Border Wait Time Technologies and Information Systems White Paper

Economic and Air Quality Impacts of Delays at the Border

San Diego, CA
October 31, 2017

Contents

1. Introduction

The California – Baja California border region is one of the most important and dynamic economic zones in North America due to its geographic location, comparative advantages, and the infrastructure in both countries. However, demand is posed to outstrip supply at the region's border crossings. While the crossings have become a critical element of the bi-national region's economic integration and competitiveness, growing demand has led to increased congestion at border crossings and generated delay and unreliable crossing times for cars, trucks, and pedestrians at California-Baja California land ports of entry (LPOEs). These delays and unreliability at the border have the potential to reduce the region's economic competitiveness and attractiveness to business, which can translate into lower levels of economic activity and growth.

In 2006, SANDAG and Caltrans conducted studies that showed and quantified how border delays cause significant reductions in economic output and employment. These studies highlighted the need for improving border crossings and infrastructure and helped make the case for developing a third crossing between San Diego and Tijuana (the future Otay Mesa East-Mesa de Otay II border crossing). Similarly, in 2007, the former Imperial Valley Association of Governments and Caltrans conducted an economic delay study for Imperial County border crossings. Much has changed since these earlier studies – the local economy has rebounded from the 2008 recession and there are new emerging industry clusters that depend on cross-border trade.

As a result, SANDAG has commissioned the HDR team (led by HDR Inc., and supported by T. Kear Transportation Planning and Management, Inc., Crossborder Group and Sutra Research) to support the development of the study on Economic and Air Quality/Climate Impacts of Delays at the Border.

This document was developed by **Sutra Research** and it is part of the subject study, providing a description of the available technologies to estimate and disseminate information about border-crossing wait times at the different LPOEs along the U.S.-Mexico border.

2. Purpose

This white paper addresses the following Task for the Economic and Air Quality Impacts of Delays at the Border study:

> ***Task 2.1.2 (as written in the Study Scope of Work)***
> *Finally, the Consultant will develop recommendations for the monitoring of wait times at the border and dissemination of this information to users of LPOEs in the study area. To do this, the Consultant will generate a list of the strengths and weaknesses of each method analyzed that will include considerations such as cost, maintenance requirements, ease of operation, quality of data collected and ease of dissemination.*

Monitoring and reporting northbound and southbound wait times at the border has been conducted through a variety of methods over time, from simple manual observations to more complex systems of technologies that automate the collection, transmission, processing, storage, and dissemination of this information to end-users. The value of this information varies with its intended use and the perspective of the end-user. End-users and their information needs may include:

- Commuters desiring total crossing times and trends;
- Commercial vehicles and businesses desiring total crossing times and trends,
- Leisure travelers and one-time crossers desiring current total crossing times;
- Government agencies desiring wait times to specific points in the queue to assist with operations management;
- Government agencies desiring wait times or crossing times to understand trends for planning purposes;
- Private sector businesses desiring to understand how border crossing environments and end-user behaviors may affect how they develop or deploy services or technologies to support these clients or customers.

Given this, the automation of wait time or crossing time data collection and dissemination must support a variety of needs and objectives for each type of user. This white paper examines the purposes of using technology for monitoring and information dissemination, a brief discussion of previous studies, the individual characteristics and environment of the San Diego County and Imperial County border crossings (relative to and in the context of technology deployments), the most common technologies in use or considered for use in the border environment, and recommendations.

3. Purpose of using Technologies for Information & Monitoring

The primary purpose of using technologies for border crossing wait time data collection is to provide a continuous, reliable data source that can be used for monitoring and information to support operations, security, management, and planning decisions at the border facilities, in the local community, in the region, and at the U.S. and Mexico national levels. To date, technology deployments have largely been temporary, but some permanent installations now exist along the northern and southern U.S. borders.

The temporary use of technologies in border wait time studies and pilot tests have provided an opportunity to understand how well the tested technologies and methods operate in the border environment. Short term and temporary deployments support border crossing studies with snapshots of data and information.

Permanent, high-resolution, reliable, and technologically flexible deployments of a wait-time data collection systems at border crossings assist in providing the continuous stream of information required to identify trends, behaviors, and operational challenges at the border. To understand current conditions, improve processes, model predictive operations, and prepare for the future in border crossing performance requirements, an automated wait-time data collection system must be deployed that allows a baseline of wait-time information to be established. This baseline must encompass all days of the week, months of the year, seasons, and conditions to be truly useful and comprehensive.

Finally, and ultimately, technology deployments must produce data that is or can be normalized and combined into larger data sets to provide a bigger picture of how border operations occur and perform under various conditions, and in comparison, to one another. To begin this process, the terminology used to define aspects of the border crossing process and technologies must be agreed upon and standardized. The following section discusses some basic definitions used in this document.

A. Definition of Wait and Crossing Times

To provide consistency in the discussion of technologies that support the monitoring and collection of wait time data in the border crossing environment, there are a few terms that must be defined. These definitions have been used in previous studies and will allow continuity of discussion in this document. A 2012 SANDAG study prepared by IBI Group indicates that wait and crossing times can be defined as follows:

> ***Wait time*** *is defined as "the time it takes for a vehicle to reach the CBP's Primary Inspection booth after arriving at the end of the queue"[2] for U.S. bound vehicles. In the case of Mexico bound vehicles (or southbound traffic), the CBP Primary Inspection booth would be replaced with the Mexican Customs' (Aduana) Inspection booth.*

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[2] Implementing a System to Measure and Disseminate Wait and Crossing Times at California Border Crossings, SANDAG, IBI Group/Texas Transportation Institute, October 2012.

Crossing time has the same beginning point in the flow as wait time, but its terminus is the departure point from the last compound that a vehicle transits in the border crossing process. For U.S. bound commercial vehicles, that last point is the California Highway Patrol (CHP) vehicle safety facility. For Mexico bound commercial vehicles, it is the inspection facility of Aduana. For U.S.- bound POVs, there would not be much difference between wait and crossing times since agencies do not inspect them, other than CBP.

As a metric, wait time is of greater significance to CBP and Aduana operations, whereas crossing time is of greater interest to carriers, Secretaría de Comunicaciones y Transportes (SCT), and Federal Highway Administration (FHWA). For SANDAG, ICTC, and Caltrans purposes, wait times may be of higher value than crossing times when it comes to providing traveler information to the general public and determining variable toll pricing.

Furthermore, border crossing time is of significant interest to travelers in passenger vehicles. Processing time within the government compounds are variable and dependent upon many factors. Therefore, while this metric is of interest to the border-crossing public, it is more difficult to establish a baseline case; trends are the most probable indicator for this highly variable datum. **Figure 1** depicts the definitions suggested by the 2012 IBI Group study; it is a Mexico to U.S. northbound crossing.

Figure 1 - Definition of Wait Time, Crossing Time, and Delay
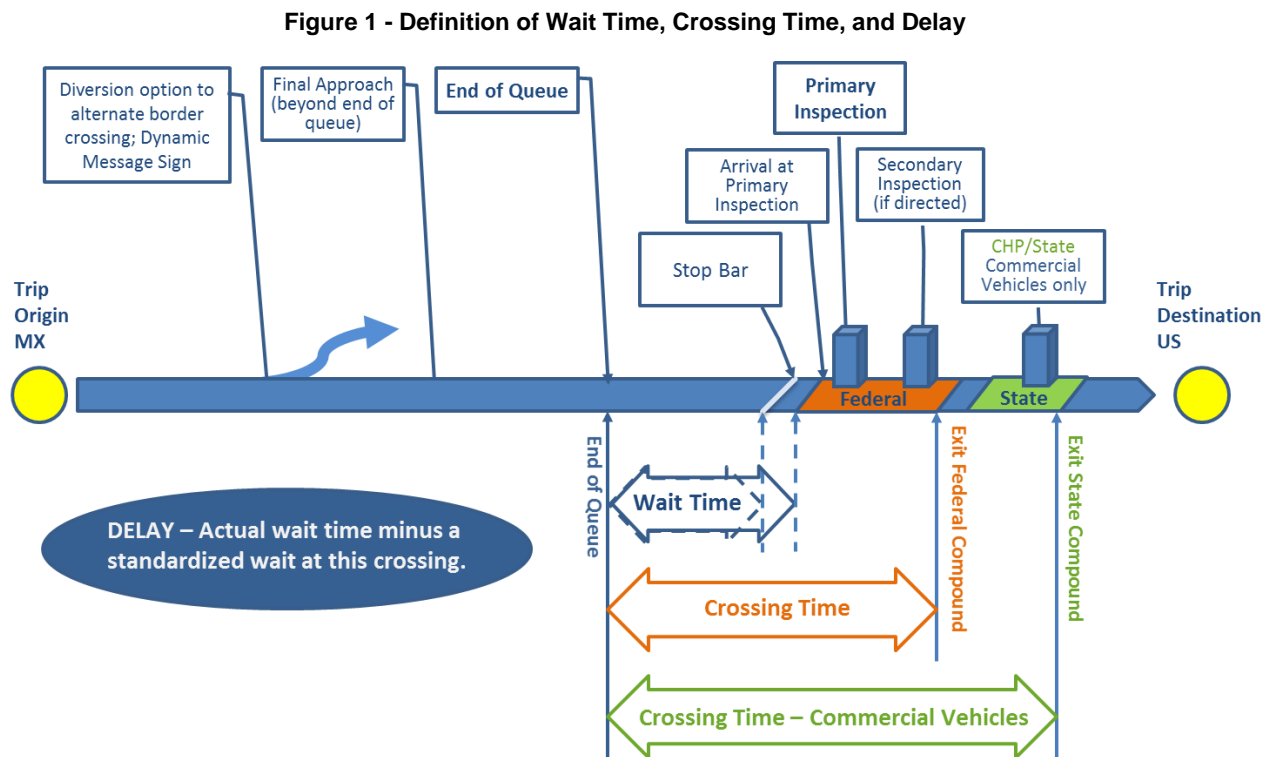
For the purposes of the discussion in this document, wait time will be distinguished from crossing time based on the above definitions. Additionally, wait time will be considered to end upon arrival at the primary inspection booth.

B. Users of Border Crossing Wait Time Data and Information

The value of different types of border crossing wait time data and information varies with its intended use and the perspective of the end-user. End-users and their information needs may include:

- **Commuters** desiring total crossing times and trends to make daily decisions about when and where they cross the border, and to arrange or plan for continued transportation or inform others of estimated arrival times or exceptional delays;
- **Commercial vehicles** and businesses desiring total crossing times and trends to understand their costs and plan for appropriate equipment and labor resources to accommodate their continuous border crossing needs, and to inform others of estimated arrival times or exceptional delays;
- **Leisure travelers** and irregular or one-time crossers desiring current total crossing times to arrange or plan for continued transportation and to estimate arrival to destination;
- **Government agencies desiring wait times to specific points in the queue** to assist with operations management and plan for appropriate human resources;
- **Government agencies desiring wait times or crossing times to understand trends** for regional transportation, infrastructure, or economic planning, budgetary, capital improvement, and performance measurement purposes;
- **Businesses** desiring to understand border crossing environments and end-user behaviors, wait times, or crossing times such that they may develop or deploy services or technologies to support client's or customer's needs for transportation, information, or other services.

C. Measurement Methodologies

Additionally, technology "systems" may be classified by the methodology that is used to measure the travel time for the desired roadway segment or points in the wait time queue. Three approaches to measuring wait times, as defined by FHWA in a 2008 study*, Inventory of Current Programs for Measuring Wait Times at Land Border Crossings,* include:

- **Queue Length Measurement**: Uses humans or technology to measure arrival and departure rates of vehicles and estimate the number of vehicles in the queue. This estimate is usually based on a measure of the length of the queue and an estimated average of the density of vehicles within it. The data is fed into an algorithm that estimates the time that it takes the next vehicle arriving at the end of the queue to move through the queue and reach the Primary Inspection booth. This method is ideal for providing real-time information for traveler information purposes. As soon as the data is recorded, it becomes archived data that can also be used for performance monitoring and other analyses.
    - o Human involved methods include visual observations, cameras, driver surveys, and time stamp card/toll receipts;
    - o Automated methods include inductive loop detectors, ranging radar detectors, video image processing.

- **Fixed Point Vehicle Re-identification**: Variations of this approach are also referred to as Point Vehicle Time Detection (PVTD), Anonymous Re-identification (ARID), and simply re-identification in various documents reviewed for this study. This approach can use a variety of technologies to identify individual vehicles at a fixed point upstream of the queue, and then again at the Primary Inspection booth, or at interim points along the queue and/or at some point beyond the inspection facilities. Methods currently used for Fixed Point Vehicle Re-identification (further discussed in the Technologies and Systems for Data Collection and Monitoring section of this document) include:

  - o Timestamped cards, toll receipts, human observations;
  - o Automated methods include Radio Frequency Identification (RFID), Automated License Plate Recognition (ALPR);
  - o Current automated methods generally include some combination of technologies, such as ARID Wi-Fi or Bluetooth readers supported by wired or wireless communications.

> **Suggested Improvement**
>
> Logged data can be made available more quickly by installing readers in the border region or along the queue that can download the data as soon as a vehicle completes the crossing.

The time difference between two timestamps provides the travel time between the two points. The wait time attributed to the queue alone can be calculated by subtracting out the average (baseline) time required to travel that distance when there is no queue (i.e. under optimal conditions). This approach is well-suited to the calculation of wait time data for archival purposes. In terms of real-time measures, the data is already out of date by the time the vehicle reaches Primary Inspection. In other words, if it took the vehicle one hour to get through the queue, then the system accurately provides the wait time for a vehicle that reached the queue one hour ago. The "current" wait time may have radically changed within that hour. The next-arriving driver may experience a very different wait time, which can lead to issues of trust in the data.

> **Suggested Improvement**
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> A more current estimate of the wait time can be achieved by increasing the number of readers along the length of the queue and using trip segment information from multiple vehicles that are in the measurement zone at the same time.

The lag time is then reduced to the time it takes for a vehicle to travel between readers. In addition, it is possible to include predictive components to the algorithm that allow the provision of a forecast delay. Additionally, the vehicle re-identification approach provides some flexibility in terms of what segments are measured because readers can be placed at any point in the crossing process. ARID is a type of Fixed Point Vehicle Re-identification that ensures that the unique identifier provided by the vehicle or technology that is on or in the vehicle, does not

readily correlate to a specific vehicle when the data is analyzed; thus, the data source becomes "anonymous".

- **Dynamic Vehicle Tracking**: Uses some form of wireless signal to determine the location of a vehicle dynamically, at various or multiple times, along its route. The archived data can then be analyzed to determine how far the vehicle traveled between time intervals on the approach to the border. If a segmented approach is used, the segments in the border zone are summed to produce a wait time. This approach is well-suited to the collection of archived data for performance monitoring purposes. Data is either transmitted on a continuous basis, or logged continuously on board the vehicle or device for later download.

    This method may still be subject to the same lag as the vehicle re-identification method—that is, the data may already out of date by the time the vehicle reaches Primary Inspection. As with the vehicle re-identification method, it is possible to include predictive components to the data analysis algorithm that allow the provision of a forecast delay. Additional flexibility to measure wait times along individual segments of the crossing process can be achieved by "geofencing" (defining virtual geographic zones) specific regions at each crossing.

A simplified example of a fixed-point vehicle re-identification approach could be as follows:

At a point along a roadway, unique identifying data is made available by a mobile phone (data source) inside the vehicle to Wi-Fi reader on the roadside (data collection mechanism) that transmits the data through a cellular phone network (communications infrastructure) to a server sitting on the cloud (data warehouse). These steps are then repeated at one or more additional points along the roadway. When the same unique identifier on the mobile phone is read at one or more points down the road, a travel time can then be calculated for the distance between two points. This travel time data is then analyzed, processed, repackaged into useful information, and made available via an app or website (data dissemination) to the user.

Figure 2 depicts a conceptual data collection and dissemination system that could include the use of technologies and infrastructure such as described in the previous example.

Figure 2 - Conceptual Data Collection & Dissemination System

Figure 2 - Conceptual Data Collection & Dissemination System
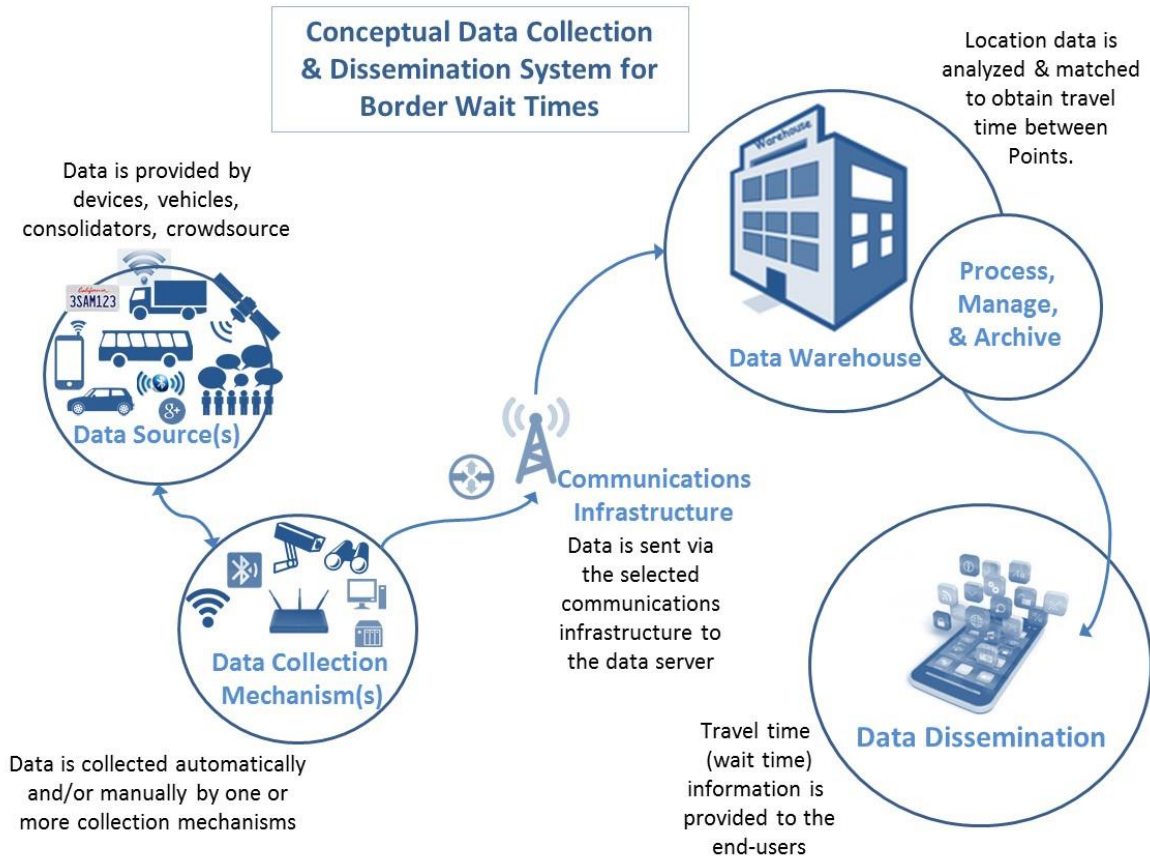
4. Systems and Technologies Currently Used

A. Technologies and Systems for Data Collection and Monitoring

Technologies used for collecting, transmitting, storing, and disseminating data that depicts border crossing delay are often used in combination to achieve the desired travel time measure. Therefore, when we talk about using a technology, such as Bluetooth, Wi-Fi, Cellular, or RFID, for border wait time data collection, we are really talking about a data collection system that may be interdependent on a few technologies, working together, to collect, store, analyze, and disseminate that data.

In a border crossing environment, a variety of factors will dictate which technologies are best suited to each leg of the data flow. Border crossings have some common characteristics and many unique physical, environmental, infrastructure, security, and suitability characteristics and considerations. So, technology approaches considered may need to be flexible to accommodate:

- The unique characteristics of the crossing,
- Continual changes and advances in technologies,
- Needs of the various stakeholders that desire and require the border crossing information.

The following sections more specifically address each of the potential technologies that can be used independently or in combination with others for the collection/detection, communication, and analysis of border wait times. Technologies addressed in this document include:

- Cellular Networks and Data
- Bluetooth
- Wi-Fi
- GPS
- Radio Frequency Identification (RFID) & Dedicated Short-Range Communications (DSRC)
- Automatic License Plate Recognition
- Connected Vehicles
- Inductive Loop Detectors
- Radar, Microwave, and Laser Technologies
- Crowdsourced/Aggregated Data
- Other Emerging Technologies

CELLULAR NETWORKS AND DATA

Cellular technologies can support all types of measurement methodologies. Cellular technologies can be used in a border wait time system for the generation of location data and/or the transmission of data from mobile devices or other data sources where a wireless communication method would be beneficial, such as when a wired communications infrastructure is unavailable. Cell phones and other mobile devices on a cellular network

continually generate location data that is used by the cellular carriers for providing continuous service and for providing or monitoring roaming and other location dependent services used. Cellular networks are also used for transmitting data to or from other devices and are often the wireless mechanism of choice for data transmissions that exceed the range of other wireless technologies, such as Wi-Fi.

Mobile Devices

A 2008 study by Florida Department of Transportation, *Travel Time Estimation Using Cell Phones (TTECP) for Highways and Roadways* verified cell phones and other mobile devices and their respective location data as viable sources for travel time; and the reliability, accuracy, and resolution of this data continues to improve as smartphone manufacturers refine or adopt more capable components. The reason location data exists for cellular based mobile devices is due to the way cellular signals are transmitted and carried on the cellular network. Specifically, cellular carriers periodically probe mobile devices on their networks, which may or may not be in use, to obtain the device identification and location. This probing is possible because the area serviced by the network is divided into many sectors, called cells, and each cell is serviced by a base station. To communicate with a specific mobile device and select the proper base station, the network must know the area the cell phone is in. So, when a mobile device moves from one sector to another, the cell must be handed off to the appropriate base station. In this way, the network is continually identifying and tracking mobile devices and performing the handoffs. There are many complexities to the operation of cellular networks along with the complexities of territories, ownership, and rights to base stations; each of these complexities impacts the way cellular devices are used when users must cross the US-Mexico border.

Travel Time Calculation

Generally, cell phone location is determined by signal tower triangulation using a variety of statistical methods and algorithms with varying degrees of accuracy. Depending on the method used, cell phone location accuracy can vary widely with the best providing location accuracy within 90 to 120 feet. Older methods may only be accurate to within 1500 feet or greater. For travel time, cell phone location data has been used with GPS as a complementary technology to improve accuracy. In rural settings, cell phone location accuracy may be suitable, but for urban settings accuracy is insufficient.

Suitability for Travel Time Measurement in a Border Environment

In the border environment, the use of cellular mobile devices to calculate wait time or crossing time is dependent upon continuity of location data from a mobile device that is traveling among a myriad of cellular service providers with closely spaced base stations and overlapping service areas. For cell phone customers, this may result in additional costly service charges for "roaming" into the territory of another carrier, data charges and service fees for international service. Given this, border crossers often switch back and forth between mobile devices – having a device specifically for use in Mexico with a Mexican carrier, and another device specifically for use in the U.S. with a U.S. carrier. Depending on which country they are entering, the traveler turns off the device from the country they are leaving, some time prior to

crossing the border – thereby eliminating the generation of some location data for that device. Increasingly, there are bi-national plans with some carriers; as prices for these plans become more affordable, there will likely be less phone switching at the border, and more continuous location data available.

Cellular Technology as a Communications Infrastructure

As a communications infrastructure, cellular networks provide an essential transmission mechanism, using devices like cellular modems, for data collected or generated by other technologies or devices. A 2015 Arizona border travel time study conducted by Cross-Border Group and Lee Engineering, evaluated the penetration rate or the sampling rate of Bluetooth or Wi-Fi anonymous re-identification (ARID) technology at the six Arizona-Mexico POEs. In this study, a cellular modem was used and cellular communication allowed for monitoring and processing the ARID device data in real- time and alerted data collection staff to tampering, theft, or malfunction. If cellular service was not available at a deployment location, the data was stored within the device for upload to a computer and post-processing.

Data

Cellular location data collected via the cellular network must be made available by the cellular network owner/service provider (the carrier) or by a third-party data application or processing entity; this may be at a cost. The location accuracy of mobile devices on cellular networks continues to improve by way of new technologies for base stations, antenna arrays, and the use of differential and assisted-GPS.

BLUETOOTH

Bluetooth wireless technology is a short-range communications technology originally intended to replace the cables connecting portable and/or fixed communications devices while maintaining high levels of security. Bluetooth technology is included commonly on devices such as smartphones, hands-free kits in cars, tablet computers, wireless headsets, and other devices. The key features of Bluetooth technology are robustness, low power, and low cost. Bluetooth is a mature technology that has been in use for about 20 years.[3] The Bluetooth specification defines a uniform structure for a wide range of devices to connect and communicate with each other. A feature of Bluetooth technology is that it has achieved global acceptance so that any Bluetooth-enabled device, almost anywhere in the world, can connect to other Bluetooth-enabled devices in proximity. While not all vehicles contain mobile phones emitting Bluetooth or Wi-Fi signals the proportion that do is now dense enough that meaningful travel time data can be obtained by tracking signals from these devices.[4]

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[3]Bluetooth, Our History, https://www.bluetooth.com/about-us/our-history
[4] ITS International, Bluetooth and Wi-Fi offer new options for travel time measurements, http://www.itsinternational.com/categories/detection-monitoring-machine-vision/features/bluetooth-and-wi-fi-offer-new-options-for-travel-time-measurements, 2013.

Bluetooth-enabled devices can communicate with other Bluetooth-enabled devices from a range of 1 meter to about 100 meters, depending on the class of radios attached to the device.

Bluetooth systems are best suited for vehicle/device re-identification detection methodologies and have been tested extensively in recent years to determine viability for travel time applications. The Bluetooth protocol uses a unique electronic identifier in each device called a media access control (MAC) address. Bluetooth readers can search for nearby devices using a refresh rate defined by the software running inside the reader and can obtain the MAC addresses of Bluetooth-enabled devices along with a timestamp. Because each MAC address is unique, traditional matching algorithms like those used for license plate, cellular, or toll tag tracking can be used to estimate travel time between two locations on a roadway. MAC addresses are not directly associated with any of the users' personal information, thus minimizing privacy concerns. Bluetooth signals used in the previously mentioned methodologies are discoverable signals – meaning that the device emitting the signal has not been paired or is open to pairing with multiple devices. Other Bluetooth methodologies combine discoverable and non-discoverable segments of Bluetooth signals and may increase the number of detections resulting in higher detection density and additional data[5].

Data sources for Bluetooth signals include devices such as:

- Cellular phones and other Bluetooth-equipped mobile devices
- Vehicles equipped with Bluetooth
- Headsets, speakers, and other Bluetooth accessories

Roadside data collection hardware, Bluetooth readers, must be installed along the queue to support Bluetooth data collection methodologies. As mentioned in the previous section, the Crossborder Group and Lee Engineering Study in Arizona evaluated Bluetooth as an anonymous re-identification technology to collect travel times. Bluetooth, was compared with Wi-Fi in this study by deploying it on opposite sides of the road at the same location. In this study, the

Suggested Improvement

A solution to intermittent cellular service is to create a virtual private network as a back-up option when cellular service is not functioning. Another solution (used by the Peace Bridge border wait time system) is to hardwire data/internet connections to the Bluetooth readers, as this is much more reliable but can have large upfront costs

penetration rate (similar to sampling rate), was essentially the number of unique devices detected by the ARID technology divided by the traffic volume for the same time window; Bluetooth had a lower penetration rate than Wi-Fi by 4 to 5 times. In other words, the Wi-Fi

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[5] Bluetooth readers that detect non-discoverable Bluetooth signals may be configured to detect only 6 of the usual 12 characters of the MAC address to provide another layer of privacy protection when using this methodology.

readers detected more mobile devices than Bluetooth readers. Bluetooth readers for the CBG/Lee study detected discoverable Bluetooth signals only.

When depending on cellular data service for communication to a data warehouse, test studies and pilot deployments have shown that cellular service may be intermittent.

WI-FI

Like Bluetooth technology, and in the context of border wait time systems, Wi-Fi is another short-range communications technology intended to provide communications among devices while maintaining high levels of privacy. Wi-Fi technology is most often included commonly on modern devices such as smartphones, hands-free kits in cars, tablet computers, other media streaming devices. The Wi-Fi signal emitted from these devices has made Wi-Fi another highly viable candidate technology for capturing the travel time of vehicles when drivers or passengers carry these devices, or vehicles with OEM or third-party Wi-Fi capabilities.

In a series of 2013 Danish travel time trials, in Aalborg, Denmark using Bluetooth, Wi-Fi, and a combination of the two respectively, data from the combined technologies trial indicated that 20% more vehicles were identified by Wi-Fi than Bluetooth[6].

Wi-Fi is the subject of current and recent tests in the San Diego regional border environment and is considered well-suited for Vehicle Re-identification (VRID), Anonymous Re-Identification (ARID) or Point Vehicle/Time Detection (PVTD) data (detection) collection methodologies. Wi-Fi is currently widely available in mobile devices and for roadside reader applications. A device must have Bluetooth or Wi-Fi enabled to be visible to the network and available for detection and be within range of the PVTD device (in this case approximately 500 ft.). Previous surveys indicate that mobile device users often leave Wi-Fi enabled on their devices, vs Bluetooth which is often disabled when not in use. Given this user behavior, Wi-Fi provides a higher probability data point for roadside readers. Currently, an application of Wi-Fi is being tested to collect border crossing travel times at the southbound San Ysidro US-Mexico border crossing. The San Ysidro Southbound Border Wait Time Pilot program is currently using the region's solar powered freeway call boxes by retrofitting them to house the sensors/readers and equipment required to gather anonymous data (a portion of the MAC address of the device) as vehicles drive by the equipped call boxes. The device is identified and then reidentified at multiple points (call boxes) along the route and then the time points are used to calculate travel time along the route into Mexico.

The use of Wi-Fi in the current Border Wait Time Detection pilot required the following modifications to the call boxes:

- Replacing the existing single antenna with a 3-function antenna that includes:
  - A data communication antenna (Cellular)

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[6] Bluetooth and Wi-Fi Offer New Options for Travel Time Measurements, ITS International, Blip Systems, October 2013, http://www.itsinternational.com/categories/detection-monitoring-machine-vision/features/bluetooth-and-wi-fi-offer-new-options-for-travel-time-measurements/.

- A voice communication antenna (Call Box system)
- A PVTD antenna
- Adding a PVTD device board into the existing call box enclosure
- Adding an underground box containing a 12V battery for the PVTD detector
- Replacing the existing solar panel with one that will furnish enough energy to both call box and PVTD systems.

Note that cellular communication (with a cellular modem) is being used for this pilot, eliminating the need for a physical communication connection (see also the previous discussion of cellular communications).

Maintenance of these installations is expected to be minimal and device functions can be tested remotely with the system web interface, if or when a communications link is available.

Another advantage of Bluetooth and Wi-Fi over Automatic Number Plate Recognition (ANPR)/Automatic License Plate Recognition (ALPR) systems is that, in bumper to bumper traffic, these technologies can detect and track device in vehicles at locations where the license plate is not visible an ALPR/ANPR camera. Additionally, the Wi-Fi and Bluetooth readers can detect Wi-Fi and Bluetooth devices in vehicles traveling at high speeds (200 km/h (124mph)). Further these technologies are bi-directional and can measure vehicles passing in both directions, if they are within range. Additionally, a single sensor is generally required, where ALPR requires cameras for each lane of the installation. These technologies can be combined for more complex solutions requiring more than travel time data. (ALPR and ANPR are discussed in more detail in the Automatic License Plate Recognition (ALPR) section of this document).

GPS

As a location data source, Global Position System (GPS) transceivers are currently used with smartphones and other mobile devices, navigation systems, data loggers, and in-vehicle units (IVUs - often for transit and commercial vehicles).

One primary strength of GPS over other technologies is that it does not necessarily require a roadside reader to retrieve or transmit the raw location data collected by the GPS unit. However, for the location data to be retrieved from a GPS unit, it must be downloaded manually from the unit, or combined with and transmitted using some other communications technology. GPS transceivers can transmit data through the cell phone network (Octel technology, for example), via satellite (e.g., Skybitz or Qualcomm), or through other short-range communications technologies such as Bluetooth, to report location and time information. The location and time stamp information can then be used to calculate cross-border travel time. Additionally, with GPS and cellular enabled mobile devices, such as smartphones, the GPS works together with cellular technology to "calculate" location, and then the cellular technology is the communication mechanism responsible for transmission of the data to a data warehouse. The combination of cellular and GPS technologies results in more accurate position data.

In 2009 FHWA study, Delcan & Cheval Research evaluated GPS alongside Automatic License Plate Recognition (ALPR) for the purposes of determining suitability as a border wait time data

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collection technology[7]. The following attributes of GPS were noted in the context of requirements for border wait time applications and remain relevant:

- GPS can provide total cross border time measurement, or any segment thereof with proper "geofencing" of segments.
- GPS can provide detailed data regarding movements of vehicles on approach to and within inspection facilities at the border.
- Data collection is dependent on the private sector cooperation and collaboration for the use of data collected by IVUs, data loggers, and some other privately owned or controlled devices.
- There are no known issues with safety and security – particularly when data is made anonymous (via a third party or through other data processing techniques).
- Stakeholders (participating in this FHWA study) generally supported sharing and selling of GPS data.[8]

Data must be normalized for outlying data points that periodically occur with this technology; it is also subject to occasional atmospheric anomalies. GPS requires the installation of equipment in individual vehicles and a center for receiving and processing information. In addition, some telemetry systems may not be able to provide data at sufficiently fine time increments. Overall, GPS is a reliable and essential assistive technology with potentially high resolution (depending on sampling rates) and wide-ranging data collection capabilities.

RFID/DSRC

RFID technologies include a variety of passive and active transponders, toll tags, and other types of tags that serve as vehicle identifiers. The best use of RFID for border wait times is for vehicle re-identification applications. RFID readers detect the ID of automated toll tags using dedicated radio frequencies. RFID is a mature technology that has been used in vehicle identification applications for more than 25 years[9]. Accuracy of this technology decreases with distance but has a directional advantage. Certain border crossers (such as commercial vehicles) warrant the use of RFID to measure travel time due to the higher levels of RFID tag fleet penetration for the various cargo, vehicle, and fleet pre-screening programs or membership with toll service providers, such as FastTrak.

RFID readers are placed along the roadside or above the roadway using existing infrastructure. Readers are most accurate when located near the target vehicle and serving a single travel lane. Distance and obstructions decrease sensor accuracy. Depending on the generation and type of RFID tag and reader system, the range is approximately 12-15 meters.

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[7] Measuring Cross-Border Travel Times for Freight: Otay Mesa International Broder Crossing, Technology Evaluation, FHWA, Delcan & Cheval Research, March 2008.
[8] Measuring Cross-Border Travel Times for Freight: Otay Mesa International Broder Crossing, Technology Evaluation, FHWA, Delcan & Cheval Research, March 2008
[9] Department of Transportation, Federal Highway Administration (FHWA), http://www.ops.fhwa.dot.gov/publications/fhwahop13029/ch2.htm

RFID technology is only applicable for cross-border travel time applications on roadways where a sufficient number of vehicles are equipped with tags – such as a toll road, SR125 for instance, or tolled crossing, such as the one planned for the Otay Mesa East facility, or for fixed commercial vehicle routes on the way to the border crossing.

RFID tag privacy is generally protected by truncating the tag IDs before the data are transmitted to the managing agency. This truncation prevents the tag ID from being matched to the tag owner in the managing agency's database of owners. Some emerging connected vehicle (CV) technologies use a very similar detection technology; however, privacy restrictions may make CV technology an unsuitable replacement for segment travel time data collection.[10]

RFID readers are also protocol specific and not all tags and readers are interoperable. This limits the ability for RFID readers to be used with any tag that may enter its sensing field. A Texas A&M study is testing a 3-protocol reader which may prove to overcome this limitation.

Most land POEs already use RFID technologies for other purposes, and many national border agencies have already installed RFID-based systems. The re-use of transponders already in border crosser's vehicles for travel time and border wait time calculations is a possibility.

AUTOMATIC LICENSE PLATE RECOGNITION (ALPR)

ALPR is a mature technology that has been used in the context of the border environment for many years. The 2008 FHWA/Delcan study compared it with GPS for border wait time collection. While ALPR is stable and reliable overall, the roadside equipment indicated a more complex installation subject to higher infrastructure costs with equipment security concerns. Current applications of ALPR technologies are being tested by the Buffalo & Fort Erie Public Bridge Authority in combination with Bluetooth and Wi-Fi to create a more robust data set and with positive preliminary results. Delcan's primary findings, that are largely applicable to today's systems, are summarized as follows:

- The specific location of ALPR camera at beginning of queue must be pre-determined
- Travel times may be estimated based on statistical distributions of trip types within the total sample.
- The total travel time using ALPR can be reported in real-time, but only after a vehicle passes both the first and last reader locations.
- ALPR data for multiple measurement points can be collected using portable ALPR stations at temporary points. This requires additional analysis and estimation for segments not measured.
- The sponsoring agency will own both the infrastructure and the raw data, but will also be responsible for maintenance of the physical assets, which include camera/antenna/power "out station" assemblies, and corresponding "in station" to receive transmitted data.

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[10] [10]Department of Transportation, Federal Highway Administration (FHWA), http://www.ops.fhwa.dot.gov/publications/fhwahop13029/ch2.htm

- Safety and security of ALPR infrastructure is primary concern. Life span of equipment is 3- 5 years; more information is needed to assess useful life under rugged border conditions. Potential security risk from theft or damage to fixed infrastructure.
- Historical precedent exists regarding ability of agencies to support long-term maintenance, security, and life-span of equipment. At the time of the study, FHWA identified trends in state-of-practice that suggested, fixed infrastructure for travel time measurements would likely be replaced by probe technologies; the outcome of this prediction is still uncertain, given the variety of infrastructure, environmental, and political conditions that surround each such installation
- Initial cost of infrastructure along with maintenance and security issues were sources of high stakeholder concern. Cameras near border may add additional privacy concerns for carriers.

ANPR/ALPR system requires high quality cameras with fast frame rates to capture an image of the license plate with the proper definition for the system to recognize and interpret the vehicle's plate number. Cameras for these systems are relatively costly to install and maintain.[11]

CONNECTED VEHICLES

Connected vehicles include short range radio communications technologies for vehicle-to-vehicle (V2V), where vehicles on the roadway communicate with one another, and vehicle-to-infrastructure (V2I) applications, where vehicles on the roadway communicate with roadside technologies and devices. Connected vehicle technologies are still in early stages of development, but have been maturing, and have been prototyped and tested for a couple of decades. With currently defined standards, connected vehicles communicate using DSRC technology – a reliable, low-latency radio-frequency communication standard selected for use with U.S. DOT's connected vehicle initiative. DSRC is capable of two-way communication, allowing both vehicle and infrastructure devices to send and receive data, possibly up to distances of 3280 ft. (1 kilometer). DSRC transceivers may be built into vehicles or mobile devices such as smartphones. In V2V communications, vehicles can anonymously exchange information about their position, speed, and heading, allowing each vehicle to be aware of surrounding vehicles enabling cooperative safety features to warn drivers of potential conflicts or collisions. In V2I communications, DSRC technologies may communicate location-specific and roadway condition information such as curve speed warnings, weather, pavement conditions, incidents, and detours. Conversely, vehicles with embedded devices or transponders, can indicate their presence to infrastructure, enabling features such as traffic signal actuation or priority, automatic toll payment, incident detection, credentials verification (for commercial vehicles at CBP inspections stations and with PrePass™ enabled California Highway Patrol (CHP) Inspection stations) and importantly for this study, travel time.

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[11] ITS International, Bluetooth and Wi-Fi offer new options for travel time measurements, http://www.itsinternational.com/categories/detection-monitoring-machine-vision/features/bluetooth-and-wi-fi-offer-new-options-for-travel-time-measurements, 2013.

At minimum, DSRC requires a small radio frequency transceiver to be present in the vehicle or host device, and for basic travel time data collection purposes, the vehicle-based transceiver only needs to send its current speed to an infrastructure transceiver.

INDUCTIVE LOOP DETECTORS

Magnetic loops are in-pavement, electrically conductive wire loops that detect the presence of a vehicle. This technology is very simple and mature and widely used for vehicle detection, speed, and classification applications, however it is not well suited for travel time applications. Paired loops can measure spot speeds, and special processors can match vehicle signatures at multiple locations using single loops. The vehicle signature capabilities have not been widely deployed. Vehicle signatures create the possibility of vehicle re-identification, but this also requires special processors that are not widely available.

Loop detectors have a high detection rate and are inexpensive. However, installation and maintenance costs are more expensive due to the requirement to cut or dig up the pavement for retrofit installations, repairs, or replacements.

Loop detectors cannot capture any unique or personal identification information from devices or vehicles, thus there are no security or privacy issues.

Even though loop detectors are widely used for traffic detection, there are currently no federally identified deployments of loop detectors used to measure segment or vehicle travel times. There are companies that continue to actively research the use of loops for future travel time applications.

Some agencies, such as the Canada Border Services Agency, have observed that the accuracy and reliability are not as high as with some other technologies, such as Bluetooth or Wi-Fi.

RADAR, MICROWAVE AND LASER TECHNOLOGIES

Radio wave (Radar), microwave, and laser light wave (or light detection and ranging (LIDAR)) technologies are mature, widely-used, spot speed and distance measurement technologies. These technologies all work on a similar principle in which an active sensor emits a radio wave, microwave, or light (LIDAR) wave that is reflected off a target vehicle, and the return time of the reflection or the frequency shift of the reflected energy is used to determine the vehicle's speed. Microwave and radar emit energy in a wide cone that can monitor a broad section of roadway whereas LIDAR emits a narrow laser beam that can be used in a single lane over a longer range.

These wave technologies, although in use for decades by highway law enforcement and in other industries, have not been widely used for travel time detection. There are a wide variety of wave technology products available with equally variable capabilities and applications. Generally, sensing equipment must directly face arriving or departing vehicles. There are perpendicular (also known as "sidefire") radar technologies that can be used perpendicular to traffic flow.

Wave technologies are used for spot speed measurements but do not have intelligent communications capabilities required for vehicle matching that is essential to accurate travel time applications. Speed can be used to calculate estimates of travel time, but in the border environment where speeds and location dwell times may vary on the border approaches and departures, wave technologies would not be the best choice for a travel time application. Additionally, heavy precipitation can reduce the functionality of radar; although this would not be a frequent problem for San Diego of Imperial County regional border crossings.

Also, because there is no identifying information required to measure spot speeds using these technologies, there are no privacy or security concerns. Finally, due to the viability and lower cost of other probe technologies, these wave detection technologies will continue to diminish in importance as choices for travel time applications.

CROWDSOURCED DATA

Generally, crowdsourcing leverages the combined intelligence, knowledge data, or experience of a group of people (or their devices) to answer a question, solve a problem, or manage a process.[12] For travel time data collection and information dissemination, crowdsourced methods are the most commonly used private sector mechanism today. Mobile devices carried by drivers or their passengers, or installed in their vehicles, can provide information about their location, speed, and possibly additional information to a public or private entity, and that information is used to generate traffic/ travel time information. Essentially, vehicles carrying passengers or a driver with a mobile device that provide location information become "probe vehicles", meaning its anonymous location is provided providing data points for speed and travel time in the transportation network.

The typical model for crowsourced data involves location-aware (GPS or cellular network-based) devices running an application that automatically sends information to a central server using cellular transmission. One advantage of location-based crowdsourcing is that vehicles can be individually tracked in near real-time, allowing more precise and timely speed and travel time estimates than can be achieved by other data collection technologies.

For the public sector, obtaining crowdsourced data could be more challenging; however, third-party aggregated crowdsourced data is being obtained by many transportation agencies to avoid the difficulties associated with accessing the data and the complex collection, data cleaning, management, and security tasks, and privacy considerations. Third-party, commercial providers offer access to proprietary data with clearly defined products, services, customer support, and professional expertise.

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[12] Michigan Department of Transportation, Center for Automotive Research, "Crowdsourcing Transportation Systems Data", February 2015.

Third party commercial special, traffic and location data providers include companies such as:

- Inrix, http://www.inrix.com/
- HERE, http://here.com/
- Cellint, http://www.cellint.com/
- Telenav, http://www.telenav.com/
- TrafficCast, http://trafficcast.com/
- TomTom, http://www.tomtom.com/en_gb/licensing/products/traffic/
- Cuebiq, https://www.cuebiq.com

Crowdsourced information dissemination platforms, such as Google Maps, Waze, Apple Maps, MapQuest, generally are used by travelers to receive live traffic information and turn-by-turn navigation directions. Web and mobile Application Programming Interfaces (APIs), such as Google's API for its online map (launched in 2005) can be used by agencies to reference this live traffic data. There are similar APIs from Bing Maps, MapQuest, HERE, TomTom and others that provide similar reference data. Each of these sources vary regarding their policies for access to free (unlimited) data (i.e., the number of queries that are allowed before a paid commercial account is required). Crowdsourcing the internet sources for travel time estimation has been found to be nearly as accurate by traditional sensor networks and less prone to errors and gaps in data provision as long as traffic volumes are not low (such as with rural highways)[13].

Other potential data sources for the public sector can include dedicated platforms and custom-built, dedicated applications, such as San Diego's 511 app. The apps must be frequently used by travelers along the roadway segments of interest to provide the volume and density of data required to derive useful information.

Social media mining and aggregation of social media data has provided some information about the condition of the border and transportation system in general; however, the precision desired in determining border wait times may not be possible using this source. Social media is an effective public engagement tool and is highly effective in disseminating information distilled from data collected through other methods.

Crowdsourced data is often fused with traditional data sources from sensor readings to create a richer data set that provides a higher level of detail and accuracy. This fusion of data and the resulting information is currently and predominantly disseminated by third-party service providers. A part of this fused data is often public agency data, and partnerships have been created to benefit both entities. An example of this type of partnership is the crowdsourced traffic speed and travel time data sets that are pre-aggregated and structured and provided to Michigan DOT by HERE.

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[13] Kurkcu, Abdulla; Ender Faruk Morgul; Kaan Ozbay. "Extended Implementation Methodology for Virtual Sensors: Web-based Real Time Transportation Data Collection and Analysis for Incident Management." *2015 Annual Meeting of the Transportation Research Board.* Washington, D.C. Compendium of Papers. 2015.

Challenges specific to the border crossings, when considering cellular geo-positioning data as the collection method for crowdsourced data, may include cell phone service provider incompatibilities and the user's switching of devices or providers at the border (to avoid international roaming, calling, and data charges), which interrupts the continuity of the data stream for one person or vehicle as they cross the border.

Advantages

- No need to procure, install, and maintain equipment in the field; and,
- Less vulnerability to outages related to unforeseen circumstances such as extreme weather, vandalism, power outages, or collisions.
- Variety of API capabilities, data access plans and cost tiers (some free) for multiple types of agency uses and users.

Disadvantages

- Systems will not count all vehicles. The sample size will vary based on technology penetration rate in a region for a given type of vehicle (e.g. commercial versus passenger vehicles) at a given time – and partnership agreements held by the aggregator.
- System may not have the ability to provide distinct information by lane or vehicle type, unless supplemented by other data sources.
- Agencies may need to contract with, possibly pay, a 3rd party vendor for supplemental data, or install supplemental data collection systems, and possibly develop unique applications for data collection, processing, or management.

OTHER EMERGING TECHNOLOGY CONSIDERATIONS

Multi-technology Readers

Many emerging traffic counting and travel time detection systems gather data by using multi-technology readers or other equipment to detect and/or connect with various devices in vehicles. These include the following:

- Radio frequency identification (RFID);
- Bluetooth;
- Wi-Fi; and,
- Global positioning system (GPS).

Common Advantages

These emerging hardware-based technologies share certain advantages:

- Vehicles equipped with the relevant technology can be uniquely identified while preserving privacy;
- Can provide real-time data;
- Can provide distinct geospatial data; and,

- Continuing costs of operation are relatively low.

Common Disadvantages

These emerging hardware-based technologies share certain disadvantages:

- Systems will not count all vehicles. The sample size will vary based on the penetration rate of each technology in each region for a given type of vehicle (e.g. commercial versus passenger vehicles) at a given time.
- Initial costs to create a system can be high.
- Requires the installation of hardware, if not already present.
- Many hardware-based systems may be vulnerable to weather impacts and may require ongoing maintenance.

Agencies have developed a variety of solutions to address these challenges. For example, agencies conduct feasibility studies to estimate the sample sizes for a technology prior to implementing a system. They may also combine technologies to validate data and/or develop estimating algorithms based on ground-truthing. Agencies have addressed potential equipment failure through a variety of strategies, such as:

- Maintain spare equipment;
- Monitor readers automatically to proactively detect and address issues; and,
- Develop software solutions that can adapt to continue providing data when one piece of hardware fails.

B. Information Dissemination Systems and Data Management

A variety of information dissemination mechanisms now exist that allow border crossers to obtain estimates of wait times. Television, radio, and word of mouth continue to be prominent sources of information with websites, mobile device apps, and social media also prevalent.

Smartphone navigation apps with live traffic information are available and used by border crossers, but the extent of use for the purposes of obtaining border wait time information were not addressed in this report. The type of data and methods used to calculate wait times vary according to the publisher of the information. Most applications rely on CBP's manually observed estimations of wait times and combine this with other data points such as live updates and reports from people crossing the border, analysis of historic wait time data and algorithms developed from live video feeds. While users suggest that these information sources seem more accurate than solely relying on the official CBP information, there is still a need to improve accuracy of the information. Crowd sourced data is becoming more available, and sources of data from academic and pilot programs are used for some applications and websites.

Figure 3 below demonstrates the lack of consensus of users of the various border wait time mobile apps that are currently available. Users expect and demand more accuracy than is currently possible through existing applications.

Figure 3 - Border Crossing Mobile App User Reviews

User reviews

KornShaDoW097 March 31, 2017
★★★★★

Although it relies on bwt, with enough people submitting their real-time data, this could become the next waze type app.

BW Malcolm October 22, 2015
★★★☆☆

Crashing & Lack of user reports limits usability App uses Gov data which is (supposed to be) updated hourly, so user reports are important for real time data. But crashes prevent using the timer and frequently prevent submitting the wait time. Saved preferences does not save the choice of lanes ie Std, Ready or Sentri. Historical trend graphs are great for picking a good time to cross. With thousands of people crossing at TJ every day, this could be a great app if it really collected real time data, but with only Gov data, it is only so-so.

ricardo ruiz December 26, 2016
★★★★★

Great app

phil manis April 30, 2016
★★☆☆☆

Not very accurate The whole point of this app is to let you know how long the wait is to cross an international border. The app currently says the wait time to cross into Windsor Ontario via the tunnel is 0:00 yet I'm in bumper to bumper traffic in the tunnel. Not sure how it gets it's data but it isn't accurate.

Michael Campbell August 8, 2015
★★☆☆☆

Not being updated often enough Showed zero wait time at Peace bridge, actual wait time well over an hour. I used to rely on the site, now it's as accurate as weather. Not impressed

Domenic Pagliaro December 16, 2014
★★★☆☆

Good, but... In case you're wondering why it only updates hourly, that info comes from US CBP. It has nothing to do with the app. However, when reporting user wait times the app should disregard "false" iReports. In other words, toss out times that do not reflect other iReports. These skew the average wait times. Also, I'd like to see old iReports so I can see wait time trends.

November 20, 2016
★★★★☆

Use regularly In my experience the CPB reported wait times are almost never accurate for the California San Ysidro auto crossing...they generally report a significantly shorter wait time than is reality. The 'user reported' data however is generally spot on.

Tony Cervi April 6, 2016
★☆☆☆☆

Crossing times are not accurate at all. Although the last update time it reports on the app is recent the wait times are not accurate, I have been caught multiple times where wait time was seemingly minimal but had to wait much longer. I have also set the timer provided within the app twice now and uploaded them and neither time was the time reflected on the wait times at my border crossing.

Pete Dunn December 19, 2015
★★★☆☆

OK, but updates way behind. I sometimes use the video because the wait time feature is always delayed so long. Not minutes, last 2 times were 30 an 42 minutes, and definitely not out of data coverage zone.

Apps and other border-focused websites that specifically address border crossing travel time and conditions have been developed by a variety of interested parties and some notable examples are described in the following section. The section titled Other Border Environments and Projects Reviewed in this document includes a more detailed discussion of the use of information dissemination mechanisms, predominantly web sites, by other agencies and organizations at border crossings in Washington, New York, Arizona, and Texas in their respective border environments.

INFORMATION DISSEMINATION

Smart Phone and Tablet Navigation Apps with Live Traffic Information

Many drivers use popular smartphone navigation apps to monitor traffic conditions and to obtain navigation information, and some provide basic border traffic and wait time information. The details of border wait time information and border area travel times vary with the app, the number of users at any point in time, and user reporting. A list of these apps is included in this

report in the following section. The apps that have been developed, and are available and operational, continually evolve; therefore, this list is representative of what was available at the time this report was written.

Table 1- Smart Phone and Tablet Navigation Apps with Live Traffic Information

App Name	Cost	Comments
Apple Navigation	Free	Proprietary map and traffic data. iOS only.
Co-Pilot HD	$15+$10/yr	From ALK Technologies, Ltd. Traffic data by Inrix.
Garmin Viago	$2+$20/yr	Unique 3D views and lane choice guidance. Traffic data from HERE.
Google Navigation	Free	Proprietary map and traffic data. The world's most popular smartphone app.
Inrix	$10	Inrix Traffic data. Google Map data.
MapQuest	free	Owned by AOL. Uses OpenStreetMap. Traffic from TomTom/Inrix
MotionX GPS Drive	$10/yr	Traffic data from Trafficast.
NAVIGON	$50+$20/yr	Owned by Garmin, maps and traffic data by HERE.
Scout	Free	By Telenav, Inc. Uses OpenStreetMap. free Allows crowdsourced user reports. Proprietary traffic data
Sygic	$40+ $15/yr	Offline maps only. Traffic data provided by TomTom/Inrix.
TomTom	$39+ $20/yr	Traffic data from Inrix.
Waze	Free	Proprietary map and traffic data. No offline option. Crowdsourced traffic hazard reporting and map editing

Border Wait Time Smart Phone and Tablet Apps

Introduction here…
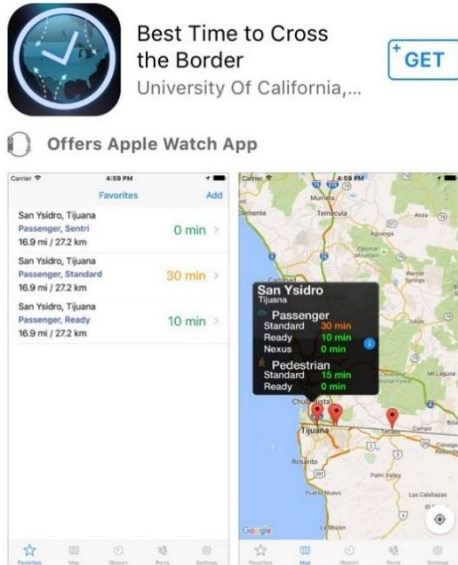
The **UCSD Calit2 app/website Best Time to Cross the Border App and Website** has been developed by students at University of California San Diego (UCSD). The app and website lets commuters report wait times via its *iReport* (crowdsourcing) feature which is fused with the CBP data to improve accuracy. Social media integration via Twitter and historical graphs showing trends allow users to make decisions as to when to cross. http://traffic.calit2.net/border/border-crossing-wait-times-map.php

The **Border Crossings Times** app was developed by a person who lives along and frequently crosses the Ciudad Juarez to El Paso, Texas border. Its popularity is rooted in the limited content for pedestrian and vehicle crossing times only at this border as provided by the U.S Customs and Border Protection

The **CBP BWT** app provides a smart phone app that reflects the same data that is available on the Customs and Border Protection web site. The app was first launched in December 2014. The app covers the US-
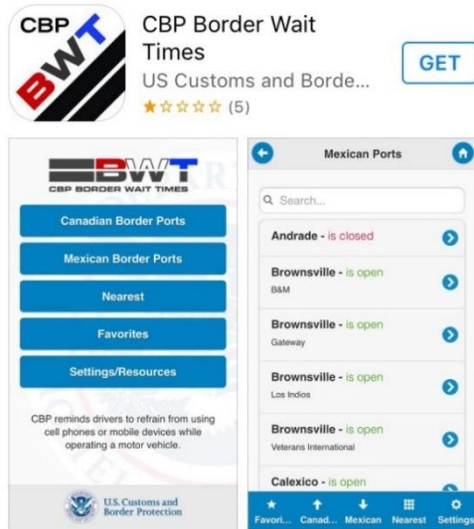
Canadian and US-MX border crossings and reports estimated wait times and open lane status for Standard, SENTRI, FAST, Ready Lane, and Nexus. Users of the app are generally more satisfied* with reported wait times relating to SENTRI and Ready lanes. Data for the app is derived from visual observations and cameras. Users of the app that are inquiring about wait times for standard lanes are dissatisfied with the accuracy of the reported wait times. The app is a free service provided by the Department of Homeland Security/U.S. Customs and Border Protection.

*Google Play and Apple App Store Reviews

Metropia is an app funded by City of El Paso that provides real-time POE wait time estimation and prediction and incentives (points collected and redeemed for gift cards). City of El Paso's goals are to reduce traffic congestion and wait times across the El Paso-Juarez border. This app went live in May 2018. The app incorporates user insights into their predictive models.
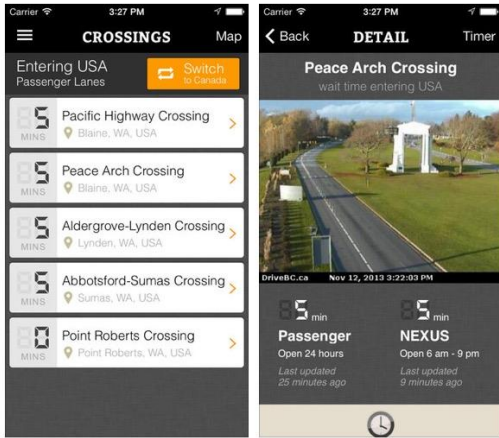
Mr. Border provides wait times for the USA/Canada and USA/Mexico border crossings by combining both official wait times with real-time wait information reported by actual border-crossing travelers (crowd-sourcing). An additional feature that increases usage of the app is the gas prices at the border crossings that are updated by users as they cross.

Border Wait Times US Ports of Entry is a simple app, released in 2016 provides the estimated wait times for US/Mexico border crossings.
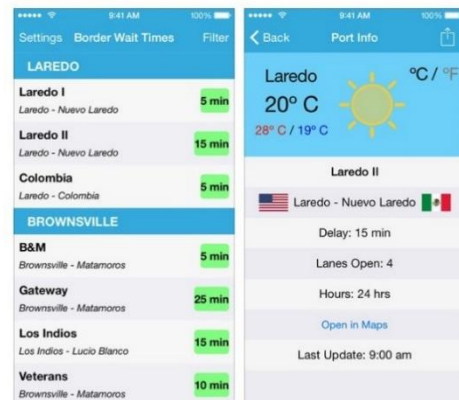
Garitas is a simple app developed in 2015 to provide wait time for lanes at a specified US-MX crossing. The app is in Spanish or English. It allows the user to save a favorite crossing/mode for viewing when the app is opened. Color coding of the icons gives a visual indication of the delay expected for the specific lane. User reviews indicate there are some issues with accuracy of the estimated times.

The **Border Traffic** app provides near real time videos of the San Ysidro (San Diego) / Tijuana and the Otay Mesa / Tijuana border crossings, 24 hours a day, 7 days a week (the front of vehicle lanes plus all available pedestrian views). The app feature, AccuWait, generates estimated wait times using analytics of BorderTraffic.com videos. It also provides, My Alerts, which notifies users when wait times meet criteria that they have set. For example, users can create an alert when the wait in the San Ysidro Ready Lane is less than 20 minutes.
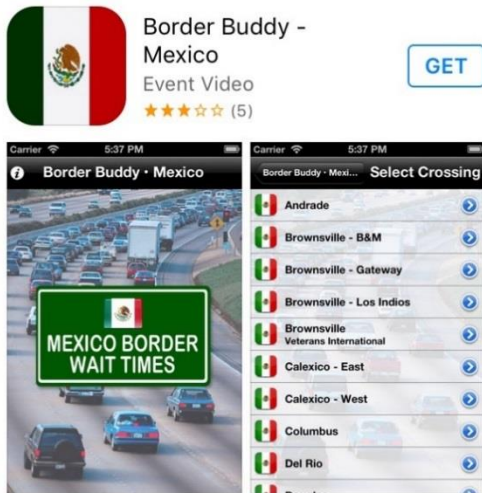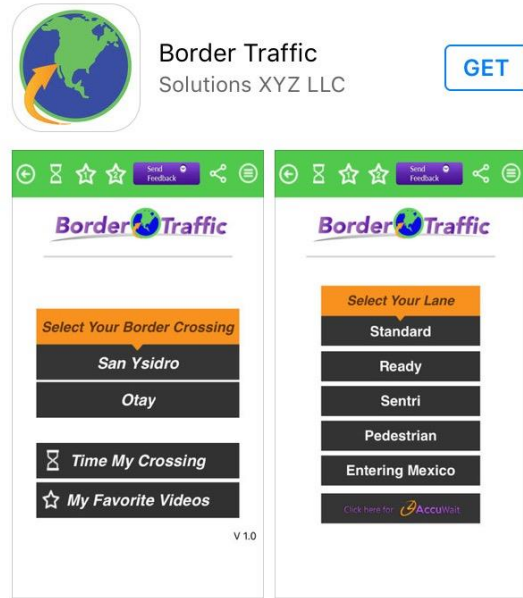
Border Buddy Mexico, released in 2012, provides wait times at US/Mexico border crossings. No further information was provided by the developer or users.

The **US Border Wait Time** application shows the wait times to cross into the U.S. from Mexico or Canada through the pedestrian border or by car.

The app also includes maps of the border crossings so you can choose another one should there be a long wait time in your border crossing point.

5. Border Crossing Environment: Information and Monitoring Foundations and Needs

A. Past Border Wait Time Studies

Past border wait time studies are numerous and are motivated by a variety of data and information needs. Studies include public and private sponsors with varying levels of detail; some used existing and available data and others generated data through manual and/or technology based collection methods.

Studies reviewed included tests and pilot programs of a variety of data collection and monitoring technologies. These technologies and their applications are evolving so quickly that a study completed just a few years ago, may have been overtaken by new information, new tests, new pilots and new versions or generations of the technology involved. Agencies and organizations interested in ways to automate border wait time data collection are continually testing new combinations of technologies that provide more robust and accurate data sets that may be distilled into more accurate and useful border crossing travel time and wait time information for the end users – the people traveling on foot, by car, or operating commercial vehicles.

Lessons learned from some of these studies are timeless, and usually pertains to planning, stakeholder engagement, policy, operation, maintenance, and inter-agency and international coordination, collaboration, and cooperation. These studies are footnoted throughout this document as attributable information is woven into the relevant section or topic.

Below is a list of the relevant studies reviewed for this white paper:

1. Commercial Trade Statistics, Department of Homeland Security, Customs and Border Protection, August 2017.
2. Wireless Technologies for Motor Carrier Efficiency: Update, Draft, Sutra Research & Analytics, January 2017.
3. NOW: Taking it to the Streets: Collecting Travel Time Data, Speed with Bluetooth Technology, Texas Transportation Institute, Texas Transportation Researcher Article, 2016.
4. Assessment of Existing "Gaps" on Border Data (Including Wait Times); Economic and Air Quality Impacts of Delays at the Border, SANDAG, HDR, July 2016.
5. Data Collection and Uses at International Border Crossings – Technology Options, Texas Transportation Institute; Villa, Juan Carlos; July 26, 2016
6. Border Waits Analysis at the Nogales-Mariposa Port of Entry, FHWA, ADOT, January 14, 2016.
7. Border Wait Time Detectors Temporary Installation Procedure, IBI Group, January 14, 2016.
8. Memorandum to SANDAG: Results of Temporary Installation of Bluetooth and Wi-Fi Point Vehicle Time Detection (PVTD) Devices, SANDAG, IBI Group, January 28, 2016.
9. Memorandum to SANDAG: Border Wait Time Detection System Installation and Maintenance, IBI Group, December 1, 2015.
10. Border Corridors and Trade Report, Texas Department of Transportation, December 2015.

11. Analysis of Bluetooth and Wi-Fi Technology to Measure Wait Times of Personal Vehicles at Arizona-Mexico Ports of Entry, Arizona Department of Transportation, Lee Engineering, LLC, October 16, 2015.
12. San Ysidro Southbound Border Wait Time Pilot, IBI Group, September 2015.
13. Border Wait Time Detection Pilot Program, Fact Sheet, SANDAG, March 2015.
14. Crowdsourcing Transportation Systems Data, Michigan Department of Transportation, Center for Automotive Research, February 2015.
15. Technical and Bureaucratic Challenges to National Data Warehouses: Summary of the US-Canada Data Warehouse Project, Whatcom Council of Governments, IBI Group, 2014.
16. Joint Interim Committee to Study the Effects of Border Wait Times, Interim Report 2014: A Report to the House of Representatives 84th Texas Legislature, September 2014.
17. Border Wait Time – Buffalo-Niagara Region, US/Canada Transportation Border Working Group, Niagara Falls Bridge Commission and Buffalo & Fort Erie Public Bridge Authority, Dafoe and Ripa, May 2014.
18. Measuring and Documenting Truck Activity Times at International Border Crossings, USDOT Region V NEXTRANS Project No. 067OY03, Ohio State University, McCord, Mark, April 2, 2014.
19. State of the Practice on Use of Intelligent Transportation Systems at US-Mexico Land Border Crossings, 92nd Annual Meeting of the Transportation Research Board; Texas Transportation Institute, Rajbhanddari, Rajat, January 2013.
20. SR 11/Otay Mesa East Port of Entry ITS Pre-Deployment Strategy, SANDAG, IBI Group, October 2012.
21. Implementing a System to Measure and Disseminate Wait and Crossing Times at California Border Crossings, San Diego Association of Governments (SANDAG), Prepared by IBI Group, October 2012.
22. Commercial Border Crossing and Wait Time Measurement at Laredo World Trade Bridge and Colombia-Solidarity Bridge, Texas Department of Transportation, Texas Transportation Institute, March 31, 2012.
23. SR 11/Otay Mesa East Port of Entry ITS Pre-Deployment Strategy, State of the Practice Scan, Final Technical Memorandum I, Version 3.0, SANDAG, IBI Group, February 2012.
24. Field Experiment to Identify Potentials of Applying Bluetooth Technology to Collect Passenger Vehicle Crossing Times at the U.S. – Mexico Border, Center for International Intelligent Transportation Research, TTI, 2009.
25. Field Experiment to Identify Potentials of Applying Bluetooth Technology to Collect Passenger Vehicle Crossing Times at the U.S.-Mexico Border; Texas Transportation Institute, Rajbhanddari, Rajat, July 2009.
26. Inventory of Current Programs for Measuring Wait Times at Land Border Crossings, Transport Canada, May 2008.
27. Measuring Cross-Border Travel Times for Freight: Otay Mesa International Broder Crossing, Technology Evaluation, FHWA, Delcan & Cheval Research, March 2008.
28. Travel Time Estimation Using Cell Phones (TTECP) for Highways and Roadways, Florida Department of Transportation, Wunnava, Subbarao, et. al., January 29, 2007.

B. Regional Border Environments

This section is included to provide context for understanding challenges associated with selecting and deploying data collection technologies and systems for border wait or crossing time assessments. The border crossing environments in San Diego and Imperial counties are varied in population, demographics, climate, and usage. Each crossing has unique

characteristics that are favorable for certain types of technologies and data collection methodologies. Each crossing is uniquely managed to accommodate the specific characteristics of the local environment, community, infrastructure, facilities, and government agency staffing and capabilities. The following snapshots provide a quick summary of the environments, populations, any notable unique characteristics, and recent Bureau of Transportation Statistics estimates of crossing volumes for personal vehicles, trucks, buses, and pedestrians. This context is important when reading the following section, Other Border Environments and Projects Reviewed, such that reasonable comparison may be made between the crossings and technology deployments.

SAN DIEGO BORDER ENVIRONMENTS

San Diego region includes the crossings at San Ysidro, CA (crossing with Tijuana, BC), Otay Mesa, CA (crossing with Mesa de Otay, BC), and Tecate, CA (crossing with Tecate, BC). In general, the San Diego area crossings are subject to coastal and Mediterranean climates with warmer, dryer environments to the east; this environment is conducive to the use of a variety of technologies. Any technology deployed in an outdoor environment is subject to weather, thus appropriately hardened or protected technologies are among the considerations from an environmental standpoint.

Security of the equipment must be analyzed and considered for deployment of each technology - security has proven to be challenging in some border environments and must be a primary consideration when selecting deployment sites, infrastructure requirements, monitoring capabilities, technology housing, and operations and maintenance requirements and procedures.

San Diego's land ports of entry each have the following described unique characteristics:

San Ysidro straddles the border between metropolitan Tijuana and the community of San Ysidro (12 miles to the south of downtown San Diego). San Ysidro is a crossing for passenger vehicles (privately owned vehicles (POVs) and buses) and pedestrians only. Data collected from this crossing will be limited to passenger vehicles and pedestrians; information disseminated for this crossing will need to be most useful to passenger vehicle and pedestrian crossers along with the government agencies and private businesses that will use the data for their own purposes. Major highways connect vehicles and pedestrians to this crossing. This crossing is also served by two transit centers (San Ysidro and Virginia Avenue) that offer bus connections (MTS, Greyhound, and Mexican providers), trolley connections to the "Blue Line," taxi and jitney services. These services, routes, and transit centers, are depicted in **Figure 4**.

Figure 4 - San Ysidro and Virginia Ave Transit Centers (Blue Line)
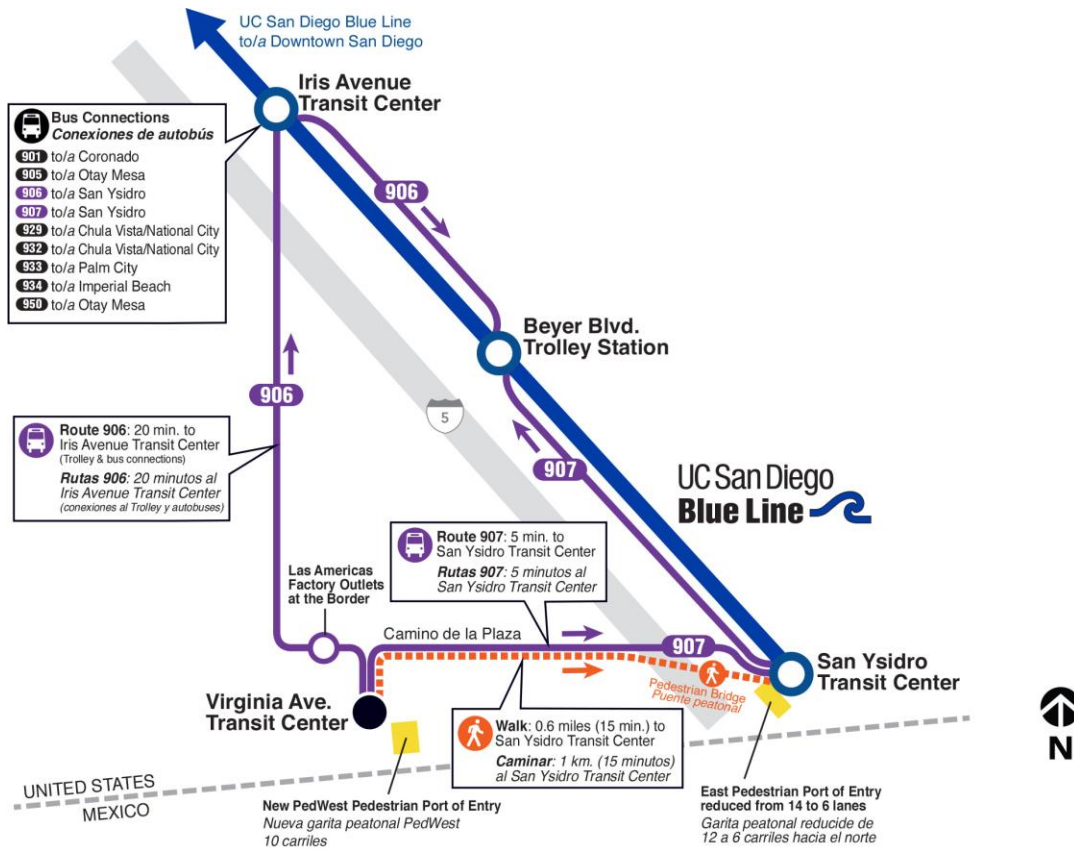
The crossing has infrastructure and communications capabilities to support a variety of data collection technologies. Cellular services are plentiful and often conflicting in this busy border environment.

The U.S. Bureau of Transportation Statistics reports that the annual northbound San Ysidro crossing volumes (2016) are as follows[13]:

Personal Vehicles	Trucks	Buses	Pedestrians
13,701,967	NA	NA	7,382,363

San Ysidro is ranked the number one U.S. – Mexico border crossing for volumes of personal vehicles and pedestrians for the period January to December 2016.

Otay Mesa accommodates passenger vehicles, pedestrians, and commercial vehicles (within a specific commercial vehicle only section of the facility). Otay Mesa East, when completed, will accommodate the same mix of passenger and commercial vehicles. Data collected and information disseminated for these crossings will need to be useful to all three types of crossers

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[13] U.S. Bureau of Transportation Statistics,
https://transborder.bts.gov/programs/international/transborder/TBDR_BC/TBDR_BC_QuickSearch.html

along with the government agencies and private businesses that will use the data for their own purposes. Major highways connect passenger and commercial vehicles and pedestrians to these crossings. Construction is underway at for the new Otay Mesa Transit Center with dedicated access to South Bay Rapid service (anticipated to begin in 2018) and local bus routes operated by MTS. The crossings have infrastructure and communications capabilities to support a variety of data collection technologies. Cellular services are plentiful and often conflicting. The future Otay Mesa East crossing has similar capabilities currently under construction and will include fiber optic communications.

The U.S. Bureau of Transportation Statistics reports that the annual northbound Otay Mesa crossing volumes (2016) are as follows:

Personal Vehicles	Trucks	Buses	Pedestrians
7,722,264	899,336	32,877	3,504,800

Tecate accommodates passenger vehicles, pedestrians, and commercial vehicles (within a commercial vehicle only section of the facility). The Tecate crossing is located in a rural part of San Diego County served by rural State Route 94, a two-lane road with curves that limit some types of commercial vehicles. On the Mexican side of the crossing is the busy city of Tecate. The Tecate crossing has infrastructure and some communications capabilities to support certain data collection technologies. Cellular service in Tecate is improving, but dependent on service provider and often wrought with connection issues and "dead zones".

The U.S. Bureau of Transportation Statistics reports that the annual northbound Tecate crossing volumes (2016) are as follows:

Personal Vehicles	Trucks	Buses	Pedestrians
971,193	56,269	94	673,605

IMPERIAL COUNTY BORDER ENVIRONMENTS

The border crossings at Andrade, CA (crossing with Los Algodones, BC) and Calexico East and West (crossings with Mexicali, BC) occupy the dry desert climate and terrain of the Imperial Valley with temperatures often exceeding 100 degrees for four to five months of the year. Wind, sand, excessive heat, and periodic monsoon rains create a challenging environment for electronic technologies. As technologies are selected for these crossings, consideration must be given to whether they require cooling, additional protection, or hardened components that can withstand the harsher than average conditions that may be outside of equipment tolerances for temperature, humidity, or contaminants.

Calexico West serves a frequently crossing population that is passenger vehicle dominant with some pedestrians. The only wait time or crossing time data that can be collected for this crossing is from pedestrians and passenger vehicles. Commercial vehicles are not permitted at this port of entry. Therefore, information disseminated for this crossing will need to be most

useful to passenger vehicle and pedestrian crossers along with the government agencies and private businesses that will use the data for their own purposes.

The U.S. Bureau of Transportation Statistics reports that the annual northbound Calexico West crossing volumes (2016) are as follows:

Personal Vehicles	Trucks	Buses	Pedestrians
4,327,034	NA	NA	4,270,911

Calexico East serves the city of Calexico on the U.S. side and the city of Mexicali on the Mexican side. Calexico has a population of about 40,000 people and Mexicali has a population of about 690,000 people. The Calexico East/Mexicali crossing accommodates passengers, pedestrians, and commercial vehicles (within a commercial vehicle only facility). Data collected and information disseminated for these crossings will need to be useful to all three types of crossers along with the government agencies and private businesses that will use the data for their own purposes.

The U.S. Bureau of Transportation Statistics reports that the annual northbound Calexico East crossing volumes (2016) are as follows:

Personal Vehicles	Trucks	Buses	Pedestrians
3,829,484	349,727	2,906	253,992

Andrade is a border crossing that sits near the Colorado River along the border of Arizona and shares the border crossing with the Mexican town of Los Algodones. Andrade had a population of 49 people during the last census. Los Algodones is a busy Mexican town with a population of about 5,500 people. Pedestrians and passenger vehicles dominate this crossing. Andrade/Los Algodones border crossing ranks 11th among pedestrian border crossers and is used heavily by tourists and those seeking medical supplies and services. The crossing is served by rural State Route 186 in the US.

The U.S. Bureau of Transportation Statistics reports that the annual northbound Andrade crossing volumes (2016) are as follows:

Personal Vehicles	Trucks	Buses	Pedestrians
506,230	NA	NA	833,296

C. Other Border Environments and Projects Reviewed

Other border crossing environments that provide relevant and recent experience with technology deployments, pilot tests, or studies that are relevant to San Diego and Imperial County include Nogales, AZ (crossing with Nogales, Sonora, Mexico); Whatcom County, WA (Including I-5 Peace Arch, SR 543 Pacific Highway, SR 539 Lynden/Aldergrove, SR 9 Sumas/Huntingdon crossings); Peace Bridge in Buffalo, NY (crossing with Fort Erie, ON, Canada); and the Texas border crossings (including Brownsville, Pharr, Eagle Pass, Laredo,

and El Paso, TX). The following sections provide comparison information about these crossings with descriptions of wait-time technology deployments, pilot programs, or tests conducted the crossing location.

NOGALES, ARIZONA

The environmental conditions of the Nogales area border crossings, situated along the southern border of Arizona and northern border of Sonora, Mexico, are very similar to harsh, arid desert conditions and temperature extremes of the crossings in Imperial County at Calexico and Andrade. Nogales, AZ has a population of about 20,400 people; and Nogales, Sonora, Mexico is a much larger city with a population estimated at 220,292 (in 2010). Arizona shares 9 land ports of entry with Mexico. Three border crossing facilities are located within, or in the vicinity of, the cities of Nogales, AZ and Nogales, Sonora, MX along the southern border of Arizona and northern border of Sonora, Mexico. The three crossings, as they are commonly referred to, are:

- **Nogales-Mariposa** crossing at Nogales, AZ/Nogales, Sonora, Mexico at Mariposa Rd. serves trucks and cars along SR189 in AZ and Fed. 15 in Mexico; this is the only crossing for trucks in the Nogales area.
- **Nogales-Grand Avenue** crossing (also sometime referred to as the Nogales – DeConcini crossing) serves cars only (no trucks) along Interstate 19 in AZ and Boulevard Adolfo Lopez Mateos in Nogales, Sonora, Mexico.
- **Nogales-Morley Gate** crossing at Morley Avenue serves pedestrians only.

The U.S. Bureau of Transportation Statistics reports that the approximate combined annual northbound Nogales ports crossing volumes are as follows:

Personal Vehicles	Trucks	Buses	Pedestrians
3,477,415	312,010	9,423	3,420,708

Arizona currently uses the CBP estimated crossing volumes for all their ports of entry. Wait times have also been historically compiled through manual observation of the end of the queue by CBP personnel and traveler surveys. New Wi-Fi readers are being installed at the Nogales-Mariposa and Nogales-Grand Avenue crossings as part of a larger installation of readers that began in 2016 and is pending completion in 2017. The intent of the installation is to make wait time data available to motorists via the CBP website once testing for reliability has been completed.

A recent comparison study by Arizona Department of Transportation (ADOT) and Lee Engineering of border crossing installations of Bluetooth and Wi-Fi equipment included co-located detectors along the highway to detect Bluetooth and Wi-Fi enabled devices in passenger vehicles traveling to and from the port of Entry. The study installed test devices along primary access roads to six U.S. – Mexico ports in Arizona; the Nogales-Mariposa and Nogales-Grand Avenue (DeConcini) crossings were among the six.

Some notable findings from this study include:

- Anonymous Re-identification travel time data collection using Wi-Fi technology resulted in higher penetration rates for this Port of Entry study application than using Bluetooth technology.
- Travel time data collection using Wi-Fi technology resulted in higher penetration rates for this Port of Entry study application than other Arizona deployments on freeways and urban arterial roadways within the past year.
- ARID (Wi-Fi) technology collects enough valid data to estimate border crossing times with 95% confidence, except for the Mariposa POE in the northbound direction. This is due to low penetration rates at the Mariposa POE, which may have been related to deployment location or technology interference.
- Due to security concerns, the equipment at each location was taken down each day by 10:00 PM to ensure the security of the devices. Data was collected between the hours of 4:00 AM and 10:00 PM at this POE.

At the Nogales – Mariposa crossing, another ADOT study is underway to measure commercial vehicle wait times that uses existing RFID equipment installed in trucks already enrolled in the FAST program and used by ADOT at state inspection facilities. For this study, no new in-vehicle equipment installation is required and continuing costs of operation are expected to be low. Agreements must be made among the U.S. and Mexican agencies to install RFID readers at appropriate locations on both sides of the border. The first reader is located at the Aduana (Mexican Customs) facility, 8 miles from the border. The second reader is located near the anticipated end of the queue, about 0.5 miles south of the U.S. CBP primary inspection booths. A third reader is located at the CBP primary inspection booths, and the last reader is located at the exit of the ADOT rapid inspection lanes. The RFID-generated data is processed and reported as wait time using Texas A&M Transportation Institute (TTI) Border Crossing Information System (BCIS) website as shown in **Figure 5**. A more detailed mapped view of the wait time for specific segments along the route through the Nogales – Mariposa crossing is shown in **Figure 6**. Additionally, ADOT intends to disseminate this date using dynamic message signs, the Arizona 511 (AZ511) system, and smart phone apps.

Figure 5 - Border Crossing Information System - Nogales - Mariposa

Figure 6 - BCIS Detailed Segment Travel Time maps
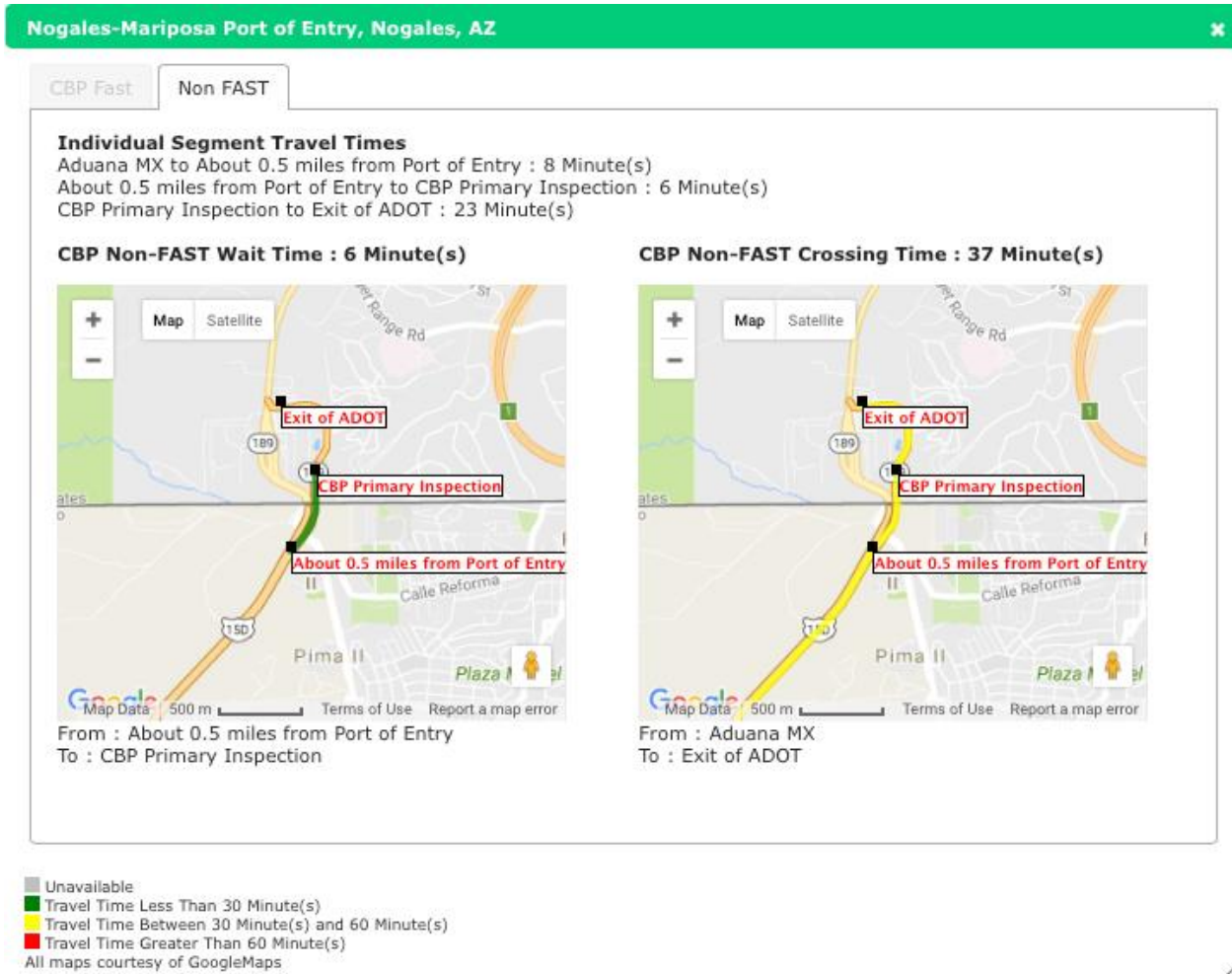
WASHINGTON STATE AND WHATCOM COUNTY

The U.S. – Canadian border crossings in Whatcom County in Washington State are situated along a stretch of the northern U.S. and Canada border that begins at the Pacific coast and continues into the Cascade Mountains, sharing this border with British Columbia, Canada. **Figure 7** depicts the relative locations of these crossings. The environment is four seasons with frequent rain throughout the year and snow in the winter. Populations along the northern border crossing in Washington State are relatively sparse. The border crossings in Whatcom County include 2 crossings at Blaine, WA (Peace Arch and Pacific), Aldergrove at Lynden, WA, and Sumas at Sumas, WA:

- **Peace Arch, Blaine** – is located at Blaine, WA and serves cars (personal vehicles) only and includes a Nexus lane (I-5). This crossing operates 24 hours a day;
- **Pacific Highway, Blaine** – is located at Blaine, WA just east of the Peace Arch crossing and serves cars and trucks. This crossing includes Nexus and FAST lanes (Hwy 543). This crossing operates 24 hours per day;

- **Aldergrove, Lynden** – is located at Lynden, WA and serves cars and trucks. (Hwy 539). This crossing has no Nexus lanes and operates 8:00AM to midnight daily.
- **Sumas** – is located at Sumas, WA (Hwy 9). This crossing operates 24 hours per day. Sumas has the highest volume of northern border pedestrian crossings on the west coast and is rated #2, with Buffalo-Niagara Falls at #1.

The U.S. Bureau of Transportation Statistics reports that the annual southbound Whatcom County-based crossing volumes are as follows:

Crossing	Personal Vehicles	Trucks	Buses	Pedestrians
Blaine (combined)	3,900,537	365,489	14,961	NA
Aldergrove (Lynden)	512,823	46,221	29	1,236
Sumas	841,997	158,257	531	33,531

Figure 7 - Whatcom County (Washington State) Border Crossings Map

Washington State Department of Transportation (WSDOT) uses different types of data collection devices, predominantly inductive loops embedded in the roadway, to monitor traffic flow and travel times. Data is sent from roadside equipment to WSDOT TMCs to monitor operations and provide traffic conditions to websites, variable message signs, and the WSDOT

511 traffic information hot line. WSDOT operates seven regional Traffic Management Centers that gather real-time traffic information around the clock.

The Cascade Gateway Border Traveler Information System collects wait time data at the following U.S.-Canadian border crossings: Blaine-Peace Arch passenger vehicle crossing including Nexus lane (I-5), Blaine-Pacific Highway passenger and commercial vehicle crossing, including Nexus and FAST lanes (Hwy 543), Lynden-Aldergrove (Hwy 539), and Sumas (Hwy 9).

Loop detectors near border inspection booths and further up the highways were installed initially in 2001, with additional installations in 2003 at the Peace Arch and Pacific Highway crossings. Loop detector systems are also in place at the Lynden-Aldergrove and Sumas border crossings. An additional smaller wait time measurement system that uses loop detectors and license plate readers is in place at the Oroville border crossing site. All loop detectors and license plate readers are located on DOT owned and operated roads.

The system uses an algorithm that calculates wait times by the estimated number of vehicles in the queue by the service rate. Loop detectors prior to the inspection booths determine service rate by counting the vehicles per minute and loop detectors further upstream determine the number of vehicles in the queue. WSDOT also has a set of 16 traffic cameras that allow monitoring of traffic conditions at the four U.S. Canada border crossings.

The SR 539 border crossing was a study site in 2011 for Bluetooth MAC address detection devices and methodologies. The distance between the Bluetooth sensors for this study was about 2.64 miles. Delay for this study was measured as follows*: Delay = Travel Time – Free Flow Travel Time*. Although this study is now a few years old, it provided important early information about Bluetooth reader and data processing capabilities compared with ALPR and loop detectors, and validated it as a viable, low-cost, minimal infrastructure alternative method for collecting travel time data using MAC address detection.[14]

Canada-bound border traffic is reported on the WSDOT website, https://www.wsdot.wa.gov/traffic/border/, and displayed as shown in **Figure 8**.

U.S.-bound border traffic is reported on the B.C. Ministry of Transportation and Infrastructure, B.C./U.S. Border Traveler Information website, http://www.th.gov.bc.ca/ATIS/atis.htm, and displayed as shown in **Figure 9**.

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[14] Wang, *Error Modeling and Analysis for Travel Time Data Obtained from Bluetooth MAC Address Matching*, WSDOT, Washington State Transportation Center, December 2011.

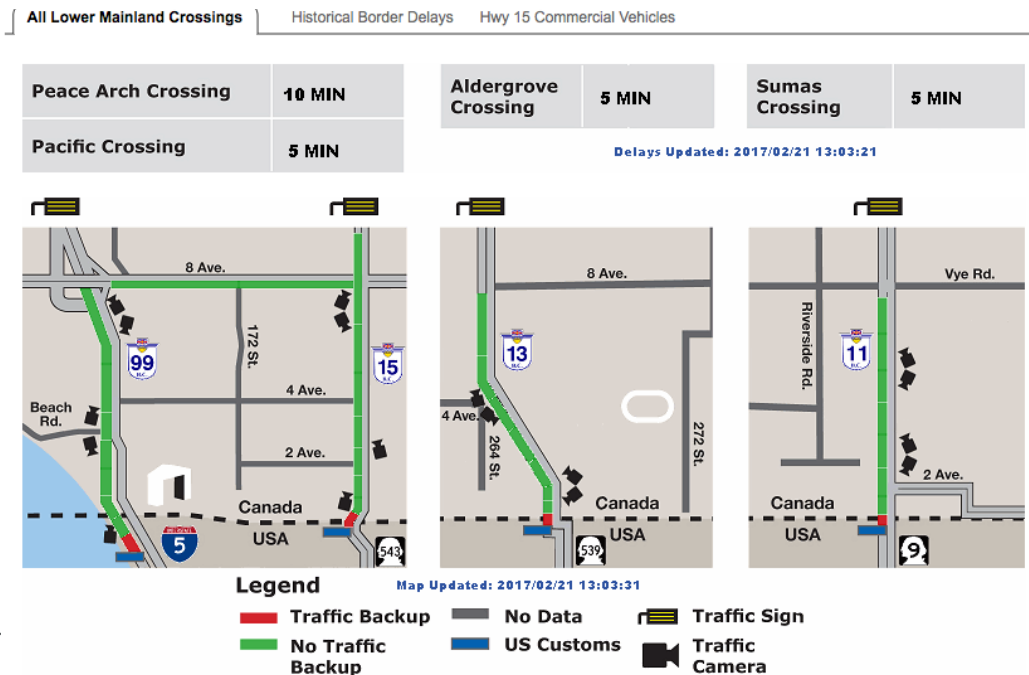**Figure 8 - WSDOT Canadian Border Traffic Website (Canada-bound Traffic)**

Figure 9 - BC MTI B.C/U.S. Border Traveler Information Website (U.S. Bound Traffic)

In the International Mobility and Trade Corridor (IMTC) Program: Dynamic Border Management studies, led by the Whatcom Council of Governments (WCOG), identified three initiatives that contain priorities for border wait time system management, accuracy, and validation. These projects include[15]:

1. **Border facility simulation modeling** to enable detailed comparisons of investment alternatives and other operations and policy changes to border transportation and inspection systems.
2. **Cascade Gateway RFID pilot** to complete data collection, modeling, and a business case for a proposed pilot project to distribute vicinity readable RFID border crossing documents to frequent crossers already in possession of valid passports.
3. **Integrated border wait time validation and calibration methodology** will develop, implement, and document a standardized method of validating regional border wait time systems.

The integrated border wait time validation and calibration methodology project is particularly important for any agency or consultants planning the operation and maintenance of a technology system to assist with measurement and monitoring of border wait times, or any other similar system. For this project, WCOG provided the following summary of the need for regular periodic validation and calibration in the operation and maintenance of their technology-based system:

> *Since B.C. Ministry of Transportation and WA State Department of Transportation installed border wait time measurement systems, typical incremental changes to facilities (roadway and inspection) have resulted in often unexpected impacts to border wait time system accuracy. Other sources of periodic error have included failed hardware (loops, controllers, etc.) or operational changes (changed location of dedicated commuter lanes, etc.).*

> *Border wait time measurement systems are a relatively new and geographically limited feature of the transportation network. They were installed without a program of periodic validation and, if needed, calibration (refinement of the estimation algorithm or other software or hardware fixes). Over the years, it has become clear that the regional border wait time measurement systems should be validated on a scheduled basis and supported by sufficient resources for ongoing adjustments and maintenance.*

The IMTC documents reviewed indicate that Bluetooth would be the proposed technology of choice for the wait time validation system. However, in conversation with WCOG staff, they indicated that the interest in installing a Bluetooth-based system has been indefinitely delayed

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[15] Whatcom Council of Governments, International Mobility and Trade Corridor Program, Dynamic Border Management website, http://theimtc.com/dbm/

due to lack of required funding. Canada Border Services Agency primarily advanced the concept to help measure times for standard (non-Nexus lane) traffic. The system currently in place is based on data collection through the inductive loops installed along the route to the inspection facilities. Overall, WCOG staff indicate that this system is good at estimating wait time of next arriving vehicle; but not actual wait times.[16]

More specifically, the Bluetooth system would have required the addition of new power and IT connections at an unacceptable cost. Further, the agencies are also now concurrently looking at Wi-Fi as the underlying technology for any future supplementary or validating systems due to perceived better coverage and reliability.

In the interim, WCOG addressed the validation issues with updates to the underlying algorithm. Additional validation measures were conducted with ALPR in a temporary installation of mobile license plate readers. The agencies jointly analyzed data and figured out where errors where originating. Systems were brought into integrity by working with DOT and inspection agencies to adjust the system's algorithm accordingly. The system wait times have been corrected and now take into consideration and integrate newly available data – based on the CBSA's new dynamic booth management. Dynamic booth management allows the agency to re-purpose lanes as demand changes. To do this the agency installed corresponding LED signage – to be able to move Nexus booth to open additional lanes during peak traffic.

**Figure 10 - Peace Arch Border Crossing, near Blaine, WA (WSDOT)**

Border Wait-time data collected is consolidated, archived, and disseminated from the US-Canada Border Data Warehouse, a dynamic database accessible online. The objective of the

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[16] Phone conversation with WCOG IMTC Program staff, Hugh Conroy, Director of Planning, February 6, 2017.

database and online access site are to provide a single source for high resolution border wait time data that is comparable to all connected crossings. The database and website are scalable to allow for new wait time systems to be added as they are installed. The wait times provided are historic and depicted in **Figure 11**. The site is located at the following URL: www.borderdatawarehouse.com .[17]

Figure 11 - U.S. - Canada Border Data Warehouse Crossing Archive Report
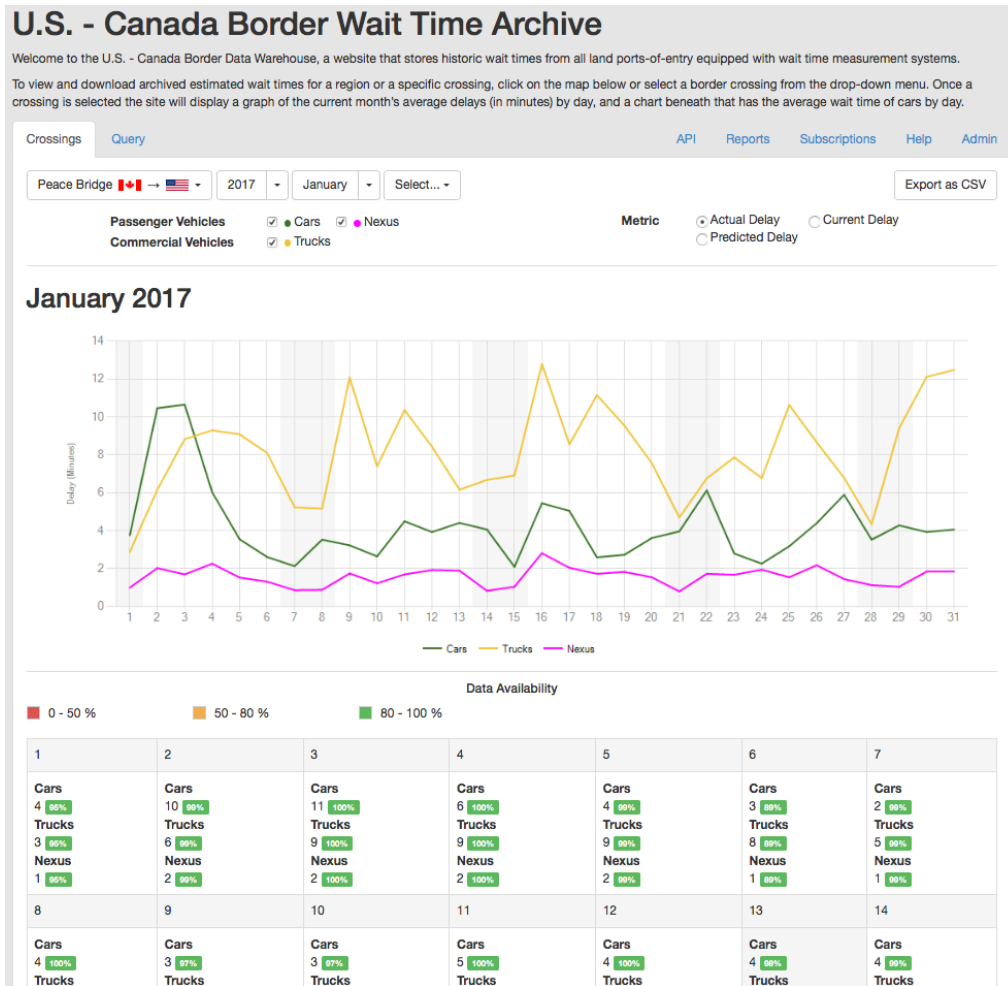
BUFFALO, NEW YORK AND FORT ERIE, ONTARIO REGION

There are four bridges in the Buffalo / Niagara Falls area. The Peace Bridge, the most heavily used bridge in the area, is operated by Buffalo and Fort Erie Public Bridge Authority. Pedestrians, bike, passenger, and commercial vehicles can all cross here. The Rainbow (no trucks), Whirlpool (only NEXUS) and Lewiston/Queenston Bridges (no pedestrians) are operated by the Niagara Falls Bridge Commission which handles customs and immigrations on

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[17] Beyond the Border: Border Wait Time Measurement, Regional Round Table Discussions, http://www.thetbwg.org/downloads/8.19.15%20-%20Pacific%20Region-%20IrvineJulien.pdf, 2015

both sides of the border. The lower left side of the map in **Figure 12** shows the approximate locations of Commission's four facilities near Niagara Falls.

The city of Niagara Falls is home to just 50,000 people, yet nearly 10 million people per year visit the area. It is located just 15 miles from Buffalo, which is the second most populous city in New York with over 260,000 residents.

Figure 12 - Niagara - Fort Erie Border Crossings Map

In 2011, the U.S. and Canada agreed to implement border wait-time systems at the top 20 high-priority US-Canada land border crossings. Among these crossings, is the Peace Bridge at Buffalo, NY (I-190) and Fort Erie, ON (QEW).

The U.S. Bureau of Transportation Statistics reports that the annual southbound crossing volumes for the Buffalo-Niagara Falls crossings are as follows:

Crossing	Personal Vehicles	Trucks	Buses	Pedestrians
Buffalo – Niagara Falls (2 crossings)	4,791,851	956,491	18,100	340,674

The Peace Bridge crossing is capturing automated border wait time data on commercial and personal travel lanes using a Bluetooth data collection system. During the time, this border wait time system has been in operation, valuable lessons have been learned.

The following is a summary of these as presented by the Buffalo & Fort Erie Public Bridge Authority in problem and solution format:

Problem: **Improper placement of readers**.
Solution: Hands-on investigation by all parties to track down issues and to tune and relocate readers. Testing to insure proper separation of vehicle types (auto, truck, NEXUS)

Problem: Improper configuration of readers and links.
Solution: Live system monitoring by agencies working together with software developer receiving the data

Problem: **Separating distinct vehicle types**.
Solution: **Directional antennas** to detect certain areas of traffic separately from others (ex. NEXUS lanes). **"Tagging" of vehicles** – record an ID and classify it as car or truck for future visits. Currently a 34.7% repeat use rate. **Queue mode** versus cumulative mode wait times

Problem: **Wait time lag (slow to show changes in delay)**.
Solution: Shorter distances between links; Queue mode helps.

Problem: **Cellular internet communication issues near the border**.
Solution: Hardwiring readers into existing networks where possible. Switching to a private cellular network versus the public network.

In a 2015 report to FHWA Border Working Group, the authority also presented the following regarding flexibility to changing border inspection facility operations. The Authority indicated that this Bluetooth installation will accommodate changes if:

- There is a physical separation between cars and trucks at some point upon approaching the crossing. Peace Bridge and Queenston/Lewiston bridge have this on the U.S. bound side.
- The lane designations (e.g., general purpose, Nexus, etc.) are not constantly changing from one type to another without some early upstream vehicle type classification.

The system would require notification of these changes and various methods could then be implemented to allow for operational changes on the fly.

Next steps indicated by the Authority for this border wait time system are included below and followed by an update from the Authority representative as of February 2017. These updates

also include some important insights regarding the installation, operation, and performance of the selected technologies for the border wait time system[18]:

- **Hardwire power and data to all readers where possible;**
  UPDATE: Installations have been completed at Peace Bridge. All onsite readers are wired for power and data communications; cellular communications services have been discontinued thereby also eliminating the associated monthly fees. The original Bluetooth (Trafax) readers (detectors only) have been replaced with dual-reader technologies that track Bluetooth and Wi-Fi signals. The Authority is also currently experimenting with automatic license plate readers (ALPRs), (cameras with wide-angle lenses and infrared capabilities produced by Genetec) that have all software built-in to the unit to capture the license plate numbers and process the images – no server is required. In other words, this data collection device becomes just another node on the network. After testing, the Authority may add this as another technology to enhance and enrich the current data set. The ALPR's are somewhat more expensive to implement, but provide lane specific capabilities and fill gaps in Bluetooth/Wi-Fi penetration. More cameras are needed to be more lane specific, to capture Nexus, FAST, and other specific lanes. The company (Fast Lane Software) that created the Authority's border wait time software just sold the software to Genetec; thus, better integration of technology is now possible.
  - **ALPR Test Configuration** – two (2) cameras are being used in the current test configuration. The first camera is set up on US side catching all Canada-bound traffic. The second camera is set up just after truck inspection on Canadian side towards toll booths. This set up provides ALPR wait times for all trucks crossing into Canada on the Peace Bridge. The Authority is working with CBSA to participate in the acquisition and implementation of additional cameras to accommodate the newly opened FAST truck lane and to assist them with their operational performance monitoring. The ALPR and Bluetooth/Wi-Fi technologies' data are now mixed together for a richer data set.
- **Outfit Rainbow Bridge with Bluetooth readers;**
  UPDATE: Rainbow Bridge has been outfitted with a border wait time system. Niagara Falls Bridge Commission finalized a contract with Fast Lane to outfit the bridge with dual-readers as a first step. Only auto traffic is using Rainbow Bridge at this time. The expected date for completion is unknown at this time.
- **More users of the data (Ontario Ministry of Transportation (MTO)/Ontario 511 service);**
  UPDATE: Have given out data feeds for free to anyone that wants one. MTO has not progressed on this yet. When Rainbow Bridge is also on line, then there may be more movement to use the available data. Niagara International Transportation Technology

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[18] All Peace Bridge and Rainbow Bridge border wait time systems and technology updates are courtesy of the Buffalo & Fort Erie Public Bridge Authority staff member, Roger Ripa, Senior Systems Analyst, via phone conversation February 2017 and update August 2017.

Coalition (NITTEC) is the grant holder and lead on the Rainbow Bluetooth/Wi-Fi reader project.

- **Live data feeds to highway signs in Canada and USA (NITTEC/MTO);**
  UPDATE: NITTEC is ready to install the data collection equipment on the Rainbow Bridge project; they are now waiting for MTO prioritization of the installation and integration of the equipment and data.

- **Monitor the volume of Bluetooth data available to the system;**
  UPDATE: The authority is currently conducting a comparison of the volume of detections vs. volume of traffic over time. They are specifically looking for reductions or increases in volumes. More data is better for supporting statistical analysis.

- **Possible integration/addition of Wi-Fi, E-Z Pass or license plate data feeds into the existing software solution;**
  UPDATE: The Authority indicates that since they are using ALPR they won't need EZ Pass [data and systems to be integrated]. Now have 30% of cars, 80% of trucks, and 60% of buses. In 2018 the Authority is looking to budget for additional ALPR cameras. Having the redundant technologies is proving to create a more robust system with better overall volumes and accuracy. Bluetooth and Wi-Fi dual-readers are producing a penetration rate of 30% all trucks, 14% all autos, 25% of Nexus only traffic. With the ALPRs, the rate increases to 80% of all vehicles.

Figure 13 - Buffalo- Fort Erie Bridge Authority border wait time website

On the current Peace Bridge website home page, operated by the Buffalo and Fort Erie Public Bridge Authority, www.peacebridge.com , a display of current wait times or wait time trends that are updated hourly are provided. A footnote (**) indicates that certain crossing times for certain locations as shown, are not supported by real-time technology yet. **Figure 13** is a screen shot of this border wait time display provided by the Authority.

TEXAS BORDER CROSSINGS

Texas and Mexico share 1,254 miles of common border and are joined by 28 international bridges and border crossings. Twenty-five of these crossings allow some combination of commercial, personal vehicle and/or pedestrian traffic. The other three crossings include two (2) dams and a ferry.[19] The Texas border is shared with the states of Tamaulipas, Nuevo Leon, Coahuila, and Chihuahua.

Border wait times for commercial vehicles are being monitored at seven (7) Texas Border Crossings using a point to point estimation method with DSRC technology by Texas A&M Transportation Institute (TTI). For the DSRC methodology, RFID tags (that are used for CBP programs and toll tags) are read by 2 DSRC readers installed on the Mexican side of the border and two readers installed on the U.S. side of the border[20]. DSRC readers were installed in locations that captured the average end of the queue at peak crossing times. Enough trucks were equipped with RFID tags at these crossing that penetration rates were sufficient to allow accurate wait time reporting without deploying additional tags. Additionally, in 2014-15, TTI conducted a study to analyze the penetration rate of Blue-tooth enabled devices for passenger vehicles at five Texas U.S. – Mexico border crossings, indicated with a *. The crossings currently using the DSRC/RFID methodology for trucks indicated below and five of the crossings were included in the Bluetooth study. Currently, only El Paso's Zaragoza/Ysleta crossings are using Bluetooth readers (northbound and southbound to estimate wait times for POV'. The following list includes brief information about what technologies are used at leach location with brief descriptions of each crossing/bridge:

- **Veterans Memorial Bridge, Brownsville*** - is a 4-lane bridge that connects U.S. Highway 77 in Brownsville, Texas to Matamoros, Mexico using Boulevard Luis Donaldo Colossio which extends to Ciudad Victoria and Reynosa. This border crossing has FAST lanes in both directions and a dedicated commuter lane using SENTRI. DSRC technologies for wait time data collection for trucks are being used at this crossing.
- **Pharr-Reynosa International Bridge, Pharr** - is a 4-lane bridge with 3 lanes in the northbound direction and 1 lane in the southbound direction. It connects Highway 281 in Pharr, Texas to Mexico's Highway 2 and the City of Reynosa, Tamaulipas. FAST lanes are available at this border crossing. DSRC technologies for wait time data collection for trucks are being used at this crossing.
- **World Trade Bridge, Laredo*** - is a commercial bridge over the Rio Grande River between the cities of Laredo, Texas and Nuevo Laredo, Tamaulipas in Mexico. It is owned and operated by the City of Laredo and Mexico's federal Secretariat of Communication and Transportation. The World Trade Bridge is accessed via I-35 in Laredo and Highway 2 in Mexico. DSRC technologies for wait time data collection for trucks are being used at this crossing.

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[19] Texas Department of Transportation (TXDOT), http://www.txdot.gov/inside-txdot/projects/studies/statewide/border-crossing.html
[20] DSRC/RFID system information provided by Juan Carlos Villa, Texas Transportation Institute, October 2017.

- **Colombia-Solidarity Bridge, Laredo** – is an 8-lane bridge with pedestrian walkways that connects Laredo, Texas over the Rio Grande river with Colombia in Anáhuac, Nuevo León in Mexico. This bridge is a tolled crossing owned and operated by the City of Laredo and the Secretaría de Comunicaciones y Transportes. The crossing is open to personal and commercial vehicles (except on Sunday for commercial vehicles). The bridge connects to Texas State Highway 255 (a toll road) that bypasses downtown Laredo and connects downstream to Interstate 35. On the Mexico side, the bridge connects to the Nuevo Leon State Highway 1 Spur which connects downstream to Highway 1 proper. FAST lanes are available. DSRC technologies for wait time data collection for trucks are being used at this crossing.
- **Camino Real International Bridge, Eagle Pass*** – is a 6-lane bridge with 3 lanes in each direction, 2 pedestrian walkways, and connects Highway 480 in Eagle Pass, Texas over the Rio Grande to Piedras Negras, Coahuila and Mexico's super highway that extends to Mexico City. The bridge is open to personal and commercial vehicles. DSRC technologies for wait time data collection for trucks are being used at this crossing.
- **Zaragoza (Ysleta) Bridge, El Paso** - connects El Paso, Texas with Ciudad Juarez, Chihuahua in México. The border crossing consists of 2 bridges, one for passenger vehicles and pedestrians and the other for commercial vehicles. The bridge used for passenger vehicles consists of 2 northbound lanes, 2 southbound lanes, and 1 lane dedicated for commuter traffic. The commercial bridge consists of 2 southbound lanes and 2 northbound lanes, one of which is a designated FAST lane. Plans are underway to expand the commercial bridge throughput without adding additional width to the bridge by creating 2 southbound lanes and 2 northbound lanes in addition to a northbound FAST lane. DSRC technologies for wait time data collection for trucks are being used at this crossing. For passenger vehicles, Bluetooth readers have been installed Northbound and Southbound to estimate wait times.
- **Bridge of the Americas, El Paso*** - crossing between El Paso, Texas and Ciudad Juarez, Mexico consists of a northbound structure and a southbound structure and is used by passenger vehicles using Boulevard Ing. Bernardo Norzagaray and Avenida Abraham Lincoln in Mexico and I-110, Highway 54, I-10, and Loop 375 in Texas while commercial vehicles access the crossing from Cuatro Siglos Street and Highway 45 in Mexico and Gateway Boulevard, East Paisano Drive, and Highway 54 in Texas. FAST lanes are available. DSRC technologies for wait time data collection for trucks are being used at this crossing.

The map in **Figure 14** shows the approximate locations of the Texas border crossings currently equipped with wait-time measurement systems.

Figure 14 - Texas Border Crossings with Wait-Time Measurement Systems Map[21]

Texas border crossings have some of the highest volumes of crossings along the southern border with Mexico.

The U.S. Bureau of Transportation Statistics reports that the annual northbound crossing volumes for selected Texas crossings are as follows:

Crossing	Personal Vehicles	Trucks	Buses	Pedestrians
Brownsville	4,635,919	217,331	10,217	2,550,833
Eagle Pass	2,729,400	159,538	1,035	824,560
El Paso (2 crossings)	12,525,548	763,868	15,050	7,032,715
Laredo (2 crossings)	5,092,204	2,083,964	41,856	3,573,992
Pharr-Reynosa (Hidalgo)	4,721,387	568,235	25,045	2,414,852

Note: this data collection project is also reporting RFID-based wait times for the Nogales-Mariposa Port of Entry at Nogales, AZ/Nogales, MX (see section titled Other Border Environments and Projects Reviewed for more information on this crossing and Nogales border crossing technologies).

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[21] Texas A&M Transportation Institute (TTI), Using RFID Readers to Measure Wait Times at the U.S.-Mexico Border (2013), https://tti.tamu.edu/2013/03/01/using-rfid-readers-to-measure-wait-times-at-the-u-s-mexico-border/

The wait time for selected crossings for commercial vehicles is estimated based on the travel time between the RFID station at the exit of the toll booth in Mexico and the RFID station at the exit of the U.S. CBP primary booth at each of the crossings.

The crossings have been equipped with the various technologies and are collecting data from trucks and cars as follows:

Texas A&M Transportation Institute provides this information on their Border Crossing Information System (BCIS) website as shown in **Figure 15**.

Figure 15 - Texas Border Crossing Information System (BCIS) for Commercial Vehicles

An online tool, a dashboard, to communicate border delays and the economic impacts of those delays was developed by Texas Transportation Institute specifically focused on commercial vehicles. Two sets of metrics were discussed in a report that described this project and the outcomes – delay measures and economic costs of the delay. The data source for the delay measures included an RFID-based system to collect raw crossing times. These systems provide a continuous stream of crossing time data from northbound trucks equipped with transponders issued by various agencies, such as U.S. Customs and tolling agencies. Data from the RFID systems are archived in a centralized data warehouse where crossing times of trucks are

aggregated into different temporal granularities and converted into various performance measures for purposes of the project. The data collected were not able to provide lane-by-lane assessments or breakdowns by FAST and non-FAST status at the time of this study[22].

Finally, during a 2015 study conducted by TTI to analyze the penetration rates of Bluetooth devices in passenger vehicles crossing the border at five ports of entry, it became clear that Bluetooth is subject to a variety of limitations based on the behaviors and preferences of the users of the mobile devices that are crossing the border along with the physical configuration of the crossing facility. The TTI conclusion for this study indicates that 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[23].

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[22] Rajbhandari, Saman, Valadi, and Kang, Dashboard Tool to Communicate Delays and Economic Cost of Delays at International Border Crossings, 2012.

[23] Analysis of Bluetooth Technology to Measure Wait Times of Passenger Vehicles at International Border Crossings, Final Report, Texas Department of Transportation, Texas A&M Transportation Institute, June 10, 2015.

6. Summary Analysis of Current Systems and Technologies

The following table summarizes the advantages and disadvantages of selected available technologies and systems discussed in this report for border travel time data collection.

Table 2 - Summary of Current Systems and Technologies

(Table begins on the following page.)

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
Cellular Networks & Data	Source, Collection, Communication, Dissemination	On-going monthly costs, depending on use; may need to be combined with other technology systems	**Advantages** • Mature technology, widely available; • Easy implementation; • Variable cost depending on application as source, collection, communication, or dissemination technology; • Privacy concerns are filtered through cellular service provider; • Large, mature data sets collected via cellular user's devices provides opportunity for predictive capabilities. **Disadvantages** • Cellular services can be intermittent and service coverage is not always reliable; • Service providers at the border vary by country, and cellular device users may switch devices mid-crossing (to avoid international use fees) causing probable interruption in crossing time data; • Complex algorithms are required for location triangulation and are dependent on cellular service provider; • Subscriptions, periodic service charges are charged by owning service provider; • Cellular data must be purchased from cellular service provider; or, • Cellular data must be collected via custom developed applications for mobile devices that are to provide the data; • Triangulation of cellular data does not always produce the vehicle location accuracy required for wait time applications.	Depends on use; None is required for data collection or dissemination on established cell service provider networks. Modems and other cellular communications devices are required for data collection infrastructure using cellular as a communications mechanism.	Easy; highly available.	Medium (combine with other methods for accuracy and reliability)	Low - Medium

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
Bluetooth	Collection, Communication, Dissemination	Low installation, requires longer range communication and power	**Advantages** • Mature technology (about 20 years on the market[24]); • Easy implementation; • Low cost; • Allows anonymous device detection addressing privacy concerns. **Disadvantages** • Complex algorithms are required for data processing and reduction; • Low penetration and match rate; • Tests show overestimation of travel time (via low sample rate and multiple detections); • Performs best when combined with other technologies (such as Wi-Fi).	Low	Moderate	High (if enough volume)	High
Wi-Fi	Collection, Communication, Dissemination	Low installation, requires longer range communication and power	**Advantages** • Mature technology; • Easy implementation; • Low cost; • Allows anonymous device detection addressing privacy concerns. **Disadvantages** • Complex algorithms are required for data processing.	Low	Moderate	High (if enough volume)	High

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[24] Bluetooth, Our History, https://www.bluetooth.com/about-us/our-history

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
GPS	Source, Communication	Low- Medium initially installation, depending on use. Requires receiver, longer range communication, and power	**Advantages** • Satellite-based location system with wide geographical coverage; • Low operations cost; • High data availability; • Medium to high accuracy; • Combines effectively with other technologies. **Disadvantages** • Insufficient number of GPS-equipped vehicles; • Signals periodically subject to (obscured by) urban canyons or natural topographical conditions; • Privacy concerns; • Data collection dependent on cooperation of owner or carrier of GPS equipment or device; • Low penetration rate.	Medium	Easy	Medium	High

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
RFID/DSRC	Source, Collection	Varies with component: *Low* – transponders; if used for commercial vehicle wait time applications *High* – readers require communication and power; *Medium* - Initial cost for DSRC use in connected vehicles; *Medium* – subsequent data collection cost due to private sector ownership of the data.	**Advantages** • Mature technology (40 years on the market); • Easy implementation; • Low operating cost; • Precise data collected; • Performs well for commercial vehicle wait times due to wide-spread deployment of transponders for other programs. **Disadvantages** • Roadside equipment and hardware required (high cost); • Requires careful tuning/re-tuning to prevent data loss and multiple detection; • Low penetration rate for POVs due to fewer transponders deployed; • Insufficient deployment for POV wait-time measurement.	Medium	Moderate	High	High, for commercial vehicle wait time/crossing time measurement
ALPR/ANPR	Collection	High, requires power, ancillary equipment, and communications	**Advantages** • Mature technology; • Good identification rates; • No onboard equipment required; • Easy implementation; • Low operating cost; **Disadvantages** • Cameras are negatively affected by slow-moving, or turning vehicles, and heavy traffic. • Cameras affected by weather, dirt, or other conditions that would occlude the camera lenses; • Readers required at many locations along border approach to be able to accurately estimate border crossing travel time.	Low	Moderate	Medium – High (availability depends on weather, other obscuring conditions)	Medium

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
Inductive Loops	Collection	Low device cost, Medium cost for initial installation (when considering required controller, software, communications, and power) or replacement	**Advantages** • Installation is inexpensive and easy when coordinated with new roadway construction (otherwise installation has disadvantages); • Mature, proven technology (50 years on the market)[25]; • Flexible design to meet a wide variety of applications; • Good presence detection; • High frequency models can provide data classification; • No onboard equipment required; • Candidate technology to be combined with other technologies with better spatial coverage (i.e., Bluetooth, Wi-Fi, GPS, RFID). **Disadvantages** • Initial installation on existing roadways is intrusive and requires road closure and pavement removal/replacement; • Repair and maintenance requires lane closure; • High errors possible depending on placement (traffic conditions are not captured between detectors); • Low reliability of detectors (25% of installed detectors fail every year)[26]; • May require manual tuning; • May be damaged by heavy vehicles; • High rate of failure.	Low (unless there is a failure)	Easy	High (when working properly), None when failed	Medium, requires controller and controller software, communications, and power

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[25] Villa, Juan. Texas A&M Transportation Institute, Enterprise Technology Options, July 2016.
[26] IBID.

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
Radar, Microwave, Laser	Collection	High	**Advantages** • Low cost; • Can be installed to detect laterally in multiple lanes with a single detector; • Directly measures speed when installed overhead; • Operation not affected by vibration. **Disadvantages** • Calculates average speed only when in lateral mode; • Lower accuracy in distant lanes; and, • Overhead installation requires an appropriate mounting structure.	Low	Moderate	High (depending on weather, placement, and other obscuring conditions)	Medium
Crowdsourced & Aggregator Data	Collection	No device cost (devices serving as data sources are usually owned by private sector); On-going monthly or other periodic cost for data or 3rd party data aggregator/ provider service	**Advantages** • No procurement, installation, or maintenance of hardware/equipment in the field; • Not subject to weather, vandalism, power outages or collisions; • Growing data sets and contextual information provide continually improving opportunities for predictive capabilities and insights. **Disadvantages** • Sample sizes vary based on technology penetration rate on the corridor or at the border crossing; • Must be combined with other data sources to provide lane usage, vehicle type, or other distinguishing information.	Low	Easy	High (if enough volume)	High

Technology	Use	Initial Deployment Cost	Advantages/ Disadvantages	Operation/ Maintenance Cost	Ease of Operation	Quality of Data	Suitability for Border Wait Time Systems
Connected Vehicles	Source, Collection, Communication, Dissemination	No device cost, possible on-going monthly cost for data or 3rd party data provider service	• Advantages and disadvantages are being proven and disproven through pilot programs and testing of connected vehicles in a variety of contexts. • The primary estimated advantage is the opportunity is downline queue and wait time estimates to other connected vehicles; this provides drivers/passengers with the opportunity to make routing and travel decisions in real-time. • Technologies used for vehicle to vehicle and vehicle to infrastructure are still evolving. • DSRC is the current standard; however, 5G applications are being tested and expected to be available in the next year.	Low	Easy		Predicted to be High; not enough data yet to determine

7. Key Institutional and Technological Findings and Recommendations

The literature review and the analysis of current practices on the use of technologies and information systems to collect border wait time resulted in the following findings and recommendations:

- Coordination between agencies on opposite sides of the border may vary when implementing a data collection solution. Budget constraints, priorities, political climate, changes in agency leadership, all contribute to the ability of an agency to carry out plans cooperatively.

- Privacy considerations, policies, and laws protecting border-crossers may differ among agencies and jurisdictions. Collected data that may be acceptable in one jurisdiction may not be permitted in another. San Diego and Imperial regional governments and policy-makers will need to coordinate with private companies and other public agencies to find the best fit for the data providers and users.

- Border crossing agencies, such as CBP, continue to use unaided visual observation or cameras to determine wait times, with varying levels of accuracy based on recent evaluations by the General Services Administration (GSA). Collaboration with CBP is needed to assist in providing the more accurate data feeds to CBP from other agency and private sector deployments.

- Newer applications of technologies are being compared with clear performance differences resulting, such as Wi-Fi edging out Bluetooth in ADOTS's 2015 study of ARID technologies and in a 2016 SANDAG study at the San Ysidro border crossing. Systems will need to remain modular and highly-flexible to accommodate changing technologies and performance enhancements.

- Tests of various combinations of technologies, such as RFID, ALPR, Video, Loop Detectors, Radar, Bluetooth, and Wi-Fi have been pilot tested or deployed to monitor wait times – with an increasing knowledge base developing on which technologies work well under specific conditions. However, because no two crossings or deployments are alike, each deployment needs to be tailored and cannot be replicated on a larger scale.

- Continuing education of deployment sponsors is helpful in conveying the fact that multiple technologies are required to achieve the desired end-to-end data collection, data communication, warehousing, processing, and dissemination of the data that produces border travel time, crossing time, and wait time information.

- Ports of entry (POEs) with adequate capacity and free flow traffic will have less travel time variability than other POEs with constricted traffic and "stop and go" delays. Consideration of required sample size (the number of vehicles needed during a specified period to accurately represent the travel time of passenger vehicles) must be determined in tests of MAC address detection and other re-identification technology methods.

- Systems and technologies for border wait time must be customized to each unique deployment location. Therefore, the overarching trend in systems deployed is to combine technologies that serve the traffic patterns, border crosser characteristics, terrain, and infrastructure of the crossing.

- Technologies continue to rapidly evolve. Therefore, periodic evaluations of previously deployed systems and technologies for monitoring, data collection and information dissemination must be conducted to compare them with the capabilities of new or evolving systems and technologies.
- Data collected from mature and evolving sources, like cellular location data, connected vehicle, and crowdsourced data, provide enormous numbers of data points to assist with predictive analytics and estimates. Care must be exercised to elicit the most valuable insights from this "big data" and ensure that the appropriate context for these insights is applied or considered. Context is the biggest current challenge for data-driven and machine assisted automation, intelligence, and predictive applications. Contextualization is crucial in transforming mountains of senseless data into real information – information that can be used as actionable insights that enable intelligent decision-making.

For the purposes of this discussion, context includes a variety of tangible and intangible factors that affect or are affected by the body of travel time and travel behavior knowledge and information attained through the acquisition, analysis, and incorporation of large amounts of data. These factors include, but are certainly not limited to, physical infrastructure, communications infrastructure, system interfaces, human-machine interfaces, human behaviors and quality of life, outcomes of behavior changes, environmental impacts, and the consequential policy and regulatory decisions surrounding these factors. Additionally, further contextualization occurs when these localized factors are compared with and integrated into similar factors from other installations, communities, and regions. It is then that we have a more sensible and holistic understanding of the data collected.