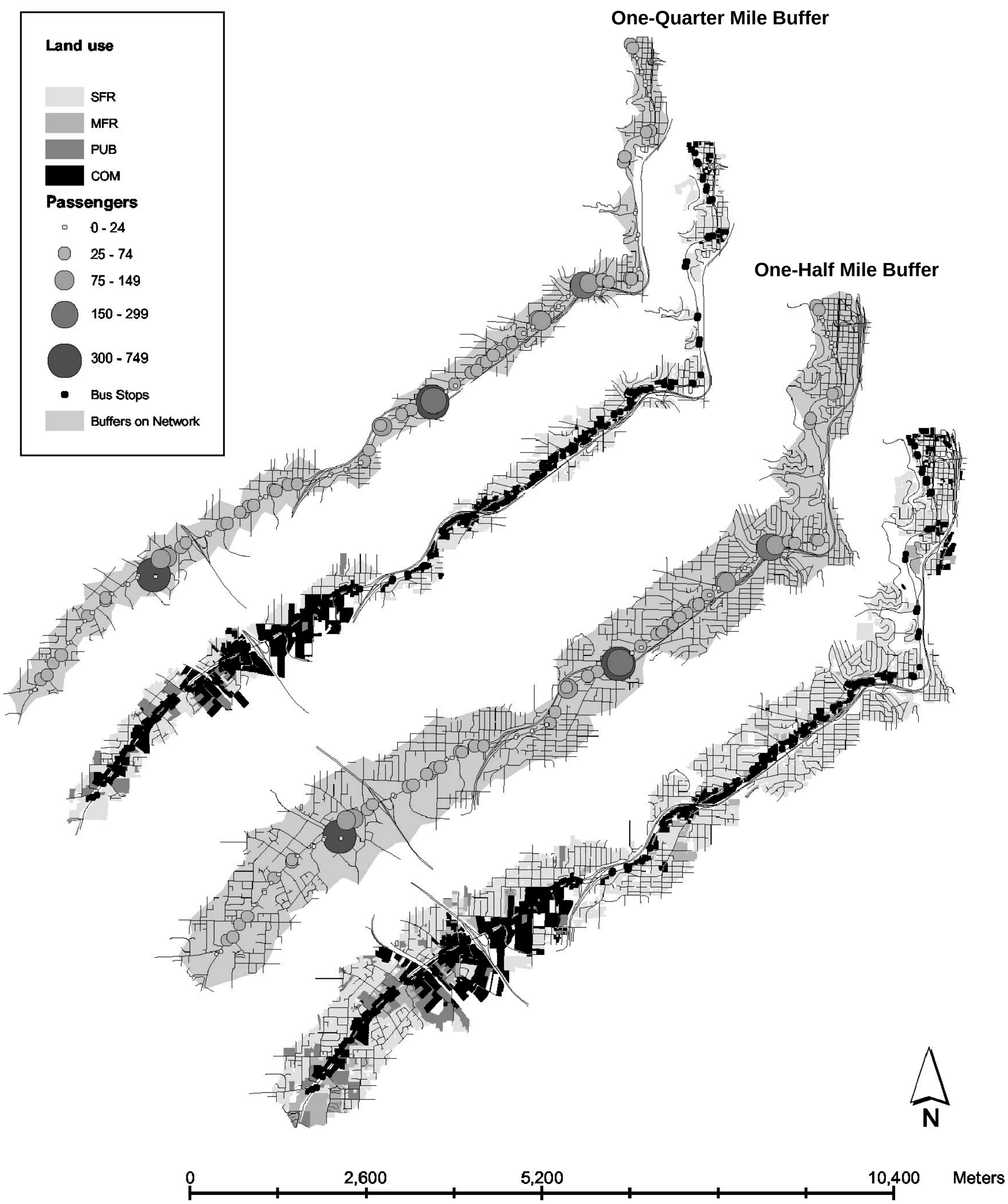


FIGURE 9 Segment from Route 12 with land use around stops.

CONCLUSIONS

Actually measuring the performance of a transit system is the first step toward efficient and proactive management. In recent years, the use of performance measures for transportation planning and operations has gained a great deal of attention, particularly as transportation agencies are required to provide service with diminishing resources. In the past, it was very difficult and costly to collect comprehensive performance data. Thus, until recently, the transit industry has relied on few, general, and aggregate measures for reporting performance to external funding and regulatory agencies. It was difficult to actually tie these measures to service standards and nearly impossible to track the benefits of individual service improvements.

On the basis of a review of the recent literature, a sampling of transit performance measures has been developed. This experiment has shown that by using real archived data from a BDS, it is possible to obtain information assessing the functionality of the transit system. The tools shown here will help to determine the best performance measures for use by various entities within the transit organization. With simple, directly measurable variables, it is possible to compare performance from day to day and from route to route.

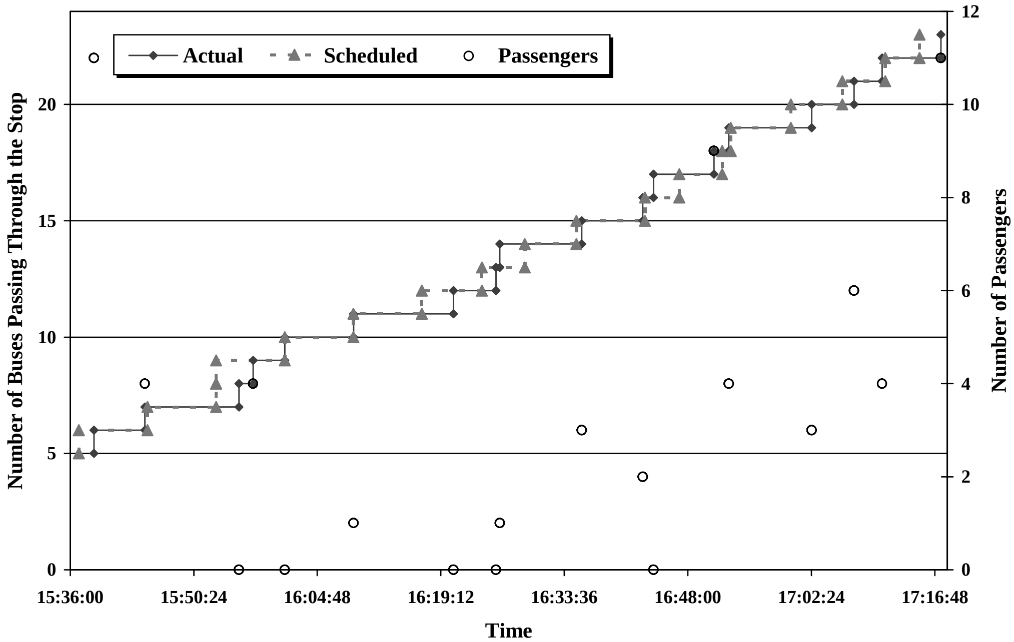


FIGURE 10 On-time performance at stop at Hawthorne and 39th Avenue.

Most significantly, TriMet had the foresight to develop a system to archive all of its stop-level data, which are then available for conversion to performance indicators. This paper demonstrates the powerful ways that the data collected by the BDS can be converted into potentially valuable TPMs. These TPMs have been proposed in the past but were not implemented owing to data limitations. It is envisioned that systematic use of TPMs can assist a transit agency in improving the quality and reliability of its service, leading to improvements for customers and operators alike.

The value of such an ongoing generator of performance data is that it eliminates the need to make assumptions and estimates about time-varying behavior that find their way into aggregate performance metrics. The TriMet BDS data are being archived every day, so long-term averages can be calculated rather than estimated. The next step in this research will be to introduce these and other performance measures to TriMet and other transit properties and to test their usefulness to planners, schedulers, and dispatchers. It is conceivable that some of these measures could be generated automatically each day for later analysis and research. By getting performance information into the hands of the transit agency employees, and providing them with tools to help them perform their jobs more effectively, it is likely that an agency will be able to see measurable improvements in a relatively short time.

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