USING BLUETOOTH™ TO MEASURE TRAVEL TIME ALONG ARTERIAL CORRIDORS

A Comparative Analysis

Submitted To:

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Department of Streets
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Introduction

As funds available for infrastructure betterment become scarcer, a greater emphasis has been placed upon establishing methods to validate such spending. Increasingly gaining in importance, “performance measures” have become the tool agencies depend upon to justify improvements and to distribute funds more efficiently and fairly among competing projects. Travel time is one of the fundamental methods to measure the efficiency of traffic operation on both arterials and highways.

The purpose of this paper is to compare the efficiency and viability of two different methods to collect travel time data on a signalized arterial corridor. Traditional average/floating (hybrid) test car runs is one of the techniques studied. The other method is the deployment of technology to monitor and measure the actual travel time as experienced by the drivers on the corridor. (Quality and accuracy of the data collected by these methods has been established by others and, therefore, is not the topic of this paper.)

There are numerous research papers and guidelines in the literature that help determine the steps and measures to be taken to increase the accuracy of the sampling method. However, it is universally accepted that more data (i.e. larger sample size) usually translates to “better” results in attempts to simulate the characteristics of the whole population (i.e. travel time experienced by all vehicles in the corridor).

A sample signalized arterial corridor (Verree Road in Philadelphia, PA) has been chosen for the purposes of this exercise. Travel time experienced by drivers in the corridor is sampled by using a hybrid (average/floating) test car run method. This is the widely accepted traditional method to collect travel time data. In addition, the roadway was instrumented with sensors that anonymously trace an individual vehicle from the entry point to the exit point in the corridor, hence enabling the collection of “real” travel time experienced by that individual vehicle.

This paper is divided in the following sections:

- *Study Corridor* explains the characteristics of the sample corridor
- *Travel Time Methods* provides a detailed account of the two distinct methods used to collect travel time data on the sample corridor
- *Better Sampling of Travel Conditions* checks the viability of the methods from sampling size perspective
- *Cost Comparison* identifies and compares capital and operational cost of each method to verify that they are not cost prohibitive, and
- *Conclusion* provides final thoughts summarizing the findings.

Study Corridor

The study data for this paper was collected on Verree Road, a signalized arterial parallel to US Route 1, in the northeast section of Philadelphia. The study area, referred to as the "Verree Road corridor", extends from Oxford Avenue to Red Lion Road, and it is approximately 3.9 miles long with 13 signalized intersections along the corridor. The posted speed limit is 35 MPH. Sensors were placed at the termini locations, Oxford Avenue and Red Lion Road, and at one mid-point location, Bloomfield Avenue. Test car runs were conducted for the entire corridor during two peak periods on a typical weekday. Specifically, data was collected on Tuesday and Wednesday, April 26 and 27, 2011, during the morning and afternoon peak periods, respectively. *(Examination of this corridor is part of a broader project for the City of Philadelphia Traffic Signal Retiming Project being conducted as part of its Transportation Improvement Program (TIP). It is the first undertaking of its kind in more than a decade. A total of 21 corridors, including approximately 600 intersections, will be analyzed and retimed (as needed) to improve mobility in the City.)*

Travel Time Methods

Two distinct methods were employed to measure travel time along the Verree Road Corridor. These methods are: 1) Bluetooth™ technology through deployment of BlueTOAD™ products, 2) Hybrid test car runs using GPS equipment and PCTravel™ software to reduce the effort to collect and compile the data.

The Bluetooth Technology and the *BlueTOAD* Product

Bluetooth is an open, wireless communication platform used to connect myriad electronic devices. Many computers, car radios and dashboard systems, PDAs, cell phones, headsets, or other personal equipment are, or can be, Bluetooth-enabled to streamline the flow of information between devices. As a result, the amount of data readily obtained is significant. Each Bluetooth device captures the MAC address and places a timestamp. A pair of devices is needed to obtain the travel time. *BlueTOAD* (Travel-time Origination And Destination)[1] devices were placed along Verree Road to collect travel time and speed data. Photographs of a sensor installation are presented in Figure 1.

Figure 1 – Typical Solar Powered BlueTOAD™ Device Installation

[1] The *BlueTOAD™* device is a product by TrafficCast (www.trafficcast.com)

Easily installed and mounted six to ten feet above the travel lane, the radius of Bluetooth detection is approximately 175 feet enabling a single device to collect data from both sides of the roadway. Bluetooth is a proven method to collect travel times for vehicles and pedestrians with successful real-time commercial deployments in many states including Wisconsin, Florida, New Jersey and Pennsylvania.

Hybrid Test Car Runs and the *PC Travel™* Product

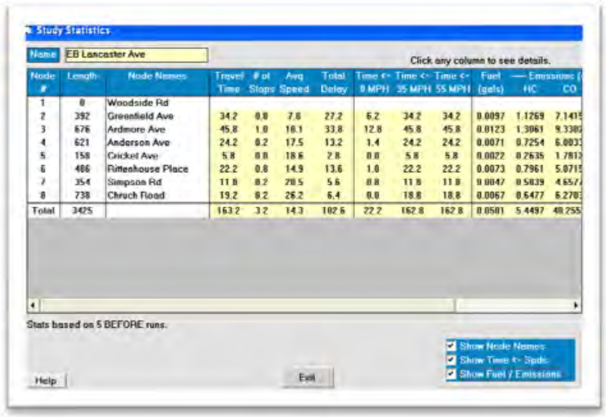
Test car run method has been used for travel time data collection since the early 1900s. An observer in the test car records cumulative travel time at predetermined checkpoints, such as intersections. Since the distance between checkpoints is fixed, the observer can then calculate travel time, speed and delay for each segment (the portion of the roadway between two checkpoints). There are three methods to conduct test car runs: Average Car, Floating Car, and Maximum Car. Most travel time studies incorporate a *hybrid* of the floating car and average car driving styles[2].

In its early days, the observations were recorded manually. Later, a device called "distance measuring instrument (DMI)" connected to a vehicle's transmitter automated the data collection to an extent and reduced the human error. Currently, test car run method benefits from Global Positioning System (GPS). GPS satellites transmit signals indicating its location and current time. The signals, radiating from several satellites at once, arrive at the GPS receiver. The GPS receiver estimates the distance to at least four originating satellites and calculates its position.

This technology has been valuable in conducting travel time and delay studies. A GPS receiver collects the time and location of position of a vehicle along the study corridor.

There are several products in the market that utilize GPS technology to track speed and time of a moving entity, which can be a runner, a bicyclist, or a motorized vehicle. For the purposes of this study, a software program called *PC Travel™* has been used along with its accompanying supplies (GPS equipment and a laptop) to collect and store data. PC Travel processes the collected data and translates it into summaries of travel time, speed, delay and number of stops along the corridor for multiple "nodes" or study intersections, identified along the subject corridor through a mapping interface. Figures 2 and 3 are examples of the summary report and graphics available through the *PC Travel* software. For the remainder of this paper, the hybrid (average/floating) test car run method used for this study, will be known as the "test car run method."

[2] Travel Time Data Collection Handbook, Report No. FHWA-PL-98-035, Office of Highway Information Management, FHWA, March 1998



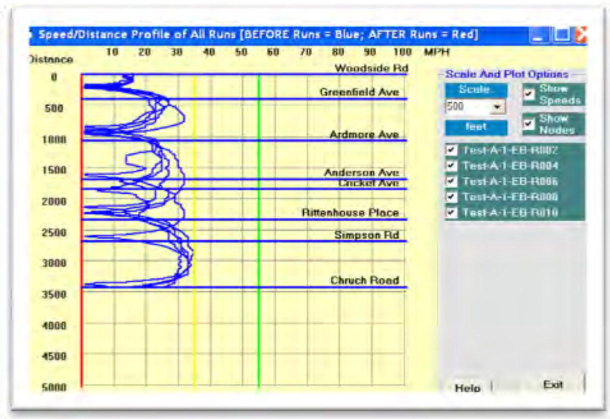


Figure 2 – Example PC Travel™ Study Statistics

Figure 3 – Example PC Travel™ Speed Profile

On the Verree Road Corridor, two vehicles equipped with GPS receivers and laptops loaded with *PC Travel™*, travelled the study corridor during the weekday morning (7:00 AM to 9:00 AM) and weekday afternoon (4:00 PM to 6:00 PM) peak periods.

Better Sampling of Travel Conditions

The amount of travel time data that can be collected through these two methods varies considerably. The test car run method is restricted to a limited amount of time to prevent being cost prohibitive. These periods usually do not extend beyond the morning and afternoon peak periods, typically defined as the two-hour time space that encapsulates the peak hour (AM or PM), e.g. 7AM to 9AM in the morning, 4PM to 6PM in the afternoon/evening.

As with any human operated/powered data collection effort in traffic engineering, the expense of expanding the duration of data collection becomes very high due to increased cost of labor and equipment. However, today's technologies, such as roadside devices that collect traffic data, are not time constrained. These sensors have low operational cost while collecting data, and continue to do so unless their power or memory limits are exceeded. BlueTOAD is such a technology. It collects data all day, every day, (24/7), without interruption. Figure 4 depicts the speed data collected on a typical signalized arterial by BlueTOAD and by PC Travel. Sensor data is collected on three consecutive weekdays over a 24-hr period and shown below in blue dots. For cost reasons, the test car run method was only used on one weekday for two peak periods and indicated by red dots.

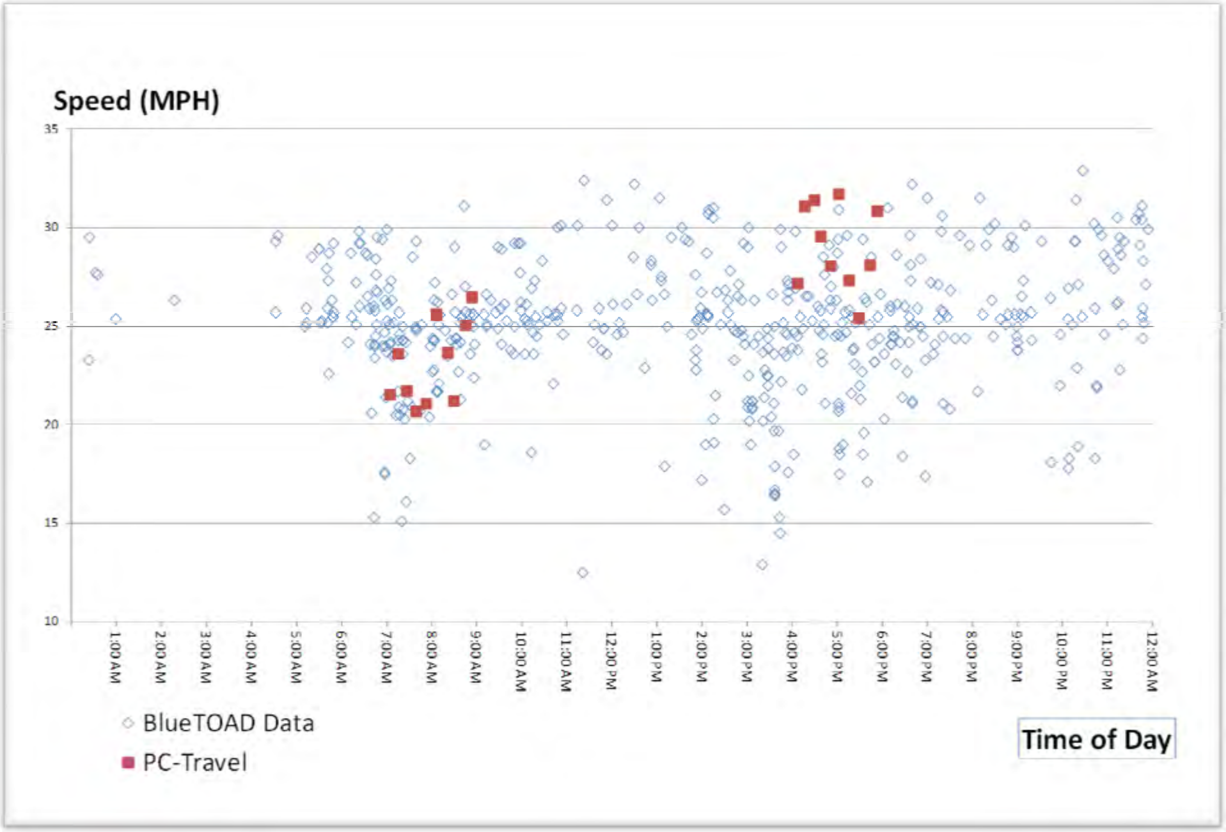


Figure 4 – Speed Scatter Diagram

To perform a fair assessment of these two methods, a unit case for the test car run method needs to be identified. For this paper, a unit case for manual test car runs is an approximate three-mile signalized arterial corridor and two test cars. With a typical 12 to 15 MPH running speed, two test cars can yield four to five runs during one peak hour. During a two-hour peak period, it is possible to collect eight to ten travel time runs on a three-mile corridor. The only way to increase the amount of data collected during a peak period with the test car run method is to increase the number of test cars used during the same peak period or increase the number of days the data are collected.

On the other hand, the amount of data collected by Bluetooth sensor technologies is governed first by the number of devices available to be detected and second by the number of device matches along the segment of roadway being tested. On a signalized arterial in urban setting, such as Verree Road, the average match rate (sample size) ranged from approximately 5% to 7% (See Table 1). Table 1 also provides a comparison between the amounts of data collected by either method on this typical signalized arterial.

Table 1 – Match rate compilation for BlueTOAD and PC-Travel on Verree Road during Peak Hours (two tandem segments)

Verree Road – Between Red Lion Road and Bloomfield Road

	Number of PC Travel Runs		BlueTOAD Match Count		Volume Entering Segment		Sample Size for PC Travel		Sample Size for BlueTOAD	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Northbound	5	4	45	20	715	718	0.70%	0.56%	6.29%	2.79%
Southbound	5	4	35	49	637	730	0.78%	0.55%	5.49%	6.71%
							Avg.	0.65%	Avg.	5.32%

Verree Road – Between Bloomfield Road and Oxford Avenue

	Number of PC Travel Runs		BlueTOAD Match Count		Volume Entering Segment		Sample Size for PC Travel		Sample Size for BlueTOAD	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Northbound	5	4	30	25	353	575	1.42%	0.70%	8.50%	4.35%
Southbound	5	4	32	39	590	610	0.85%	0.66%	5.42%	6.39%
							Avg.	0.90%	Avg.	6.17%

The FHWA Travel Time Data Collection Handbook (Report No. FHWA-PL-98-035) gives clear direction for the amount of sampling required while conducting travel time studies by test vehicle techniques. Table 2 illustrates that with 95% confidence, and ± 5 % error margin, a typical arterial such as Verree Road with three to six signals per mile, requires a minimum sample size of 25 in order to accurately measure the actual travel time along the corridor. In addition, the handbook also recommends that these test vehicle runs be conducted on different days of the week. By utilizing this "minimum sample size" of 25, it is possible to assess the feasibility of each method.

Table 2 – Illustrative Test Vehicle Sample Sizes on Arterial Streets[3]

Traffic Signal Density (signals per mile)	Average Coefficient of Variation, (%) Table 3-2	Sample Sizes		
		90% Confidence, ± 10 % Error	95% Confidence, ± 10 % Error	95% Confidence, ± 5 % Error
Less than 3	9	5	6	15
3 to 6	12	6	8	**25**
Greater than 6	15	9	12	37

(To obtain a sample size of 25 using the test car run method, the equivalent of approximately six hours worth of peak period travel time data needs to be collected. Sampling both the morning and afternoon

[3] Travel Time Data Collection Handbook, Report No. FHWA-PL-98-035, Office of Highway Information Management, FHWA, March 1998, Page 3-6, Table 3-4.

weekday peak periods translates to a three-day effort in which 24 to 30 samples would be collected by using the base three-mile corridor case, with two test cars performing four to five runs per hour during each two-hour peak period.)

A typical one-day test run per car takes approximately four hours on average to conduct, including one hour travel to/from the study area. To meet the minimum sample size of 25, assuming a three-day effort as explained above, a 48-hour effort is required. The same corridor can be sampled by using BlueTOAD for the same duration by simply spending two hours for installation and dismantling of equipment. By taking Verree Road as a typical example, Table 1 demonstrates (under BlueTOAD match count column) that BlueTOAD technology has been able to collect 20 to 49 samples during <u>one</u> hour only.

Data compilation duration for both methods is comparatively similar and is not taken into consideration in this comparison. In addition, since it is continuously operational the Bluetooth technology allows the analyst to create 24-hour speed profiles of the segments. See Figure 5 for a typical 24-hour speed profile created by using Bluetooth data. This figure also depicts the speed data collected by the test car run method during the two peak periods on a typical weekday.

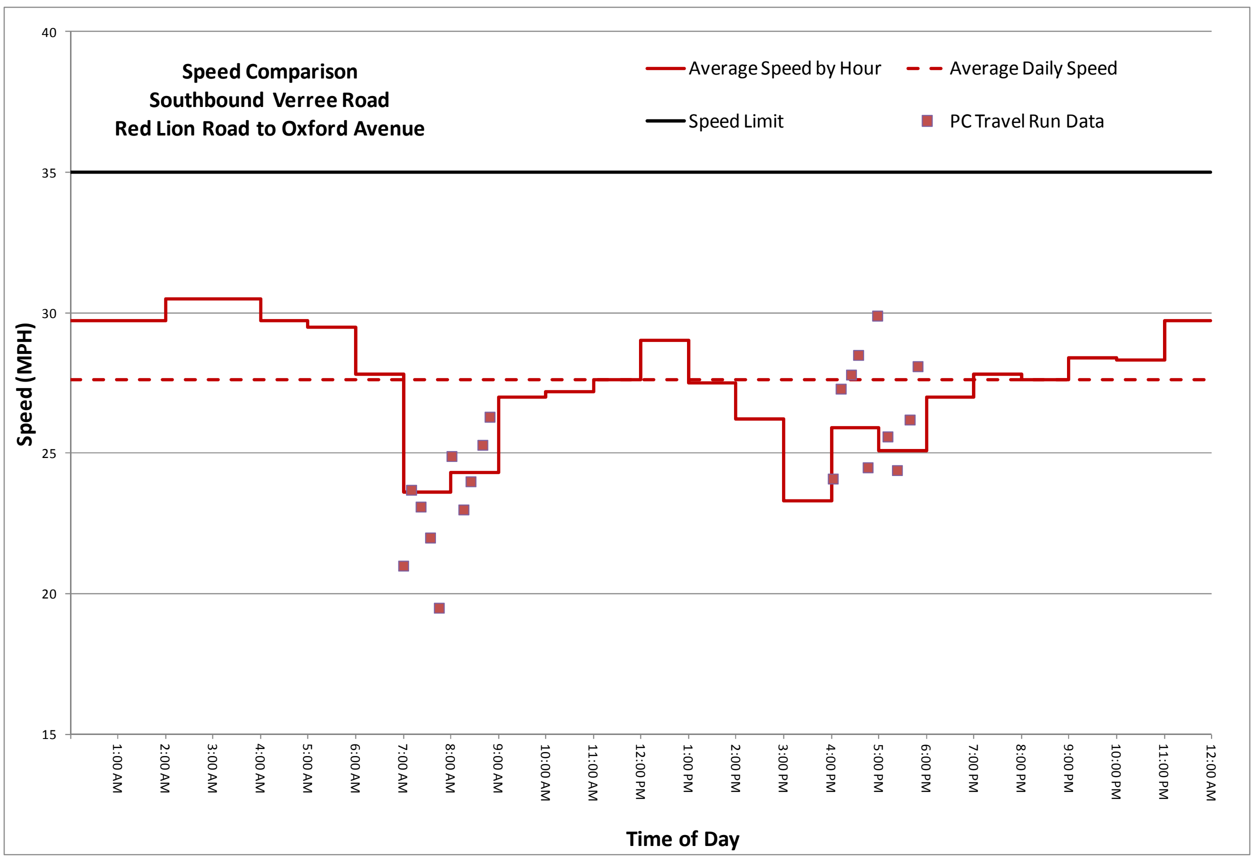


Figure 5 – Typical 24-hourSpeed Profile by using Bluetooth Method vs. Test car run method.

Cost Comparison

A simplified cost assessment was performed to establish the relative cost difference and breakeven point between BlueTOAD and PC-Travel. The analysis presented includes the standard BlueTOAD and Mini-TOAD (each data-period independent) and PC-Travel over a period of three, five and seven days. The main difference between the standard BlueTOAD equipment and the Mini-TOAD equipment is that the latter is battery powered and archives the collected data. Therefore it is limited by power and memory requirements, typically ranging from one week to two weeks per use, whereas the former is solar powered and can stream data through cellular data network, hence is suitable for real-time data collection and continuous use. The equipment, labor and direct costs to perform the studies are presented in Table 3 below. As shown, the labor costs required to collect data with the BlueTOAD are one-third that of the traditional PC-Travel runs. Yet, the total cost for an individual data collection event, is significantly lower using the test car run method (PC-Travel equipment and software) for each alternative. The capital cost of acquiring Bluetooth detector, regardless of the type, is substantially higher than the capital cost of PC-Travel. However, this comparison does not do justice to the real economic effectiveness of the former. There are two specific areas where the Bluetooth technology excels compared to traditional test car runs.

Table 3 – Summary of Costs

	BlueTOAD		PC Travel		
	Standard	Mini			
	Data Period Independent	Data Period Independent	PC Travel 3 days	PC Travel 5 days	PC Travel 7 days
Equipment Cost	$14,265.00	$11,240.00	$1,766.48	$1,766.48	$1,766.48
Labor Cost	$400.00	$400.00	$1,200.00	$2,000.00	$2,800.00
Mileage Cost	$ -	$ -	$179.82	$299.70	$419.58
Total Cost	$14,665.00	$11,640.00	$3,146.30	$4,066.18	$4,986.06

First, the Bluetooth method collects more data points in the same period of time, therefore offering a substantially reduced “cost per data point” rate. Since the variables are numerous, it is difficult to perform an economic analysis to compare those rates. But, it is a fair effort to compare the cost of PC-Travel method to the cost of Bluetooth method based on a number of typical three-mile segments. Figure 6 graphically presents this comparative cost analysis. The intersection of PC-Travel lines with the BlueTOAD lines represent a break-even point in terms of the number of a typical three-mile segments on which data can be collected by using either method. For instance, after performing approximately nine three-mile segments, using MiniToads become the more economically feasible alternative (based on a three-day, two peak period only PC-Travel runs). Since MiniToads are capable of collecting travel time continuously for at least a week, it is interesting to see what the resulting break-even point is comparatively the same to a seven-day PC-Travel runs. It only takes slightly more than three three-mile segments to justify acquiring three MiniToad devices.

The comparisons provided in Table 3 and Figure 6 are for illustrative purposes only. There may be instances where the need and frequency of travel time data collection would not justify the upfront cost of acquiring Bluetooth technology. However, when the continuity of such need is substantial, it is evident that the Bluetooth method becomes more cost effective than the manual test car run method which increases in cost very quickly as the number of segments increases.

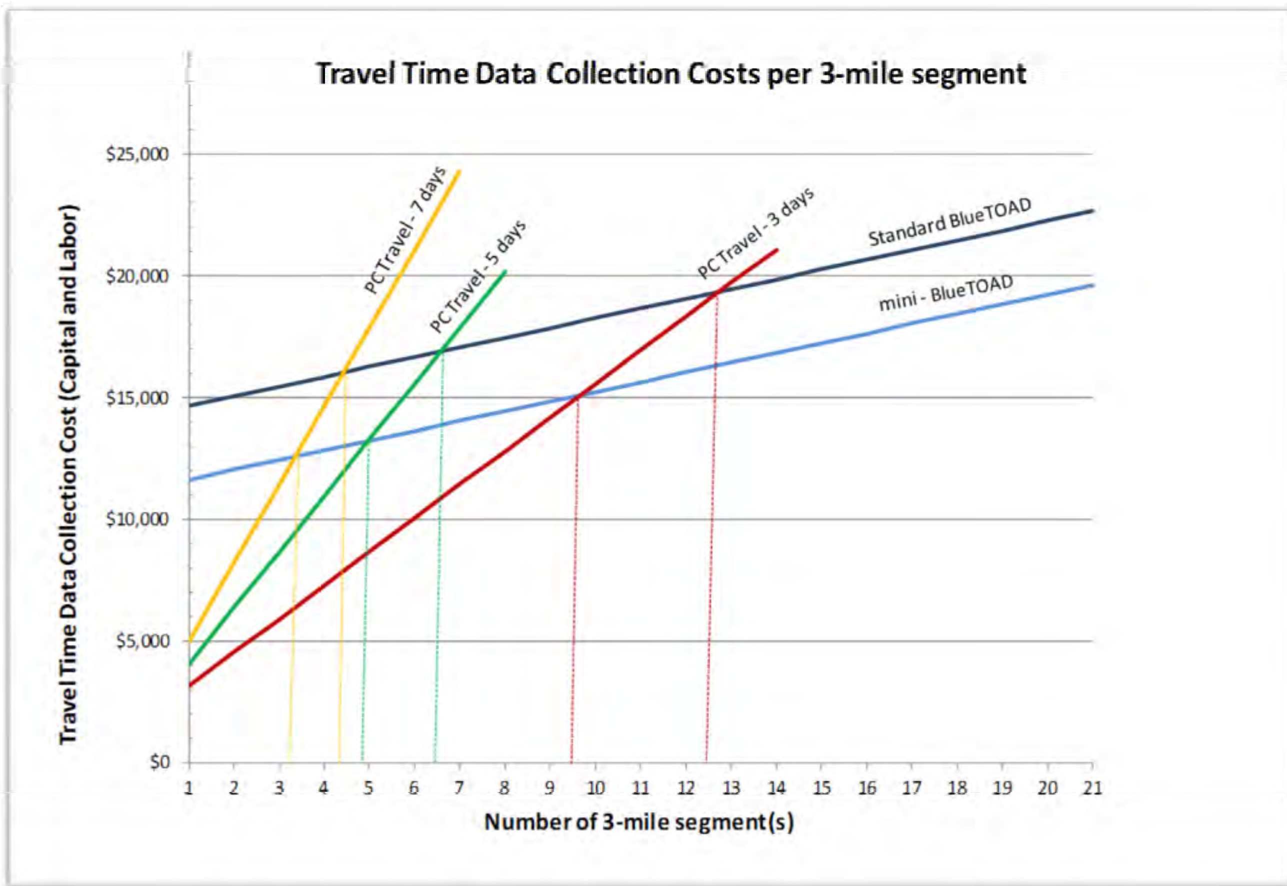


Figure 6 – Travel Time Data Collection Costs per 3-Mile Segment

Conclusion

This paper provides a comparative approach to the utilization of a new technology vs. a more traditional method. As proclaimed in the introduction, it does not seek to demonstrate the quality or accuracy of the data in reference to one another. Depending on conditions, one method can always prove to be better than the other. However, there are obvious advantages to using modern technology, such as tracking Bluetooth signals to obtain a good sample of traveling vehicles to measure travel time. The following is a summary of the benefits and shortcomings of the Bluetooth method.

Advantages

- **Collects a lot more travel time data** per time period and can do so **continuously for a minimum of one week** with the least capable technology. There are commercially available devices that provide real-time continuous travel time data
- Is significantly less prone to human error. When installed properly, it is **very unlikely that an error will occur**.
- Is **easy to install and operate**. Advances in technology (for power and memory requirements) makes travel time data collection with Bluetooth more accurate and more efficient as any other technology improvements.
- Is not limited to vehicular traffic. Bluetooth devices are the ones that are being tracked. Therefore it creates an **opportunity to track pedestrians, bicyclers, transit vehicles**, etc.
- In addition to travel time, it offers the added **built-in advantage to conduct origin-destination studies without extra cost or effort**.
- **Can create 24-hour speed, delay or travel time profiles of the segment**, since the data collection is continuous for 24 hours.
- Offers a **more realistic approach to measure travel time as experienced by the drivers**. Test car run method requires that the test car driver proceed through the intersections. On multi-lane approaches, this creates a bias if the test car driver is familiar with the study area. Bluetooth method however takes into consideration all delays experienced by a good sample size of travelers. This includes the delay experienced at the intersections. **It is also possible to isolate the vehicles stopped at the intersections and measure the individual intersection delay in addition the segment delay**.

Disadvantages

- More expensive to acquire. If the need to collect travel time data is very limited and infrequent, more traditional methods are more economically feasible.
- Requires a certain technology awareness/knowledge to operate the device (installation, downloading data, etc.)
- High amount of data can pose analytical challenges from a statistical perspective
- Requires access to publicly or privately own infrastructure, such as utility poles, traffic signal poles, etc. for installation

- Vulnerable to vandalism

With these thoughts and considerations in mind, the BlueTooth technology and the BlueTOAD device in particular was found to be more than adequate for the purposes of this study effort and given the volume of data required, is the most cost effective alternative.