Bluetooth based dynamic critical route volume estimation on signalized arterials

Asmita Gharat

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Civil Engineering

Montasir M. Abbas, Chair

Antoine G. Hobeika

Antonio A. Trani

September 9th 2011

Blacksburg, VA

Keywords: Traffic Responsive Control, VISSIM, Signal Control

Bluetooth based dynamic critical route volume estimation on signalized arterials

Asmita A. Gharat

ABSTRACT

Bluetooth Data collection technique is recently proven as a reliable data collection technique that provides the opportunity to modify traditional methodologies to improve system performance. Actual volume in the network is a result of the timing plans which are designed and modified based on the volume which is generated using existing timing plans in the system. This interdependency between timing plan and volume on the network is a dynamic process and should be captured to obtain actual traffic states in the network. The current practice is to calculate synthetic origin destination information based on detector volume that doesn't necessarily represent the volume scenario accurately. The data from Bluetooth technology can be utilized to calculate dynamic volume on the network which can be further used as input for signal timing design. Application of dynamic volume improves the system performance by providing the actual volume in system to design optimal timing plans. This thesis proposes a framework that can be used to integrate data obtained from the Bluetooth technology with the traditional methods to design timing plans. The proposed methodology utilizes the origin destination information obtained from Bluetooth data, detector data, characteristics of intersections such as number of lanes, saturation flow rate and existing timing plans as a basis for the calculation of the dynamic volume for the various movements at each intersection. The study shows that using the Bluetooth based OD matrix to calculate accurate dynamic volumes results in better system performance compared to the traditional way of using the static detector volume alone.

ACKNOWLEDGEMENTS

While writing this thesis I have received valuable advice and help, for which I am deeply obliged.

First and foremost, I am heartily thankful to my advisor, Dr. Montasir Abbas, for giving me the opportunity to work on this project. His guidance and encouragement helped me during the research and writing of this thesis. I am indebted to my committee members, Dr. Antoine Hobeika and Dr. Antonio Trani for their suggestions and advice. I also want to thank Virginia Department of Transportation for sponsoring the project I have been working on.

I am greatly thankful to Zain Adam for his immense help and support throughout my masters. I thank Bryan Higgs, Linsen Chong, Milos Mladenovic, Lakshmi Rajshekar and Pooja Dwivedi for their help, generosity and friendship.

A special note of appreciation to my friends Sudeeksha, Saloni, Chayanika, Siddharth, Gaurav, Jaideep, Keyur for being there whenever I needed them and making me feel like at home in United States. I am also thankful to Rahul Menon for making me smile during all the stressful days and otherwise.

Special thanks to my friends Savita, Rahul, Kuldeep and Jaspreet for encouraging me to pursue higher education.

I would like to take this opportunity to thank my family for the unconditional love, support and encouragement.

DEDICATION

I dedicate this thesis to my Father, Ananta Gharat, whose love, support, patience, and encouragement provided me with the strength and perseverance I needed to achieve my goal.

TABLE OF CONTENTS

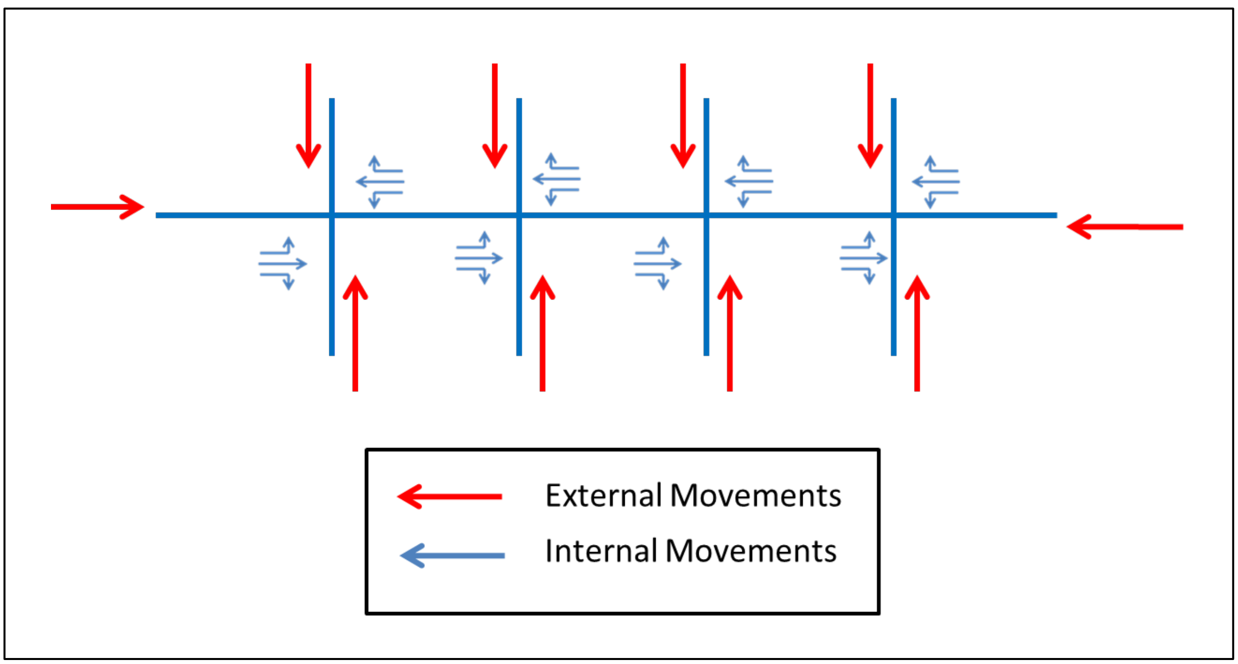
LIST OF FIGURES

LIST OF TABLE

1 Introduction

Efficient operation of signalized intersections is typically achieved through optimal design of timing plans as well as the mode of operation, such as time of the day or traffic responsive control. Timing plans are optimized using various software packages such as PASSER and Synchro. In order to develop optimal timing plans, an accurate representation of traffic states is needed. The optimization is carried over to yield better signal performance in terms of delay, number of stops, or other objectives.

The accuracy of designed and optimized timing plans is based on the accuracy of traffic states representation. Traffic state in this context refers to the existing traffic pattern for all approaches at a certain point in time. Traffic state for an arterial consist of major external movement, cross street movements and internal movements as illustrated in Figure 1.The first two movements describing traffic states and internal movements are generally calculated.



Traditionally, internal movements in an arterial are obtained from either manual counts or system detector logs. Alternatively, if the OD distributions are known, then internal movements can be calculated based on the summation of relevant OD pairs passing through each link. However, none of these two methods take into account the metering effect of timing plans at the peripherals of the network.

Traffic engineers has been limited to static estimation of internal movements due to the lack of resources and detailed OD knowledge at the intersection level. However emerging technology brought new solutions to this challenge. Conventionally the origin destination information was calculated using different statistical approaches. Synthetic OD estimation is one among the popular approaches. The statistical approaches are based on various assumptions which reduce their reliability. Introduction of Bluetooth technology in traffic data collection introduced advanced features in data collection. It has various significant applications like travel time calculation, speed calculation, etc. This technology provided solutions to various challenging problems; obtaining actual origin destination information was one of the major solutions brought by this technology.

Bluetooth Data collection technique collects OD data using Bluetooth Units that capture information from vehicles equipped with any Bluetooth device. It detects the unique MAC Address associated with Bluetooth device and time of detection. By installing number of Bluetooth detection unit at different desired location, it is possible to track the path followed by a vehicle. If the detection units are located at every entrance and exit of an arterial, it is possible to collect the origin destination information of each detected vehicle. Traffic patterns can be derived from collection of origin destination information for significant period of time.

Here, OD information provided by Bluetooth data is applied to calculate the volume associated with internal movement. The distribution of the volume is majorly affected by the green time provided for the respective phase. The volume is dependents on timing plans and the timing plan optimization is based on volume. This interdependency leads to dynamic volume for internal movements.

Dynamic critical route volume associated with network is the continuous changing volume due to change in timing plans provided for the network. Calculation of dynamic volumes involves distribution of external volume. This distribution is based on the OD matrix obtained from Bluetooth data and capacity. Capacity is calculated by using timing plans, amount of green time and saturation flow rate.

1.1 Thesis Objective

The main objectives of this thesis are:

- To develop stepwise procedure to obtain Origin Destination Matrix from Bluetooth data
- To formulate the concept for calculation of Dynamic critical route volume applying OD information obtained from Bluetooth data
- To Design a framework for timing plans optimization based on dynamic critical route volumes.

1.2 Thesis Contribution

This thesis aims at using the Bluetooth technology to design effective timing plans. Traffic signal system performance is predominantly dependent on the selection of accurate mode of operation and selection of precise timing plans. The common practice is to design timing plans with the help of synthetic origin-destination analysis utilizing detector counts obtained from loop detectors. The detector counts are based on the current timing plans. Objective of modification of timing plans is to protect the oversaturated links and inflate the volume in links with higher storage. This metering is based on capacity and it reflects in the form of actual volume which passes through the intersection. The optimization of timing plan should be based on this actual volume which can be calculated by applying Origin Destination information derived from Bluetooth data and demand capacity ratios. This thesis focuses on the development of a stepwise procedure which uses the benefits from the new world technologies to improve the current practice.

1.3 Thesis Layout

The thesis is organized into five chapters. This chapter presented an introduction, research objectives, and contribution of the thesis. Chapter 2 presents the literature review for the concepts used. Chapter 3 describes the development of the methodology used for the implementation of the Bluetooth data to obtain critical routes based on Origin destination matrix for the network. Chapter 4 describes implementation of dynamic critical volume to design and optimization of timing plan. Chapter 5 presents the study conclusions and recommendations for further research.

2 Literature Review

2.1 Overview

Bluetooth Technology proved its application in the traffic management field. It provides the information which was very difficult to obtain for traffic engineers. Using Bluetooth technology it is possible to track vehicle equipped with Bluetooth devices. This Detection of vehicle provides data with unique id and time of detection. The data is used to obtain Origin Destination information within the network. This information is used to highlight Critical route on the network.

In the process of design of timing plans for signalized intersection, the accurate calculation of volume is required. Volume distribution on network is dynamic. It changes with changes in time plans. This change in volume is identified by using origin destination data. The use of dynamic volume in the process of timing plan design and optimization would help to increase the accuracy of the existing methods. This chapter presents the basics of Bluetooth technology, Origin Destination concept, Design and optimization of timing plans.

2.2 Bluetooth data collection technique

Bluetooth is Short-range open wireless communication technology which Works on frequency hopping principle in which random frequency is chosen for each time slot of transmission. Every Bluetooth device has a 48-bit unique address known as Median Access Control (MAC) address-12 digits long. As example: "00:03:6E:21:C6:92" .While detection Bluetooth adapter searches for all discoverable Bluetooth devices in range. This state is termed as Enquiry state.MAC address is sent and received during device inquiry stage[2]. Received MAC addresses are time-stamped and stored. This Bluetooth detection mechanism is explained in following figure.

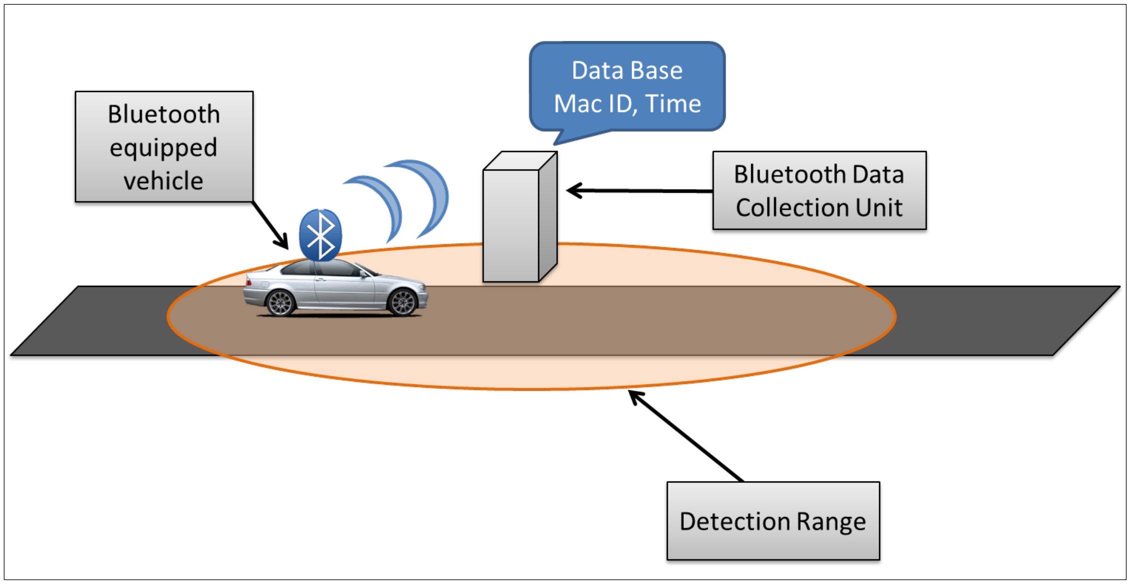


Figure 2 Bluetooth Detection Technique

The Bluetooth data collection units are available in market for purchase or on rent by several different vendors[3]. Along with data collection units some vendors provide the service for collection of data.

The Bluetooth data collection has benefits over other techniques as following:

- It gives Direct measurement of travel time, speed, OD data
- It has Minimal privacy intrusions as only MAC -Median Access Control address is stored[4]
- It doesn't need addition/modification to existing road infrastructure
- It's possible to collect continuous 24 hours database compared with other methods like Automatic License Plate Recognition (ALPR), Toll tag reading, etc.
- It is more economical than existing methods (e.g., ALPR, Road-side surveys, etc.)
- It is possible to perform data collection in locations inaccessible to other types of sensors

The Bluetooth data collection technique provides the MAC address which is equivalent to unit identification number and time of detection of the devices which pass through the range of detection over the period of collection[5].

The most useful application of Bluetooth data is to measure travel time and to estimate origin-destination matrices[6]. Traditional technologies, such as inductive loop detectors, do not usually produce measurements of the quality required by real-time applications.

Bluetooth technology has some drawbacks like it only captures a fraction of vehicles in the traffic stream which has Bluetooth unit. To obtain true representation of field Origin destinations, large amount of data should be collected. Several efforts have been taken to check the reliability and accuracy of media access control (MAC) technology. Bluetooth technique is tested by measuring travel time using MAC readers and comparing with traditional floating-car method[7]. The effort have been taken to evaluate work zone mobility performance by the automated collection and processing of Bluetooth probe data from multiple field collection sites, communicating travel delay times to the motoring public, assessing driver diversion rates, and developing proposed metrics for a state transportation agency.

2.3 Loop detector data applications

The design and selection of timing plans which are best suitable to the traffic states is important tsk in improvement of the performance of overall system. The data used by practitioners to design timing plans is generally detector data collected by various detection techniques such as loop detector, Video Detection, Microwave, Radar, Sonar, Magnetic field detection[8]. The most commonly used data is loop Detector data. The loop detector detection is basically electromagnetic communication and detection system. The vehicle detections loops are generally located near the stop line and also at certain important point on roadway at which the detector data need to be monitored. In this method an insulated electrically conducting loop is installed under the road and electric current circulate through the loop at all times. When a ferrous body which can be iron of steel passes close to the wire loop it results in change in inductance of loop and the vehicle is detected. The loop detector data collection method provides with vehicle count, occupancy and speed of vehicle for specific interval of time based on which controller decides the traffic state and mode of operation the operation[9]. The loop detector data significant applications while dealing congestion problems and travel time calculation.

2.4 Significance of O-D information in process of Signal time plan optimization

The design of signal timing is based on the accurate identification of traffic state. Using loop detector data the volume associated with external movement is calculated. The external volume required to be distributed to obtain volume belongs to internal movement. This distribution involves assumption of equal attraction between two nodes which is unrealistic. The distribution is dependent of origin destination matrix for the network. To obtain the distribution either the simulation need to be done or the actual O-D need to be obtained[4]. The several mathematical approaches are taken to calculate dynamic O-D flow[10]. This is a high-dimensional problem and needs to be decomposed into smaller sub-problems at the intersection and corridor levels. Several schemes have been proposed to decompose this complex problem[11].

3 Validation of Critical routes utilizing Origin-Destination Matrices in Reston Parkway Using Bluetooth Data Collection Methods

Asmita Gharat
Graduate Research Assistant
Charles Via Department of Civil and Environmental Engineering
301-D, Patton Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061
Phone: (540) 449-2721
E-mail: asmita2@vt.edu

Montasir M. Abbas, Ph.D., P.E. (Presenter)
Associate Professor
Charles Via Department of Civil and Environmental Engineering
301-A, Patton Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061
Phone: (540) 231-9002
Fax: (540) 231-7532
E-mail: abbas@vt.edu

Lakshmi Rajshekar
Graduate Research Assistant
Charles Via Department of Civil and Environmental Engineering
301-D, Patton Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061
E-mail: lakshmir@vt.edu

Submission date: August 1st, 2011

Word count: 5880 words (2880 words for text and 3000 words for 2 Tables and 10 Figures)

Prepared for the

Transportation Research Board 2012

ABSTRACT

Bluetooth-based data collection techniques have been recently proven as effective and reliable traffic data collection methods. Several research efforts have been undertaken to utilize Bluetooth information for various important applications, such as travel time and speed estimation. This article aims to add an application of Bluetooth technique to estimate origin-destination matrices thereby to obtain the critical routes on urban arterials, along with the procedure for installation of cost-effective Bluetooth data collection system in the field. The information about critical routes for an oversaturated signalized arterial plays a significant role in the process of designing the signal control system. By applying the information about the origin-destination pairs for an arterial, it is possible to obtain the traffic pattern which provides the fundamental information to identify the critical routes on the arterial. The prioritization of these identified critical routes facilitates the application of traffic signal control strategies. By applying the Bluetooth technique, it is possible to keep track of vehicles equipped with Bluetooth devices such as mobile phones, hands-free kits, global positioning system onboard units, and laptops. The data obtained from detection of these Bluetooth equipped vehicles at various Bluetooth detection unit locations at an arterial was used for identification of critical routes using origin-destination trip matrices for different times and days. The variation observed between these matrices is utilized to validate the critical routes obtain by detector data and presented in this paper to highlight the importance of using such information in designing effective control strategies.

Keywords: Bluetooth data, Origin Destination, Traffic Signal Control

3.1 Introduction

Bluetooth-based traffic data collection is an innovative and reliable method for data collection and travel time calculation [2].Using this evolving data collection method can provide a viable and cost-effective alternative for laborious and time-consuming traditional data collection methods, such as probe vehicles and roadside surveys. Bluetooth data collection methods have already seen an increasing level of interest for estimating travel time on freeways [3][12].The Bluetooth equipment on moving vehicles has a relatively low penetration rate at the movement (8-10%), but is expected to increase with time[13].There is limited literature describing analytical application and use of Bluetooth technology in transportation [14][13]. Implementation of Bluetooth data collection methods is mostly facilitated by several companies in the market for installation and service cost. The cost to implement this technique is high at present, which limits its frequent use by traffic professionals and agencies. However, this is expected to change as the cost of implementation reduces with time. In this paper, we apply a time-offset searching technique to extract and tabulate O-D matrices during different times and dates. This O-D information is useful to understand and design effective control strategies for an arterial network. The last section of the paper explains how this information could be used for this purpose.

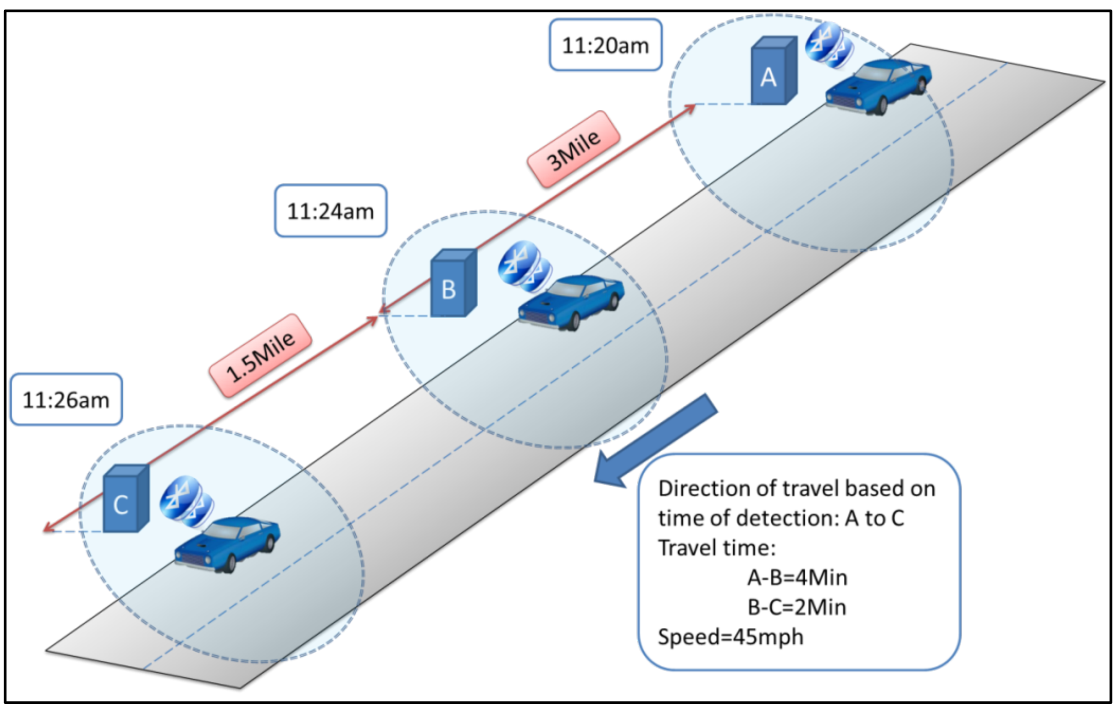


Figure 3 Application of Bluetooth Technology

Bluetooth wireless capabilities are available in most electrical devices in today's market. These devices utilize a Bluetooth protocol with an electric identifier known as the Media Access Control Address (MAC Address)[15]. This MAC Address is unique for any device and can be treated similar to vehicle signature. Each Bluetooth device in the vehicle has a unique MAC Address. A vehicle can therefore be tracked by tracking the MAC Address of any device in the vehicle. The Mac Address can be detected by roadside Bluetooth detection units, along with the time of detection. This information can be utilized as traffic data for various applications as shown in Figure 3. The direction of travel of a vehicle can be obtained by observing the order of detection at consecutive units. Travel time can be estimated by calculating the time difference between detection at two consecutive units. The speed of vehicles can be obtained using the estimated travel time and the distance between units.

3.2 Reston Parkway Arterial

We implemented our Bluetooth data collection technique along Reston Parkway. Reston Parkway is located in the Fairfax County in the state of Virginia, USA. The network has a total of 13 intersections as shown in Figure 4. The length of the entire network is 16,572 feet. The maximum link length is 3,800 feet and the minimum link length is 621 feet .The speed limit for the main arterial is 45 mph, and it ranges between 15 mph and 45 mph for the side streets.

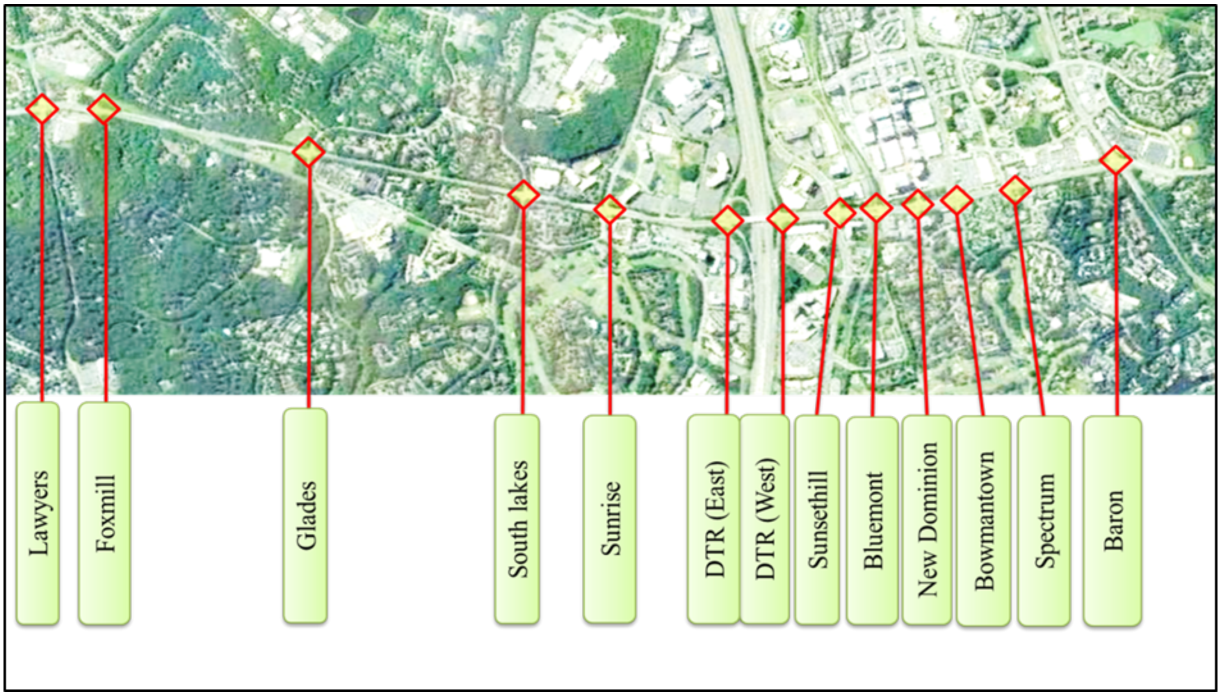


Figure 4 Reston Parkway Network with Intersections

The Traffic condition of Reston Parkway is fairly oversaturated during peak hours, especially at closely spaced intersections such as Sunset Hill road and Bluemont. The Reston Parkway network overpasses the Dulles Toll Road with two intersections from the on- and off-ramp .This configuration results in atypical O-D matrices that are not usually observed in normal arterial networks which in turn justifies the need to obtain accurate measures of O-D matrices for traffic patterns on the Reston Parkway.

Field observation and loop detector data is applied to obtain various Volume profiles along each movements as shown in sample volume profiles in figure 3.The obtained volume profiles suggested some primary critical paths on the network as shown in Figure 5.

A critical path is defined as a series of intersections along which the traffic volume shows a high value or variation throughout the time of day. System detectors installed in Reston Parkway were used to obtain the total number of vehicles passing through or originating from any particular link in the network. The primary critical routes are studied and utilized to decide the location of Bluetooth detection units. The number of Bluetooth units is restricted due to the cost factor. Hence the number of Bluetooth units to be installed was decided based on the criteria that the location of a Bluetooth unit should cover the maximum number of critical routes without confounding the information obtained from each unit (i.e., any significant traffic origin or destination should be covered by one unit to allow the analyst to trace down the source of significant sink or source of traffic on the network).

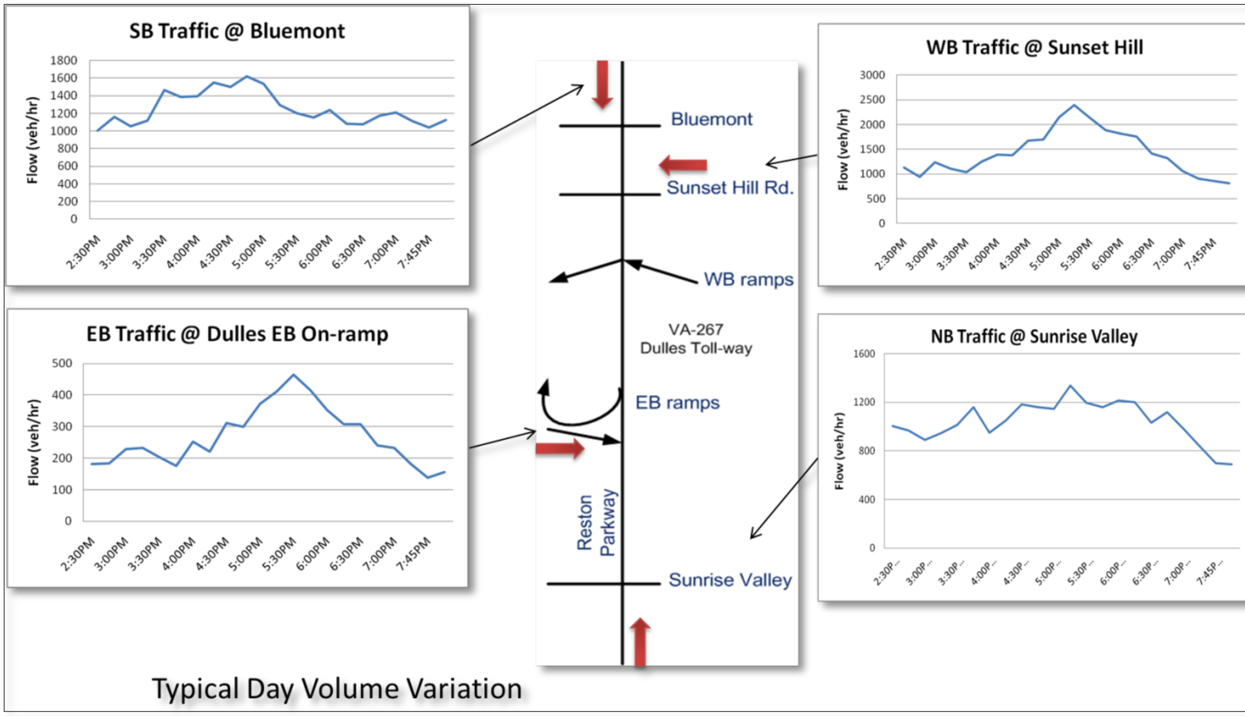


Figure 5 Sample Volume Profiles Estimation based on Detector Counts

The location of Bluetooth units is fixed based on the entrance and exit of the critical routes. The number of Bluetooth units used for this implementation was 9 units that were located and numbered as shown in Figure7.

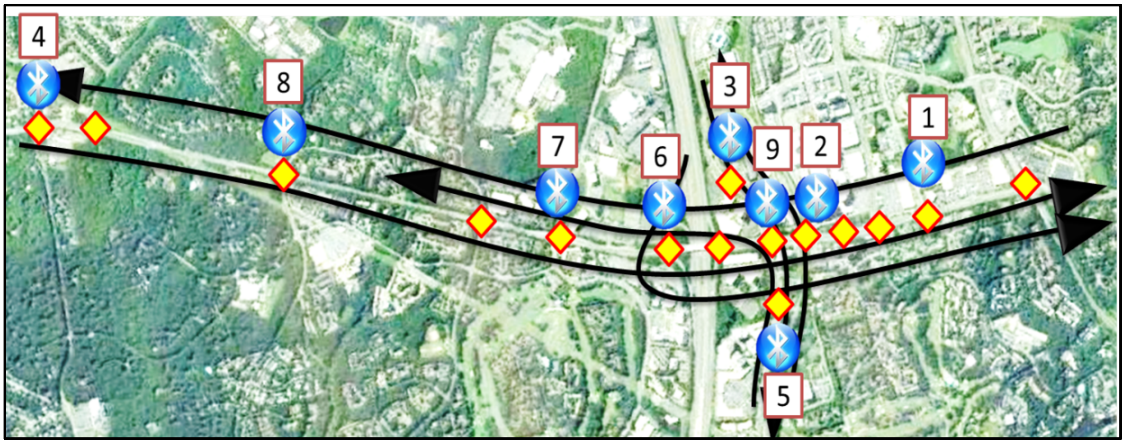


Figure 7 Network with Bluetooth Unit Locations

3.3 Bluetooth Data Collection Setup

There are several types of Bluetooth data collection units that are available in the market. Some of these units require an external electric power supply. It would be a difficult and costly process to provide an external electric power supply in the field at the required locations. There are some Bluetooth equipments which have solar panels embedded, but the cost of these are high, exceeding the available budget of the project. Hence the whole setup of the Bluetooth detection unit was developed to meet the cost requirement and other influencing factors such as the power supply and security of equipment after installation. The data collection unit is developed using the following components shown in Figure 8:

1. Controller Cabinet
2. Netbook (a)
3. Bluetooth adapter (b)
4. Antenna - 5dbi dipole (d)
5. USB extension cable (c)

The Bluetooth technique implementation was part of a project funded by Virginia Transportation Research Council and for the Virginia Department of Transportation, which facilitated the access to the controller cabinet.

Traffic signal controller cabinets are generally located near the intersection where the data collection is required. The controller cabinet is chosen for the installation location of the Bluetooth unit because it has an uninterrupted power supply and it provides security of the installed units to ensure large data collection period.

The netbook with a Bluetooth adapter was used as a data collection unit. The netbook has a Linux operating system, which can run Bluetooth sniffing code to obtain the data. A 5dbi dipole antenna was used to amplify the range of detection. This allowed a range of 100 meters on each side of the road. The netbook with a Bluetooth adapter was kept inside the controller cabinet and the antenna was fixed outside of the cabinet using the USB extension cable. A continuous electrical supply was provided using the plug point available inside the cabinet. Cooling pads were used to reduce the chances of damaging the netbooks due to heat and/or continuous use.

The provided range of the antenna was to maintain a sufficient gap between the detection zones of Bluetooth units which reduces the chances of dual detection. The Bluetooth units were installed at every location and data was collected for 16 consecutive full days.

3.4 Raw Data and Primary Data Processing

Bluetooth data was collected for 18 days, including the day of installation and the day of the collection of units. The days for which the units were installed and collected were excluded from the analysis for data coordination purposes. Hence the complete data set was available for 16 consecutive full days. The total data collection contains 4.5 million data points.

Table 1 Sample Bluetooth Data

MAC ID	Unix Time	Date	Time	Unit No
00:1B:DC:50:14:76	1291004260	11/28/2010	11:17:40 PM	1
00:1B:DC:50:14:76	1291004266	11/28/2010	11:17:46 PM	2
00:1B:DC:50:14:76	1291004274	11/28/2010	11:17:54 PM	3

The raw data was obtained in log files and was extracted to excel file format as shown in Table 1. The first column in Table 1 contains the MAC Address. A single MAC Address will get detected several times at any particular unit. The frequency of enquiry sent by the Bluetooth unit was once every 5 seconds. If the vehicle stays in the range for a large period of time, it can get detected several times.

The second column consists of the time in UNIX time format, which can be converted to date and normal time format using simple formulae. The formulae were applied to the entire dataset. The unit number (ID) was also included in respective data sets for O-D analysis.

Data sets were extracted for each day for each unit and were combined to get the Bluetooth data for each day.

3.5 O-D Estimation Methodology

The collected dataset consisted of all detected MAC Addresses with its time of detections at different units. This information was analyzed to get O-D pairs for the network. Figure 8 explains the methodology applied to extract the O-D pairs. As shown in Figure 8, every vehicle follows a particular path and as a result it gets detected at every unit it passes through. The number of detections at each unit depends on the speed of the vehicle. In our preliminary analysis, the first detection for any particular MAC address at any unit was extracted and arranged in ascending order. This will give the sequence of intersections that the vehicle has passed through. The intersection at which the vehicle appeared first was considered as the origin and the intersection at which it appeared last was considered as the destination. After getting detected at the destination, a vehicle leaves the network. This concept is used to get the O-D pair for each MAC Address. The large number of MAC Addresses are analyzed in an excel sheet using pivot tables to extract the O-D pair for each time period.

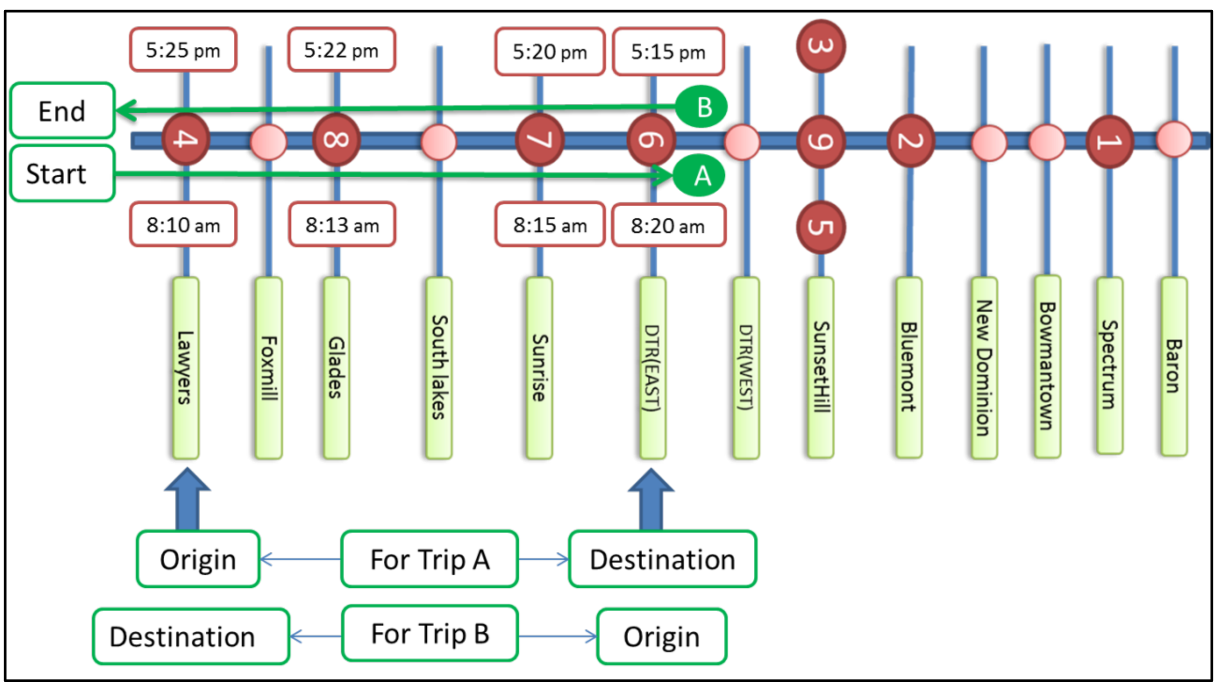


Figure 9 Methodology adopted for O-D Estimation

Detailed observation of the data provided very significant information that there are more O-D pairs available for some MAC Addresses. This is due to the fact that the location of the experiment is basically a commercial zone and most of the vehicles belong to commuter traffic. Hence it was logical that they would have at least two trips a day, one trip is when they drive to work and another trip is when they return home (or any other destination). Any particular O-D pair was associated with a 15-minute time period corresponding to the time of its first detection. The total number of origins present in every 15-minute time period is calculated. Each MAC address is scanned in the network within two time periods to determine the last time it appeared. Two time periods (30 minutes) was deemed enough (and was later validated) to clear the 3-mile long network during congested conditions. This time-offset searching technique resulted in extracting the first O-D pair for any vehicle. The procedure was repeated again by starting with the latest time a MAC address was observed in the network. This latest time was considered as the destination for the second trip. A time-offset search within the previous two periods resulted in the determination of the origin for the second trip. If a vehicle made only one trip on the network, this procedure will result in extracting two identical trips for the vehicle, for which one of them was discarded as a redundant trip.

Table 2 Output from analysis: O-D Matrix

YEAR	MONTH	DATE	ORIGIN UNIT	TIME PERIOD		DESTINATION UNIT								
				Start	End	1	2	3	4	5	6	7	8	9
2010	November	23	1	12:00AM	12:15AM	2	0	3	4	2	1	3	1	1
2010	November	23	1	12:15AM	12:30AM	1	3	4	2	1	1	2	2	1
2010	November	23	1	12:30AM	12:45AM	2	1	2	5	3	4	2	0	2

The 15 minute time period interval was used to match the loop detector data tabulation that was originally used to find the initial critical routes. The MAC Addresses were not considered after this stage in the analysis. The final output of the analysis was conducted in Excel and consisted of summing the total number of O-D pairs for each time period and for each day as illustrated with the example in Table 2.

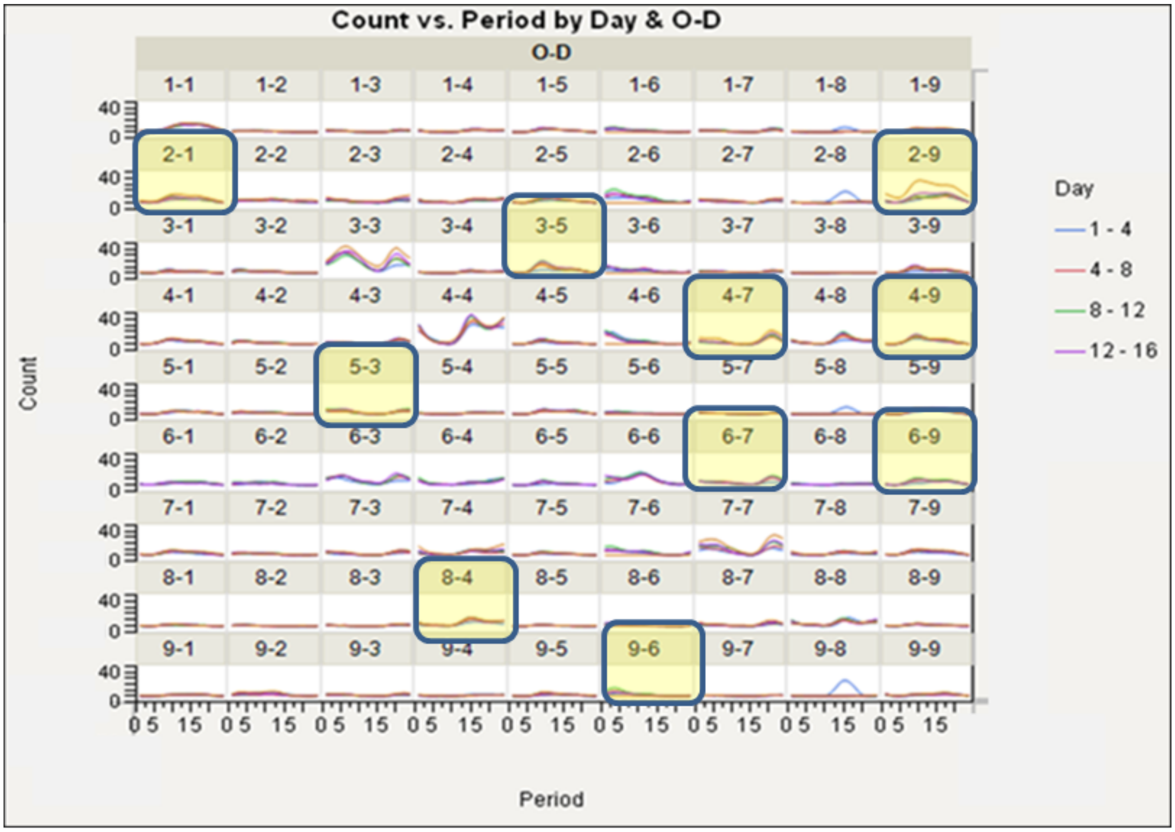


Figure 10 Graphical Representation of O-D Matrix

The output of the final analysis is presented in Figure 8 as obtained from SAS JMP Software. In Figure 10, the analyst can observe that certain O-D pairs do not change significantly over time or over different days. These movements can be treated as a background or base layer of traffic in the network. This critical movements obtained using Bluetooth data are coincides with the critical movement observed using field condition and loop detector data. This observed critical movements that change significantly during the day or during different days emphasize the need for the analyst to address them by designing different timing plans that change in response to changes in these movement (either by a time-of-day or traffic responsive control mechanisms).

In addition, knowing that a critical route has significant number of trips can justify applying certain control strategies. For example, an upstream through movement could be coordinated with a downstream left movement, rather than the through movement if that is what defines the critical route (O-D).

3.6 Conclusions and Further Research

The Bluetooth technique provides a cost effective and high quality traffic data collection method by which the origin destination information of trips within a network can be estimated. The MAC Address obtained is accurately used to obtain data that is otherwise very difficult to obtain. The final output obtained is critical route information based on O-D Pair Matrices for the network during different time periods and days. The information obtained can be utilized in various ways to improve traffic control systems, including optimal design and activation of optimal control strategies.

Future research includes the utilization of real-time O-D estimation in optimal control, as well as the robust analysis of synthetic O-D estimation techniques that are currently used in commercial planning software.

3.7 References

1. Darcy M. Bullock, Alexander M. Hainen, Jason S. Wasson, (2011) “Estimating Route Choice and Travel Time Reliability using Field Observations of Bluetooth Probe Vehicles”, *Transportation Research Board 90th Annual Meeting,* Transportation Research Board, Washington, D.C.
2. Samiul Hasan, Charisma F. Choudhury, (2011) “Modeling Travel Time Variations on Urban Links in London”, *Transportation Research Board 90th Annual Meeting*, Transportation Research Board, Washington, D.C.
3. Jiwon Myung, Dong-Kyu Kim, (2011) “Travel Time Prediction Using the K-Nearest Neighborhood Method with Combined VDS and ATC Data”, *Transportation Research Board 90th Annual Meeting,,* Transportation Research Board, Washington, D.C.
4. James K. Richardson, (2011) “Network Stratification Method to Classify Links by Travel Time Variation”, *Transportation Research Board 90th Annual Meeting,* Transportation Research Board, Washington, D.C.
5. Seth Rogers, (2011) “Travel Time Quality in a Probe Vehicle Network”, *Transportation Research Board 90th Annual Meeting*, Transportation Research Board, Washington, D.C.
6. Dan Van Boxel, William H. Schneider IV, Casey Bakula, (2011) “An Innovative Real-Time Methodology for Detecting Travel Time Outliers on Interstate Highways and Urban Arterials”*, Transportation Research Board 90th Annual Meeting,* Transportation Research Board, Washington, D.C.
7. Stan Young, (2008), Bluetooth traffic monitoring Technology concept of operation and development guideline, Center for Advanced Transportation Technology, University of Maryland, Maryland, USA
8. Xuesong Zhou, Nagui M. Rouphail, (2011) “Analytical Models for Quantifying Travel Time Variability Based on Stochastic Capacity and 4 Demand Distributions”, *Transportation Research Board 90th Annual Meeting*, Transportation Research Board, Washington, D.C.

4 Detector data Analysis

4.1 Preliminary Analysis

System detector data was provided by VDOT for Reston Parkway Network of signalized intersections situated at Fairfax County in Northern Virginia. The data consisted of Count, Occupancy, and Speed for every fifteen minutes time period interval. The preliminary study is done for database of eight month.

The Objective for preliminary study on detector data was to observe traffic variability during different months of year, different days of month and different hours of day. It is possible to derive the traffic patterns based on the variability of the traffic. The initial critical routes are based on this observed traffic patterns.

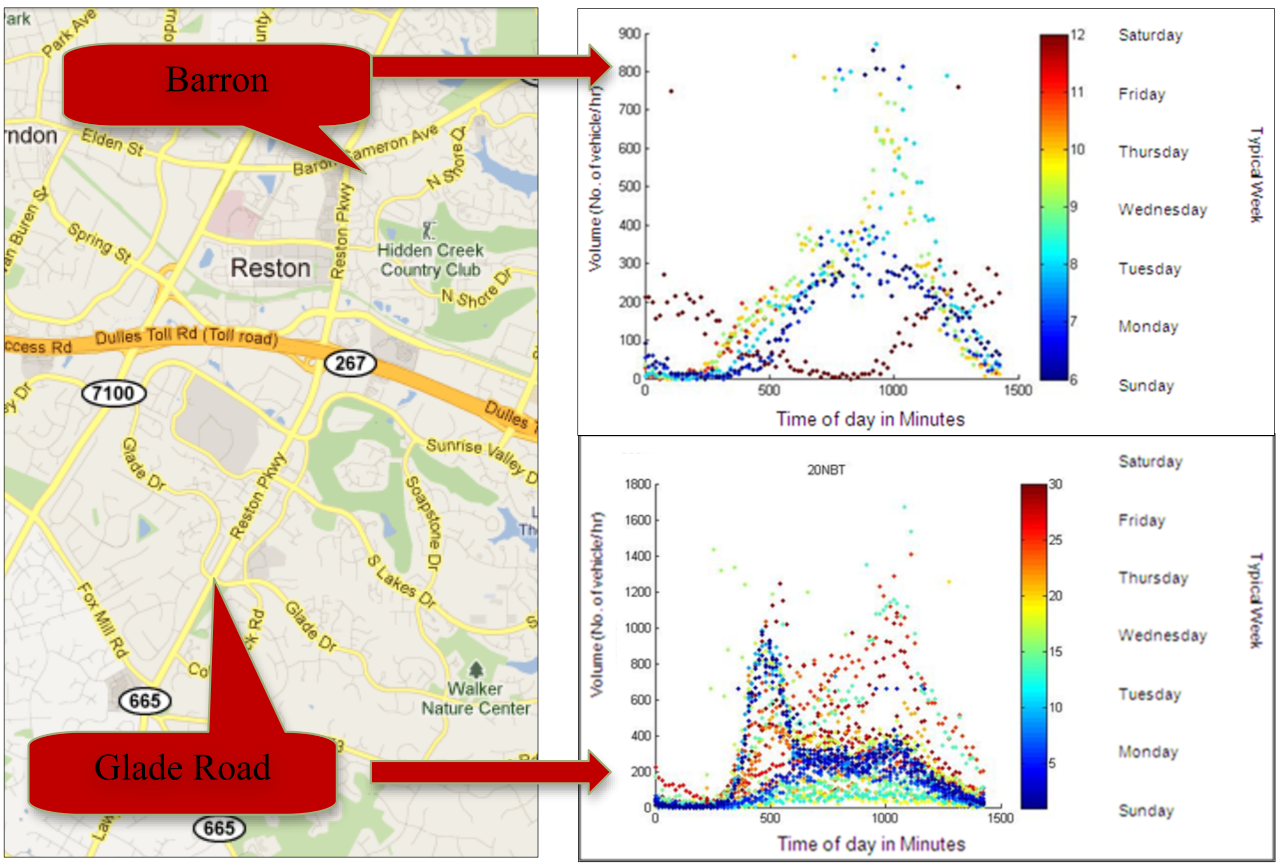
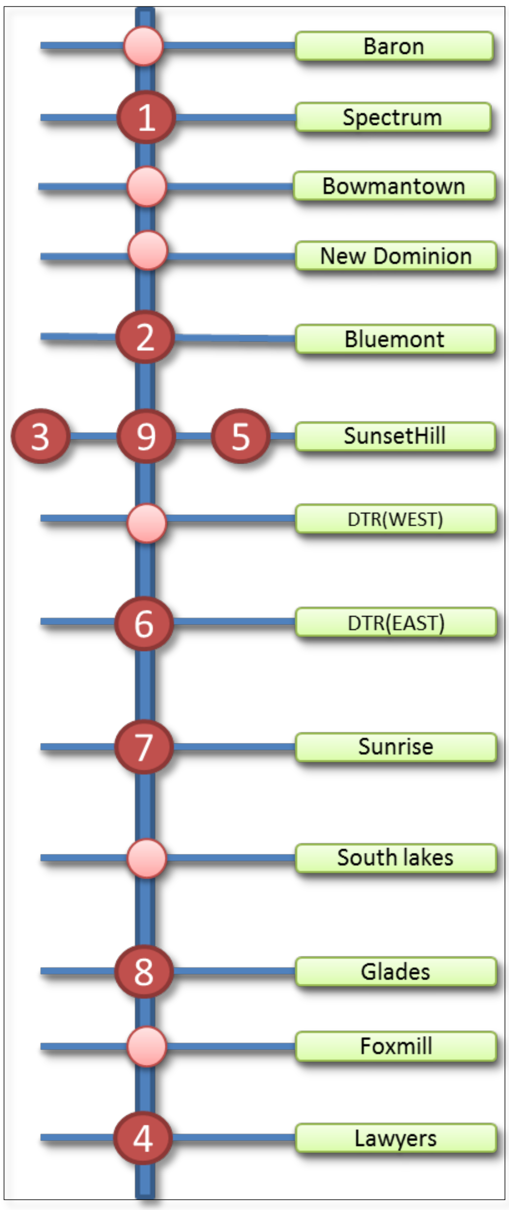


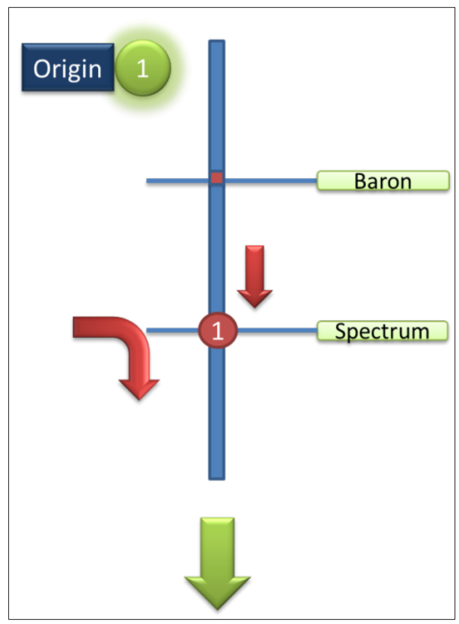
Figure 11 Sample Traffic variation Plots

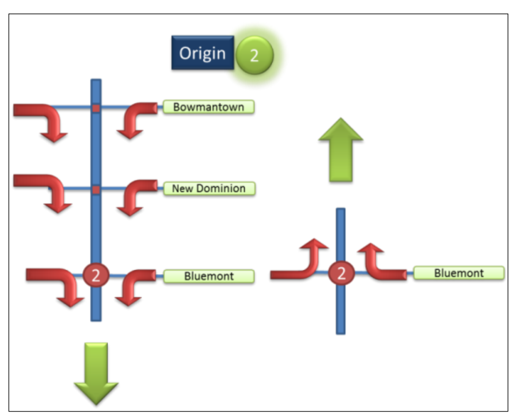
The Figure 11 indicates the variation during time of day and also during day of week. The high variation routes are decided observing plots for all thirteen intersections. The critical routes obtained in preliminary study are used to decide the location for Bluetooth Units.

4.2 Detector Data Based Common Origin Trips Calculation

The objective of performing penetration analysis is to verify the reliability of Bluetooth data. The analysis is performed using detector data. The detector data contains the vehicle count for detectors associated with particular lane. The vehicle count for particular movement can be calculated by adding data from all detectors associated with that particular movement.







All movements belonging to the network are differentiated as inbound movements and outbound movements. The inbound movements at each intersection are basically the turning movements entering the network. In this way that intersection will become origin for all the vehicles which are associated with these movements. Using this concept the number of vehicle that originates from each intersection can be calculated. The addition of vehicle count for all movements starting from particular intersection will provide the total number of vehicle originated from it.

This procedure applied to calculate the number of vehicles originate at each intersection with bluetooth unit and travel to north or south. The addition of South bound and North bound provide total vehicle trip originated from each intersection with bluetooth unit.Following table shows the total number of trips started from intersection consisting Bluetooth unit.The data mentioned start from 24th of November 2010 to 7th December 2010.

Table 3 Detector Data Based Origin Trips

Based on Detector data									
	Origin Unit No.								
Date	1	2	9	6	7	8	4	3	5
24	17278	19508	63099	9058	17798	13621	16287	20690	16709
25	6658	8981	18928	4251	5676	5830	6152	6560	6331
26	12724	16349	40410	6016	9261	8924	10331	12541	12709
27	11903	14072	35334	5680	8412	8340	9991	11192	11198
28	10328	12471	29918	4973	7114	7462	8835	9691	9394
29	14263	18018	64494	9620	18436	13270	15890	21958	15250
30	14603	19176	65920	9808	19259	13366	16140	22220	15671
1	14290	19423	66889	10287	19176	13310	16012	22883	15766
2	14937	19958	69269	10841	21191	13824	16925	23667	16459
3	15877	20637	56834	10534	19334	14231	17352	18887	13968
4	14536	17069	45919	7217	11288	10420	12135	14970	13820
5	11193	13008	33140	5074	7852	8169	9839	10703	10317
6	14326	18579	64677	9576	20079	13497	16389	21946	15098
7	14660	19385	68186	10509	20867	13438	16905	23396	16103

4.3 Bluetooth Data Based Common Origin Trips Calculation

The basic sample of O-D Matrix is shown in followng table.It is modified to make it compairable to the table obtained from the Detector data.The Bluetooth O-D are added for every day.

Table 4 Bluetooth Based Sample O-D table for each time period

Date	Origin Unit	Time period	Destination Unit									Total
			1	2	3	4	5	6	7	8	9	
24	1	1	2			1						3
24	1	2				1						1
24	1	3		1							1	2
24	1	4			1							1
24	1	5							1			1
24	1	6							1		1	2
24	1	7					1					1
24	1	8										
24	1	9	1									1
24	1	10										
24	1	11										
24	1	12										

Following is O-D matrix summerised for 24th November 2010.

Table 5 Bluetooth Based O-D table for a Day

Date		Destination unit									
24		1	2	3	4	5	6	7	8	9	Total
Origin unit	1	271	41	43	49	68	68	68	24	25	657
	2	76	209	60	101	107	141	94	29	179	996
	3	40	52	580	27	221	82	48	11	59	1120
	4	63	107	48	615	68	132	101	142	30	1306
	5	67	67	120	22	154	24	28	6	61	549
	6	84	105	191	96	86	269	167	48	60	1106
	7	74	97	63	67	46	150	322	23	45	887
	8	17	39	12	156	17	48	26	228	4	547
	9	39	131	55	28	68	30	29	13	73	466
	Total	731	848	1172	1161	835	944	883	524	536	7634

Then the O-D starting for one origin are added together daywise to obtain the following table.

Table 6 Bluetooth Unit Based Origin Trips

Based on Bluetooth data									
	Origin Unit No.								
Date	1	2	9	6	7	8	4	3	5
24	657	996	2135	1106	887	547	1306	1120	549
25	316	490	924	581	431	324	598	586	177
26	574	815	1540	732	609	406	895	869	318
27	546	772	1394	813	609	394	850	864	271
28	445	647	1295	808	492	361	785	862	204
29	563	971	2172	1259	961	535	1374	1240	515
30	351	709	4932	747	548	332	680	663	298
1	694	1137	2127	1301	1195	512	1404	1140	552
2	589	1127	2236	1319	1097	552	1435	1078	648
3	621	1150	2284	1294	1010	557	1506	1180	623
4	660	1032	1688	996	735	453	1048	945	367
5	424	767	1264	815	540	381	847	814	254
6	566	1036	2167	1388	966	504	1410	1150	583
7	649	1199	2317	1617	1038	593	1396	1282	559

4.4 Penetration Rate

The Penetration Rate is the percentage trip obtained by Bluetooth dat compared to Detector Data.

Penetration rate=Bluetooth based trip Count Detector based trip Count$\times 100$

Penetration Rate Calculated for each installed using above fomulation.

Table 7 Calculated Penetration Rate in Percentage

	Unit No.								
Date	1	2	9	6	7	8	4	3	5
24	3.80	5.11	3.38	12.21	4.98	4.02	8.02	5.41	3.29
25	4.75	5.46	4.88	13.67	7.59	5.56	9.72	8.93	2.80
26	4.51	4.99	3.81	12.17	6.58	4.55	8.66	6.93	2.50
27	4.59	5.49	3.95	14.31	7.24	4.72	8.51	7.72	2.42
28	4.31	5.19	4.33	16.25	6.92	4.84	8.89	8.90	2.17
29	3.95	5.39	3.37	13.09	5.21	4.03	8.65	5.65	3.38
30	2.40	3.70	7.48	7.62	2.85	2.48	4.21	2.98	1.90
1	4.86	5.85	3.18	12.65	6.23	3.85	8.77	4.98	3.50
2	3.94	5.65	3.23	12.17	5.18	3.99	8.48	4.55	3.94
3	3.91	5.57	4.02	12.28	5.22	3.91	8.68	6.25	4.46
4	4.54	6.05	3.68	13.80	6.51	4.35	8.64	6.31	2.66
5	3.79	5.90	3.81	16.06	6.88	4.66	8.61	7.61	2.46
6	3.95	5.58	3.35	14.49	4.81	3.73	8.60	5.24	3.86
7	4.43	6.19	3.40	15.39	4.97	4.41	8.26	5.48	3.47
Average	4.12	5.43	3.99	13.30	5.80	4.22	8.33	6.21	3.06

The results indicate that the obtained penetration rate is very high at unit 6 which is 13.3%.The location of unit 6 was very near to the freeway which has exit and entrance on both side also there is an over bridge on the freeway which results in large number of vehicle detection. For rest of the units the average penetration rate ranged is 3 % to 9 %.

5 Framework for dynamic critical route volume estimation on signalized arterials

Asmita Gharat
Graduate Research Assistant
Charles Via Department of Civil and Environmental Engineering
301-D, Patton Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061
Phone: (540) 449-2721
E-mail: asmita2@vt.edu

Montasir M. Abbas, Ph.D., P.E. (Presenter)
Associate Professor
Charles Via Department of Civil and Environmental Engineering
301-A, Patton Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061
Phone: (540) 231-9002
Fax: (540) 231-7532
E-mail: abbas@vt.edu

Lakshmi Rajshekar
Graduate Research Assistant
Charles Via Department of Civil and Environmental Engineering
301-D, Patton Hall
Virginia Polytechnic Institute and State University
Blacksburg, VA, 24061
E-mail: lakshmir@vt.edu
Keywords: Bluetooth data, Origin Destination, Traffic Signal Control

Submission date: August 1st, 2011

Word count: 7750 words (3500 words for text and 4250 words for 7 Tables and 10 Figures)

Prepared for the

Transportation Research Board 2012

ABSTRACT

Traffic signal system performance is predominantly dependent on the accurate mode of operation and best selection of timing plans. Recent development in signal timing indicates that it is desirable to design timing plans utilizing synthetic origin-destination information from loop detector counts. Detector movement counts are result of amount of green time allotted to associated phase ultimately to timing plan provided. The relationship between timing plans and traffic counts is dynamic. Hence the change in volume due to improved timing plans should be taken into account while optimizing for best suitable timing plans. The change in volume due to modified timing plans is significant for critical routes. Critical routes are those routes on a particular network which has higher volumes or higher variability in volume or combination of both compared to other routes on the same network. The relevant change in volume for critical route due to modification in timing plan is termed as dynamic critical route volume. This paper proposes the procedure to derive dynamic critical route volume by applying Bluetooth technology. The data obtained from detection of Bluetooth equipped vehicles at various Bluetooth detection unit locations at an arterial was used for identification of critical routes by using origin-destination trip matrices for different times and days. Prioritization of identified critical routes facilitates the application of traffic signal control strategies. The prioritization can be done by calculating dynamic volume with the help of amount of OD passing through this route and capacity for the movement associated with it. The calculation of dynamic volume is proved effective in generation for timing plans and in process of selecting best suitable timing plans based on performance evaluation.

5.1 Introduction

Bluetooth-based traffic data collection is an innovative and reliable method for data collection and travel time calculation [2]. Using this evolving data collection method can provide a viable and cost-effective alternative for laborious and time-consuming traditional data collection methods, such as probe vehicles and roadside surveys. Bluetooth data collection methods have already seen an increasing level of interest for estimating travel time on freeways [3][10]. The Bluetooth equipment on moving vehicles has a relatively low penetration rate at the movement (8-10%), but is expected to increase with time [11] There is limited literature describing analytical application and use of Bluetooth technology in transportation [12][11]. Implementation of Bluetooth data collection methods is mostly facilitated by several companies in the market for installation and service cost. The cost to implement this technique is high at present, which limits its frequent use by traffic professionals and agencies. However, this is expected to change as the cost of implementation reduces with time. In this paper, we apply a time-offset searching technique to extract and tabulate O-D matrices during different times and dates. This O-D information is useful to understand and design effective control strategies for an arterial network[16]. The last section of the paper explains how this information could be used for this purpose.

Bluetooth Data Collection Technique

Bluetooth wireless capabilities are available in most electrical devices in today's market. These devices utilize a Bluetooth protocol with an electric identifier known as the Media Access Control Address (MAC Address)[13]. This MAC Address is unique for any device and can be treated similar to vehicle signature. Each Bluetooth device in the vehicle has a unique MAC Address. A vehicle can therefore be tracked by tracking the MAC Address of any device in the vehicle. The Mac Address can be detected by roadside Bluetooth detection units, along with the time of detection. This information can be utilized as traffic data for various applications in traffic management. The direction of travel of a vehicle can be obtained by observing the order of detection at consecutive units. Travel time can be estimated by calculating the time difference between detection at two consecutive units. The speed of vehicles can be obtained by using the estimated travel time and the distance between units.

Introduction of Reston Parkway

Bluetooth data collection method was implemented along Reston Parkway. Reston Parkway is located in the Fairfax County in the state of Virginia, USA. The network has a total of 13 intersections as shown in Figure 11. The length of the entire network is 16,572 feet. The maximum link length is 3,800 feet and the minimum link length is 621 feet .The speed limit for the main arterial is 45 mph, and it ranges between 15 mph and 45 mph for the side streets.

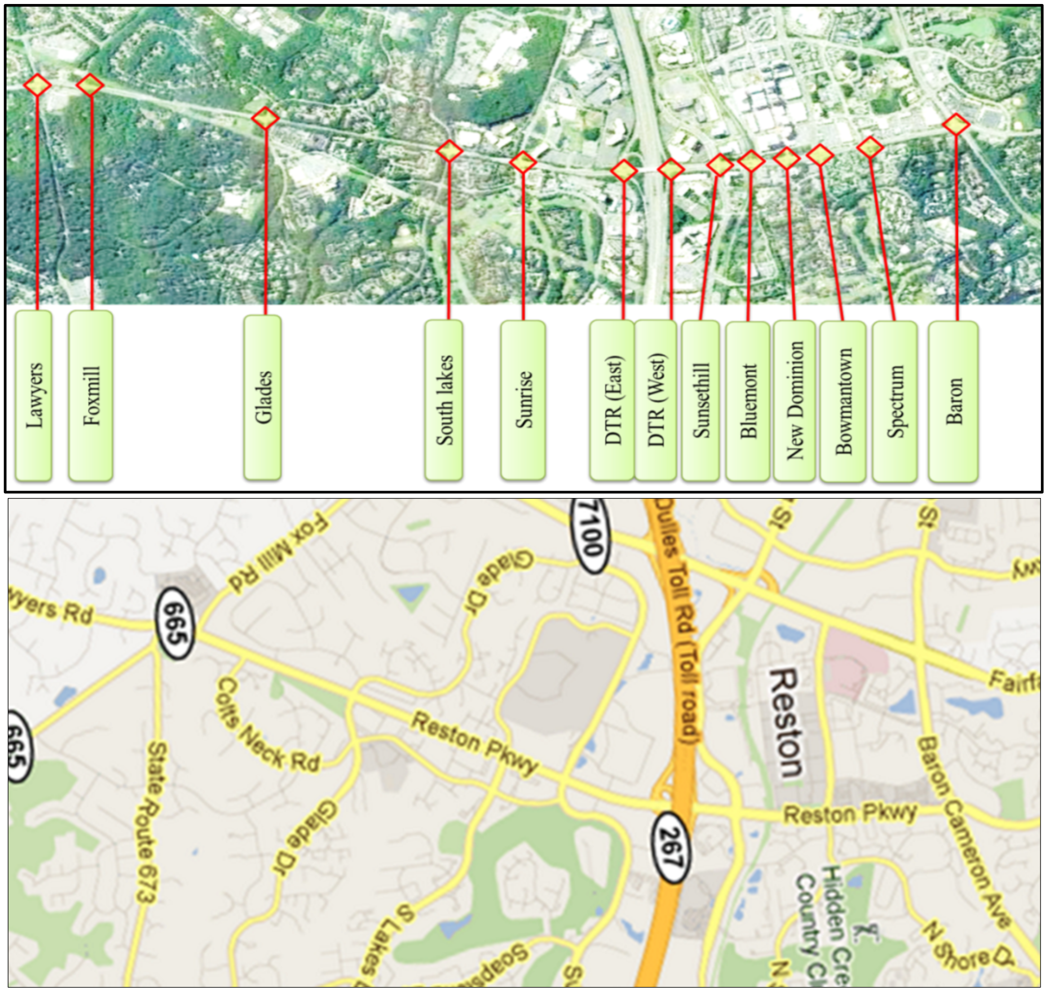


Figure 13 Reston Parkway Network with Intersections

Field observation and loop detector data is applied to obtain various volume profiles along each movement. The obtained volume profiles suggested some primary critical paths on the network as shown in Figure 14. A critical path is defined as a series of intersections along which the traffic volume shows a high value or variation throughout the time of day. System detectors installed in Reston Parkway were used to obtain the total number of vehicles passing through or originating from any particular link in the network. The primary critical routes are studied and utilized to decide the location of Bluetooth detection units. The number of Bluetooth units is restricted due to the cost factor. Hence the number of Bluetooth units to be installed was decided based on the criteria that the location of a Bluetooth unit should cover the maximum number of critical routes without confounding the information obtained from each unit (i.e., any significant traffic origin or destination should be covered by one unit to allow the analyst to trace down the source of significant sink or source of traffic on the network).

The location of Bluetooth units is fixed based on the entrance and exit of the critical routes. The number of Bluetooth units used for this implementation was 9 units that were located and numbered as shown in Figure 14.

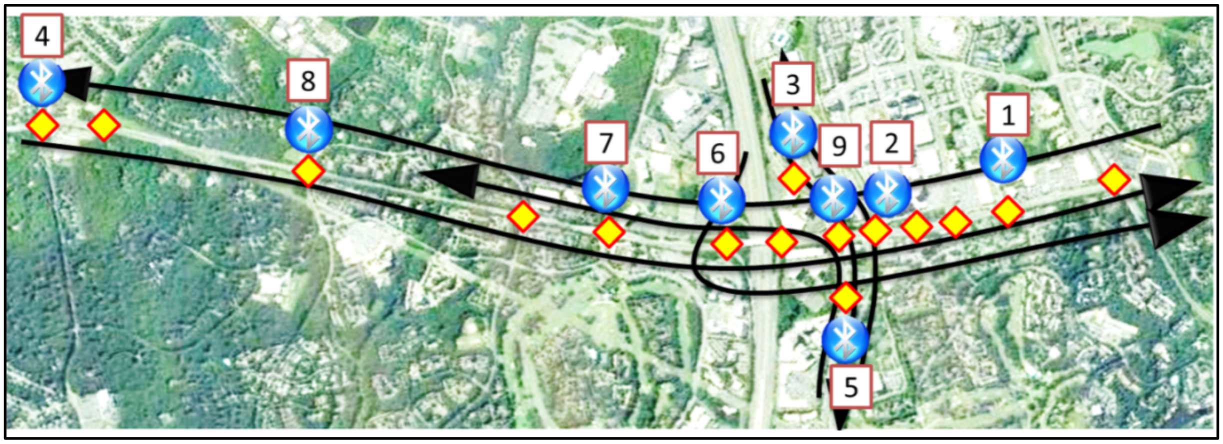


Figure 14 Locations of Bluetooth Units

5.2 Stepwise procedure dynamic critical route volume

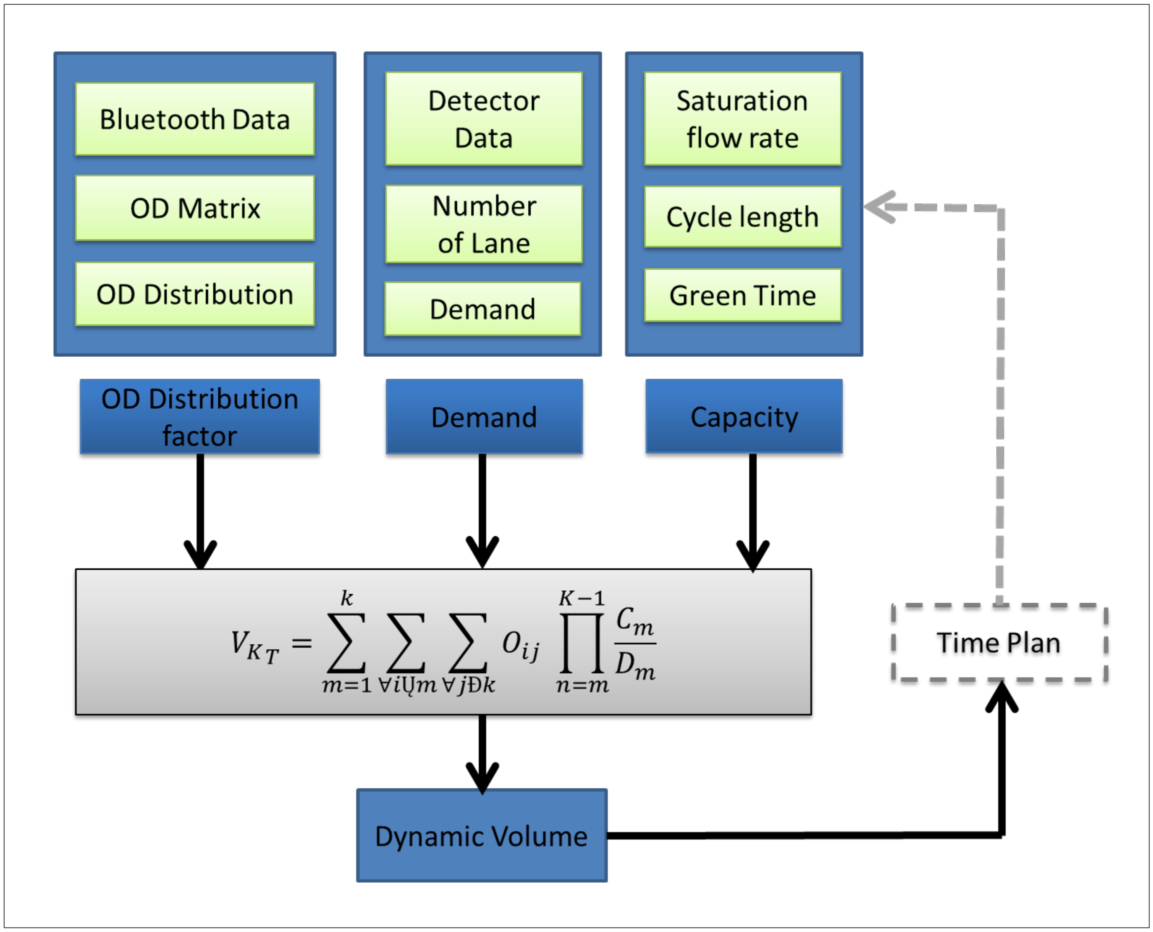


Figure 15 Flowchart for Dynamic Critical Volume

Dynamic Volume is the actual volume which pass through the intersection in the given green time. This volume is based on the capacity , O-D Distribution and Demand.The flowchart shown in Figure13 explain the stepwise procedure to calculate the Dynamic Volume.

The detector data give certain volume for each time period but that volume might not be same if the time plan is changed.If the green time for perticular phase is changed,it will affect the capacity of the movement associated with that phase. Based on the capacity the volume which will actually pass throught will change dynamically.Here the bluetooth data is used to calculate O-D Distribution factor which will be multiplier for the volume. Detector data provide the volume which termed as demand.Existing time plans and Network charateristics such as number of lanes, desired speed ,saturation flow rate are used to calculate the capacity.The dynamic volume is calculated for all outbound movement which are affected by the capcity and O-D Distribution.Following sections are consist of the explaination of the above procedure stepwise in detail.

Estimation of Origin Destination for Network

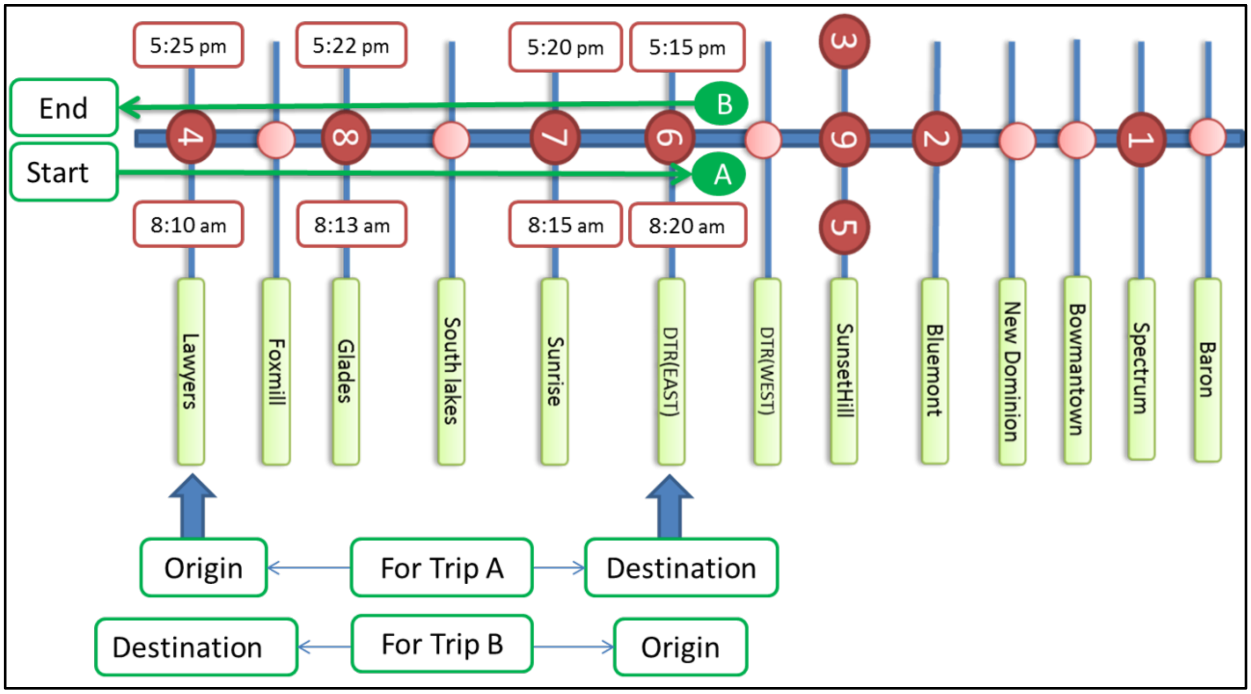


Figure 16 Methodology adopted for O-D Estimation

The collected dataset consisted of all detected MAC Addresses with its time of detections at different units. This information was analyzed to obtain O-D pairs for the network. Figure15 explains the methodology applied to extract the O-D pairs. As shown in Figure 16, every vehicle follows a particular path and as a result it gets detected at every unit it passes through. The number of detections at each unit depends on the speed of the vehicle. In our preliminary analysis, the first detection for any particular MAC address at any unit was extracted and arranged in ascending order.

Table 8 Output from Analysis – O-D MATRIX

YEAR	MONTH	DATE	ORIGIN UNIT	TIME PERIOD		DESTINATION UNIT								
				Start	End	1	2	3	4	5	6	7	8	9
2010	November	23	1	12:00AM	12:15AM	2	0	3	4	2	1	3	1	1
2010	November	23	1	12:15AM	12:30AM	1	3	4	2	1	1	2	2	1
2010	November	23	1	12:30AM	12:45AM	2	1	2	5	3	4	2	0	2

This will give the sequence of intersections that the vehicle has passed through. The intersection at which the vehicle appeared first was considered as the origin and the intersection at which it appeared last was considered as the destination. After getting detected at the destination, a vehicle leaves the network. This concept is used to get the O-D pair for each MAC Address. The large number of MAC Addresses are analyzed in an excel sheet using pivot tables to extract the O-D pair for each time period.

Detailed observation of the data provided very significant information that there are more O-D pairs available for some MAC Addresses. This is due to the fact that the location of the experiment is basically a commercial zone and most of the vehicles belong to commuter traffic. Hence it was logical that they would have at least two trips a day, one trip is when they drive to work and another trip is when they return home (or any other destination). Any particular O-D pair was associated with a 15-minute time period corresponding to the time of its first detection. The total number of origins present in every 15-minute time period is calculated. Each MAC address is scanned in the network within two time periods to determine the last time it appeared. Two time periods (30 minutes) was deemed enough (and was later validated) to clear the 3-mile long network during congested conditions. This time-offset searching technique resulted in extracting the first O-D pair for any vehicle. The procedure was repeated again by starting with the latest time a MAC address was observed in the network. This latest time was considered as the destination for the second trip. A time-offset search within the previous two periods resulted in the determination of the origin for the second trip. If a vehicle made only one trip on the network, this procedure will result in extracting two identical trips for the vehicle, for which one of them was discarded as a redundant trip.

The 15 minute time period interval was used to match the loop detector data tabulation that was originally used to find the initial critical routes. The MAC Addresses were not considered after this stage in the analysis. The final output of the analysis was conducted in Excel and consisted of summing the total number of O-D pairs for each time period and for each day as illustrated with the example in Table8.

Distribution of Origin Destination for Movements

The obtained origin destination pairs are utilized to distribute the percentage of O-D pair for each movement in the network. The inboud movement are all movement by which vehicles are entering in the network and outbound movement are the movement which are leaving the network.A perticular outbound movement is considered to be contributed by various inbound movements .The Table 9 shows the combination of inbound movement for perticular outbound movement. The contributing inbound movements are seperated by northbound and southbound as shown in Figure16 and Figure17.

As an example If outbound movement no 7 is considered, which is southbound right at 3rd intersection.This movement has input listed as 1 and 5.here movement mumber 1 is southbound through at 2nd intersection and movement number 5 is southbound right at 2rd intersection.Here movement 4 is not taken as the intersection 2 is T-Intersetction and movement 4 is absent.aslo the reason for absence of movement 6 is that movement 6 and 7 are belong to same OD Pair.

Table 9 Combination O-D Inbound and Outbound Movements

ORIGIN UNITS	DESTINATION UNITS													
	1		2		9		6		7		8		4	
1			1,5	7,8,9,10,11	1,5	12,13	1,5	15,16	1,5	18,19	1,5	20,21,22,23	1,5	24,25,26,27,28
2	10,11	1, 5,7,8,9			6,7,8,9,10,11	12,13	6,7,8,9,10,11	15,16	6,7,8,9,10,11	18,19	6,7,8,9,10,11	20,21,22,23	6,7,8,9,10,11	24,25,26,27,28
9	12,13,14	1, 5,7,8,9	12,13,14	10,11			12,13	15,16	12,13	18,19	12,13	20,21,22,23	12,13	24,25,26,27,28
6	17	1, 5,7,8,9	17	10,11	17	12,13			14,17	18,19	14,17	20,21,22,23	14,17	24,25,26,27,28
7	18,19,20,21	1, 5,7,8,9	18,19,20,21	10,11	18,19,20,21	12,13	18,19,20,21	16			18,19	20,21,22,23	18,19	24,25,26,27,28
8	22,23,24,25	1, 5,7,8,9	22,23,24,25	10,11	22,23,24,25	12,13	22,23,24,25	16	22,23,24,25	18,19,20,21			20,21,22,23	24,25,26,27,28
4	26,27,28	1, 5,7,8,9	26,27,28	10,11	26,27,28	12,13	26,27,28	16	26,27,28	18,19,20,21	26,27,28	22,23,24,25		
	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound

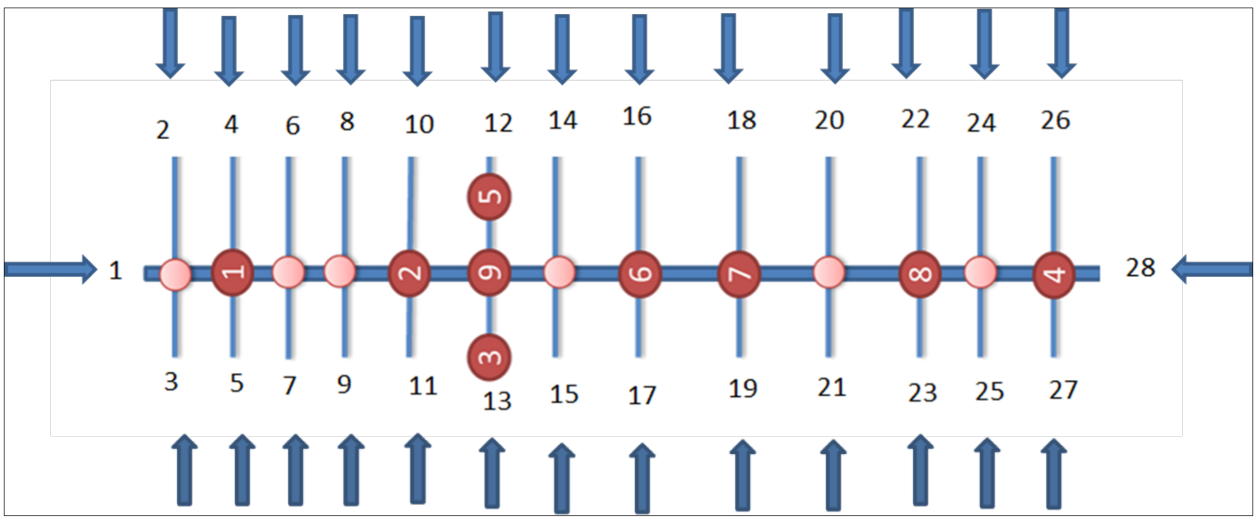


Figure 17 Inbound Movement for O-D Distribution

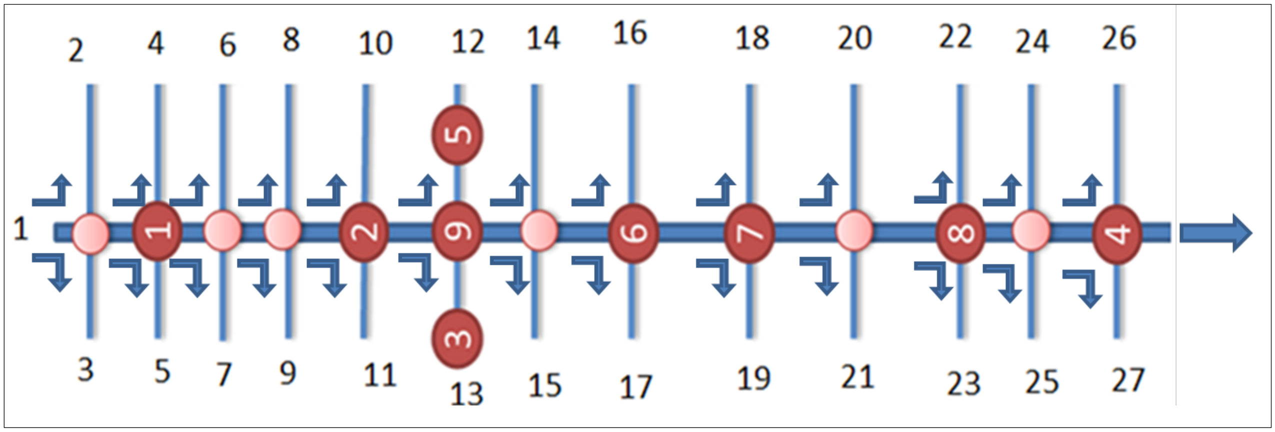


Figure 18 Southbound Outbound Movement for O-D Distribution

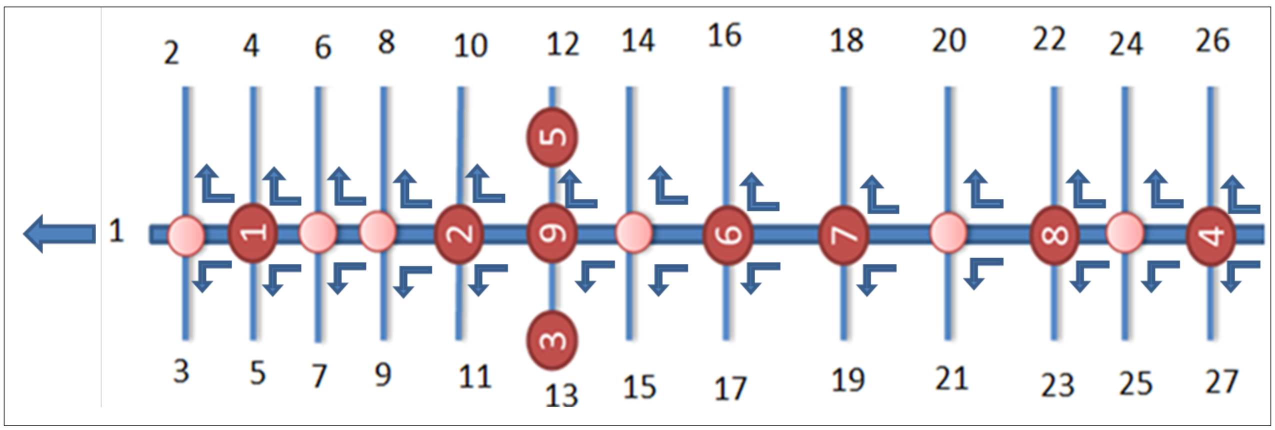


Figure 19 Northbound Outbound Movement for O-D Distribution

The table is used to distribute the 9X9 combination of O-D pair as a fraction into 28X28 combination of movement.

Table 10 Bluetooth Unit based sample O-D Table

Origin	1	1	1	1	…	9	9	…	9
Destination	1	2	…	9	…	1	2	…	9

Table 11 Movement based sample O-D Table

Inbound	1	1	1	1	…	28	28	…	28
Outbound	1	2	…	28	…	1	2	…	28

The Distribution of O-D pair from unit wise to movement wise is done by utilizing the combination given in Table 9.The originally the Unit wise O-D are shown in Table 10 and output after distribution is shown in to Table 11**.**

Example: O-D count for unit 2 to unit 1 is used to calculate movement wise O-D of all combinations using 10 and 11 as origin and 1, 5, 7, 9, 8 as destination movements, referring to figure19, O-D value belongs to Origin 2 and Destination 1 is considered and further it is divided by five as this O-D has five numbers of outbound movements in total. The O-D value obtained is converted in to percentage value for each origin.

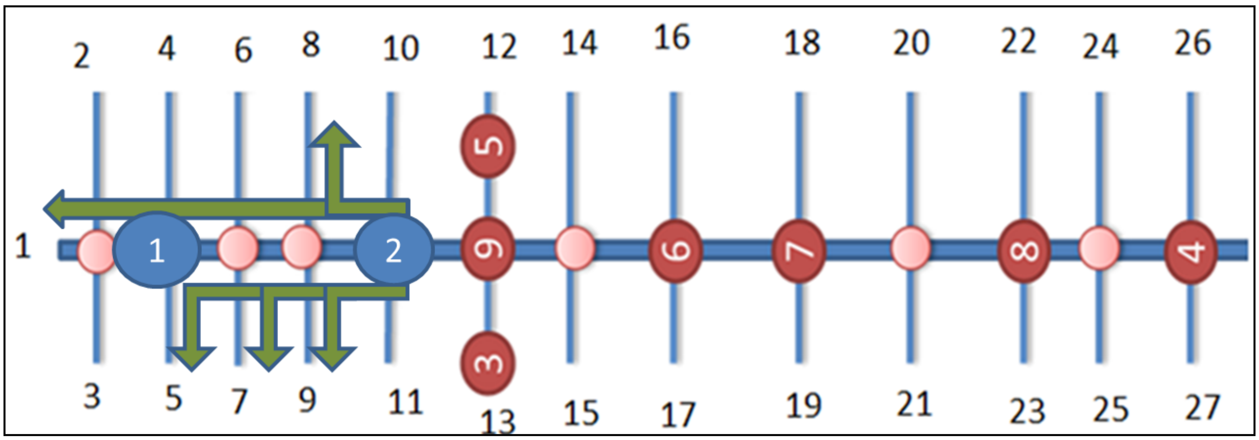


Figure 20 Sample O-D Distribution

The distribution factor for combination of movements is used as a multiplier for the volume for the outbound movements.

Outbound Dynamic Volume Calculation

The significant inputs needed to calculate the dynamic volume consists of capacity associated with particular movement. The capacity is calculated by using the equation from HCM (Highway Capacity Manual)

Capacity Equation from HCM,

□=□×□□

Where,

c = Lane Group Capacity

s = Adjusted Saturation Flow Rate

g = Effective Green Length

C = Cycle Length

Formulation for Dynamic Volume calculation

The formulation is used to calculate the dynamic volume for outbound movements is shown below:

□□□=□=1□∀□Ų□∀□Đ□□□□ □=□□−1□□□□

Where,

□□□ = Dynamic Volume for intersection number k and time period T

□ = Time period

□ = Intersection number for which the volume is calculated

□ =Number of upstream Intersection to the Intersection for which the volume is calculated

Ų = Upstream intersection

Đ = Downstream Intersection

□□ = Capacity of corresponding movement m

□□= Demand of corresponding movement m

□□□ = Distribution factor of Origin Destination

The above formula would provide the dynamic volume for outbound movement, which consists of turning movements leaving the intersection and through movement at last intersection leaving the network. The formula takes into account the OD Distribution and Capacity Demand Ratio for movement at the intersection and at movements at previous Intersections that contribute the movement for which the formula is applied.

The volume is calculated for all outbound movements leaving the network for each time period of 14 days. The combination of this new volume for outbound movements and the original volume for inbound movements gives the actual volume scenario for the Network.

5.3 Implementation on the Reston Parkway Network

The formulation is applied to the selected four intersections at Reston Parkway .The dynamic volume is calculated for south bound left (SBL) movement at fourth intersection shown in red color in the above figure. The green color movements are the contributing movement for SBL AT fourth intersection. The timing plans are obtained from passer V simulating the vehicle count from detector data. West bound movement at second intersection is absent as it is T-intersection.

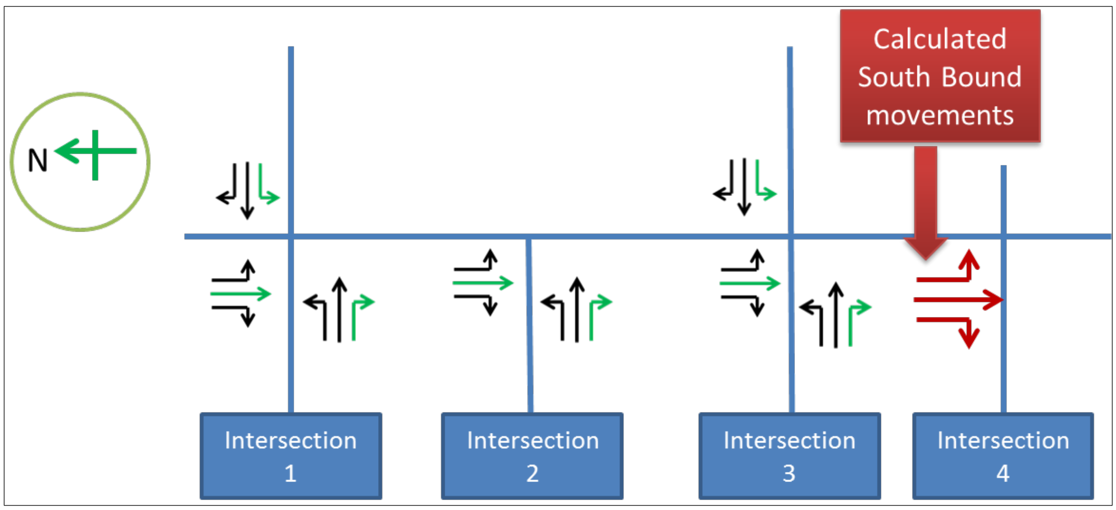


Figure 21 Network use for Implementation

Following are the green times according to the three timing plans provided for all movements of four intersections.

Table 12 Timing plans (Green time in seconds) by PasserV

Intersection 1-Baron Cameron	Movement	Plan 1	Plan 2	Plan 3
	NBL	17	24	23
	NBT	17	24	23
	NBR	17	24	23
	SBL	39	27	26
	SBT	39	27	26
	SBR	-	-	-
	EBL	20	17	19
	EBT	24	22	22
	EBR	-	-	-
	WBL	20	17	19
	WBT	24	22	22
	WBR			

Intersection 2-Spectrum	Movement	Plan 1	Plan 2	Plan 3
	NBL	24	18	17
	NBT	34	41	50
	NBR			
	SBL	58	59	67
	SBT	58	59	67
	SBR	58	59	67
	EBL	42	31	32
	EBT			
	EBR	42	31	32
	WBL			
	WBT			
	WBR			

Intersection 3-Bowmantown	Movement	Plan 1	Plan 2	Plan 3
	NBL	17	17	17
	NBT	38	38	46
	NBR	38	38	46
	SBL	17	17	17
	SBT	38	38	46
	SBR	38	38	46
	EBL	45	35	27
	EBT	45	35	27
	EBR	45	35	27
	WBL	45	35	27
	WBT	45	35	27
	WBR	45	35	27

Intersection 4-New Dominion	Movement	Plan 1	Plan 2	Plan 3
	NBL	17	17	17
	NBT	38	37	28
	NBR	38	37	28
	SBL	23	18	19
	SBT	44	38	30
	SBR	44	38	30
	EBL	22	18	26
	EBT	22	18	26
	EBR	22	18	26
	WBL	17	17	17
	WBT	17	17	17
	WBR	17	17	17

Saturation flow rate is 1770 and Cycle Length is100 second is used to calculate capacity. Following table consist of capacity based on above timing plans and demand for three different time period of day contributing movement.

Table 13 Capacity(Vehicle/hr) and Demand (vehicle/hr)calculation

Intersection	Movement	Time Period 1						Time Period 2						Time Period 3					
		Demand			Capacity			Demand			Capacity			Demand			Capacity		
		TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3
1	EBR	280	280	280	673	673	1381	372	372	372	673	673	1381	240	240	240	673	673	1381
	SBT	552	552	552	850	814	1097	628	628	628	850	814	1097	686	686	686	850	814	1097
	WBL	284	284	284	248	283	531	268	268	268	248	283	531	233	233	233	248	283	531
2	EBR	200	200	200	496	513	301	204	204	204	496	513	301	240	240	240	496	513	301
	SBT	1968	1968	1968	1982	2266	1841	2016	2016	2016	1982	2266	1841	2120	2120	2120	1982	2266	1841
	WBL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	EBR	74	74	74	566	425	832	84	84	84	566	425	832	107	107	107	566	425	832
	SBT	1894	1894	1894	1239	1522	2513	1845	1845	1845	1239	1522	2513	1962	1962	1962	1239	1522	2513
	WBL	48	48	48	566	425	832	60	60	60	566	425	832	100	100	100	566	425	832

Using above parameters the volume is calculated using the proposed formulation and respective OD Distribution Factors. Following are the internal volumes obtained:

Table 14 Calculated Dynamic Volumes (Vehicle/hr)

Intersection 4	Time Period 1			Time Period 2			Time Period 3		
	TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3
SBR	109	131	150	19	23	26	18	19	30
SBL	109	131	150	19	23	26	18	19	30
SBT	1630	1645	1553	1811	1866	1725	1860	1889	1990

The observation of calculated internal volume for 4^{th} intersection indicates that the volume varies significantly if the time period is changed. The reason for this is the OD distribution factor for the contribution movement change due to change in OD Count per period. Here the volume is same for south bound left and south bound right as the contribution movements are same and the O-D distribution factors are same. The volume show changes for change in time period also change in timing plan.

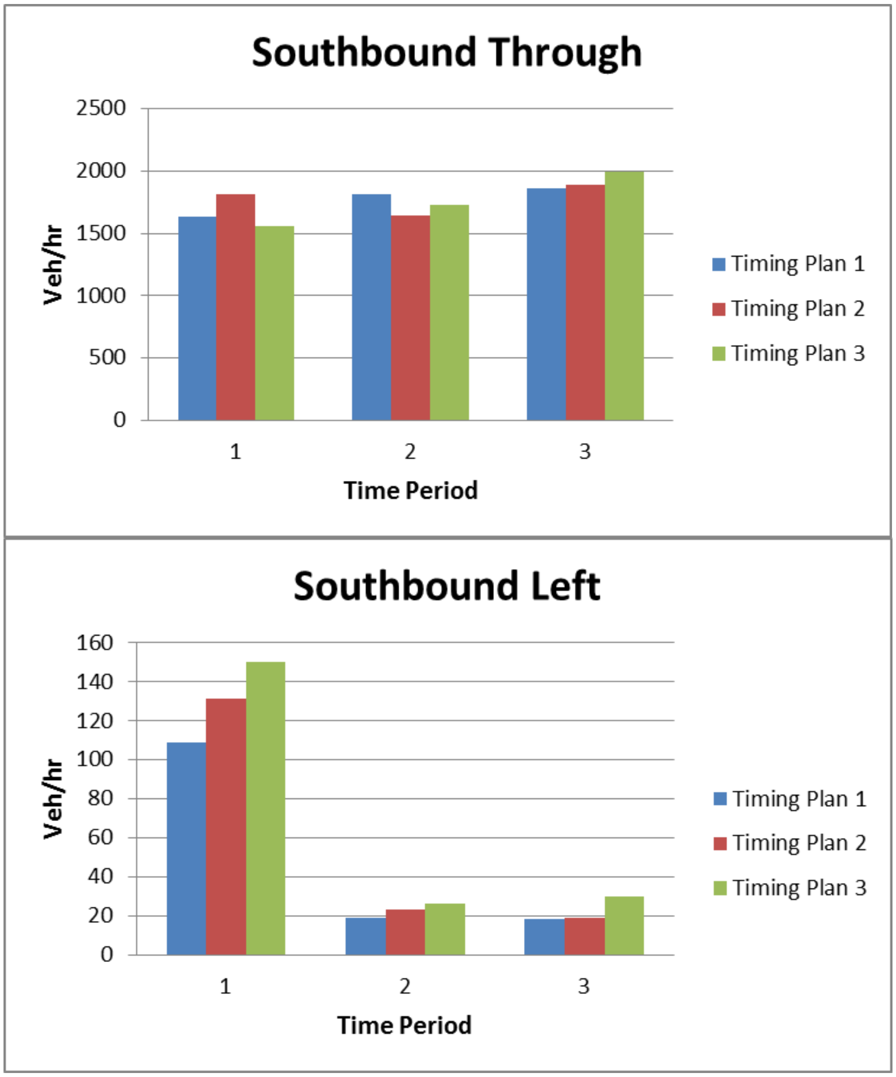


Figure 22 Variation of Volume

Figure here shows that the volume variations for different time period are higher than variations for different timing plans. The O-D distribution factor varies significantly and affects the internal volume during different time period. This proves the significance of actual O-D calculation while calculating internal volume as a part of timing plan design process.

5.4 Conclusions and Future Research

This paper proposes a method that can be used to integrate the Bluetooth data to improve the timing plan generation. Thirteen intersections of the Reston Parkway arterial were considered for this study and the use of detector volume was compared with the use of proposed Bluetooth based dynamic volume for generation and optimization of timing plans.

It was found that the calculated dynamic volume change significantly for various timing plans. So, this change in volume should be considered while designing timing plans. While optimizing timing plans, selection of the time plan is based on the evaluation parameters such as delay, stops and it varies with change in volume. The values of evaluation parameters select the best suitable timing plan based on the traffic state.

Future work includes the implementation of this proposed method in design and optimization of timing plans. The integration of dynamic volume calculation process with design and optimization of timing plan would give us a sound methodology of obtaining time plan which can be then further applied for various modes of operation. It is now possible to study many traffic scenarios with real volume distribution using many different plans. Other than this, to further study the effectiveness of the proposed system, the timing plans of the traffic can be can be calculated by using optimization soft wares such as Syncro, PasserV etc. and compared with the timing plans generated by the integrated system using the proposed method of volume calculation.

5.5 References

1. Rodier, C.J. and S.A. Shaheen, *Transit-based smart parking: An evaluation of the San Francisco Bay area field test.* Transportation Research Part C: Emerging Technologies, 2010. **18**(2): p. 225-233.
2. Darcy M. Bullock, A.M.H., Jason S. Wasson *"Estimating Route Choice and Travel Time Reliability using Field Observations of Bluetooth Probe Vehicles"*, 2011, Transportation Research Board Washington, D.C.
3. Haseman, R., J. Wasson, and D. Bullock, *Real-Time Measurement of Travel Time Delay in Work Zones and Evaluation Metrics Using Bluetooth Probe Tracking.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2169**(-1): p. 40-53.
4. Barceló, J., et al., *Travel Time Forecasting and Dynamic Origin-Destination Estimation for Freeways Based on Bluetooth Traffic Monitoring.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2175**(-1): p. 19-27.
5. Haghani, A., et al., *Data Collection of Freeway Travel Time Ground Truth with Bluetooth Sensors.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2160**(-1): p. 60-68.
6. Young, S., *"Bluetooth traffic monitoring Technology concept of operation and development guideline"*, 2008,Center for Advanced Transportation Technology, University of Maryland, Maryland, USA.
7. Burnham, T., M. Vasudevan, and A. Tewfik, *Development of a Global Positioning System-Based Vehicle Tracking System for the Minnesota Road Research Facility.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2153**(-1): p. 153-161.
8. Yin, Y., *Robust optimal traffic signal timing.* Transportation Research Part B: Methodological, 2008. **42**(10): p. 911-924.

9. Coifman, B. and S. Krishnamurthy, *Vehicle reidentification and travel time measurement across freeway junctions using the existing detector infrastructure.* Transportation Research Part C: Emerging Technologies, 2007. **15**(3): p. 135-153.
10. Caggiani, L., M. Ottomanelli, and D. Sassanelli, *A fixed point approach to origin-destination matrices estimation using uncertain data and fuzzy programming on congested networks.* Transportation Research Part C: Emerging Technologies. **In Press, Corrected Proof**.
11. Lou, Y. and Y. Yin, *A decomposition scheme for estimating dynamic origin-destination flows on actuation-controlled signalized arterials.* Transportation Research Part C: Emerging Technologies, 2010. **18**(5): p. 643-655.
12. Samiul Hasan and C.F. Choudhury, *Modeling Travel Time Variations on Urban Links in London.* Transportation Research Board 90th Annual Meeting, Transportation Research Board, 2011.
13. Jiwon Myung and D.-K. Kim, *Travel Time Prediction Using the K-Nearest Neighborhood Method with Combined VDS and ATC Data*, in *Transportation Research Board 90th Annual Meeting,Transportation Research Board*2011: Washington, D.C.
14. Rogers, S., *"Travel Time Quality in a Probe Vehicle Network"*, in *Transportation Research Board 90th Annual Meeting, Transportation Research Board*2011: Washington, D.C.
15. Dan Van Boxel, William H. Schneider IV, and C. Bakula, *"An Innovative Real-Time Methodology for Detecting Travel Time Outliers on Interstate Highways and Urban Arterials"*, in *Transportation Research Board 90th Annual Meeting, Transportation Research Board* 2011: Washington, D.C.
16. Zhou, X., S. Erdogan, and H. Mahmassani, *Dynamic Origin—Destination Trip Demand Estimation for Subarea Analysis.* Transportation Research Record: Journal of the Transportation Research Board, 2006. **1964**(-1): p. 176-184.

6 Summary and Conclusion

6.1 Summary

Traffic management system consists of efficient working of signalized intersection. Effective design of timing plans play major role in efficient working of intersection. Design and optimization of timing plans is based on the volume of various movements of intersection in the network. The volume for external movement and cross street is obtained by detector data vehicle counts. The distribution of volume within the network is assumed as equally distributed considering equal attraction in different nodes. In the field the distribution vary according to origin destination of trip within the network. To obtain the actual origin destination information was challenging due to limitation of traditional data collection techniques. Introduction of the Bluetooth data collection technique provides a way to obtain this information from field at reasonable cost and efforts.

Bluetooth technology based data collection technique has proved contribution to existing data collection techniques such as probe vehicle, loop detector data, video detection. This technique has several applications in calculation of travel time, speed. This thesis proposes application of Bluetooth data in designing timing plans. The description of implementation of Bluetooth data collection technique in field to is provided. The setup of Bluetooth unit and procedure to decide the location of units in field in field based on analysis of detector data is discussed.

The methodology to derive the origin destination matrix from data collected by using Bluetooth is the explained. The main objective of the research is to develop stepwise procedure to calculate dynamic volume distribution for the signalized arterial based on this obtained origin destination information.

The proposed procedure needs capacity calculation using various parameters such as existing time plans which provide green time and cycle length, saturation flow rate for the network. It also needs demand for every approach of all intersections. Demand is calculated by using detector counts. For every approach number of lanes and associated detector are identified. Demand for particular approach is obtained by adding up the vehicle counts belongs to all detectors associated with that approach. After calculating capacity demand ratio for all intersection the formulation is applied to calculate dynamic volume for all internal movement. The volume obtain is compared with the volume calculated assuming equal distribution. The calculated dynamic volume is the true representation of field scenario. The application of this volume while designing and optimizing timing plans would be more realistic compare to current assumption based methodology.

Conclusion

Use of Bluetooth technology in traffic data collection technique solved various challenges in traffic management field. Bluetooth data has an ability to provide information that would be useful in improving the existing traffic management methodologies and approaches. The reliability and accuracy are the major issues while practicing the traditional methodologies. Traditional mythologies are based on various assumptions due to the absence of efficient technology to assist in obtaining required information to implement the methodologies. Designing and optimizing time plans for signalized arterial is significant task in process of traffic management. These timing plans are based on traffic state on an arterial. The traffic state is defined by the volume associated with all approaches at certain point in time. In the process of designing efficient timing plan it is required to input the accurate volume. These volumes are associated with three movements external movements, cross street movements and internal movements. Among these three volumes the external movement volume and cross street volumes are available directly from vehicle counts. The volume associated with internal movements is obtained by assuming equal internal distribution of volume .This assumption is not based on any practical observation and that reduce the reliability of the entire process of designing optimal timing plans. The distribution is based on the origin destination of trips within the network. To obtain the actual origin destination information of the traffic was a challenging task due to limitation of traditional data collection technique.

This research proposes the application of the recently proven Bluetooth data collection technique to obtain the origin destination information of trips within the network. The study shows that using the Bluetooth data it is practically possible to calculate the number of trips from particular origin and destination within the network. The thesis proposes a formulation to obtain the volume distribution among the internal movement of the arterial. With the help of collecting data Reston parkway arterial the proposed formulation is tested and it is observed that the amount of distribution is based on actual O-D obtained in field.

The ultimate aim of any methodology is to decrease the error in existing system and improve the overall efficiency by suggesting the feasible alternatives. The thesis covers the new concepts of calculation of O-D with the network from data obtained applying Bluetooth technique.

The results indicate that the proposed method has a potential to provide the significant input in current practice of designing timing plans.

References

1. Rodier, C.J. and S.A. Shaheen, *Transit-based smart parking: An evaluation of the San Francisco Bay area field test.* Transportation Research Part C: Emerging Technologies, 2010. **18**(2): p. 225-233.
2. Darcy M. Bullock, A.M.H., Jason S. Wasson *"Estimating Route Choice and Travel Time Reliability using Field Observations of Bluetooth Probe Vehicles"*, 2011, Transportation Research Board Washington, D.C.
3. Haseman, R., J. Wasson, and D. Bullock, *Real-Time Measurement of Travel Time Delay in Work Zones and Evaluation Metrics Using Bluetooth Probe Tracking.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2169**(-1): p. 40-53.
4. Barceló, J., et al., *Travel Time Forecasting and Dynamic Origin-Destination Estimation for Freeways Based on Bluetooth Traffic Monitoring.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2175**(-1): p. 19-27.
5. Haghani, A., et al., *Data Collection of Freeway Travel Time Ground Truth with Bluetooth Sensors.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2160**(-1): p. 60-68.
6. Young, S., *"Bluetooth traffic monitoring Technology concept of operation and development guideline"*, 2008, Center for Advanced Transportation Technology, University of Maryland, Maryland, USA.
7. Burnham, T., M. Vasudevan, and A. Tewfik, *Development of a Global Positioning System-Based Vehicle Tracking System for the Minnesota Road Research Facility.* Transportation Research Record: Journal of the Transportation Research Board, 2010. **2153**(-1): p. 153-161.
8. Yin, Y., *Robust optimal traffic signal timing.* Transportation Research Part B: Methodological, 2008. **42**(10): p. 911-924.
9. Coifman, B. and S. Krishnamurthy, *Vehicle reidentification and travel time measurement across freeway junctions using the existing detector infrastructure.* Transportation Research Part C: Emerging Technologies, 2007. **15**(3): p. 135-153.
10. Caggiani, L., M. Ottomanelli, and D. Sassanelli, *A fixed point approach to origin-destination matrices estimation using uncertain data and fuzzy programming on congested networks.* Transportation Research Part C: Emerging Technologies. **In Press, Corrected Proof**.
11. Lou, Y. and Y. Yin, *A decomposition scheme for estimating dynamic origin-destination flows on actuation-controlled signalized arterials.* Transportation Research Part C: Emerging Technologies, 2010. **18**(5): p. 643-655.
12. Samiul Hasan and C.F. Choudhury, *Modeling Travel Time Variations on Urban Links in London.* Transportation Research Board 90th Annual Meeting, Transportation Research Board, 2011.

13. Jiwon Myung and D.-K. Kim, *Travel Time Prediction Using the K-Nearest Neighborhood Method with Combined VDS and ATC Data*, in *Transportation Research Board 90th Annual Meeting,Transportation Research Board*2011: Washington, D.C.
14. Rogers, S., *"Travel Time Quality in a Probe Vehicle Network"*, in *Transportation Research Board 90th Annual Meeting, Transportation Research Board*2011: Washington, D.C.
15. Dan Van Boxel, William H. Schneider IV, and C. Bakula, *"An Innovative Real-Time Methodology for Detecting Travel Time Outliers on Interstate Highways and Urban Arterials"*, in *Transportation Research Board 90th Annual Meeting, Transportation Research Board* 2011: Washington, D.C.
16. Zhou, X., S. Erdogan, and H. Mahmassani, *Dynamic Origin—Destination Trip Demand Estimation for Subarea Analysis.* Transportation Research Record: Journal of the Transportation Research Board, 2006. **1964**(-1): p. 176-184.