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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

BLUETOOTH TRAFFIC DETECTORS FOR USE AS PERMANENTLY INSTALLED TRAVEL TIME INSTRUMENTS

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CENTER FOR ADVANCED TRANSPORTATION TECHNOLOGY

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FINAL REPORT

February 6, 2012

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Maryland State Highway Administration. This report does not constitute a standard, specification, or regulation.

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16. Abstract In February 2009, the University of Maryland's (UMD) Center for Advanced Transportation Technology (CATT) via a research grant from the Maryland State Highway Administration (SHA) set out to extend Bluetooth™ traffic monitoring (BTM) technology for use as permanent sensors, delivering travel time 24 hours per day, 7 days a weeks, 365 days a year on Maryland freeways. As of October 2011, UMD CATT through partnership with Traffax Inc., a private commercial business manufacturing and selling Bluetooth-based sensors based off technology developed at UMD, has designed, deployed and tested six prototype units on a corridor along I-95 and I-495 between Baltimore and Washington, DC. Installation of the six prototype sensors began in early 2011. The successful demonstration of the real-time, permanently installed BTM sensors was the ultimate goal of this project, and with the sensors and the corresponding central processing having operated for the majority of 2011, that objective has been met. This report documents the hardware, software and deployment of the prototype units.			
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Bluetooth Traffic Detectors for Use as Permanently Installed Travel Time Instruments – Final Report



Final Report

Title: Bluetooth Traffic Detectors for Use as Permanently Installed Travel Time Instruments

SHA Project #: SP909B4D

Principal Investigator: Stanley E. Young

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Executive Summary

In February 2009, the University of Maryland (UMD) Center for Advanced Transportation Technology (CATT) via a research grant from the Maryland State Highway Administration (SHA) set out to extend Bluetooth™ traffic monitoring (BTM) technology for use as permanent sensors, delivering travel time 24 hours per day, 7 days a week, 365 days a year on Maryland freeways. As of October 2011, UMD CATT through partnership with Traffax Inc., a private commercial business manufacturing and selling Bluetooth-based sensors based off technology developed at UMD, has designed, deployed and tested six prototype units on a corridor along I-95 and I-495 between Baltimore and Washington, DC. Installation of the six prototype sensors began in early 2011. The successful demonstration of the real-time, permanently installed BTM sensors was the ultimate goal of this project, and with the sensors and the corresponding central processing having operated for the majority of 2011, that objective has been met.

The sensor design has proven rugged, and the firmware has been upgraded to improve reliability of communication on the cellular network. Data from the six sensors is communicated to a central server where media access control (MAC) identifiers are matched, and travel time information calculated and displayed. This report consolidates the findings and accomplishments of this research project. The project timeline was extended primarily due to unforeseen installation delays, as explained in the body of the report. The project deliverables including documentation on the design, operations, installation, and accuracy of the prototype system are included in this report and associated appendices.

The six prototype units continue to operate 24 hours a day, seven days a week and have been combined into a larger BTM sensor deployment funded by a Small Business Innovate Research (SBIR) grant from the Federal Highway

Administration (FHWA).

Deployment for the SBIR began

in mid-2011, and with the six prototype units from this project further leverage the investment in the permanent BTM sensor research by Maryland SHA. Data from this network is available both in real-time as well as in archive data sets for engineering, planning and performance measure studies. In addition to the SBIR project, the data will be incorporated into the Regional Integrated Transportation Information System (RITIS) hosted by the CATT Laboratory. The latter was enabled by a grant from the Maryland Industrial Partnerships program.

The UMD CATT would like to thank the Maryland SHA for their funding support, interaction, and cooperation in a successful research and development project. As a result, BTM technology is proliferating throughout the US, providing effective new data sources for monitoring traffic, assessing performance measures, and providing engineering and planning level study data.

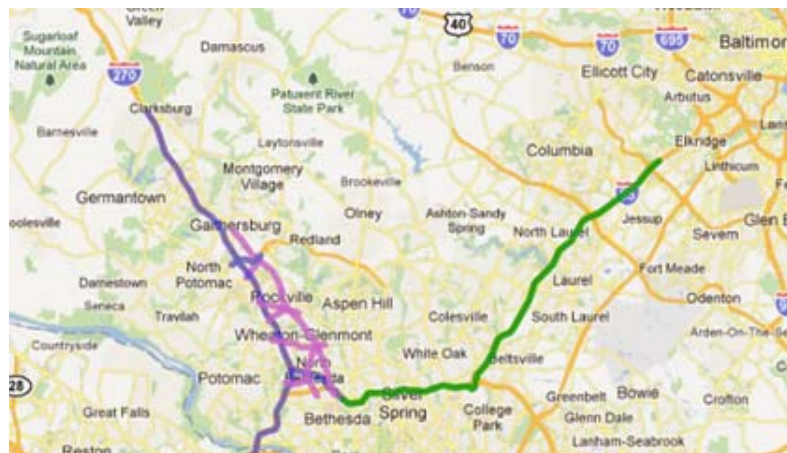


Figure 1 SBIR Bluetooth Deployment in Maryland

Table of Contents

Executive Summary.....	2
Project Background and Description	4
Overview of Bluetooth™ Traffic Monitoring Technology.....	4
Research and Development Results	6
Objective 1: Specifications for Permanently Mounted Bluetooth Detectors.....	6
Objective 2: Equipment Design for Permanent Mount Bluetooth Detector	8
Objective 3: Specifications for Application Monitoring Software.....	9
Objective 4: Develop, Test, and Demonstrate Prototype	9
Objective 5: Validate accuracy, effectiveness, and operational parameters of the system.....	10
Conclusions, Lessons Learned, and Future Work	13
<i>See attachment for Appendices A-J</i>	
Appendix A Specification Sheet for BTM Real-time Sensor Units	
Appendix B CONOPS	
Appendix C BluFax Real-Time User’s Manual	
Appendix D Diagram of System Architecture and Data Flow	
Appendix E BluFaxWeb – User Manual	
Appendix F I-95 and I-495 Sensor Installation Sheets	
Appendix G Original proposal	
Appendix H Maryland Route 29 Comparison Report	
Appendix I Comparison of BluFax Travel Time with Toll Tag Data	
Appendix J BluFaxWeb Interface Control Document	

List of Tables and Figures

Figure 1 SBIR Bluetooth Deployment in Maryland	2
Figure 2 Bluetooth traffic monitoring operation concept	5
Figure 3 Sample Bluetooth data taken along a segment of I-95 between Baltimore and Washington, D.C.	6
Table 1 Life Cycle Cost Estimate for BTM Technology.....	8
Figure 4 Sample Permanent Installation.....	8
Figure 5 Actual Installation of BTM Unit.....	9
Figure 6 Comparison of Bluetooth speed and volume data with ATR on US-29 Northbound on October 25, 2008	11

Project Background and Description

In support of the Maryland State Highway Administration (SHA) business objectives related to mobility and congestion relief, in 2009 the University of Maryland (UMD) Center for Advanced Transportation Technology (CATT) proposed to develop the use of Bluetooth™ traffic monitoring (BTM) technology as permanently installed sensors on the Maryland highway network. These sensors would be used to directly measure travel time at a high level of accuracy continuously – 24 hours per day, 7 days a week, 365 days per year (24/7/365). Previous research and development demonstrated that BTM data can provide accurate and objective measures of vehicle delay, travel time and origin-destination data to support Maryland SHA performance measures, operations, incident management, and to provide effective traveler information. The initial development of BTM technology at UMD in 2007-2009 targeted portable, easily deployable sensors. In 2008 a prototype system of 25 sensors was produced and remains in use with the SHA Highway Information Services Division (HISD) to this day. Additionally, a similar system developed by UMD CATT has been in use to validate the I-95 Corridor Coalition Vehicle Probe Project (VPP) since July of 2008. BTM data collected by the validation effort of the VPP using the portable system has demonstrated the unsurpassed high-fidelity traffic data that can be obtained using BTM technology.

Building on the success of the portable BTM sensors, the objective of this project was to enable BTM technology to be permanently installed on highways and arterials in order to deliver real-time, continuous and highly accurate travel times 24/7/365. The resulting design and prototypes meet the demanding environment for permanently deployed equipment along roadways including consideration of environmental extremes (temperature and humidity), continuous and sustainable power sub-systems, and robust wireless cellular communications. Concurrently real-time central processing was established to handle continuous traffic reporting in support operations.

Overview of Bluetooth™ Traffic Monitoring Technology

Beginning in late 2007 the University of Maryland, with support from the Maryland SHA, developed an anonymous probe technique to monitor the travel time on highways and arterials based on signals available from the point-to-point networking protocol commonly referred to as Bluetooth™. The majority of consumer electronic devices produced today come equipped with Bluetooth™ wireless capability to communicate with other devices in close proximity. For example, many digital cameras use Bluetooth™ for downloading pictures to a laptop computer. It is also the primary means to enable hands-free use of cell phones. Bluetooth™ enabled devices can communicate with other similarly equipped devices from distances ranging from one meter to about 100 meters, depending on the power rating of the respective sub-systems.

The Bluetooth™ protocol uses an electronic identifier, or tag, in each device called a Media Access Control address, or MAC address for short. The MAC address serves as an electronic nickname so that electronic devices can keep track of who's who during data communications. It is these MAC addresses that are used as the basis for obtaining traffic information. The concept for deriving traffic information in this manner is illustrated in Figure 2.

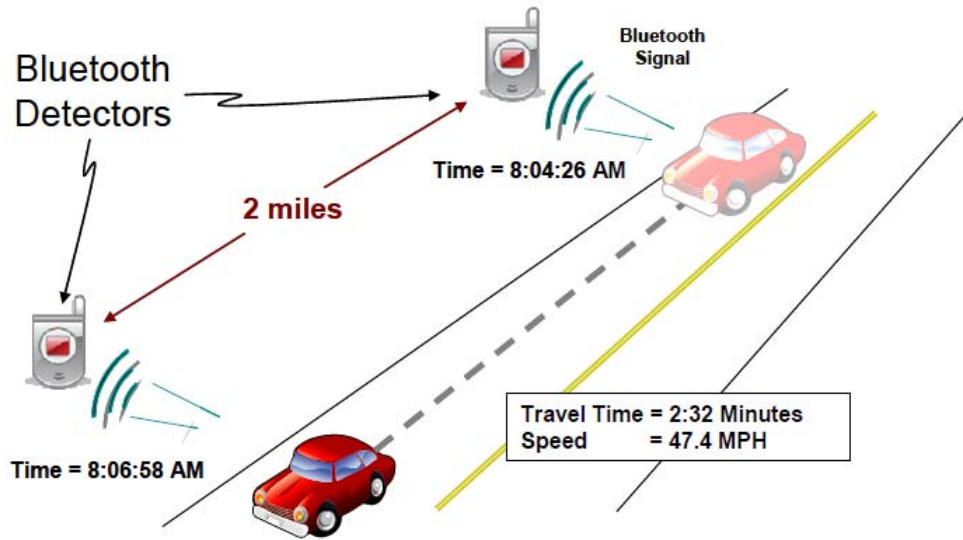


Figure 2 Bluetooth traffic monitoring operation concept

A vehicle containing a detectable Bluetooth device is observed at two stations. The MAC address and time of detection is logged, and the information is used to obtain a sample travel time for the segment. Observations of multiple vehicles containing Bluetooth devices provide a highly accurate estimate of traffic conditions. Experiments have indicated that approximately one automobile in 20 contains some type of Bluetooth device that can be detected. Not every Bluetooth device is detected at every station so the number of matched detections (a device detected at two consecutive detectors) is lower. Even so, a majority of the detected devices are seen at multiple stations. The density of matched pairs can be used not only to develop a sample of travel time for a particular segment of the roadway, but to also estimate the variance of the traffic stream. Figure 2 shows data from a segment of Interstate I-95 between Washington, DC and Baltimore, Maryland between 6:30 AM and 12:45 PM obtained with an early generation of prototype equipment. Each data point represents the travel time from a matched detection at each end of the segment. Figure 3 depicts the impact on travel time as a result of an incident that began around 10 AM, was cleared at approximately 10:50 AM and traffic returned to normal flow around 11:15 AM.

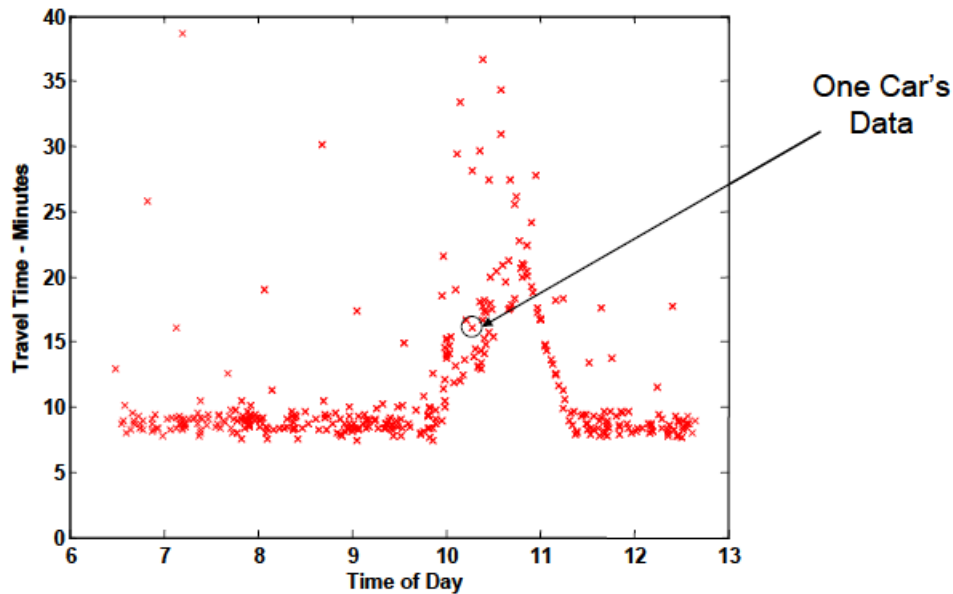


Figure 3 Sample Bluetooth data taken along a segment of I-95 between Baltimore and Washington, D.C.

Research and Development Results

The effort to develop a system for continuous monitoring of travel time on freeways was divided into a series of objectives, with related tasks and corresponding deliverables. The research results are organized along the original proposed objectives. Each of the objectives are briefly summarized, the key findings discussed. The original proposal detailing the tasks and deliverables is included in Appendix G for reference. Specific contract deliverables and documentation related to the project are included in the appendices and referenced in the research discussions that follow.

Objective 1: Specifications for Permanently Mounted Bluetooth Detectors

The roadside operating environment has unique requirements for reliable long-term operations. Life-cycle costs include not only the capital investment of the sensors, but also infrastructure expenses for mounting, communications and power as well as any maintenance and calibration activities. Cost-effective travel time monitoring includes not only well designed hardware, but well thought out concept of operations, and adaptable and configurable hardware and software to minimize installation and upkeep.

Specifications were obtained through review of existing roadside equipment, discussions with SHA personnel related to life-cycle cost of systems, and experience from related industries. The primary issues considered for the permanent sensor (over and above what was designed for portable operations) included key life-cycle cost items such as installation, power, communications, and maintenance. Whereas the portable BTM sensor operated on battery and stored data to an internal memory card with opportunities for maintenance and service between data collection activities, the permanent sensor needs continuous power, a means to communicate data in real-time, and reliability to avoid expenses of field maintenance.

In order to support efficient deployment, the power sub-system of the permanent BTM sensor needed to easily run on solar energy, inferring an overall power budget of less than 5 watts, preferably less than 2 watts, of equivalent power draw. The inherent low-power of the BTM technology designed for the portable unit to maximize battery life provided a baseline power budget of approximately a 2 watt equivalent continuous power draw. As a result, solar re-charging was easily accommodated with a 30 watt solar panel array, even in northern reaches of the continental United States.

Field communications have historically been a major contributor to cost. Installation of landlines (either telephone or fiber) is expensive, and, if the service is leased from a telecommunication carrier, monthly service charges are also incurred. The specifications of the permanent unit required the ability to use cellular wireless data connections, as well as take advantage of permanent landline communications where available. The permanent BTM design incorporates a global system for mobile communication (GSM) cellular modem. The bandwidth needed for BTM data is minimal, typically less than 100Kbytes per month. Such bandwidths are easily accommodated even on older 2G (GPRS) networks. Reliability of cellular communications is a critical design issue. Several firmware upgrades were needed in the prototypes to insure recovery from network outages.

Both the solar and cellular sub-systems can be omitted if the installation site is already served by grid power and/or landline communications. If not present, the life-cycle cost of the solar/cellular combination is much less than providing for grid power and/or landline communications. Additionally, the solar/cellular combination provides flexibility in order to take advantage of existing structures for installation – further minimizing costs.

Appendix A contains the specification sheet that is a result of the real-time development. Appendix B contains the concept of operations (CONOPS) for the entire system – including both sensor hardware as well as central processing (discussed in objective 2). This CONOPS was initially drafted in support of this project, and later refined for the SBIR effort. The environmental and temperature operating ranges for permanent sensors were the same as that for portable unit, and were derived from the NEMA TS-2 standards, as applicable to traffic control devices.

Life-cycle costs include several factors. Assuming a five-year life, the per-sensor cost estimate for BTM is provided in Table 1 for a solar/cellular sensor unit. Apart from the capital cost for the sensors, the two primary cost issues include installation and carrier communications. Installation is estimated at \$500 per sensor based on experience installing prototype units that use solar power and take advantage of existing structures. Installation costs are further minimized due to rapid deployment (less than 30 minutes per sensor), and the ability to mount to structures on side of road, off the shoulder (requiring only short-term shoulder closure). This combination minimizes safety concerns during deployment, further minimizing installation costs. If the location requires additional safety precautions such as bumper trucks on narrow shoulder roads for example, the installation costs will increase. However, experience from the prototypes, and subsequent SBIR project experience indicated that maintenance of traffic (MOT) is absolutely minimal with BTM. Recurring data charges are based on a \$40 per month plan for 200 MB data. Plans currently range from \$30 to \$60. If local communication options are available, recurring data charges may be eliminated.

As of the writing of this report, the prototype units have been in place for approximately 12 months, which is insufficient to validate long-term maintenance needs. The sensor design contains no parts that

require periodic or routine maintenance. The sensor consists of a field hardened processor with various radio subsystems. No field tuning or calibration is required or foreseen for the BTM sensor. The primary maintenance items may arise from the power sub-system, particularly if a solar power option is used. Typical batteries for solar applications are specified for a five year life. Field visits to the prototype units have been prompted by firmware upgrades, which will soon be done remotely. The need for firmware upgrades has been driven primarily to increase the reliability of communication between the internal cellular modem and the cellular network for real-time reporting. With the prototype units becoming a part of the larger SBIR deployment which is scheduled to last through December of 2012, approximately two years of maintenance experience will be available for reference.

Table 1 Life Cycle Cost Estimate for BTM Technology

Life Cycle Costs per sensor - based on 5 year deployment

Equipment Capital Cost - Solar / Cellular option	\$ 4,000.00
Installation	\$ 500.00
Communications - data charges	\$ 2,400.00
Based on \$40 per month data plan	
Central Server	\$ 300.00
Total	\$ 7,200.00

In Table 1, no ongoing maintenance is listed. As these are primarily digital devices, no tuning or calibration is required.

Objective 2: Equipment Design for Permanent Mount Bluetooth Detector

The sensor equipment design was based on the core technology of the portable detector. Figure 4 illustrates a sample installation on a telephone pole near CATT. An actual installation is depicted in Figure 5 in which a BTM sensor is mounted on the same pole as a radar based speed detector (top of pole) and a traffic cabinet (near the bottom.)

A user manual for the permanent sensor is included in Appendix C. It represents the configuration as deployed in the six prototypes as well as in the extended deployment to support SBIR.



Figure 4 Sample Permanent Installation



Figure 5 Actual Installation of BTM Unit

Objective 3: Specifications for Application Monitoring Software

Unlike portable units that log data only for short time durations from a few hours up to a few days, permanent installations will require 24/7/365 data logging, reporting, and archiving. Also, the data architecture must include adequate protection to safeguard the data transmission and storage from eavesdropping.

The architecture for data flow is reflected in the diagram in Appendix D. The specifications and requirements specific to a real-time server are also included in the CONOPS in Appendix B. The resulting real-time software currently in operation servicing the six prototype units was developed in cooperation with Fast Lanes software. The operations manual is available in Appendix E. The real time software can be accessed at:

URL: Traffax1.BluFaxWeb.com
Login: mduser
PW: mdpw

Objective 4: Develop, Test, and Demonstrate Prototype

Real-time units were produced in coordination with Traffax Inc. The six sensors were installed starting in early 2011 and have been running the majority of the year. The demonstration will continue as the units are being combined with another 24 units deployed on I-270, I-495, Rockville Pike and other crossing-linking arterials. Appendix F contains the installation sheets for each of the six prototype deployments. These units will continue to operate as part of the SBIR project through 2012.

Objective 5: Validate accuracy, effectiveness, and operational parameters of the system

The prototype system has been running for the majority of 2011. As reliability issues have occurred, software and hardware have been altered. All data is recorded to a central database and data sets are downloaded nightly. Management of these large data sets have proven challenging. Nightly data downloads are currently stored offline with plans to organize and make them available through a protected web resource. Base data averages about 1MB per day per sensor. Similarly the real-time server has storage capacity for approximately six months if servicing 50 sensors. Archive and long-term retention policies are currently being developed.

The level of travel time accuracy and granularity available on the deployed BTM sensors is significantly greater than other data assets. The accuracy and operating parameters of BTM technology has been verified both externally to UMD (independent tests) and internally within the department of Civil and Environmental Engineering and CATT. A number of these studies are summarized and cited below. Moving forward, the parallel traffic detection within the SBIR project will be compared against other traffic data devices, and ultimately directly compared in real-time in RITIS.

As BTM is a direct sample of travel times, it is difficult to get data sources for direct comparison, that is other data sources that directly sample travel time. Such data is typically associated with either drive testing, license plate matching, or automated toll tag data, all of which are not prevalent and costly when conducted. Some of the studies cited were examples of data sources for direct comparison. Comparison with spot speed sensors is possible, and one such study on an ATR on US29 was cited. Consistency of BTM data with existing speed sensor data on I95 in the corridor monitored with the prototype BTM system could be valuable, both as a validation measure as well as to determine operational differences between differing monitoring approaches.

1) *Validation of BTM data against Automatic Traffic Recorders*

Data taken, in cooperation with Maryland SHA HISD, at an automated traffic recorder (ATR) on US route 29 west of Baltimore was compared with speed and count data taken with BTM equipment. The results of one such comparison is shown in Figure 6. The entire results are included in Appendix H. Figure 6 shows the relative agreement between the ATR and Bluetooth data for a single day. The top two graphs depict the daily speed profile on this 0.3 mile segment. The bottom two charts compare traffic volume distribution throughout the day. The number of Bluetooth detections was factored by the detection rate in order to create the volume density charts for comparison with the ATR.

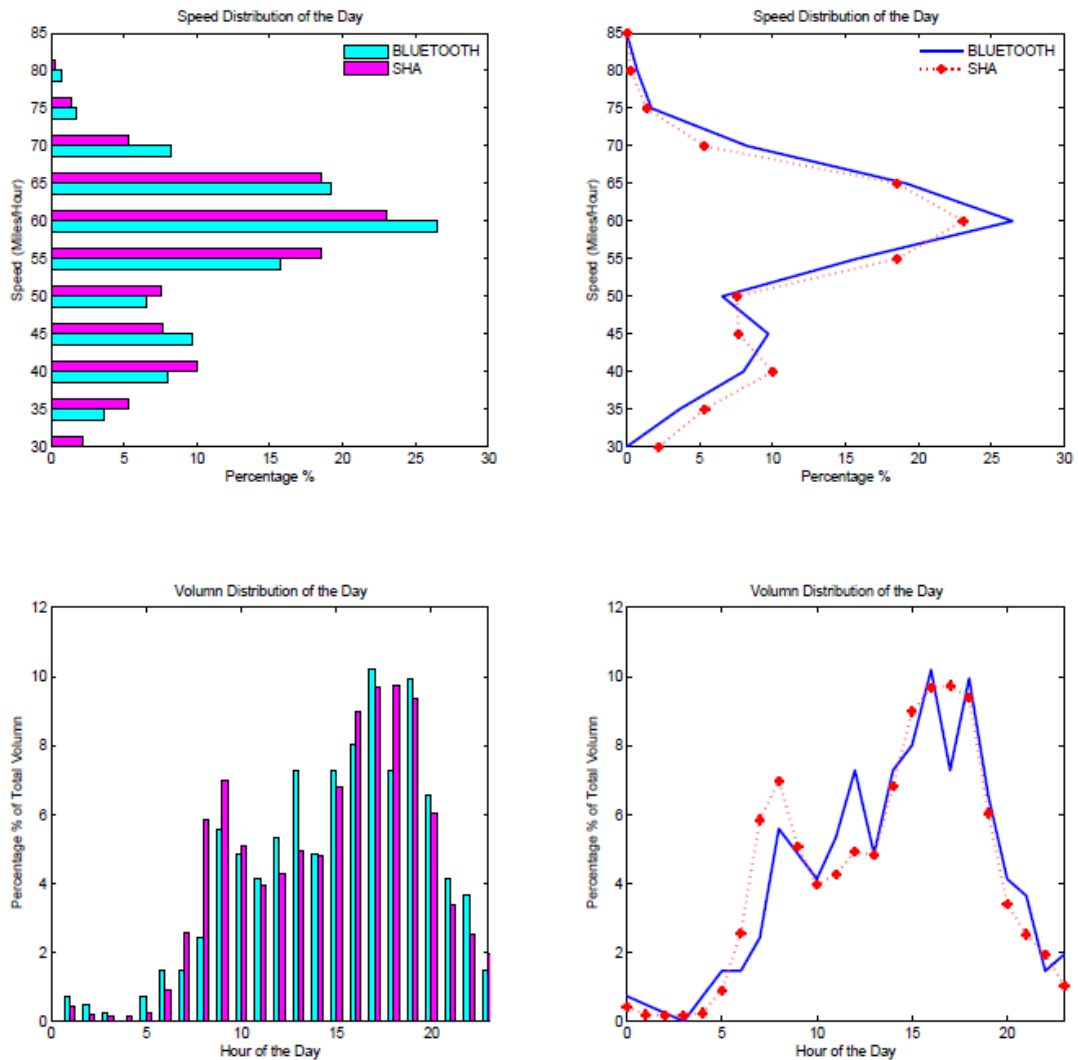


Figure 6 Comparison of Bluetooth speed and volume data with ATR on US-29 Northbound on October 25, 2008

The Bluetooth speeds compare favorably with speed sensor data of the ATRs with no apparent biases. Note that the data was taken on a 0.3 mile section of roadway which is less than the recommended minimum of 1.0 miles for freeways; even so the speeds were shown to be consistent with ATR data at one hour averages. The volume of Bluetooth samples is shown to be proportional to absolute volume throughout the entire day, not changing with peak hour versus off-peak hour, or daylight versus nighttime, or any daily temperature cycling.

2) Comparison with Toll-Tags

Bluetooth Traffic Monitoring (BTM) technology was compared directly against travel times obtained from the toll tag system on a section of I-80 in San Francisco. BluFax sensors were collocated with toll tag stations, data was collected over a period of two weeks, and travel time

and speeds were compared directly. The experiment tested whether the sampling rate of BTM technology was sufficient to reflect accurate travel times and speeds as compared to toll tag derived data, and to test the percentage of vehicles sampled as compared to toll tag readers. The travel times and speeds were shown to be equivalent to those measured by toll tags. Furthermore, the sampling rate was sufficient not only to characterize central tendency (mean and median) but also to estimate variance measures (standard deviation and percentile measures). A description (including graphics) of this study is included in Appendix I.

3) *Analysis of Vehicle Detection Rate for Bluetooth*

Detection rate for BTM technology varies with region. In the Maryland and Mid-Atlantic States, detection rates from 2 percent to 7 percent have been observed. The physical factors impacting detection are primarily distance and proximity to the traffic stream. The detection rate experience throughout the I-95 Vehicle Probe Project validation program is documented in *Analysis of Vehicle Detection Rate for Bluetooth Traffic Sensors: A Case Study in Maryland and Delaware*, by Elham Sharifi of the University of Maryland presented at the Intelligent Transportation Society (ITS) World Congress in October 2011. It documents observed detection rates in the two to seven percent range from direct placement on the ground during validation activities.

Through partnership with Purdue University, the sensitivity of sensor height to detection rate was well documented in a paper titled, *Influence of Vertical Sensor Placement on Data Collection Efficiency from Bluetooth MAC Address Collection Devices*, by Thomas M. Brennen Jr. and others published in the December 2010 issue of the Journal of Transportation Engineering. The work analyzed the impact of antenna height and found that an antenna placed at 10 feet elevation relative to the roadway maximized detection rates, about twice that observed with sensors which were set on the ground.

Additional analysis related to antenna type, placement and reliability of detection can be found in the following articles, the base research of which was performed in consultation or cooperation with either the UMD CATT or Traffax Inc.:

R.A. Rescot and S.D. Schrock. Evaluation of Antenna Options for Bluetooth Traffic Data Collection, University of Kansas

J.D. Porter, D.S. Kim, and M.E. Magaña. *Wireless Data Collection System for Real-Time Arterial Travel Time Estimates, Final Report*, Oregon State University, RS 500-410 OTREC-RR-10-16 for the Oregon Department of Transportation Research Section

4) *Accuracy of BTM as Compared Against Drive Testing*

Drive testing is considered by many as the most accurate method to obtain travel time data, though expensive and typically obtaining minimal samples as compared to other methods. The validation of the Vehicle Probe Project provides one such analysis. The initial validation report titled, *I-95 Corridor Coalition Vehicle Probe Project: Validation of INRIX Data July-September 2008, Final Report*, and available on the I95 Corridor Coalition website at http://www.i95coalition.org/i95/Portals/0/Public_Files/uploaded/Vehicle-Probe/I-95-CC-Final-Report-Jan-28-2009.pdf, details the statistical comparison made between BTM and drive test.

The result was that BTM was considered sufficient source of ground truth data for validating Vehicle Probe Project Data delivered by INRIX Inc.

In a paper titled, *On Measuring Traffic with Wi-Fi and Bluetooth*, presented at ITS World Congress in October 2011, researchers Andreas Luber, MarekJunghans, Sascha Bauer, and Jan Schulz compared BTM and WiFi technology to actual speeds and travel times on a controlled test track. Even though findings were primarily to contrast Bluetooth™ to WiFi approaches, the controlled test environment definitively documented the speed and travel time accuracy of the system.

As the SBIR continues the deployment and operation of the BTM technology in Maryland, further opportunities to compare and contrast sensing technologies through the integration of the data into RITIS will emerge. Not only is confirmation of travel time an objective, but also the confluence of data sources (INRIX, Bluetooth, ATRs, and RTMS detectors) to create full observation of traffic flow – that is both speed, travel time and volume. Such metrics are critical to begin to predict future conditions and actively manage the system

Conclusions, Lessons Learned, and Future Work

From late 2007 to the present, the University of Maryland (UMD) Center for Advanced Transportation Technology (CATT) with support from the Maryland State Highway Administration (SHA) has developed a new traffic monitoring technology based on re-identification of Bluetooth™ media access control (MAC) addresses commonly found in consumer electronic devices. The proof of concept, prototypes, and subsequent commercialization of the technology is fundamentally changing the way many traffic data analyses are performed for operations, planning, and traffic engineering applications. The latest project, developing a Bluetooth™ traffic monitoring (BTM) system for permanent installation and continuous monitoring, has extended the use of BTM technology from special studies to a real-time continuous source of travel time data.

The design, development, testing, and operations of the six prototype units fulfilled the primary objective of demonstrating BTM as a real-time sensor. The base electronics from portable units were combined with power and communication sub-systems to produce an easily deployable sensor that can be mounted on existing structures quickly and inexpensively. The sensors can take advantage of local power and communications resources if available. Data from each sensor is forwarded via the internet to a central host processor. At the central server, the individual observations of MAC addresses are combined and processed to yield real-time estimates of travel time and speed. Archive data from the system are also available to support engineering and planning analysis.

Critical issues in the execution of the project were primarily reliability of wireless cellular communications, and understanding and working within the procedures for roadside deployment of equipment. In the former, several firmware upgrades were needed so that sensors could reliably operate and report BTM data over the cellular network. Cellular data is subject to outages and downtime, and the sensor must accommodate by sampling network availability, and if needed, store data and reconnect when data connectivity is available. Whereas landline communications are more

reliable, the capital and maintenance cost must be measured against the quickly deployable, minimal (if not zero) capital cost of wireless communications, and its ongoing subscription fees.

With respect to the procedures for roadside deployment, BTM's ability to be mounted on existing structures, off of the right-of-way, with installation times of less than 30 minutes provides the minimum exposure to safety hazards, and thus minimizes deployment costs associated with extensive maintenance of traffic (MOT) procedures. Original deployment concepts of mounting the sensor in the median were converted to left-side or right-side installation to avoid unnecessary cost and hazard exposure during deployment.

An unanticipated challenge that emerged was management of the volume of data collected with BTM. Combined with its ever expanding breadth of applications, it became imperative to keep archive data online for engineering and planning analysis after its real-time benefits were realized. Whereas the original concept envisioned BTM as primarily a real-time monitoring tool, the central software anticipated keeping the data online for only a short period associated with operations applications – possibly a week of historical look-back for real-time comparison. It did not anticipate keeping a perpetual archive. Data storage requirements for a perpetual archive exceeded the server capacity within six months of operation, requiring archive data sets to be off-loaded to other storage facilities. Each prototype sensor contributes approximately 25 to 50 megabytes per day (fully processed) on average to the real-time server. The quantity of data is not large when compared to available disk capacities, but is substantial for conventional database processing. The base 'raw' data contributed by each sensor (prior to processing) is roughly 1.0 megabytes per day. This indicates substantial room for storage efficiency. An appropriate database organizational scheme for the base and processed data is needed for fast retrieval and more efficient long-term storage. For this reason long-term, storage costs are not anticipated to be substantial. As part of the SBIR initiative, the Maryland Industrial Partnerships program is funding integration of the Bluetooth data into RITIS. This is expected to come online later in 2012, and will provide an opportunity to measure the long-term storage requirements and costs.

The use of BTM data for Origin & Destination (O&D) analysis, planning, performance measures and other applications have extended the shelf life of the data from the real-time monitoring system. Likewise an efficient storage, retrieval and processing architecture to support other applications is currently being pursued as the Small Business Innovate Research (SBIR) program continues. Data from the Maryland State Highway Administration (SHA) prototypes will be combined and made available.

Other opportunities for BTM technology and data have emerged in the past twelve to eighteen months. As the BTM technology has matured, application areas continue to expand. Future consultation with Maryland SHA is requested to prioritize additional analysis and development in light of CHART's business needs:

(A) Real-time O&D is a growing area of study used to observe the impacts of congestion and diversion of traffic during major incidents. The deployment of the SBIR network directed units on Rockville Pike could be used to observe diverting traffic from I-270 during incidents. Similarly, a fully instrumented freeway network would allow observation of changes in traffic patterns as a result of perturbations to flow, such as severe weather, major incidents, and holiday travel – and not just in travel time but also in the prevailing volumes and origin and destination patterns. The ability to do this on a continuous, real-time basis is the next evolution in operations capability.

(B) Use of BTM to characterize arterial corridor operations is growing. BTM is currently in use to document before and after impacts of signal retiming for one or more signals. It is growing as a tool to assess flow performance measures. Performance measures for arterials are in development. Prior to BTM, the traffic engineering community did not possess the granularity of data available at large scale as is now possible with BTM technology. UMD, Traffax Inc., Purdue University, and the I-95 Corridor Coalition all are pursuing work related to the characterization and performance measure aspect of arterial corridors based on high-resolution re-identification data (namely BTM data).

(C) As BTM is a direct sample of travel times, it is difficult to get data sources for direct comparison because few data sources directly sample travel time. Consistency of BTM data with existing speed sensor data on I-95 in the corridor monitored with the prototype BTM system could be valuable to characterize and contrast spot speed measurements system versus travel time sampling.

(D) The use of non-contact sensors such as BTM with a broad detection range with low power requirements provides a means to cost effectively provide real-time observability into the highway system. Whereas a state or local jurisdiction formerly would invest ten to one hundred thousand dollars into a single installation, BTM type technology can be deployed on a life-cycle cost basis that is an order of magnitude less expensive. The primary recurring cost of BTM systems (using wireless communication and solar power) is the recurring data communications subscription charges. BTM is typically low bandwidth, so that several sensors could be served with one internet point of presence. Methods to create effective mesh networks that accumulate multiple sensor's data (BTM, RTMS, and video) to minimize commercial connection charges, and minimize the cost of proliferating new sensors appears feasible. Freeways and major arterials also offer a great potential to serve traveling customers with mobile data. As such it may be possible to create a sustainable business model to not only minimize sensor bandwidth charges, but to also insert a data system that serves information to travelers and provides bandwidth for emergency communications, while minimizing or eliminating cost to the state or local jurisdiction.

The UMD CATT would like to invite Maryland SHA Research to discuss the above ideas, and others, as an outgrowth of this project.