THE ARCHIVES OF TRANSPORT *ISSN (print):* *0866-9546*
Volume 34, Issue 2, 2015 ***e-ISSN (online):*** *2300-8830*
DOI: *10.5604/08669546.1169215*

DEVELOPMENT AND IMPLEMENTATION OF TECHNOLOGY TO MEASURE TRUCK CROSSING TIME AT INTERNATIONAL LAND PORTS OF ENTRY

Juan Carlos Villa

Texas A&M Transportation Institute, Texas A&M University System, College Station, Texas, USA

e-mail: j-villa@tamu.edu

Abstract: *Public and private stakeholders that operate land border crossings are increasingly concerned about long wait times for trucks crossing from Mexico into the United States. Long wait times are detrimental to the regional competiveness, supply chain operations, the environment in the region adjacent to the border crossings, and to the overall economic development. In order to have reliable and systematic information on border crossing time and delay, a system to measure travel time through the border is required. This paper describes the basic border crossing operations at the Texas/Mexico border that serves as the foundation to identify a technology that could be used to collect border crossing information. The design and deployment processes that were used for the implementation of the border crossing time measurement system for U.S.-bound commercial vehicles are described. The paper also presents the results of the system that was developed to disseminate border crossing and wait time data. Benefits to supply chain operators at land border crossings and next steps in the development of more border-related performance measures are described.*

Key words: *cross border transportation, technology, truck crossing, international freight transportation and logistics*

1. Introduction

Trade between the United States and Mexico increased rapidly since the North American Free Trade Agreement (NAFTA) started in 1994. Land trade by truck and rail between the United States and Mexico increased from US$92.76 billion in 1995 to $434.36 billion in 2014, an increase of almost five times in the 19-year period (Fig. 1).

Most of the merchandise trade between the two NAFTA partners is done by truck; in 2014, 85 percent of the total land trade by value was done by truck, with more than 5 million trucks crossing the U.S./Mexico border in that year, increasing at an average annual growth rate of 4.28 percent between 2009 and 2014 (Fig. 2).

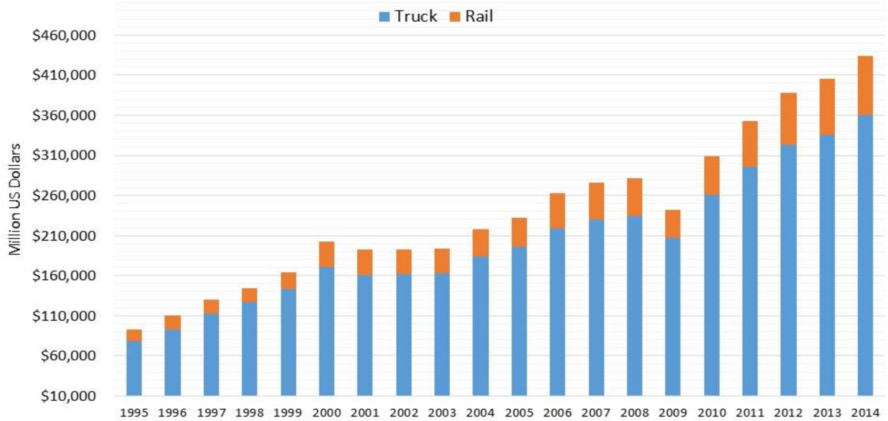

Fig. 1. Total U.S./Mexico Trade by Truck and Rail
Source: U.S. Department of Transportation (2015).

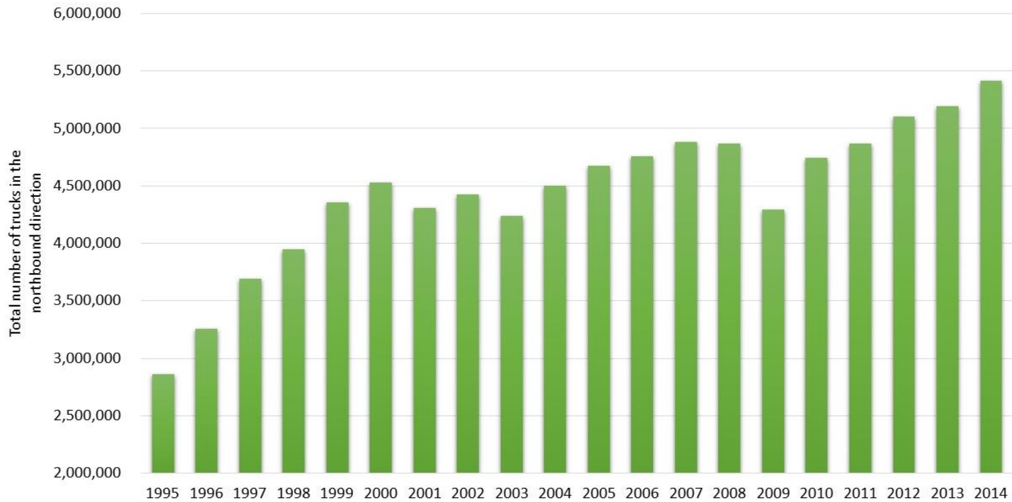

Fig. 2. Total U.S.-Bound Trucks Crossing from Mexico
Source: U.S. Department of Transportation (2015).

Even though there are 27 truck-handling land border crossings between Mexico and the United States, land trade is concentrated in a few land ports of entry (POEs). In 2014, 75 percent of the total number of trucks crossing from Mexico to the United States concentrated in four POEs: Laredo, Otay Mesa, El Paso, and Hidalgo (Fig. 3.)

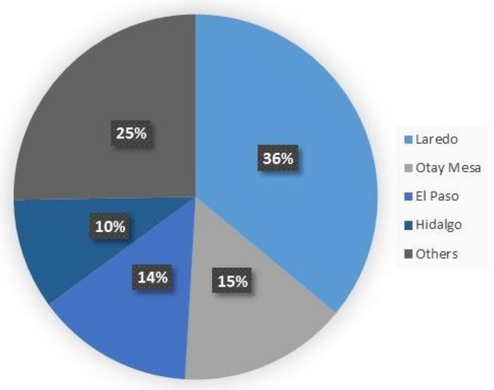

Fig. 3. 2014 Trucks Crossing by Port of Entry
Source: U.S. Department of Transportation (2015).

This high volume of trucks at a few POEs creates congestion and delay that impacts cross-border supply chains and has negative implications to the competitiveness in the region. Shippers and carriers need to have reliable information that allows them to plan international shipments. Through research across the U.S./Mexico border, the supply chain community that participates in cross-border operations mentioned one valuable element is reliable and consistent information related to border crossing time and delay.

This paper summarizes various research projects that have been conducted over a 10-year period and is on-going. The objectives of these research projects were to identify technologies, and develop and implement a system to consistently measure border crossing time and delay for trucks crossing the border from Mexico into the United States.

2. The north bound border crossing process

2.1 General assumptions

In order to clearly understand the border crossing process, it is important to map activities that take place and stakeholders that participate in each of them. The northbound border crossing process requires a shipper in Mexico to file shipment data with both Mexican and U.S. agencies, and use a drayage or transfer tractor to move goods from Mexico to the United States. Once the shipment is at the border with the drayage or transfer tractor and an authorized driver, the process flows through three main physical potential inspection areas (Villa, 2006):

– Mexican export lot.
– U.S. Federal compound.
– State safety inspection facility.

2.2 Mexican Export Lot

The drayage driver with the required documentation proceeds into the Mexican Customs compound. For audit and interdiction purposes, Mexican Customs (Aduana) conducts inspections consisting of a physical review of the cargo of randomly selected outbound freight prior to its export. Shipments that are not selected proceed to the exit gate, cross the border, and continue on to the U.S. POE.

2.3 U.S. Federal Compound

At the primary inspection booth, the driver of the truck presents identification and shipment documentation. The U.S. Customs and Border Protection (CBP) inspector at the primary inspection booth uses a computer terminal to cross-check the basic information about the driver, vehicle, and load with information sent previously via the e-Manifest that has to be sent at least one hour ahead of the shipment arriving to the U.S. CBP primary inspection booth. The CBP inspector makes a decision to refer the truck, driver, or load for a more detailed secondary inspection of any or all of these elements or releases the truck to the exit gate.

A secondary inspection includes any inspection that the driver, freight, or conveyance undergoes between the primary inspection and the exit gate of the U.S. Federal Compound. Personnel from CBP usually conduct these inspections, which can be done by physically inspecting the conveyance and the cargo, or by using non-intrusive inspection equipment (such as x-ray). Within the compound, the U.S. Department of Transportation Federal Motor Carrier Safety Administration, and the Food and Drug Administration have personnel and facilities to perform inspections when required. A vehicle audit could happen at the Federal Compound or the State Safety Inspection Facility depending on practice.

2.4 State Safety Inspection Facility

Most of the major POEs on the U.S./Mexico border have developed stations located adjacent to the Federal compounds. State police inspect conveyances to determine whether they are in compliance with state vehicle safety standards and regulations. When the initial visual inspection finds any violation, the truck proceeds to a more detailed inspection at a special facility.

After leaving the State inspection facility, the driver typically drives to the freight forwarder or customs broker yard to drop off the trailer for later pickup by a long-haul tractor bound for the final destination. Fig. 4. presents a diagram depicting the three potential inspection points in the process.

The time required for a truck shipment crossing from Mexico into the United States is dependent on the number of secondary inspections required, the number of inspection booths in service, and traffic volume at that specific time of day. This creates travel time uncertainty that impacts cross-border supply chains.

3. Measuring Border Crossing Time and Delay

3.1 Defining Border Crossing Time and Delay

In order to measure truck border crossing time, first it is important to define the concept, as it can mean different things to various stakeholders that operate at international borders. Border crossing time can be as simple as the travel time required from the border line that divides both countries to the first CBP inspection; or in a regional context, border crossing time could be defined as the travel time between the origin in the Mexican side of the border and the destination of the trip at the U.S. side of the border. For the research that was performed, crossing time is defined as the time elapsed between a pre-established location on the Mexican side of the border and the exit from the state safety inspection facility on the U.S. side.

Since this definition of crossing time depends on the physical and operational characteristics of the POE and on the traffic volume, the location of the initial point will vary, as each POE has different characteristics. The location of the first measuring point is defined as to ensure that the truck queue never extends beyond that point.

In order to measure border crossing time and delay, first define several concepts:

– Free-flow crossing time would be where the truck would not have to stop at any time during the border crossing trip. Obviously, this scenario is not realistic and should not be set as a reference.

– Optimal crossing time is set as the base time, since it represents the case where there are no queues at any of the stops. This optimal crossing time is achieved under very low traffic volume conditions and takes into account the processing time at all inspection facilities.
– High-volume crossing time accounts for all delays caused by high traffic volume that cause lower traffic speeds and queues.
– The border crossing associated delay is determined by the difference between the observed crossing time and the optimal crossing time. Fig. 5 describes the differences between the free flow travel time, the optimal crossing time, and the high volume crossing time.

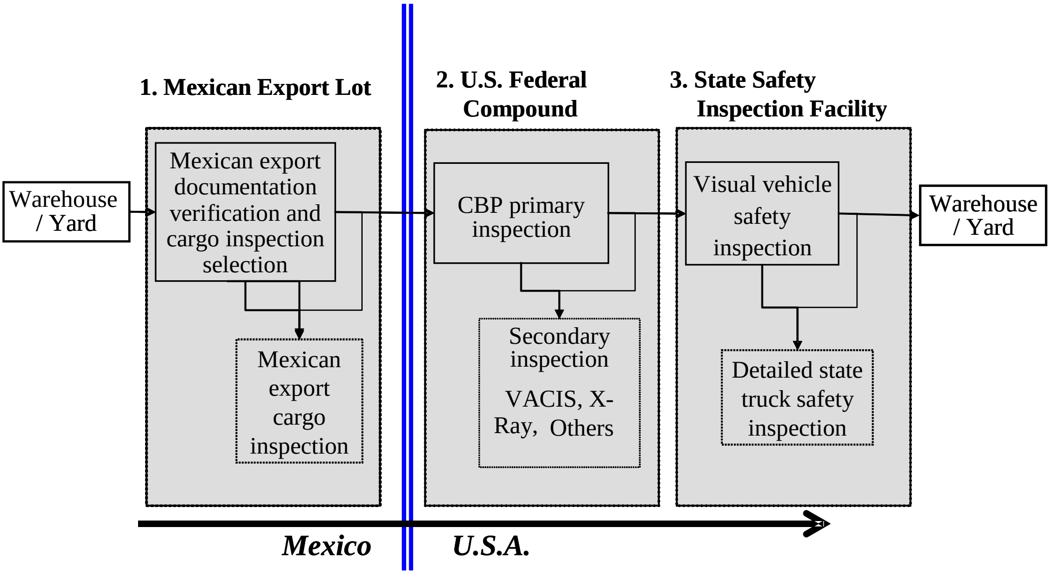

Fig. 4. U.S.-Bound Commercial Border Crossing Process

$$\text{Border Crossing Delay} = (\text{observed truck crossing time}) - (\text{optimal truck crossing time})$$

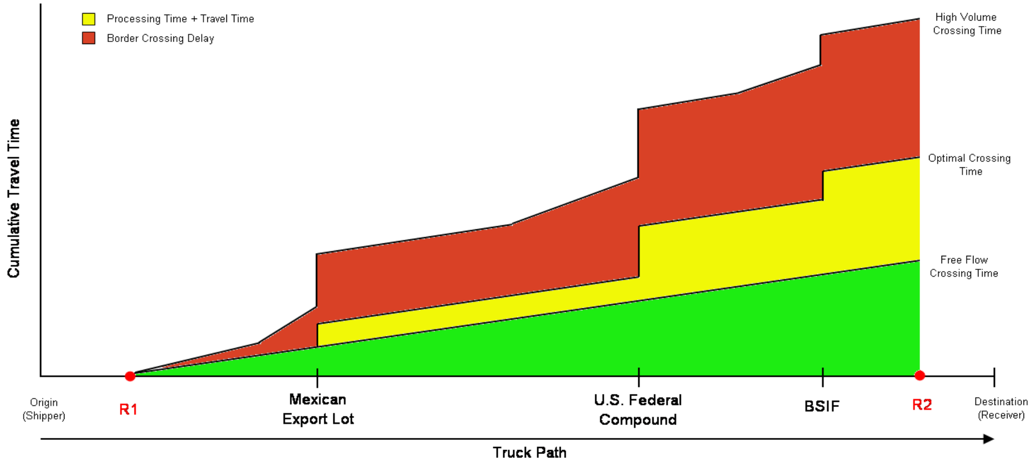

Fig. 5. Border Crossing Times under Different Scenarios

In order to have a better estimate of the status of the border crossing time, a similar concept as the travel time index (T_{indx}) can be used. The T_{indx} is defined as: $T_{indx} = \frac{\text{observed truck travel time}}{\text{truck free - flow travel time}}$.

3.2 Vehicle Sensing Technologies

The technology that is required to detect trucks that are crossing the border has to be flexible enough to cover the complete trip from Mexico to the United States, and be implementable in various POEs. Researchers identified that several technologies meet these criteria (Texas A&M Transportation Institute, 2007):

a) Automatic Vehicle Identification (AVI).
b) Automatic Vehicle Location (AVL).
c) Mobile Phone Locating.
d) License Plate Readers.
e) Vehicle Matching.
f) Inductive Loop Detectors.

Re a. Automatic Vehicle Identification

This technology identifies the vehicle when it passes through a detection area. There are three different means to identify the vehicles with this technology, by the use of Laser, Radio Frequency, or Infrared frequencies. In general terms, these systems work following these steps (Carvell et al., 1997):

1) A communication unit located in the roadside broadcasts an interrogation signal from its antenna.
2) When a vehicle equipped with an AVI device enters to the antenna coverage range, the transponder or tag returns the signal to the roadside unit with the vehicle's identification.
3) The information is retransmitted for further process and storage.

AVI Using Laser Frequency. The system reads a bar code attached to the truck when the vehicle passes through the scanner. The truck only needs the bar code, but weather and dirt can make the reading difficult and the distance between the readers and the bar code has to be relatively small.

AVI Using Radio Frequency. This technology is commonly known as radio-frequency identification (RFID) and its capabilities depend on the characteristics of the tag located in the vehicle. There two classification methods, one depends on the type of power source of the tag and the other depends on the capabilities of the tag.

AVI Using Infrared Frequency. This technology is very similar to the RFID. The most important difference is AVI with infrared operation can be impeded by adverse weather conditions (i.e., fog, rain, clouds) and has inconsistent reliability under high volume conditions.

Re b. Automatic Vehicle Location

AVL systems locate and track the position of the vehicle in the transportation network. There are many techniques used to locate vehicle and some of them include:

– Dead-Reckoning and Map-Matching.
– Ground-Based Radio Navigation.
– Global Positioning Systems (GPS).

GPS is the most popular of the AVL technologies and it uses a 24 earth-orbiting satellites network where real-time latitude and longitude information of the GPS receiver is collected. Coupled with Geographic Information System, it is able to track the speed and location of the device and viewed on a road network map on a real time basis. It can collect accurate travel times and its variability across different days, weeks, or any time period. The most important limitations are privacy issues with the vehicle owner and the difficulty the establish connection with the satellite if the device is close to tall buildings, tunnels, or under dense foliage.

Re c. Mobile Phone Locating

There are two different approaches to estimate travel times through the use of mobile phones. The first one uses the equipment at the cell tower to determine when the mobile phone switches from one cell to the next. This location technique is good as long as the phone is turned on. The biggest disadvantages of this method are the cell size, as it varies widely depending on the location, and the accuracy of the method. Generally urban areas have smaller cell sizes than rural areas. There is some additional network equipment that can improve accuracy, like relative signal strength, time delay, or triangulation (Delcan, 2005). This method can potentially provide a rich source of inexpensive and useful information. This technology works this way:

– First, the time is registered.
– Then, the latitude and longitude are calculated.
– Location is checked to ensure it is within the interest boundaries.

– A confidence factor related with the location is calculated.
– Since the location of the mobile phones is continuously being updated for a determined roadway segment, the travel time and speed can be calculated.

The second approach is mobile phones with GPS technology capabilities. The location of the mobile phone is achieved by using GPS. This method provides an excellent source of travel time, but requires an agreement with the telecommunication service providers and a considerable amount of users with this type of mobile phone (Battelle, 2002).

Re d. License Plate Readers (LPRs)

This system works by electronically recording the front and rear license plates of the vehicles. This technology has been used in the POEs to identify stolen cars, but has the potential to be used to identify vehicles like any other AVI device. It has a relatively high identification rate but it has problems to identify dirty, damaged, or bent-over licenses plates. In order to obtain travel times, one camera has to be located at the normal end of the queue. This camera captures and decodes license plates images. A second camera generally located at or after the plaza, also captures and decodes license plates. The information is matched and the travel time is calculated.

Re e. Vehicle Matching

This technology uses the same principles to estimate travel time as LPRs technology. It captures images of the vehicles and created an identity of them, which includes date, time, and position. At another location, the system also captures images of the vehicles and matches them. Since this system is independent of the license plate and its condition, it is more flexible. This technique also has a high rate of identification.

Re f. Inductive Loop Detectors

It consists of one of more turns of insulated wire embedded in a narrow cut in the road connected to a control box located in the roadside. The loop is excited by signal that usually ranges between 10 kHz and 200 KHz. When a vehicles passes over the loop, it creates a change in the electrical properties of the loop (reduction of its inductance) announcing the vehicle's presence. These loops can operate in two difference modes, pulse or presence mode. The pulse mode is used for volume counts by sending a short signal from the loop to the detector. The presence mode is used to provide volume counts and occupancy. In this mode, the loop sends a signal to the detector as long as the vehicle is in the detection area.

The strengths and limitations of the six technologies were compared to identify the best candidates for the border crossing and wait time measurement.

Table 1 shows a brief description of the advantages and disadvantages of the potential candidates and other characteristics.

From the analysis, AVI (specifically with RFID) and AVL (specifically with GPS) appeared to have the requisite characteristics to be considered for a crossing time measurement system. AVI with RFID was selected for a pilot test as it had these advantages against the GPS system:

– Most of the trucks have an RFID tag installed for CBP programs or for tolling.
– CBP is currently using RFID transponders in commercial vehicles that could be used to capture data by this proposed system.
– Data collected for the border wait times can easily be shared with CBP and the Texas Department of Public Safety (DPS) that operates the Border Safety Inspection Facility (BSIF).
– DPS was planning to install more RFID readers at the entrance to their safety inspection facility to measure performance of the BSIF.

4. Implementing Technology

4.1 General description

With the RFID technology selected, the research team developed a pilot test at the Bridge of the Americas (BOTA) at the El Paso/Ciudad Juárez border crossing. The technology implementation followed the systems engineering methodology that includes these steps.

4.2 System Requirements

In order to meet the needs of the public and private stakeholders, the research team confirmed the following list of system requirements. These system requirements were formulated through analyses of BOTA operations, RFID technology, and stakeholder meetings/interviews:

Table 1. Summary of Advantages and Disadvantages of Potential Technologies

Technology	Advantages	Disadvantages
AVI	Can send and/or receive information. Commonly used in POEs for toll collection. Low operating cost.	Requires investment on infrastructure (transponders and signal readers) and operational agreements between the participating countries. Card readers have to be installed in many locations to be able to have a good estimate of the border crossing travel time.
AVL	Can track vehicle location and speed over the predetermined area with very good accuracy. No need of installing any fixed roadside equipment.	Requires some investment on infrastructure (GPS devices). Privacy issues with the vehicle owner. Obtaining truck tracking data from truckers might be difficult.
Mobile phone locating	No infrastructure required. Can track vehicle location and speed.	Relies on the size of the cell. Specially affected in rural areas. Not as accurate as other in-site technologies
License Plate Readers	Good identification rate. No on-board equipment is needed.	Negatively affected by slow-moving or turning vehicles (might not suitable for Border crossings). Readers have to be installed in many locations to be able to have a good estimate of the border crossing travel time.
Vehicle Matching	Good identification rate. No on-board equipment is needed.	Readers have to be installed in many locations to be able to have a good estimate of the border crossing travel time.
Loop Detectors	Relatively low installation cost on a per detector basis.	Detector subject to stresses of traffic. In order to have a general sense of traffic patterns, a large amount of detectors are needed and a large investment is required.

– The system needs to automatically measure the time required for a northbound truck to cross from a pre-determined point upstream of the typical queue on the Mexican side to the exit of the BOTA POE on the U.S. side.
– The system must not require the interaction of either drivers or employees of agencies manning the POE on either side of the border during normal operation, other than to report on a visible anomaly such as damaged system hardware (e.g., a tag reader antenna).
– System failure must not affect operations at the POE.
– The system will not require an interface to any current equipment or data streams in use at the POE. The system will not rely on data from other parties to be effective although data from these parties may be incorporated at some point to increase the overall value of the project.
– The commercial vehicles are expected to have RFID tags using either the TransCore eGo or ATA tag protocol. The field tag reader equipment shall be able to read tags of either protocol.
– The reader stations are not required to read and record every tag as in a tolling application. There is room for misreads, with an expected tags from any field station read rate between 60 percent and 85 percent of readable (i.e., correct protocol, properly installed, undamaged).
– The field station design must also include a solar powered option to support deployment in a more remote area or an area with unreliable electrical service.
– The field stations shall be capable of maintaining an accurate time clock, at least accurate to the minute, for use in time stamping tag reads. Other approaches that can maintain time synchronization are also acceptable.

- The field tag reading stations should be physically compact as components may need to be installed on current traffic signal or new light weight pole installations.
- All field equipment should exhibit sufficient environmental specifications to ensure proper operation in the El Paso area climate.
- The field station design should incorporate a method to detect malfunctioning equipment and attempt to self-correct or otherwise compensate for the problem. This is particularly necessary for the communication link.
- The design shall use off-the-shelf components that can readily be purchased in case a repair is required.
- The field station design shall be such that little ongoing maintenance is required since the sites may be difficult to access without prior authorization.
- The field station should be designed to remain operational after the term of this research project. It is anticipated that another agency will assume responsibility for the operation and maintenance of the system at the end of the project.
- The project's Central System will reside at the Texas A&M Transportation Institute's server.
- All data created during the course of the project shall be stored in an archive for potential future use.
- The project will calculate current average border crossing times for northbound commercial vehicles using BOTA.
- Project output data shall follow accepted Internet standards for data subscription/syndication.
- Processed travel time data need to be available through Web viewing.

4.3 System Engineering Methodology

With a system requirements list in place, the research team developed a concept of operations for the border crossing time measurement system. The concept of operations describes the organization and operation of the system.

The border crossing measurement solution is organized into three subsystems representative of each component's function. The three subsystems are the:

- Field Subsystem.
- Central Subsystem.
- User Subsystem.

The Field Subsystem is comprised of the tag detection stations including the communication equipment. A minimum of two detection stations are required, one in Mexico and one in the United States. The detection station reads RFID tags and passes the data to the Central Subsystem via the communication equipment. The Central Subsystem receives tag reads from the field detection stations and performs all processing to derive and archive the aggregate travel times between the two stations. The User Subsystem interacts with the Central Subsystem to provide an internet web portal for data users (stakeholders, the public, etc.) to access current border crossing times and to access archived crossing time data (Fig. 6.).

Northbound commercial vehicles (trucks in Mexico destined to cross the border into the United States) pass an RFID tag reader installed at a point sufficiently ahead of the end of any queue on the Mexican Export Lot. This reader station is defined as R1. The RFID tags on the trucks are read as they pass the reader station. The tag query process recovers a unique identifier for each vehicle similar to a serial number. The reader station applies a time stamp to the tag read and forwards the resulting data record to a central location for further processing via a data communication link. A similar tag reading station is installed at the exit of the BSIF (R5). This station also time stamps tag reads and forwards the data record to the central facility.

There are several options for a communication link including public and private wireless and wireline. The data bandwidth requirements for each station are not excessive and could easily be met by each of these alternatives. Fig. 7. shows an example detection station. The central facility receives data from all tag reading stations associated with the project. For the initial pilot test at BOTA, there were two stations installed; however, all border crossing measurement systems in Texas now have at least four reading stations, two in Mexico and two in the United States. The facility stores all inbound raw reader station data and subsequent processed data in an archive for future access and use by regional transportation agencies and other authorized stakeholders. In essence, the central facility acts as a data center for the project and should be located in a reasonably secure building with reliable electric service and with personnel available to provide technical support as needed.

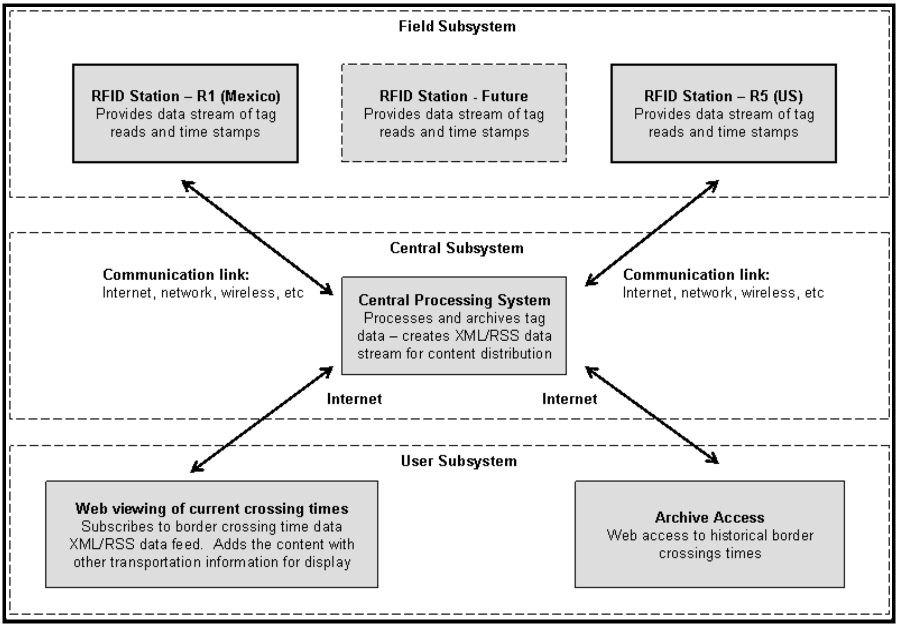

Fig. 6. Subsystem Organization Diagram

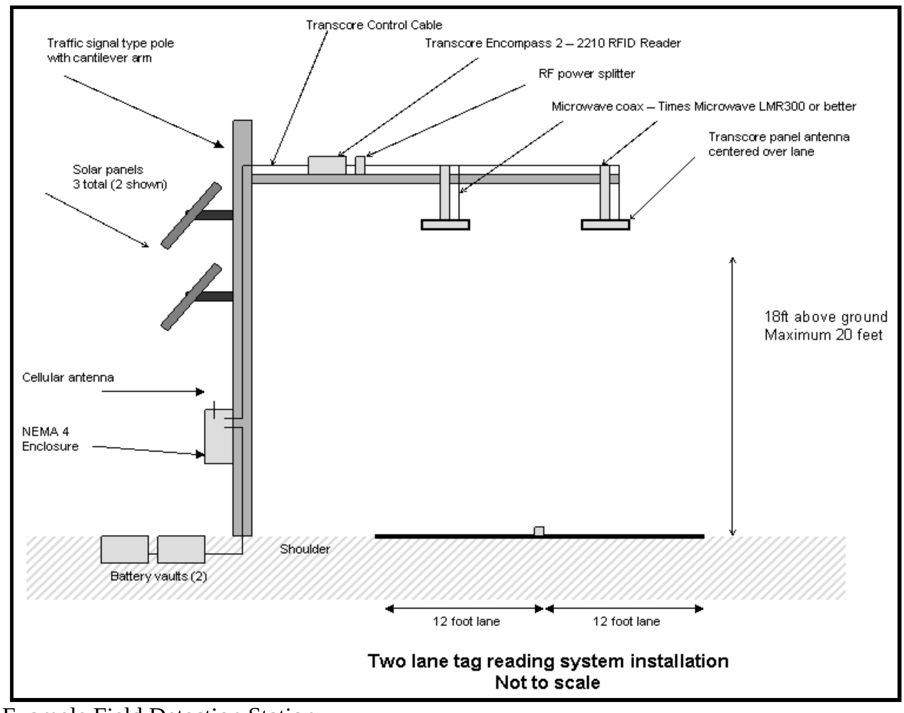

Fig. 7. Example Field Detection Station

The raw data are processed to match tag reads of individual trucks at the entrance point on the Mexican side and the exit point on the U.S. side. The difference in time stamps yields a single truck's progression as a function of time through the POE.

The border crossing time is the sum of the time incurred on the Mexican side (Aduana, or Mexican customs), the CBP facility, and the BSIF. As more reader stations are incorporated, a better picture of the progression can be obtained using the same technique. The tag matching process is executed periodically to obtain a reasonable sample of trucks to produce an average.

The average northbound crossing time will be made a shareable resource. The User Subsystem manages access and creates web displays using the border crossing time data. The crossing time data are available via a simple subscription service and a project related webpage. Archived data may also be available through the project website.

5. Border Crossing Time Information Dissemination

The pilot test at the BOTA proved to be successful, and the system has been implemented at seven crossings at the Texas/Mexico border and one at the Arizona/Mexico border. CBP requested adding a new bank of readers in Mexico before trucks cross into the United States so that travel time from that point to the CBP Primary Inspection could be measured. The research team developed a web tool to disseminate the information. The Border Crossing Information System (BCIS) contains real time and archived data for the seven crossings at the Texas/Mexico Border. The site can be accessed in English or Spanish (Figure 8).

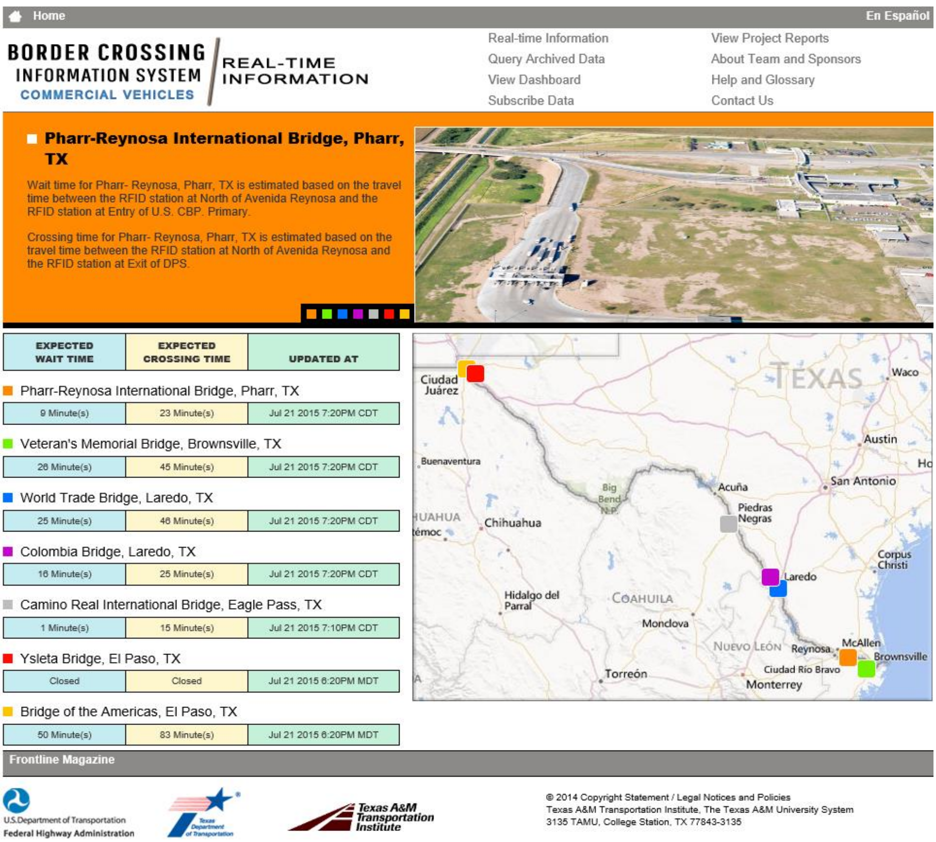

Figure 8. Border Crossing Information System

The real time information section of the website provides individual segment travel time for each crossing in map. Travel times have been color-coded in time intervals as seen in Fig. 9.

The archived or historical information section of the website includes the following potential queries for wait and crossing times in a specific date range:

– 10-minute Average Travel Time
– Hourly Average Travel Time
– Histogram of Raw Travel Data
– Monthly performance indicators

Fig. 10 presents a sample histogram of wait times for the Pharr-Reynosa International Bridge

6. Conclusions

The technology that was identified to measure border wait and crossing time tested positively and has been implemented at all major land POEs at the Texas/Mexico border. Data collected in the field provides valuable information for cross-border trade and logistics stakeholders. The main reasons for developing this research were:

– To have a technology based solution to measure truck crossing time.
– To get consistent, continuous, reliable data.
– To remove guesswork.
– To have the same information disseminated to all stakeholders.
– To make better informed decisions about border crossing issues, look for trends, test, and evaluate solutions.

The border crossing information system is a decision tool for stakeholders that collects thousands of data samples per month, provides real time and historical data, and now covers 95 percent of commercial traffic that flows from Mexico to Texas.

The information could be used to develop logistics performance indicators. Currently additional research to develop a "Fluidity Index" is under way. The Fluidity Index will analyze several supply chains to identify travel time reliability and costs at the Texas/Mexico border. The information from the BCIS will be a valuable input in the next phase of the research at the supply chain level.

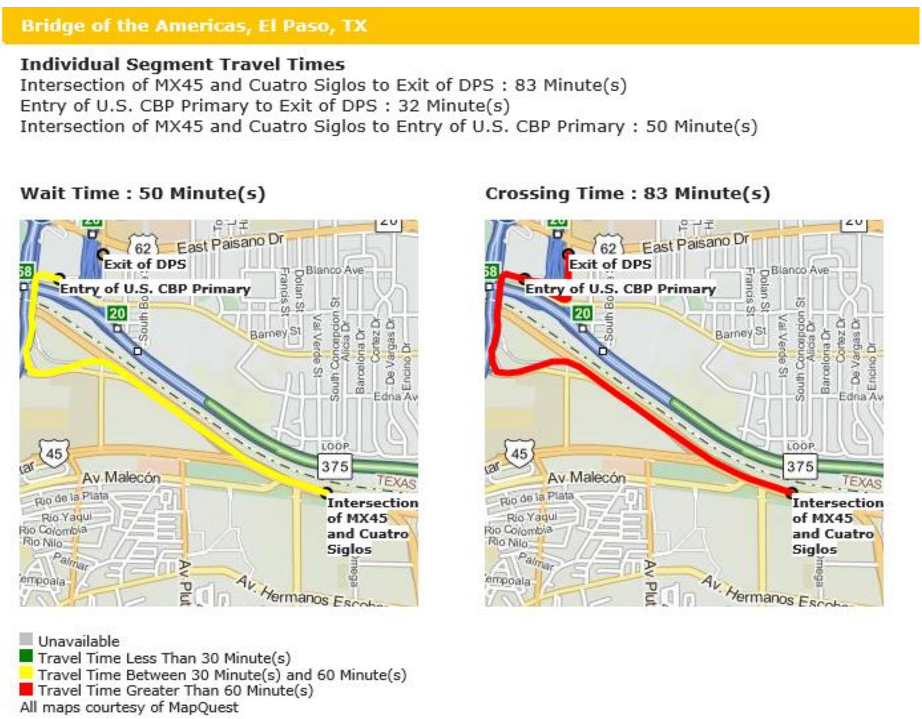

Fig. 9. BCIS Real Time Information for the Bridge of the Americas

Fig. 10. Border Wait Time Histogram, Pharr International Bridge

Abbreviations

AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
BCIS	Border Crossing Information System
BOTA	Bridge of the Americas
BSIF	Border safety Inspection Facility
CBP	Customs and Border Protection
DPS	Department of Public Safety
GPS	Global Positioning Systems
LPRs	License Plate Readers
NAFTA	North American Free Trade Agreement
POEs	ports of entry
RFID	radio-frequency identification

Acknowledgments

Funding for research projects that are mentioned in this paper was provided by the Texas Department of Transportation and the Federal Highway Administration.

References

[1] BCIS, The Border Crossing Information System [Homepage of Texas A&M Transportation Institute], [Online]. Available: http://bcis.tamu.edu, [2015].

[2] VILLA, J. C., 2006. Status of the US-Mexico Commercial Border Crossing Process: Analysis of recent studies and research. *Transportation Research Record: Journal of the Transportation Research Board*, 1966, pp. 10-15.

[3] TEXAS A&M TRANSPORTATION INSTITUTE, 2007. *Measuring Border Delay and Crossing Times at the U.S. – Mexico Border, Part I–Tasks 1 and 2 Report*

[4] CARVELL JR, J.D., BALKE, K., ULLMAN, J., FITZPATRICK, K., NOWLIN, L. and BREHMER, C., 1997. *Freeway Management Handbook.* FHWA-SA-97-064. Federal Highway Administration. U.S. Department of Transportation.

[5] DELCAN, 2005. *Action Plan for the Intelligent Border Crossing. Project Alignment Report.* Transport Canada.

[6] BATTELLE, 2002. *Assessment of Automated Data Collection Technologies for Calculation of Commercial Motor Vehicle Border Crossing Travel Time Delay.* Columbus, Ohio