



Lives, Time and Resources
Lives, Time and Resources
Lives, Time and Resources



**ANALYSIS OF BLUETOOTH TECHNOLOGY TO MEASURE
WAIT TIMES OF PASSENGER VEHICLES
AT INTERNATIONAL BORDER CROSSINGS**

FINAL REPORT

Final Version
June 10, 2015

Submitted to:
Texas Department of Transportation

VERSION HISTORY

Version #	Implemented by	Revision Date	Approved by	Approval Date	Reason for Revision
1	Rajbhandari	06.03.14	Rajbhandari	-	-
2	Beltran	03.24.15	Rajbhandari		

TABLE OF CONTENTS

1. INTRODUCTION	1
2. OBJECTIVE OF THE STUDY	1
3. DATA COLLECTION PLAN	2
4. FIELD DATA COLLECTION	4
5. DATA ANALYSIS AND RESULTS	5
6. CONCLUSION.....	8
7. APPENDIX: IMAGES OF FIELD DATA COLLECTION.....	9

LIST OF TABLES

Table 1. List of Ports of Entry Studied	2
Table 2. Dates of Data Collection at the POEs	4
Table 3. Median Penetration Rate of Bluetooth Devices at the Bridge of the Americas in El Paso	6
Table 4. Median Penetration Rate of Bluetooth Devices at the Camino Real International Bridge in Eagle Pass	6
Table 5. Median Penetration Rate of Bluetooth Devices at the Eagle Pass Bridge I in Eagle Pass	7
Table 6. Median Penetration Rate of Bluetooth Devices at Gateway to the Americas in Laredo	7
Table 7. Median Penetration Rate of Bluetooth Devices at the Veterans International Bridge in Brownsville	8

LIST OF ABBREVIATIONS

CAPUFE	Camino y Puentes Federales de Ingresos y Servicios Conexos
CBP	Customs and Border Protection
MAC	Media Access Control
MX	Mexico
NB	Northbound
POE	Port of Entry
POV	Privately Owned Vehicle
SB	Southbound
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
US	United States

1. INTRODUCTION

Bluetooth® technology is being widely used throughout the country to measure performance of transportation systems. Such performance measures include travel times, delays, and traffic demand. Bluetooth technology is also used to provide advanced traveler information to motorists by measuring travel time between fixed locations and relaying them to motorists via roadside message signs, the Internet, and handheld devices.

The general concept of using Bluetooth technology to measure wait times of passenger vehicles crossing the border is that during a vehicle's trip across the border, Bluetooth signals emitting from mobile devices carried by a driver and/or passengers or a vehicle are read by reading stations at multiple locations. If a readable Bluetooth signal is present, then the station identifies it and sends the Media Access Control (MAC) address of the signal to a server via wireless signal. The server timestamps the data and archives them in a database. Data from two or more reader stations are compared looking for a match of MAC addresses. If a match is found, then an algorithm in the server determines wait times for individual vehicles.

In Texas, the first Bluetooth-based system to measure wait times of passenger vehicles was recently deployed at the Zaragoza-Ysleta port of entry (POE). The Texas Department of Transportation (TxDOT) contracted with the Texas A&M Transportation Institute (TTI) to analyze whether the Bluetooth technology would be appropriate to measure wait times of passenger vehicles at other major POEs on the Texas-Mexico border. TxDOT is the sponsoring agency for the project using funding support from the United States Department of Transportation, Federal Highway Administration, and TxDOT itself.

2. OBJECTIVE OF THE STUDY

The objective of this study was to analyze the penetration rate of Bluetooth-enabled devices for both southbound and northbound passenger vehicles at five of the United States (US)-Mexico (MX) ports of entry located along the Texas-Mexico border. This is an addendum to a previous project where TTI performed the study at 10 US-MX border crossings. After the completion of the study, it was determined that 3 out of 10 border crossings needed further data collection to ensure that the penetration rates observed during the study were reflective of the ground conditions. Two additional border crossings, Eagle Pass Bridge I and Gateway to the Americas, include bridges that are in close proximity to the previously studied bridges and may have competing traffic. The outcome of this study was recommendations to the stakeholder agencies on the border about which crossings could employ Bluetooth technology to measure wait times of passenger vehicles crossing the border. The POEs that were included in this study are listed in Table 1.

Table 1. List of Ports of Entry Studied

Port of Entry	City/Region	Total Volume of Passenger Vehicles Entering US in 2011
Bridge of the Americas	El Paso	3,268,176
Veterans International Bridge	Brownsville	1,294,560
Camino Real International Bridge	Eagle Pass	1,229,088
Eagle Pass Bridge I (in close proximity to the Camino Real International Bridge)	Eagle Pass	1,042,748
Gateway to the Americas Bridge (in close proximity to the Juarez-Lincoln Bridge)	Laredo	977,121

Source: TxDOT

3. DATA COLLECTION PLAN

TTI developed plans for individual POEs where the data collection was to be performed. The first step in developing such a plan was to gather points of contact from both US and MX sides of the POE. The second step was to inform the points of contact about the upcoming data collection and objectives of the data collection, and seek their support and assistance to deploy test equipment at the POEs. The points of contact from all 10 POEs are as follows:

- **Bridge of the Americas:**
 - Customs and Border Protection (CBP), Isaiah Alva, Supervisory CBP Officer, (915) 730-7191, isaias.alva@dhs.gov.
 - CBP, Francisco J. Cuevas, CBP/AO-MSA, (915) 730-7183, francisco.j.cuevas@cbp.dhs.gov.
 - Aduana, Lic. Alberto Morales Arrechavaleta, Administrador de Equipamiento e Infraestructura Aduanera “4,” (555) 802-0000, alberto.arechavaleta@sat.gob.mx.
 - Aduana, Lic. Cesar Ricardo Hernández Cardoso, Administrador de la Aduana de Cd. Juárez, (656) 227-5401, aduanacduarez@sat.gob.mx.
 - Aduana, Lic. Martin Muñoz, Subadministrador de la Aduana de Cd. Juárez, (656) 227-5404, martin.munoz@sat.gob.mx.
- **Veterans International Bridge:**
 - CBP, Armando Taboada, Jr., Supervisory Program Manager, (956) 753-1773, armando.taboada@cbp.dhs.gov.
 - Cameron County, Marty Peña, Director of Operations, (956) 574-8771, mpena@co.cameron.tx.us.
 - Cameron County, David Silva, Bridge Supervisor, (956) 574-8767, DSilva@co.cameron.tx.us.
 - Caminos y Puentes Federales de Ingresos y Servicios Conexos (CAPUFE), Lic. Marco Amaro Olivares Olvera, Delegado Regional VIII Reynosa, (899) 921-1015, molivares@capufe.gob.mx.
 - CAPUFE, Ing. Ricardo Rodríguez, Administrador General, (868) 814-4890, c171Adm@capufe.gob.mx.

- **Camino Real International Bridge:**
 - City of Eagle Pass, Mario Diaz, Bridge Director, (830) 773-2621, mdiaz@eaglepasstx.us.
 - City of Eagle Pass, Mary Martinez, Bridge Operations Specialist, (830) 773-2622, mmartinez@eaglepasstx.us.
 - US Department of Homeland Security, Pete Macias, Assistant Port Director, (830) 752-3568, pete.macias@dhs.gov.
 - Puente Intl. Piedras Negras II, Jorge Alfredo De Lara Marrufo, Coordinador Administrativo del Fideicomiso, (844) 986-1233, fidein.puente2@sefincoahuila.gob.mx.
 - Puente Intl. Piedras Negras II, Ing. Milton Olavarrieta, Administrador General, (878) 782-3850, miltonolavarrieta@hotmail.com.
- **Eagle Pass Bridge I:**
 - City of Eagle Pass, Mario Diaz, Bridge Director, (830) 773-2621, mdiaz@eaglepasstx.us.
 - City of Eagle Pass, Mary Martinez, Bridge Operations Specialist, (830) 773-2622, mmartinez@eaglepasstx.us.
 - US Department of Homeland Security, Pete Macias, Assistant Port Director, (830) 752-3568, pete.macias@dhs.gov.
 - CAPUFE, Lic. Marcos Amaro Olivares Olvera, Delegado Regional VIII Reynosa, (899) 921-1015, molivares@capufe.gob.mx.
 - CAPUFE, Lic. Gerardo Dávila, Administrador General, C62adm@capufe.gob.mx.
- **Gateway to the Americas:**
 - CBP, Armando Taboada, Jr., Supervisory Program Manager, (956) 753-1773, armando.taboada@cbp.dhs.gov.
 - City of Laredo, Mario Maldonado, Bridge Director, (956) 791-2200, mmaldonado@ci.laredo.tx.us.
 - City of Laredo, Yvette Limon, Assistant Bridge Manager, (956) 721-2074, ylimon@ci.laredo.tx.us.
 - CAPUFE, Lic. Marcos Amaro Olivares Olvera, Delegado Regional VIII Reynosa, (899) 921-1015, molivares@capufe.gob.mx.
 - CAPUFE, Sr. Manuel Padilla, Administrador General, c66adm@capufe.gob.mx.

The third step was to identify tentative locations to deploy Bluetooth readers and pneumatic tube counters at the POEs. The locations of the readers and counters were identified using the aerial maps. TTI researchers then communicated with the points of contact from the POEs to discuss the locations of the field equipment, availability of power sources, equipment security, times and dates at which to collect data, and any other information pertinent to the crossing.

4. FIELD DATA COLLECTION

The data collection commenced at the Bridge of the Americas in September 2014 and ended with the Veterans International Bridge in February 2015. Pneumatic tube counters were used to collect the volume of northbound traffic crossing the border. Volume counts were collected continuously for a minimum of 48 hours at each crossing. When the counters had to be close to the primary facility of CBP, proper approvals were obtained from the agency. Since tube counters were only placed in the US for northbound traffic, southbound counts were requested from each city tolling facility. An exception existed at the Bridge of the Americas POE since it does not have a tolling agency. Consequently, both northbound and southbound pneumatic tubes were placed to account for total volume counts at that POE.

Bluetooth readers were placed on both sides of the border—one on each side. Each Bluetooth reader identified signals from passenger vehicles in both directions of traffic. On the MX side, the readers were placed inside or on top of the CAPUFE facility. This ensured a continuous supply of power, and the readers were secured. On the US side, the readers were placed at several different locations depending on the crossing, including on toll booths, on the roadside, and inside traffic controller cabinets. The appendix of this document includes images of data collection at all five POEs.

Table 2 includes the dates TTI collected data at the POEs.

Table 2. Dates of Data Collection at the POEs

Port of Entry	Start Date	End Date
Bridge of the Americas (Southbound)	September 23, 2014*	September 24, 2014*
Bridge of the Americas (Northbound)	September 26, 2014 (1 st test) November 6, 2014 (2 nd test)	September 29, 2014 (1 st test) November 11, 2014 (2 nd test)
Camino Real International Bridge (Northbound and Southbound)	December 9, 2014	December 10, 2014
Eagle Pass Bridge I (Northbound and Southbound)	December 10, 2014	December 11, 2014
Gateway to the Americas (Northbound and Southbound)	January 27, 2015	January 28, 2015
Veterans International Bridge (Northbound and Southbound)	February 24, 2015	February 25, 2015

* Because the Bridge of the Americas was having some construction on the southbound lanes, TTI researchers spent more days to gather data.

5. DATA ANALYSIS AND RESULTS

At individual POEs, hourly penetration rates of Bluetooth signals were computed using the following procedure:

1. Count unique mobile device IDs from privately owned vehicles (POVs) crossing the border (in each direction).
2. Determine the sample size (matched IDs) of mobile devices at every hour.
3. Count the volume of POVs crossing the border (hourly in each direction).
4. Calculate the penetration rate of Bluetooth signals as a ratio of the total number of matched MAC IDs and POV volume.

Then, the median penetration rate for a particular day was computed by taking the median value of all the hourly values for that day. There has not been a previous study to identify the minimum penetration rate of Bluetooth devices to measure border wait times. A study performed by Ferman et al.¹ recommended a minimum sample size of 3 percent for freeways and 5 percent for surface roads while using a global positioning system to measure travel time in a real-time environment. However, wait times vary much more than travel time of vehicles on freeways; hence, the higher value of a 10 percent penetration rate was chosen to ensure an adequate number of travel time samples from the Bluetooth devices. A 10 percent penetration rate was chosen as a benchmark to determine if the ports are suitable for deploying Bluetooth readers to measure wait times of passenger vehicles.

Bridge of the Americas in El Paso

The Bridge of the Americas is located several miles west of the Paso Del Norte Bridge in El Paso. It serves both northbound and southbound traffic. Motorists do not have to pay tolls to cross the bridge.

Table 3 shows the daily values of the median penetration rate at the POE, which was less than 10 percent during most days. This result was surprisingly low given the high penetration rate observed at the Paso Del Norte Bridge. The researchers had thought that the demographics of motorists would not vary between the bridges because of their proximity and the communities served by the bridges.

¹ Ferman, M. A., Blumenfeld, D. E., and Wen, X., An Analytical Evaluation of Real-Time Traffic Information System Using Probe Vehicles, *Journal of Intelligent Transportation Systems*, Volume 9, Issue 1, 2005.

Table 3. Median Penetration Rate of Bluetooth Devices at the Bridge of the Americas in El Paso

Date	Day of Week	Direction	Median Penetration Rate (%)
September 26, 2014	Friday	Northbound	6
September 27, 2014	Saturday	Northbound	7
September 28, 2014	Sunday	Northbound	6
September 29, 2014	Monday	Northbound	7
November 6, 2014	Thursday	Northbound	8
November 7, 2014	Friday	Northbound	8
November 8, 2014	Saturday	Northbound	8
November 9, 2014	Sunday	Northbound	7
November 10, 2014	Monday	Northbound	9
November 11, 2014	Tuesday	Northbound	8
September 23, 2014	Tuesday	Southbound	7
September 24, 2014	Wednesday	Southbound	9

Camino Real International Bridge in Eagle Pass

The Camino Real International Bridge connects the city of Eagle Pass in the US to the city of Piedras Negras in MX. It serves both northbound and southbound traffic 24 hours a day. Motorists have to pay tolls to cross the bridge.

Table 4 shows the daily value of the median penetration rate at the POE, which was slightly lower than 10 percent during most days of data collection.

Table 4. Median Penetration Rate of Bluetooth Devices at the Camino Real International Bridge in Eagle Pass

Date	Day of Week	Direction	Median Penetration Rate (%)
December 9, 2014	Tuesday	Northbound	6
December 10, 2014	Wednesday	Northbound	6
December 9, 2014	Tuesday	Southbound	8
December 10, 2014	Wednesday	Southbound	6

Eagle Pass Bridge I in Eagle Pass

The Eagle Pass Bridge I connects the city of Eagle Pass in the US to the city of Piedras Negras in MX. It serves both northbound and southbound traffic between the hours of 7:00 a.m. and 11:00 p.m. Motorists have to pay tolls to cross the bridge.

Table 5 shows the daily value of the median penetration rate at the POE, which was slightly lower than 10 percent during most days of data collection.

Table 5. Median Penetration Rate of Bluetooth Devices at the Eagle Pass Bridge I in Eagle Pass

Date	Day of Week	Direction	Median Penetration Rate (%)
December 10, 2014	Wednesday	Northbound	8
December 11, 2014	Thursday	Northbound	9
December 10, 2014	Wednesday	Southbound	7
December 11, 2014	Thursday	Southbound	7

Gateway to the Americas in Laredo

The Gateway to the Americas Bridge connects the city of Laredo on the US side to the city of Nuevo Laredo in MX. It serves both northbound and southbound traffic 24 hours a day. Motorists have to pay tolls to cross the bridge.

Table 6 shows the daily value of the median penetration rate at the POE, which was all greatly above 10 percent for all days of data collection.

Table 6. Median Penetration Rate of Bluetooth Devices at Gateway to the Americas in Laredo

Date	Day of Week	Direction	Median Penetration Rate (%)
January 27, 2015	Tuesday	Northbound	25
January 28, 2015	Wednesday	Northbound	28
January 27, 2015	Tuesday	Southbound	14
January 28, 2015	Wednesday	Southbound	16

Veterans International Bridge in Brownsville

The Veterans International Bridge connects the city of Brownsville in the US to the city of Matamoros in MX. It is also locally called Los Tomates Bridge. It serves both northbound and southbound traffic 18 hours a day. The motorists have to pay tolls to cross the bridge.

Table 7 shows the daily value of the median penetration rate at the POE, which was lower than 10 percent during all days of data collection.

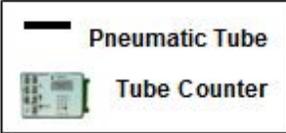
Table 7. Median Penetration Rate of Bluetooth Devices at the Veterans International Bridge in Brownsville

Date	Day of Week	Direction	Median Penetration Rate (%)
February 24, 2015	Tuesday	Northbound	1
February 25, 2015	Wednesday	Northbound	3
February 24, 2015	Tuesday	Southbound	2
February 25, 2015	Wednesday	Southbound	4

6. CONCLUSION

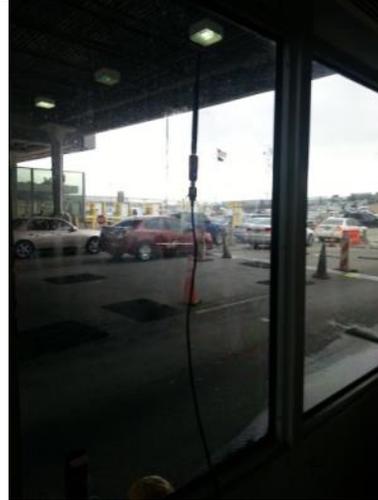
Based on the penetration rates observed during the study, out of five ports, only the Gateway to the Americas Bridge in Laredo has consistently higher than 10 percent penetration rates and hence is appropriate for deploying Bluetooth technology to measure wait times of passenger vehicles.

7. APPENDIX: IMAGES OF FIELD DATA COLLECTION

Bridge of the Americas	
	
	
 <p>Bluetooth reader placed in MX detecting northbound (NB) traffic.</p>	 <p>Pneumatic tube counter placed in US detecting NB traffic.</p>



Bluetooth reader placed in MX detecting southbound (SB) traffic.



Bluetooth reader placed in MX detecting SB traffic.



Pneumatic tube counter placed in US detecting SB traffic.

(2nd Test)



(2nd Test)

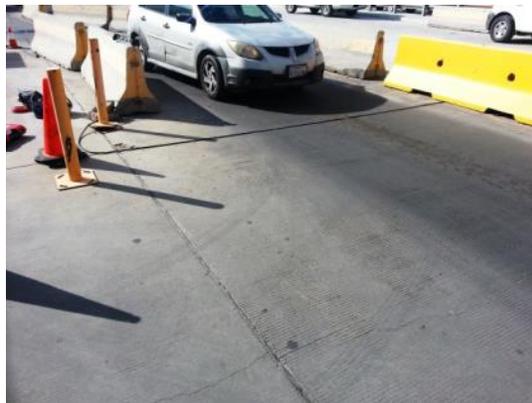




Bluetooth reader placed in MX detecting NB traffic.

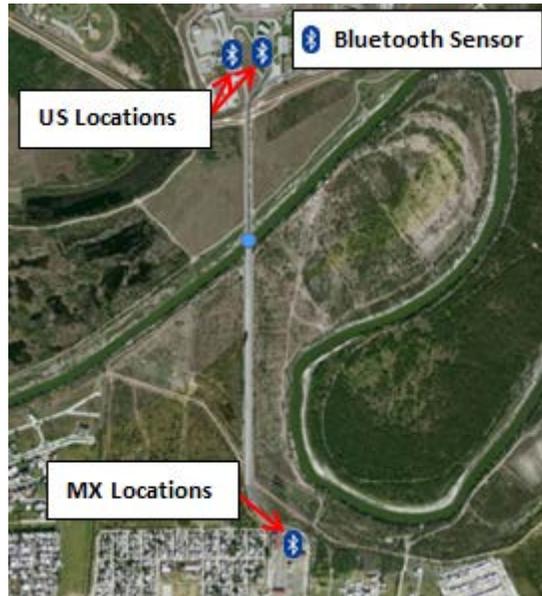


Bluetooth reader placed in US detecting NB traffic.



Pneumatic tube counter placed in US detecting NB traffic.

Veteran's International Bridge





Bluetooth reader placed in US, Cameron County.



NB, Bluetooth reader placed inside a CAPUFE toll booth in MX.



Bluetooth reader placed in US, CBP.



Pneumatic tube counter placed in US detecting NB traffic.

Camino Real International Bridge



NB, Bluetooth reader placed inside a toll booth in MX.



Bluetooth reader placed in US, close to CBP.



Bluetooth reader placed in MX detecting SB traffic.



Bluetooth reader placed inside toll booth in El Paso.



Pneumatic tube counter placed in US detecting traffic.

Eagle Pass Bridge I



 Pneumatic Tube



Bluetooth reader placed in MX.



Bluetooth reader placed in US, near CBP.



Bluetooth reader placed inside toll booth
in El Paso.



Pneumatic tube counters in US.

Gateway to the Americas





NB, Bluetooth reader placed inside toll booth in MX.



Bluetooth reader placed inside City of Laredo toll booth in MX.



Bluetooth reader placed by CBP in US.



Pneumatic tube counter placed in US.