Evaluating Traffic Signal Improvements Using Archived Transit AVL Data

THE OBJECTIVE OF THIS FEATURE IS TO ASSESS A NEW EVALUATION METHODOLOGY FOR VERIFICATION OF BENEFITS RESULTING FROM TRAFFIC SIGNAL TIMING IMPROVEMENTS AND SIGNAL COORDINATION USING ROUTINELY ARCHIVED, AUTOMATICALLY COLLECTED TRAVEL TIME DATA.

BY ROBERT L. BERTINI, PH.D., P.E., J. CAMERON GLASGOW AND JIM PETERS, P.E.

INTRODUCTION

Traffic signal coordination and timing improvements are proven methods for reducing delay on arterial roadways. The costs for these improvements generally are moderate and the benefits include reduced travel time (analogously, speed is increased and delay is reduced), improved air quality, reduced fuel consumption and, possibly, enhanced safety.[1]

Drivers generally are satisfied when they experience improved efficiency on arterial roadways. These improvements also can improve transit operations by reducing run times and delay imposed on transit users at signalized intersections throughout a corridor.

To measure the impact of congestion reduction measures such as signal coordination, traffic engineers commonly dispatch one or more probe vehicles into the traffic stream to record a series of travel time and delay data on multiple runs along a corridor, both before and after the strategy is implemented.[2] The before and after data are recorded and analyzed and mean travel time values are computed and compared so that the improvements can be quantified. These improvements typically are measured in terms of savings in vehicle-hours traveled, vehicle-miles (kilometers) traveled, tons of emissions and gallons (liters) of fuel.

Costs are associated with employing the probe vehicle method (in contrast to not using this method), because a driver plus an observer must physically collect the data in a vehicle, often assisted by software and/or data collection devices. Data collection typically occurs for more than one day and for several hours each day. Therefore, the method includes labor costs for data collection time as well as vehicle operating costs during the experiment.[3]

This study explores whether there is a feasible, more cost-effective and less time-consuming method to measure the same data and achieve similar results without deploying dedicated probe vehicles.

One alternative to dedicated probe-based data collection and analysis is to use vehicles that already are in the traffic stream and equipped with automatic vehicle location (AVL) technology. With the nationwide deployment of intelligent transportation systems (ITS), an increasing number of agencies are equipping their vehicle fleets with AVL for real-time operations and management purposes.

In Portland, OR, USA, the Tri-County Metropolitan Transportation District of Oregon (TriMet) has implemented a unique bus dispatch system (BDS) on more than 600 buses as part of its overall operations control system. The main components of the BDS include:[4]

- AVL using a satellite-based global positioning system (GPS);
- Wireless voice and data communications between vehicles and the dispatch center;
- An on-board computer and control head displaying schedule adherence to operators; detection and reporting of schedule and route deviations to dispatchers; and two-way, pre-programmed messaging between operator and dispatchers;
- Automatic passenger counters on most vehicles; and
- A dispatch center with computer-aided dispatch AVL consoles.

Most existing transit AVL systems are used for managing transit operations in real time. TriMet's BDS is unique in the United States. It records detailed operating information in real time and routinely archives all stop-level BDS data for all buses on all routes every day. These ubiquitous data are available for later analysis on a system-wide basis.[5]

Using the archived BDS data, actual bus trip times with and without dwell times can be measured both before and after the implementation of a specific traffic improvement measure. It should be noted that the TriMet data generally are available at no cost for research purposes.

The purpose of this experiment was to take advantage of a fortuitous situation in which archived signal coordination before/after probe vehicle data were available for a particular corridor that happened to coincide with a portion of a TriMet bus route. TriMet archived AVL data also were available for the same section of roadway at no cost to the researchers for the same days and times as the probe vehicle data. Therefore, the study was opportunistic in the sense that the experiment was not designed *a priori*, but conveniently available historical data for testing this concept were relied upon *a posteriori*.

This feature compares the analysis of probe vehicle travel time data with archived transit AVL data from the same days and times at one site. The test site was a segment of Powell Boulevard in the City of Gresham, OR, USA, between the intersections of NE Birdsdale Avenue and SW Walters Road, as shown in Figure 1.

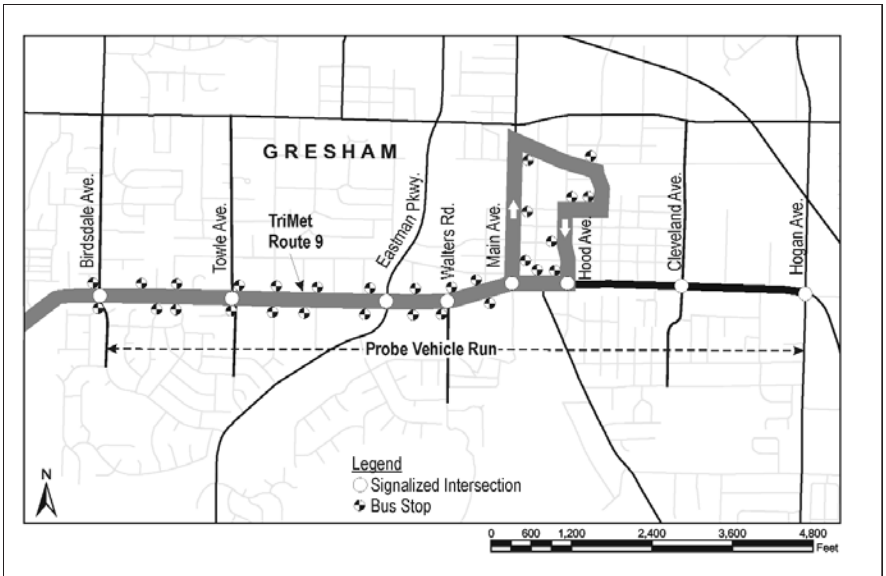

Figure 1. Portland, OR, USA, site map.

In 2000, the City of Gresham implemented a 2-mile (3.2-kilometer) traffic signal improvement project along Powell Boulevard. TriMet operates its Route 9 service on the western 1-mile (1.6-kilometer) segment of the corridor. Based on data availability, this portion of the arterial was selected for the analysis.

DATA

As part of the validation process for the signal coordination project, probe vehicle travel time and delay data were recorded by the City of Gresham between 7:00 a.m. and 9:00 a.m. (morning peak) and between 4:00 p.m. and 6:00 p.m. (evening peak) on Wednesday, June 14, 2000 (before) and Tuesday, September 12, 2000 (after).

Table 1. Summary of probe vehicle and transit AVL runs.

	Mean speed (mph)	Standard deviation of speed (mph)	Need runs	Have runs	Mean travel time (sec.)	Mean speed (mph)	Standard deviation of speed (mph)	Need runs	Have runs	Mean travel time (sec.)
a.m.	**Eastbound probe vehicle**					**Westbound probe vehicle**				
Before	27.7	2.99	6	8	117	23.2	3.18	7	7	151
After	27.6	3.66	8	8	120	26.7	3.28	7	8	126
Savings					–3 percent					17 percent
p.m.	**Eastbound probe vehicle**					**Westbound probe vehicle**				
Before	21.3	4.49	11	7	172	19.9	2.13	4	6	178
After	21.5	4.48	11	7	169	27.4	6.27	19	7	130
Savings					2 percent					27 percent
a.m.	**Eastbound hypothetical bus**					**Westbound hypothetical bus**				
Before	29.8	3.07	6	6	133	30.3	4.10	10	14	131
After	30.2	1.10	3	5	131	31.7	2.97	6	6	125
Savings					2 percent					5 percent
p.m.	**Eastbound hypothetical bus**					**Westbound hypothetical bus**				
Before	27.5	5.63	16	17	144	27.5	2.57	5	5	144
After	31.7	3.72	9	10	125	28.3	2.21	5	6	140
Savings					13 percent					3 percent

As shown in Table 1, the archived data set included a total of 58 runs, with 6 to 8 travel time runs in each direction during each peak period on each day. The cost to perform these travel time runs was not inconsequential. The mean probe vehicle directional headway was approximately 16 minutes. In addition to intersection spacing, arrival times and departure times for each intersection were recorded, as well as queue position, if applicable.

The results from the probe vehicle travel time runs were used in the year 2000 to demonstrate to the City of Gresham that the traffic signal improvements were beneficial. These data were available for this study based on the generosity of the City of Gresham.

Because this study was performed *a posteriori*, it was not possible to design our own experiment. To check the validity of the probe vehicle data, a sample size analysis was conducted.[6,7] The estimation of sample size n is based on specifying probability statements about the level of confidence in the acceptable error. The permitted error E is expressed as:

$$E = Z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} \quad (1)$$

where
n = minimum sample size required
$Z_{\alpha/2}$ = standard normal for a confidence level of $1 - \alpha$
σ = standard deviation of population
E = maximum estimation error

For small sample sizes, a t-distribution with $n - 1$ degrees of freedom can be used, for the same confidence level $(1 - \alpha)100$ percent, resulting in a new equation for n:[8]

$$n = \left[\frac{t_\alpha \cdot s}{E}\right]^2 \quad (2)$$

where
s = standard deviation of random sample
t_α = t-distribution statistic
E = maximum estimation error

The permitted estimation error for travel time analysis is selected based on the study purpose. For traffic operations, trend analysis, or economic studies, ±2 miles per hour (mph) to ±4 mph is acceptable.[9] For this study, a 95-percent confidence interval ($\alpha = 0.05$) and a maximum estimation error of ±3 mph were selected based on accepted practice.

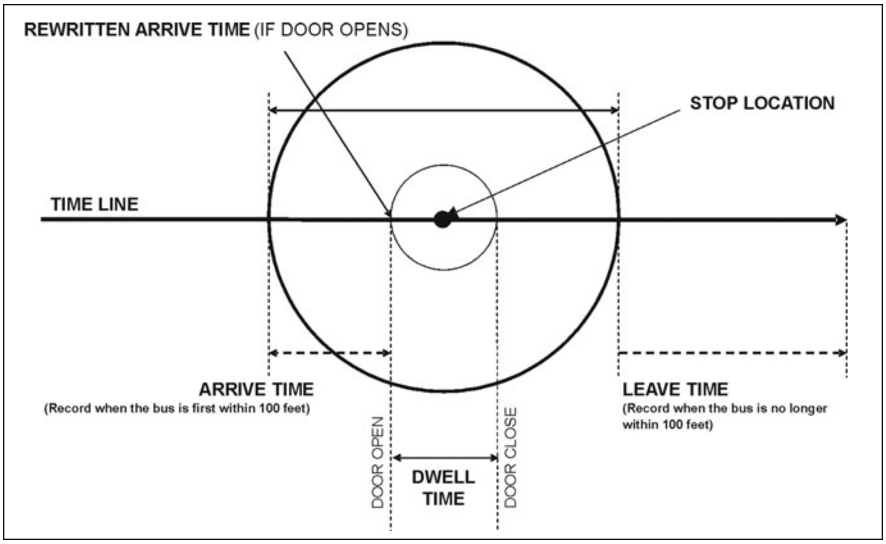

Figure 2. Stop circle.

Because the t_α-statistic is a function of n, an iterative procedure is needed to solve for n. For example, for the eastbound a.m. before scenario, Table 1 shows that data were given from eight probe vehicle runs with a mean velocity of 27.7 mph. The standard deviation of the corridor speed from this data set is 2.99 mph. Therefore, a total of six runs would be needed to ensure a maximum estimation error of ±3 mph at a 95-percent confidence level.

Recalling that the probe vehicle travel time runs were not part of this experiment, and that additional probe vehicle runs could not be dispatched for the days analyzed, there was interest in the sufficiency of the travel time runs in comparison with the sufficiency of the transit AVL data. As shown in Table 1, there are sufficient probe vehicle runs for the a.m. peak. However, for the p.m. peak, only one scenario (westbound before) satisfies the sample size analysis described above.

As a result of close collaboration with the City of Gresham and TriMet, a corridor was found for which archived probe vehicle and transit AVL data existed simultaneously. Although we were not able to design our experiment, archived TriMet BDS data were retrieved for the same days and time periods as described above.

On Route 9, TriMet operates 80 eastbound trips per day, with 15 to 20 minute headways in the morning peak and 12 to 18 minute headways in the afternoon peak. A total of 76 westbound trips are provided per day, with morning peak headways of 9 to 24 minutes and afternoon peak headways of 14 to 30 minutes. There is a parallel light rail transit (LRT) line in the vicinity of the study corridor. It should be noted that typical TriMet headways would be much shorter in the absence of LRT. There are no crossing bus routes in the study corridor.

TriMet has geo-coded each stop location using geographic information systems. Therefore, the distance between each successive stop can be calculated easily. The GPS-equipped buses calculate their position every second with a spatial accuracy of ±10 meters or better. Successive positions are weeded and corrected by odometer input.

As shown in Figure 2, when the bus is within 30 meters of the known location of the next bus stop (which is stored on a data card along with the schedule), an arrival time is recorded. When the bus is no longer within 30 meters of the known bus stop location, a departure time is recorded. If the bus stops and the door opens to serve passengers, a dwell is recorded and the arrival time is overwritten by the time when the door opens.

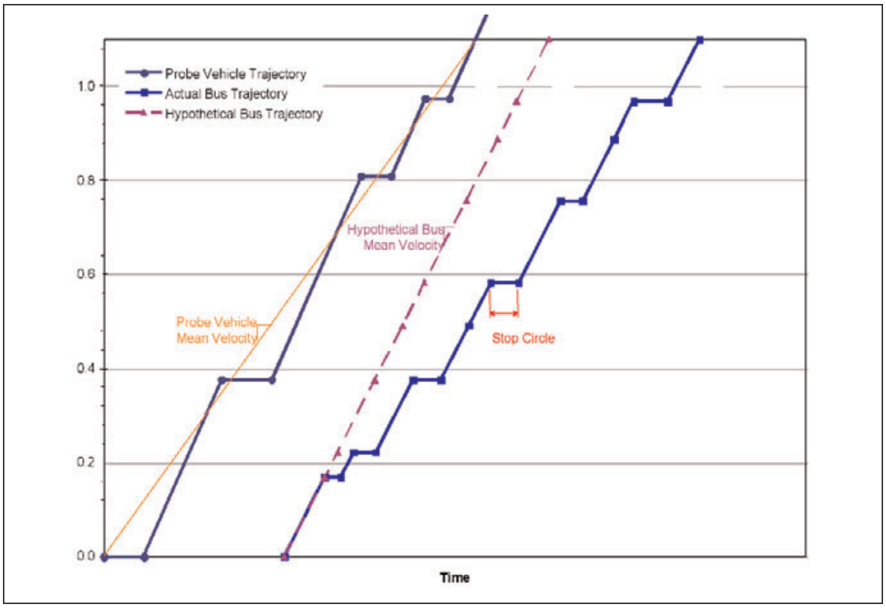

Figure 3. Time-space diagram.

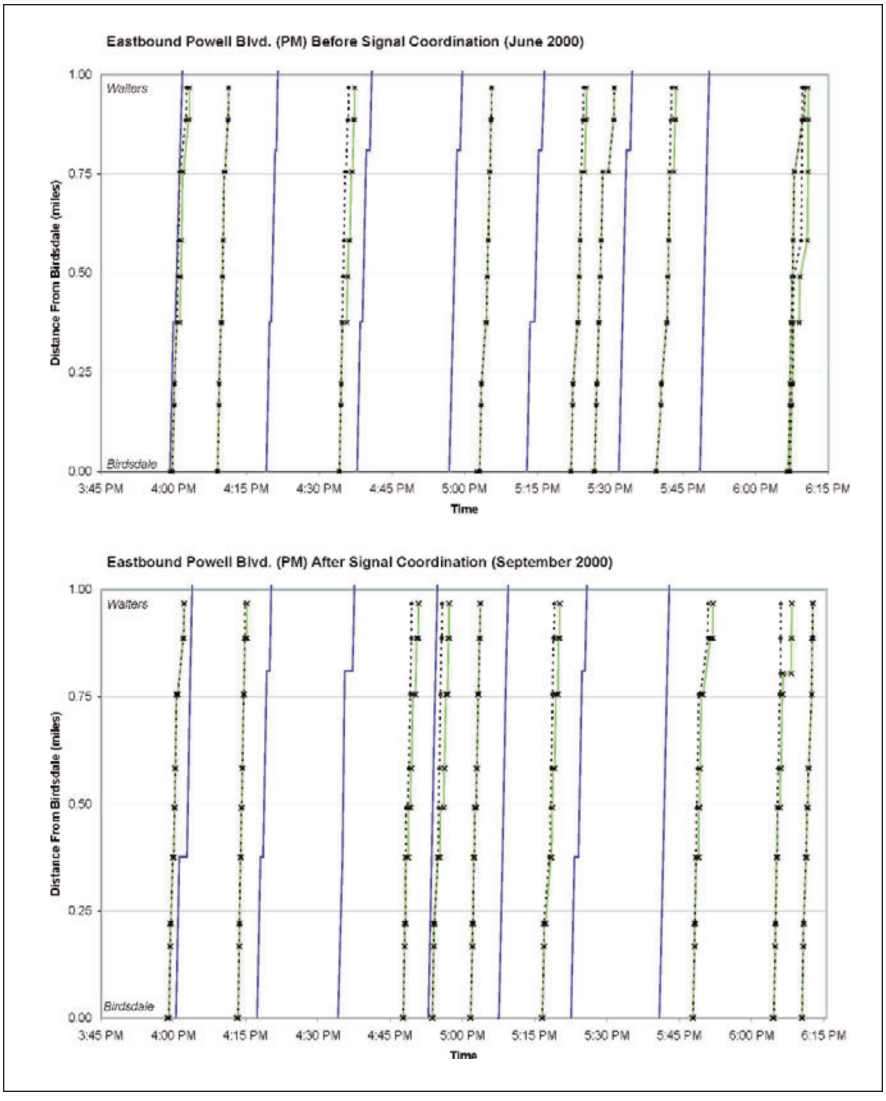

Figure 4. Eastbound p.m. before and after time-space diagrams.

Dwell time (in seconds) is recorded as the total time that the door remains open.

The system also records the number of boarding and alighting passengers (through both doors). Therefore, it is possible to separate the activity of buses between stops from the deceleration and acceleration associated with stopping to serve passengers.

As shown in Figure 3, the probe vehicle and BDS data can be plotted in the form of a time-space diagram for the study corridor. With time on the *x*-axis and distance along the study corridor on the *y*-axis, Figure 3 shows a sample probe vehicle trajectory. The speed between intersections is the slope of the trajectory; the times it was stopped are shown as horizontal line segments.

A bus trajectory also is shown in Figure 3. Its stop circle activities are clearly shown as the horizontal segments of the trajectory. The mean actual bus velocity is shown as the slope of a line connecting the two endpoints of the trajectory. Similarly, the actual bus travel time would be the horizontal projection of this line.

Non-transit vehicles do not decelerate and accelerate to serve passengers. Buses are large vehicles and their operations often are motivated by schedule adherence and are impacted by individual driver characteristics.[10] Therefore, even without stopping, the travel characteristics of buses will be different than those of passenger cars.

For this study, hypothetical non-stop bus trajectories were constructed by subtracting the dwell times from the actual trajectory. To accomplish this, AVL data from the same days and times were used (a.m. and p.m. peak periods on June 14 and September 12, 2000) for bus trips passing over the study site (roadway). The time spent in the stop circle was removed. As shown in Figure 3, the resulting hypothetical non-stop bus trajectory is an approximation of how a bus would travel if it did not stop to serve passengers. Its mean speed is labeled in the figure.

The archived TriMet AVL data for Route 9 were extracted for 69 runs during a.m. and p.m. peak periods on eastbound and westbound Powell Boulevard on June 14 and September 12, 2000.

These data were provided without cost and are routinely collected and archived by TriMet every day for every bus and route on the system. Run times were calculated for both the actual bus (with stop circle activities) and the hypothetical bus (stop circle activities removed).

Table 1 contains mean speed data as well as sample size analysis for the hypothetical bus scenarios. It should be noted that additional buses could not be dispatched. Using the a.m. eastbound hypothetical bus runs in the before scenario as an example, it is shown that the mean hypothetical bus speed for six runs was 29.8 mph and the standard deviation of the speed was 3.07 mph. To ensure with 95-percent confidence that the maximum error was no more than ±3 mph, six runs were needed.

Therefore, for this scenario and for all other bus scenarios, the minimum sample size requirements were satisfied. We have confidence that the estimated mean corridor speeds and travel times are at least as good as the probe vehicle estimates (if not better). This is important because the objective is to determine whether the bus run times can be used for preliminary analysis prior to dispatching probe vehicles or, perhaps, as a substitute.

Hypothetical non-stop bus trajectories will be used in the next section to compare the probe vehicle travel time data with the bus AVL data before and after the signalization improvements. The research question is whether bus run times improved after the signal coordination project.

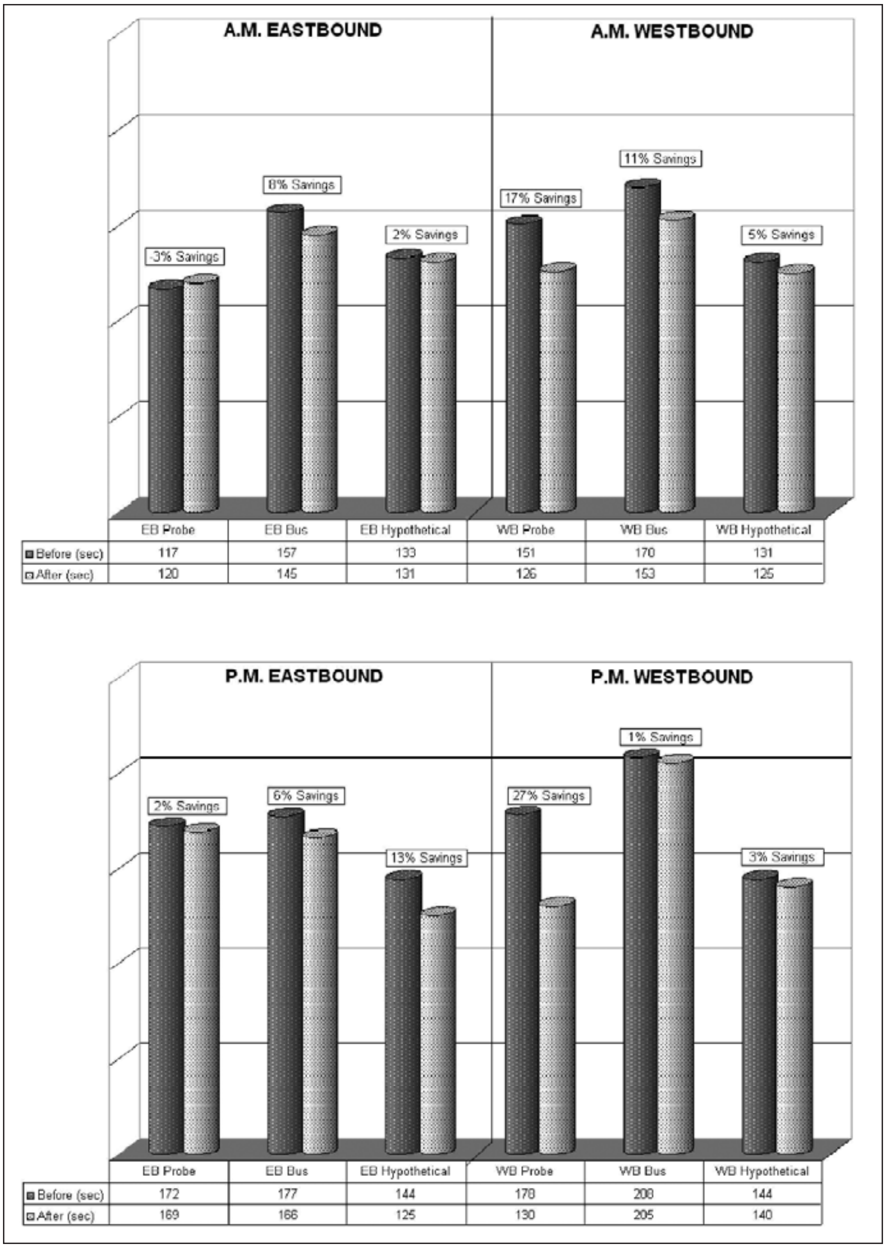

Figure 5. Travel time savings.

PROBE VEHICLE ANALYSIS

The probe vehicle travel time and delay data were plotted on time-space planes along the study corridor (NE Birdsdale Avenue to SW Walters Road). Figure 4 shows trajectories for the eastbound trips during the afternoon peak period, both before and after the signal improvements were implemented. The trajectories clearly show the vehicle speeds (the slope of the trajectory is speed by definition) as well as the times and locations where the vehicles were stopped.

Table 1 contains the summary of the mean probe vehicle travel times (in seconds) for the 1-mile segment of Powell Boulevard that overlaps TriMet Route 9. These results are tabulated by peak period and direction both before and after the signal improvements.

As shown in the table, the before and after analysis indicates that the mean eastbound morning travel time increased by 3 seconds (–3 percent savings) and the mean westbound morning travel time decreased by 25 seconds (17 percent savings). Furthermore, in the afternoon peak, the mean eastbound travel time decreased by 3 seconds (2 percent savings) and the mean westbound travel time decreased by 48 seconds (27 percent savings).

By themselves, these data were used by the City of Gresham to suggest that the signal improvements were effective. These results also are summarized in Figure 5, which shows that the mean probe vehicle travel time decreased in the two peak period directions (morning westbound and afternoon eastbound) and decreased in the morning westbound direction.

TRANSIT VEHICLE AVL ANALYSIS

This analysis will demonstrate that the transit AVL data could have been used to demonstrate travel time reductions along this corridor. The actual bus trajectories obtained from the transit AVL data, including dwell times, were plotted on the time-space plane in Figure 4 for the 1-mile (1.6-kilometer) segment of Powell Boulevard between NE Birdsdale Avenue and SW Walters Road that overlaps with TriMet Route 9.

The figure also shows the hypothetical non-stop bus trajectories (dashed lines), where the time that elapsed between the door opening and the departure from the stop circle was subtracted horizontally from each trajectory. This was done for 69 bus trips along the study corridor on the same days that the probe vehicles were dispatched. This may approximate a hypothetical vehicle traveling through the corridor without stopping to serve passengers.

The actual mean bus trip times (including dwell times, all passenger activity and signal/traffic delay) decreased in all cases after the signal coordination project was implemented (see Figure 5). The results of the analysis of the mean hypothetical non-stop bus travel times are shown in detail in Table 1; these results closely match the results from the probe vehicle.

As indicated in the table, for the morning peak, the mean eastbound non-stop hypothetical bus travel time decreased by 2 seconds (2 percent savings) and the mean westbound hypothetical bus travel time decreased by 6 seconds (5 percent savings). Additionally, in the afternoon peak, the mean eastbound hypothetical bus travel time decreased by 19 seconds (13 percent savings) and the mean westbound hypothetical bus travel time decreased by 4 seconds (3 percent savings). These data are shown in Figure 5.

This indicates that the signal improvements resulted in reduced delays for automobiles and transit vehicles minus the time spent in the stop circles. In addition, the transit agency and its customers benefited from swifter travel through the corridor.

CONCLUSIONS

The results of this unique analysis are shown in Figure 5, made possible because archived probe vehicle data from the City of Gresham and archived TriMet BDS data were available more than two years after the signal improvements were implemented. The changes in mean travel times for the morning peak period are shown, as measured by the probe vehicles and by the transit AVL system (both actual and hypothetical).

The eastbound travel times increased slightly as measured by the probe vehicles. The actual and hypothetical mean bus trip times decreased by a few seconds. The small increase measured by the probe vehicle is not necessarily a concern given that it is the off-peak direction during this time of the day.

The westbound travel times clearly decreased for the probe vehicle and the hypothetical buses—the magnitude of the improvement is roughly similar using both measurement techniques. The actual bus trip time also decreased.

Figure 5 shows that the afternoon peak period travel times also decreased as measured by the probe vehicles and the hypothetical buses; however, the magnitudes of the decreases are somewhat different between the two methods.

It is important to note that although the probe vehicle method indicated a 27-percent reduction in p.m. peak westbound travel time, the number of runs was not sufficient to verify this based on the rather high standard deviation (see Table 1). There is more confidence in the range of travel time improvements reported by the AVL data at a higher degree of statistical reliability.

The use of transit AVL data for measuring traffic signal timing improvements is promising. As a result of this study, it can be concluded that, for this particular site, AVL data from a transit agency is sufficient to verify the benefits of signal coordination (based solely on travel time).

However, given the rather small sample sizes (from both methods), it is suggested that this same kind of comparison be conducted more systematically for more days and for more locations. Along these lines, further research is under way on a longer nearby corridor to examine the validity of transit AVL data.[11]

ACKNOWLEDGMENTS

The authors gratefully acknowledge Steve Callas of TriMet for generously providing the BDS data; the City of Gresham and DKS Associates for providing the probe vehicle data; Ahmed El-Geneidy of Portland State University for assisting in the interpretation of the data and providing bus stop locations and corridor mapping; and Jaturapat Bhiromkaew of Portland State University for performing some preliminary analysis of the probe vehicle data. ■

References

1. Robertson, H.D. (ed). "Manual of Transportation Engineering Studies." Washington, DC, USA: Institute of Transportation Engineers (ITE), 1994.

2. Texas Transportation Institute. "Travel Time Data Collection Handbook." Washington, DC: U.S. Department of Transportation, Report FHWA-PL-98-035 (1998).

3. Robertson, note 1 above.

4. Strathman, J.G. "TriMet's Experience with Automatic Passenger Counter and Automatic Vehicle Location Systems." Portland, OR, USA: Portland State University, Center for Urban Studies, 2002.

5. Ibid.

6. Robertson, note 1 above.

7. Tantiyanugulchai, S. and R.L. Bertini. "Analysis of a Transit Bus as a Probe Vehicle for Arterial Performance Measurement." Presented at the ITE 2003 Annual Meeting and Exhibit, Seattle, WA, USA, 2003.

8. Johnson, R.A. "Miller and Freund's Probability and Statistics for Engineers," 6th Edition. Prentice-Hall, New Jersey, 2000.

9. Robertson, note 1 above.

10. Strathman, J.G., T.J. Kimpel, K.J. Dueker, R.L. Gerhart and S. Callas. "Evaluation of Transit Operations: Data Applications of TriMet's Automated Bus Dispatching System." Portland, OR: Portland State University, Center for Urban Studies, 2001.

11. Strathman, note 4 above.

ROBERT L. BERTINI,
Ph.D., P.E., is an assistant professor of civil and environmental engineering and urban studies and planning at Portland State University. He also is the director of the Center for Transportation

Studies. He earned a B.S. in civil engineering at California Polytechnic State University, an M.S. in civil engineering at San Jose State University and a Ph.D. in civil engineering at the University of California at Berkeley. He is a registered professional engineer in California and Oregon.

J. CAMERON GLASGOW *works for the Federal Highway Administration (FHWA) as a participant in FHWA's Professional Development Program. His area of concentration is structures, which includes design, construction and federal aid experience. He received a B.S. in civil engineering from Santa Clara University in 2002 and an M.S. in structural engineering from Portland State University in 2003.*

JIM PETERS, *P.E., holds a B.S. in civil engineering from the University of Washington. He has 10 years of experience in traffic engineering, traffic operations and ITS planning and design as an ITS engineer at DKS Associates in Portland, OR, USA.*