Buses as Probe Vehicles for Travel Time Data Collection on Urban Arterials

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ABSTRACT

Floating car method, technologies such as global positioning system (GPS) units or data from private sources such as INRIX are used for travel time data collection on urban streets. Time, man-power, and cost deter (limit) collection and purchase of such data for the entire transportation network. An alternate source of the travel time data is using buses as probe vehicles. This is practically feasible and inexpensive as most buses operating in urban areas are equipped with automatic vehicle location (AVL) units. However, the travel time of buses is generally greater than the travel time of a typical vehicle (car). The use or applicability could only be justified if there is strong correlation between car and bus travel times. This paper, therefore, examines the relationship between car and bus travel time. The role of key influential factors (such as the number of signalized intersections, the number of unsignalized intersections, the number of driveways, the number of bus-stops, traffic volume, the number of lanes and the number of turns made by the bus) on the ratio between the two travel times is also evaluated and examined to assess the use of buses as probe vehicles. Results indicate a moderately strong relationship between car and bus travel time. Variables other than the number of signalized intersections per unit distance, the number of lanes, and traffic volume do not seem to play a statistically significant role on the ratio of car to bus travel time irrespective of time-of-the-day. Models by time-of-the-day, developed to estimate car travel time, could be used if bus travel time, the number of signalized intersections per unit distance, the number of lanes, and traffic volume are known.

KEYWORDS: Bus, Probe Vehicle, Travel Time, Arterial Streets, AVL, Car

INTRODUCTION

Travel time at link-level helps travelers make route, mode or departure time decisions and operators to plan, control, and manage traffic on urban streets. It is captured using probe vehicles, which are moving sensors responding to changes in traffic flow as they traverse the links on the network and transmit location and travel time data to a traffic management center at regular intervals. The travel time data from probe vehicles provide a great potential for improving the estimation accuracy of traffic conditions, especially where no traffic detectors are installed (Bertini & Tantiyanugulchai, 2003; Tantiyanugulchai, 2004).

Floating car method (test car as a probe vehicle with a passenger noting time at different points along the travel path), probe vehicle (test car) with a GPS unit, and data from private sources such as INRIX are used for travel time data collection on urban streets. Time, man-power, and cost deter or limit collection and purchase of such data for the entire transportation network every hour / day / year. An alternate source of the travel time data is using public transportation system buses as probe vehicles.

The use of buses as probe vehicles adds little or no financial burden to a transit agency because most buses operating on urban streets are equipped with GPS units for tracking and predicting bus arrival times. Also, bus drivers generally observe traffic rules and speed limits. Further, a large number of buses run on the most used arterial streets and generally have higher frequencies during peak periods (Chakroborty & Kikuchi, 2004).

The primary advantage of using buses as probes is that they are a closed and controllable group of vehicles. Consistent maintenance is relatively easy to ensure safe and efficient transportation, and bus drivers can be instructed on how to use the system (Hall & Vyas, 2000).

The main disadvantage, on the other hand, is that bus speeds do not entirely represent general traffic speeds. Buses must stop to pick up and drop off passengers, must follow a schedule, and have different acceleration and deceleration profiles (Hall & Vyas, 2000). So, the fundamental question would be how related are car and bus travel times on urban streets. The difference between bus travel time and average traffic travel time arises primarily because of the following (Chakroborty & Kikuchi, 2004):

- the stopping time of the bus at the bus-stops;
- the time lost by the bus because of repeated accelerations and decelerations from and to a stop;
- the basic difference between the operating abilities of the bus and the automobile;
- adherence (by the bus and the automobile) to the posted speed limits; and
- the tendency of the bus to use the right lane.

Travel time estimates and prediction may yield acceptable results in the case of freeways. For arterial travel time, however, the estimation gets more complicated due to traffic signals and interruption from side traffic as well as other influential factors. Therefore, the estimation of arterial travel time requires more accurate traffic measurement and more detailed estimation approaches (Ping et al., 2012).

The main focus of this paper is to evaluate the accuracy of using buses as probe vehicles in the estimation of general traffic (car) travel time on arterial streets. Further, the aim is also to look at the role of various influential factors (such as the number of signalized intersections, the number of unsignalized intersections, the number of driveways, the number of bus-stops, traffic volume within the link, the number of lanes and the number of turns made by the bus) on the difference between car and bus travel time. To better assist in modeling and analysis, travel times were captured without accounting for bus stopping time at the bus-stops.

METHODOLOGY

Five transit routes in the city of Charlotte, North Carolina (Figure 1) were selected for analysis, evaluation of buses as probe vehicles, and to assess the role of influential factors on travel time. These routes were identified considering data availability (time points or bus stops at which AVL data is available), transit service on weekdays (headway equal to at least 30 minutes), coverage area of transit routes, and roadway classification (major and minor arterials). The transit routes were also selected such that they are spatially distributed throughout the study area.

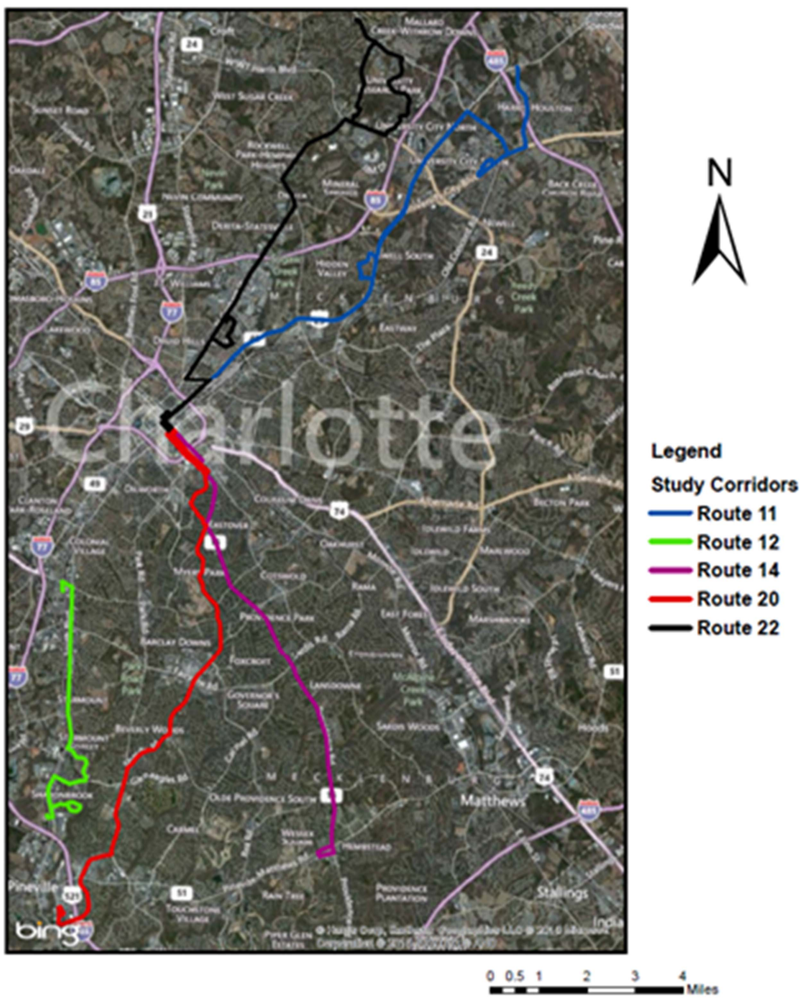

Figure 1. Selected Transit Routes.

Travel time data was manually collected using floating car method. The travel time between fixed bus stops (i.e., driving along the route; in the travel direction) was noted using a stopwatch by a passenger in the vehicle, for morning, off-peak and evening periods, two days for each route. In addition, a GPS unit was installed in the test car to collect the information. The GPS data was processed to compute travel time between the fixed bus-stops by travel direction as well.

The bus travel times were extracted from AVL units for the same links by direction, same day, and same periods of time. Only the time from departure at a bus-stop to arrival at the next bus-stop was considered as travel time. The acceleration and deceleration effects at bus-stops were not considered in the analysis. Merging was not observed to be a major problem as most of the bus-stops are conventional bus-stops along the right-most travel lane.

The travel time captured using buses as probe vehicles were compared with manual and GPS datasets for each individual travel time run (by day and hour) to examine the differences and accuracy of data from AVL units. The variation in the percent difference between bus and manually captured test car travel times was compared with the percent difference between GPS and manually captured test car travel times.

Statistical tests were then conducted to examine if the percent difference is statistically significant. This was followed by statistical tests to examine the relation between test car travel time to bus travel time ratio and influential factors such as the number of signalized intersections, the number of unsignalized intersections, the number of driveways, the number of bus-stops, traffic volume within the link, the number of lanes, and the number of turns made by the bus by time-of-the-day.

As the routes are in core urban area, no significant variations in factors such as speed limit and other geometric conditions were observed. They were, hence, ignored in this paper. Traffic signal timings, though critical could not be considered as they varied by time-of-the-day and based on traffic conditions. As the lengths of links varied, influential factors such as signalized intersections, unsignalized intersections, driveways, bus-stops, and turns were expressed as numbers per unit distance.

RESULTS

Data collected by run was processed and tabulated for analysis and assessment. As the test car with passenger noting time and GPS did not traverse the section at the same time as a bus, data was summarized by data collection hour. In general, two to three runs were made by the test car during each hour. Two to three samples of data were also available from bus AVL units as the headway along the selected corridors was 20 to 30 minutes.

Table 1 summarizes travel time data from test car (collected by a passenger in the car and using GPS) and AVL units by travel time run (data collection hour) on a given day for one of the corridors. The values under GPS and AVL columns are percent difference compared to manually collected test car travel time.

As expected, GPS and manually collected test car travel times were very close to each other (as the GPS was installed in the test car). However, the bus travel times from AVL units are higher than the manually collected test car travel times. Table 2 summarizes the percent difference between test car and bus travel times by time-of-the-day for selected segments. The average percent differences varied from 35% to 40%, while the maximum percent differences were observed to be greater than 70%.

Table 3 summarizes the range of percent difference for all samples (each data collection hour on each data is considered as a sample). The percent difference between GPS and manually collected test car travel time is less than 10% for all samples (100%). On the other hand, the percent difference between bus and manually collected test car travel time is greater than 30% for more than 60% of data samples.

Table 1. GPS and Bus Travel Time Compared to Manually Collected Test Car Travel Time by Travel Time Run (Data Collection Hour).

Link ID	Test Car (Manual) Travel Time (secs)	% Difference		Test Car (Manual) Travel Time (secs)	% Difference		Test Car (Manual) Travel Time (secs)	% Difference	
		GPS	Bus		GPS	Bus		GPS	Bus
6/5/2013	Run 1			Run 2			Run 3		
1	340	0.5	44.9	465	0.2	6.0	314	0.7	45.9
2	251	8.8	67.0	270	0.3	55.0	306	0.2	46.0
3	223	2.7	92.6	282	1.1	52.3	220	0.2	101.8
4	251	0.4	78.2	237	0.2	88.9	219	0.0	105.4
5	291	0.1	42.6	294	0.2	40.8	231	0.8	84.7
6	222	0.8	130.5	298	0.4	72.1	217	0.4	151.3
6/5/2013	Run 1			Run 2			Run 3		
1	422	0.1	25.8	340	0.1	32.5	510	0.1	32.5
2	318	0.6	35.9	314	0.6	41.2	280	0.2	96.6
3	309	0.2	33.1	313	0.3	44.3	314	0.5	25.2
4	321	0.0	37.2	359	0.2	36.7	342	0.3	46.9
5	392	0.0	27.9	380	0.3	32.9	381	0.1	35.5
6	331	0.0	37.9	491	0.3	20.0	472	6.4	18.4

To compare the travel times obtained from GPS and bus with the manually collected test car travel times, tests were conducted at a 95% confidence level. The Null hypothesis, H_0: $H_{Manual} = H_{GPS} = H_{Bus}$, while the alternate hypothesis, H_1: $H_{Manual} \neq H_{GPS} \neq H_{Bus}$. The results obtained from the tests along with the mean and standard deviation are shown in Table 4.

Considering all the samples of arterial streets, results obtained show a statistically significant relation between the computed means. The correlation coefficient for manual and GPS test car data on arterial streets is 1.00 (high correlation), while it is 0.47 for test car (manually captured data) and bus travel time data (moderate correlation). This indicates that, while buses could be used as probe vehicles, some differences do exist. The strength of the relationship between the two travel times is moderate.

Table 2. Percent Difference - Bus Compared to Manually Collected Test Car Travel Times for Selected Segments by Time-of-the-day.

Route #	From	To	7 - 8 AM	9 - 10 AM	5 - 6 PM
11	Tryon St & WT Harris Blvd	Tryon St & Tom Hunter Rd	23.0	46.3	33.9
11	Tryon St & Tom Hunter Rd	Tryon St & Sugar Creek Rd	30.7	43.5	48.5
11	Tryon St & Sugar Creek Rd	Tryon St & Dalton Ave	43.2	38.8	23.8
11	Tryon St & Dalton Ave	Tryon St & Sugar Creek Rd	45.5	38.5	38.5
11	Tryon St & Sugar Creek Rd	Tryon St & Tom Hunter Rd	29.4	32.0	21.3
11	Tryon St & Tom Hunter Rd	Ken Hoffman Dr & Tryon St	49.3	22.9	53.9
14	Walmart @ Arboretum	Providence Rd & Sardis Ln	38.9	43.3	42.7
14	Providence Rd & Sardis Ln	Providence Rd & Sharon Amity Rd	31.9	44.4	20.3
14	Providence Rd & Sharon Amity Rd	Elizabeth Ave & Hawthorne Ln	63.0	47.5	41.8
20	Carolina Place Mall	Park Rd & Hamlin Park Dr	71.8	74.3	77.2
20	Park Rd & Hamlin Park Dr	Sharon Rd & Coltsgate Rd	24.5	15.8	-4.3
20	Queens Rd & Hopedale Ave	Sharon Rd & Fairview Rd	22.4	17.1	23.8
20	Sharon Rd & Fairview Rd	Park Rd & Hamlin Park Dr	7.9	-1.0	35.6
22	Dalton Ave & Tryon St	Graham St & Ennis Ave	59.8	62.7	69.9
22	Graham St & Ennis Ave	Graham St & Cannon Ave	50.9	3.8	51.7
22	Graham St & Cannon Ave	Mallard Creek Rd & WT Harris Blvd	38.6	45.1	8.3
Minimum			7.9	-1.0	-4.3
Average			40.7	36.6	36.7
Maximum			71.8	74.3	77.2

Table 3. Variation in Percent Difference.

Range of % Difference	Frequency (%)	
	GPS	Bus
0-10	100	4
10-20	0	12
20-30	0	11
30-40	0	19
40-50	0	18
>50	0	23

Table 4. Results Comparing GPS and Bus Travel Time Data with Manually Captured Test Car Travel Time Data.

Category	Difference in Mean	Standard Deviation	Correlation
Test car (manual) travel time compared to GPS based travel time	-0.4	5.4	1.00
Test car (manual) travel time compared to bus travel time	-184.6	148.7	0.47

Table 5 shows results obtained from statistical analysis performed to examine the relationship between various influential factors and the ratio of car to bus travel time by time-of-the-day (morning peak, off-peak, and evening peak). The computed Pearson correlation coefficient between the selected influential factors and the ratio by time-of-the-day are shown in the table.

From the table, the computed Pearson correlation coefficient is less than -0.3 (at a 95% confidence level) for signalized intersections per unit distance and the number of lanes in case of morning peak period and only the number of lanes in case of off-peak period. On the other hand, the number of lanes and traffic volume had Pearson correlation coefficients less than -0.3 (at a 95% confidence level) in case of evening peak period. The negative sign indicates that an increase in the value of the influential factor decreases the ratio of car to bus travel time.

A linear regression model was then developed for all the three periods using the test car to bus travel time ratio as the dependent variable and the correlated factors as the independent variables. The models developed and related statistical parameters (R^2, F-statistic, and regression sum of squares) are shown in Table 6.

Table 5. Correlation Coefficient between Selected Influential Factors and Test Car Minus AVL Based Travel Times.

Influential Factor	Morning Peak Hour	Off-peak Hour	Evening Peak Hour
SIPM	-0.38	0.03	-0.20
UIPM	0.00	-0.21	0.11
DPM	-0.19	0.11	-0.01
TPM	0.09	0.03	0.07
BSPM	0.08	-0.03	0.07
# Lanes	-0.59	-0.57	-0.69
Traffic Volume	-0.01	-0.25	-0.33

Note: SIPM is # of signalized intersections per mile; UIPM is # of unsignalized intersections per mile; DPM is # of driveways per mile; TPM is # of left- and right-turns made by bus per mile; and BSPM is # of bus-stops per mile

The R^2 is highest for evening peak hour model and lowest for off-peak hour model. The F-statistic is greater than 4 for all the three models, while the regression sum of squares is observed to be reasonably low.

Table 6. Travel Time Models – Results Summary.

Time-of-the-day	Model	R^2	F-statistic	Regression Sum of Squares
Morning Peak	Car Travel Time = AVL Travel Time × (1.1 - 0.19 × SIPM - 0.05 × # Lanes)	0.42	5.3	0.19
Off-peak	Car Travel Time = AVL Travel Time × (1.1 - 0.23 × # Lanes)	0.32	7.5	0.20
Evening Peak	Car Travel Time = AVL Travel Time × (1.2 - 0.28 × Traffic Volume - 0.000066 × # Lanes)	0.50	7.5	0.34

Note: SIPM is # of signalized intersections per unit distance.

CONCLUSIONS

Research findings comparing travel time captured using buses as probes with test car (manually gathered information by a passenger) and GPS travel time are presented in this paper. While GPS based travel times are closer to manually collected travel times, the travel time from AVL units are higher than those collected manually. The difference is greater than 30% for more than 60% of samples collected.

Tests performed indicate a moderately strong relationship between bus and manually collected travel times. Barring signalized intersections, the number of lanes and traffic volume, other influential factors considered do not seem to play a significant role on test car to bus travel time ratios. Results from linear models developed indicate that the number of lanes play a statistically significant role on the ratio between travel time. While signalized intersections per unit distance was observed to play a statistically significant role during morning peak period, traffic volume was observed to play a statistically significant role during evening peak period.

The findings indicate that buses can be used as probe vehicles for travel time data collection. They also indicate that influential factors do play a role on the ratio of car to bus travel time.

Data for only five corridors was considered in this research. The possible use of larger datasets or comparing bus travel time with travel time captured from private data sources such as INRIX merit an investigation. The possibility of non-linear relationship between the ratio in travel times and influential factors found insignificant in this paper also merit an investigation.

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DISCLAIMER

The views, opinions, findings, and conclusions reflected in this paper are the responsibility of the authors only and do not represent the official policy or position of the USDOT/RITA, or any State, or the University of North Carolina at Charlotte or other entity. The authors are responsible for the facts and the accuracy of the data presented herein. This report does not constitute a standard, specification, or regulation.

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