Developing a Concept of Operations for an Innovative System for Measuring Wait Times at Land Ports of Entry

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EXECUTIVE SUMMARY

The vast majority of people and goods entering, exiting, and traversing the U.S. land borders represent lawful travel and trade. These flows are a main driver of U.S. economic prosperity. Border wait times at land ports of entry (POEs) are an important measure of port performance, trade, and regional competitiveness. A reliable and systematic method of measuring border wait times is needed in order to make better operation, construction, and planning decisions at land POEs.

Currently, U.S. Customs and Border Protection (CBP) officers estimate wait times in a non-scientific way with different criteria on a POE-by-POE basis. CBP officers have to dedicate time to collect information on border wait times to populate CBP's website and mobile application—time that could be spent performing border inspection activities at the POEs. CBP has determined that it needs to move away from visual and anecdotal methods and gather wait time data scientifically.

The overall objective of this research project was to develop a Concept of Operations (ConOps) for an enhanced border wait estimation system for commercial and passenger vehicles at land POEs that takes advantage of emerging technologies such as connected vehicles (CVs), automated vehicles, and global positioning systems (*1*). Current systems also need to be enhanced by adding new capabilities, such as queue prediction, approach management, and lane management. These new technologies have the potential to significantly improve the accuracy of wait time estimates because they are sensitive to variables such as queue length and lane closures. They also have the potential to integrate wait time estimation with approach management, queue estimation, and lane management.

In coordination with CBP's project champion, the research team was able to identify CBP's border wait time data needs, which include the following items:

- Wait time indicators are used to initiate CBP's Active Lane Management procedures.
- CBP measures both wait times and processing times as a separate metric. Processing times (i.e., the time measurement from when the license plate is read to when the vehicle is admitted) are used to measure CBP's improvement and optimization efforts.
- With an automated system, CBP expects to discover more enforcement violations with the resources currently dedicated to wait time measurement activities.
- CBP is striving for a wait time update at 5-minute intervals.
- CBP needs wait time data to perform trend analysis and forecasting.
- CBP currently accepts an accuracy measurement of ±10 minutes from an automated Bluetooth® solution in use in the Buffalo/Niagara Region. This is due to limited capability of the system to provide more accurate wait times.
- CBP needs to measure FAST and non-FAST CV wait times, and wait times for Dedicated Commuter Lanes (DCL) (i.e., NEXUS, SENTRI), Ready Lanes, and non-DCL lanes.

- CBP needs to store historical wait time data indefinitely.
- CBP currently disseminates border wait time data via the public CBP Border Wait Time website and via the CBP Border Wait Time mobile app. CBP's key stakeholder for providing accurate wait time measures is the traveling public.

A literature review was conducted to investigate the various technologies currently being used or that could be used in the future to measure vehicle travel time at POEs. The objective of this technology assessment was to identify potential technologies that could be used in the border crossing measurement system ConOps. After conducting an analysis of potential technologies to be used for border crossing time measurement, researchers found the following technologies are currently used to measure border wait time:

- Inductive loop detectors.
- Bluetooth.
- Radio frequency identification (RFID).

The emerging technologies identified that have potential to be used for travel time measurement in the future are:

- Global positioning system (GPS).
- CVs.

An analysis of strengths, weaknesses, opportunities, and threats (SWOT) was conducted to determine if the technologies can support the needs assessed previously and the parameters influencing border wait times. The SWOT analysis considered the technology's functional capabilities, market trends, deployment costs, and maturity. Table 1 summarizes the analysis.

The SWOT analysis results identified that CV technology is the one that provides the highest value for the enhanced border wait time measurement system.

Table 1. SWOT Analysis of Automatic Measurement Systems.

<table>
<tr><th></th><th>Inductive Loop Detectors</th><th>Bluetooth</th><th>RFID</th><th>GPS</th><th>CVs</th></tr>
<tr><td rowspan="5">Strengths</td><td>Mature technology</td><td>Mature technology</td><td>Mature technology</td><td rowspan="2">Wide geographical coverage</td><td>Reliable</td></tr>
<tr><td>High temporal sampling</td><td>Cost-effective</td><td>Precise data collected</td><td>Efficient</td></tr>
<tr><td>No on-board equipment required</td><td>Easy implementation</td><td>Easy implementation</td><td>High data availability</td><td>Fast</td></tr>
<tr><td>Low installation costs per detector</td><td rowspan="2">Almost absent privacy violation</td><td>Low operating cost</td><td>Low operating cost</td><td>Secure</td></tr>
<tr><td>Low maintenance costs per detector</td><td>Can be simultaneously used with sensors</td><td>Potentially high accuracy</td><td>No interference in message transmission</td></tr>
<tr><td rowspan="5">Weaknesses</td><td rowspan="3">High errors</td><td>Complex algorithms required</td><td rowspan="2">High investment for roadside infrastructure</td><td rowspan="4">Insufficient number of GPS-equipped vehicles</td><td>Technology still in development</td></tr>
<tr><td>Low sample rate</td><td>Roadside equipment and infrastructure deployment</td></tr>
<tr><td>Overestimation of travel time</td><td rowspan="2">Multiple detection</td><td rowspan="3">Licensing fees</td></tr>
<tr><td rowspan="2">Low reliability</td><td>Multiple detections</td></tr>
<tr><td>High inquiry time and low number of maximum detections</td><td>Possible data loss</td><td>Privacy concern</td></tr>
<tr><td rowspan="3">Opportunities</td><td rowspan="3">Fusion techniques</td><td>Performs well in crowded environments</td><td rowspan="3">Performs well for fright wait time measurement at the border</td><td rowspan="2">Low penetration rate is sufficient</td><td>Market growth</td></tr>
<tr><td>Technology advancement- more powerful devices</td><td>Lower congestion at border crossings</td></tr>
<tr><td>Can be used as a complimentary method</td><td>Increased accuracy</td><td>Wait time forecast</td></tr>
<tr><td rowspan="3">Threats</td><td rowspan="3">Substitute products</td><td>Low penetration rate</td><td rowspan="2">Low penetration rate for privately owned vehicles</td><td rowspan="3">Substitute technologies</td><td rowspan="3">Privacy concern</td></tr>
<tr><td>Low match rate</td></tr>
<tr><td>Substitute technologies perform better (e.g., WiFi)</td><td>Insufficient technology for wait time measurement</td></tr>
</table>

Wait time information assists motorists and travelers with making efficient travel-related decisions—before starting the trip, en route, and while waiting to cross the border. Wait time is also one of the key indicators of performance of a land POE. CBP has determined that it needs to move away from visual and anecdotal methods and gather wait time data scientifically. Figure 1 shows the existing method (upper chart) and desired changes (bottom chart) for wait time and overall traffic management at land POEs. The upper chart illustrates how existing wait time deployments receive identification of vehicles at static locations. This information is processed to estimate expected wait time and broadcast as generalized information (i.e., not tailored to vehicle location).

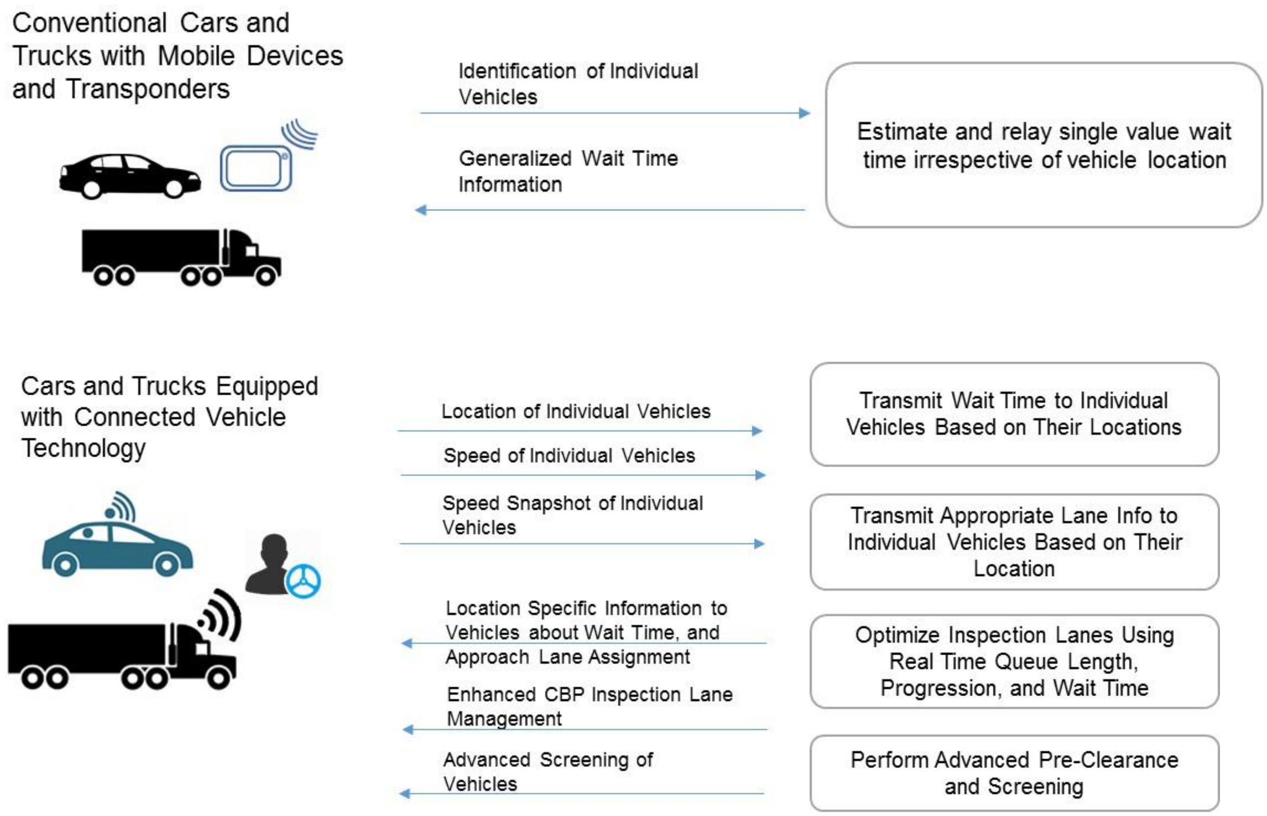


Figure 1. Existing Method (Upper Image) and Desired Changes (Lower Image) for Wait Time and Overall Traffic Management at Land Ports of Entry.

The proposed ConOps uses the power of CV technology including roadside and onboard devices integrated with internal systems to provide location and CBP program wait time information directly to individual vehicles. Thus, based on their location relative to CBP's primary inspection facility, vehicles receive individualized wait times rather than a single wait time broadcast to all. The ConOps architecture is based on dedicated short range communication (DSRC) technology as a means to communicate (exchange data payload) between in-vehicle and roadside sensors. DSRC is a two-way short- to medium-range wireless communications capability that permits very high data transmission critical in communications-based active safety applications. In Report and Order FCC-03-324 (*2*, *3*), the Federal Communications Commission allocated 75 MHz of spectrum in the 5.9 GHz band for vehicle safety and mobility applications.

Figure 2 illustrates how CVs communicate with roadside sensors spatially and strategically distributed along approaches and at a CBP facility. CVs transmit location and speed snapshots to roadside sensors spread around the CBP facility and along the roadway approaching the facility. These data are transmitted to a centralized service, which then estimates wait times, queue lengths, queue progression, and approach lane assignment. Roadside sensors then transmit the information back to individual vehicles based on their current location.

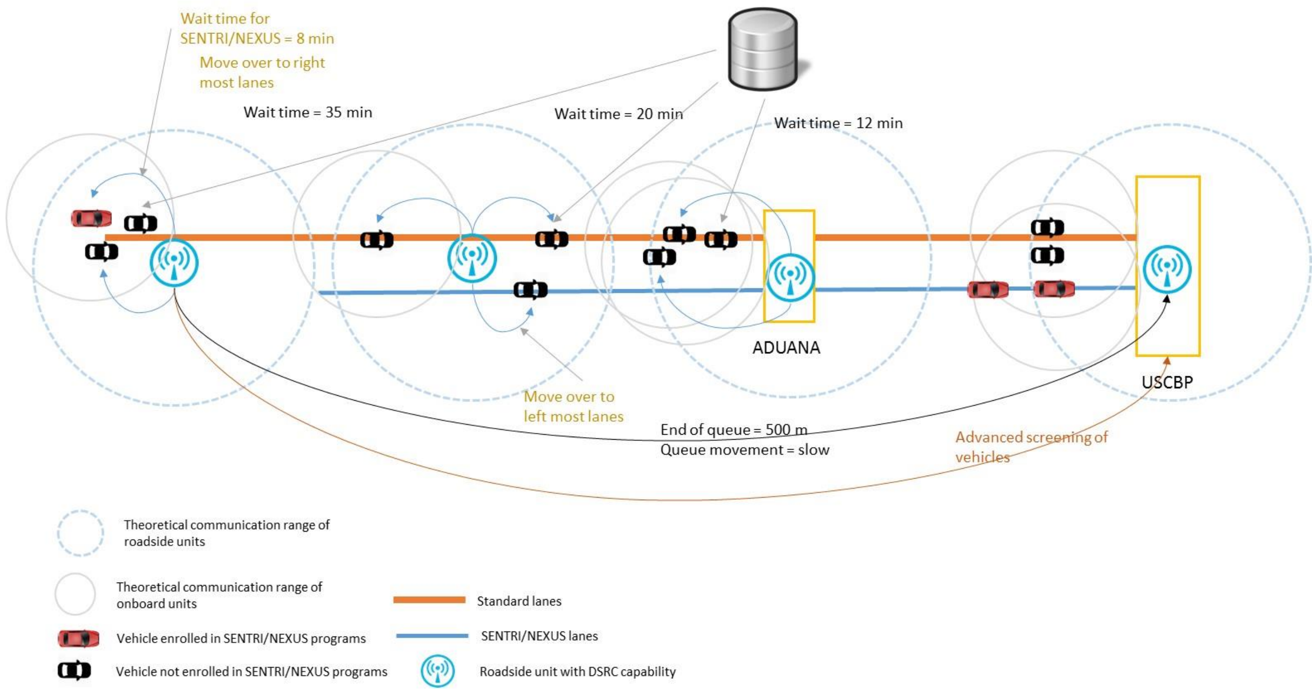


Figure 2. High-Level Overview of the Enhanced System.

The research team conducted three sets of field tests at the RELLIS campus in College Station, Texas, to ensure that the technology when deployed at a land POE will satisfy basic communication requirements for vehicles to communicate with each other and roadside units, and also read lane positioning accurately:

- ***Vehicle to roadside unit communication.*** TTI tested two-way communication in the form of high frequency data transfer between on board units and roadside units. Two moving vehicles equipped with on board units were driven several times inside the campus to identify such issues as latency and line of sight. The test showed that even when vehicles are closely driven (next to one another), data communication was not affected. This is important because in real-world conditions, vehicles approach POE in stop and go conditions.
- ***Vehicle to vehicle communication.*** TTI also tested data communication between two moving vehicles at different separation distances. When vehicles were in communication range, data transfer between the on board units was consistent. Even though the use case for vehicle to vehicle communication at a land POE is not critical at the moment, it might be in the future.
- ***Lane separation test.*** TTI also tested the positional accuracy of two vehicles traveling side by side in two different lanes. The test showed that the technology can separate vehicles based on lane. This is useful since the technology will need to identify if vehicles are in non-FAST vs FAST lanes.

The development and preliminary testing of the ConOps required by this research project showed that the use of CV technology in estimating wait times at land POEs is feasible, with potentially significant reductions in implementation and operations costs.

To demonstrate the functionality of the wait time measurement system ConOps developed and tested for this project, future research should test the enhanced wait time system using CV technology in a real-world environment at a selected land POE. Potential benefits to CBP were identified as a part of this project, and the real costs and costs and benefits could be measured and compared of deploying DSRC technology versus other technologies to measure wait and crossing times, and to better manage lane separation, queues, and pre-screening of drivers.

The benefits to DHS of conducting this future research are significant. The 2014 Quadrennial Homeland Security Review (QHSR) has as one of its strategic priorities the adoption of a risk segmentation approach to securing and managing flows of people and goods that expedites and safeguards legal trade and travel. This project will benefit DHS by testing the feasibility of CV technology to measure border wait time in a real-world land POE application, and will enable the deployment of CV technology at other land POEs in the future. This will facilitate the implementation of the QHSR priority and will allow CBP field officers to dedicate more time for inspection by relying on an advanced technology-based border wait time measuring system.

CHAPTER 1. INTRODUCTION

OVERVIEW

The vast majority of people and goods entering, exiting, and traversing the U.S. land borders represent lawful travel and trade. These flows are a main driver of U.S. economic prosperity. Border wait times at land ports of entry (POEs) are an important measure of port performance, trade, and regional competitiveness. A reliable and systematic method of measuring border wait times is needed in order to make better operation, construction, and planning decisions at land POEs.

Currently, U.S. Customs and Border Protection (CBP) officers estimate wait times in a non-scientific way with different criteria on a POE-by-POE basis. CBP officers have to dedicate time to collect information on border wait times to populate CBP's website and mobile application—time that could be spent performing border inspection activities at the POEs. At the majority of POEs, CBP uses visual and random surveys of drivers to get a sense of queue length and estimate wait times. At smaller POEs, this method may be adequate. However, at larger POEs with high traffic volumes, visual methods significantly underestimate the wait times because the end of the queue may not be visible to CBP officers. CBP has determined that it needs to move away from visual and anecdotal methods and gather wait time data scientifically.

In recent years, technologies such as Bluetooth®, wireless fidelity (Wi-Fi), magnetic loops, and radio frequency identification (RFID) have been deployed at a select few POEs to estimate wait times of U.S.-bound commercial and passenger vehicles. These deployments have been successful in estimating wait times using ubiquitous electronic devices such as mobile phones and transponders. However, these deployments cannot be used for purposes other than wait time estimation. Because these deployments measure travel time between fixed locations and use algorithms to estimate wait times, they are unsuitable for activities such as approach management, inspection lane management, and queue determination. These systems are also based on after-the-fact estimations of travel time from a small sample of vehicles crossing the border.

The overall objective of this research project was to develop a Concept of Operations (ConOps) for an enhanced border wait estimation system for commercial and passenger vehicles at land POEs that takes advantage of emerging technologies such as connected vehicles (CVs), automated vehicles, and global positioning systems (GPS) (*1*). Current systems also need to be enhanced by adding new capabilities, such as queue prediction, approach management, and lane management. These new technologies have the potential to significantly improve the accuracy of wait time estimates because they are sensitive to variables such as queue length and lane closures. They also have the potential to integrate wait time estimation with approach management, queue estimation, and lane management.

Enhancing the existing system by adding new capabilities requires an understanding of CBP's current and future needs for port operation and planning; understanding these needs was key to the success of this research project.

REPORT STRUCTURE

This report is organized by chapter, each of which corresponds to a specific project task. Each chapter details the objective, methodology, and significant results for its corresponding task. Any interim reports that were required for each task are included in the Appendices, with more detail on task activities.

Chapter 1 provides an introduction to the report, with overall objectives and a description of the report structure.

Chapter 2 presents findings related to CBP's current and future needs regarding border wait time measurement. Background information for U.S. land POEs is presented, followed by a description of the current border crossing processes for privately owned vehicles (POVs) and commercially operated vehicles (COVs).

The fourth section presents a description of current border wait time measurement techniques and the data dissemination tool. In the fifth section, a summary of CBP wait time measurement needs and analysis is presented, and the sixth section presents data needs for the development of the ConOps.

More detailed information resulting from this task, including a complete list of Border Crossings at the U.S./Canada and U.S./Mexico borders, can be found in Appendix A – Milestone 1 Report: Needs Assessment.

To develop a future wait time system, it is important to understand the factors that influence wait time at POEs. Chapter 3 details how the project team determined whether there are significant correlations between wait times and external factors such as inbound volume, number of lanes open, time of day, etc.

Once these correlations were identified, the parameters were taken into account to more accurately estimate and predict wait times. This correlation was integrated with a wait time estimation algorithm. This information can be also used to predict (short term) wait times if field devices are not working properly or CBP needs to suddenly shut down a significant number of lanes and warn the public of long wait times right away. Knowing the correlation allows the system designers to model the sensitivity and impact of these external parameters on wait times. When significant correlation between wait time and the external parameters was found, the ConOps document includes that the new system must have functionalities to measure/capture inbound volume and number of lanes open. It will also take into account these parameters in the wait time measurement algorithms.

A detailed report detailing the results of the analysis for each POE is presented in Appendix B – Task 2: Analysis of Relationships between Various Parameters Influencing Wait Times.

Chapter 4 presents the results of a review of literature on various technologies that were identified as currently being used or that could be used in the future to measure vehicle travel time at POEs. The objective of this technology assessment was to identify potential technologies that could be used in the border crossing measurement system ConOps document. The ConOps lays the foundation necessary to design an enhanced wait time system at the POEs. More detailed information can be found in Appendix C, which includes the report for this task.

Chapter 5 details the ConOps. A ConOps is a scientific and consensus-based process initially developed by the Department of Defense. Its sole purpose is to capture the high-level needs and requirements of stakeholders of a system under consideration. A ConOps clearly identifies the needs and requirements for a new or revised system, as well as the high-level functional design of a new or upgraded system that meets the needs of the stakeholders. For this project, a key stakeholder is the CBP, and the related ConOps includes the high-level design of enhancements to the existing wait time and traffic management system in use at land POEs.

This ConOps does not apply to any particular POE; it focuses on how the enhanced system should fulfill the needs of CBP. However, the ConOps does include scenarios that may be unique to one or more POEs in order to exemplify how the enhanced system would work at a specific POE.

The first section describes the current high-level border crossing process for COVs and POVs. It is important to understand that the border crossing process is different for COVs versus POVs, as well as for U.S.-bound and Mexico-bound vehicles. The second section outlines the justification for improvement of current wait time systems and nature of changes recommended by this ConOps. The third section describes the high-level architecture of the enhanced wait time measurement system along with its assumptions and constraints, and requirements for performance, quality, operations, security, environmental resistance, durability, and supportability. The fourth section provides a summary of the impact that the enhanced system would have at POEs.

The detailed ConOps report, including a description of how the system would operate/behave under hypothetical scenarios, what users would do during typical and extraordinary circumstances, and what user services and functions would be provided/not provided during these scenarios, is provided in Appendix D – Milestone 2 Report: Concept of Operations for an Innovative System for Measuring Wait Times at Land Ports of Entry.

The objective of the field test was to test the CV technology in a controlled environment to ensure it is suitable for future deployments in real world conditions. Chapter 6 details the methodology used to conduct the field tests, develop and analyze scenarios for different volume conditions, calculate and assess the performance of the proposed system considering implementation and operation costs, and establish baseline metrics for implementation and operations.

Chapter 7 describes the interaction that the research team had with another BTI-sponsored project “Modeling Methodology and Simulation of Port-Of-Entry Systems”.

Chapter 8 provides conclusions and recommendations for future research based on the results of this project.

CHAPTER 2. CBP'S BORDER WAIT TIME MEASUREMENT NEEDS

BACKGROUND

The U.S. borders with Canada and Mexico are among the longest in the world, 5,500 and 2,000 miles long, respectively. There are 110 border crossings at the U.S./Canada border and 44 border crossings at the U.S./Mexico border. Figure 3 shows locations of land POEs. Appendix A includes the list of land border crossings at the U.S./Canada and U.S./Mexico borders with the type of traffic served by each crossing.

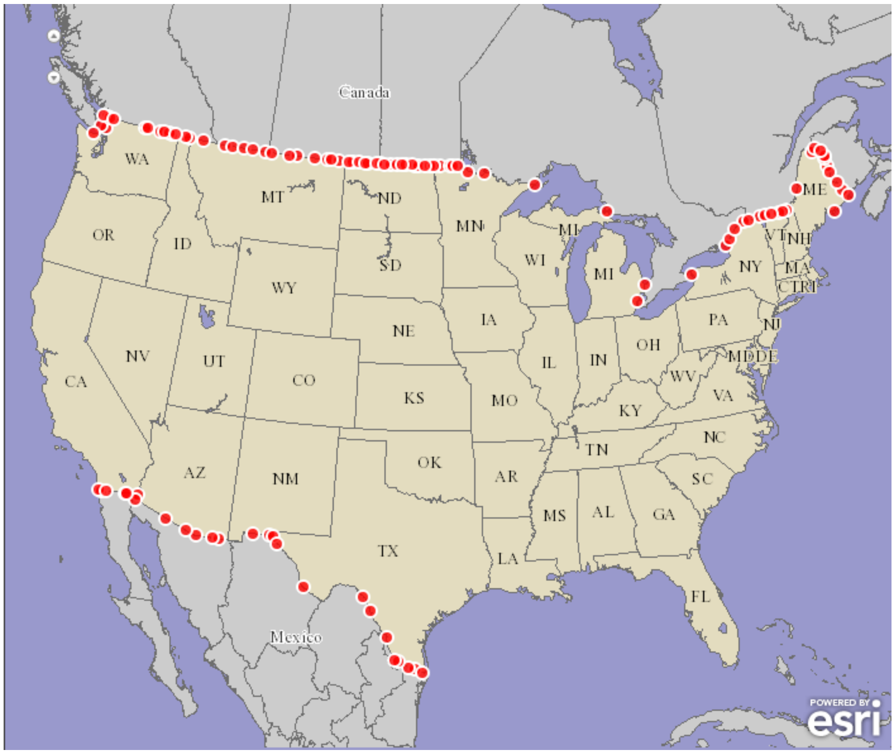


Figure 3. Canada-U.S. and Mexico-U.S. Land POEs (*4*).

Canada and Mexico are among the largest suppliers of U.S. goods in 2015, accounting for 27 percent of overall U.S. imports (*5*). Border movement of people and goods is an essential element of the U.S. economy, so the efficient operation of land POEs is of high priority.

CURRENT BORDER CROSSING PROCESS AND SYSTEMS

This chapter describes the border crossing process for U.S.-bound commercial and passenger vehicles and how CBP screens and inspects commercial and passenger vehicles crossing the international border. It also describes special pre-clearance programs that are currently available at the land POEs.

CURRENT BORDER CROSSING PROCESS

U.S.-Bound COV Crossing Process

The typical northbound border crossing process requires a shipper in Mexico to share shipment data with both Mexican and U.S. federal agencies, prepare both paper and electronic forms, and use a drayage or transfer tractor to move the goods from one country to the other. Once the shipment is at the border with the drayage or transfer tractor and an authorized driver, the process flows through three main potential physical inspection areas: Mexican export lot, U.S. federal compound, and/or U.S. state safety inspection facility.

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

There are several international crossings along the U.S.-Mexico border that are tolled. Tolls are collected in Mexico for northbound traffic and in the United States for southbound traffic. Toll collection is manual (cash) and electronic. All of the crossings along the Texas-Mexico border are bridges that cross the Rio Grande River, and most of them are tolled. Before crossing into the United States, COVs pay tolls and proceed to the U.S. federal compound.

At the primary inspection booth, the driver of the truck presents identification and shipment documentation to the processing agent. The CBP officers at the primary inspection booth use computer terminals to cross-check the basic information about the driver, vehicle, and cargo with information sent previously by the carrier via the CBP's Automated Cargo Environment electronic manifest (e-Manifest). The CBP officer then makes a decision to refer the truck, driver, or cargo for a more detailed secondary inspection of any or all of these elements, or alternatively releases the truck to the exit gate.

The e-Manifest is electronically submitted by motor carriers and enables CBP to pre-screen the crew, conveyance, equipment, and shipment information before the truck arrives at the border. This practice allows CBP to focus its efforts and inspections on high-risk commerce and to minimize unnecessary delays for low-risk commerce.

A secondary inspection includes any inspection that the driver, freight, or conveyance undergoes between the primary inspection and the exit gate of the U.S. federal compound. Personnel from CBP usually conduct these inspections, which can be done by physically inspecting the conveyance and the cargo or by using non-intrusive inspection equipment (such as x-rays). Within the compound, several other federal agencies have personnel and facilities to perform other inspections when required.

COV Border Crossing Pre-clearance Program

The Free and Secure Trade (FAST) program is in operation at most of the major land border crossings. Its objective is to offer expedited clearance to carriers that have demonstrated supply chain security and are enrolled in the Customs-Trade Partnership against Terrorism (C-TPAT) program. The FAST program allows U.S.-Canada and U.S.-Mexico partnering importers expedited release for qualifying commercial shipments.

For a shipment to be considered a FAST shipment, it needs to comply with very specific regulations. The shipper in Mexico, the carrier that is transporting the cargo across the border, and the driver all have to be C-TPAT certified.

The time required for a typical Mexican export shipment to make the trip from the yard, the distribution center, or the manufacturing plant in Mexico to the exit of the state safety inspection facility depends on the number of secondary inspections required, number of inspection booths in service, traffic volume at that specific time of day, and shipment eligibility for FAST.

Mexico-Bound COV Crossing Process

The southbound COV crossing process has only one inspection station by Aduanas. The process in Mexico is a red-light/green-light decision in which a loaded commercial vehicle is randomly selected for a secondary inspection if it gets a red light. Empty vehicles cross with no need to stop at the Aduanas booths. Aduanas uses weigh-in-motion technology to measure the weight of COVs at the POE to make red-light/green-light decisions.

Recently, CBP has started to perform random manual inspections on the U.S. side of the border for commercial vehicles crossing into Mexico, aiming to identify illegal shipments of money and weapons. The border crossings are not designed for southbound commercial inspections on the U.S. side of the border; consequently, these inspections have created congestion.

U.S.-Bound POV Crossing Process

On the Mexican side of the border, passenger vehicles are required to pay tolls at those crossings that have tolls, usually the international bridges. Tolls are paid manually or via electronic collection systems. Once passenger vehicles pay the toll, if necessary, they proceed to the U.S. federal compound, where they go through primary and sometimes secondary inspections. At the primary inspection booths, CBP officers must ask the individuals who want to enter the country to show proper documentation, such as proof of citizenship, and state the purpose of their visit to the United States. Additionally, during this stage of the process, a query on the Interagency Border Inspection System is executed to review the past records of violations that the traveler(s) may have. If necessary, the vehicle is sent to secondary inspection.

At the primary inspection booth, license plate readers and computers perform queries of the vehicles against law enforcement databases that are continuously updated. A combination of electric gates, tire shredders, traffic control lights, fixed iron bollards, and pop-up pneumatic bollards ensures physical control of the travelers and their vehicles.

At the secondary inspection station, a more thorough investigation is performed concerning the identity of an individual and the purpose of his or her visit to the United States. During this step, individuals may also have to pay duties on their declared items. Upon completion, access to the United States is either granted or denied.

POV Border Crossing Pre-clearance Program

Similar to the FAST program for commercial vehicles, the Secure Electronic Network for Travelers Rapid Inspection (SENTRI) program provides expedited CBP processing for pre-approved, low-risk travelers at the U.S.-Mexico border. Applicants must voluntarily undergo a thorough biographical background check against criminal, law enforcement, customs, immigration, and terrorist indices; a 10-fingerprint law enforcement check; and a personal interview with a CBP officer.

Once an applicant is approved, he or she is issued a document with the RFID that will identify his or her record and status in the CBP database upon arrival at the border crossing. A sticker decal is also issued for the applicant's vehicle or motorcycle. SENTRI users have access to specific, dedicated primary lanes into the United States. Dedicated SENTRI commuter lanes exist at the Otay Mesa, El Paso, San Ysidro, Calexico, Nogales, Hidalgo, Brownsville, Anzalduas, Laredo, and San Luis POEs on the U.S.-Mexico border.

When an approved international traveler approaches the border in the SENTRI lane, the system automatically identifies the vehicle and the identity of its occupant(s) by reading the file number on the RFID card. The file number triggers the participant's data to be brought up on the CBP officer's screen. The data are verified by the CBP officer, and the traveler is released or referred for additional inspection.

Participants in the program wait for much shorter times than those in regular lanes waiting to enter the United States. Critical information required in the inspection process is provided to the CBP officer in advance of the passenger's arrival, reducing the inspection time. The program helps ease traffic congestion, but it is still not widely used.

When crossing from Mexico into the United States using tolled SENTRI lanes, users need to enroll in the Linea Express (Express Lane) program. The Linea Express program was created to allow SENTRI users use of dedicated lanes as they enter the border crossing from the Mexican side and for toll payment. Enrollment in the Linea Express program can only be obtained after the users have been granted SENTRI status. In addition, the users have to pay an annual toll fee that allows them unlimited crossing privileges in the northbound direction. Users still need to pay the regular toll to the U.S. bridge operator each time they cross in the southbound direction.

In terms of technology, the Linea Express program technology is very similar to that used for tolling. Caminos y Puentes Federales de Ingresos y Servicios Conexos (CAPUFE) issues a transponder valid only on the border crossings that it operates to grant access to the dedicated Linea Express lanes. Unlike the SENTRI membership that can be used at any border crossing along the U.S.-Mexico border, the Linea Express program rules, membership, and fees vary by bridge/crossing operator.

A READY Lane is a dedicated primary vehicle lane for travelers entering the United States at land border POEs. Travelers who obtain and travel with a Western Hemisphere Travel Initiative–compliant, RFID-enabled travel document receive the benefits of using a READY Lane to expedite the inspection process while crossing the border. The U.S. passport card, the SENTRI card, the NEXUS card, the FAST card, the new enhanced permanent resident green card, and the new border crossing card are all RFID-enabled documents.

RFID technology allows information contained in a wireless tag to be read from a distance, enabling officers to process travelers more quickly, reliably, and accurately. The driver stops at the beginning of the lane and makes sure each passenger has his or her card out. The driver slowly proceeds through the lane, holds all cards up on the driver's side of the vehicle, and stops at the officer's booth.

Mexico-Bound Passenger Vehicle Crossing Process

Unless POVs that enter Mexico are tolled on the U.S. side, POVs entering Mexico do not go through rigorous processing compared to U.S.-bound POVs. Typically, wait times of vehicles entering Mexico are very small. Vehicles do have to go through weigh in motion and may be subject to random checks by Mexican law enforcement officers.

CURRENT MEASUREMENT TECHNIQUES AND INFORMATION DISSEMINATION

Measurement Techniques

Wait times are currently estimated by CBP officers through visual inspection of the queue length or driver surveys. These subjective estimates are used to populate CBP's website and mobile application. Wait time collection is outside of CBP officer's primary mandate. Effective CBP examination is diluted by data collection when the officer's efforts are diverted away from inspection.

All POEs use at least one of the following manual methods to collect wait time data (*6*):

- *Unaided visual observation*: The CBP officer records where the formed queue ends in relation to predetermined markers. Inspectors use their experience to estimate queue density and wait times. In order to ensure higher accuracy and consistency of their reports, some offices use the Border Wait Time Calculator, which is a table that incorporates additional elements, such as number of open booths. One of the drawbacks of these methods is that the queue during peak periods can extend beyond line of sight of the officers. Hence, the wait time can be significantly underestimated during peak periods.
- *Cameras*: Some civilian agencies have installed traffic cameras on the Mexican side of the border. Camera snapshots are publicly available. CBP officers can use snapshots to estimate queue. At some POEs, CBP has installed traffic cameras inside its premises. However, the visual range of these cameras is limited and suffers from the same drawback as unaided visual inspection. Queue end is compared to the predetermined landmarks and wait times are assigned. Some offices use a spreadsheet formula that incorporates number of booths open and processing times, resulting in more accurate estimation.
- *Driver surveys*: This approach is the most commonly used among wait time measurement techniques. The officer working at the primary inspection asks the drivers to estimate how long they have been waiting in the queue. Subjective time perception of drivers typically causes overestimation of wait time.
- *Time stamped cards*: Drivers are issued a card or toll receipt at an upstream location of POE. This time stamp is compared to the current time when the driver arrives at the inspection booth. The difference between these two times is used as a transit time

concerning these two locations. Transit time from toll collection booth is not the same as border wait time.

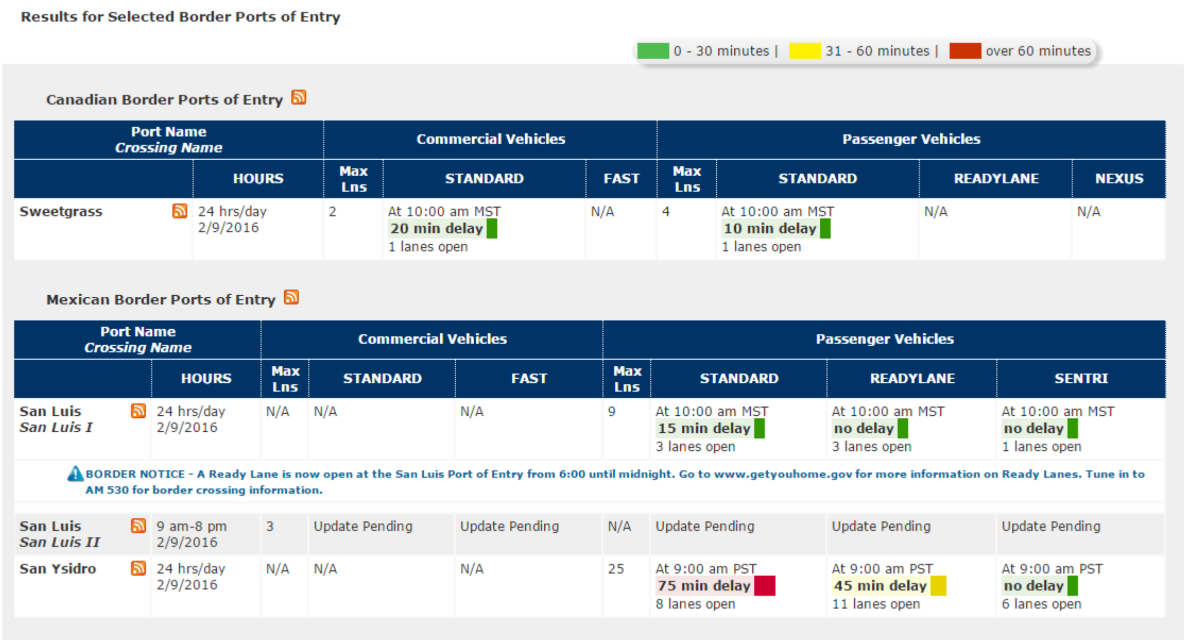
- *License plate readers*: Vehicles are identified by their license plates. This is done manually in Detroit by the Detroit-Windsor Tunnel Company, and the list of license plates and times from the entry location is sent by email to CBP. This time is then compared with the time the same vehicle crossed the primary inspection booth. The moment when the vehicle crossed the inspection point is acquired from the Treasury Enforcement Communication System.

Various federal state and local transportation agencies have implemented systems and technologies to measure border wait times. The objective of these projects is to develop a system that could measure border wait times in a systematic and consistent way across the two border regions. The three technologies that have been implemented are:

- RFID. An RFID transponder or tag is mounted in the windshield of participating vehicles. Readers are installed at various points in the travel pattern, including at CBP primary inspection booths. The system reads tags and posts a time stamp at each read. The time elapse between the two readings of each transponder represents the travel time between the two points. RFID is the technology that was selected to measure border wait time at the U.S./Mexico border, as a large proportion of trucks have an RFID tag in the windshield already installed.
- Bluetooth is a data communications protocol used for wireless mobile communications. Bluetooth technology has been implemented at three border crossings to measure POV wait times. This process is similar to the RFID-based measurement with readers installed at various locations in the roadway leading to the border crossing. Bluetooth-enabled devise in the vehicle are read at each station and travel time is estimated based on time stamps at each location.
- Loop detectors are coils of wire embedded in the roadway to detect the presence of vehicles, measure their speed, and classify each vehicle as a car or a truck.

Wait Time Data Dissemination

Border wait times are currently disseminated through the public CBP Border Wait Time website (https://bwt.cbp.gov/) and via the CBP Border Wait Time mobile app (*7*). Figure 4 and Figure 5 present the user interfaces for both.


Results for Selected Border Ports of Entry

0 - 30 minutes | 31 - 60 minutes | over 60 minutes

Canadian Border Ports of Entry

Port Name *Crossing Name*	HOURS	Commercial Vehicles Max Lns	Commercial Vehicles STANDARD	Commercial Vehicles FAST	Passenger Vehicles Max Lns	Passenger Vehicles STANDARD	Passenger Vehicles READYLANE	Passenger Vehicles NEXUS
Sweetgrass	24 hrs/day 2/9/2016	2	At 10:00 am MST 20 min delay 1 lanes open	N/A	4	At 10:00 am MST 10 min delay 1 lanes open	N/A	N/A

Mexican Border Ports of Entry

Port Name *Crossing Name*	HOURS	Commercial Vehicles Max Lns	Commercial Vehicles STANDARD	Commercial Vehicles FAST	Passenger Vehicles Max Lns	Passenger Vehicles STANDARD	Passenger Vehicles READYLANE	Passenger Vehicles SENTRI
San Luis *San Luis I*	24 hrs/day 2/9/2016	N/A	N/A	N/A	9	At 10:00 am MST 15 min delay 3 lanes open	At 10:00 am MST no delay 3 lanes open	At 10:00 am MST no delay 1 lanes open
BORDER NOTICE - A Ready Lane is now open at the San Luis Port of Entry from 6:00 until midnight. Go to www.getyouhome.gov for more information on Ready Lanes. Tune in to AM 530 for border crossing information.								
San Luis *San Luis II*	9 am-8 pm 2/9/2016	3	Update Pending	Update Pending	N/A	Update Pending	Update Pending	Update Pending
San Ysidro	24 hrs/day 2/9/2016	N/A	N/A	N/A	25	At 9:00 am PST 75 min delay 8 lanes open	At 9:00 am PST 45 min delay 11 lanes open	At 9:00 am PST no delay 6 lanes open

Figure 4. CBP Border Wait Time Website.

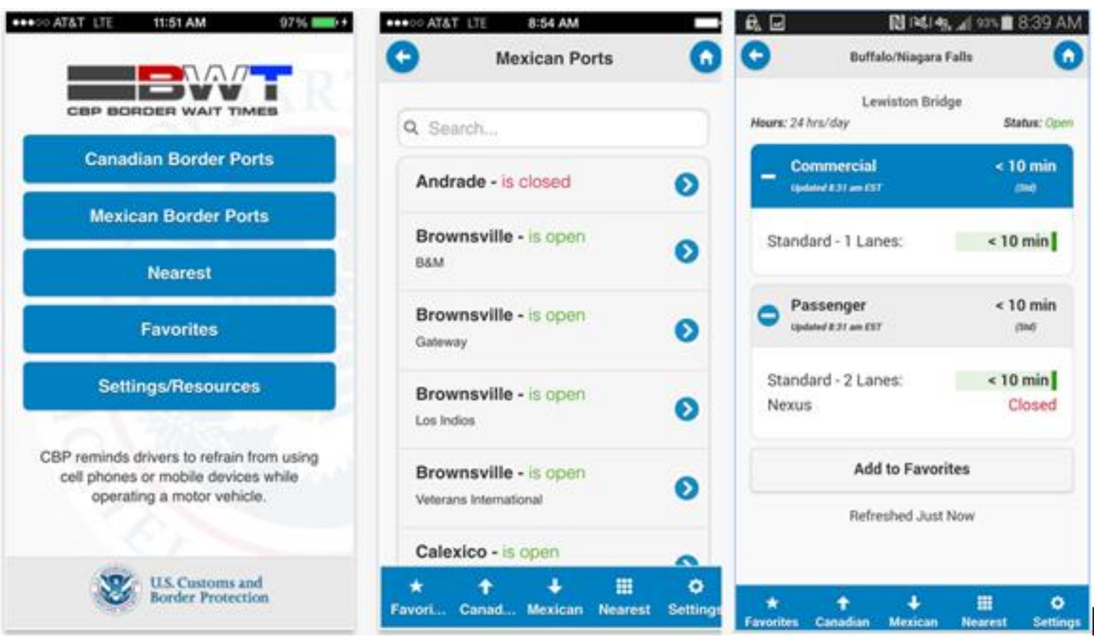


Figure 5. CBP Border Wait Time Mobile App.

CBP WAIT TIME NEEDS

Enhancing the existing system and adding new capabilities require an understanding of the Department of Homeland Security and CBP's current and future needs for port operation and planning. The comprehension of these needs is crucial to the success of this research project.

The research team contacted project champion James Pattan to gather information on CBP's border wait time data needs. The information that was collected is summarized below:

- Wait time indicators are used to initiate CBP's Active Lane Management procedures.
- CBP measures both wait times and processing times as a separate metric. Processing times (i.e., the time measurement from when the license plate is read to when the vehicle is admitted) are used to measure CBP's improvement and optimization efforts.
- With an automated system, CBP expects to discover more enforcement violations with the resources currently dedicated to wait time measurement activities.
- CBP is striving for a wait time update at 5-minute intervals.
- CBP needs wait time data to perform trend analysis and forecasting.
- CBP currently accepts an accuracy measurement of ±10 minutes from an automated Bluetooth® solution in use in the Buffalo/Niagara Region. This is due to limited capability of the system to provide more accurate wait times.
- CBP needs to measure FAST and non-FAST CV wait times, and wait times for Dedicated Commuter Lanes (DCL) (i.e., NEXUS, SENTRI), Ready Lanes, and non-DCL lanes.
- CBP needs to store historical wait time data indefinitely.
- CBP currently disseminates border wait time data via the public CBP Border Wait Time website and via the CBP Border Wait Time mobile app. CBP's key stakeholders for providing accurate wait time measures is the traveling public.

IMPLICATIONS OF BORDER WAIT DATA NEEDS TO BORDER WAIT TIMES CONOPS

The system that will be defined as part of this research project shall have the following elements:

1. Data Collection

- Wait time information would need to be collected for all traffic types:
  - FAST and non-FAST.
  - NEXUS, SENTRI.
  - READY Lanes.
  - Non-DCL lanes.
- The accuracy of the measurement should be within a range of ±10 minutes for all lane types.
- Wait time information collected in the field shall be integrated with a system CBP is developing internally. This system is designed to gather wait time data from POEs and update the CBP's website. It recognizes the fact that not all POEs are alike and different technologies and systems can be deployed based on local preferences and environment.

2. Storage

- Historical wait time information needs to be stored indefinitely.
- Historical information should be made available for trend analysis and forecasting.

3. Dissemination

- Information should be refreshed at 5-minute intervals.
- The traveling public should be able to receive information via a web-based system or a mobile app.

CHAPTER 3. PARAMETERS INFLUENCING WAIT TIMES

METHODOLOGY

The research team requested detailed information on current volumes and border wait time information from CBP's database. The project champion from CBP provided historical data including hourly aggregates of U.S.-bound volumes of commercial and POVs, wait times, cycle time, and number of lanes opened for six POEs (three on the U.S./Canada border and three on the U.S./Mexico border):

- Blaine, Washington.
- Champlain, New York.
- Detroit – Ambassador Bridge, Michigan.
- Mariposa, Arizona.
- San Ysidro, California.
- Ysleta, Texas.

The methodology used to analyze the data included: a) summary statistics of all the data provided; b) analysis of incoming hourly volumes; c) analyses of hourly average wait times for weekdays and weekends to determine how wait time impacts hourly volume; and d) regression and correlation analysis.

RESULTS

The research team found strong correlations between wait time and volume, number of lanes open, and cycle time. Out of those three independent variables, number of lanes open appears to have the most impact on wait times. A detailed report detailing the results of the analysis for each POE is presented in Appendix B – Task 2: Analysis of Relationships between Various Parameters Influencing Wait Times.

CHAPTER 4. ANALYSIS OF CURRENT AND FUTURE TECHNOLOGIES

A literature review was conducted to investigate the various technologies currently being used or that could be used in the future to measure vehicle travel time at POEs. The objective of this technology assessment was to identify potential technologies that could be used in the border crossing measurement system ConOps document.

After conducting an analysis of potential technologies to be used for border crossing time measurement, it was found that the following technologies are currently used to measure border wait time:

- Inductive loop detectors.
- Bluetooth.
- RFID.

The emerging technologies identified that have potential to be used for travel time measurement in the future are:

- GPS.
- CVs.

CVs include several technologies that have been grouped under the CV concept.

The task report detailing the literature review conducted for this task is included in Appendix D – Vehicle Travel Time Estimation Technology Literature Review. Appendix D includes a brief description of each technology, followed by an analysis of strengths, weaknesses, opportunities, and threats (SWOT). The SWOT analysis was conducted to determine if the technologies can support the needs assessed previously and the parameters influencing border wait times. The SWOT analysis considered the technology's functional capabilities, market trends, deployment costs, and maturity. Table 2 summarizes the analysis.

Table 2. SWOT Analysis of Automatic Measurement Systems.

<table>
<tr><th></th><th>Inductive Loop Detectors</th><th>Bluetooth</th><th>RFID</th><th>GPS</th><th>CVs</th></tr>
<tr><td rowspan="5">Strengths</td><td>Mature technology</td><td>Mature technology</td><td>Mature technology</td><td rowspan="2">Wide geographical coverage</td><td>Reliable</td></tr>
<tr><td>High temporal sampling</td><td>Cost-effective</td><td>Precise data collected</td><td>Efficient</td></tr>
<tr><td>No on-board equipment required</td><td>Easy implementation</td><td>Easy implementation</td><td>High data availability</td><td>Fast</td></tr>
<tr><td>Low installation costs per detector</td><td rowspan="2">Almost absent privacy violation</td><td>Low operating cost</td><td>Low operating cost</td><td>Secure</td></tr>
<tr><td>Low maintenance costs per detector</td><td>Can be simultaneously used with sensors</td><td>Potentially high accuracy</td><td>No interference in message transmission</td></tr>
<tr><td rowspan="5">Weaknesses</td><td rowspan="3">High errors</td><td>Complex algorithms required</td><td rowspan="2">High investment for roadside infrastructure</td><td rowspan="4">Insufficient number of GPS-equipped vehicles</td><td>Technology still in development</td></tr>
<tr><td>Low sample rate</td><td>Roadside equipment and infrastructure deployment</td></tr>
<tr><td>Overestimation of travel time</td><td rowspan="2">Multiple detection</td><td rowspan="3">Licensing fees</td></tr>
<tr><td rowspan="2">Low reliability</td><td>Multiple detections</td></tr>
<tr><td>High inquiry time and low number of maximum detections</td><td>Possible data loss</td><td>Privacy concern</td></tr>
<tr><td rowspan="3">Opportunities</td><td rowspan="3">Fusion techniques</td><td>Performs well in crowded environments</td><td rowspan="3">Performs well for fright wait time measurement at the border</td><td rowspan="2">Low penetration rate is sufficient</td><td>Market growth</td></tr>
<tr><td>Technology advancement-more powerful devices</td><td>Lower congestion at border crossings</td></tr>
<tr><td>Can be used as a complimentary method</td><td>Increased accuracy</td><td>Wait time forecast</td></tr>
<tr><td rowspan="3">Threats</td><td rowspan="3">Substitute products</td><td>Low penetration rate</td><td rowspan="2">Low penetration rate for POVs</td><td rowspan="3">Substitute technologies</td><td rowspan="3">Privacy concern</td></tr>
<tr><td>Low match rate</td></tr>
<tr><td>Substitute technologies perform better (e.g., Wi-Fi)</td><td>Insufficient technology for wait time measurement</td></tr>
</table>

CHAPTER 5. THE DEVELOPMENT OF A CONCEPT OF OPERATIONS FOR THE ENHANCED SYSTEM

CURRENT BORDER WAIT TIME MEASURING TOOLS AND THEIR LIMITATIONS

Wait time information assists motorists and travelers with making efficient travel-related decisions—before starting the trip, en route, and while waiting to cross the border. Wait time is also one of the key indicators of performance of a land POE. Archived wait time data help operators, planners, and policy makers make informed decisions to improve operation of the POE. Long wait time is detrimental to the operation of a POE in many ways. It undermines the attractiveness of the port among travelers and negatively affects the economic competitiveness of the region and the environment surrounding the port.

CBP provides wait time and other associated information (e.g., lane openings and closures) to the traveling public via its website.

CBP has determined that it needs to move away from visual and anecdotal methods and gather wait time data scientifically. Before vehicles reach CBP's primary booth, Aduanas screens U.S.-bound vehicles. CBP feels that the wait time of vehicles in Mexico is not entirely its problem. While this is certainly true at POEs where distance between Aduanas and CBP may be several miles (e.g., Pharr-Reynosa International Bridge), there are other crossings where the distance between CBP Primary and the Mexican toll booth or inspection is relatively short. Crossings outside Texas do not require to cross the Rio Grande, so the distance could be very short.

In recent years, technologies such as Bluetooth, Wi-Fi, magnetic loops, and RFID have been deployed at a select few POEs, as illustrated in Figure 5, to estimate wait times of U.S.-bound COVs and POVs. These deployments have been successful at estimating wait times using ubiquitous electronic devices such as mobile phones and transponders. However, these deployments cannot be used for purposes other than wait time estimation. Because these deployments measure travel time between fixed locations and use algorithms to estimate wait times, they are unsuitable for activities such as approach management, inspection lane management, and queue determination.

Figure 5. RFID Technology–Based System to Estimate Wait Times of COVs at Ysleta-Zaragoza POE (Source: Texas A&M Transportation Institute [TTI]).

Existing Operational Constraints

Deployment of wait time estimation systems based on RFID technology is expensive. They run more than US$200,000 per POE,[1] not including costs related to distribution and administration of transponders. Bluetooth- and Wi-Fi-based systems are relatively cheap but have privacy and low sampling issues. Magnetic loops in pavements have high maintenance costs and can incur delay to the traveling public during maintenance.

None of these technology-based systems are systematically integrated with CBP's internal systems that manage primary inspection lanes. CBP officers anticipate queue length and wait times using visual methods and then use this information to decide which and how many inspection lanes to open or close. This practice may result in longer wait times due to inadequate open lanes during lengthier queues.

At most POEs, CBP has designated FAST (for COVs) and READY (for POVs) lanes. CBP has the ability to process FAST or READY vehicles in any standard lanes, as well. CBP has at some POEs deployed signs above inspection areas, as shown in Figure 6. Traffic close to the areas is well separated according to which documentation travelers have. However, farther upstream, travelers can be mixed since there are no message signs upstream in Mexico.

1 Based on previous experience at POEs in the Texas/Mexico border.

Figure 6. Lane Management with Dynamic Signs at a CBP Primary Inspection Facility (Source: CBP).

JUSTIFICATION FOR AND NATURE OF CHANGES

This section describes why and how the current system needs to be modified for wait time estimation and traffic management. The results from this analysis drive the requirements of a proposed new system.

Motivation of Changes

The efficiency and effectiveness of the current wait time system will increase significantly if changes mentioned in this ConOps are implemented at land POEs. The desired changes will not only reduce wait times but also improve management of vehicles approaching POEs, allocation of resources at inspection facilities, and customer service. However, for the system to reach its full potential, large penetration of CVs is required. The next-generation system is expected to provide the following benefits:

- **Improved accuracy of wait time information**—The estimates of end-of-queue location and how the queue is progressing will improve short-term prediction of wait times. At the same time, the enhanced system can transmit wait time directly to vehicles based on their location relative to CBP's facility.
- **Enhanced approach lane management**—At many POEs, vehicles enrolled in different types of pre-clearance programs mix together because they do not know which approach lane leads to which inspection lane at the CBP facility. This is especially true when queues extend beyond static signs that separate vehicles. If the enhanced system knows queue lengths of FAST and standard trucks, and if queues of standard truck lanes are much longer than FAST lane queues, then roadside sensors can suggest that standard trucks move to the FAST lanes to reduce the overall queue length.

- **Improved efficiency of resource allocation at inspection facility**—With better estimation of queue lengths and how queues are progressing against time, CBP can make better decisions about allocating resources at its primary facility in order to reduce wait time.
- **Improved customer service**—Long wait time has always been a major complaint of motorists crossing the border. While CBP can play a limited role in controlling the demand, it can provide a better customer experience by implementing a system that is more sensitive to queues forming at the back and reduces wait time.
- **Improved pre-clearance**—While CV technology is designed to be anonymous, motorists can opt in and register their SENTRI/NEXUS or FAST vehicles to work with the CV devices. This arrangement allows these vehicles to send, via roadside sensors, "I'm here" messages to CBP, which can then perform screening even before the vehicle has reached the CBP primary booth. This capability allows vehicles to minimize interaction with CBP officers and reduces time to process them.

Justification of Changes

At present, CBP officers estimate queue visually using nearby landmarks as a reference for distance. The officers then use length of queue as a basis to open/close inspection lanes and post wait times. However, at some POEs during peak hours and special events, queue can extend beyond officers' field of vision. This condition results in underestimation of wait times and number of lanes that should be opened.

CBP estimates wait times using random surveys of drivers or visible queue length, or a combination. CBP officers ask random drivers when they approach the inspection lane about how long they had to wait. The drawback of this approach is that wait times from random surveys are gathered after the fact and are not indicative of what is happening upstream from the queue. Thus, surveys can be biased, especially during peak periods.

Existing technologies such as Bluetooth, RFID, and Wi-Fi measure travel times between fixed locations where vehicles are identified using mobile or transponder IDs. Travel times between static locations are calculated as vehicles pass by these locations. Using the most recent travel times, expected wait times (EWTs) and actual wait times (AWTs) are estimated. EWTs are wait times that motorists can expect when they join the end of the queue. AWTs are wait times that motorists actually experience. EWT is determined using short-term prediction models based on AWTs. These technologies unfortunately cannot directly measure queue length and how the queue is progressing.

Loop detectors measure speed and volume of vehicles at fixed locations using in-pavement electromagnetic loops. This technology uses inflow and outflow models to determine EWT and AWT. However, loop detectors are expensive to install. Another drawback of loops is that travel lanes may have to be closed during maintenance.

No POEs provide in-vehicle and individualized warnings about wait times. Technologies mentioned in the previous paragraphs are not designed for two-way communication. This ConOps assumes that individualized warnings about wait time provided directly to motorists will significantly improve service to motorists if they can be informed about wait times before and after they have joined the queue.

At present, CBP's signs that separate inspection lane types are available at its facilities only. At some POE facilities that process COVs, there are static signs that separate FAST and non-FAST vehicles farther upstream. However, they are static signs. Motorists and drivers do not know where lanes separate until they see the signs. Better approach management is feasible if lane assignment can be provided to motorists inside the vehicles in real time. In-vehicle warning is a much better information delivery method than static or dynamic message signs at fixed locations upstream of inspection booths. This ConOps assumes that an in-vehicle information delivery method will result in better utilization of approach lanes.

The ConOps also assumes that the next-generation wait time and traffic management system should be able to measure changing queue lengths, lane openings and closures at a CBP inspection facility, and wait times. Wait time is much more sensitive to the number of inspection lanes open. At present, this integration happens manually. However, the ConOps contends that queue measurement, approach lane management, inspection lane assignment, and wait time estimation should be fully integrated.

Description of Desired High-Level Changes

Desired high-level changes for the next-generation wait time estimation and traffic management system are as follows:

- The wait time estimation system should be based on speed snapshots and location breadcrumbs of vehicles when they approach the end of the queue and are in the queue. This approach is a shift from traditional methods, which measure travel times of individual vehicles between fixed locations. However, wait times measured by this approach can be augmented with travel times between fixed locations in order to verify and calibrate wait time estimation models. For vehicles approaching the end of the queue, the system should estimate wait time based on their locations and the types of pre-clearance programs (FAST, SENTRI, NEXUS) they are enrolled in or eligible for (e.g., READY). Such notifications should be sent as in-vehicle messages unique to individual vehicles.
- The system should directly measure the length of the queue and its progression in real time. Queue length and progression should be integrated with wait time estimation and inspection lane management processes. Based on the queue forming on the other side of the U.S. border and the number of lanes currently open, the system should trigger warnings to open more lanes or close lanes.
- The system should notify vehicles approaching the end of the queue about which lane they ought to use based on their locations and the types of pre-clearance programs they are enrolled in or eligible for. Such notifications should be sent as in-vehicle messages unique to individual vehicles.
- CBP should be able to perform advanced screening of vehicles after they enter the queue and before they reach the CBP primary booth. However, those vehicles have to be enrolled in the SENTRI/NEXUS program and opt in for advanced screening.

Figure 7 shows the existing method (upper chart) and desired changes (bottom chart) for wait time and overall traffic management at land POEs. The upper chart illustrates how existing wait time deployments receive identification of vehicles at static locations. This information is processed to estimate expected wait time and broadcast as generalized information (i.e., not tailored to vehicle location).

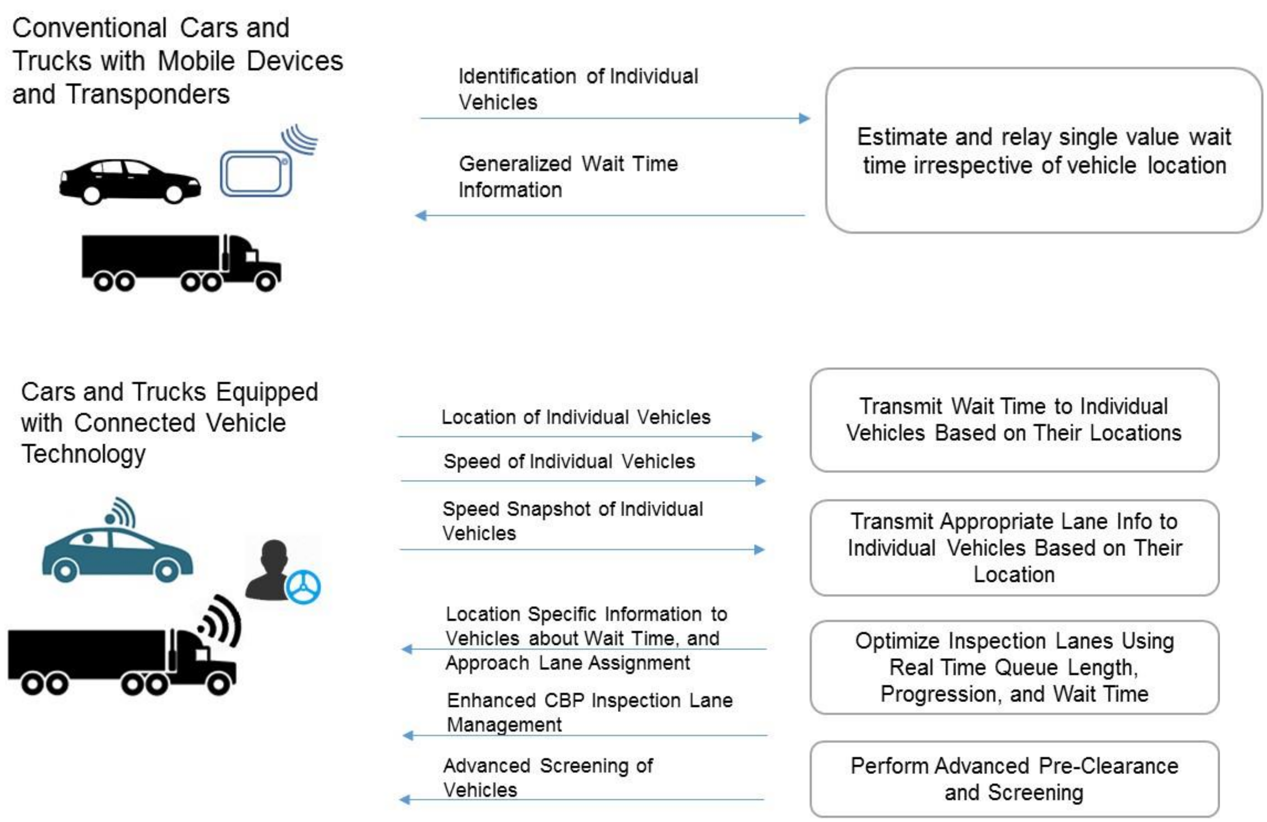


Figure 7. Existing Method (Upper Image) and Desired Changes (Lower Image) for Wait Time and Overall Traffic Management at Land POEs.

CONCEPTS OF THE PROPOSED SYSTEM

This section provides an overview of the proposed changes to the wait time estimation and traffic management system and key considerations for its design. It includes key components of the proposed system and describes the changes in operations.

High-Level System Architecture

The next-generation wait time and traffic management system concept uses the power of CV technology including roadside and onboard devices integrated with internal systems to provide location and CBP program wait time information directly to individual vehicles. Based on their location relative to CBP's primary inspection facility, vehicles receive individualized wait times rather than a single wait time broadcast to all.

The system sends in-vehicle messages to drivers to change lanes if they are in the wrong approach lane. The system also measures location and progression of queue more efficiently than existing technologies. This information is crucial to estimate wait times and manage inspection lanes at CBP (and Aduanas).

By design, CV technology does not identify in-vehicle devices (or on board units [OBU]). However, motorists can opt in by registering their in-vehicle devices with the relevant authorities or information providers. By opting in, motorists can receive individualized messages about wait times and appropriate approach lanes based on the pre-clearance program in which they are enrolled.

The architecture is based on dedicated short range communication (DSRC) technology as a means to communicate (exchange data payload) between in-vehicle and roadside sensors. DSRC is a two-way short- to medium-range wireless communications capability that permits very high data transmission critical in communications-based active safety applications. In Report and Order FCC-03-324 (*2*, *3*), the Federal Communications Commission allocated 75 MHz of spectrum in the 5.9 GHz band for vehicle safety and mobility applications.

The architecture assumes that a significant portion of vehicles in the traffic mix will have DSRC-enabled devices either installed as an aftermarket device or embedded within the vehicle. Vehicles with such capability are called CVs. Because the DSRC technology allows two-way low-latency communication, roadside sensors can continuously exchange data with CVs.

Figure 8 illustrates how CVs communicate with roadside sensors spatially and strategically distributed along approaches and at a CBP facility. CVs transmit location and speed snapshots to roadside sensors spread around the CBP facility and along the roadway approaching the facility. These data are transmitted to a centralized service, which then estimates wait times, queue lengths, queue progression, and approach lane assignment. Roadside sensors then transmit the information back to individual vehicles based on their current location.

In the illustration shown in Figure 8, roadside sensors send messages to vehicles (shown in red) enrolled in the SENTRI program to move from the right lane to the left lane since right lanes are designated for SENTRI vehicles. The roadside sensors also send wait times to vehicles based on their current location. As vehicles get closer to the CBP facility, their wait time decreases. The system also provides wait times for SENTRI/NEXUS lanes to vehicles enrolled in such programs. Vehicles not enrolled in SENTRI (shown in black) do not receive lane-specific information, but they do receive location-specific wait times at pre-defined intervals.

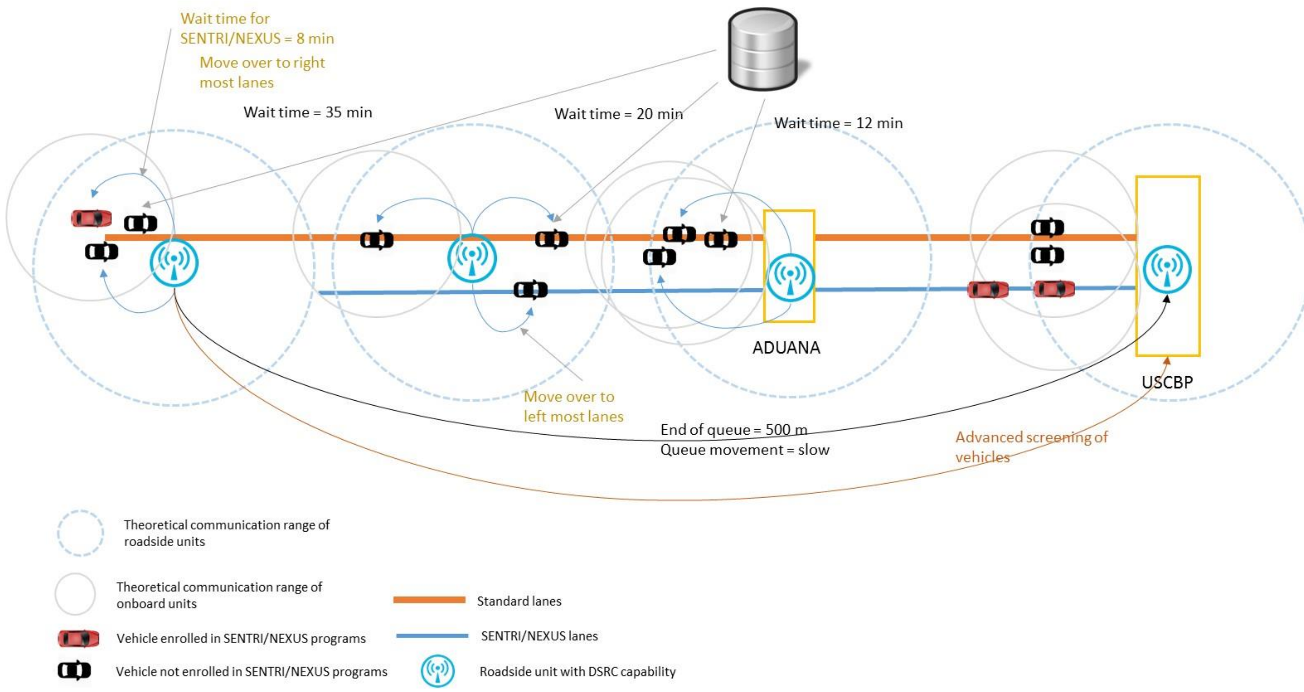


Figure 8. High-Level Overview of the Enhanced System.

Figure 9 shows the high-level logical modules in the enhanced system. These modules perform domain-level functions and communicate with other modules as needed. The module recognizes the fact that in the interim, there will be a mix of CV and non-CVs with and without DSRC capabilities. However, non-CVs may have existing technology such as Bluetooth, RFID, and Wi-Fi. These vehicles can still be identified by roadside sensors to determine travel time between static locations to estimate wait time and complement the enhanced system by providing calibration parameters.

Ultimately, in the future, the majority of vehicles will have CV technology embedded in them. The CVs transmit location and speed data to the central database via roadside sensors. The database then reallocates all or parts of the data to various modules, which then estimates queue lengths, wait times, etc., and sends the information back to vehicles using the same roadside sensors.

Vehicles without CV technology can receive broadcast information about wait times using roadside displays, web-based tools, mobile apps, etc. However, the information drivers receive will not be customized for their current location because the system cannot transmit data directly to conventional vehicles using Bluetooth or Wi-Fi or mobile phones without significant latency.

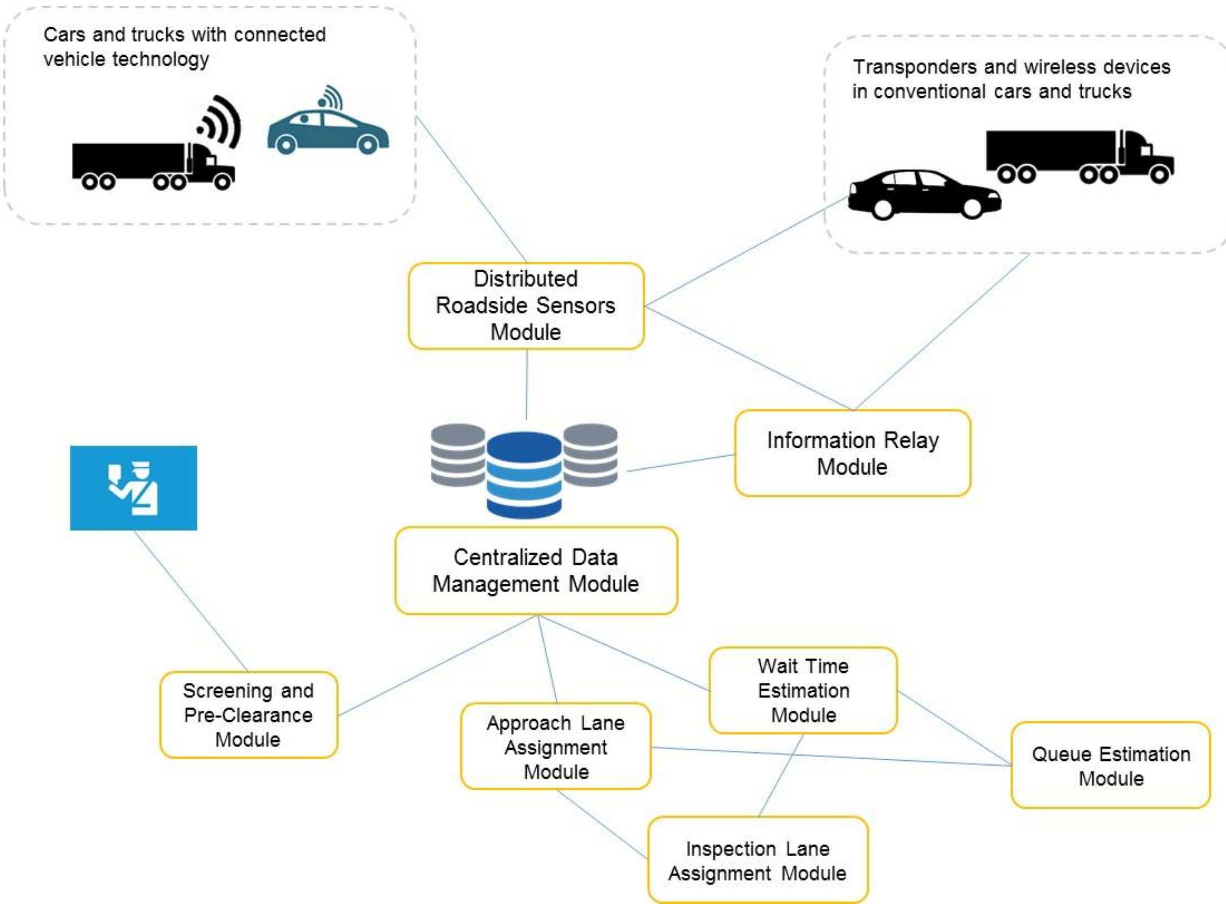


Figure 9. High-Level Overview of the Individual Modules in the System.

Major System Modules and Requirements

The enhanced system includes eight logical modules. These modules have to work in a collaborative environment in real time in order to function properly as a system. Figure 10 shows how individual modules interact with each other to estimate queue length and wait time and relay the information to vehicles. Figure 11 illustrates the data exchange between modules to perform lane assignment functions to warn vehicles to use the right lanes while approaching POEs. Both figures show high-level data messages received and transmitted between the modules and on to vehicles approaching POEs.

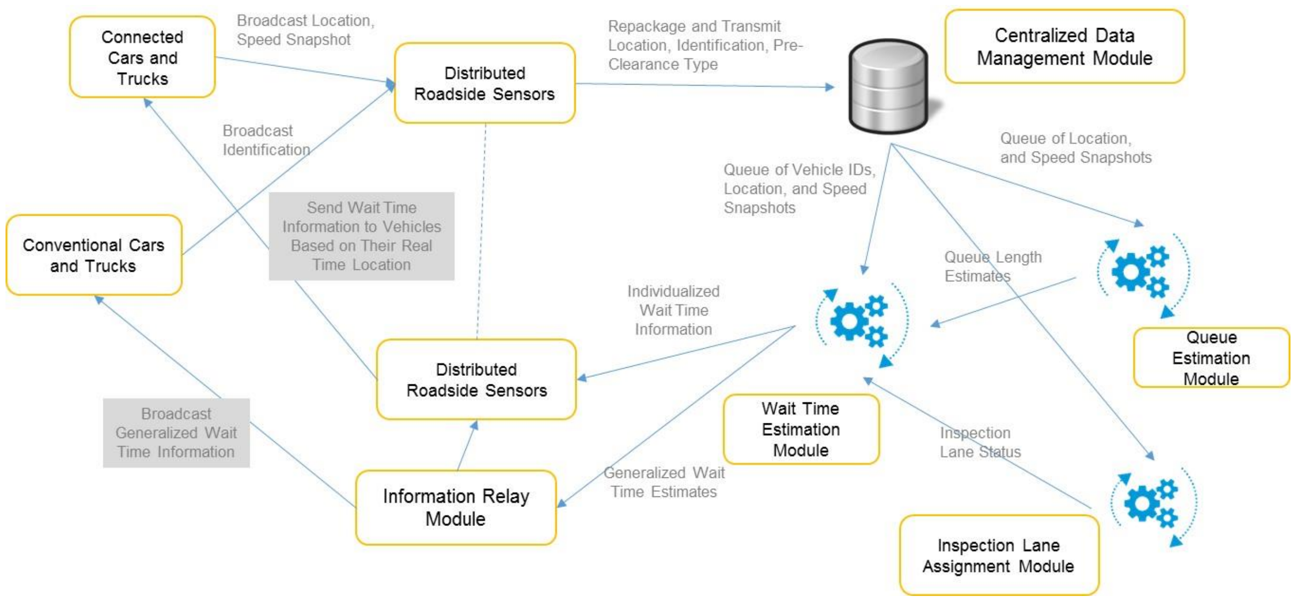


Figure 10. Interactions between Modules to Provide Wait Times to Connected and Conventional Vehicles.

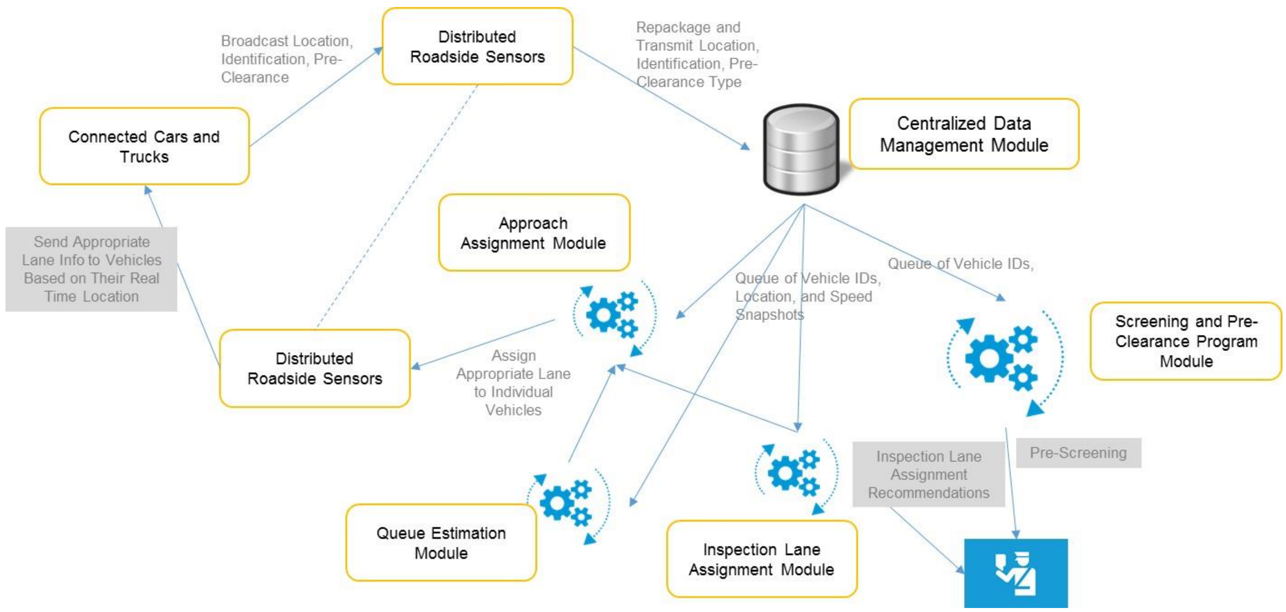


Figure 11. Interactions between Modules to Provide Lane Assignments to CVs.

Distributed Roadside Sensors Module

Depending on the physical layout of POEs, the locations of roadside sensors have to be laid out to ensure minimal obstruction to the line-of-sight coverage. Physically, these sensors may be installed to work independently from one another. However, this module ensures that the sensors properly function to transmit data from vehicles to the information relay module.

In the enhanced system, CVs send basic safety messages (BSMs) and probe data messages (PDMs) to roadside sensors when they come within communication range (approximately

300 m) of each other. A BSM includes current location (i.e., latitude, longitude) and speed, among other information. Transmission rates of BSMs from OBU are typically 10 times per second unless congestion control algorithms prescribe a reduced rate. PDMs include a snapshot of a vehicle's speed recorded over a short time period.

The sensors then send the data packets to a centralized data management module for further processing. It is not clear if existing long-term evolution (LTE) and future 5G technology can transmit data packets between the two locations. Otherwise, such transmission will have to take place using a wide area network or fiber optics. Roadside sensors that detect connected cars can be installed on existing utility poles alongside Bluetooth and RFID readers, where already deployed.

Roadside sensors may also be deployed to read MAC IDs and transponder IDs from conventional vehicles. Radios deployed in the sensors to detect Bluetooth and Wi-Fi signals from vehicles are different from radios that communicate with CVs with DSRC capabilities. Both radios can be installed in a single roadside sensor unit and send data to the central module in single or multiple data packets.

Centralized Data Management Module

CVs transmit data packets to roadside sensors every 10 milliseconds or more, depending on configuration of onboard devices. BSMs may arrive in much shorter frequencies than PDMs since PDMs are by design configured to be less frequent than BSMs. Hundreds of vehicles approaching a POE, especially during congested conditions, may generate large amounts of small data packets at a very high frequency. Roadside sensors may be configured to perform limited data verification and cleaning before transmitting to a centralized data management module.

The module is also responsible for receiving identification information from conventional vehicles equipped with traditional technology such as Bluetooth and Wi-Fi. The size of data packets from a CV will be bigger than the simple ID from conventional vehicles because both BSMs and PDMs have more attributes and are designed to send data to roadside sensors at a much higher frequency than Bluetooth or Wi-Fi sensors.

The module then archives, prunes, and geospatially clusters the data (both from connected and conventional vehicles) before retransmitting them to other modules for queue estimation, wait time, etc. The module also receives results from other estimation/assignment modules and archives and retransmits the data to vehicles via the information relay module.

Information Relay Module

The key function of the information relay module is to broadcast information to CVs via roadside sensors and to broadcast information to conventional vehicles via traditional media such as websites, mobile apps, and roadside display signs. The module receives messages to be broadcast to vehicles from the central database management module. It uses rule-based methods to broadcast messages to vehicles based on their relative location to the CBP primary inspection booth. This module does not receive data from CVs.

Queue Estimation Module

The queue estimation module uses a combination of speed snapshots (from PDMs) and location (from BSMs) to estimate the location of the end of the queue and its speed of progression. Speed snapshots include the speed of vehicles taken over a few milliseconds of time stored in the device at pre-defined intervals. The accuracy of queue length estimation depends on a statistically significant number of vehicles transmitting the PDM data at the same time. The module receives PDM and BSM data from the centralized data management module. As shown in Figure 10, it then sends the end of the queue and its progression information to the wait time estimation module since queue location is critical information for estimating wait time. Although not shown in Figure 10, CBP officers may benefit from knowing where the queue is and how quickly or slowly it is moving. This might help the officers verify if their actions to address long wait times (e.g., opening additional lanes) are working.

Wait Time Estimation Module

Location breadcrumbs from vehicles can be used to determine travel times between roadside sensors. That information can be complemented with queue progression information and the number of inspection lanes open to increase accuracy of wait times. The wait time estimation module estimates wait times for vehicles based on their locations relative to the CBP primary inspection booth. The module sends geospatially clustered wait times to the information relay module, which sends data to individual roadside sensors and then to vehicles directly.

Approach Lane Optimization Module

Most motorists know which lane to stay in while approaching a POE. At some POEs, there are signs that suggest motorists use certain lanes depending on which pre-clearance program they are enrolled in. At some POEs, there are separate lanes for POVs and COVs. However, when the queue is exceptionally long and extends beyond static signs, the traffic can mix. The approach lane assignment module requires that motorists send some kind of identification information to the system in order to track vehicles as they move downstream toward the CBP primary booth. The identification information should include a unique ID number, whether it is a POV or a COV, and the pre-clearance program the motorist is enrolled in. Using the ID and real-time location of vehicles, the module can send a message to the vehicles' OBU about which lane they should be in.

Screening and Pre-clearance Module

Because roadside sensors can communicate with vehicles several thousand feet beyond the border, CBP can identify motorists and perform screening before they reach the CBP primary inspection booth. However, the system needs to consider the fact that CV technology uses the privacy by design concept, which means onboard devices can be identified only temporarily (for a few minutes) using a public key. Whether these public keys will be shared with law enforcement agencies is still unresolved. Nonetheless, CBP can design a program whereby motorists can opt in and receive a CBP-specific static unique ID of onboard devices. When those devices come within the range of a roadside sensor, they transmit their ID along with BSMs and PDMs to CBP.

Assumptions and Constraints

Adequate market penetration of CVs will be necessary to maximize the benefit of deploying the enhanced system at POEs. However, it is unclear what adequate means. One thing is certain: market penetration of CVs will rise exponentially once the National Highway Transportation Safety Administration (NHTSA) makes a rule on the subject, possibly in 2017. NHTSA is expected to make it mandatory for all new passenger cars and light trucks to have CV technology built in. It is unclear about the scope of such a rule in terms of types of applications that should be built into vehicles.

A significant portion of POVs and COVs that enter the United States from Mexico are vehicles sold in Mexico. There is a possibility that market penetration of CVs in Mexico may significantly lag that of the United States. However, CBP can get rid of original transponders that it distributes to COVs and replace them with DSRC-capable devices. At present, doing so is unfeasible because of the high cost of DSRC-capable devices.

Auto manufacturers are heavily marketing connected car services, which include infotainment, roadside assistance, and other safety features. This service primarily works off 4G/LTE connections between vehicles and service providers. Some industry experts believe that 5G and further improvements in wireless technology may outdate the need for DSRC technology in CVs. Thus, cellular technology advancements can change the picture entirely and may make the need to install roadside devices with DSRC technology unnecessary.

Performance and Quality Requirements

This section discusses technical performance needs that may be considered when assessing and evaluating the system. The topics considered here may form the basis for later work addressing the building engineering requirements and specifications for the system.

Capabilities and Performance

The system must be able to support a wide range of operational scenarios and applications. It must be capable of capturing data accurately and reliably across this range of conditions. Placement of roadside sensors may vary depending on the operational type and location of deployment. The reading range of devices may vary depending on obstruction, height of installation, antenna type, etc.

Vehicle Speed and Location

Communication between roadside and onboard devices must happen at all relative speeds. These devices must be within range of each other long enough to transfer the required data. Data transfer rates of the technology must be high enough to support the transfer of payload between devices. Onboard devices send location and speed snapshots at pre-defined frequencies to roadside sensors.

Transmit/Receive Range

The required range for the communications channel will vary depending on the specific border crossing operation type. The transmit/receive range needs must also be balanced by the need for selectivity if it is desirable to identify the lane that a vehicle is traveling in.

Message/Data Size and Rate

As discussed above, the maximum message or data size and the minimum rate at which that data can be sent over the data link are important so that the data can be sent in time to support the application. Data retries due to error rates and/or data collisions must be factored into the calculation in such a way that the identification can be transmitted reliably given the range and vehicle speeds for the application.

Operational Requirements

Staffing Needs

Consideration should be given to the staffing required to operate and maintain the system. The technology should require minimal staffing needs for operation of the equipment. The system should automatically detect when a truck is in range, query the truck for an identifier, and process the identifier within the database to determine the related truck information. In normal operation, the only requirement for staff should be to assess the data presented and make a decision on whether to inspect the vehicle. Consideration should be given to the need for preventive maintenance and routine management of the system.

Power

In-vehicle components must operate on power available in the vehicle and the environment, such as 12V DC, integral battery, solar power, or no external power. Passive RFID tags operate from power supplied by the reader. For components with integral batteries, consideration must be given to the trade-off between replacing batteries and having permanent batteries that last the life of the device. For example, battery life may need to be at least one year if a battery can be removed and replaced or five years if it is not replaceable. Roadside equipment may be powered by municipal power, but it is preferable to operate as many components as possible using batteries recharged from renewable resources such as solar cells.

Health and Safety

All equipment should protect the health and safety of operators and maintainers. In-vehicle components should not require the vehicle occupant to interact directly with the device while the vehicle is moving. Roadside equipment should protect personnel from exposure to high-voltage electrical or high-power radiated signals. Readers for universal electronic truck identification should meet the performance and safety requirements for roadside hardware used on the National Highway System, such as those identified at http://safety.fhwa.dot.gov/roadway_dept /policy_guide/road_hardware/.

Security Requirements

Authorized Access

The system should detect and prevent non-authorized personnel and/or subsystems from interfacing with the system.

Resistance to Removal or Tampering

Field hardware should be installed permanently in the field in such a way that it is resistant to removal, replacement, or tampering. At the same time, the field equipment should be easily accessible to authorized personnel for maintenance purposes.

Identifier Verification

The truck identification system should include an automated means for verifying its accuracy (i.e., that the identifier is on the correct truck). This verification may require an independent reader system that compares the identifier to other information in the truck identification record, such as license plate.

Installation Method and Location

The identifier should be designed to be quickly, permanently installed, or mounted on all power units in a standard location that can be reliably read by the roadside equipment. While ease of installation is important, the technology should be installed in a permanent manner such that its removal will destroy its functionality and minimize tampering.

Environmental Resistance and Durability

Environmental conditions to be considered for onboard and off-board equipment include extremes in temperature, humidity, wind, snow, rain, dust, sand, salt, fog, vibration, shock, electromagnetic interference, petroleum exposure, oils and lubricants, fungus, and lightning.

The in-vehicle technology should comply with applicable Society of Automotive Engineers (SAE) and industry standards for onboard equipment exposed to the rigors of commercial vehicle operation throughout its service life, such as the Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks) (J1455). Similarly, the roadside equipment should comply with applicable industry standards for roadside and stationary equipment exposed to the rigors of outdoor service.

Supportability

Availability and Reliability

The system should be capable of automatically operating continuously without operator intervention. The operational availability of the system should be specified, typically in terms of percent time available, and meet the needs of the application. Reliability should be specified, typically in terms of mean time between failure and availability.

Maintainability

The system should have a built-in test function to validate that the system is operating within normal parameters. The maintainability of the system should be specified in terms of mean time to repair.

Portability and Transportability

The universal electronic truck identification system should support portable readers installed permanently or temporarily on mobile enforcement vehicles or in small trailers. It should support handheld readers, which interface with laptop computers. It should also support transportable units that can be setup quickly on the roadside and remain operable using vehicle or generator power.

Expandability and Extensibility

The system should be upgradeable to allow for application of repairs when failures occur and to allow for new functionality to be programmed into the system.

Logistics Constraints

Roadside readers and other equipment should be installed permanently, should be transportable, and should be able to be installed by experienced roadside equipment contractors.

SUMMARY OF IMPACT

This section describes operational impacts of the enhanced system on CBP. This information will allow CBP to prepare for the changes that will result from the new system and plan for impacts.

Operational Impacts

The enhanced system will have an impact on CBP's field operation where it is deployed. In order to achieve the benefits from the system, CBP officers will have to continuously use the system (i.e., monitor queue progression and wait time, take action by opening/closing more lanes, and relay information to vehicles). If the system is designed to learn from actions taken by the officers, then constant use of the system is even more critical for its improvement.

Organizational Impacts

CBP officers will require training in using the enhanced system, especially on how to use the information generated by the system and react. However, interaction with the system will have to be governed by clearly outlined policies and practices. For example, what should the officers do if the system shows wait times have exceeded the maximum threshold? CBP should have clear policies about what kind of automated and manual messages need to be sent to vehicles.

Impacts during Deployment

Most likely, CBP will outsource deployment of the enhanced system to a private contractor. The contractor will need access to CBP facilities in order to install DSRC sensors. Typically, sensors can be installed on different types of vertical elements such as utility poles and walls. Because the footprint of the sensors is minimal, there is no need to close inspection lanes or any part of the facility during installment.

CHAPTER 6. FIELD TESTS OF TECHNOLOGY PRODUCTS AND PERFORMANCE ANALYSIS

METHODOLOGY

The objective of this task was to test the CV technology in a controlled environment. The research team used the resources available at TTI's RELLIS proving ground to test the technology. The team procured CV technology hardware as per the technical specification of the vendors and also developed software modules so that the entire set up satisfied the basic requirements of the enhanced system, for example, data communication between OBU and roadside units (RSU).

The test was conducted on October 16, 2016, with TTI and University of Houston staff in attendance. The team retrofitted TTI vehicles with OBU, display units, and an RSU as shown in Figure 12, Figure 13, and Figure 14.

Figure 12. OBU in One of the TTI Vehicles.

Figure 13. Display Unit Using Tablet Computer.

Figure 14. RSU Installed on Top of a Pole.

FIELD TESTS CONDUCTED

Three sets of field tests at the RELLIS campus were conducted to ensure that the technology when deployed at a land POE will satisfy basic communication requirements for vehicles to communicate with each other and RSU, and also read lane positioning accurately.

Vehicle to Roadside Unit Communication

TTI tested two-way communication in the form of high frequency data transfer between OBU and RSU. Two moving vehicles equipped with OBU were driven several times inside the campus to identify such issues as latency and line of sight. The test showed that even when vehicles are closely driven (next to one another), data communication was not affected. This is important because in real-world conditions, vehicles approach POE in stop and go conditions.

Vehicle to Vehicle Communication

TTI also tested data communication between two moving vehicles at different separation distances. When vehicles were in communication range, data transfer between the OBU was consistent. Even though the use case for vehicle to vehicle communication at a land POE is not critical at the moment, it might be in the future.

Lane Separation Test

TTI also tested the positional accuracy of two vehicles traveling side by side in two different lanes. The test showed that the technology can separate vehicles based on lane. This is useful since the technology will need to identify if vehicles are in non-FAST vs. FAST lanes.

QUANTITATIVE PERFORMANCE

One of the goals of this project is to develop a ConOps based on promising technology. If implemented, the system outlined in the ConOps would provide CBP a reliable and cost effective border wait time measurement system. As stipulated in the scope of work, TTI measured the following performance goals if the enhanced system is deployed at a land POE.

Reduce Wait Time Measuring System Implementation Cost by 15 Percent

In recent years, TTI deployed an RFID-based wait time measurement system at the Zaragoza POE in El Paso, Texas. At the POE, RFID sensors were deployed at fixed locations. They are powered locally and communicate with a central server using cellular modem. The system also includes a backend system, which receives identification data from transponders, determines travel time between segments, and estimates wait times. Assuming power requirements, communication, and back end deployment would not be different, the difference would be in the RSU (radio unit). While for pilot deployment, onboard radios would have to be distributed to participating vehicles to test the technology; in future vehicles it will be provided as a standard feature.

At four locations of the POE, the cost of RFID readers and antennas were approximately $34,000. Comparatively, if RSU were deployed at the same four sites, DSRC radio units would cost approximately $20,000 ($5,000 per location). Hence, it is obvious that DSRC technology will save deployment cost.

Reduce Wait Time Measuring System Operation Cost by 20 Percent

The RFID-based system was deployed at the Zaragoza POE in 2012. Since then, the annual operation and maintenance cost has been approximately $20,000 per year. In the past 6 years, TTI has performed extensive maintenance to field equipment, including securing a power source for each of the RFID reading points, maintaining antennas at each lane, and perform hardware updates to readers. Assuming DSRC equipment is replaced at the same rate, maintenance costs will be similar for both systems. However, pilot and early stage projects may have higher operation costs because of the learning curve for the system owner.

Ability to Determine Border Wait Time under Six Scenarios

When the proposal for this project was prepared, the technology that would be selected was not defined. At that time, it was assumed that RFID technology would be selected for testing. However, based on findings from the technology assessment, CV technology was identified as having the most potential to fulfill CBP's current and future needs for border wait time measurement. The project proposal included six scenarios under which the selected technology should be tested. The CV technology was tested according to the proposed potential scenarios as much as possible. Accordingly, the test area was divided into eight lanes. One of those eight lanes was designated as a FAST lane and remaining as non-FAST lanes. For the scenarios tested, Table 3 describes test results and observations.

Table 3. Scenarios Depicting Different Volume Conditions.

Scenario	Traffic Type	
	FAST*	**non-FAST**
1	**Low number of vehicles**	**Low number of vehicles**
	In an RFID-based system, during low volume conditions, sample size is small and can impact accuracy of wait times. However, in CV technology location breadcrumbs of even a small number of vehicles can be used to determine speed and travel time. During the test at the RELLIS campus, TTI simulated one vehicle in FAST and another in non-FAST. The system was able to record location breadcrumbs of both vehicles to plot speed trajectory and estimate travel times.	
2	**Low number of vehicles**	**High number of vehicles**
	TTI was not able to test the high number of vehicles in this scenario, due to the absence of a large number of test vehicles. However, TTI did test two vehicles driving in close proximity in FAST and non-FAST lanes alongside one another. The OBU in vehicles were still able to send data to RSU without loss in latency.	
3	**High number of vehicles**	**Low number of vehicles**
	TTI was not able to test the high number of vehicles in this scenario, due to absence of large number of test vehicles. However, TTI did test two vehicles driving in close proximity in FAST and non-FAST lanes alongside one another. The OBU in vehicles were still able to send data to RSU without loss in latency.	
4	**Constant number of vehicles arriving at the POE**	**Sudden variations of the number of vehicles arriving at the POE**
	TTI tested two vehicles driving at the same speed one after another to emulate the constant flow of vehicles and also sudden variations. The test did not show loss of data communication with the RSU. However, in the real world deployment, there might be loss of data due to larger bandwidth needed to receive data from vehicles to RSU and on to backend.	
5	**Sudden variations of the number of vehicles arriving at the POE**	**Constant number of vehicles arriving at the POE**
	TTI tested two vehicles driving at the same speed one after another to emulate the constant flow of vehicles and also sudden variations. The test did not show loss of data communication with the RSU. However, in the real world deployment, there might be loss of data due to larger bandwidth needed to receive data from vehicles to RSU and on to backend.	
6	**Sudden variations of the number of vehicles arriving at the POE**	**Sudden variations of the number of vehicles arriving at the POE**
	TTI did not test this scenario because earlier tests in Scenario 4 and 5 showed that the technology can adequately identify vehicles in separate lanes and transmit data without loss.	

CALCULATION AND ASSESSMENT OF PERFORMANCE METRICS BASELINE

Implementation Costs

The implementation base line cost was estimated based on current implementation cost for an RFID-based border wait time crossing measurement system at the Zaragoza-Ysleta POE. The research team deployed and has been maintaining an RFID-based system at this POE for the last few years.

In order to measure border wait times with an RFID-based system, at least two set of reading stations are needed. At the Zaragoza-Ysleta POE, the first station is at the toll booth in the Mexican side of the border and has two lanes. The second location is at the CBP primary inspection booths, and there are seven lanes equipped with RFID antennas. The typical installation requires one RFID reader for every two lanes. The implementation costs at this POE was $20,000 for the first reader location at the Mexican toll booth, and $40,000 at the CBP primary inspection booths. The total implementation cost for the RFID reader system is $60,000 plus time for the research team to prepare material, order equipment and supervise the installation on site.

The CV system that is proposed, will require a maximum of two “reading” stations, one at the CBP primary and the second one at the international bridge or in Mexico, depending how far back the identification of the queue is needed. There is no cost per vehicle or lane as the information will be transmitted from vehicles already equipped with OBUs. The estimates costs for the equipment and installation of the two stations is $15,000.

The proposed CV-DSRC-based technology implementation cost is four times lower to implement than the RFID-based system, assuming backend, software development cost is similar for both systems. None of these technologies require human intervention, as the current border wait time data collection that requires CBP officers to collect information and input it into the system manually.

Operation and Maintenance Costs

The operation and maintenance cost includes hardware replacement costs and labor for regular and on-demand maintenance. So far, TTI has spent approximately $100,000 in operation and maintenance at the Zaragoza POE. These costs include maintaining and in some cases replacing antennas and RFID readers that malfunction. The CV DSRC-based system does not require antennas, readers or other field equipment.

The other component of the operation cost of the two systems is the communication charges to transmit information to a central system. RFID-based system requires one cellular model for every station, and in the Zaragoza POE, there are two stations to measure wait time. The CV DSRC-based system requires one or probably two central systems with a cellular modem to transmit the information to a central location, depending on the POE layout. The communication costs for the two systems should be similar. However, with two cellular modems, the CV DSRC-based system is capable of capturing travel time information beyond the Mexican toll booth, providing not only wait time information to CBP, but total queue length in Mexico, as well as the other travel information described earlier, such as vehicle lane location.

The advantages of the CV DSRC-based border wait time measurement system is that it will have a substantially lower implementation, maintenance and operation costs, while providing additional valuable information than the RFID-based system.

CHAPTER 7. SYNERGY WITH OTHER DHS PROJECTS AT BTI

During the course of this project, the Research Team has interaction with the BTI project "Modeling Methodology and Simulation of Port-Of-Entry Systems", which is being conducted by Rutgers University.

The Rutgers-led project aims to develop a suite of simulation models of both vehicular and pedestrian POE systems. These will include traffic streams of freight-hauling trucks, passenger vehicles, and pedestrians across POEs located on the U.S. international borders. The simulation models will serve as an *in vitro* lab to conduct experiments with various POE configurations and parameters, primarily for planning purposes. The key performance metrics of interest are time and cost statistics, such as statistics of waiting times (prior to processing) and crossing times (total time through the system), as well as the time opportunity cost of waiting experienced by drivers.

Simulation models need to be validated before using for decision support purposes. Validation refers to the process of checking that the model's output (performance metrics) are sufficiently close to their counterparts in the real-world system under study. In our case, validation of a POE model calls for obtaining real-life (empirical) traffic data from measurements of crossing times between fixed RFID receiver locations.

TTI has been collecting border crossing and wait times at major land POEs in Texas since 2014, for a sub-stream of RFID-equipped vehicles. The data is available on their website (http://bcis.tamu.edu/index.aspx), titled Border Crossing Information System (BCIS[2]). These data are obtained via RFID readers which communicate with RFID-equipped trucks.

TTI shared one-month worth of RFID tag reads (dating back to March 2016) for the Bridge of the Americas POE in El Paso, Texas. The data set contains time stamps of each RFID equipped commercial vehicle passing through the RFID readers. These information will be used by Rutgers University to recover the corresponding waiting and crossing times, and to compute their key statistics (e.g., average crossing time).

The simulation models will be validated by comparing these statistics to their simulation-generated counterparts. The empirical data will also be used to calibrate simulation model parameters. The validation goal is to achieve a no more than 10% relative deviation of the simulation-generated statistics from their empirical counterparts.

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[2] BCIS is funded by the Texas Department of Transportation, the Federal Highway Administration, and U.S. Customs and Border Protection, and is developed and maintained by the TTI.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

CONCLUSIONS

Enhancing the existing border wait time measurement system requires a comprehensive understanding of CBP's and other border agencies' current and future needs for port operation and planning; understanding these needs was key to the success of this research project. Accordingly, as a part of the project, a detailed study was conducted of the type of traffic and other characteristics of the land POEs on the Canadian and Mexican borders. The border crossing process was evaluated and documented along with current measurement techniques and information dissemination methods. The research team found strong correlations between wait time and volume, number of lanes open, and cycle time. Out of those three independent variables, number of lanes open appears to have the most impact on wait times.

The SWOT analysis performed comparing strengths, weaknesses, opportunities, and threats of the proposed system found that the technology is reliable, efficient, fast, secure, and unlikely to have interference in message transmission. Concerns were that the technology is still in development, not yet widespread, and may have licensing fees. While privacy concerns were seen as a potential threat, opportunities included better wait time forecasting, better management of congestion, and anticipated growth in the market.

In accordance with the needs identified in the course of the research, it was determined that the proposed system contains the following elements.

Data Collection

Wait time information would need to be collected for all traffic types, including FAST and non-FAST, NEXUS, SENTRI, Ready Lanes, and non-DCL lanes. The accuracy of measurements should be within a range of ±10 minutes for all lane types. Wait time information collected in the field shall be integrated with a system CBP is developing internally. This system is designed to gather wait time data from POEs and update the CBP's website. It recognizes the fact that all POEs are not alike, and different technologies and systems can be deployed based on local preferences and environment.

Storage

Historical wait time information needs to be stored indefinitely, and historical information should be made available for trend analysis and forecasting.

Dissemination

Information should be refreshed at 5-minute intervals, and the traveling public should be able to receive information via a web-based system or a mobile app.

The proposed system is shown in Figures 8 and 9, which show how the system modules would interact to provide lane assignments to CVs, and wait times to connected and conventional vehicles. These configurations were used to design the preliminary test at RELLIS. The field test was successful, as detailed in Chapter 6.

The development and preliminary testing of the ConOps required by this research project showed that the use of CV technology in estimating wait times at land POEs is feasible, with potentially significant reductions in implementation and operations costs.

RECOMMENDATIONS FOR FUTURE RESEARCH

To demonstrate the functionality of the wait time measurement system ConOps developed and tested for this project, future research should test the enhanced wait time system using CV technology in a real-world environment at a selected land POE. Potential benefits to CBP were identified as a part of this project, and the real costs and costs and benefits could be measured and compared of deploying DSRC technology versus other technologies to measure wait and crossing times, and to better manage lane separation, queues, and pre-screening of drivers.

The benefits to DHS of conducting this future research are significant. The 2014 Quadrennial Homeland Security Review (QHSR) has as one of its strategic priorities the adoption of a risk segmentation approach to securing and managing flows of people and goods that expedites and safeguards legal trade and travel. This project benefited DHS by testing the feasibility of CV technology to measure border wait time in a real-world land POE application, and enabled the deployment of CV technology at other land POEs in the future. This facilitates the implementation of the QHSR priority and allows CBP field officers to dedicate more time for inspection by relying on an advanced technology-based border wait time measuring system.

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APPENDIX A – MILESTONE 1 REPORT: NEEDS ASSESSMENT

T.3.1 Developing a Concept of Operations for an Innovative System for Measuring Wait Times at Land Ports of Entry

Milestone 1 Report: Needs Assessment

Prepared for the

CBTIR
CENTER FOR BORDERS, TRADE, AND IMMIGRATION RESEARCH

A DHS Center of Excellence led by the University of Houston

By

Texas A&M Transportation Institute

Submitted on **03/16/2016**

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1. INTRODUCTION

Border wait times at land ports of entry (POEs) are an important measurement of port performance, trade, and regional competitiveness. A reliable and systematic method of measuring border wait times is needed in order to make better construction, planning, and operations decisions at land POEs.

Currently, U.S. Customs and Border Protection (CBP) officers measure border wait times in a non-scientific way with different criteria on a POE by POE basis. CBP officers have to dedicate time to collect information on border wait time to populate CBP's website and mobile application, while this time could be spent performing inspection activities at land POEs.

The objective of this project is to develop a Concept of Operations (ConOps) document that lays the foundation necessary to design an enhanced wait time management system at the land POEs in a later project phase.

ConOps development is a process by which the current and future needs of CBP and other stakeholders at the ports are systematically captured in order to develop a high-level design of a system. This report presents findings related to CBP's current and future needs for border wait time measurement.

After this introduction, background information for U.S. land POEs is presented in Section 2, followed by a description of the current border crossing processes for privately owned vehicles (POVs) and commercially operated vehicles (COVs) in Section 3.

Section 4 presents a description of current border wait time measurement techniques and the data dissemination tool. In Section 5, a summary of CBP wait time measurement needs and analysis is presented, and Section 6 presents data needs for the development of the ConOps.

2. BACKGROUND

The U.S. borders with Canada and Mexico are among the longest in the world, 5,500 and 2,000 miles long, respectively. There are 110 border crossings at the U.S./Canada border and 44 border crossings at the U.S./Mexico border. Figure A-1 shows locations of land POEs. The appendix presents the list of land border crossings at the U.S./Canada and U.S./Mexico borders, identifying the type of traffic that is served by each crossing.

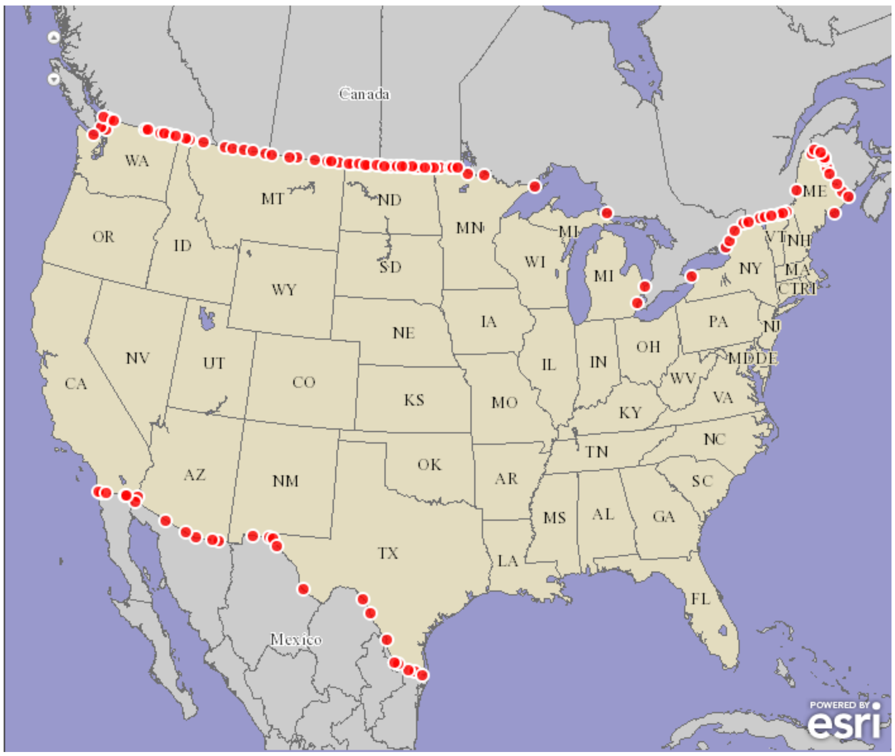
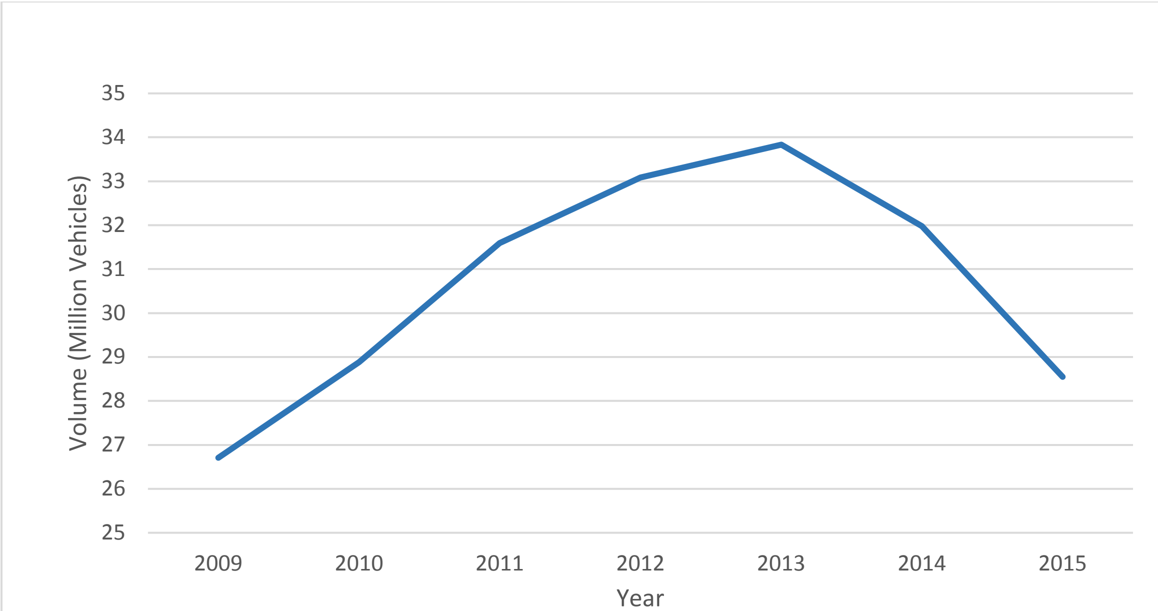


Figure A-1. Canada-U.S. and Mexico-U.S. Land POEs (U.S. Census Bureau, 2016).

Canada and Mexico are among the largest suppliers of U.S. goods in 2015, accounting for 27 percent of overall U.S. imports (U.S. Census Bureau, 2016). Border movement of people and goods is an essential element of the U.S. economy, so the efficient operation of land POEs is of high priority.

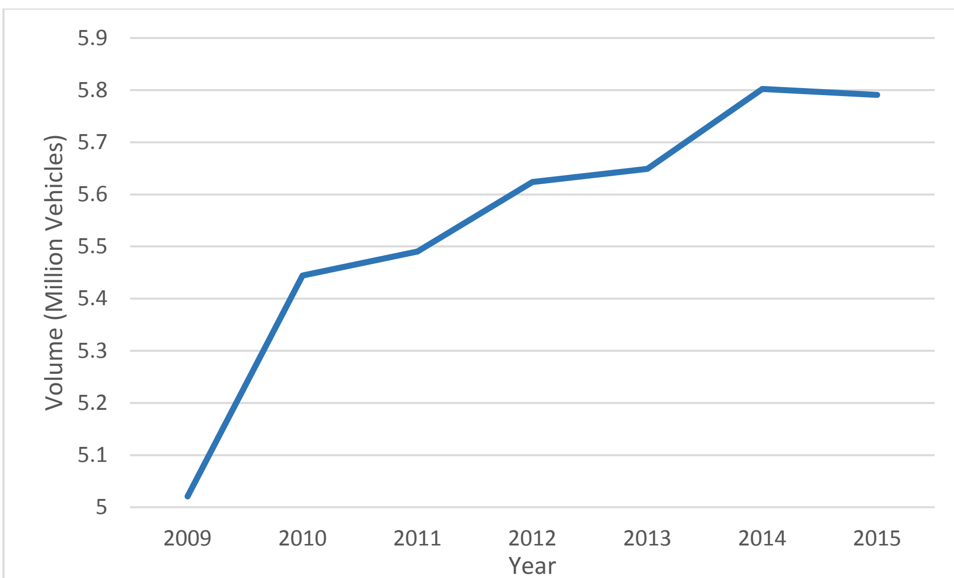
More than 28 million POVs and 5.8 million COVs entered the United States from Canada in 2015. Another 74 million POVs and 5.5 million COVs entered the United States from Mexico in the same year. The increase in vehicle volumes crossing the border into the United States results in high crossing and wait times at land POEs. COV crossings into the United Sates from Canada and Mexico increased 21.6 percent since 2009, while POVs crossings increased at a lower rate of 5.9 percent (U.S. DOT, Bureau of Transportation Statistics, 2015).

Annual volumes of POVs and COVs entering U.S. from Canada for the period of 2009–2015 are presented in Figure A-2 and Figure A-6, (U.S. DOT, Bureau of Transportation Statistics, 2015). POV volume annual growth rate for this period was 1.1 percent, while COV volume annual growth rate was 2.4 percent.



Source: U.S. Department of Transportation, Bureau of Transportation Statistics

Figure A-2. Number of POVs Crossing from Canada to the United States.



Source: U.S. Department of Transportation, Bureau of Transportation Statistics

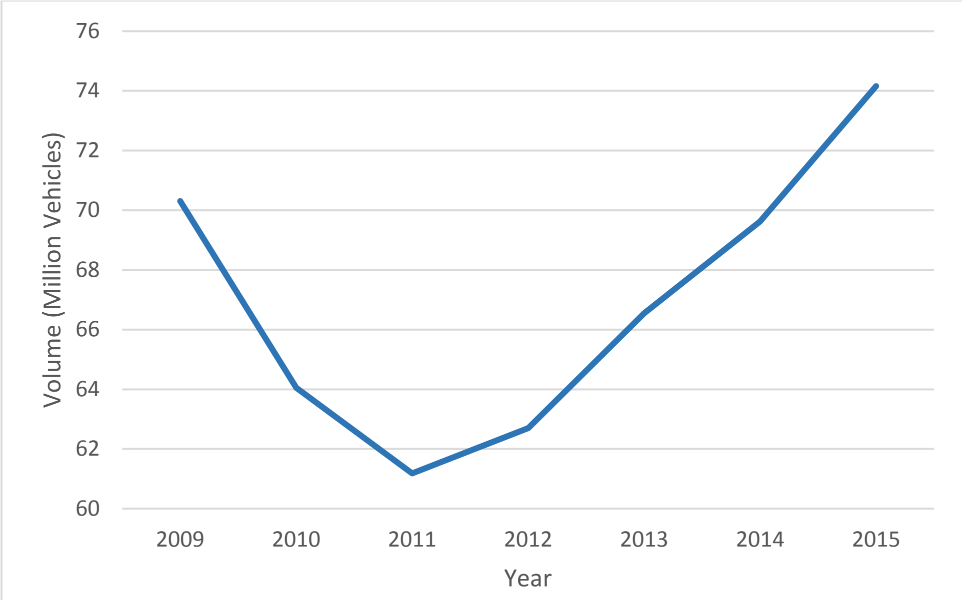
Figure A-3. Number of COVs Crossing from Canada to the United States.

Commercial traffic at the U.S.-Mexico border has increased substantially since the implementation of the North American Free Trade Agreement. Source: U.S. Department of Transportation, Bureau of Transportation Statistics

Figure A-4 and Source: U.S. Department of Transportation, Bureau of Transportation Statistics

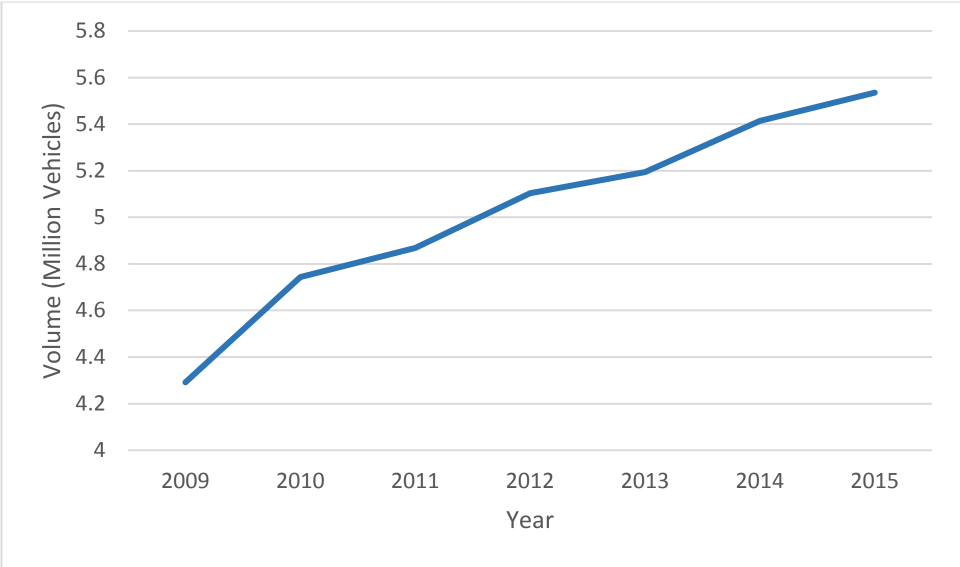
Figure A-5 illustrate the number of POVs and COVs entering the United States from Mexico for the 2009–2015 period (U.S. DOT, Bureau of Transportation Statistics, 2015).

POVs crossing from Mexico into the United States in this period decreased at an average annual rate of 0.9 percent, while COV crossing grew at an annual rate of 4.3 percent.



Source: U.S. Department of Transportation, Bureau of Transportation Statistics

Figure A-4. Number of POVs Crossing from Mexico to the United States.



Source: U.S. Department of Transportation, Bureau of Transportation Statistics

Figure A-5. Number of COVs Crossing from Mexico to the United States.

The number of vehicle crossings is expected to continue increasing given the nature of cross border trade and passenger vehicles in the North American region. This requires optimization of currently available resources in order to improve border crossing levels of service. Availability of the accurate information on border wait times is a first step toward making informed decisions to improve operations and security

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3. CURRENT BORDER CROSSING PROCESS

More vehicles are arriving to the United States from Mexico through a significantly lower number of available POEs, in comparison to vehicles from Canada. The border crossing process between Mexico and the United States requires additional steps than the crossing from Canada into the United States, resulting in higher wait times. Therefore, entrance into the United States from Mexico is examined in more detail.

VEHICLES ENTERING FROM CANADA

POV Crossing Procedure

The crossing process begins when a POV goes to a designated primary inspection plaza. Secondary inspection follows when the situation demands additional inspection (incomplete/incorrect paperwork). However, vehicles may be randomly selected for the secondary inspection booth. This inspection phase is thorough and time consuming. Canada and the United States have a long tradition of collaboration with a common goal of faster and more secure trade and travel. This cooperation is conducted through enhanced information sharing and traveler prescreening.

COV Crossing Procedure

The first point of contact at the border is with the primary inspection officer. If all paperwork is processed ahead of time, this is usually the only stop for COVs. Customs is able to receive shipment information before the border arrival through the e-manifest process. The officer at the primary inspection booth receives the Automated Commercial Environment e-manifest coversheet and all the information previously received from the carrier. If there is an irregularity, the truck will be directed to the customs broker or toward the secondary inspection for additional examination.

VEHICLES ENTERING FROM MEXICO

POV Crossing Procedure

Border crossing for POVs requires authorization by a CBP officer, and this process starts at the primary inspection station. Based on travel documents provided by the driver and passengers, and verbal communication, the officer decides if travelers are eligible to enter the United States. If the CBP officer determines that further examination is required, the vehicle and its occupants are referred to the secondary inspection location.

COV Crossing Procedure

The border crossing procedure for COVs begins when products to be imported from Mexico are prepared along with the required documentation for customs clearance. These documents are sent to both Mexican and U.S. federal agencies. Mexican Customs conducts a verification process and random physical review of the cargo. Discharged shipments proceed to the toll booth (if existent) and reach the U.S. POE Primary Inspection.

The primary inspection consists of inspection of the driver, transfer truck and cargo documents, and the cross-check with e-manifest. The vehicle can be released to the exit gate or referred to a secondary inspection, where a more thorough inspection can be conducted (e.g., x-rays, cargo unloading).

After the transfer truck is discharged, it continues toward a vehicle safety inspection facility where the U.S. state officials make sure that the vehicle is in compliance with state vehicle safety standards.

Dedicated Lane Types

CBP's Trusted Traveler Programs provide expedited travel for pre-approved, low risk travelers through dedicated lanes. Dedicated lanes for low-risk users allow lower processing time (and wait times) in comparison to standard lanes, since their background check is already conducted. POEs at both Canadian and Mexican borders are usually equipped with at least one of the following types of dedicated lanes:

- Ready lanes are used by POVs to expedite the inspection process at the border. Travelers need to be in possession of a radio frequency identification (RFID)–enabled document.
- Secure Electronic Network for Travelers Rapid Inspection (SENTRI) and NEXUS lanes used by POVs when entering the United States from Mexico and Canada, respectively. Program members enjoy expedited processing as they are pre-screened.
- Free and Secure Trade (FAST) lanes process COVs carrying low-risk shipments. FAST cardholders are certified under the Customs-Trade Partnership Against Terrorism program. Faster clearance is allowed as eligibility requirements are fulfilled and background checks are already completed.

4. CURRENT MEASUREMENT TECHNIQUES AND INFORMATION DISSEMINATION

MEASUREMENT TECHNIQUES

Wait times are currently estimated by CBP officers through visual inspection of the queue length or driver surveys. These subjective estimates are used to populate CBP's website and mobile application. Wait time collection is outside of CBP officer's primary mandate. Effective CBP examination is diluted by data collection when the officer's efforts are diverted away from inspection.

All POEs use at least one of the following manual methods to collect wait time data (Sabean & Jones, 2008):

- *Unaided visual observation*: The CBP officer records where the formed queue ends in relation to predetermined markers. Inspectors use their experience to estimate queue density and wait times. In order to ensure higher accuracy and consistency of their reports, some offices use the Border Wait Time Calculator, which is a table that incorporates additional elements, such as number of open booths. One of the drawbacks of these methods is that the queue during peak periods can extend beyond line of sight of the officers. Hence, the wait time can be significantly underestimated during peak periods.
- *Cameras*: Some civilian agencies have installed traffic cameras on the Mexican side of the border. Camera snapshots are publicly available. CBP officers can use snapshots to estimate queue. At some POEs, CBP has installed traffic cameras inside its premises. However, the visual range of these cameras is limited and suffers from the same drawback as unaided visual inspection. Queue end is compared to the predetermined landmarks and wait times are assigned. Some offices use a spreadsheet formula that incorporates number of booths open and processing times, resulting in more accurate estimation.
- *Driver surveys*: This approach is the most commonly used among wait time measurement techniques. The officer working at the primary inspection asks the drivers to estimate how long they have been waiting in the queue. Subjective time perception of drivers typically causes overestimation of wait time.
- *Time stamped cards*: Drivers are issued a card or toll receipt at an upstream location of POE. This time stamp is compared to the current time when the driver arrives at the inspection booth. The difference between these two times is used as a transit time concerning these two locations. Transit time from toll collection booth is not the same as border wait time.
- *License plate readers*: Vehicles are identified by their license plates. This is done manually in Detroit by the Detroit-Windsor Tunnel Company, and the list of license plates and times from the entry location is sent by email to CBP. This time is then compared with the time the same vehicle crossed the primary inspection booth. The moment when the vehicle crossed the inspection point is acquired from the Treasury Enforcement Communication System.

Various federal state and local transportation agencies have implemented systems and technologies to measure border wait times. The objective of these projects is to develop a system that could measure border wait times in a systematic and consistent way across the two border regions. The three technologies that have been implemented are:

- RFID. An RFID transponder or tag is mounted in the windshield of participating vehicles. Readers are installed at various points in the travel pattern, including at CBP primary inspection booths. The system reads tags and posts a time stamp at each read. The time elapse between the two readings of each transponder represents the travel time between the two points. RFID is the technology that was selected to measure border wait time at the U.S./Mexico border, as a large proportion of trucks have an RFID tag in the windshield already installed.
- Bluetooth is a data communications protocol used for wireless mobile communications. Bluetooth technology has been implemented at three border crossings to measure POV wait times. This process is similar to the RFID-based measurement with readers installed at various locations in the roadway leading to the border crossing. Bluetooth-enabled devise in the vehicle are read at each station and travel time is estimated based on time stamps at each location.
- Loop detectors are coils of wire embedded in the roadway to detect the presence of vehicles, measure their speed, and classify each vehicle as a car or a truck.

WAIT TIME DATA DISSEMINATION

Border wait times are currently disseminated through the public CBP Border Wait Time website (https://bwt.cbp.gov/) (CBP, 2016a) and via the CBP Border Wait Time mobile app (CBP, 2016b). Figure A-6 and Figure A-7 present the user interfaces for both.

Results for Selected Border Ports of Entry

0 - 30 minutes | 31 - 60 minutes | over 60 minutes

Canadian Border Ports of Entry

Port Name *Crossing Name*		Commercial Vehicles			Passenger Vehicles			
	HOURS	Max Lns	STANDARD	FAST	Max Lns	STANDARD	READYLANE	NEXUS
Sweetgrass	24 hrs/day 2/9/2016	2	At 10:00 am MST **20 min delay** 1 lanes open	N/A	4	At 10:00 am MST **10 min delay** 1 lanes open	N/A	N/A

Mexican Border Ports of Entry

Port Name *Crossing Name*		Commercial Vehicles			Passenger Vehicles			
	HOURS	Max Lns	STANDARD	FAST	Max Lns	STANDARD	READYLANE	SENTRI
San Luis *San Luis I*	24 hrs/day 2/9/2016	N/A	N/A	N/A	9	At 10:00 am MST **15 min delay** 3 lanes open	At 10:00 am MST **no delay** 3 lanes open	At 10:00 am MST **no delay** 1 lanes open
BORDER NOTICE - A Ready Lane is now open at the San Luis Port of Entry from 6:00 until midnight. Go to www.getyouhome.gov for more information on Ready Lanes. Tune in to AM 530 for border crossing information.								
San Luis *San Luis II*	9 am-8 pm 2/9/2016	3	Update Pending	Update Pending	N/A	Update Pending	Update Pending	Update Pending
San Ysidro	24 hrs/day 2/9/2016	N/A	N/A	N/A	25	At 9:00 am PST **75 min delay** 8 lanes open	At 9:00 am PST **45 min delay** 11 lanes open	At 9:00 am PST **no delay** 6 lanes open

Figure A-6. CBP Border Wait Time Website.

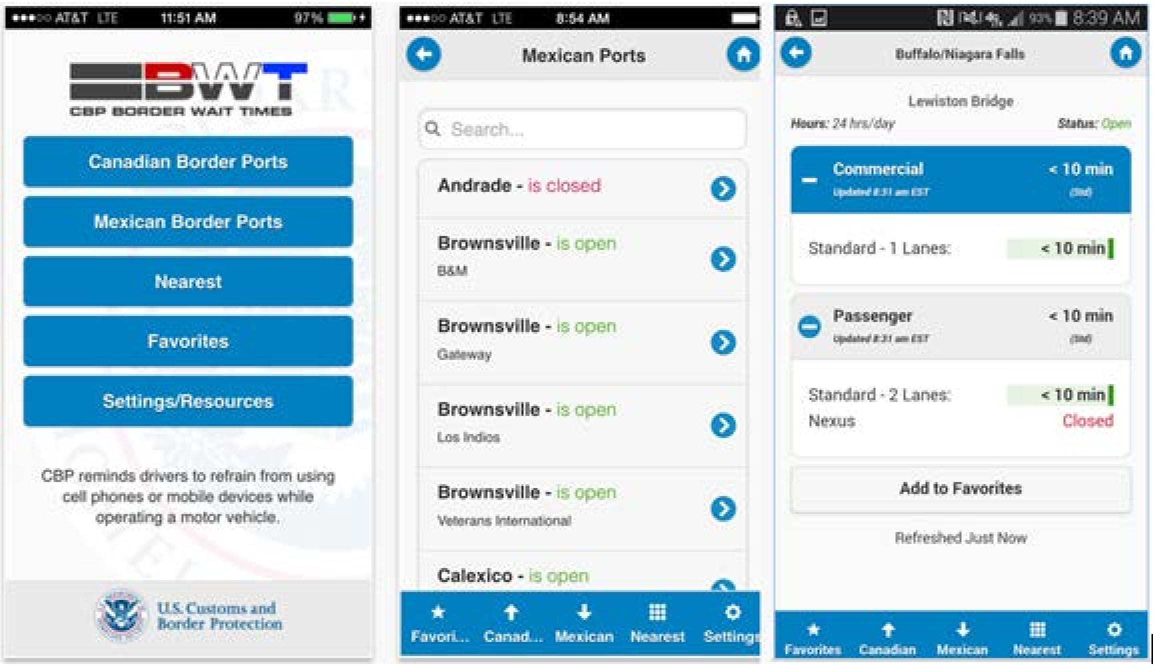

Figure A-7. CBP Border Wait Times Mobile App.

5. CBP WAIT TIME MEASUREMENT NEEDS

Enhancing the existing system and adding new capabilities require an understanding of the Department of Homeland Security and CBP's current and future needs regarding port operation and planning. The comprehension of these needs is crucial to the success of this research project. The research team contacted project champion to gather information on CBP's border wait time data needs. The information that was collected is summarized below:

- Wait time indicators are used to initiate CBP's Active Lane Management procedures.
- CBP measures both wait times and processing times as a separate metric. Processing times (i.e., the time measurement from when the license plate is read to when the vehicle is admitted) are used to measure CBP's improvement and optimization efforts.
- With an automated system, CBP expects to discover more enforcement violations with the resources currently dedicated to wait time measurement activities.
- CBP is striving for a wait time update at 5-minute intervals.
- CBP needs wait time data to perform trend analysis and forecasting.
- CBP currently accepts an accuracy measurement of ±10 minutes from an automated Bluetooth® solution in use in the Buffalo/Niagara Region. This is due to limited capability of the system to provide more accurate wait times.
- CBP needs to measure FAST and non-FAST COV wait times, and wait times for Dedicated Commuter Lanes (DCL) (i.e., NEXUS, SENTRI), Ready Lanes, and non-DCL lanes.
- CBP needs to store historical wait time data indefinitely.
- CBP currently disseminates border wait time data via the public CBP Border Wait Time website and via the CBP Border Wait Time mobile app. CBP's key stakeholders for providing accurate wait time measures is the traveling public.

6. IMPLICATIONS OF BORDER WAIT DATA NEEDS TO BORDER WAIT TIMES CONCEPT OF OPERATIONS

The system that will be defined as part of this research project shall have the following elements:

1. **Data Collection**
   - Wait time information would need to be collected for all traffic types:
     - FAST and non-FAST.
     - NEXUS, SENTRI.
     - Ready Lanes.
     - Non-DCL lanes.
   - The accuracy of the measurement should be within a range of ±10 minutes for all lane types.
   - Wait time information collected in the field shall be integrated with a system CBP is developing internally. This system is designed to gather wait time data from POEs and update the CBP's website. It recognizes the fact that not all POEs are alike and different technologies and systems can be deployed based on local preferences and environment.

2. **Storage**
   - Historical wait time information needs to be stored indefinitely.
   - Historical information should be made available for trend analysis and forecasting.

3. **Dissemination**
   - Information should be refreshed at 5-minute intervals.
   - The traveling public should be able to receive information via a web-based system or a mobile app.

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BORDER CROSSINGS AT THE U.S./CANADA AND U.S./MEXICO BORDERS

	Port Name	U.S. City	Canadian City	Traffic Type
1	Point Roberts/Boundary Bay	Point Roberts (WA)	Boundary Bay (BC)	POV, CV
2	Peace Arch	Blaine (WA)	Surrey (BC)	POV
3	Blaine- Pacific Highway	Blaine (WA)	Surrey (BC)	POV,CV
4	Lynden	Lynden (WA)	Aldergrove (BC)	POV,CV
5	Sumas	Sumas (WA)	Huntingdon (BC)	POV, CV
6	Nighthawk/Chopaka	Nighthawk (WA)	Chopaka West (BC)	POV
7	Oroville/Osoyoos	Oroville (WA)	Osoyoos (BC)	POV, CV
8	Ferry/Midway	Ferry (WA)	Midway (BC)	POV, CV
9	Danville/Carson	Danville (WA)	Grand Forks (BC)	POV, CV
10	Laurier/Christina Lake	Laurier (WA)	Billings (BC)	POV, CV
11	Frontier/Paterson	Frontier (WA)	Paterson (BC)	POV, CV
12	Boundary/Waneta	Boundary (WA)	Waneta (BC)	POV, CV
13	Metaline Falls/Nelway	Metaline Falls (WA)	Nelway (BC)	POV, CV
14	Eastport/Kingsgate	Eastport (ID)	Kingsgate (BC)	POV, CV
15	Porthill/Rykerts	Porthill (ID)	Rykerts (BC)	POV, CV
16	Piegan/Carway	Piegan (MT)	Carway (AB)	POV, CV
17	Del Bonita	Del Bonita (MT)	Del Bonita (AB)	POV, CV
18	Sweetgrass	Sweet Grass (MT)	Coutts (AB)	POV, CV
19	Whitlash/Aden	Whitlash (MT)	Aden (AB)	POV, CV
20	Wildhorse	Wildhorse (MT)	Wildhorse (AB)	POV, CV
21	Willow Creek	Willow Creek (MT)	Willow Creek (SK)	POV, CV
22	Turner/Climax	Turner (MT)	Climax (SK)	POV, CV

	Port Name	U.S. City	Canadian City	Traffic Type
23	Morgan/Monchy	Morgan (MT)	Monchy (SK)	POV, CV
24	Opheim/West Poplar River	Opheim (MT)	West Poplar River (SK)	POV, CV
25	Scobey/Coronach	Scobey (MT)	Coronach (SK)	POV, CV
26	Raymond/Regway	Raymond (MT)	Regway (SK)	POV, CV
27	Fortuna/Oungre	Fortuna (ND)	Oungre (SK)	POV, CV
28	Ambrose/Torquay	Ambrose (ND)	Torquay (SK)	POV, CV
29	Noonan/Estevan	Noonan (ND)	Estevan Highway (SK)	POV, CV
30	Portal/North Portal	Portal (ND)	North Portal (SK)	POV, CV
31	Northgate	Northgate (ND)	Northgate (SK)	POV, CV
32	Sherwood/Carievale	Sherwood (ND)	Carievale (SK)	POV, CV
33	Antler/Lyleton	Antler (ND)	Lyleton (MB)	POV, CV
34	Westhope/Coutler	Westhope (ND)	Coutler (MB)	POV, CV
35	Carbury/Goodlands	Carbury (ND)	Goodlands (MB)	POV, CV
36	International Peace Garden	Dunseith (ND)	Boissevain (MB)	POV, CV
37	St. John/Lena	St. John (ND)	Lena (MB)	POV, CV
38	Hansboro/Cartwright	Hansboro (ND)	Cartwright (MB)	POV, CV
39	Sarles/Crystal City	Sarles (ND)	Crystal City (MB)	POV, CV
40	Hannah/Snowflake	Hannah (ND)	Snowflake (MB)	POV, CV
41	Maida/Windygates	Maida (ND)	Windygates (MB)	POV, CV
42	Walhalla/Winkler	Walhalla (ND)	Winkler (MB)	POV, CV
43	Neche/Gretna	Neche (ND)	Gretna (MB)	POV, CV
44	Pembina/Emerson	Pembina (ND)	Emerson (MB)	POV, CV

	Port Name	U.S. City	Canadian City	Traffic Type
45	Lancaster/Tolstoi	Lancaster (MN)	Tolstoi (MB)	POV, CV
46	Pinecreek/Piney	Pinecreek (MN)	Piney (MB)	POV, CV
47	Roseau/South Junction	Roseau (MN)	South Junction (MB)	POV, CV
48	Warroad/Sprague	Warroad (MN)	Sprague (MB)	POV, CV
49	Baudette/Rainy River	Baudette (MN)	Rainy River (ON)	POV, CV
50	International Falls	International Falls (MN)	Fort Frances Bridge (ON)	POV, CV
51	Grand Portage/Pigeon River	Grand Portage (MN)	Pigeon River (ON)	POV, CV
52	Sault Ste. Marie-International Bridge SSM	Sault Ste. Marie (MI)	Sault Ste. Marie (ON)	POV, CV
53	Port Huron- Bluewater Bridge	Port Huron (MI)	Sarnia (ON)	POV, CV
54	Detroit- Windsor Tunnel	Detroit (MI)	Windsor (ON)	POV, CV
55	Detroit- Ambassador Bridge	Detroit (MI)	Windsor (ON)	POV, CV
56	Buffalo/Niagara Falls-Piece Bridge	Buffalo (NY)	Fort Erie (ON)	POV, CV
57	Buffalo/Niagara Falls-Rainbow Bridge	Niagara Falls (NY)	Niagara Falls (ON)	POV
58	Buffalo/Niagara Falls-Whirpool Bridge	Buffalo/Niagara Falls (NY)	Niagara Falls (ON)	POV
59	Buffalo/Niagara Falls-Lewiston Bridge	Lewiston (NY)	Queenstone (ON)	POV, CV
60	Alexandria Bay-Thousand Islands Bridge	Alexandria Bay (NY)	Prescott (ON)	POV, CV
61	Ogdensburg	Ogdensburg Bridge (NY)	Prescott (ON)	POV, CV
62	Massena- Seaway Bridge	Massena (NY)	Cornwall (ON)	POV, CV
63	Fort Covington/Dundee	Fort Covington (NY)	Dundee (QC)	POV, CV
64	Trout River	Trout River (NY)	Trout River (QC)	POV, CV
65	Chateauguay / Herdman	Chateauguay (NY)	Hinchinbrooke (QC)	POV, CV
66	Churubusco / Franklin	Churubusco (NY)	Franklin Centre (QC)	POV, CV

	Port Name	U.S. City	Canadian City	Traffic Type
67	Cannon Corners / Covey Hill	Mooers Forks (NY)	Havelock (QC)	POV, CV
68	Mooers / Hemmingford	Mooers (NY)	Hemmingford (QC)	POV, CV
69	Champlain / Lacolle	Champlain (NY)	St. Bernard-de-Lacolle (QC)	POV
70	Rouses Point / Lacolle	Rouses Point (NY)	Lacolle (QC)	POV, CV
71	Alburg / Noyan	Alburg (VT)	Noyan (QC)	POV, CV
72	Alburg Springs / Clarenceville	Alburg Springs (VT)	Clarenceville (QC)	POV, CV
73	Highgate Springs / St Armand	Highgate Springs (VT)	St Armand-Phillipsburg (QC)	POV, CV
74	Morses Line	Morses Line (VT)	Morses Line (QC)	POV, CV
75	West Berkshire / Frelighsbrug	West Berkshire (VT)	Frelighsbrug (QC)	POV, CV
76	Richford / East Pinnacle	Richford (VT)	East Pinnacle (QC)	POV, CV
77	Richford / Abercorn	Richford (VT)	Abertcorn (QC)	POV, CV
78	East Richford / Glen Sutton	East Richford (VT)	Glen Sutton (QC)	POV, CV
79	North Troy / Highwater	North Troy (VT)	Highwater (QC)	POV
80	Beebe Plain / Stanstead	Beebe Plain (VT)	Stanstead (QC)	POV
81	Derby Line / Stanstead – Surface Streets	Derby Line (VT)	Stanstead (QC)	POV
82	Derby Line – Interstate 91	Derby Line (VT)	Stanstead (QC)	POV, CV
83	Norton / Stanhope	Norton (VT)	Stanhope (QC)	POV, CV
84	Canaan / Hereford	Canaan (VT)	Hereford (QC)	POV, CV
85	Beecher Falls / East Hereford	Beecher Falls (VT)	East Hereford (QC)	POV, CV
86	New Hampshire – Pittsburg / Chartierville	Pittsburg (NH)	Chartierville (QC)	POV, CV
87	Coburn Gore / Woburn	Coburn Gore (ME)	Woburn (QC)	POV, CV
88	Jackman / Armstrong	Jackman (ME)	Armstrong (QC)	POV, CV

	Port Name	U.S. City	Canadian City	Traffic Type
89	Sainte Aurelie	Sainte Aurelie (ME)	Sainte Aurelie (QC)	POV, CV
90	Sainte Zacharie	Sainte Zacharie (ME)	Sainte Zacharie (QC)	POV, CV
91	St Juste	St Juste (ME)	St-Just-de-Breteineres (QC)	POV, CV
92	Saint Pamphile	Saint Pamphile (ME)	Saint Pamphile (QC)	POV, CV
93	Estcourt Station / Pohenegamook	Estcourt Station (ME)	Pohenegamook (QC)	POV, CV
94	Fort Kent/Clair	Fort Kent (ME)	Clair (NB)	POV, CV
95	Edmundston-Madawaska Bridge	Madawaska (ME)	Edmundston (NB)	POV, CV
96	St Leonard-Van Buren Bridge	Van Buren (ME)	St. Leonard (NB)	POV, CV
97	Hamlin / Grand Falls	Hamlin (ME)	Grand Falls (NB)	POV, CV
98	Limestone / Gillespie Portage	Limestone (ME)	Gillespie Portage (NB)	POV, CV
99	Fort Fairfield / Perth-Andover	Fort Fairfield (ME)	Andover (NB)	POV, CV
100	Easton / River de Chute	Easton (ME)	River de Chute (NB)	POV, CV
101	Bridgewater / Centreville	Bridgewater (ME)	Centreville (NB)	POV, CV
102	Monticello / Bloomfield	Monticello (ME)	Bloomfield (QC)	POV, CV
103	Houlton / Richmond Corner	Houlton (ME)	Woodstock (NB)	POV, CV
104	Orient /Fosterville	Orient (ME)	Fosterville (NB)	POV, CV
105	Forest City	Forest City (ME)	Forest City (NB)	POV, CV
106	Vanceboro / St. Croix	Vanceboro (ME)	St. Croix (NB)	POV, CV
107	Calais / International Avenue	Calais (ME)	Saint Stephen (NB)	POV
108	Milltown / Saint Stephen	Calais (ME)	Milltown (NB)	POV, CV
109	Ferry Point Crossing / Calais	Calais (ME)	Saint Stephen (NB)	POV
110	FDR Bridge	Lubec (ME)	Campobello Island (NB)	POV, CV

	Port Name	U.S. City	Mexican City	Traffic Type
1	Andrade	Andrade (CA)	Los Algodones (BC)	POV
2	Antelope Wells	Antelope Wells (NM)	El Berrendo (CH)	POV
3	Brownsville B&M	Brownsville (TX)	Matamoros (TM)	POV
4	Brownsville Getaway	Brownsville (TX)	Matamoros (TM)	POV
5	Brownsville Los Indios-Free Trade International	Los Indios (TX)	Matamoros (TM)	POV, CV
6	Brownsville Veterans International	Brownsville (TX)	Matamoros (TM)	POV, CV
7	Calexico East	Calexico (CA)	Mexicali (BC)	POV, CV
8	Calexico West	Calexico (CA)	Mexicali (BC)	POV
9	Columbus	Columbus (NM)	Puerto Palomas (CH)	POV, CV
10	Del Rio	Del Rio (TX)	Ciudad Acuna (CA)	POV, CV
11	Douglas	Douglas (AZ)	Agua Prieta (SO)	POV, CV
12	Eagle Pass Bridge I	Eagle Pass (TX)	Piedras Negras (CA)	POV
13	Eagle Pass Bridge I	Eagle Pass (TX)	Piedras Negras (CA)	POV, CV
14	El Paso- Bridge of the Americas	El Paso (TX)	Ciudad Juarez (CH)	POV, CV
15	El Paso-Paso del Norte	El Paso (TX)	Ciudad Juarez (CH)	POV
16	El Paso-Stanton	El Paso (TX)	Ciudad Juarez (CH)	POV
17	El Paso- Ysleta	El Paso (TX)	Ciudad Juarez (CH)	POV, CV
18	Fabens- Tornillo-Guadalupe Bridge	Tornillo (TX)	Guadalupe (CH)	POV
19	Fort Hancock	Fort Hancock (TX)	El Porvenir (CH)	POV
20	Hidalgo/Pharr Anzalduas International Bridge	Hidalgo (TX)	Reynosa (TM)	POV
21	Hidalgo- Reynosa Bridge	Mission (TX)	Reynosa (TM)	POV
22	Hidalgo/Pharr Pharr	Pharr (TX)	Reynosa (TM)	POV, CV

	Port Name	U.S. City	Mexican City	Traffic Type
23	Laredo Bridge I	Laredo (TX)	Nuevo Laredo (TM)	POV
24	Laredo Bridge II	Laredo (TX)	Nuevo Laredo (TM)	POV
25	Laredo Bridge Colombia Solidarity	Laredo (TX)	Colombia (NL)	CV
26	Laredo World Trade Bridge	Laredo (TX)	Nuevo Laredo (TM)	CV
27	Lukeville	Lukeville (AZ)	Sonoyta (SO)	POV, CV
28	Naco	Naco (AR)	Naco (SO)	POV, CV
29	Nogales-Deconcini	Nogales (AR)	Nogales (SO)	POV
30	Nogales-Mariposa	Nogales (AR)	Nogales (SO)	POV, CV
31	Otay Mesa Commercial	Otay Mesa (CA)	Tijuana (BC)	CV
32	Otay Mesa Passenger	Otay Mesa (CA)	Tijuana (BC)	POV
33	Presidio	Presidio (TX)	Ojinaga (CH)	POV, CV
34	Progreso- Donna International Bridge	Donna (TX)	Nuevo Progreso (TM)	POV
35	Progreso- Progreso International Bridge	Progreso (TX)	Nuevo Progreso (TM)	POV, CV
36	Rio Grande City- Camargo Bridge	Rio Grande City (TX)	Ciudad Camargo (TM)	POV, CV
37	Rio Grande City- Los Ebanos	Los Ebanos (TX) (TX)	Gustavo Diaz Ordaz (TM)	POV
38	Roma	Roma (TX)	Ciudad Miguel Aleman (TM)	POV, CV
39	San Luis I	San Luis (AZ)	San Luis Rio Colorado (SO)	POV
40	San Luis II	San Luis (AZ)	San Luis Rio Colorado (SO)	POV, CV
41	San Ysidro	San Ysidro (CA)	Tijuana (BC)	POV
42	Santa Teresa	Santa Teresa (NM)	San Jeronimo (CH)	POV, CV
43	Sasabe	Sasabe (AR)	El Sasabe (SO)	POV, CV
44	Tecate	Tecate (CA)	Tecate (BC)	POV, CV

APPENDIX B – TASK 2: ANALYSIS OF RELATIONSHIPS BETWEEN VARIOUS PARAMETERS INFLUENCING WAIT TIMES

T.3.1 Developing a Concept of Operations for an Innovative System for Measuring Wait Times at Land Ports of Entry

Task 2: Analysis of Relationships between Various Parameters Influencing Wait Times

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1. INTRODUCTION

The objective of this project is to develop a Concept of Operations (ConOps) that lays a foundation necessary to design an enhanced wait time system at the land ports of entry (POEs). The ConOps is a process by which the current and future needs of Customs and Border Protection (CBP) and other stakeholders at the ports are systematically captured in order to develop a high-level design for such a system.

As part of ConOps development, the research team will identify high level functional requirements of a future wait time system. It is important that such a system be able to measure the factors that influence wait time at POEs. The research team intends to determine if there are significant correlations between wait times and external factors such as inbound volume, number of lanes open, time of day, etc.

If there are correlations, the new wait time measurement system should be able to take those parameters into account to more accurately estimate and predict wait times. This correlation should be integrated with a wait time estimation algorithm. This information can be also used to predict (short term) wait times if field devices are not working properly or CBP needs to suddenly shut down a significant number of lanes and warn the public of long wait times right away. Knowing the correlation will allow the system designers to model the sensitivity and impact of these external parameters on wait times.

If there is significant correlation between wait time and the external parameters, the ConOps will include that the new system must have functionalities to measure/capture inbound volume, and number of lanes open. It will also take into account these parameters in the wait time measurement algorithms.

2. BASELINE DATA

CBP provided the research team historical data including hourly aggregates of U.S.-bound volume of vehicles, wait times, cycle time, and number of lanes opened for six POEs:

- Blaine, Washington.
- Champlain, New York.
- Detroit – Ambassador Bridge, Michigan.
- Mariposa, Arizona.
- San Ysidro, California.
- Ysleta, Texas.

The information included cycle times for the period from January 17–March 17, 2016. Wait time information and number of lanes open for each crossing type was provided for the January 23–March 17 period. Table B-1 presents details of the information that was obtained for the six POEs for privately owned vehicles (POVs) and commercially operated vehicles (COVs).

Table B-1. Period of Time that the Data Have Been Collected.

POE	Lane Type	Time Period			
		Volume		Wait Time	
		Weekdays	Weekends	Weekdays	Weekends
Blaine	POV Standard	5 a.m.–10 p.m.	6 a.m.–10 p.m.	5 a.m.–10 p.m.	6 a.m.–10 p.m.
	COV Standard	12 a.m.–7 p.m.	12 a.m.–7 p.m.	12 a.m.–3 p.m.	12 a.m.–3 p.m.
Champlain	POV Standard	6 a.m.–8 p.m.	6 a.m.–8 p.m.	6 a.m.–8 p.m.	6 a.m.–8 p.m.
	COV Standard	2 a.m.–6 p.m.	2 a.m.–6 p.m.	24 h	24 h
Detroit	POV Standard	5 a.m.–9 p.m.	11 a.m.–8 p.m.	5 a.m.–9 p.m.	11 a.m.–8 p.m.
	POV Ready	6 a.m.–4 p.m.	6 a.m.–11 a.m.	6 a.m.–4 p.m.	N/A
	POV NEXUS	24 h	24 h	6 a.m.–8 p.m.	11 a.m.–7 p.m.
	COV Standard	24 h	24 h	24 h	24 h
Mariposa	POV Standard	6 a.m.–11 p.m.	6 a.m.–11 p.m.	6 a.m.–11 p.m.	6 a.m.–11 p.m.
	COV Standard	6 a.m.–8 p.m.	6 a.m.–5 p.m.	6 a.m.–8 p.m.	6 a.m.–5 p.m.
San Ysidro	POV Standard	24 h	24 h	24 h	24 h
	POV Ready	24 h	24 h	24 h	24 h
	POV SENTRI	24 h	24 h	24 h	24 h
Ysleta	POV Standard	24 h	24 h	24 h	24 h
	POV Ready	24 h	24 h	24 h	24 h
	POV SENTRI	24 h	24 h	24 h	24 h
	COV Standard	6 a.m.–12 a.m.	8 a.m.–5 p.m.	6 a.m.–12 a.m.	8 a.m.–5 p.m.

At each POE, volumes and wait times were collected for weekdays and weekends and by lane type. These are further described as follows:

- **Volumes** represent the number of vehicles approaching the particular POE. The unit representing volume is vehicles per hour (veh/h). Provided volumes are aggregated for each hour that the data have been collected.
- **Number of Lanes** is the number of inspection lanes at CBP Primary open at the specific period of time (hour).
- **Wait Times** are the average wait time observed by CBP officers for a particular type of lane at a specific period of time (hour).
- **Cycle Time** consists of two components—processing time and downtime:
  - **Processing Time** is the recorded time that a CBP officer spends processing a vehicle.
  - **Downtime** represents the time required for the vehicle to pull up to the booth, time that CBP is not processing vehicles (e.g., shift change log ins/log outs, closures to escort vehicles, and other temporary lane closures).

3. METHODOLOGY

First, the team analyzed summary statistics of all the data provided (volume, cycle time, number of lanes, and wait time). This included information on minimum and maximum values, mean, standard deviation, mode, etc.

Second, the team analyzed incoming hourly volume. Average volumes for each hour of the day were determined for both weekdays and weekends, to gain an understanding of operational differences.

Third, the team analyzed hourly average wait times for weekdays and weekends to determine how fluctuation of wait time compared with hourly volume.

Finally, the team performed regression and correlation analysis. Correlation and regression analysis are related in that they both deal with relationships among variables. The correlation coefficient is a measure of linear association between variables. Values of the correlation coefficient are always between −1 and +1. A correlation coefficient of +1 indicates that two variables are perfectly related in a positive linear sense, a correlation coefficient of −1 indicates that two variables are perfectly related in a negative linear sense, and a correlation coefficient of 0 indicates that there is no linear relationship between the two variables.

In the regression analysis, wait time was considered as a dependent variable; and the vehicle volume, cycle time, and number of open lanes is marked as independent variables. This was done to understand if independent variables can be used to estimate wait times. In other words, wait time was assumed to depend on volume, cycle time, and number of inspection lanes open. Regression coefficients are calculated along with P-values. If P-value was too large (≥ 0.05), the corresponding independent variable was removed from the regression analysis. Adjusted R Square value was used as an indicator of the model quality (percentage of variation explained by the regression line).

4. SUMMARY OF FINDINGS

POEs analyzed in this study operate independently from each other. Field offices of CBP make many local decisions on day to day operations to manage resources and keep the wait time to a minimum without jeopardizing security. In general, the research team did find strong correlations between wait time and volume, number of lanes open, and cycle time. Out of those three independent variables, number of lanes open appears to have the largest coefficient and possibly most impact on wait times. CBP cannot for most part influence the demand and hence the incoming volume. However, CBP does have a significant role in optimizing its resources in managing the wait time.

In terms of peak days and maximum recorded incoming volume, the number of POVs entering the United States peaked predominantly during weekdays at Detroit (both standard and ready lanes), San Ysidro Standard and Ysleta Standard lanes compared to weekends. On the other hand, Blaine Standard, Detroit NEXUS, Ysleta (Ready and SENTRI) were busier during weekends. Table B-2 presents maximum POV volumes recorded and identified peak days for each POE.

Table B-2. Maximum Volume and Peak Days at Individual POEs.

POE	Lane Type	Volume	
		Maximum Value (veh/h)	**Peak Days**
Blaine	POV Standard	250	Friday, Saturday
	COV Standard	149	Weekdays
Champlain	POV Standard	43	N/A
	COV Standard	163	Weekdays
Detroit	POV Standard	587	Weekdays
	POV Ready	97	Weekdays
	POV NEXUS	670	Weekend
	COV Standard	368	Weekdays
Mariposa	POV Standard	442	N/A
	COV Standard	260	Monday–Saturday
San Ysidro	POV Standard	1373	Monday–Saturday
	POV Ready	1156	N/A
	POV SENTRI	1052	N/A
Ysleta	POV Standard	383	Weekdays
	POV Ready	340	Weekend
	POV SENTRI	396	Saturday
	COV Standard	185	Sunday–Friday

Note: N/A- There was no significant difference between volumes for different days of the week, so the peak days could be determined.

Table B-3 presents the number of lanes mostly frequently opened along with the available number of lanes at a particular POE. Certain lanes are used to process multiple types of travelers at the same time. For example, if the queue for standard POV is very long, CBP officers may direct those vehicles to lanes designated as ready lanes. When maximum available lanes that are intended to be used for certain type of travelers is lower than the number of lanes that are used, CBP officer may open additional lanes as soon as he/she estimates that the queue is long and if resources are available to do so.

Table B-3. Most Frequently Used and Maximum Number of Lanes at POEs.

POE	Lane Type	Number of Lanes	
		Most Frequently Used	Maximum Used
Blaine	POV Standard	2	5
	COV Standard	1	3
Champlain	POV Standard	2	7
	COV Standard	1	5
Detroit	POV Standard	5	15
	POV Ready	1	1
	POV NEXUS	1	6
	COV Standard	8	12
Mariposa	POV Standard	5	10
	COV Standard	4	7
San Ysidro	POV Standard	9	18
	POV Ready	9	12
	POV SENTRI	2	10
Ysleta	POV Standard	6	6
	POV Ready	4	5
	POV SENTRI	1	2
	COV Standard	3	5

Table B-4 summarizes cycle times (in seconds) and throughput for each POE in terms of minimum, average, and maximum values. Unlike the volume that shows the number of vehicles that are approaching the POE, throughput represents number of vehicles that can be actually be served in one hour. From the data, it appears POVs are processed most efficiently at San Ysidro POE (94 veh/h on an average), and POVs crossing the Champlain are processed the slowest (24 veh/h are being processed on an average). COV throughput is relatively consistent for all of these POEs, being between 40 and 50 veh/h on average.

Table B-4. Cycle Time and Vehicle Throughput for Each POE.

POE	Lane Type	Cycle Time (seconds)			Throughput* (veh/h)		
		Minimum	Average	Maximum	Minimum	Average	Maximum
Blaine	POV Standard	17	51	224	16	71	208
	COV Standard	42	85	198	18	42	85
Champlain	POV Standard	30	148	300	12	24	120
	COV Standard	25	77	367	10	47	144
Detroit	POV Standard	27	73	185	20	49	133
	POV Ready	30	78	156	23	46	120
	POV NEXUS	48	106	197	18	34	74
	COV Standard	32	77	152	24	47	113
Mariposa	POV Standard	44	88	144	25	41	81
	COV Standard	22	90	524	7	40	164
San Ysidro	POV Standard	18	38	132	27	94	201
	POV Ready	30	57	96	38	63	120
	POV SENTRI	46	77	114	31	47	79
Ysleta	POV Standard	16	59	300	12	61	223
	POV Ready	42	73	172	21	49	85
	POV SENTRI	26	82	300	12	44	138
	COV Standard	46	91	256	14	40	79

* Throughput is not the same as volume.

Table B-5 shows maximum recorded wait times and peak days at each of the POEs. POVs waited between 30 minutes (Champlain Standard) and 150 minutes (San Ysidro Standard). Both standard and NEXUS lanes at Detroit experienced 30 minutes of wait time on average. COVs waited to enter United States between 55 minutes (at Champlain and Ysleta) and 120 minutes (at Mariposa) on average. Also, wait times peaked during weekends for: POV standard at all POEs except Champlain, POV NEXUS at Detroit, and POV ready at Ysleta POE.

COVs typically have peak wait times during weekdays, especially Tuesdays and Wednesdays. Wait times at southern POEs were significantly higher in comparison to northern POEs.

In most POEs, volumes and wait times were directly related based on visual interpretation of hourly charts. However, certain POEs had longer wait times despite lower volumes on weekends compared to weekdays. The reason for this could be the lower number of CBP officers on duty during weekends (Table B-5).

Table B-5. Maximum Wait Times and Peak Days at Individual POEs.

POE	Lane Type	Wait Time	
		Maximum Value (minutes)	Peak Days
Blaine	POV Standard	60	Saturday–Monday
	COV Standard	85	Tuesday, Wednesday
Champlain	POV Standard	30	N/A
	COV Standard	55	Tuesday, Wednesday
Detroit	POV Standard	30	Weekend
	POV Ready	15	N/A
	POV NEXUS	30	Saturday–Monday
	COV Standard	85	Tuesday, Wednesday
Mariposa	POV Standard	75	Friday–Monday
	COV Standard	120	Monday–Saturday
San Ysidro	POV Standard	150	Saturday
	POV Ready	120	N/A
	POV SENTRI	60	Saturday
Ysleta	POV Standard	99	Weekend
	POV Ready	89	Sunday
	POV SENTRI	15	N/A
	COV Standard	55	Tuesday

Note: N/A- There was no significant difference between wait times for different days of the week, so peak days cannot be determined.

Table B-6 represents regression coefficients for different ports. Regression coefficients indicate marginal increase or decrease in wait times when volume or cycle time or number of lanes open change. Intuitively, as number of vehicles increases wait time should increase with it and that is what is observed in most instances. However, the POV ready lane at San Ysidro has a negative coefficient of −0.02. This means that as additional vehicles arrive at the border, wait time decreases by 0.02 minutes. The reason for this exception may be because CBP officers are opening additional lanes at a higher rate than needed. It may also indicate that CBP officers are opening lanes faster in anticipation of higher incoming volume.

Also, it seems reasonable to assume that as cycle time increases, wait time rise as well. But, at four ports (with the exception of Mariposa and Ysleta), it is the contrary. It is possible that by the time CBP officers make the inspection process faster (lower cycle time) in response to a longer queue, the wait time as already increased.

Finally, CBP officers are observing the queue length and opening additional lanes if needed. Therefore, it is expected that as an additional lane is being opened, wait time reduces. It is only after the queue and wait times are already long that additional lanes are opened. This is why wait times are lengthy despite the increased number of open lanes. When congestion already exists, it takes time to clear up the queue, since the number of lanes can still be insufficient.

In order to analyze this in more detail, more granular data should be obtained. The level of disaggregation that is available was on an hourly basis, and wait times and lanes open can change drastically within 1 hour.

Table B-6. Regression Coefficients for Each POE.

POE	Lane Type	Regression Coefficients			R Squared (%)
		Volume	Cycle Time	Number of Lanes Open	
Blaine	POV Standard	0.02	-0.04	3.82	68
	COV Standard	0.02	-0.04	-	64
Champlain	POV Standard	-	0.02	1.98	77
	COV Standard	0.07	-0.01	2.85	55
Detroit	POV Standard	0.00	-0.02	1.16	53
	POV NEXUS	0.02	0.03	-	78
	COV Standard	0.02	0.13	-	45
Mariposa	POV Standard	0.10	0.23	-3.51	64
	COV Standard	0.12	-	1.26	55
San Ysidro	POV Standard	0.03	-0.11	3.72	80
	POV Ready	-0.02	0.34	2.99	77
	POV SENTRI	0.00	-0.01	1.84	76
Ysleta	POV Standard	0.08	0.05	2.51	71
	POV Ready	0.06	0.04	2.20	65
	POV SENTRI	-	0.01	0.59	60
	COV Standard	0.10	0.10	-	70

5. KEY FINDINGS AT INDIVIDUAL POES

Table B-7 summarizes maximum values for variables used in the analysis for all POEs.

Table B-7. Maximum Values of Recorded Variables: Volume, Throughput, Number of Lanes, and Wait Times for All POEs.

POE	Lane Type	Maximum Values			
		Volume (veh/h)	Throughput (veh/h)	Number of Lanes	Wait Time (min)
Blaine	POV Standard	250	208	5	60
	COV Standard	149	85	3	85
Champlain	POV Standard	43	120	7	30
	COV Standard	163	144	5	55
Detroit	POV Standard	587	133	15	30
	POV Ready	97	120	1	15
	POV NEXUS	670	74	6	30
	COV Standard	368	113	12	85
Mariposa	POV Standard	442	81	10	75
	COV Standard	260	164	7	120
San Ysidro	POV Standard	1373	201	18	150
	POV Ready	1156	120	12	120
	POV SENTRI	1052	79	10	60
Ysleta	POV Standard	383	223	6	99
	POV Ready	340	85	5	89
	POV SENTRI	396	138	2	15
	COV Standard	185	79	5	55

5.1 BLAINE PORT OF ENTRY

5.1.1 POV Standard

For POVs at the Blaine POE, the following was noted:

- Average volume is highest on Fridays and Saturdays, while being consistent on other days.
- Average wait time is longest on Saturdays, Sundays, and Mondays.
- Table B-8 presents distribution of peak and off-peak hours and average wait times.
- Maximum recorded volume is 250 veh/h.
- As volume and number of open lanes increase, wait time increases. As cycle time increases, wait time reduces.
- Each additional vehicle increases wait time by 0.015 min, additional second of cycle time decreases wait time by 0.04 min and additional lane opened increases wait time by 3.8 min. This is probably due to the fact that the lane opening is a consequence of increased wait times.

Table B-8. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Blaine.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time
Weekdays	6.20	11:00–13:00	11.36	5.10
Weekend	10.75	10:00–17:00	15.63	5.87

5.1.2 COV Standard

For COVs at the Blaine POE, the following was noted:

- Average volume is higher on weekdays, while dropping significantly during weekend.
- Average wait time is longest on Tuesdays and Wednesdays.
- Table B-9 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 5 and 85 minutes, while number of open lanes is between 1 and 3.
- Maximum recorded volume is 149 veh/h.
- Volume, number of open lanes, cycle time, and wait time all increase at the same time.
- Each additional vehicle increases wait time by 0.017 min, additional second of cycle time decreases wait time by 0.04 min.

Table B-9. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Blaine.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	12.59	07:00–14:00	21.09	4.10
Weekend	6.48	08:00–12:00	9.64	4.88

5.2 CHAMPLAIN PORT OF ENTRY

5.2.1 POV Standard

At the Champlain POE, the following was noted:

- Average volume is very low on all days of the week, and there is no significant difference in wait times on weekdays and weekends.
- Wait time is between 5 and 30 minutes, while number of open lanes is between 1 and 7.
- Maximum recorded volume is 43 veh/h.
- Volume, number of open lanes, and wait time increase at the same time. As cycle time increases, wait time decreases.
- Additional second of cycle time increases wait time by 0.016 min, and additional lane opened increases wait time by 1.98 min. This is probably due to the fact that additional lane openings are a consequence of increased wait times.

5.2.2 COV Standard

For COVs at the Champlain POE, the following was noted:

- Average volume is higher on weekdays, while dropping significantly during the weekend.
- Average wait time is longest on Tuesdays and Wednesdays.
- Table B-10 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 5 and 55 minutes, while number of open lanes is between 1 and 5.
- Maximum recorded volume is 163 veh/h.
- Volume, number of open lanes, cycle time, and wait time increase at the same time.
- Each additional vehicle increases wait time by 0.007 min, additional second of cycle time decreases wait time by 0.009 min, and each additional lane opened increases wait time by 2.9 min. This is probably due to the fact that the lane opening is a consequence of increased wait times.

Table B-10. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Champlain.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	4.92	09:00–12:00	10.77	3.68
Weekend	2.60	08:00–14:00	4.61	1.72

5.3 DETROIT PORT OF ENTRY

5.3.1 POV Standard

For POVs at the Detroit POE, the following was noted:

- Average volume is higher on weekdays, while dropping significantly during the weekend.
- Average wait time is significantly higher on weekends in comparison to weekdays wait times. The reason might be fewer officers on duty during the weekend.
- Table B-11 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 2 and 30 minutes, while number of open lanes is between 1 and 15.
- Maximum recorded volume is 587 veh/h.
- Volume, number of open lanes, and wait time increase at the same time. As cycle time increases, wait time decreases.
- Each additional vehicle increases wait time by 0.004 min, additional second of cycle time decreases wait time by 0.016 min, and each additional lane opened increases wait time by 1.2 min. This is probably due to the fact that the lane opening is a consequence of increased wait times.

Table B-11. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	4.20	07:00–14:00	3.84	4.51
Weekend	7.54	08:00–12:00	6.46	8.90

5.3.2 POV Ready

For the POV Ready lanes at the Detroit POE, the following was noted:

- Average volume is higher on weekdays, while dropping significantly during Saturday (data for Sunday are not available).
- Table B-12 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 5 and 15 minutes, while one lane is always open.
- Maximum recorded volume is 97 veh/h.
- As volume increases, wait time decreases. Cycle time and wait time increase at the same time.
- Regression could not give meaningful results due to lack of data.

Table B-12. POV Ready Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	3.60	13:00–15:00	15.00	1.07
Weekends	N/A	N/A	N/A	N/A

5.3.3 POV NEXUS

For the POV NEXUS lanes at the Detroit POE, the following was noted:

- Average volume is lower on weekdays, while increasing significantly during the weekend.
- Average wait time is significantly higher on Saturdays, Sundays, and Mondays in comparison other days.
- Table B-13 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 2 and 30 minutes, while number of open lanes is between 1 and 6.
- Maximum recorded volume is 670 veh/h.
- Volume, number of open lanes and wait time increase at the same time. As cycle time increases, wait time decreases.

- Each additional vehicle increases wait time by 0.002 min, additional second of cycle time increases wait time by 0.003 min. This equation explains border process in 78 percent of cases.

Table B-13. POV NEXUS Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	2.59	07:00–09:00	5.96	2.03
Weekend	4.99	11:00–17:00	5.79	2.59

5.3.4 COV Standard

For the COV Standard lanes at the Detroit POE, the following was noted:

- Average volume is higher on weekdays, while decreasing significantly during the weekends.
- Average wait time is significantly higher on Tuesdays and Wednesdays in comparison other days.
- Table B-14 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 2 and 85 minutes, while number of open lanes is between 2 and 12.
- Maximum recorded volume is 368 veh/h.
- Volume, number of open lanes, cycle time, and wait time increase at the same time.
- Each additional vehicle increases wait time by 0.017 min, additional second of cycle time increases wait time by 0.13 min.

Table B-14. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	11.20	14:00–20:00	14.48	7.00
Weekend	6.80	15:00–20:00	8.76	2.25

5.4 MARIPOSA PORT OF ENTRY

5.4.1 POV Standard

For the Standard POV lands at the Mariposa POE, the following was noted:

- Average volume is similar during all days of the week.

- Average wait time is significantly higher on Friday, Saturday, Sunday, and Monday in comparison to the other days. The reason might be fewer officers on duty during weekend.
- Table B-15 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 2 and 75 minutes, while number of open lanes is between 2 and 10.
- Maximum recorded volume is 442 veh/h.
- Volume, number of open lanes, cycle time, and wait time increase at the same time.
- Each additional vehicle increases wait time by 0.1 min, additional second of cycle time increases wait time by 0.26 min, and each additional lane opened decreases wait time by 3.5 min.

Table B-15. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Mariposa.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	18.18	N/A	N/A	N/A
Weekend	21.37	14:00–20:00	34.39	14.26

5.4.2 COV Standard

At the COV Standard lanes at the Mariposa POE, the following was noted:

- Average volume is significantly lower on Sundays in comparison to other days of the week.
- Average wait time is significantly lower on Sundays.
- Table B-16 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 5 and 120 minutes, while number of open lanes is between 1 and 7.
- Maximum recorded volume is 260 veh/h.
- Wait time increases if volume and number of open lanes increase.
- Each additional vehicle increases wait time by 0.12 min, and each additional lane opened increases wait time by 1.3 min.

Table B-16. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Mariposa.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	11.41	10:00–14:00	23.87	6.42
Weekend	7.27	10:00–13:00	15.24	4.28

5.5 SAN YSIDRO PORT OF ENTRY

5.5.1 POV Standard

For the POV standard lanes at the San Ysidro POE, the following was noted:

- Average volume is significantly lower on Sundays in comparison to other days of the week.
- Average wait time is significantly higher on Saturdays.
- Table B-17 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 3 and 150 minutes, while number of open lanes is between 2 and 18.
- Maximum recorded volume is 1373 veh/h.
- Volume, number of open lanes, and wait time increase at the same time. As cycle time increases, wait time decreases.
- Each additional vehicle increases wait time by 0.03 min, and each additional lane opened increases wait time by 3.7 min. Additional second of cycle time decreases wait time by 0.11 min.

Table B-17. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at San Ysidro.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	35.22	05:00–14:00	49.05	25.34
Weekend	54.18	15:00–23:00	93.15	30.80

5.5.2 POV Ready

For the POV Ready lanes at the San Ysidro POE, the following was noted:

- Average volume is similarly distributed over the week.

Average wait time is similarly distributed over the week.

- Table B-18 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 5 and 120 minutes, while number of open lanes is between 2 and 12.
- Maximum recorded volume is 1156 veh/h.
- Volume, number of open lanes, cycle time, and wait time increase at the same time.
- Each additional vehicle decreases wait time by 0.02 min, and each additional lane opened increases wait time by 3 min. Additional second of cycle time increases wait time by 0.34 min.

Table B-18. POV Ready Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at San Ysidro.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	27.15	05:00–11:00	41.92	22.23
Weekend	33.09	15:00–23:00	59.24	20.02

5.5.3 POV SENTRI

For the POV SENTRI lanes at the San Ysidro POE, the following was noted:

- Average volume is similarly distributed over the week.
- Average wait time is significantly higher on Saturdays in comparison to other days of the week.
- Table B-19 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 3 and 60 minutes, while number of open lanes is between 2 and 10.
- Maximum recorded volume is 1052 veh/h.
- Volume, number of open lanes, cycle time, and wait time increase at the same time.
- Each additional vehicle increases wait time by 0.002 min, and each additional lane opened increases wait time by 1.8 min. Additional second of cycle time decreases wait time by 0.007 min.

Table B-19. POV SENTRI Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at San Ysidro.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	6.60	05:00–09:00	11.97	5.53
Weekend	8.35	12:00–23:00	13.38	4.10

5.6 YSLETA PORT OF ENTRY

5.6.1 POV Standard

At the POV Standard lanes at the Ysleta POE, the following was noted:

- Average volume is significantly lower on weekends in comparison to weekdays.
- Average wait time is significantly higher on weekends in comparison to other days of the week.
- Table B-20 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 1 and 99 minutes, while number of open lanes is between 1 and 6.
- Maximum recorded volume is 383 veh/h.

- Volume, number of open lanes, and wait time increase at the same time. As cycle time increases, wait time decreases.
- Each additional vehicle increases wait time by 0.08 min, and each additional lane opened increases wait time by 2.5 min. Additional second of cycle time increases wait time by 0.05 min.

Table B-20. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Ysleta.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	17.87	18:00–00:00	25.13	15.45
Weekend	26.21	12:00–23:00	38.37	22.15

5.6.2 POV Ready

At the POV Ready lanes at the Ysleta POE, the following was noted:

- Average volume is significantly higher on weekends in comparison to weekdays.
- Average wait time is significantly higher on Sundays in comparison to other days of the week.
- Table B-21 presents distribution of peak hours and average peak and off-peak wait times.
- Wait time is between 1 and 89 minutes, while number of open lanes is between 1 and 5.
- Maximum recorded volume is 340 veh/h.
- Volume, number of open lanes, and wait time increase at the same time. As cycle time increases, wait time decreases.
- Each additional vehicle increases wait time by 0.06 min, and each additional lane opened increases wait time by 2.2 min. Additional second of cycle time increases wait time by 0.045 min.

Table B-21. POV Ready Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Ysleta.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	14.46	15:00–21:00	20.73	12.37
Weekend	21.42	18:00–00:00	32.47	17.73

5.6.3 POV SENTRI

At the POV SENTRI lanes at the Ysleta POE, the following was noted:

- Average volume is significantly higher on Saturdays in comparison to other days of the week.

- Average wait time is very low during entire week.
- Wait time is between 1 and 15 minutes, while number of open lanes is either 1 or 2.
- Maximum recorded volume is 396 veh/h.
- Volume, number of open lanes, and wait time increase at the same time. As cycle time increases, wait time decreases.
- Each additional lane opened increases wait time by 0.59 min. Additional second of cycle time increases wait time by 0.006 min.

5.6.4 COV Standard – Summary

At the COV Standard lanes at the Ysleta POE, the following was noted:

- Average volume is significantly lower on Saturdays in comparison to other days of the week.
- Average wait time is significantly higher on Tuesdays in comparison to other days of the week.
- Wait times are relatively evenly distributed over the day, so the peak hour cannot be determined.
- Wait time is between 1 and 55 minutes, while number of open lanes is between 1 and 5.
- Maximum recorded volume is 185 veh/h.
- Volume, number of open lanes, cycle time, and wait time increase at the same time.
- Each additional vehicle increases wait time by 0.1 min, and additional second of cycle time increases wait time by 0.103 min.

6. DETAILED ANALYSIS AT INDIVIDUAL POES

6.1 DETAILED ANALYSIS – BLAINE POE

6.1.1 POV Standard Analysis

Vehicle volumes vary between 1 and 250 veh/h, having a mean of 85 veh/h and deviation of 40 veh/h. Cycle time ranges between 17 and 224 seconds, while the mean is 51 seconds and standard deviation is 23 seconds. Number of lanes open is between 1 and 5, and the mode is 2, meaning that 2 lanes are open in most cases. Wait time is between 1 and 60 minutes, and its mean value is less than 10 minutes. Table B-22 shows detailed statistical characteristics.

Table B-22. POV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Blaine.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	84.91	50.91	2.51	9.83
Standard Error	1.33	0.77	0.05	5.00
Median	85.00	43.18	2.00	5.00
Mode	93.00	69.00	2.00	5.00
Standard Deviation	40.23	23.29	0.98	8.47
Minimum	1.00	17.29	1.00	1.00
Maximum	250.00	224.00	5.00	60.00

6.1.1.1 Volume Analysis – POV Standard – Blaine

Figure B-1 presents average hourly volumes for different days of the week. The volumes are significantly higher on Fridays and Saturdays (104 veh/h and 103 veh/h, respectively) in comparison to other days of the week. The demand during the other five days is relatively consistent, being between 73 veh/h and 84 veh/h.

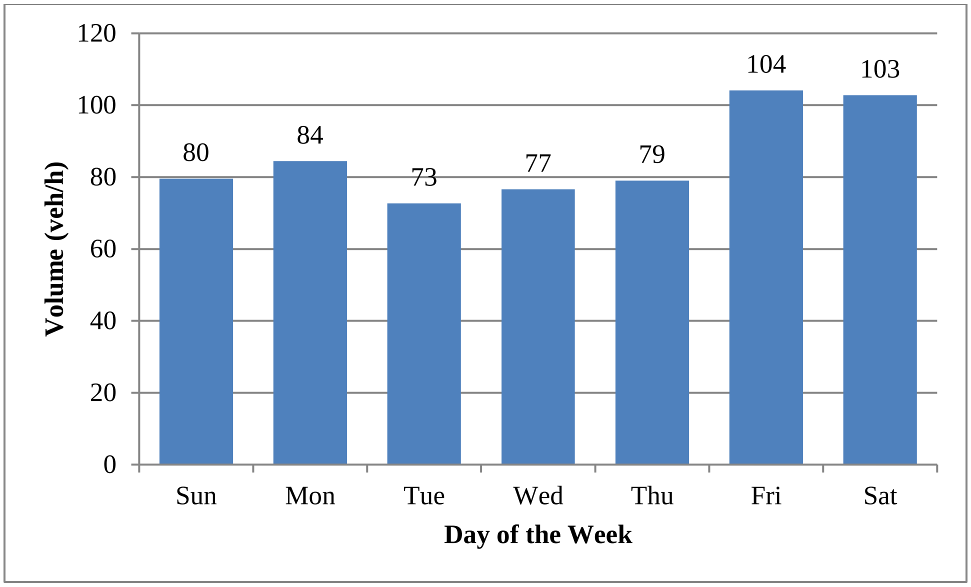


Figure B-1. POV Standard Average Hourly Volume for Each Day of the Week at Blaine.

The average hourly volume for each hour of the day during weekdays and weekend is presented in Figure B-2 and Figure B-3, respectively. It can be concluded from Figure B-2 that the highest number of vehicles crossing the border from Monday to Friday occurs between 9 a.m. and 5 p.m. with a minimum value of approximately 100 veh/h and a maximum value of 115 veh/h. The overnight volumes from 10 p.m. to 5 a.m. are not recorded, but the trend suggests very low volumes during this period.

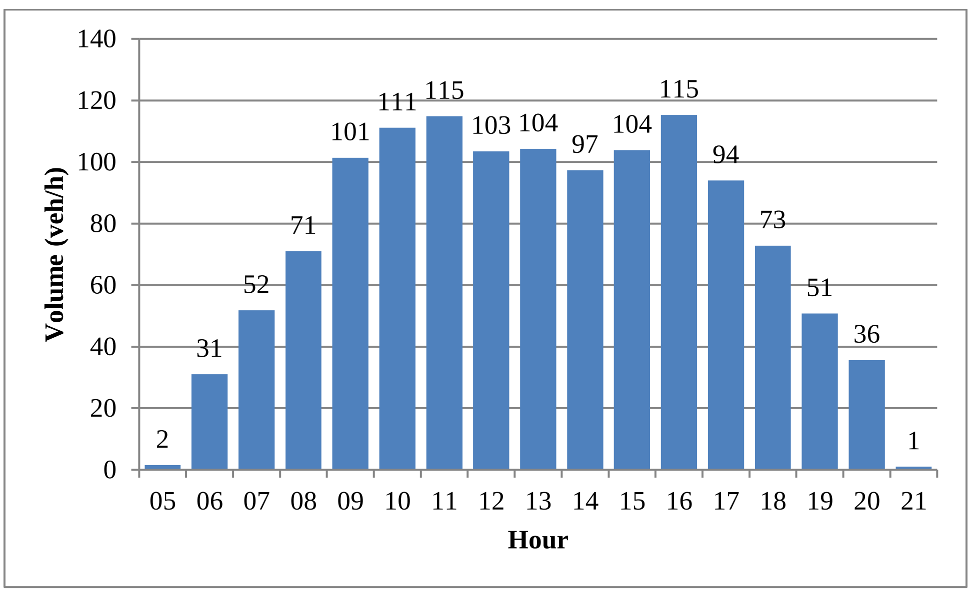


Figure B-2. POV Standard Average Volume for Different Hours of Weekdays at Blaine.

Figure B-3 displays vehicle volumes by hour for weekends. The spread of volumes is relatively similar to weekdays. However, weekend volumes have a higher maximum, reaching 144 veh/h. Peak hours are from 10 a.m. to 3 p.m. The extrapolation suggests that volumes during the night (10 p.m.–6 a.m.) are very low.

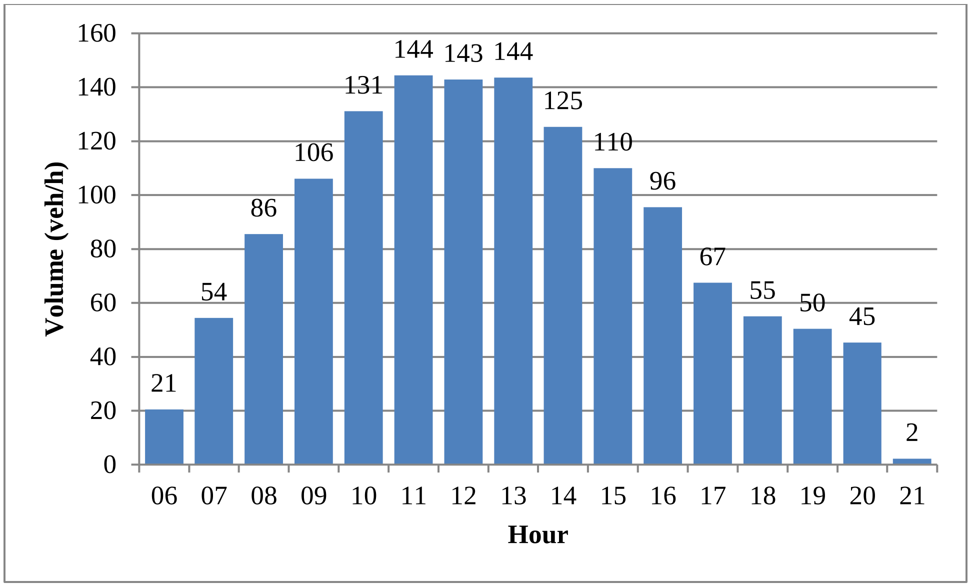


Figure B-3. POV Standard Average Volume for Different Hours of a Weekend at Blaine.

6.1.1.2 Wait Time Analysis – POV Standard

Figure B-4 presents average wait time analysis and suggests that vehicles wait longer on Saturdays, Sundays, and Mondays, in comparison to other days of the week. The shortest wait times are on Tuesdays and Wednesdays, 5 minutes, and the longest are 12 minutes on average on Sundays.

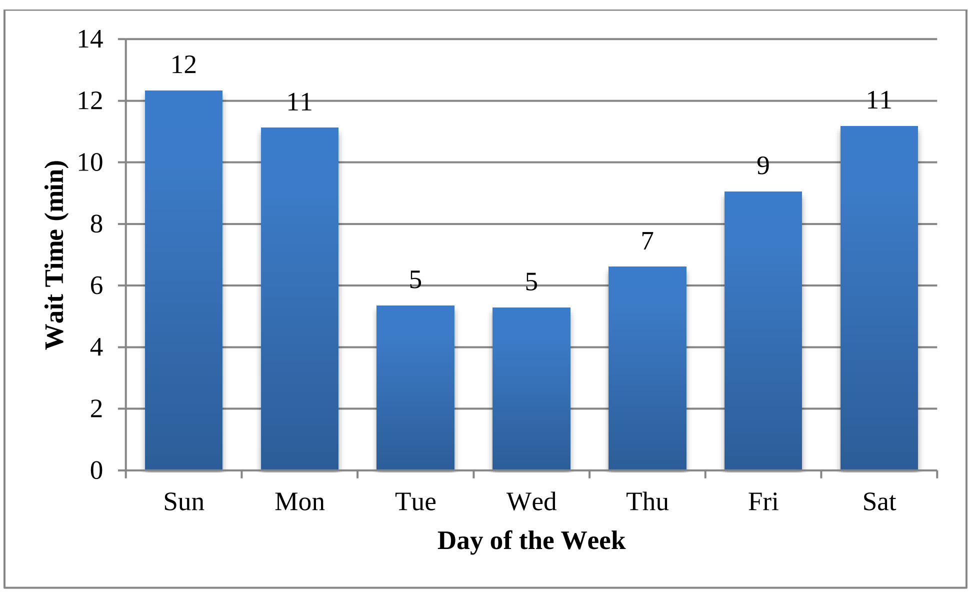


Figure B-4. POV Standard Average Wait Times for Different Days of the Week at Blaine.

Figure B-5 represents average wait times during weekdays by hour of the day, while Figure B-6 is for weekends. Table B-23 summarizes the findings from both.

Average wait times on weekdays are little over 6 minutes on average, and the peak hours are from 11 a.m. until 1 p.m., with 11 minutes on average. Off-peak wait times are 5 minutes on average for weekdays.

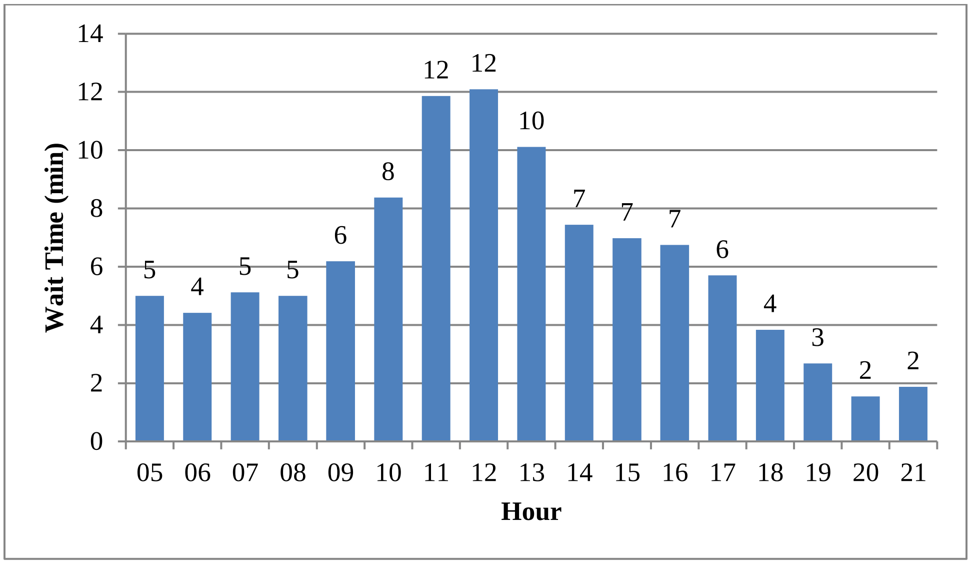


Figure B-5. POV Standard Average Wait Times for Different Hours during Weekdays at Blaine.

Weekend wait time peak is from 10 a.m. to 5 p.m., over 15 minutes on average. Off-peak wait times are close to 6 minutes on average, and the average wait times during weekends are 11 minutes. Weekdays average peak wait times are close to average off-peak wait times during weekends. This can be explained by existence of higher volumes over weekend.

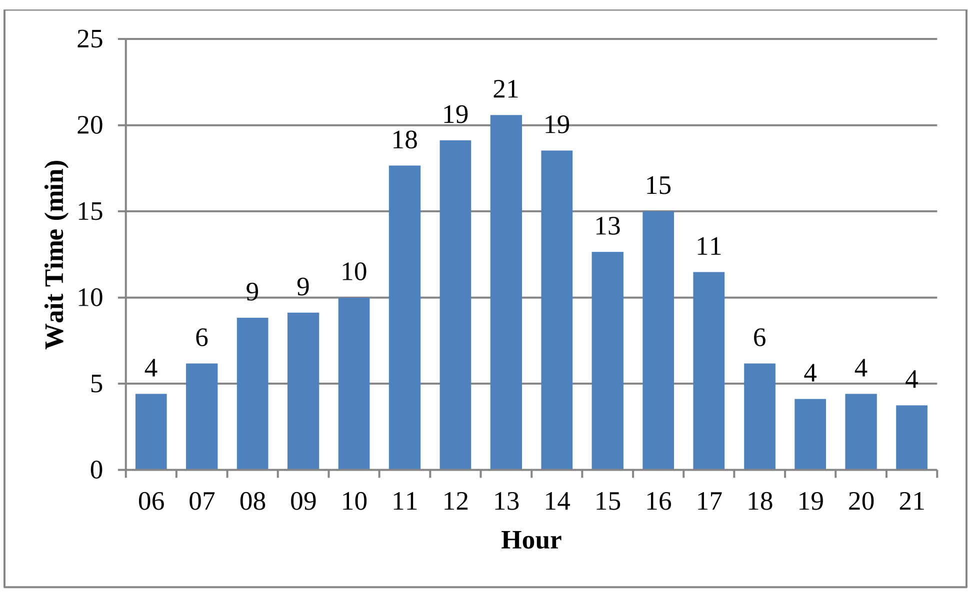


Figure B-6. POV Standard Average Wait Times for Different Hours during Weekends at Blaine.

Table B-23. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Blaine.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	6.20	11:00–13:00	11.36	5.10
Weekend	10.75	10:00–17:00	15.63	5.87

6.1.1.3 Regression and Correlation – POV Standard – Blaine

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.48 and 0.59, respectively. However, wait time is negatively correlated with cycle time with correlation coefficient of −0.37. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.62). Further, as cycle time increases, wait time decreases. It is feasible that officers may be spending more time for inspection when wait time is low than when wait times are longer. This is evidenced by negative correlation between volumes and cycle times (being −0.85), meaning that as the border crossing becomes more crowded, officers are probably working faster. As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.56). Table B-24 presents the correlation matrix.

Table B-24. POV Standard Correlation Matrix at Blaine.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1	-	-	-
Cycle Time	−0.8485	1	-	-
Number of Lanes	0.6275	−0.5599	1	-
Wait Time	0.4817	−0.3745	0.5942	1

Table B-25 and Table B-26 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.015 min, additional second of cycle time decreases wait time by 0.04 min, and additional lane opened increases wait time by 3.8 min. This is due to the fact that the lane opening is a consequence of increased wait times. This equation explains border process in 68 percent of cases (value of adjusted R square in Table B-26). In other words, this equation explains the variability (fits) of the 68 percent of data provided by CBP. The remaining 32 percent are not explained by this particular equation.

Table B-25. POV Standard Regression Coefficients at Blaine.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0152	0.0075	2.0256	0.0431
Cycle Time	−0.0410	0.0068	−6.0356	2.4E-09
Number of Lanes	3.8241	0.3050	12.5374	4.12E-33

Table B-26. POV Standard Regression Statistics at Blaine.

Regression Statistics	
Multiple R	0.8259
R Square	0.6823
Adjusted R Square	0.6802
Standard Error	6.8827
Observations	822

6.1.2 COV Standard Analysis – Blaine POE

Vehicle volumes vary between 3 and 149 veh/h, having a mean of 68 veh/h and deviation of 33 veh/h. Cycle time ranges between 42 and 198 seconds, while the mean is 85 seconds and standard deviation is 19 seconds. Number of lanes open is between 1 and 3, and the mode is 1, meaning that 1 lane are open in most cases. Wait time is between 5 and 85 minutes, and its mean value is almost 13 minutes. Table B-27 shows detailed statistical characteristics.

Table B-27. COV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Blaine.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	68.43	85.28	1.84	12.82
Standard Error	0.89	0.51	0.03	5.00
Median	66.00	84.10	2.00	5.00
Mode	87.00	71.00	1.00	5.00
Standard Deviation	33.15	19.25	0.88	12.65
Minimum	3.00	42.26	1.00	5.00
Maximum	149.00	198.20	3.00	85.00

6.1.2.1 Volume Analysis – COV Standard – Blaine

Figure B-7 presents average hourly volumes for different days of the week. The volumes are significantly lower on Saturdays and Sundays (43 veh/h and 40 veh/h, respectively) in comparison to weekdays. The demand during weekdays is relatively consistent, being between 70 veh/h and 81 veh/h.

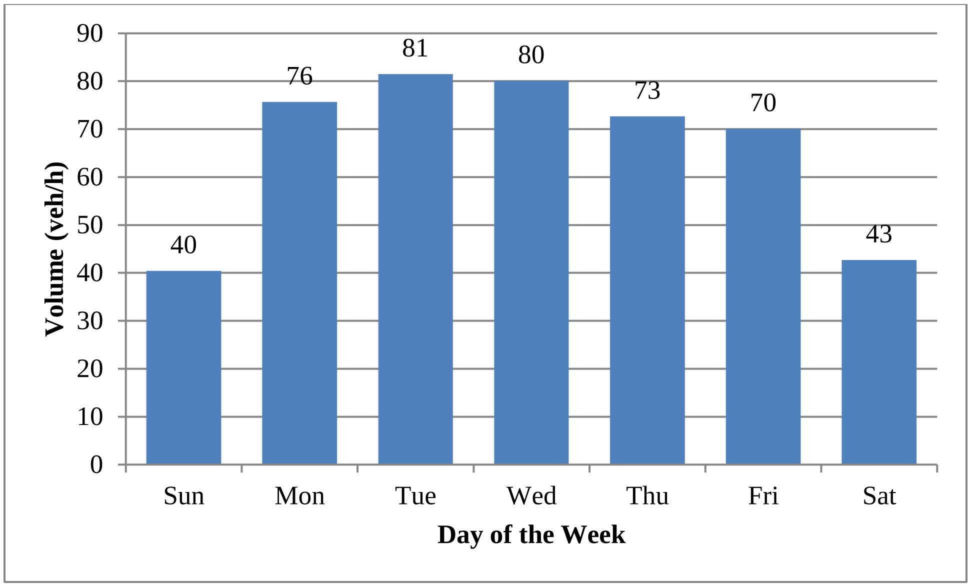


Figure B-7. COV Standard Average Hourly Volume for Each Day of the Week at Blaine.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-8 and Figure B-9, respectively. It can be concluded from Figure B-8 that the highest number of vehicles crossing the border from Monday to Friday occurs between 5 a.m. and 2 p.m. with a minimum value of approximately 100 veh/h and a maximum value of 120 veh/h. The volumes from 2 p.m. to midnight were not recorded, but the trend suggests lower volumes during this period.

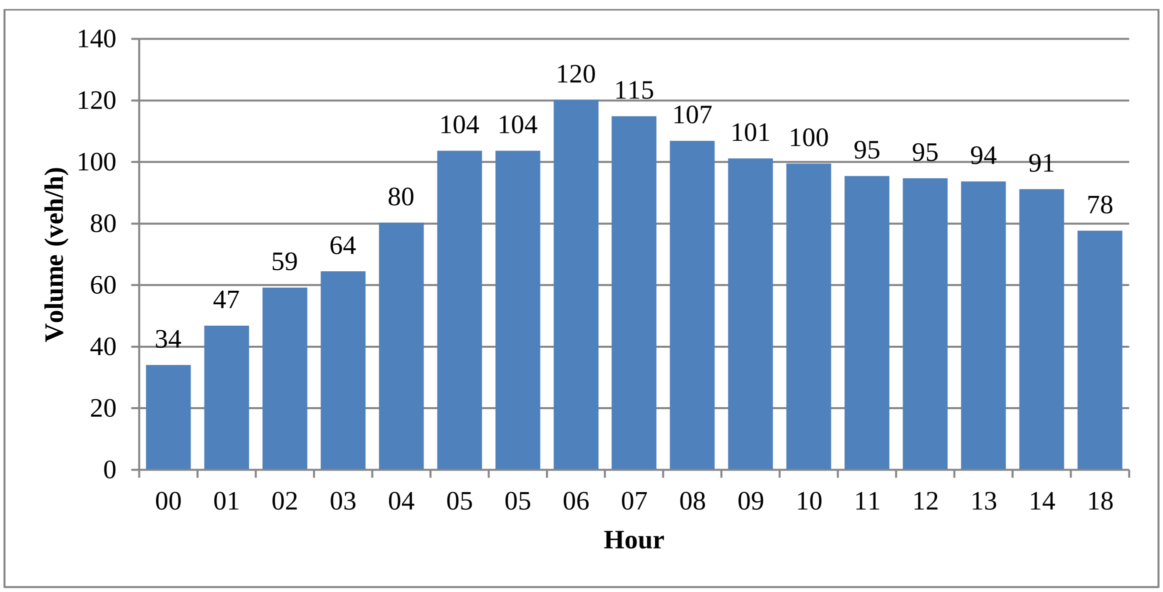


Figure B-8. COV Standard Average Volume for Different Hours of Weekdays at Blaine.

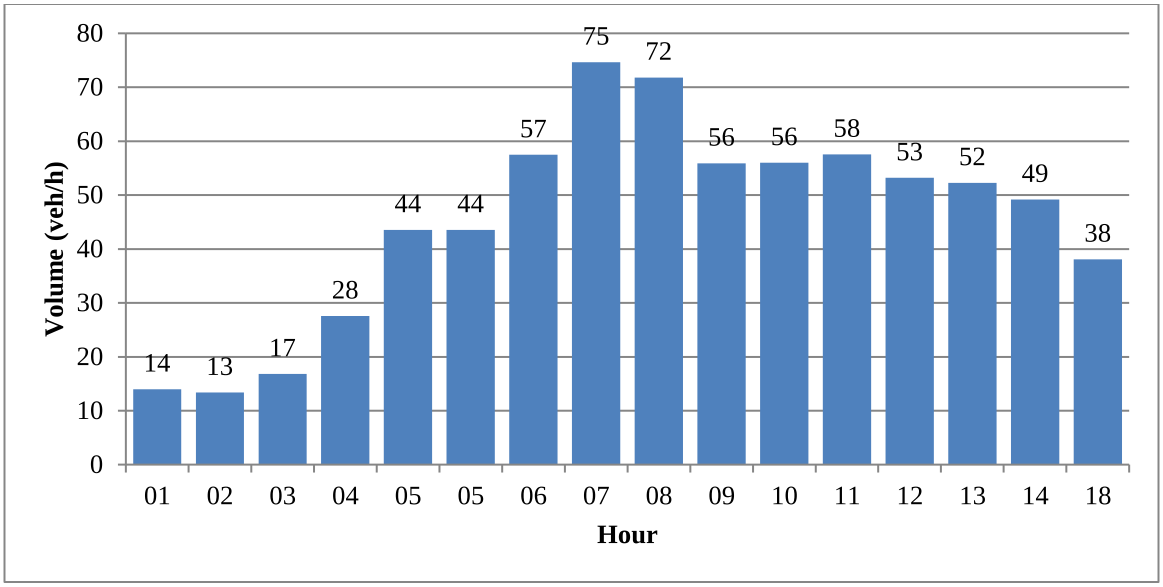


Figure B-9. COV Standard Average Volume for Different Hours of a Weekend at Blaine.

6.1.2.2 Wait Time – COV Standard – Blaine

Figure B-10 presents average wait time analysis and suggests that vehicles wait longer on weekdays, in comparison to the weekend when the wait times are 6 minutes on average. The longest waiting occurs on Tuesdays, when wait times are 17 minutes on average.

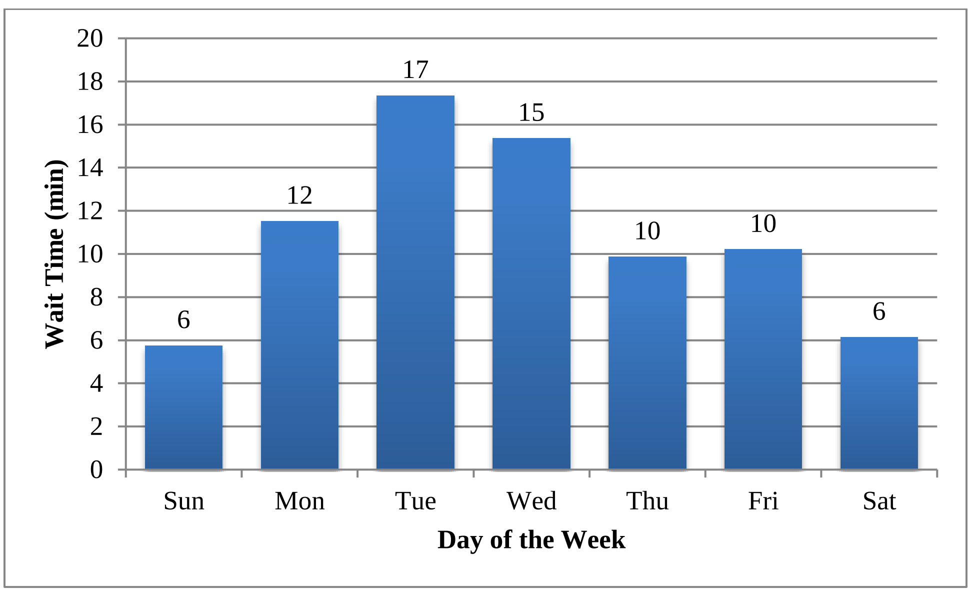


Figure B-10. COV Standard Average Wait Times for Different Days of the Week at Blaine.

Figure B-11 represents average wait times during weekdays for different hours of the day, while Figure B-12 is for weekends.

Table B-28 summarizes the findings from both.

Average wait times on weekdays are almost 13 minutes on average, and the peak hours are from 7 a.m. until 2 p.m., being 21 minutes on average. Off-peak wait times are 4 minutes on average for weekdays.

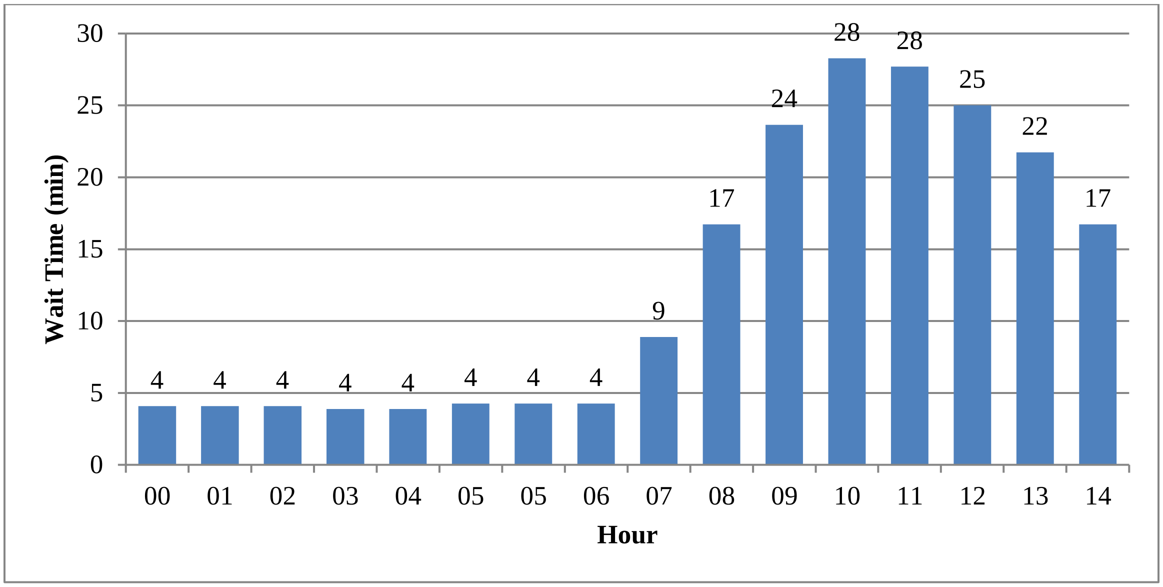


Figure B-11. COV Standard Average Wait Times for Different Hours during Weekdays at Blaine.

Weekend wait time peak is from 8 a.m. to 12 p.m. and is close to 10 minutes on average. Off-peak wait times are close to 5 minutes on average, and the average wait times during weekends are 6.5 minutes. Weekdays and weekend average off-peak wait times are very similar (between 4 and 5 minutes), while average peak wait times are significantly higher on weekdays. It is probably due to lower volumes on weekends.

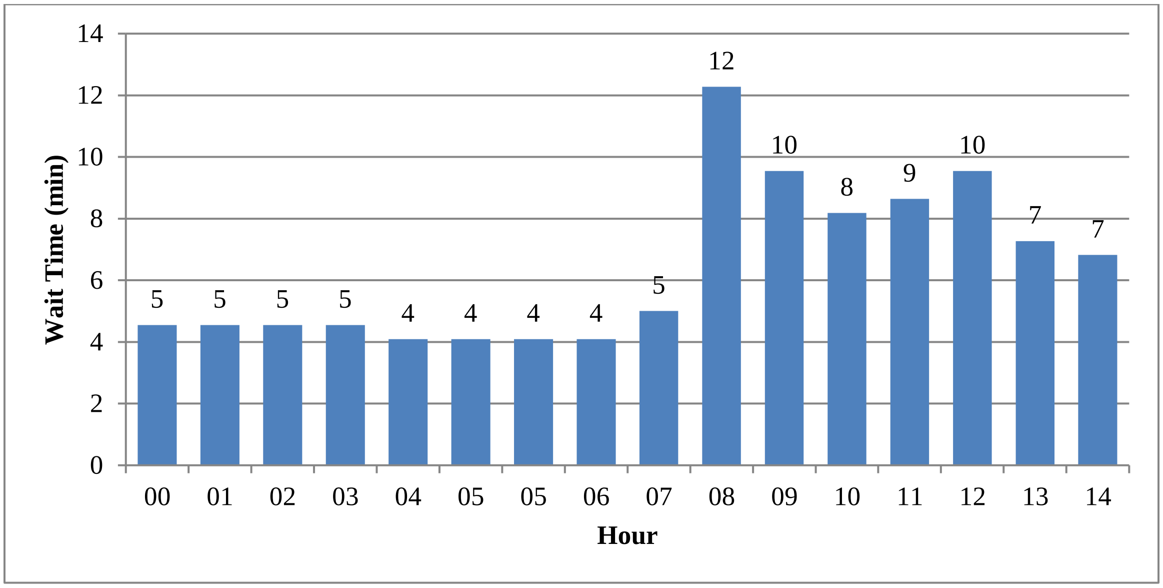


Figure B-12. COV Standard Average Wait Times for Different Hours during Weekends at Blaine.

Table B-28. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Blaine.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	12.59	07:00–14:00	21.09	4.10
Weekend	6.48	08:00–12:00	9.64	4.88

6.1.2.4 Regression and Correlation – COV Standard – Blaine

Wait time is positively correlated with volume, cycle times, and number of open lanes, having correlation coefficients of 0.48, 0.42, and 0.63, respectively. This shows that as volume, cycle times, and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlations are counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.65). Table B-29 presents the correlation matrix.

Table B-29. COV Standard Correlation Matrix at Blaine.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	0.10	1.00	-	-
Number of Lanes	0.65	0.52	1.00	-
Wait Time	0.48	0.42	0.63	1.00

Table B-30 and

Table B-31 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.017 min, and each additional second of cycle time decreases wait time by 0.04 min. This equation explains border process in 64 percent of cases (value of adjusted R square in

Table B-31). In other words, this equation explains the variability (fits) of the 64 percent of data provided by CBP. The remaining 36 percent are not explained by this particular equation.

Table B-30. COV Standard Regression Coefficients at Blaine.

	Coefficients	**Standard Error**	**t Stat**	**P-value**
Volume	0.0174	0.0105	1.6595	0.0973
Cycle Time	−0.0424	0.0088	−4.8200	1.61E-06

Table B-31. COV Standard Regression Statistics at Blaine.

Regression Statistics	
Multiple R	0.8030
R Square	0.6449
Adjusted R Square	0.6436
Standard Error	9.9626
Observations	1257

6.2 DETAILED ANALYSIS – CHAMPLAIN POE

6.2.1 POV Standard Analysis – Champlain POE

Vehicle volumes vary between 1 and 43 veh/h, having a mean of 10 veh/h and deviation of 6 veh/h. Cycle time ranges between 30 and 300 seconds, while the mean is 148 seconds and standard deviation is 25 seconds. Number of lanes open is between 1 and 7, and the mode is 2, meaning that 2 lanes are open in most cases. Wait time is between 5 and 30 minutes, and its mean value is 9 minutes. Table B-32 shows detailed statistical characteristics.

Table B-32. POV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Champlain.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	9.96	148.43	2.40	9.01
Standard Error	0.20	0.91	0.05	10.00
Median	9.00	148.00	2.00	10.00
Mode	11.00	180.00	2.00	10.00
Standard Deviation	5.66	25.46	0.86	5.21
Minimum	1.00	30.00	1.00	5.00
Maximum	43.00	300.00	7.00	30.00

6.2.1.1 Volume Analysis – POV Standard – Champlain

Figure B-13 presents average hourly volumes for different days of the week. The average volumes are low on all days of the week, being between 8 and 14 veh/h on average. Average hourly volume for each hour of the day during weekdays and the weekend are presented in Figure B-14 and Figure B-15, respectively.

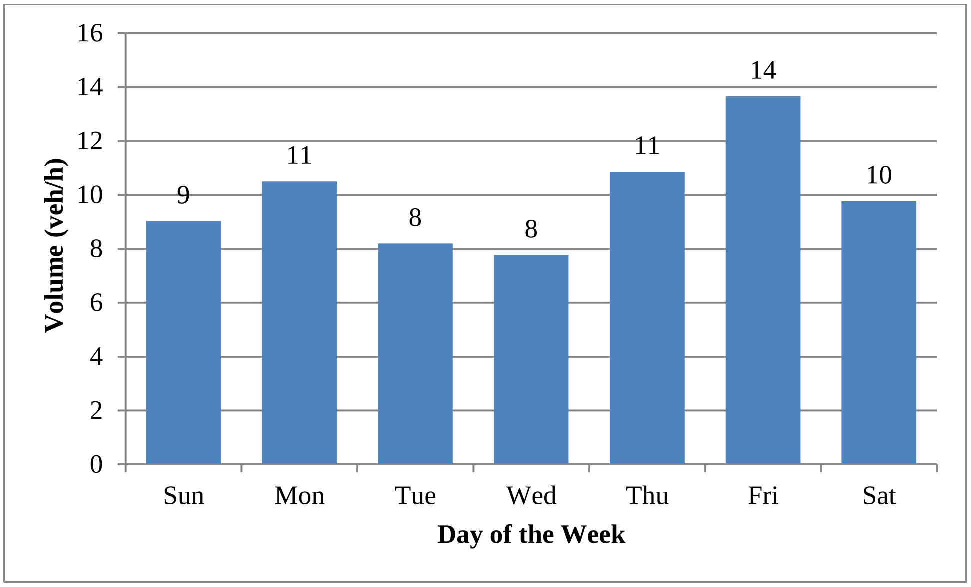


Figure B-13. POV Standard Average Hourly Volume for Each Day of the Week at Champlain.

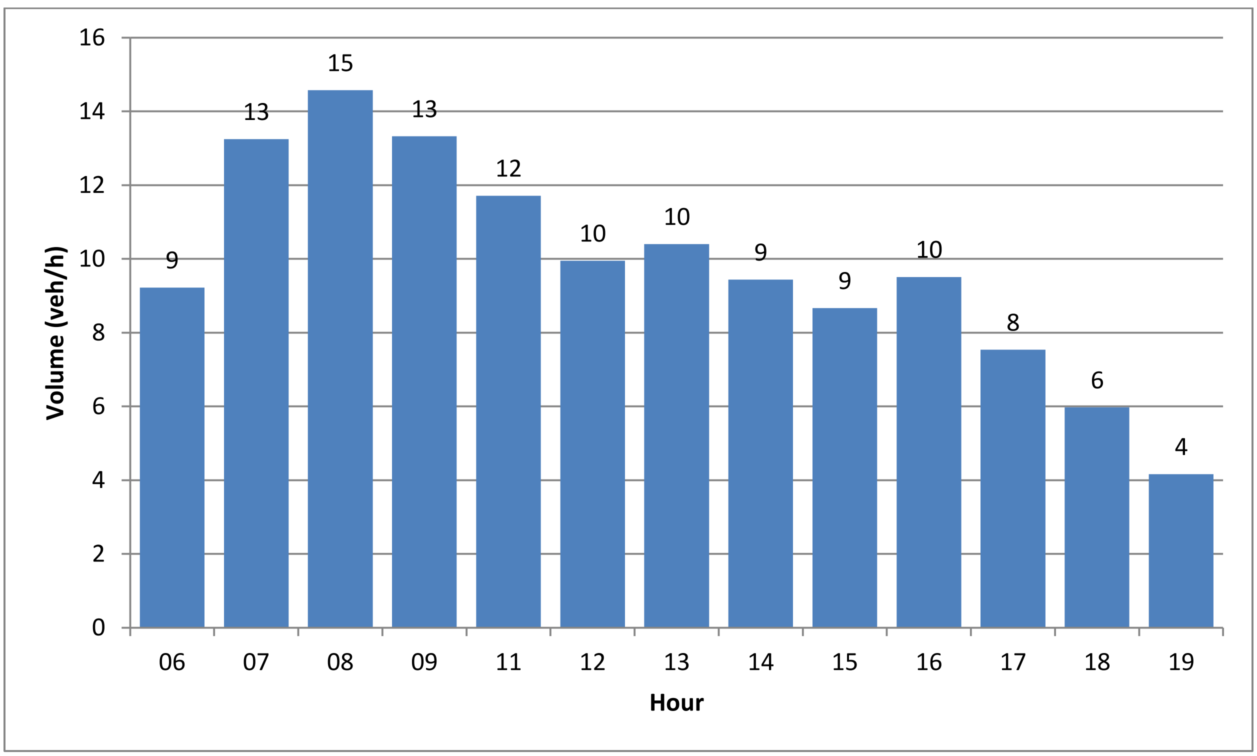
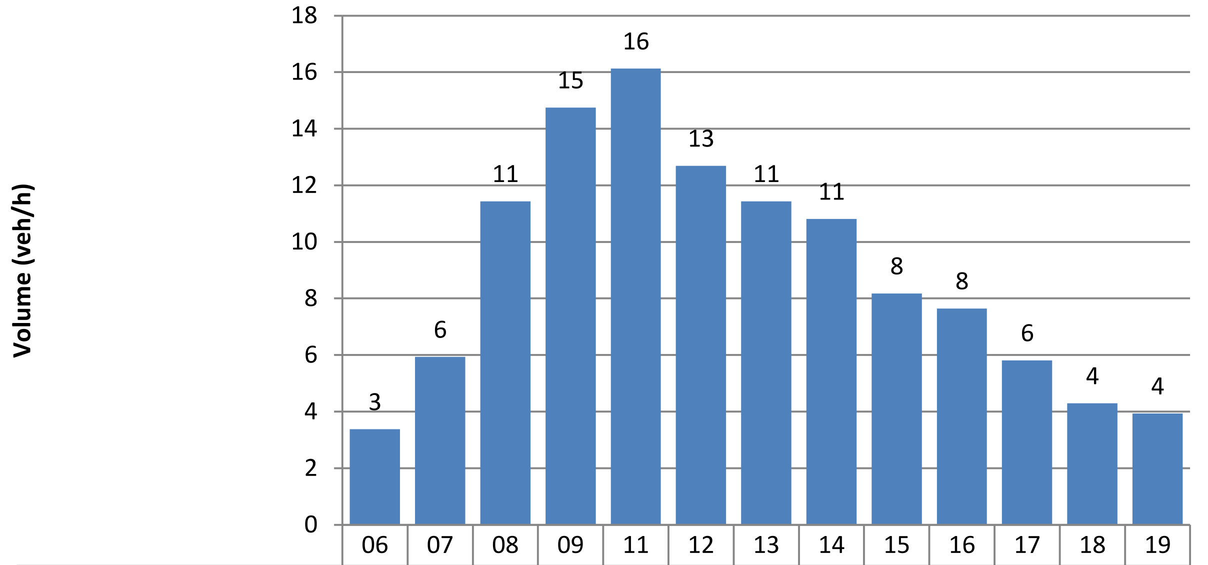


Figure B-14. POV Standard Average Volume for Different Hours of Weekdays at Champlain.



	06	07	08	09	11	12	13	14	15	16	17	18	19
Average Volume Weekend	3	6	11	15	16	13	11	11	8	8	6	4	4

Figure B-15. POV Standard Average Volume for Different Hours of a Weekend at Champlain.

6.2.1.2 Wait Time Analysis – POV Standard – Champlain

Figure B-16 presents average wait time analysis and suggests that vehicle wait times are very short (up to 3 minutes) on all days of the week. Figure B-17 represents average wait times during weekdays for different hours of the day, while Figure B-18 is for weekends. There is no significant difference in wait times on different time of day.

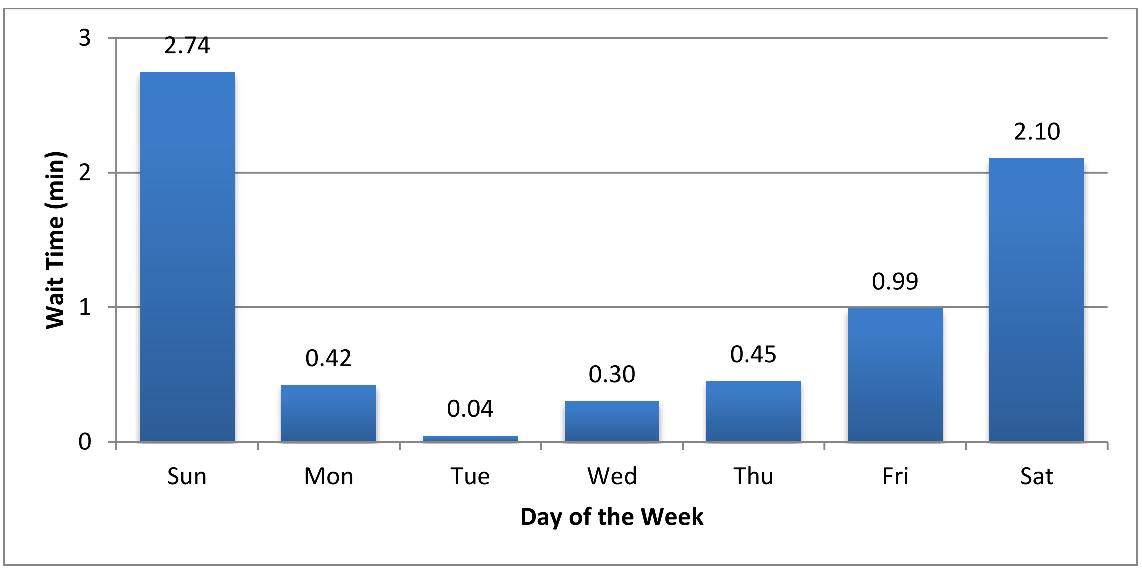


Figure B-16. POV Standard Average Wait Times for Different Days of the Week at Champlain.

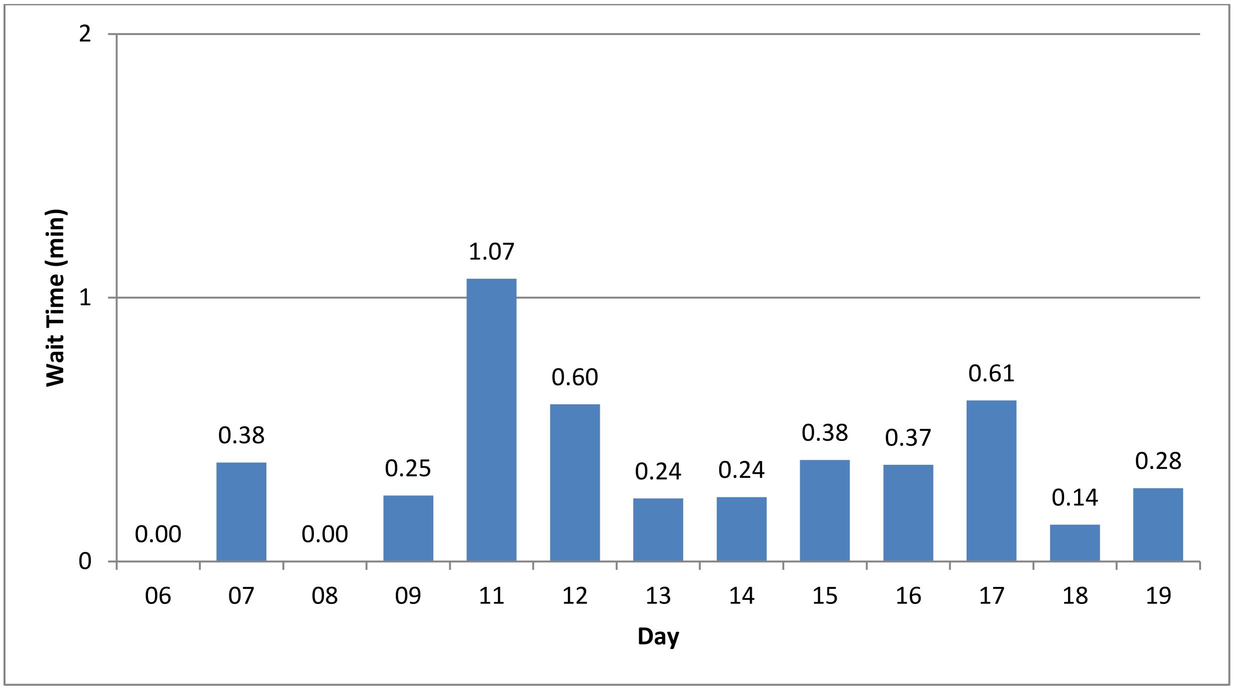


Figure B-17. POV Standard Average Wait Times for Different Hours during Weekdays at Champlain.

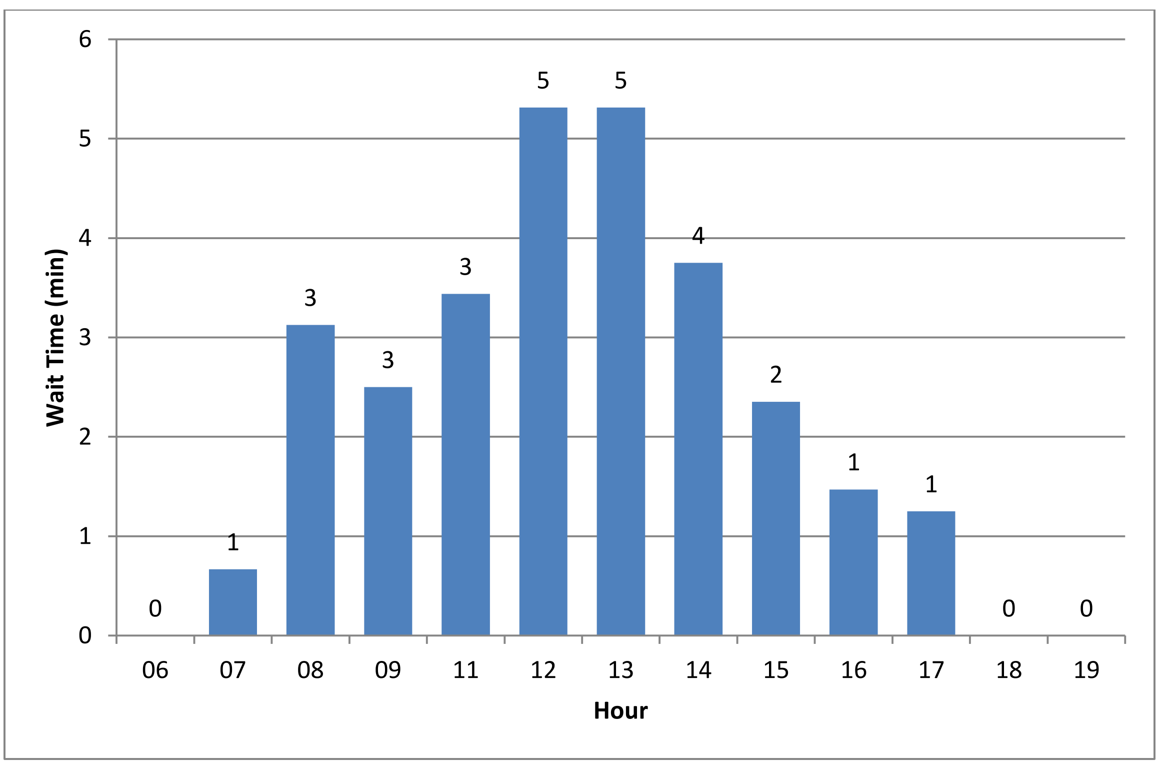


Figure B-18. POV Standard Average Wait Times for Different Hours during Weekends at Champlain.

6.2.1.3 Regression and Correlation – POV Standard – Champlain

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.16 and 0.37, respectively. However, wait time is negatively correlated with cycle time with correlation coefficient of −0.22. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.49). Further, as cycle time increases, wait time decreases. It is feasible that officers may be spending more time for inspection when wait time is low than when wait times are longer. This is evidenced by the negative correlation between volumes and cycle times (being −0.73), meaning that as the border crossing becomes more crowded, officers are probably working faster. As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.40). Table B-33 presents the correlation matrix.

Table B-33. POV Standard Correlation Matrix at Champlain.

	Volume	**Cycle Time**	**Number of Lanes**	**Wait Time**
Volume	1.00	-	-	-
Cycle Time	−0.73	1.00	-	-
Number of Lanes	0.49	−0.40	1.00	-
Wait Time	0.16	−0.22	0.37	1.00

Table B-34 and

Table B-35 explain regression between wait times (dependent variable) and independent variables (cycle times and number of open lanes). An additional second of cycle time increases wait time by 0.016 min, and an additional lane opened increases wait time by 1.98 min. This is probably due to the fact that the lane opening is a consequence of increased wait times. This equation explains border process in 77 percent of cases (value of adjusted R square in

Table B-35). In other words, this equation explains the variability (fits) of the 77 percent of data provided by CBP. The remaining 23 percent are not explained by this particular equation.

Table B-34. POV Standard Regression Coefficients at Champlain.

	Coefficients	Standard Error	t Stat	P-value
Cycle Time	0.0156	0.0088	1.7736	0.0800
Number of Lanes	1.9793	0.3523	5.6177	2.79E-07

Table B-35. POV Standard Regression Statistics at Champlain.

Regression Statistics	
Multiple R	0.8842
R Square	0.7818
Adjusted R Square	0.7663
Standard Error	4.9164
Observations	81

6.2.2 COV Standard Analysis – Champlain POE

Vehicle volumes vary between 1 and 163 veh/h, having a mean of 57 veh/h and deviation of 37 veh/h. Cycle time ranges between 25 and 367 seconds, while the mean is 77 seconds and standard deviation is 27.5 seconds. Number of lanes open is between 1 and 5, and the mode is 1, meaning that 1 lane is open in most cases. Wait time is between 5 and 55 minutes, and its mean value is less than 13 minutes. Table B-36 shows detailed statistical characteristics.

Table B-36. COV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Champlain.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	57.11	77.12	1.74	12.83
Standard Error	0.98	0.73	0.03	5.00
Median	53.00	73.65	1.00	5.00
Mode	49.00	66.00	1.00	5.00
Standard Deviation	36.67	27.50	0.84	11.48
Minimum	1.00	25.00	1.00	5.00
Maximum	163.00	366.67	5.00	55.00

6.2.2.1 Volume Analysis – COV Standard – Champlain

Figure B-19 presents average hourly volumes for different days of the week. The volumes are significantly higher on weekdays (between 56 and 74 veh/h) in comparison to weekends (38 and 31 veh/h on average).

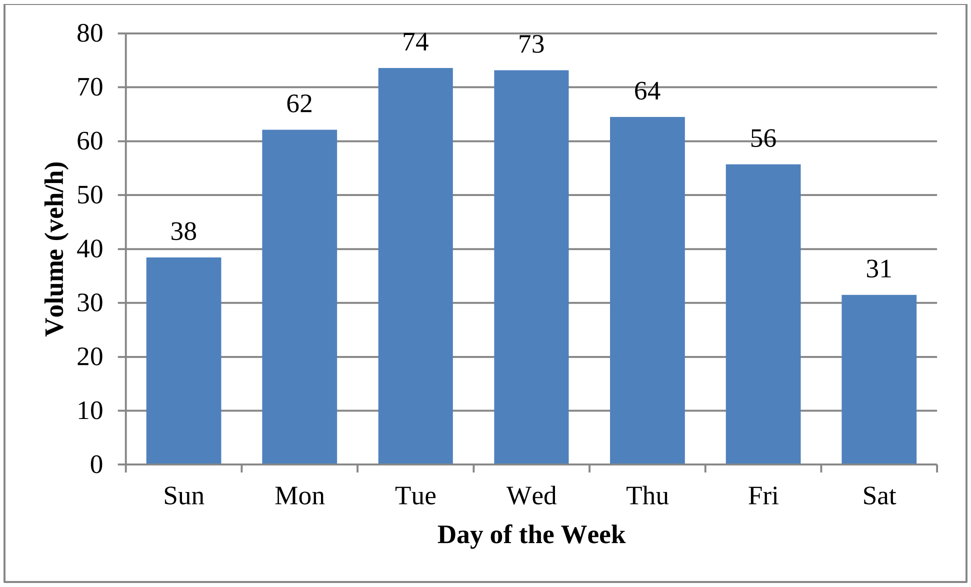


Figure B-19. COV Standard Average Hourly Volume for Each Day of the Week at Champlain.

Average hourly volume for each hour of the day during weekdays and the weekend are presented in Figure B-20 and Figure B-21, respectively. It can be concluded from Figure B-20 that the highest number of vehicles crossing the border from Monday to Friday occurs between 9 a.m. and 6 p.m. with a minimum of approximately 85 veh/h and a maximum value of 94 veh/h. The afternoon and overnight volumes from 5 p.m. to 2 a.m. are not recorded, but the trend suggests significantly lower volumes during this period.

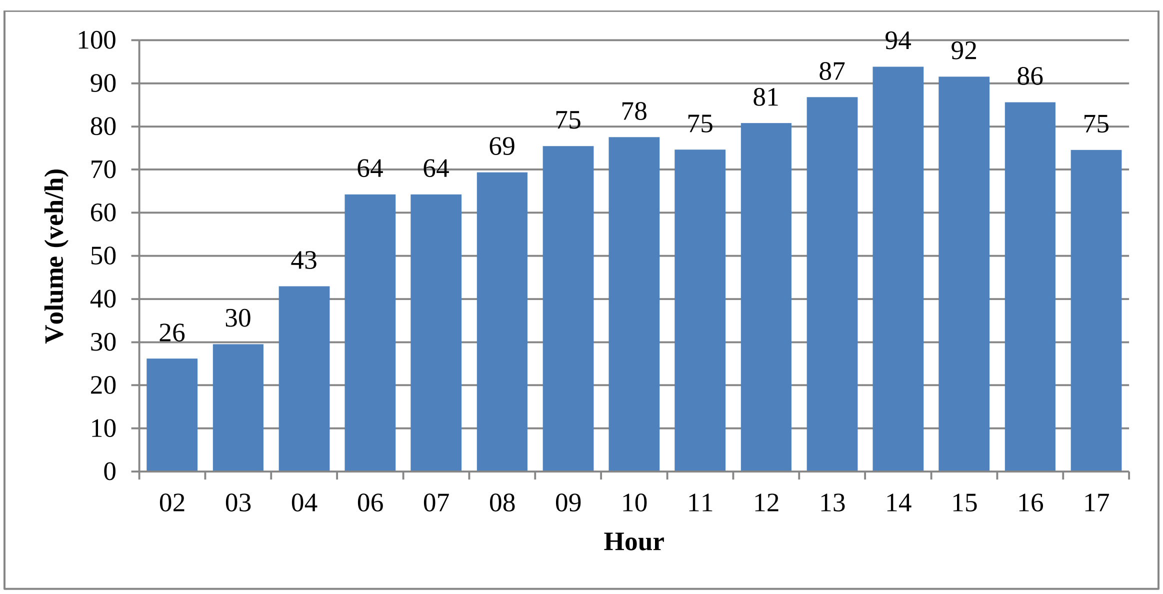


Figure B-20. COV Standard Average Volume for Different Hours of Weekdays at Champlain.

Figure B-21 displays vehicle volumes for different hours of the weekends. The spread of volumes is relatively similar to the weekdays. However, weekday volumes have a lower maximum, reaching only 53 veh/h. Peak hours are from 11 a.m. to 5 p.m.

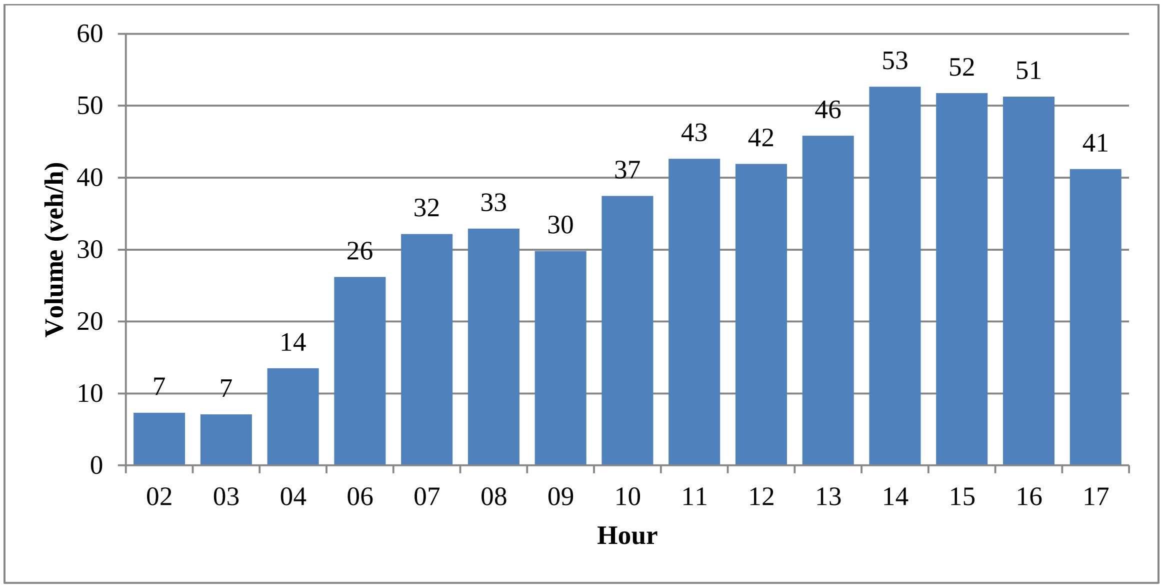


Figure B-21. COV Standard Average Volume for Different Hours of a Weekend at Champlain.

6.2.2.2 Wait Time Analysis – COV Standard – Champlain

Figure B-22 presents average wait time analysis and suggests that vehicles wait longer on weekdays, in comparison to weekends (4 minutes on average). The longest wait times are on Tuesdays and Wednesdays, being 13 and 12 minutes, respectively.

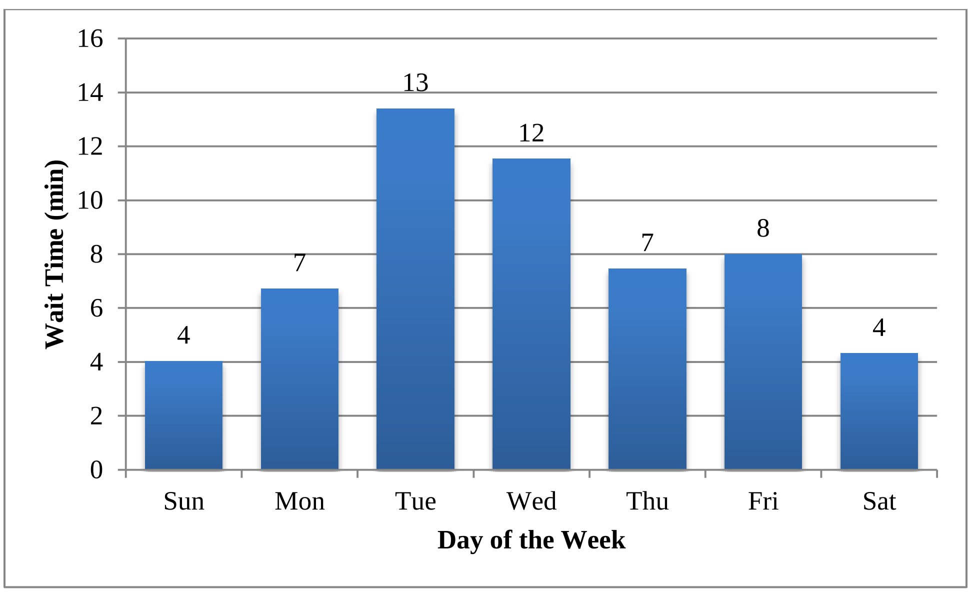


Figure B-22. COV Standard Average Wait Times for Different Days of the Week at Champlain.

Figure B-23 represents average wait times during weekdays for different hours of the day, while Figure B-24 is for weekends. Table B-37 summarizes the findings from both.

Average wait times on weekdays are little less than 5 minutes on average, and the peak hours are from 9 a.m. until 12 p.m., being 11 minutes on average. Off-peak wait times are less than 4 minutes on average for weekdays.

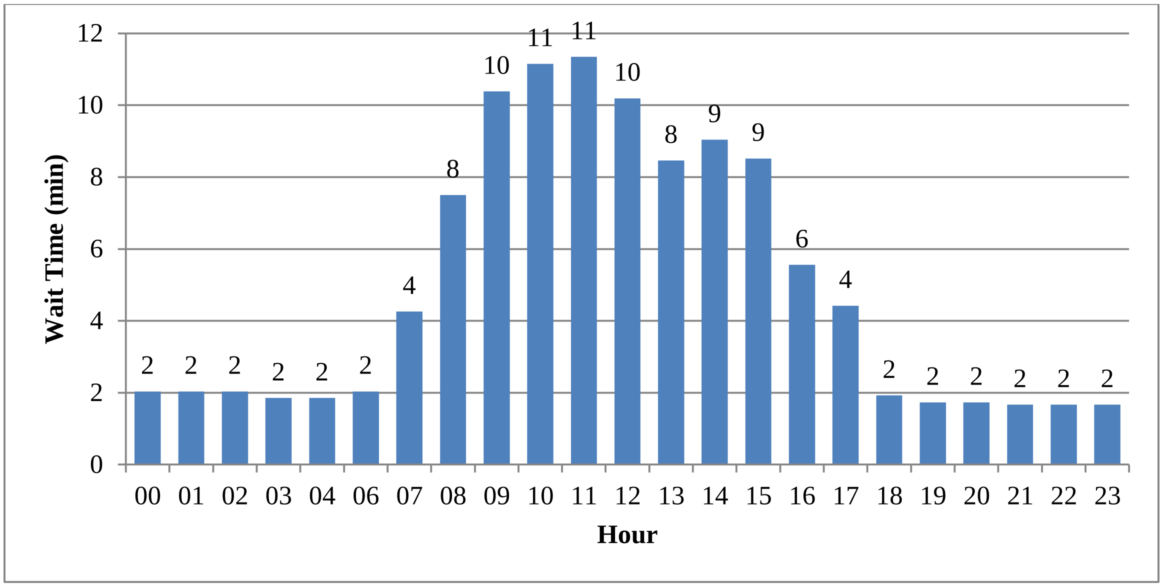


Figure B-23. COV Standard Average Wait Times for Different Hours during Weekdays at Champlain.

Weekend wait time peak is from 8 a.m. to 2 p.m. and is almost 5 minutes on average. Off-peak wait times are less than 2 minutes on average, and the average wait times during weekends are 2.6 minutes. Weekends average peak wait times are close to average off-peak wait times during weekdays. This can be explained by existence of higher volumes over weekdays.

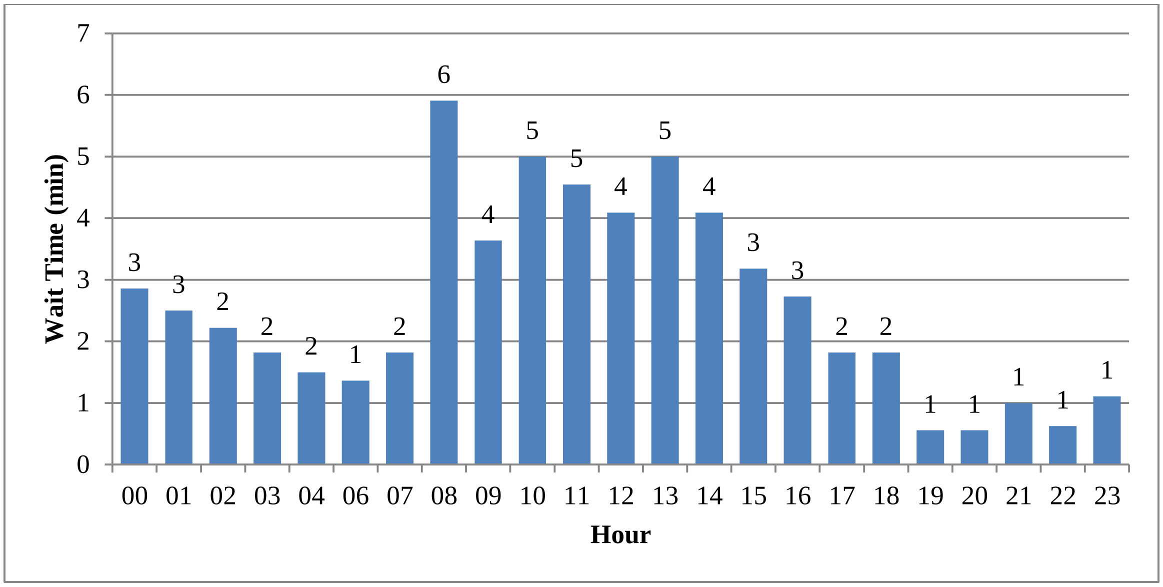


Figure B-24. COV Standard Average Wait Times for Different Hours during Weekends at Champlain.

Table B-37. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Champlain.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	4.92	09:00–12:00	10.77	3.68
Weekend	2.60	08:00–14:00	4.61	1.72

6.2.2.3 Regression and Correlation – COV Standard – Champlain

Wait time is positively correlated with volume, cycle time and number of open lanes, having correlation coefficients of 0.56, 0.36, and 0.59, respectively. This shows that as volume, cycle times, and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.68).

Table B-38 presents the correlation matrix.

Table B-38. COV Standard Correlation Matrix at Champlain.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	0.11	1.00	-	-
Number of Lanes	0.68	0.27	1.00	-
Wait Time	0.56	0.36	0.59	1.00

Table B-39 and Table B-40 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.007 min, each additional second of cycle time decreases wait time by 0.009 min, and each additional lane opened increases wait time by 2.9 min. This is probably due to the fact that the lane opening is a consequence of increased wait times. This equation explains border process in 55 percent of cases (value of adjusted R square in Table B-40). In other words, this equation explains the variability (fits) of the 55 percent of data provided by CBP. The remaining 45 percent are not explained by this particular equation.

Table B-39. COV Standard Regression Coefficients at Champlain.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0727	0.0092	7.8839	6.84E-15
Cycle Time	−0.0085	0.0066	−1.3016	0.1933
Number of Lanes	2.8519	0.4150	6.8723	9.9157E-12

Table B-40. COV Standard Regression Statistics at Champlain.

Regression Statistics	
Multiple R	0.7400
R Square	0.5475
Adjusted R Square	0.5460
Standard Error	8.8579
Observations	1260

6.3 DETAILED ANALYSIS – DETROIT POE

6.3.1 POV Standard Analysis – Detroit POE

Vehicle volumes vary between 1 and 587 veh/h, having a mean of 95 veh/h and deviation of 121 veh/h. Cycle time ranges between 27 and 184.5 seconds, while the mean is 73 seconds and standard deviation is 27 seconds. Number of lanes open is between 1 and 15, and the mode is 5, meaning that 5 lanes are open in most cases. Wait time is between 2 and 30 minutes, and its mean value is 9 minutes.

Table B-41 shows detailed statistical characteristics.

Table B-41. POV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Detroit.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	94.78	72.81	5.32	9.07
Standard Error	4.34	0.95	0.11	7.00
Median	45.00	73.45	5.00	7.00
Mode	38.00	81.00	5.00	5.00
Standard Deviation	121.36	26.65	1.94	5.25
Minimum	1.00	27.04	1.00	2.00
Maximum	587.00	184.50	15.00	30.00

6.3.1.1 Volume Analysis – POV Standard – Detroit

Figure B-25 presents average hourly volumes for different days of the week. The volumes are significantly higher on weekdays (between 96 and 114 veh/h) in comparison to weekends (around 40 veh/h).

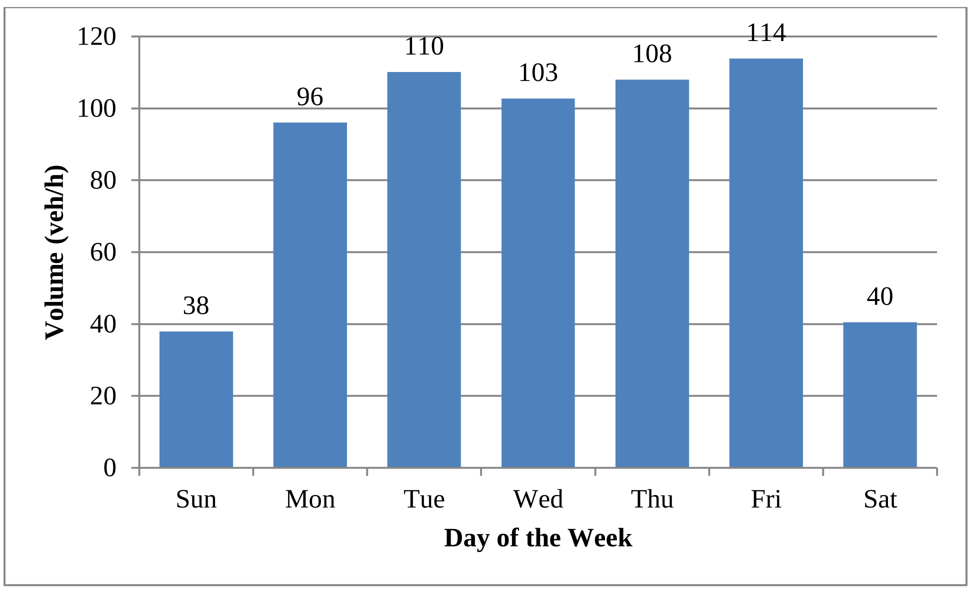


Figure B-25. POV Standard Average Hourly Volume for Each Day of the Week at Detroit.

Average hourly volume for each hour of the day during weekdays and the weekend are presented in Figure B-26 and Figure B-27, respectively. It can be concluded from Figure B-26 that the highest number of vehicles crossing the border from Monday to Friday occurs between 6 a.m. and 10 a.m., and is between 300 and 427 veh/h. The overnight volumes from 8 p.m. to 5 a.m. are not recorded, but the trend suggests very low volumes during this period.

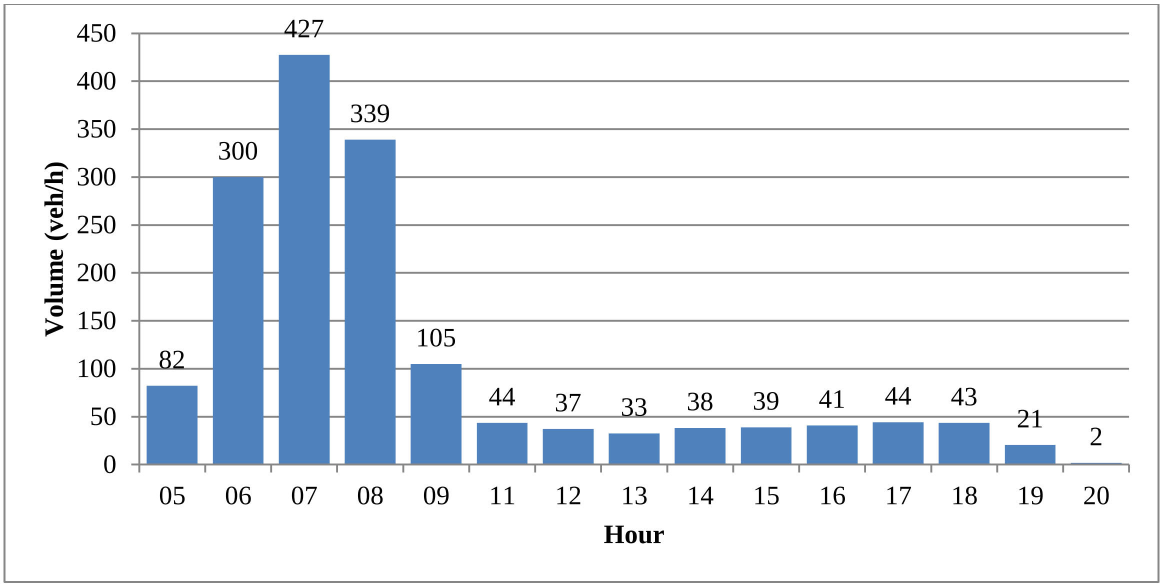


Figure B-26. POV Standard Average Volume for Different Hours of Weekdays at Detroit.

Figure B-27 displays vehicle volumes for different hours of the weekend. The volumes are recorded only from 11 a.m. to 8 p.m. The volume is relatively consistent, being around 40 veh/h for a period from 11 a.m. to 7 p.m.

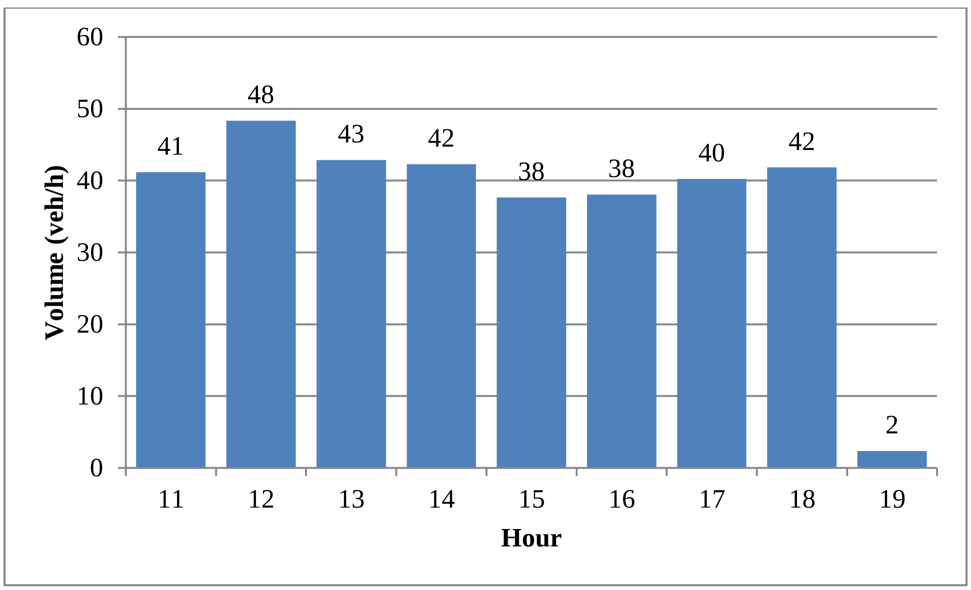


Figure B-27. POV Standard Average Volume for Different Hours of a Weekend at Detroit.

6.3.1.2 Wait Time Analysis – POV Standard – Detroit

Figure B-28 presents average wait time analysis and suggests that vehicles wait longer on Fridays, Saturdays, Sundays, and Mondays, in comparison to other days of the week (4 minutes on average). The highest wait times are on Saturdays and Sundays, and are 8 and 9 minutes, respectively.

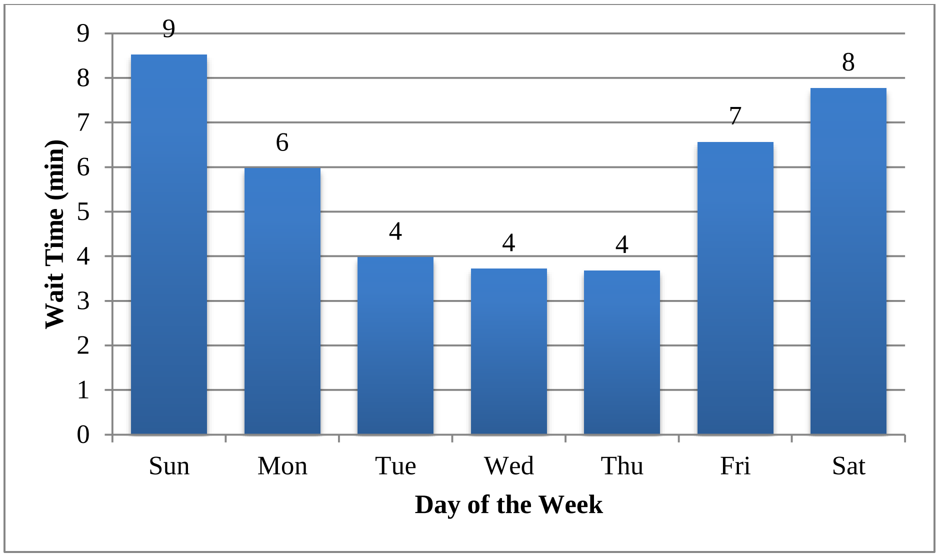


Figure B-28. POV Standard Average Wait Times for Different Days of the Week at Detroit.

Figure B-29 represents average wait times during weekdays for different hours of the day, while Figure B-30 is for weekends. Table B-42 summarizes the findings from both.

Average wait times on weekdays are little over 4 minutes on average, and the peak hours are from 7 a.m. until 1 p.m., being 6 minutes on average. Off-peak wait times are 3.3 minutes on average for weekdays.

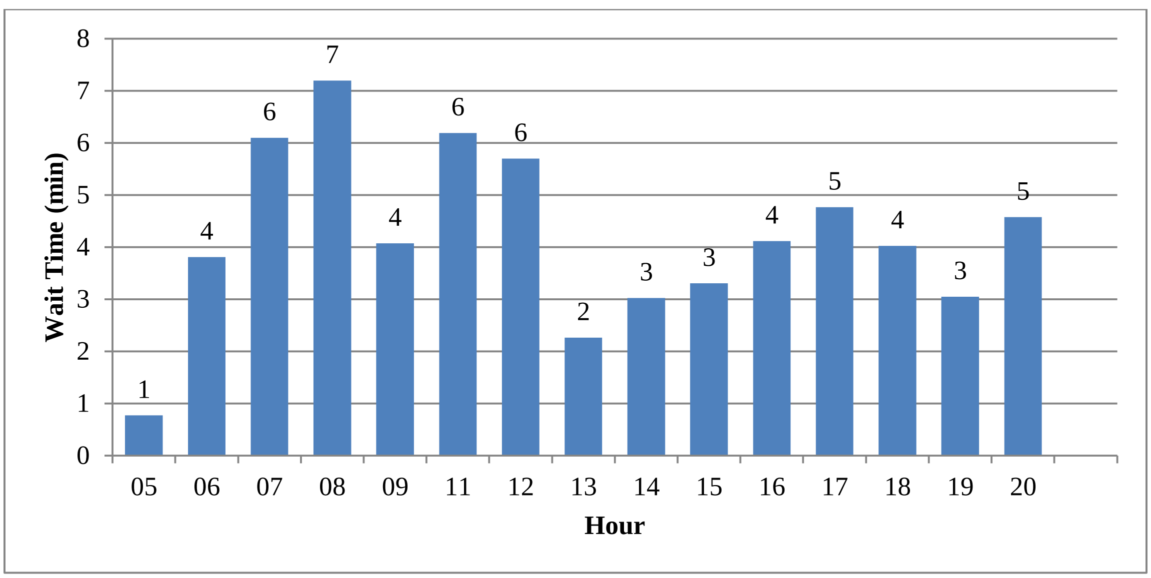


Figure B-29. POV Standard Average Wait Times for Different Hours during Weekdays at Detroit.

Weekend wait time peak is from 11 a.m. to 2 p.m. being 10.3 minutes on average. Off-peak wait times are close to 6 minutes on average, and the average wait times during weekends overall are 7.5 minutes.

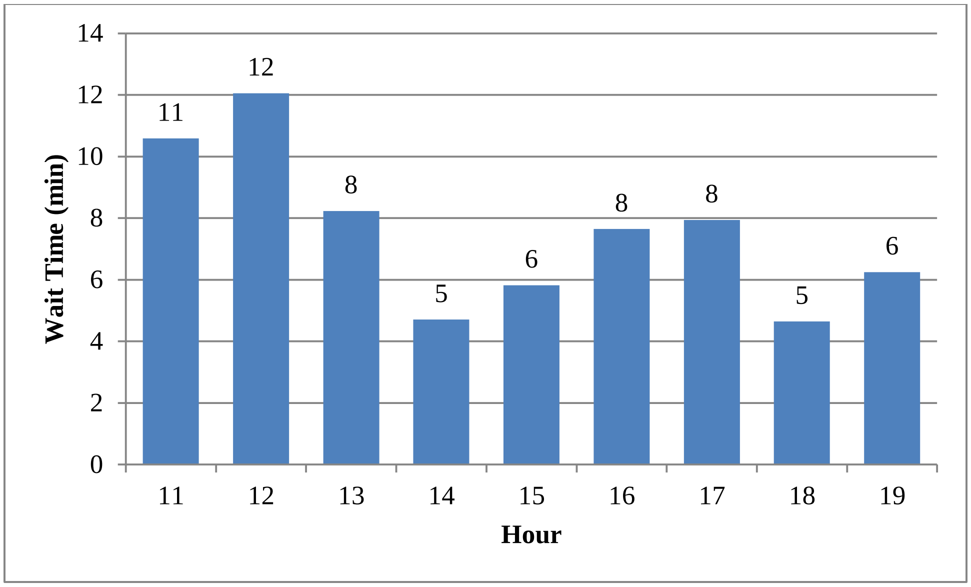


Figure B-30. POV Standard Average Wait Times for Different Hours during Weekends at Detroit.

Table B-42. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	4.20	07:00–13:00	5.85	3.37
Weekend	7.54	11:00–14:00	10.29	6.17

6.3.1.3 Regression and Correlation – POV Standard – Detroit

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.11 and 0.37, respectively. However, wait time is negatively correlated with time, with a correlation coefficient of −0.12. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened, but are not enough to reduce wait time (correlation factor is −0.07). Further, as cycle time increases, wait time decreases. It is feasible that that officers may be spending more time for inspection when wait time is low than when wait times are longer. This evidenced by negative correlation between volumes and cycle times (being −0.66), meaning that as the border crossing becomes more crowded, officers are probably working faster.

Table B-43 presents the correlation matrix.

Table B-43. POV Standard Correlation Matrix at Detroit.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.66	1.00	-	-
Number of Lanes	−0.07	0.02	1.00	-
Wait Time	0.11	−0.12	0.37	1.00

Table B-44 and Table B-45 show the results of regression analysis for wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.004 min, each additional second of cycle time decreases wait time by 0.016 min, and each additional lane opened increases wait time by 1.2 min. This is probably due to the fact that the lane opening is a consequence of increased wait times. This equation explains border process in 53 percent of cases (value of adjusted R square in Table B-45). In other words, this equation explains the variability (fits) of the 53 percent of data provided by CBP. The remaining 47 percent are not explained by this particular equation.

Table B-44. POV Standard Regression Coefficients at Detroit.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0041	0.0017	2.4200	0.0158
Cycle Time	−0.0164	0.0059	−2.7670	0.0058
Number of Lanes	1.1630	0.0905	12.8494	4.38E-34

Table B-45. POV Standard Regression Statistics at Detroit.

Regression Statistics	
Multiple R	0.7280
R Square	0.5300
Adjusted R Square	0.5272
Standard Error	5.5407
Observations	704

6.3.2 POV Ready Analysis – Detroit POE

Vehicle volumes vary between 1 and 97 veh/h, having a mean of 39 veh/h and deviation of 24 veh/h. Cycle time ranges between 30 and 156 seconds, while the mean is 78 seconds and standard deviation is 29 seconds. Number of lanes open is always one. Wait time is between 5 and 15 minutes, and its mean value is less than 8 minutes. Table B-46 shows detailed statistical characteristics.

Table B-46. POV Ready Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Detroit.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	39.35	78.07	1.00	7.92
Standard Error	2.36	2.84	0.03	5.00
Median	39.00	75.38	1.00	5.00
Mode	40.00	84.00	1.00	5.00
Standard Deviation	23.74	28.51	0.00	3.88
Minimum	1.00	30.00	1.00	5.00
Maximum	97.00	156.00	1.00	15.00

6.3.2.1 Volume Analysis – POV Ready – Detroit

Figure B-31 presents average hourly volumes for different days of the week. The volumes are significantly lower on Saturdays (28 veh/h) in comparison to other days of the week. The demand during other six days is relatively consistent, being between 35 veh/h and 43 veh/h.

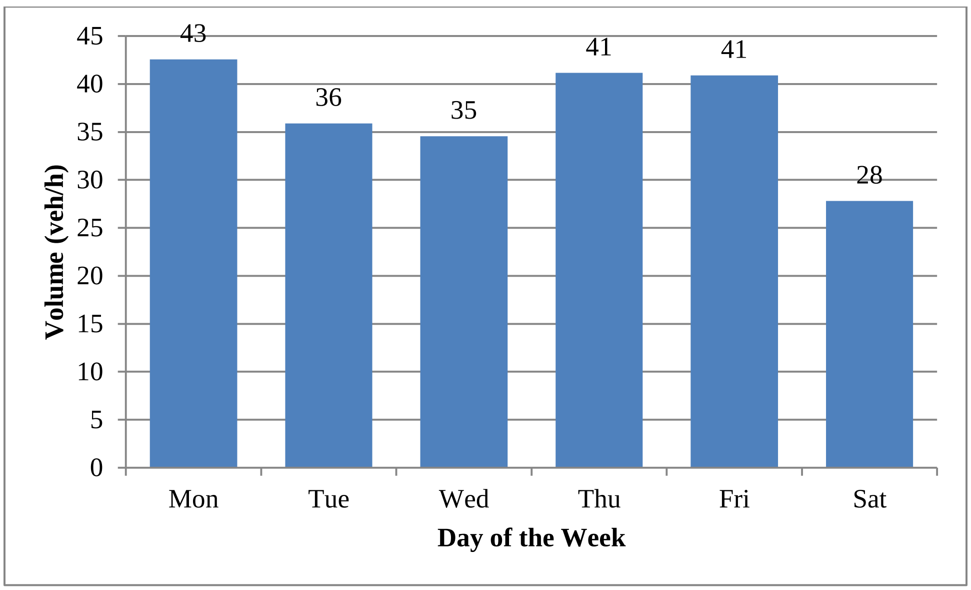


Figure B-31. POV Ready Average Hourly Volume for Each Day of the Week at Detroit.

Average hourly volume for each hour of the day during weekdays and the weekend are presented in Figure B-32 and Figure B-33, respectively. It can be concluded from Figure B-32 that the highest number of vehicles crossing the border from Monday to Friday occurs between 6 a.m. and 9 a.m., with a minimum of approximately 55 veh/h and having a maximum value of 63 veh/h. The afternoon and overnight volumes from 4 p.m. to 6 a.m. are not recorded, but the trend suggests lower volumes during this period.

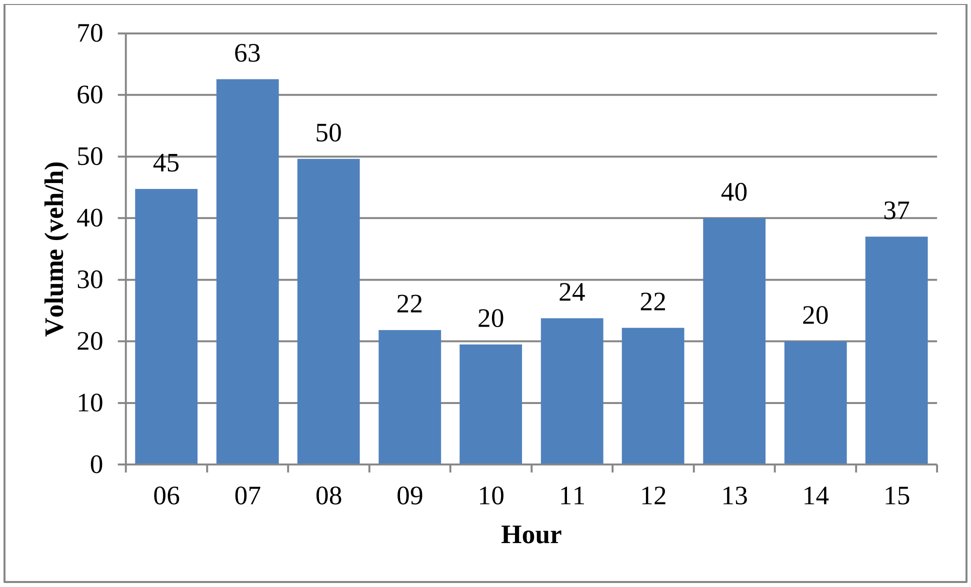


Figure B-32. POV Ready Average Volume for Different Hours of Weekdays at Detroit.

Figure B-33 displays vehicle volumes for different hours of the weekends. The data are recorded only from 6 a.m. until 11 a.m., so the peak volumes cannot be determined.

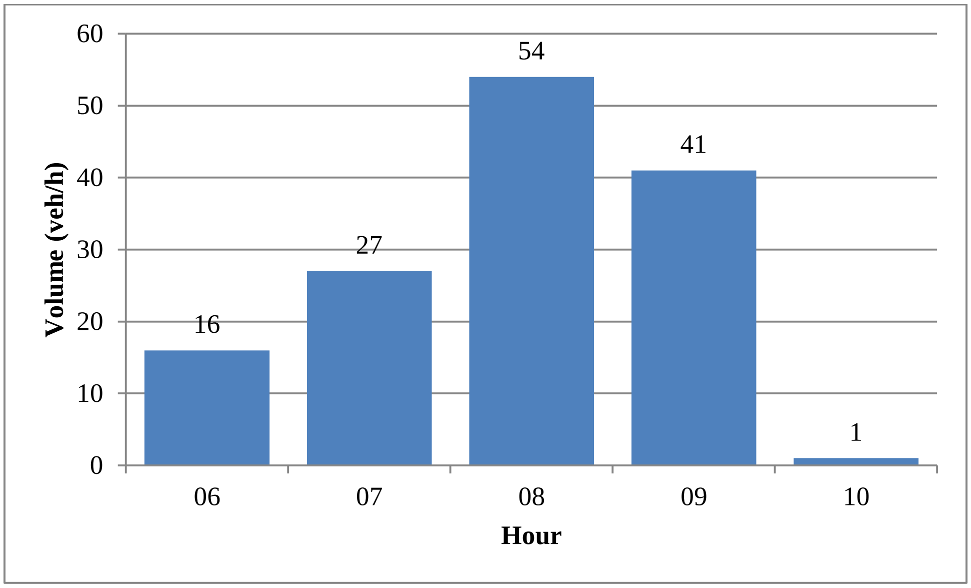


Figure B-33. POV Ready Average Volume for Different Hours of a Weekend at Detroit.

6.3.2.2 Wait Time Analysis – POV Ready – Detroit

Figure B-34 presents average wait time analysis and suggests that vehicles wait longer on Mondays (8 minutes), in comparison to other days of the week (between zero and 3 minutes).

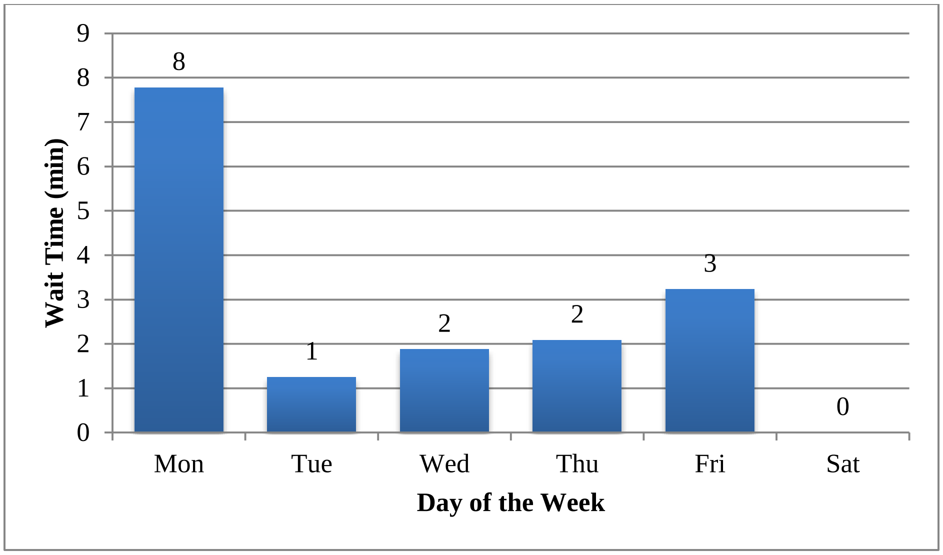


Figure B-34. POV Ready Average Wait Times for Different Days of the Week at Detroit.

Figure B-35 represents average wait times during weekdays for different hours of the day.

Table B-47 summarizes the findings for weekdays, since the weekend data are inconclusive.

Average wait times on weekdays are 3.6 minutes, and the peak hours are from 1 p.m. until 3 p.m., being 15 minutes on average. Off-peak wait times are little over 1 minute on average for weekdays.

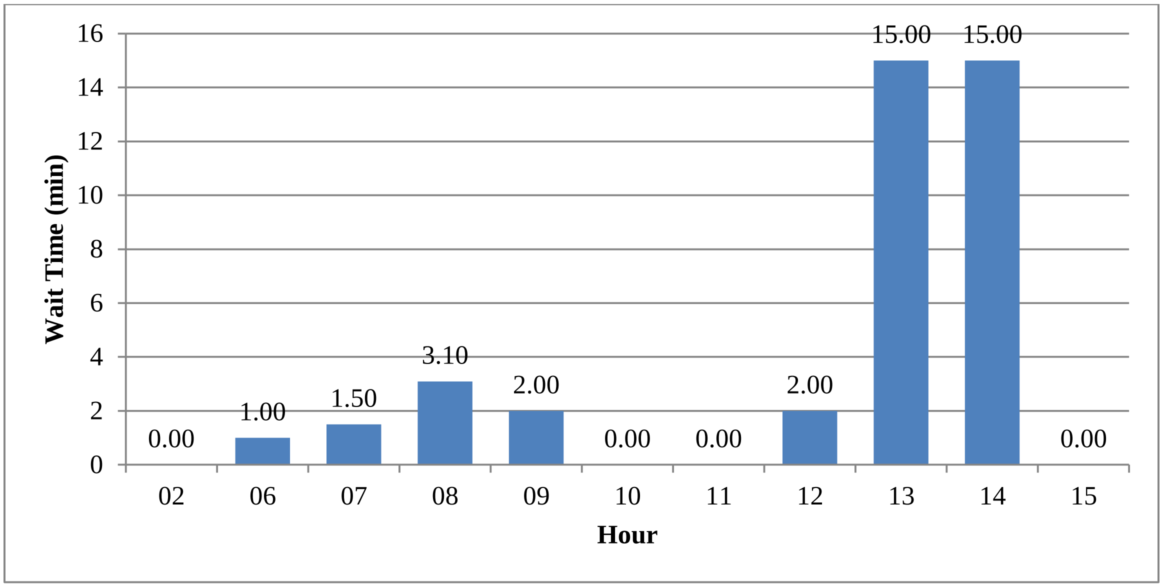


Figure B-35. POV Ready Average Wait Times for Different Hours during Weekdays at Detroit.

Table B-47. POV Ready Distribution of Peak Hours during Weekdays and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	3.60	13:00–15:00	15.00	1.07

6.3.3 POV NEXUS Analysis – Detroit POE

Vehicle volumes vary between 4 and 670 veh/h, having a mean of 145 veh/h and deviation of 101 veh/h. Cycle time ranges between 48 and 197 seconds, while the mean is 106 seconds and standard deviation is 26 seconds. Number of lanes open is between 1 and 6, and the mode is 1, meaning that 1 lane is open in most cases. Wait time is between 2 and 30 minutes, and its mean value is less than 9 minutes. Table B-48 shows detailed statistical characteristics.

Table B-48. POV NEXUS Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Detroit.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	145.19	106.24	1.54	8.77
Standard Error	2.67	0.69	0.04	5.00
Median	132.00	102.08	1.00	5.00
Mode	16.00	132.67	1.00	5.00
Standard Deviation	101.15	26.03	1.15	5.11
Minimum	4.00	48.38	1.00	2.00
Maximum	670.00	197.14	6.00	30.00

6.3.3.1 Volume Analysis – POV NEXUS – Detroit

Figure B-36 presents average hourly volumes for different days of the week. The volumes are significantly higher on Fridays, Saturdays, and Sundays (170 veh/h, 180 veh/h and 163 veh/h, respectively) in comparison to other days of the week. The demand during other four days is relatively consistent, and is between 116 veh/h and 147 veh/h.

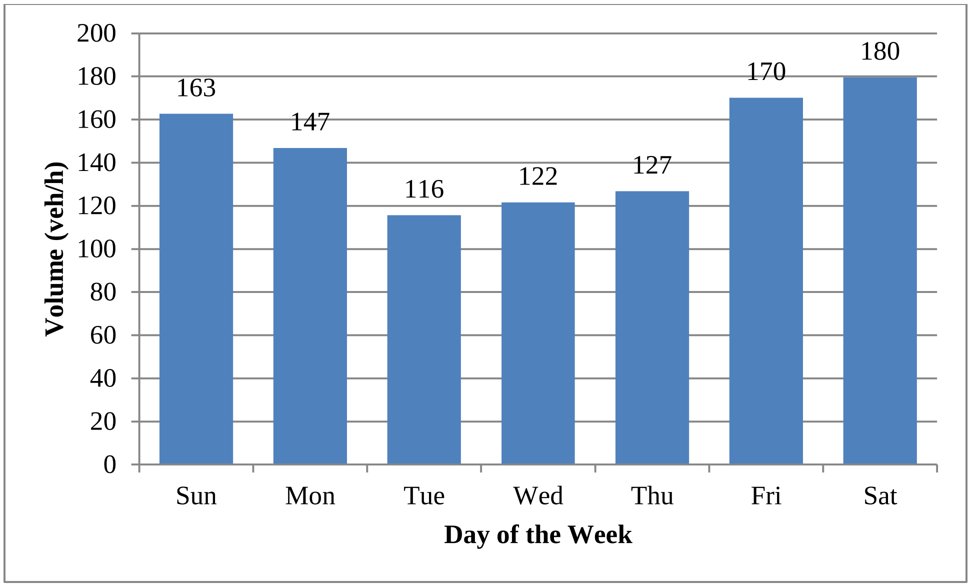


Figure B-36. POV NEXUS Average Hourly Volume for Each Day of the Week at Detroit.

Average hourly volumes for each hour of the day during weekdays and the weekend are presented in Figure B-37 and Figure B-38, respectively. It can be concluded from Figure B-37 that the highest number of vehicles crossing the border from Monday to Friday occurs between 6 a.m. and 10 a.m. with a minimum of just over 200 veh/h and a maximum value of 319 veh/h.

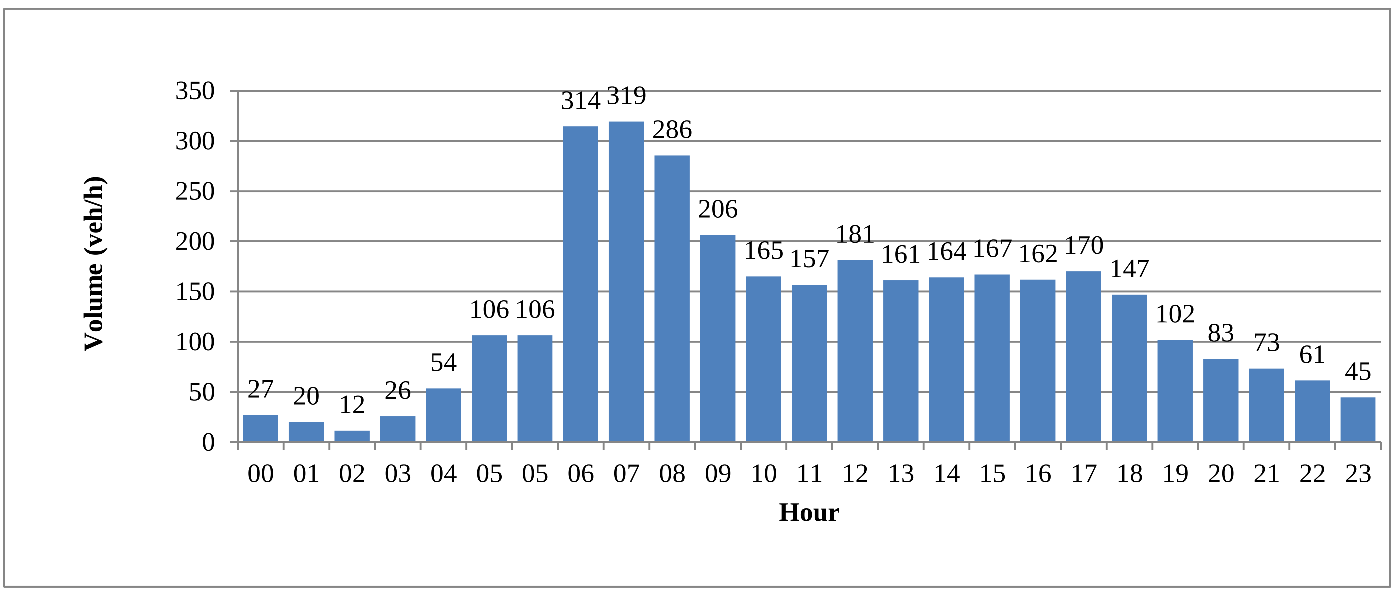


Figure B-37. POV NEXUS Average Volume for Different Hours of Weekdays at Detroit.

Figure B-38 displays vehicle volumes for different hours of the weekends. Peak hours are from 6 a.m. to 7 p.m., with over 200 veh/h in this period.

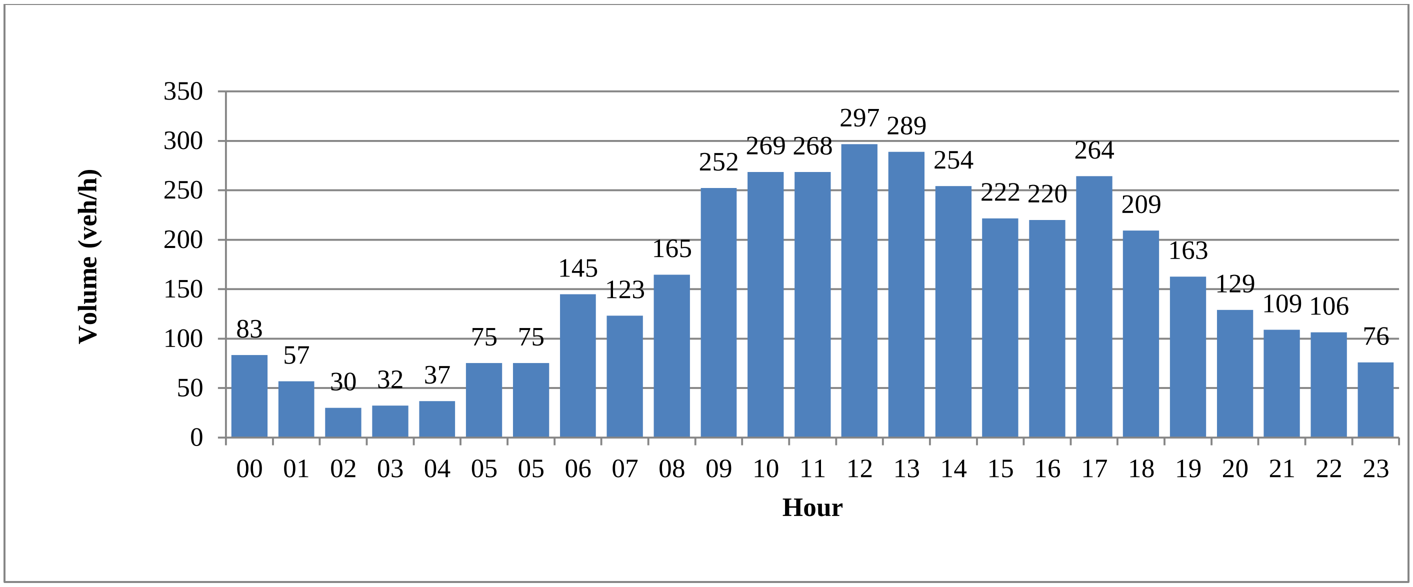


Figure B-38. POV NEXUS Average Volume for Different Hours of a Weekend at Detroit.

6.3.3.2 Wait Time Analysis – POV NEXUS – Detroit

Figure B-39 presents average wait time analysis and suggests that there is no significant difference in wait times depending on the day of the week.

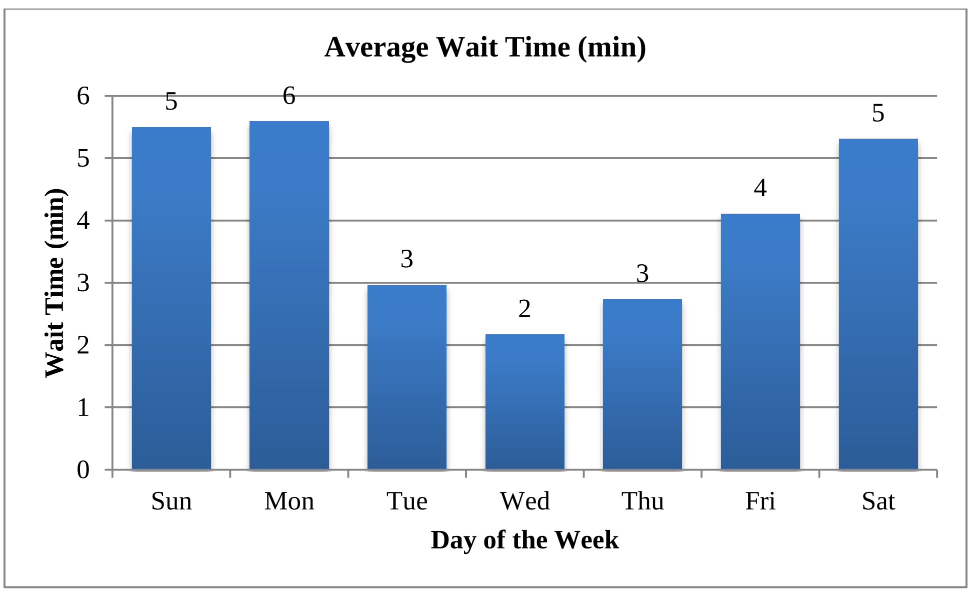


Figure B-39. POV NEXUS Average Wait Times for Different Days of the Week at Detroit.

Figure B-40 represents average wait times during weekdays for different hours of the day, while Figure B-41 is for weekends.

Table B-49 summarizes the findings from both.

Average wait times on weekdays are 2.6 minutes, and the peak hours are from 7 a.m. until 9 a.m., with 6 minute wait times on average. Off-peak wait times are 2 minutes on average for weekdays.

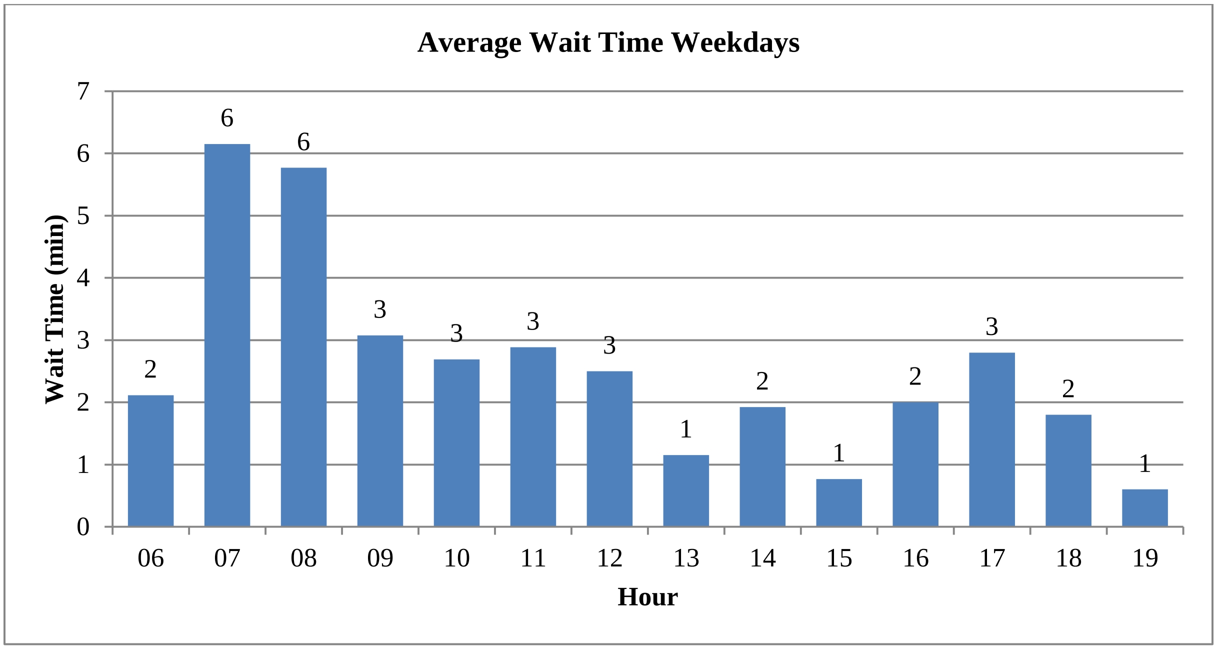


Figure B-40. POV NEXUS Average Wait Times for Different Hours during Weekdays at Detroit.

The weekend wait time peak is from 11 a.m. to 1 p.m. and is 8 minutes on average. Off-peak wait times are 2.6 minutes on average, and the average wait times during weekends are 5 minutes.

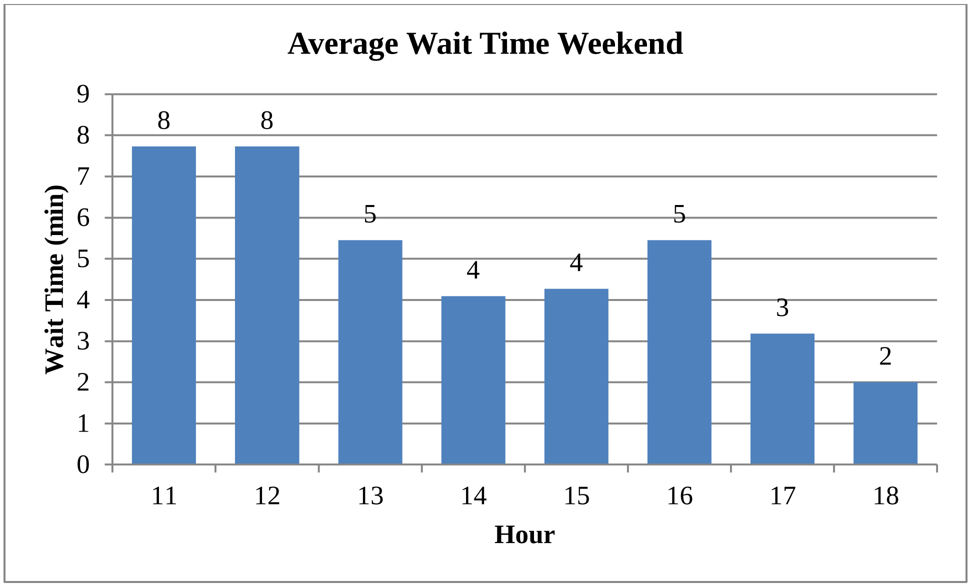


Figure B-41. POV NEXUS Average Wait Times for Different Hours during Weekends at Detroit.

Table B-49. POV NEXUS Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Average Peak Hours Wait Time (min)	Average Off-Peak Wait Time (min)
Weekdays	2.59	07:00–09:00	5.96	2.03
Weekend	4.99	11:00–17:00	5.79	2.59

6.3.3.3 Regression and Correlation – POV NEXUS – Detroit

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.39 and 0.12, respectively. However, wait time is negatively correlated with cycle time, with a correlation coefficient of −0.12. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.41). Further, as cycle time increases, wait time decreases. It is feasible that that officers may be spending more time for inspection when wait time is low than when wait times are longer. This is evidenced by negative correlation between volumes and cycle times (being −0.72), meaning that as the border crossing becomes more crowded, officers are probably working faster. As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.58). Table B-50 presents the correlation matrix.

Table B-50. POV NEXUS Correlation Matrix at Detroit.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00			
Cycle Time	−0.72	1.00		
Number of Lanes	0.41	−0.58	1.00	
Wait Time	0.39	−0.12	0.12	1.00

Table B-51 and Table B-52 explain regression between wait times (dependent variable) and independent variables (vehicle volumes and cycle times). Each additional vehicle increases wait time by 0.002 min, additional second of cycle time increases wait time by 0.03 min. This equation explains border process in 78 percent of cases (value of adjusted R square in Table B-52). In other words, this equation explains the variability (fits) of the 78 percent of data provided by CBP. The remaining 22 percent are not explained by this particular equation.

Table B-51. POV NEXUS Regression Coefficients at Detroit.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0248	0.0027	9.1473	1.15E-17
Cycle Time	0.0328	0.0072	4.5423	8.22E-06

Table B-52. POV NEXUS Regression Statistics at Detroit.

Regression Statistics	
Multiple R	0.8833
R Square	0.7801
Adjusted R Square	0.7759
Standard Error	4.7731
Observations	287

6.3.4 COV Standard Analysis – Detroit POE

Vehicle volumes vary between 1 and 368 veh/h, having a mean of 185 veh/h and deviation of 87 veh/h. Cycle time ranges between 32 and 152 seconds, while the mean is 77 seconds and standard deviation is 13 seconds. Number of lanes open is between 2 and 12, and the mode is 8, meaning that 8 lanes are open in most cases. Wait time is between 2 and 85 minutes, and its mean value is less than 15 minutes. Table B-53 shows detailed statistical characteristics.

Table B-53. COV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Detroit.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	185.30	76.76	6.68	14.76
Standard Error	2.33	0.36	0.07	10.00
Median	170.00	74.60	7.00	10.00
Mode	284.00	68.00	8.00	5.00
Standard Deviation	87.31	13.43	1.42	11.76
Minimum	1.00	31.97	2.00	2.00
Maximum	368.00	152.08	12.00	85.00

6.3.4.1 Volume Analysis – COV Standard – Detroit

Figure B-42 presents average hourly volumes for different days of the week. The volumes are significantly higher on weekdays (between 176 veh/h and 235 veh/h) in comparison to weekends (88 veh/h and 113 veh/h).

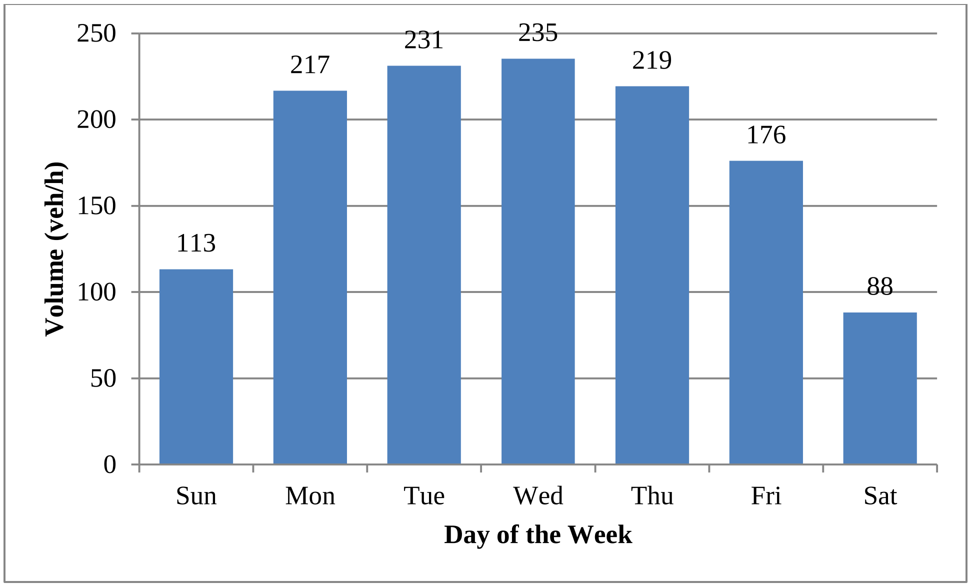


Figure B-42. COV Standard Average Hourly Volume for Each Day of the Week at Detroit.

Average hourly volumes for each hour of the day during weekdays and weekend are presented in Figure B-43 and Figure B-44, respectively. It can be concluded from Figure B-43 that the highest number of vehicles crossing the border from Monday to Friday occurs between 6 a.m. and 8 p.m. with the minimum being approximately 200 veh/h and a maximum value of 294 veh/h.

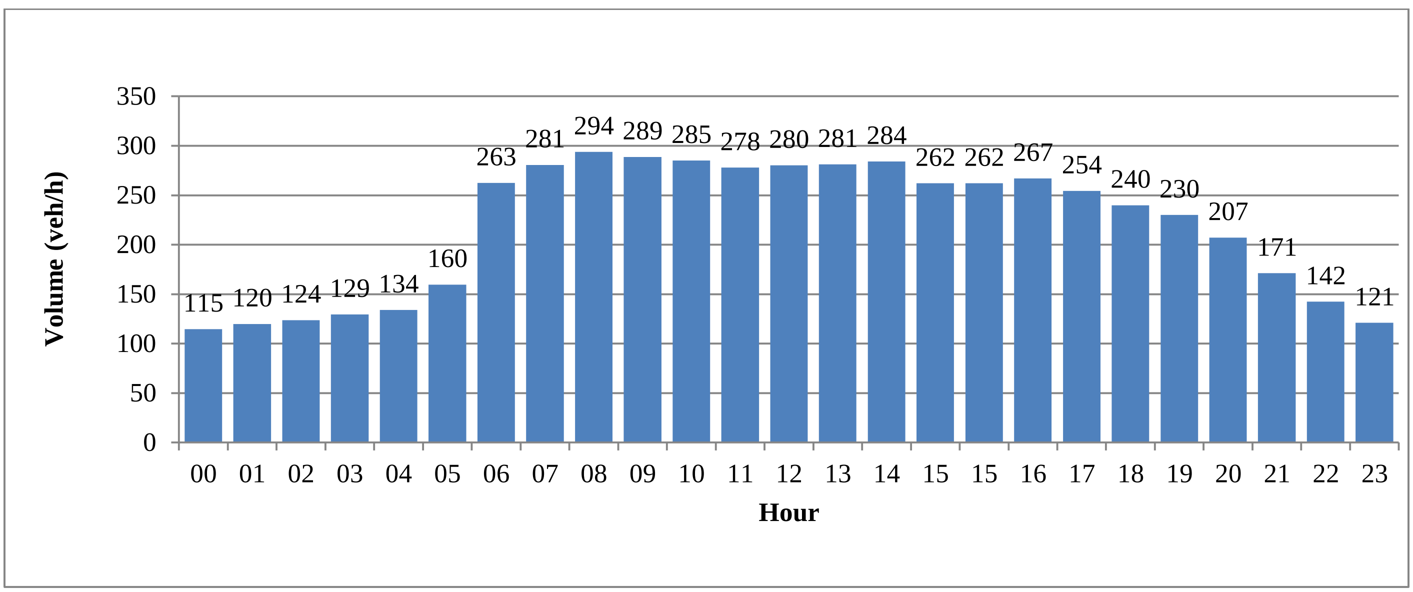


Figure B-43. COV Standard Average Volume for Different Hours of Weekdays at Detroit.

Figure B-44 displays vehicle volumes for different hours of the weekends. The spread of volumes is relatively similar to the weekdays. However, weekend volumes have a lower maximum, reaching 156 veh/h. Peak hours are from 12 p.m. to 8 p.m.

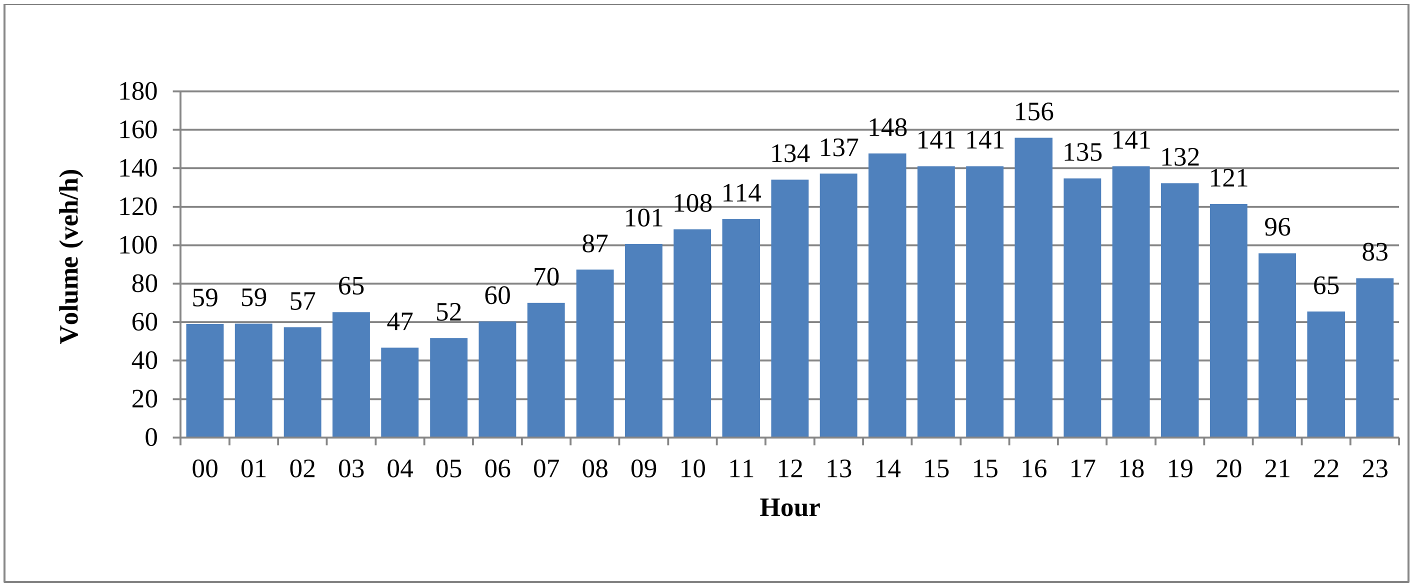


Figure B-44. COV Standard Average Volume for Different Hours of a Weekend at Detroit.

6.3.4.2 Wait Time Analysis – COV Standard – Detroit

Figure B-45 presents average wait time analysis and suggests that vehicles wait longer on Tuesdays and Wednesdays, in comparison to other days of the week. The shortest wait times are on Saturdays, being 3 minutes on average, and longest are 15 minutes on average on Wednesdays.

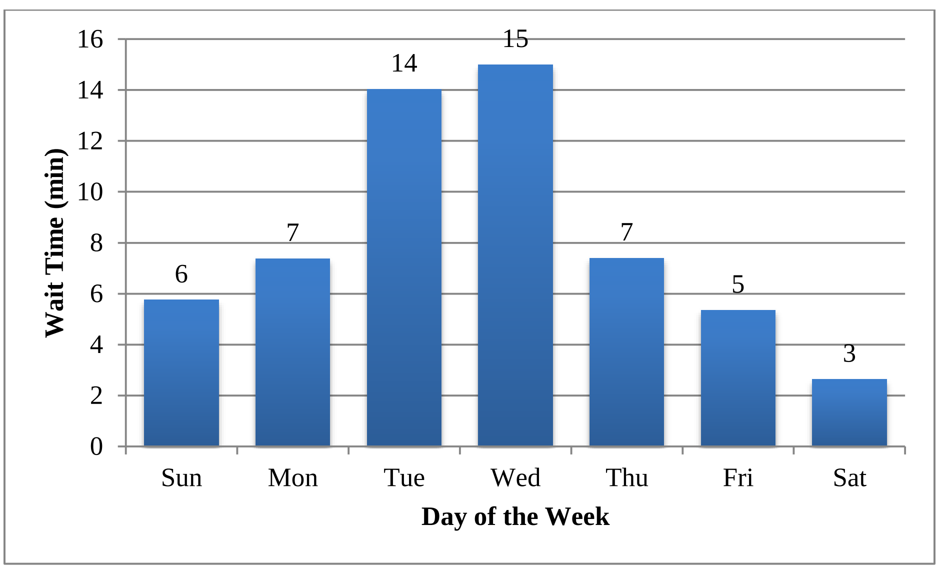


Figure B-45. COV Standard Average Wait Times for Different Days of the Week at Detroit.

Figure B-46 represents average wait times during weekdays for different hours of the day, while Figure B-47 is for weekends. **Error! Reference source not found.** summarizes the findings from both.

Average wait times on weekdays are little over 15 minutes, and the peak hours are from 2 p.m. until 8 p.m., being 14.5 minutes on average. Off-peak wait times are 7 minutes on average for weekdays.

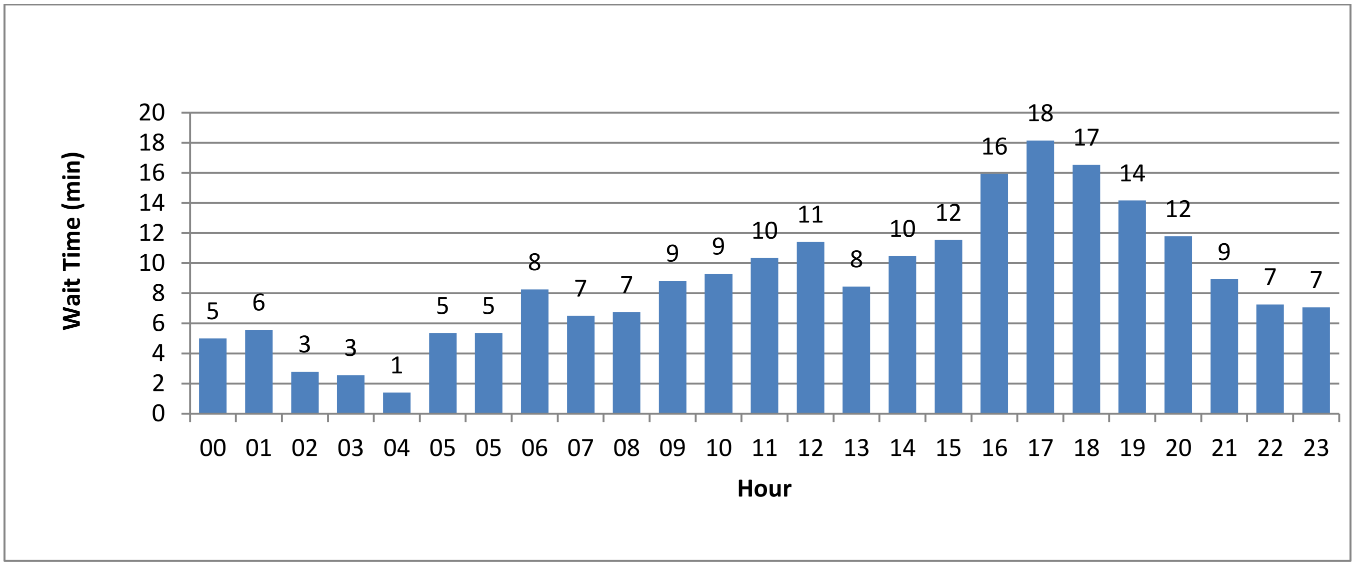


Figure B-46. COV Standard Average Wait Times for Different Hours during Weekdays at Detroit.

Weekend wait time peak is from 3 p.m. to 8 p.m. being less than 9 minutes on average. Off-peak wait times are little over 2 minutes, and the average wait times during weekends are 6.8 minutes.

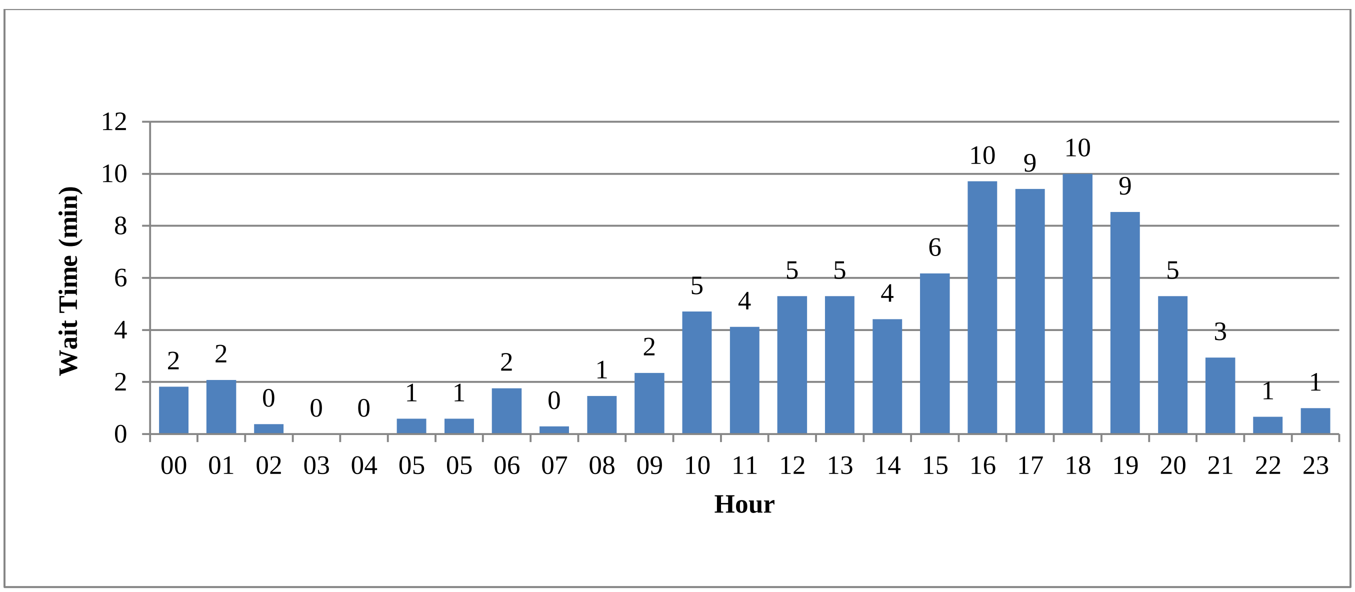


Figure B-47. COV Standard Average Wait Times for Different Hours during Weekends at Detroit.

Table B-54. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Detroit.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	11.20	14:00–20:00	14.48	7.00
Weekend	6.80	15:00–20:00	8.76	2.25

6.3.4.3 Regression and Correlation – COV Standard – Detroit

Wait time is positively correlated with volume, cycle time, and number of open lanes, having correlation coefficients of 0.44, 0.09, and 0.36 respectively.

This shows that as volume, cycle time, and number of open lanes increase, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times are at peak levels. As volume increases, additional lanes are being opened (correlation factor is 0.75). Further, as volume increases, cycle time decreases (correlation factor is −0.26). It is feasible that the officers at the border devote more of their time to inspection when volume is low, and they are trying to process vehicles faster if demand increases. Table B-55 presents the correlation matrix.

Table B-55. COV Standard Correlation Matrix at Detroit.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.26	1.00	-	-
Number of Lanes	0.75	−0.05	1.00	-
Wait Time	0.44	0.09	0.36	1.00

Table B-56 and

Table B-57 explain regression between wait times (dependent variable) and independent variables (vehicle volumes and cycle times). Each additional vehicle increases wait time by 0.017 min, every additional second of cycle time increases wait time by 0.13 min. This equation explains border process in 45 percent of cases (value of adjusted R square in

Table B-57). In other words, this equation explains the variability (fits) of the 45 percent of data provided by CBP. The remaining 55 percent are not explained by this particular equation.

Table B-56. COV Standard Regression Coefficients at Detroit.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0165	0.0055	3.0199	0.0026
Cycle Time	0.1255	0.0144	8.6895	2.49E-17

Table B-57. COV Standard Regression Statistics at Detroit.

Regression Statistics	
Multiple R	0.6688
R Square	0.4473
Adjusted R Square	0.4452
Standard Error	14.0470
Observations	714

6.4 DETAILED ANALYSIS – MARIPOSA POE

6.4.1 POV Standard Analysis – Mariposa POE

Vehicle volumes vary between 2 and 442 veh/h, having a mean of 213 veh/h and a deviation of 54 veh/h. Cycle time ranges between 44 and 144 seconds, while the mean is 88 seconds and the standard deviation is 12 seconds. Number of lanes open is between 2 and 10, and the mode is 5, meaning that 5 lanes are open in most cases. Wait time is between 2 and 75 minutes, and its mean value is less than 26 minutes. Table B-58 shows detailed statistical characteristics.

Table B-58. POV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Mariposa.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	212.55	87.67	5.19	25.74
Standard Error	1.72	0.39	0.09	25.00
Median	213.00	87.29	5.00	25.00
Mode	194.00	85.67	5.00	5.00
Standard Deviation	53.82	12.37	0.77	16.45
Minimum	2.00	44.20	2.00	2.00
Maximum	442.00	143.59	10.00	75.00

6.4.1.1 Volume Analysis – POV Standard – Mariposa

Figure B-48 presents average hourly volumes for different days of the week. The volumes are relatively consistent over different days of the week, being between 205 veh/h and 218 veh/h.

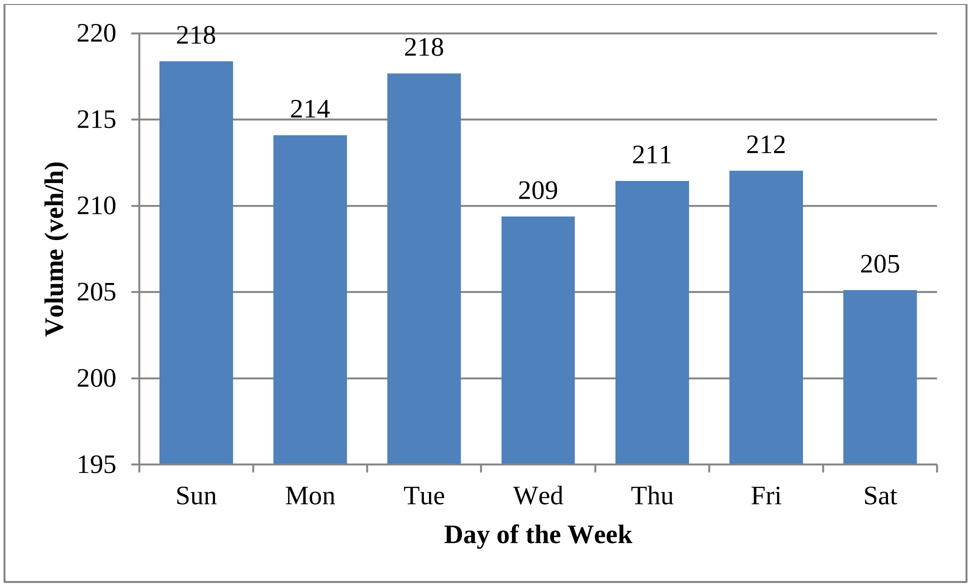


Figure B-48. POV Standard Average Hourly Volume for Each Day of the Week at Mariposa.

6.4.1.2 Wait Time Analysis – POV Standard – Mariposa

Figure B-49 presents average wait time analysis and suggests that vehicles wait longer on Fridays, Saturdays, Sundays, and Mondays, in comparison to other days of the week. The shortest wait times are on Thursdays, and are 14 minutes on average, and longest are 24 minutes on average on Fridays and Mondays.

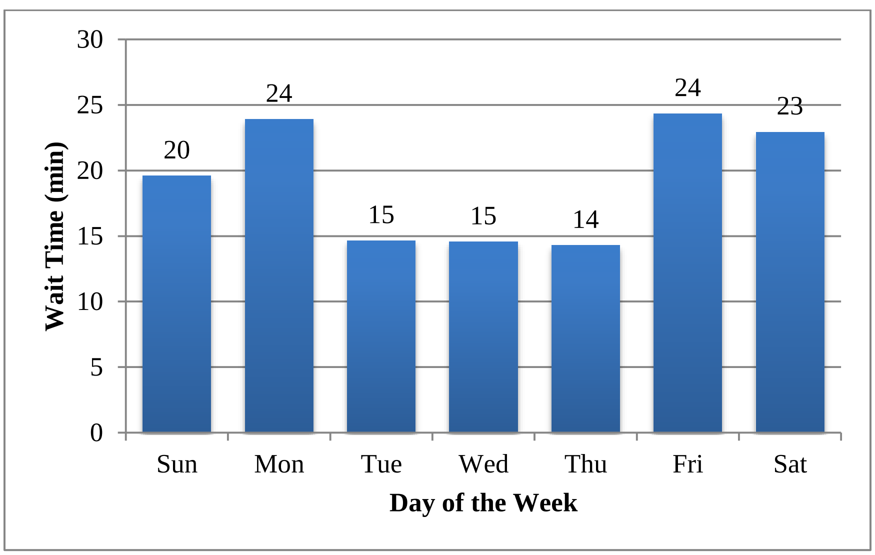


Figure B-49. POV Standard Average Wait Times for Different Days of the Week at Mariposa.

Figure B-50 represents average wait times during weekdays for different hours of the day, while Figure B-51 is for weekends.

Table B-59 summarizes the findings from both.

Average wait times on weekdays are little over 18 minutes, but the peak hour cannot be determined, since wait times are relatively consistent over the weekdays.

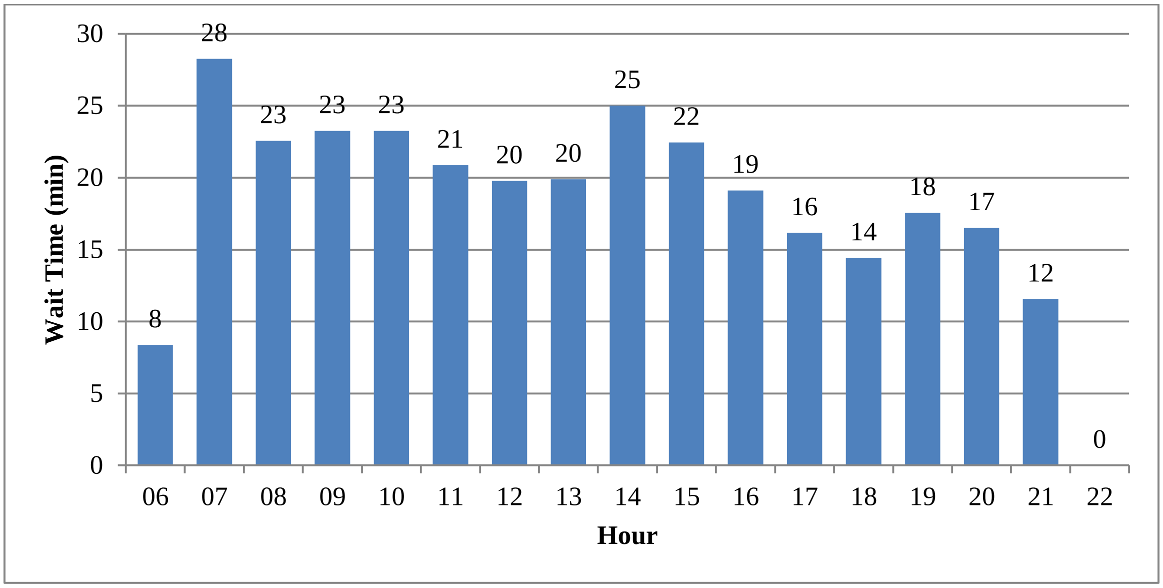


Figure B-50. POV Standard Average Wait Times for Different Hours during Weekdays at Mariposa.

Weekend wait time peak is from 2 p.m. to 8 p.m. reaching 39 minutes. Off-peak wait times averaged 14 minutes, and during weekends were 21 minutes on average.

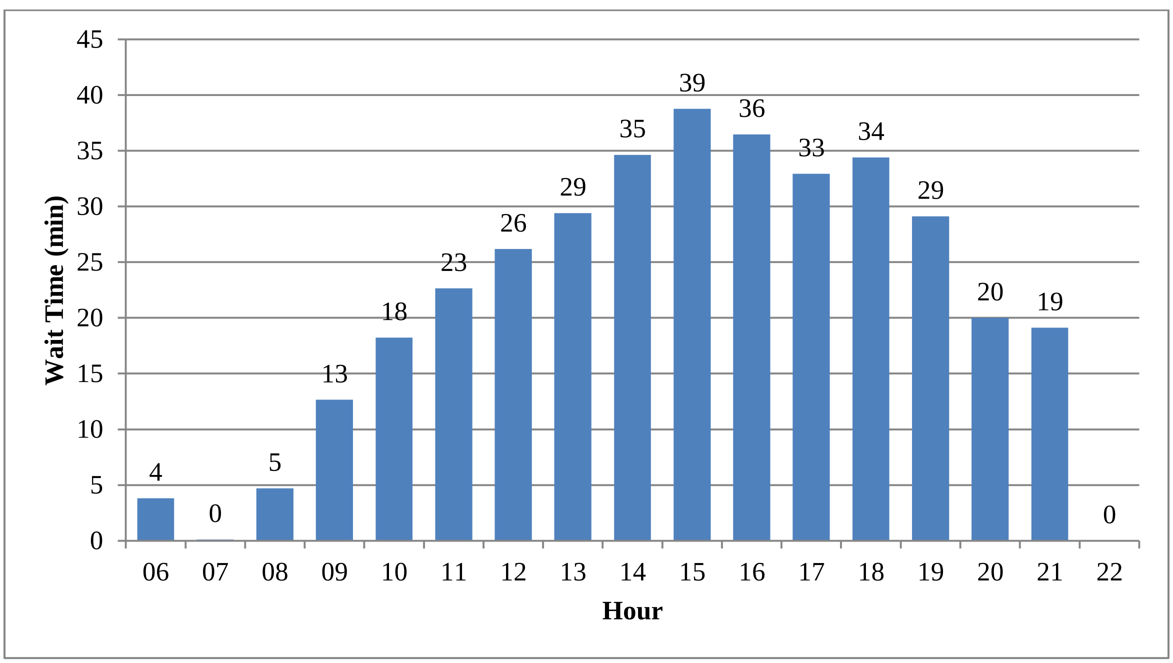


Figure B-51. POV Standard Average Wait Times for Different Hours during Weekends at Mariposa.

Table B-59. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Mariposa.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	18.18	N/A	N/A	N/A
Weekend	21.37	14:00–20:00	34.39	14.26

6.4.1.3 Regression and Correlation – POV Standard – Mariposa

Wait time is positively correlated with volume, cycle time, and number of open lanes, having correlation coefficients of 0.17, 0.07, and 0.07, respectively. Lanes are being opened as volume increases (correlation factor is 0.40). As volume increases, cycle time decreases (correlation factor is −0.53), meaning that as the border crossing becomes more crowded, officers are probably working faster. Table B-60 presents the correlation matrix.

Table B-60. POV Standard Correlation Matrix at Mariposa.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.53	1.00	-	-
Number of Lanes	0.40	0.17	1.00	-
Wait Time	0.17	0.07	0.07	1.00

Table B-61 and

Table B-62 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.1 min, each additional second of cycle time increases wait time by 0.26 min, and each additional lane opened decreases wait time by 3.5 min. This equation explains border process in 64 percent of cases (value of adjusted R square in

Table B-62). In other words, this equation explains the variability (fits) of the 64 percent of data provided by CBP. The remaining 36 percent are not explained by this particular equation.

Table B-61. POV Standard Regression Coefficients at Mariposa.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0980	0.0140	6.9855	5.69E-12
Cycle Time	0.2251	0.0389	5.7879	9.99E-09
Number of Lanes	−3.5079	1.0072	−3.4828	0.0005

Table B-62. POV Standard Regression Statistics at Mariposa.

Regression Statistics	
Multiple R	0.8036
R Square	0.6457
Adjusted R Square	0.6437
Standard Error	17.0553
Observations	862

6.4.2 COV Standard Analysis – Mariposa POE

Vehicle volumes vary between 1 and 260 veh/h, having a mean of 99 veh/h and a deviation of 49 veh/h. Cycle time ranges between 22 and 524 seconds, while the mean is 90 seconds and the standard deviation is 26 seconds. Number of lanes open is between 1 and 7, and the mode is 4, meaning that 4 lanes are open in most cases. Wait time is between 5 and 120 minutes, and its mean value is over 23 minutes. Table B-63 shows detailed statistical characteristics.

Table B-63. COV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Mariposa.

	Volume (veh/h)	**Cycle Time (s)**	**Number of Lanes**	**Wait Time (min)**
Mean	98.73	89.86	3.94	23.43
Standard Error	1.96	1.02	0.09	20.00
Median	107.00	87.69	4.00	20.00
Mode	1.00	62.00	4.00	5.00
Standard Deviation	49.18	25.52	1.54	17.55
Minimum	1.00	22.00	1.00	5.00
Maximum	260.00	523.50	7.00	120.00

6.4.2.1 Volume Analysis – COV Standard – Mariposa

Figure B-52 presents average hourly volumes for different days of the week. The volumes are significantly lower on Sundays (32 veh/h) in comparison to other days of the week (between 88 veh/h and 106 veh/h).

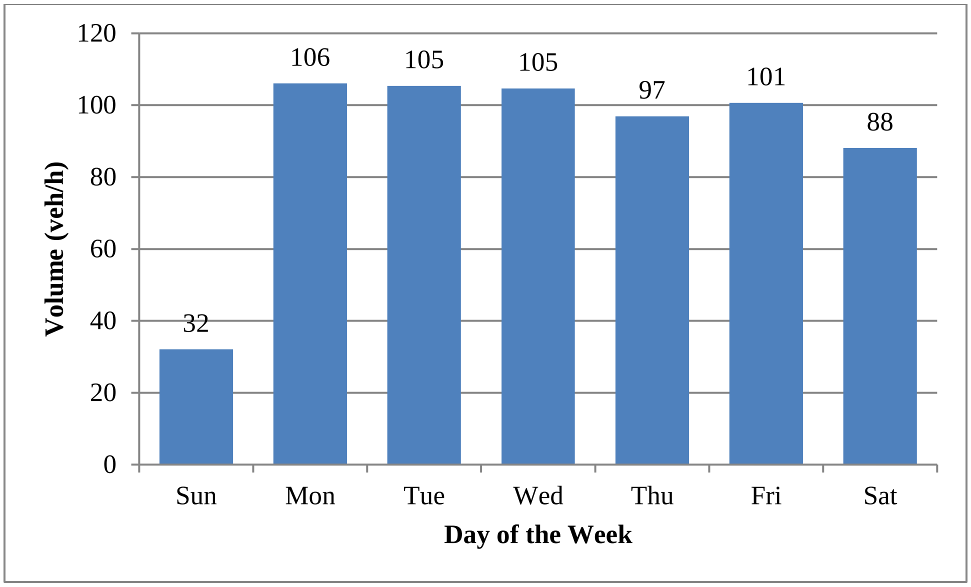


Figure B-52. COV Standard Average Hourly Volume for Each Day of the Week at Mariposa.

Average hourly volume for each hour of the day during weekdays and the weekend are presented in Figure B-53 and Figure B-54, respectively. It can be concluded from Figure B-53 that the highest number of vehicles crossing the border from Monday to Friday occurs between 11 a.m. and 6 p.m. and average around 130 veh/h with a maximum value of 148 veh/h. The overnight volumes from 7 p.m. to 6 a.m. are not recorded, but the trend suggests very low volumes during this period.

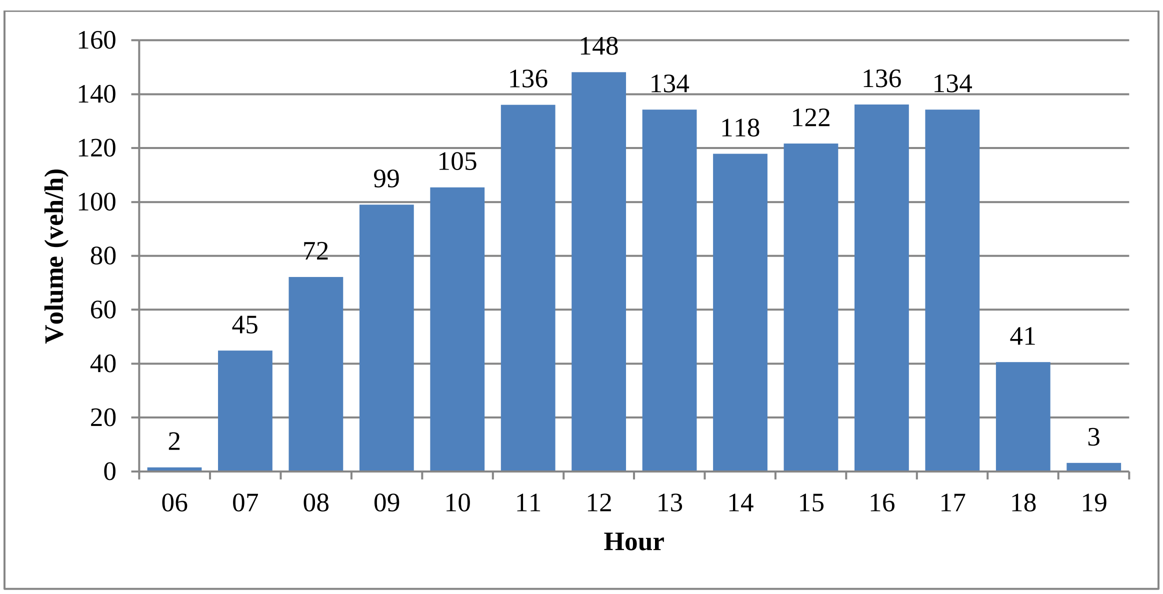


Figure B-53. COV Standard Average Volume for Different Hours of Weekdays at Mariposa.

Figure B-54 displays vehicle volumes for different hours of the weekends. The spread of volumes is relatively similar to the weekdays. However, weekend volumes have lower maximums, reaching 104 veh/h.

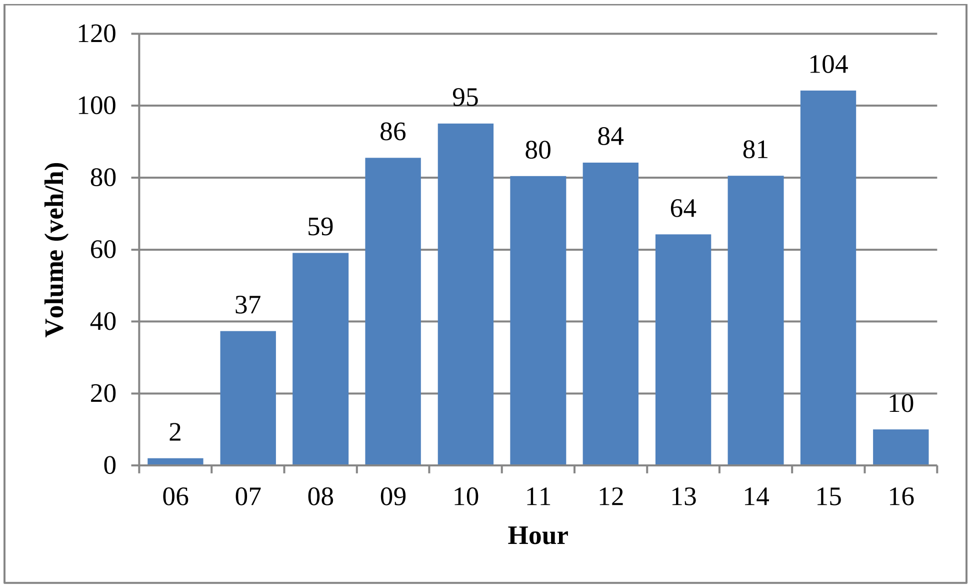


Figure B-54. COV Standard Average Volume for Different Hours of a Weekend at Mariposa.

6.4.2.2 Wait Time Analysis – COV Standard – Mariposa

Figure B-55 presents average wait time analysis and suggests that vehicles wait longer on Mondays and Tuesdays, in comparison to other days of the week. The shortest wait times are on Sundays, being 3 minutes on average, and longest are 24 minutes on average on Tuesdays.

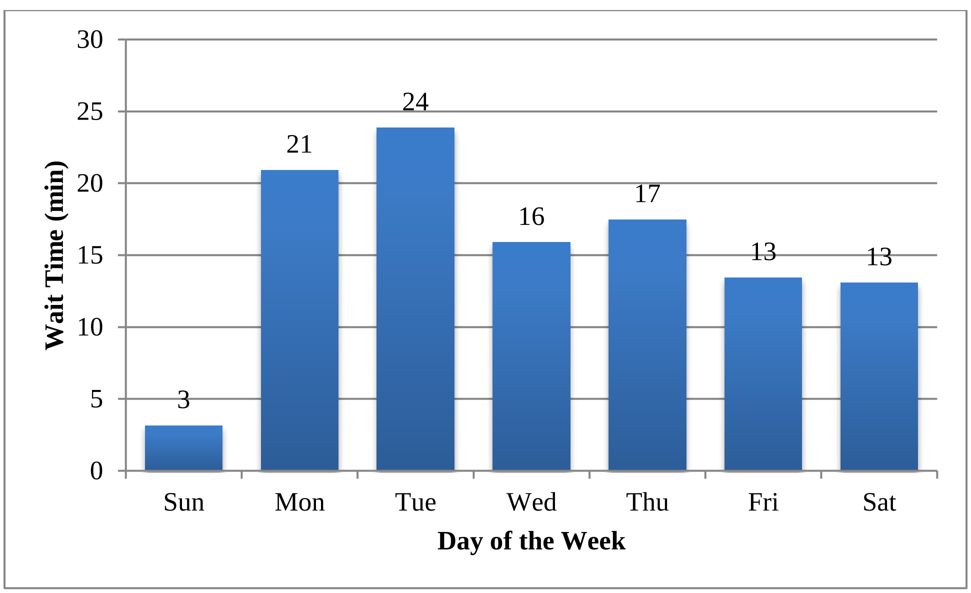


Figure B-55. COV Standard Average Wait Times for Different Days of the Week at Mariposa.

Figure B-56 represents average wait times during weekdays for different hours of the day, while Figure B-57 is for weekends. Table B-64 summarizes the findings from both.

Average wait times on weekdays are a little over 11 minutes, and the peak hours are from 10 a.m. until 2 p.m., being close to 24 minutes on average. Off-peak wait times are 6.4 minutes on average for weekdays.

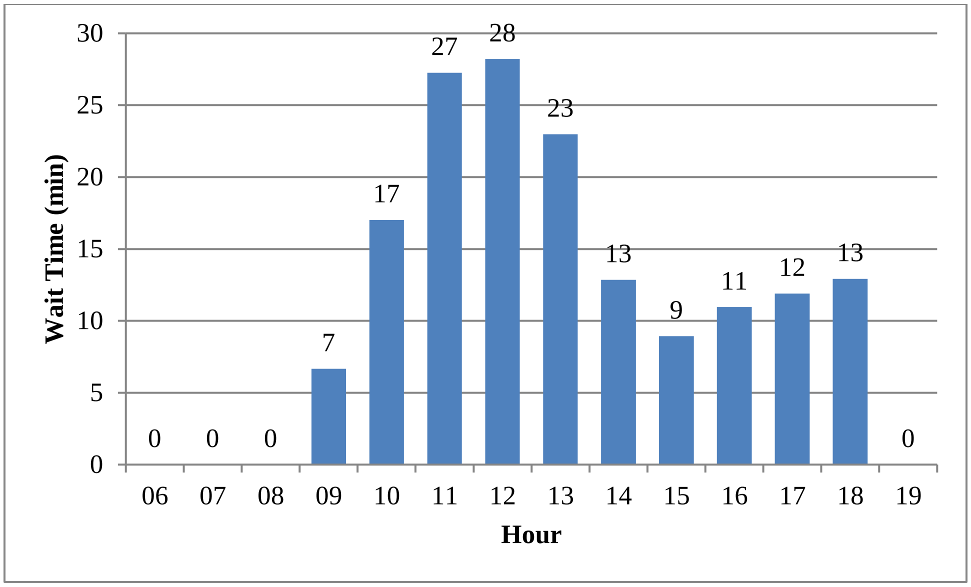


Figure B-56. COV Standard Average Wait Times for Different Hours during Weekdays at Mariposa.

Weekend wait time peak is from 10 a.m. to 1 p.m. being over 15 minutes on average. Off-peak wait times are 4.3 minutes, and the average wait times during weekends are 7.3 minutes.

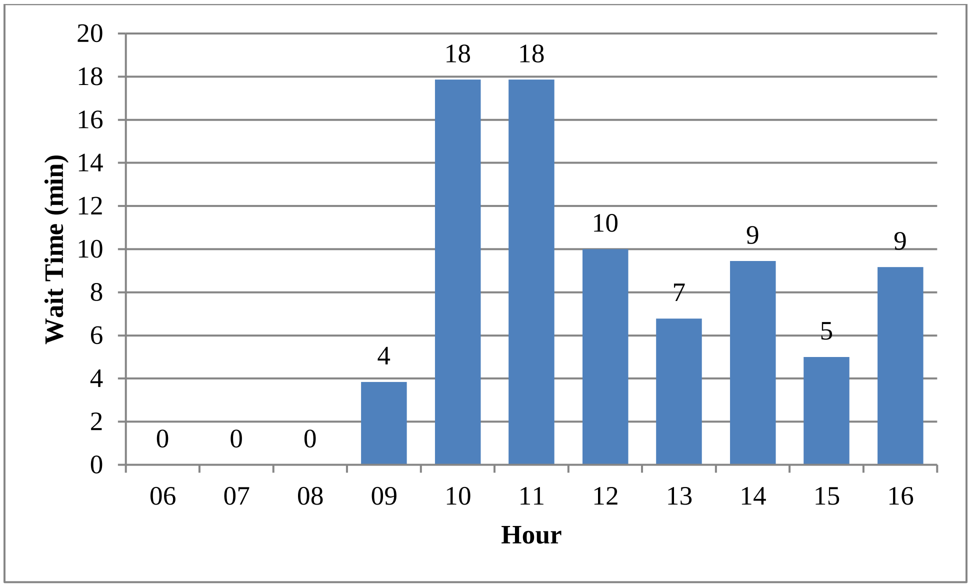


Figure B-57. COV Standard Average Wait Times for Different Hours during Weekends at Mariposa.

Table B-64. COV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Mariposa.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	11.41	10:00–14:00	23.87	6.42
Weekend	7.27	10:00–13:00	15.24	4.28

6.4.2.3 Regression and Correlation – COV Standard – Mariposa

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.40 and 0.29, respectively. However, wait time is negatively correlated with wait time with a correlation coefficient of −0.01. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being opened as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.34). Negative correlation between volumes and cycle times (being −0.23) shows that as the border crossing becomes more crowded, officers are probably working faster. Table B-65 presents the correlation matrix.

Table B-65. COV Standard Correlation Matrix at Mariposa.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.23	1.00	-	-
Number of Lanes	0.34	0.00	1.00	-
Wait Time	0.40	−0.01	0.29	1.00

Table B-66 and

Table B-67 explain regression between wait times (dependent variable) and independent variables (vehicle volumes and number of open lanes). Each additional vehicle increases wait time by 0.12 min, and each additional lane opened increases wait time by 1.3 min. This equation explains border process in 55 percent of cases (value of adjusted R square in

Table B-67). In other words, this equation explains the variability (fits) of the 55 percent of data provided by CBP. The remaining 45 percent are not explained by this particular equation.

Table B-66. COV Standard Regression Coefficients at Mariposa.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.1158	0.0160	7.2437	1.88E-12
Number of Lanes	1.2606	0.4383	2.8759	0.0042

Table B-67. COV Standard Regression Statistics at Mariposa.

Regression Statistics	
Multiple R	0.7438
R Square	0.5532
Adjusted R Square	0.5501
Standard Error	16.5752
Observations	457

6.5 DETAILED ANALYSIS – SAN YSIDRO POE

6.5.1 POV Standard Analysis – San Ysidro POE

Vehicle volumes vary between 20 and 1373 veh/h, having a mean of 592 veh/h and a deviation of 309 veh/h. Cycle time ranges between 18 and 132 seconds, while the mean is 38 seconds and standard deviation is 17 seconds. Number of lanes open is between 2 and 18, and the mode is 9, meaning that 9 lanes are open in most cases. Wait time is between 3 and 150 minutes, and its mean value is over 46 minutes. Table B-68 shows detailed statistical characteristics.

Table B-68. POV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at San Ysidro.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	591.88	38.33	8.58	46.10
Standard Error	8.18	0.44	0.09	40.00
Median	646.00	33.51	9.00	40.00
Mode	738.00	30.52	9.00	20.00
Standard Deviation	309.88	16.84	2.29	29.52
Minimum	20.00	17.92	2.00	3.00
Maximum	1373.00	131.79	18.00	150.00

6.5.1.1 Volume Analysis – POV Standard – San Ysidro

Figure B- 58 presents average hourly volumes for different days of the week. The volumes are significantly lower on Sundays (468 veh/h) in comparison to other days of the week (between 584 veh/h and 644 veh/h).

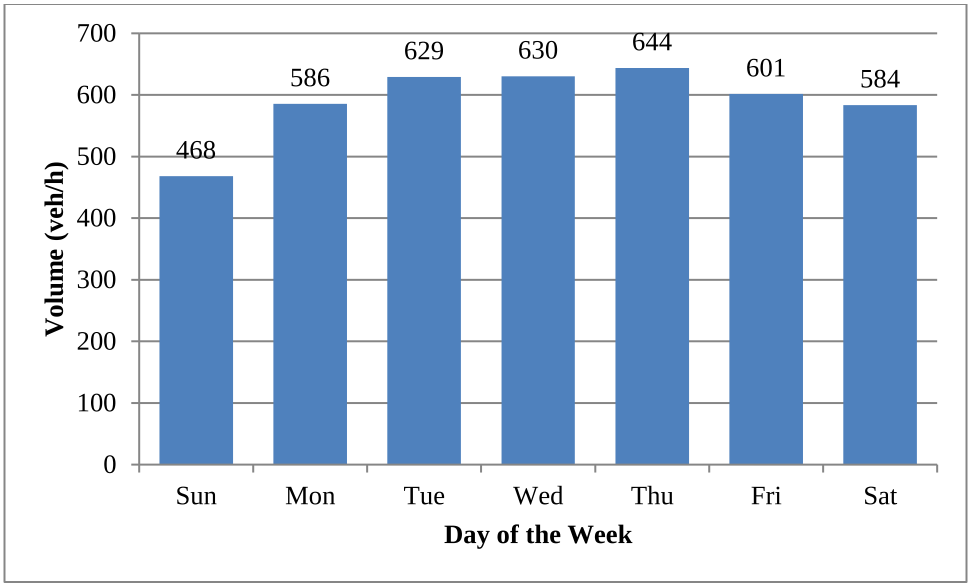


Figure B- 58. POV Standard Average Hourly Volume for Each Day of the Week at San Ysidro.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-59 and Figure B-60, respectively. It can be concluded from Figure B-59 that the highest number of vehicles crossing the border from Monday to Friday occurs between 5 a.m. and 1 p.m. being over 800 veh/h and having a maximum value of 1066 veh/h.

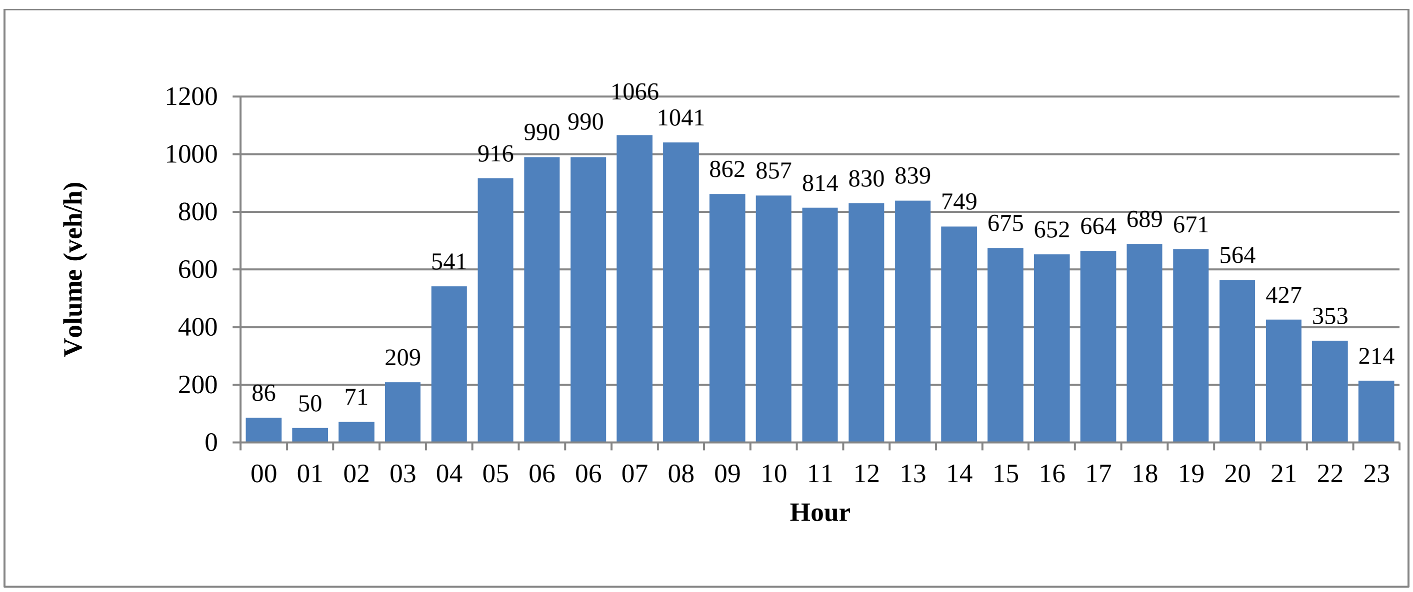


Figure B-59. POV Standard Average Volume for Different Hours of Weekdays at San Ysidro.

Figure B-60 displays vehicle volumes for different hours of the weekends. Weekend volumes have a maximum of 878 veh/h. Peak hours are from 10 a.m. to 4 p.m.

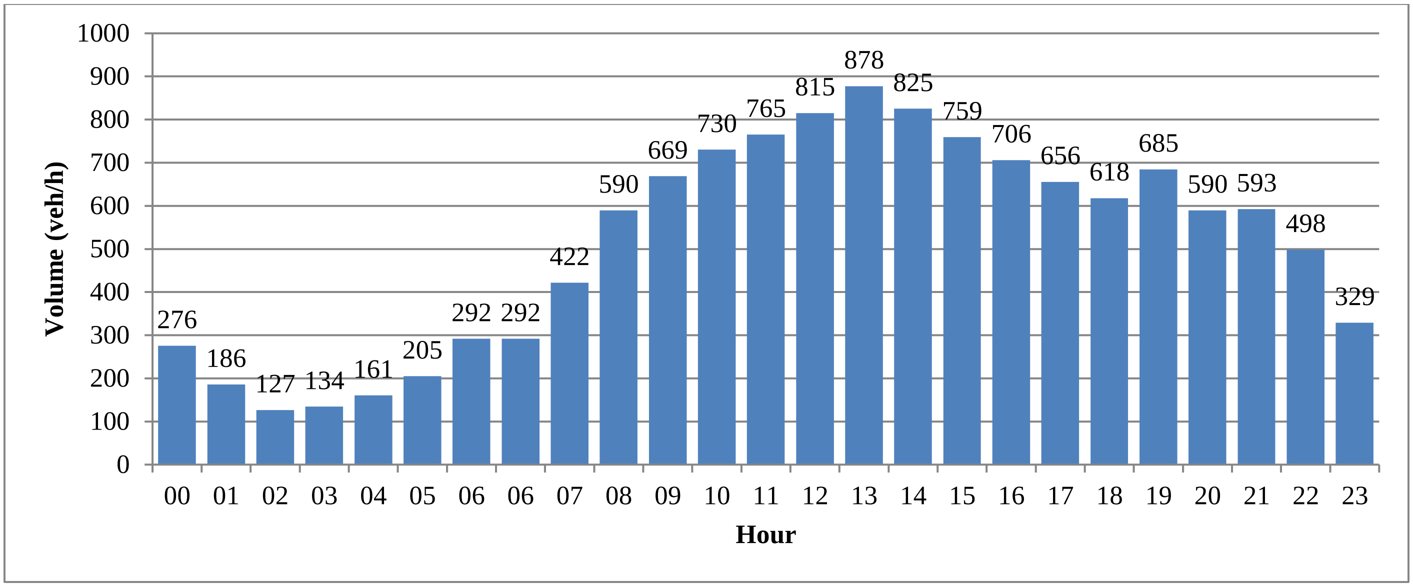


Figure B-60. POV Standard Average Volume for Different Hours of a Weekend at San Ysidro.

6.5.1.2 Wait Time Analysis – POV Standard – San Ysidro

Figure B-61 presents average wait time analysis and suggests that vehicles wait longer on Saturdays, Sundays, and Mondays, in comparison to other days of the week. The shortest wait times are on Wednesdays and Fridays, being 36 minutes, and longest are 61 minutes on average on Saturdays.

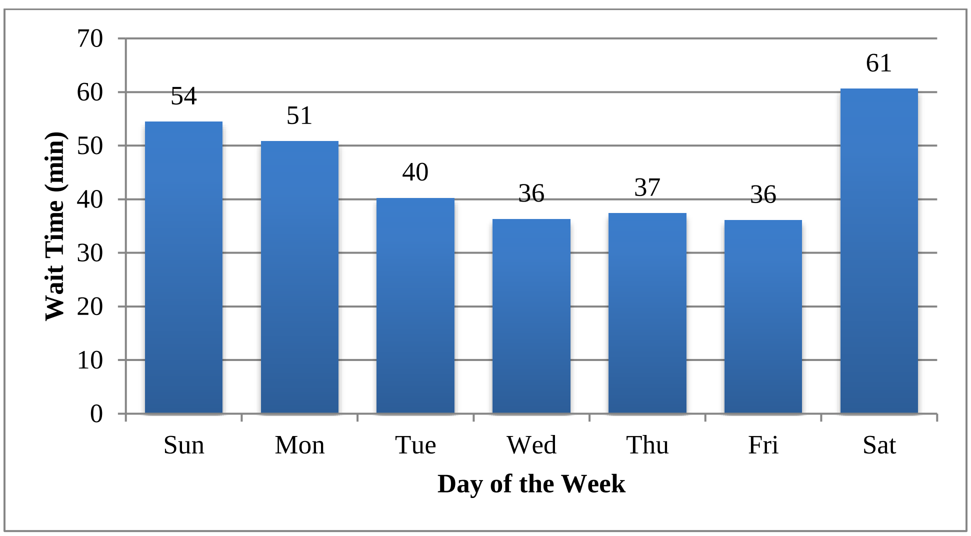


Figure B-61. POV Standard Average Wait Times for Different Days of the Week at San Ysidro.

Figure B-62 represents average wait times during weekdays for different hours of the day, while Figure B-63 is for weekends. Table B-69 summarizes the findings from both.

Average wait times on weekdays are little over 35 minutes, and the peak hours are from 5 a.m. until 2 p.m., being 49 minutes on average. Off-peak wait times are 25.3 minutes on average for weekdays.

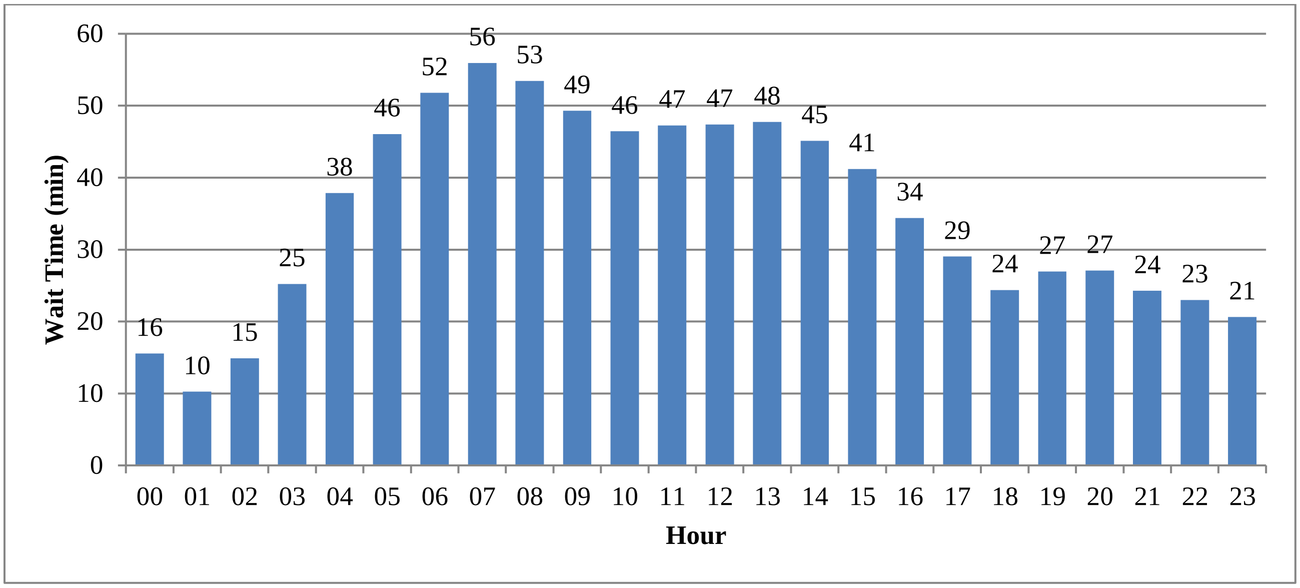


Figure B-62. POV Standard Average Wait Times for Different Hours during Weekdays at San Ysidro.

Weekend wait time peaked to 107 minutes on average between 3 p.m. to 11 p.m. Off-peak wait times are close to 31 minutes on average, and the average wait times during weekends are 54 minutes.

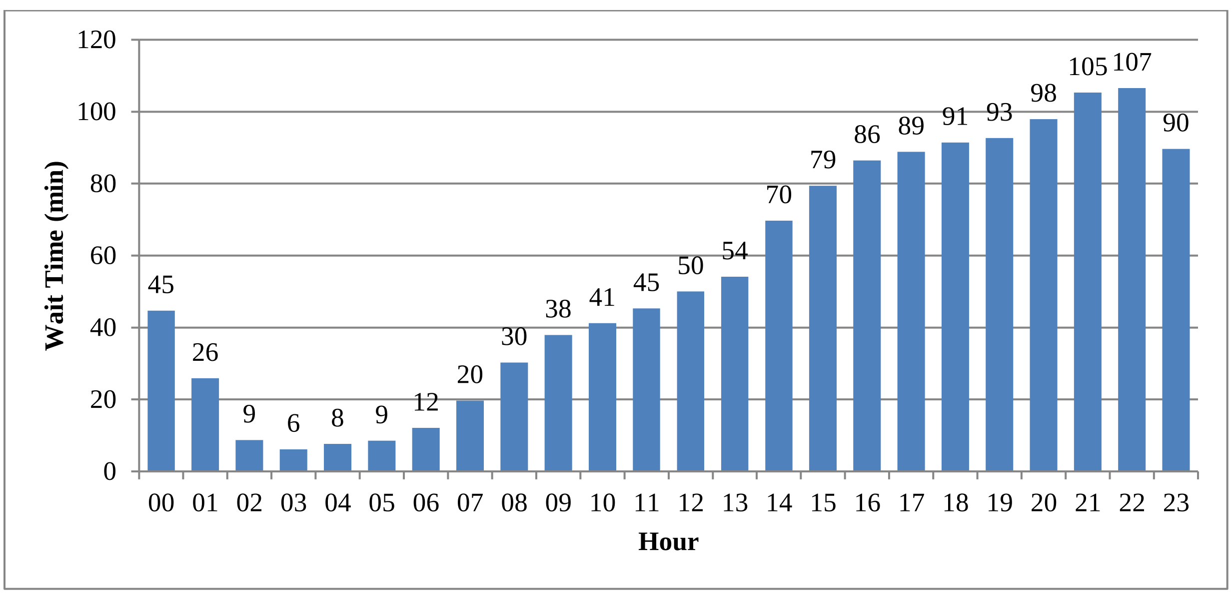


Figure B-63. POV Standard Average Wait Times for Different Hours during Weekends at San Ysidro.

Table B-69. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at San Ysidro.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	35.22	05:00–14:00	49.05	25.34
Weekend	54.18	15:00–23:00	93.15	30.80

6.5.1.3 Regression and Correlation – POV Standard – San Ysidro

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.48 and 0.46, respectively. This shows that as volume and number of open lanes increases, wait time also increases. As volume increases, additional lanes are being opened (correlation factor is 0.27). However, wait time is negatively correlated with cycle time with correlation coefficient of −0.35. Further, as cycle time increases, wait time decreases. It is possible that CBP officers may be spending more time for inspection when wait time is low than when wait times are longer. This is evidenced by negative correlation between volumes and cycle times (being −0.69). As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.35). **Error! Reference source not found.** presents the correlation matrix.

Table B-70. POV Standard Correlation Matrix at San Ysidro.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.69	1.00	-	-
Number of Lanes	0.27	−0.35	1.00	-
Wait Time	0.48	−0.35	0.46	1.00

Table B-71 and Table B-27 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.03 min, and each additional lane opened increases wait time by 3.7 min. Additional second of cycle time decreases wait time by 0.11 min. This equation explains border process in 80 percent of cases (value of adjusted R square in Table B-72). In other words, this equation explains the variability (fits) of the 80 percent of data provided by CBP. The remaining 20 percent are not explained by this particular equation.

Table B-71. POV Standard Regression Coefficients at San Ysidro.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0305	0.0023	13.0933	7.89E-37
Cycle Time	−0.1086	0.0338	−3.2136	0.0013
Number of Lanes	3.7161	0.2466	15.0721	2.44E-47

Table B-72. POV Standard Regression Statistics at San Ysidro.

Regression Statistics	
Multiple R	0.8933
R Square	0.7980
Adjusted R Square	0.7969
Standard Error	24.5613
Observations	1269

6.5.2 POV Ready Analysis – San Ysidro POE

Vehicle volumes vary between 87 and 1156 veh/h, having a mean of 553 veh/h and deviation of 162 veh/h. Cycle time ranges between 30 and 96 seconds, while the mean is 57 seconds and standard deviation is 11 seconds. Number of lanes open is between 2 and 12, and the mode is 9, meaning that 9 lanes are open in most cases. Wait time is between 5 and 120 minutes, and its mean value is 34 minutes. Table B-73 shows detailed statistical characteristics.

Table B-73. POV Ready Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at San Ysidro.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	553.63	56.93	8.35	33.94
Standard Error	4.28	0.29	0.09	30.00
Median	553.00	55.20	9.00	30.00
Mode	531.00	#N/A	9.00	20.00
Standard Deviation	161.96	11.14	2.24	20.82
Minimum	87.00	29.97	2.00	5.00
Maximum	1156.00	95.93	12.00	120.00

6.5.2.1 Volume Analysis – POV Ready – San Ysidro

Figure B-64 presents average hourly volumes for different days of the week. The volumes are relatively consistent ranging from 530 veh/h to 578 veh/h over different days of the week.

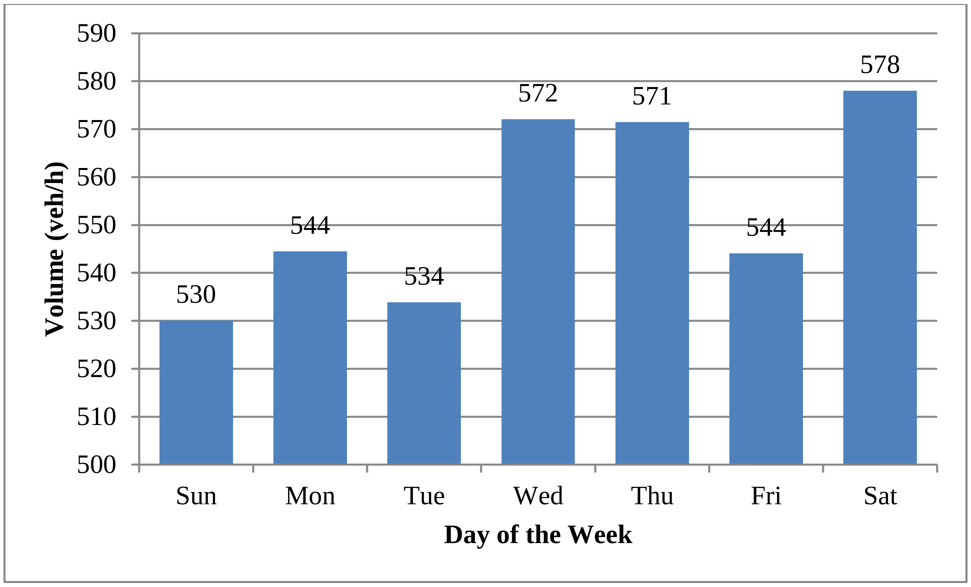


Figure B-64. POV Ready Average Hourly Volume for Each Day of the Week at San Ysidro.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-65 and Figure B-66, respectively. It can be concluded from Figure B-65 that the highest number of vehicles crossing the border from Monday to Friday occurs between 3 a.m. and 6 a.m. being over 700 veh/h and having a maximum value of 883 veh/h.

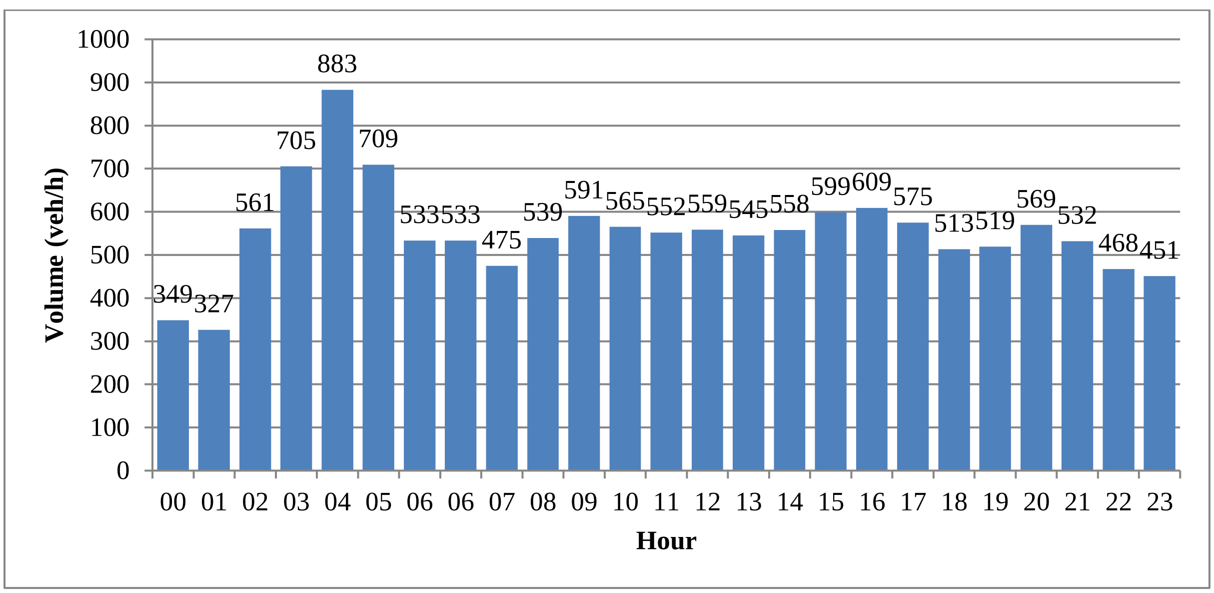


Figure B-65. POV Ready Average Volume for Different Hours of Weekdays at San Ysidro.

Figure B-66 displays vehicle volumes for different hours of the weekends. Peak hours are from 5 a.m. to 11 a.m., when volumes are over 600 veh/h, reaching 813 veh/h.

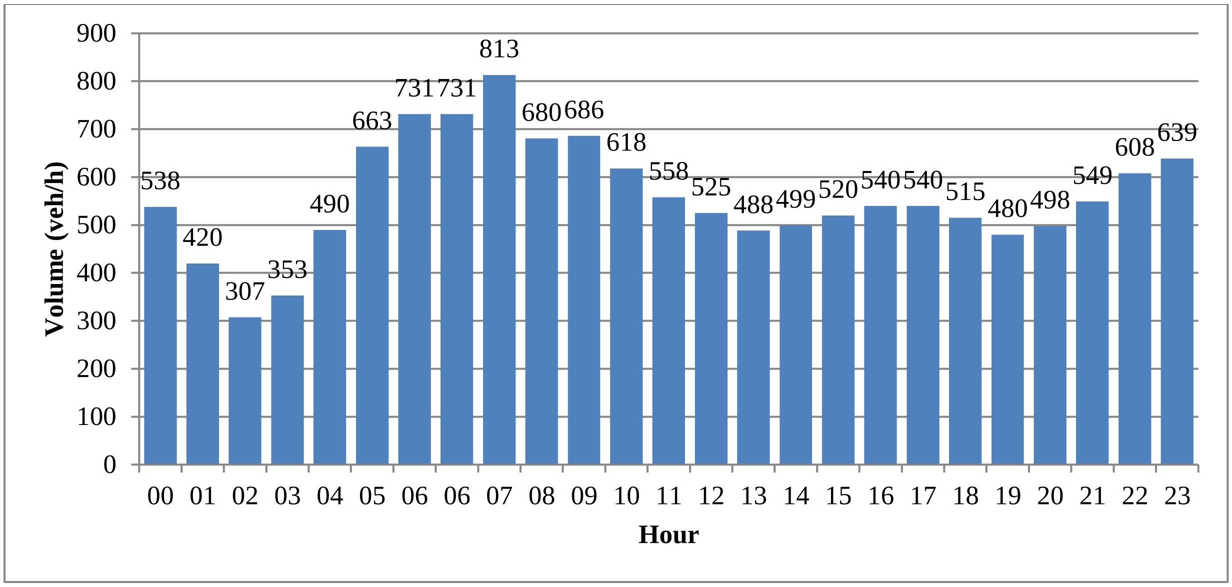


Figure B-66. POV Ready Average Volume for Different Hours of a Weekend at San Ysidro.

6.5.2.2 Wait Time Analysis – POV Ready – San Ysidro

Figure B-67 presents average wait time analysis and suggests that there is no significant difference in wait times for different days of the week.

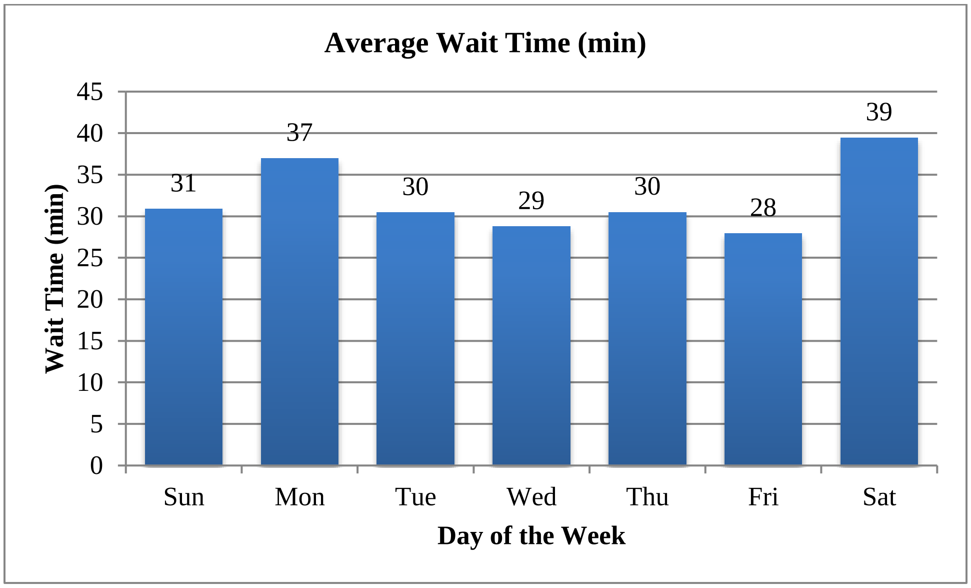


Figure B-67. POV Ready Average Wait Times for Different Days of the Week at San Ysidro.

Figure B-68 represents average wait times during weekdays for different hours of the day, while Figure B-69 is for weekends. **Error! Reference source not found.** summarizes the findings from both.

Average wait times on weekdays are little over 27 minutes, and the peak hours are from 5 a.m. until 11 a.m., reaching 47 minutes on average. Off-peak wait times averaged at 22 minutes on weekdays.

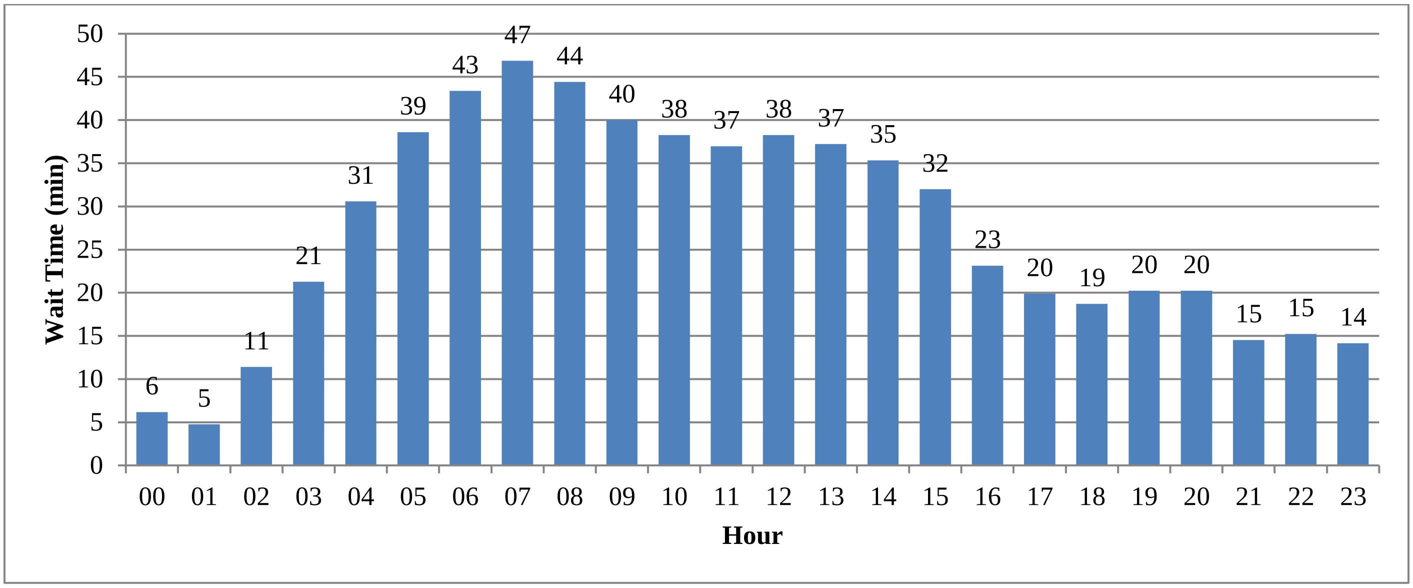


Figure B-68. POV Ready Average Wait Times for Different Hours during Weekdays at San Ysidro.

Wait time during weekends peaked at 71 minutes on average between 3 p.m. to 11 p.m. Off-peak wait times averaged at 20 minutes. Average wait times during weekends were 33 minutes. It can be concluded that off-peak average wait times are similar for weekdays and weekends, while average peak wait times are significantly higher during weekends.

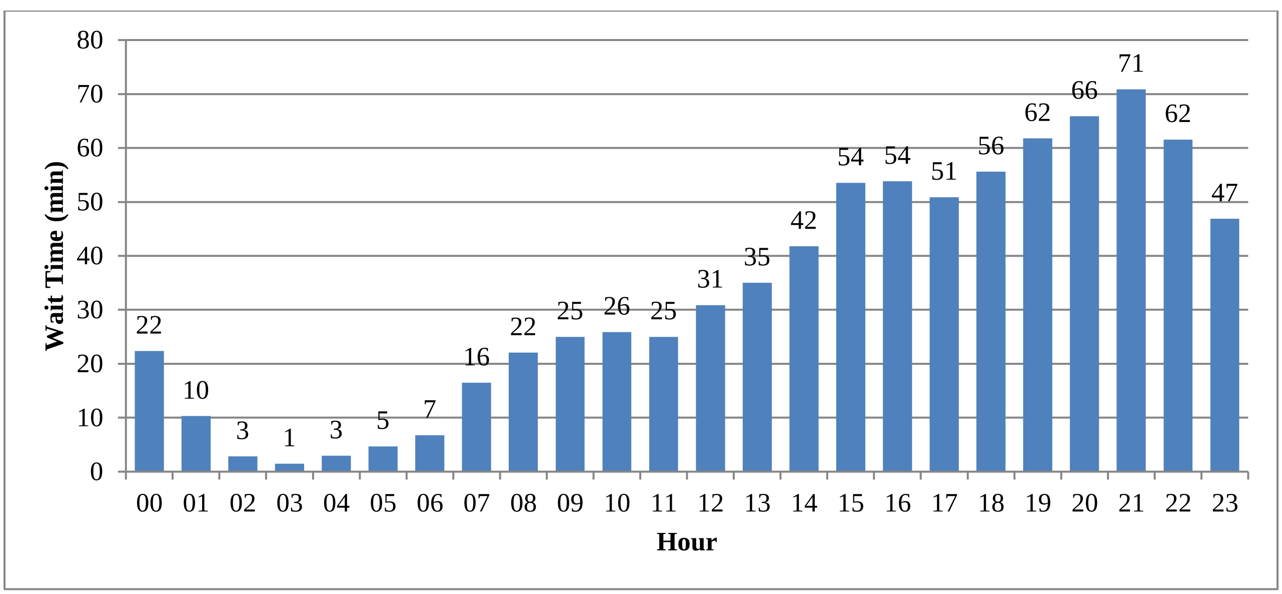


Figure B-69. POV Ready Average Wait Times for Different Hours during Weekends at San Ysidro.

Table B-74. POV Ready Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at San Ysidro.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	27.15	05:00–11:00	41.92	22.23
Weekend	33.09	15:00–23:00	59.24	20.02

6.5.2.3 Regression and Correlation – POV Ready – San Ysidro

Wait time is positively correlated with volume, cycle times, and number of open lanes, having correlation coefficients of 0.10, 0.32, and 0.39, respectively. This shows that as volume, cycle times, and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being open as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.54). Officers at the border probably devote more of their time to inspection when volume is low, and they are trying to process vehicles faster if the demand is higher. This is evidenced by negative correlation between volumes and cycle times (being −0.36). Table B-75 presents the correlation matrix.

Table B-75. POV Ready Correlation Matrix at San Ysidro.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00			
Cycle Time	−0.36	1.00		
Number of Lanes	0.54	−0.04	1.00	
Wait Time	0.10	0.32	0.39	1.00

Table B-76 and

Table B-77 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle decreases wait time by 0.02 min, and each additional lane opened increases wait time by 3 min. Additional second of cycle time increases wait time by 0.34 min. This equation explains border process in 77 percent of cases (value of adjusted R square in

Table B-77). In other words, this equation explains the variability (fits) of the 77 percent of data provided by CBP. The remaining 23 percent are not explained by this particular equation.

Table B-76. POV Ready Regression Coefficients at San Ysidro.

	Coefficients	Standard Error	t Stat	P-value
Volume	−0.0198	0.0036	−5.4747	5.30E-08
Cycle Time	0.3440	0.0301	11.4353	7.45E-29
Number of Lanes	2.9887	0.2882	10.3695	3.25E-24

Table B-77. POV Ready Regression Statistics at San Ysidro.

Regression Statistics	
Multiple R	0.8782
R Square	0.7712
Adjusted R Square	0.7700
Standard Error	18.9180
Observations	1238

6.5.3 POV SENTRI Analysis – San Ysidro POE

Vehicle volumes vary between 25 and 1052 veh/h, having a mean of 470 veh/h and deviation of 164 veh/h. Cycle time ranges between 46 and 114 seconds, while the mean is 77 seconds and standard deviation is 13 seconds. Number of lanes open is between 2 and 10, and the mode is 2, meaning that 2 lanes are open in most cases. Wait time is between 3 and 60 minutes, and its mean value is 10 minutes. Table B-78 shows detailed statistical characteristics.

Table B-78. POV SENTRI Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at San Ysidro.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	469.48	77.23	5.17	10.09
Standard Error	4.34	0.34	0.07	10.00
Median	467.00	76.32	6.00	10.00
Mode	469.00	#N/A	2.00	5.00
Standard Deviation	164.26	12.93	2.18	5.64
Minimum	25.00	45.56	2.00	3.00
Maximum	1052.00	114.49	10.00	60.00

6.5.3.1 Volume Analysis – POV SENTRI – San Ysidro

Figure B-70 presents average hourly volumes for different days of the week. The volumes are relatively consistent over the week, ranging from 418 veh/h to 526 veh/h.

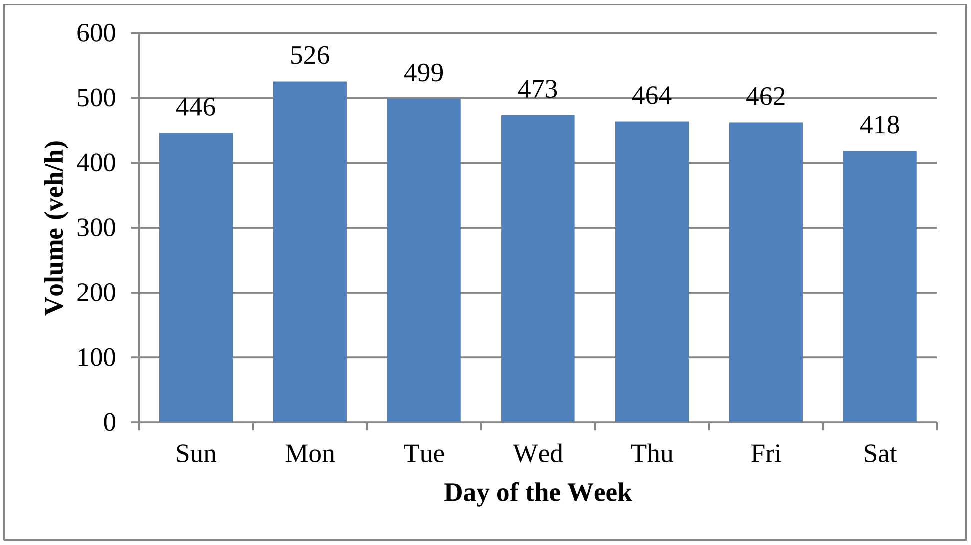


Figure B-70. POV SENTRI Average Hourly Volume for Each Day of the Week at San Ysidro.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-71 and Figure B-72, respectively. It can be concluded from Figure B-71 that the highest number of vehicles crossing the border from Monday to Friday occurs between 4 a.m. and 2 p.m. being over 600 veh/h and having a maximum value of 704 veh/h.

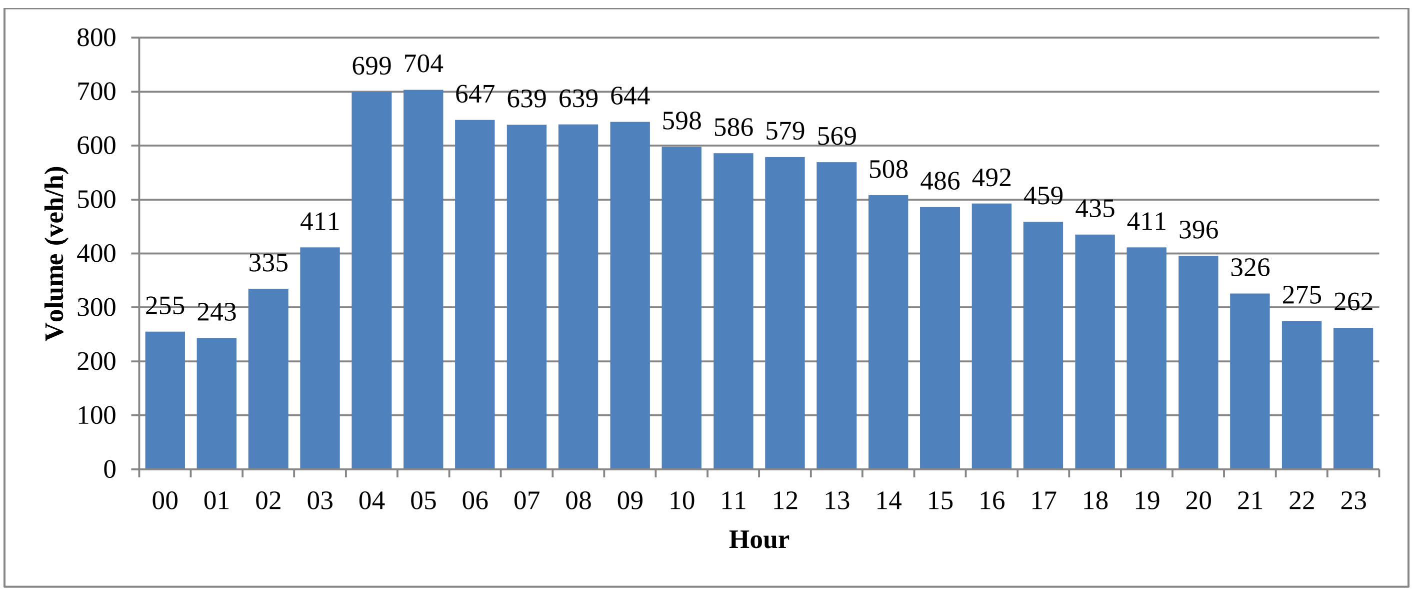


Figure B-71. POV SENTRI Average Volume for Different Hours of Weekdays at San Ysidro.

Figure B-72 displays vehicle volumes for different hours of the weekends. The spread of volumes is relatively similar to the weekdays one. However, weekend volumes have a little lower maximum, reaching 604 veh/h. Peak hours are from 6 a.m. to 2 p.m.

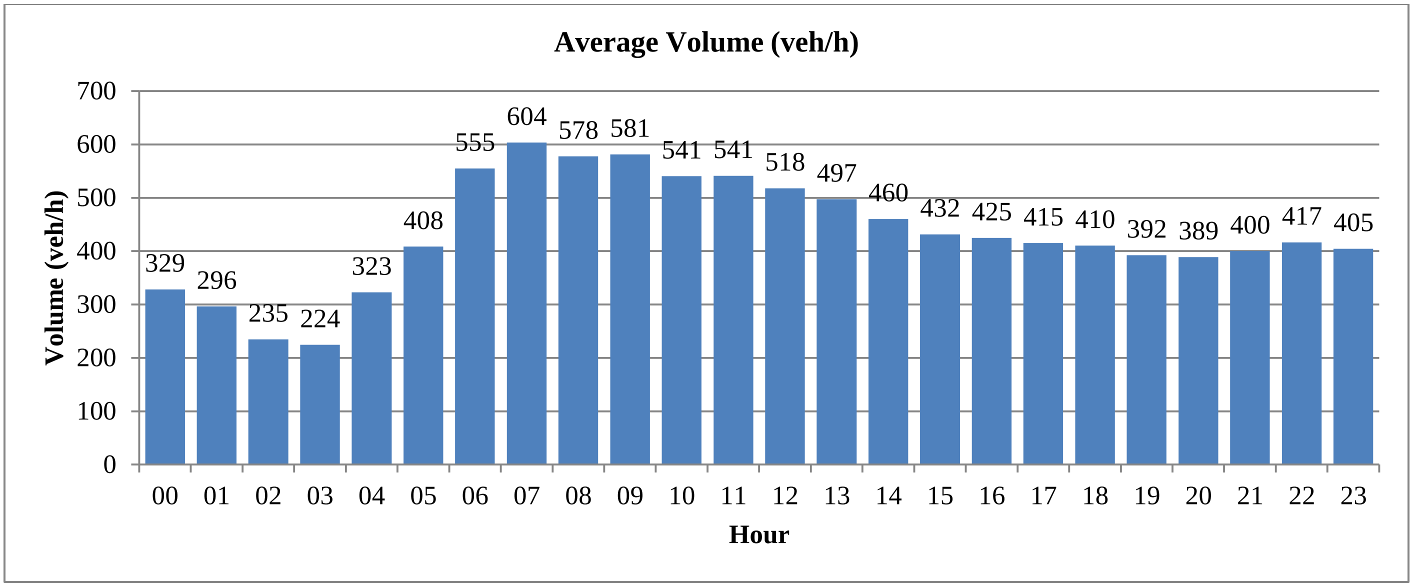


Figure B-72. POV SENTRI Average Volume for Different Hours of a Weekend at San Ysidro.

6.5.3.2 Wait Time Analysis – POV SENTRI – San Ysidro

Figure B-73 presents average wait time analysis and suggests that vehicles wait longer on Saturdays (10 minutes), in comparison to other days of the week (7 or 8 minutes).

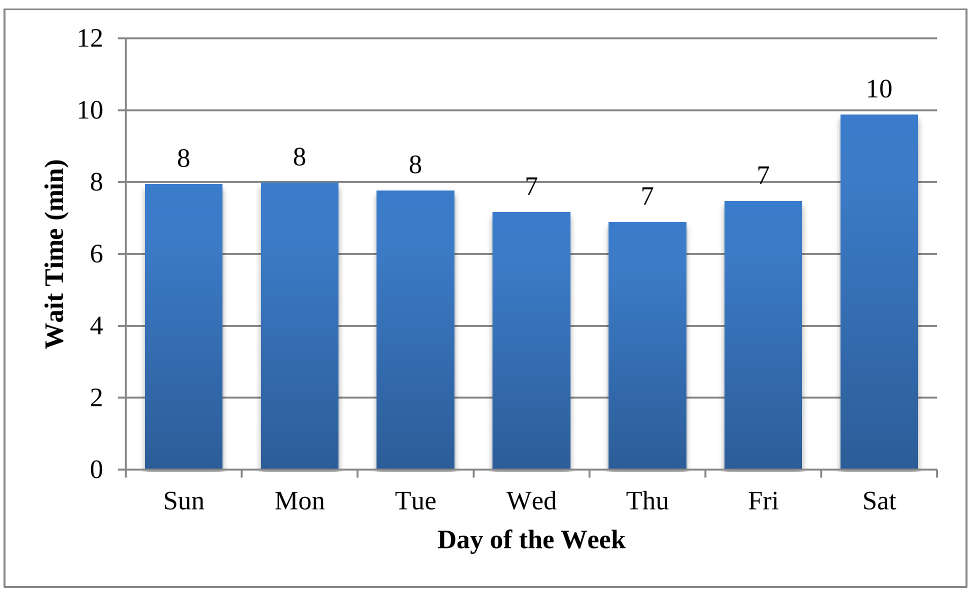


Figure B-73. POV SENTRI Average Wait Times for Different Days of the Week at San Ysidro.

Figure B-74 represents average wait times during weekdays for different hours of the day, while Figure B-75 is for weekends. Table B-79 summarizes the findings from both.

Average wait times on weekdays are 6.6 minutes, and the peak hours are from 5 a.m. until 9 a.m., being 12 minutes on average. Off-peak wait times are 6 minutes on average for weekdays.

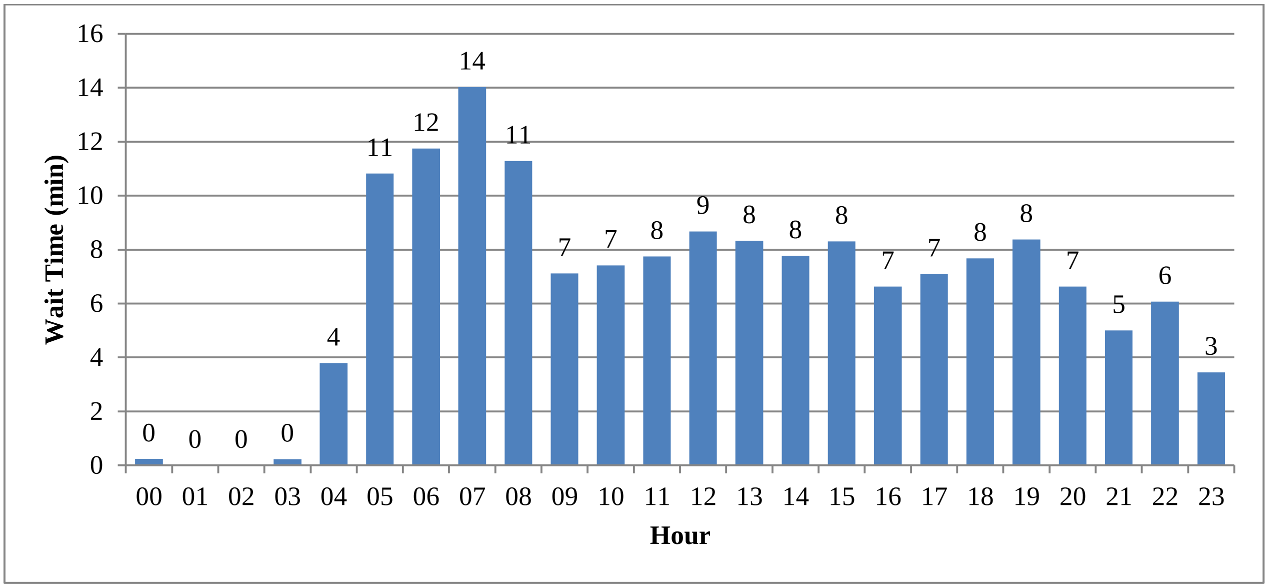


Figure B-74. POV SENTRI Average Wait Times for Different Hours during Weekdays at San Ysidro.

Weekend wait time peak is from 12 p.m. to 11 p.m. being 13.4 minutes on average. Off-peak wait times are averaged to 4.1 minutes, and the average wait times during weekends are 8.4 minutes.

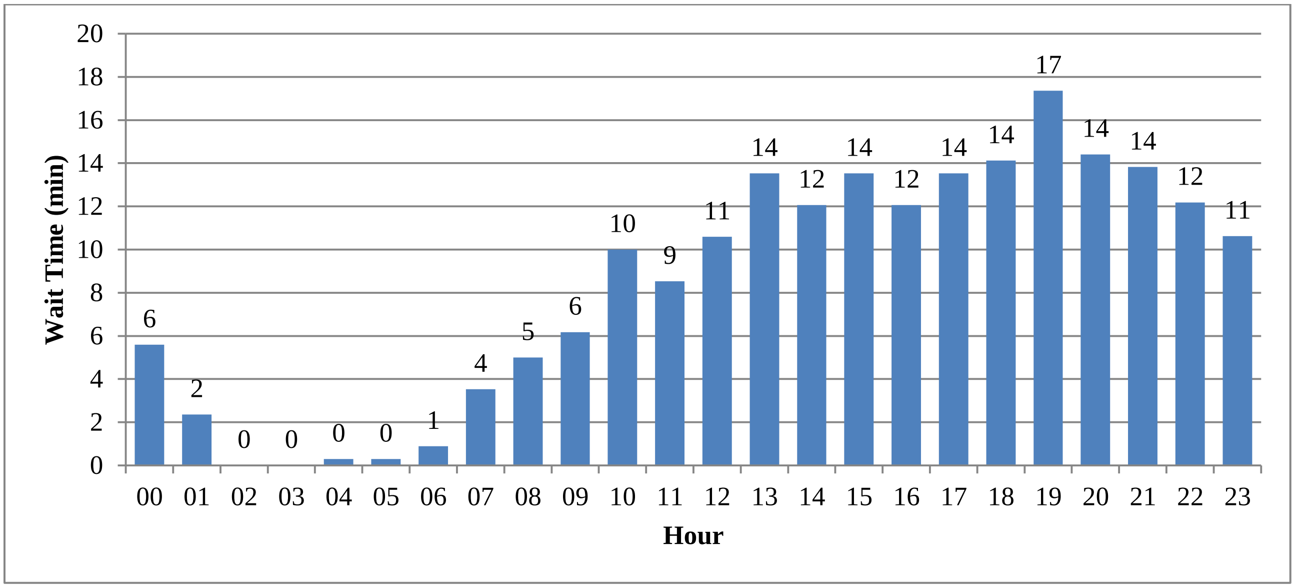


Figure B-75. POV SENTRI Average Wait Times for Different Hours during Weekends at San Ysidro.

Table B-79. POV SENTRI Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at San Ysidro.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	6.60	05:00–09:00	11.97	5.53
Weekend	8.35	12:00–23:00	13.38	4.10

6.5.3.3 Regression and Correlation – POV SENTRI – San Ysidro

Wait time is positively correlated with volume, cycle times, and number of open lanes, having correlation coefficients of 0.31, 0.08, and 0.64, respectively. This shows that as volume, cycle time, and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being open as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.48). Officers at the border probably devote more of their time to inspection when volumes are low, and they are trying to process vehicles faster if it is crowded. This is evidenced by negative correlation between volumes and cycle times (being −0.61). As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.11). Table B-80 presents the correlation matrix.

Table B-80. POV SENTRI Correlation Matrix at San Ysidro.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.61	1.00	-	-
Number of Lanes	0.48	−0.11	1.00	-
Wait Time	0.31	0.08	0.64	1.00

Table B-81 and Table B-82 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.002 min, and each additional lane opened increases wait time by 1.8 min. Additional second of cycle time decreases wait time by 0.007 min. This equation explains border process in 76 percent of cases (value of adjusted R square in Table B-82). In other words, this equation explains the variability (fits) of the 76 percent of data provided by CBP. The remaining 24 percent are not explained by this particular equation.

Table B-81. POV SENTRI Regression Coefficients at San Ysidro.

	Coefficients	Standard Error	t Stat	P-value
Volume	−0.0021	0.0008	−2.5058	0.0123
Cycle Time	−0.0066	0.0044	−1.4911	0.1362
Number of Lanes	1.8398	0.0750	24.5350	2.36E-109

Table B-82. POV SENTRI Regression Statistics at San Ysidro.

Regression Statistics	
Multiple R	0.8721
R Square	0.7606
Adjusted R Square	0.7595
Standard Error	5.0089
Observations	1289

6.6 DETAILED ANALYSIS – YSLETA POE

6.6.1 POV Standard Analysis – Ysleta POE

Vehicle volumes vary between 1 and 383 veh/h, having a mean of 120 veh/h and deviation of 83 veh/h. Cycle time ranges between 16 and 300 seconds, while the mean is 59 seconds and standard deviation is 42 seconds. Number of lanes open is between 1 and 6, and the mode is 6, meaning that 6 lanes are open in most cases. Wait time is between 1 and 99 minutes, and its mean value is less than 24 minutes. Table B-83 shows detailed statistical characteristics.

Table B-83. POV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Ysleta.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	119.87	58.78	4.20	23.84
Standard Error	2.29	1.16	0.07	23.00
Median	115.00	43.27	5.00	23.00
Mode	2.00	180.00	6.00	15.00
Standard Deviation	82.51	41.90	1.75	15.45
Minimum	1.00	16.12	1.00	1.00
Maximum	383.00	300.00	6.00	99.00

6.6.1.1 Volume Analysis – POV Standard – Ysleta

Figure B-76 presents average hourly volumes for different days of the week. The volumes are significantly higher on weekdays (between 126 veh/h and 131 veh/h) in comparison to weekends (112 veh/h and 90 veh/h).

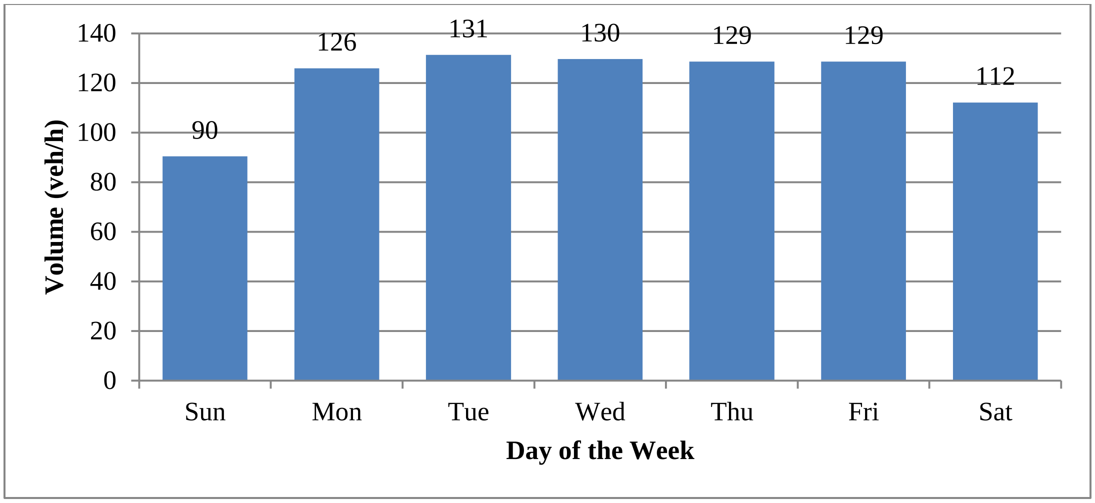


Figure B-76. POV Standard Average Hourly Volume for Each Day of the Week at Ysleta.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-77 and Figure B-78, respectively. It can be concluded from Figure B-77 that the morning peak is from 6 a.m. to 10 p.m. having a maximum value of 286 veh/h. The afternoon peak is from 5 p.m. until 8 p.m. having the maximum value of 282 veh/h.

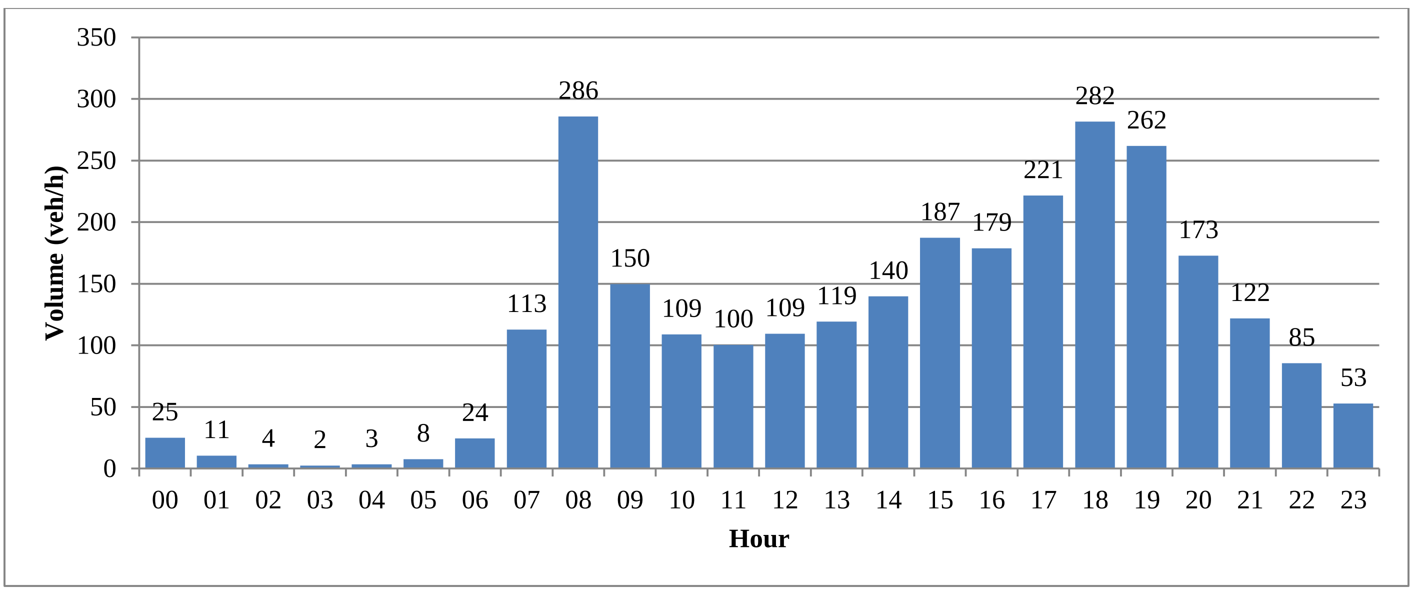


Figure B-77. POV Standard Average Volume for Different Hours of Weekdays at Ysleta.

Figure B-78 displays vehicle volumes for different hours of the weekends. Weekend volumes have peak from 1 p.m. to 8 p.m., and the highest value is 183 veh/h.

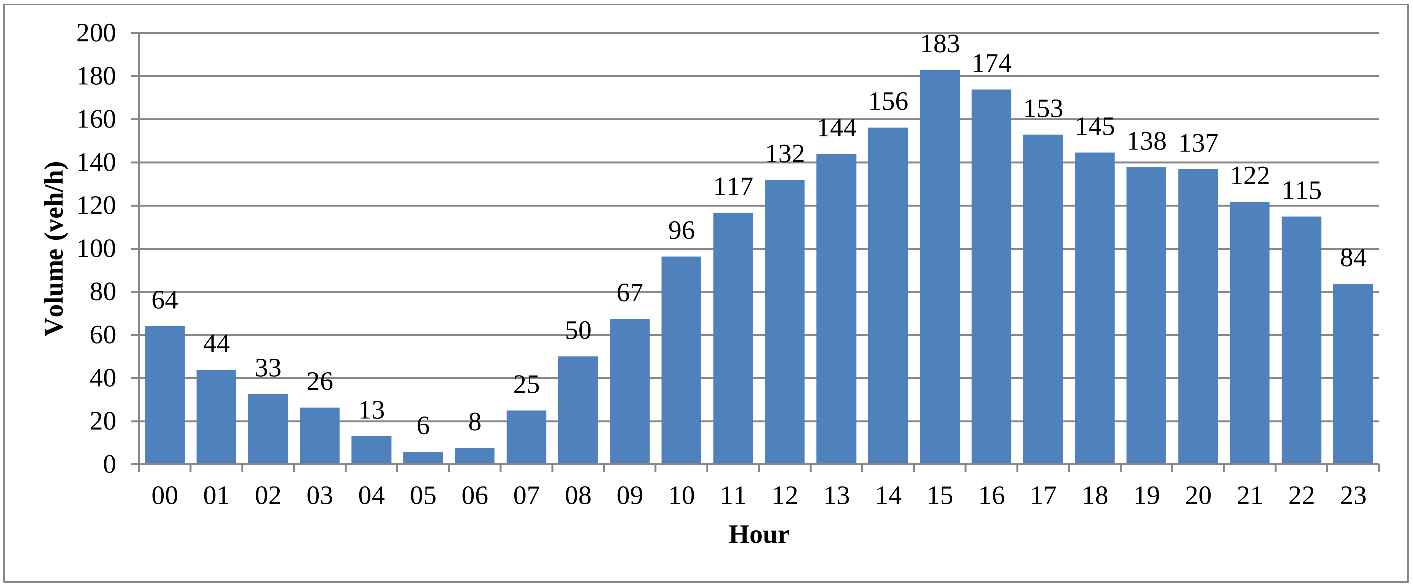


Figure B-78. POV Standard Average Volume for Different Hours of a Weekend at Ysleta.

6.6.1.2 Wait Time Analysis – POV Standard – Ysleta

Figure B-79 presents average wait time analysis and suggests that vehicles wait longer on weekends, in comparison to weekdays. The shortest wait times are on Thursdays, being 16 minutes, and longest are on Sundays being 32 minutes. Longer wait times over weekends, despite the lower volumes, can be explained with less available officers during weekends.

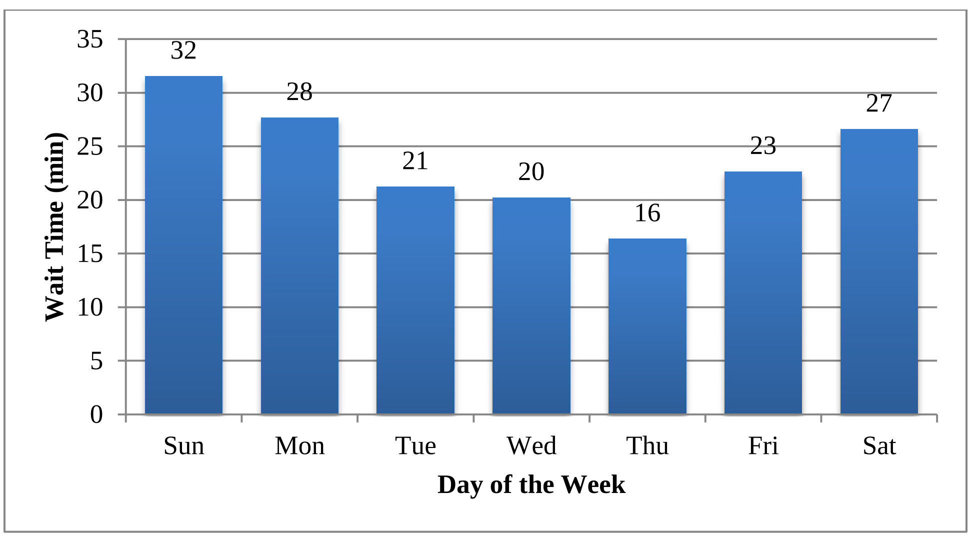


Figure B-79. POV Standard Average Wait Times for Different Days of the Week at Ysleta.

Figure B-80 represents average wait times during weekdays for different hours of the day, while Figure B-81 is for weekends.

Table B-84 summarizes the findings from both.

Average wait times on weekdays are little under 18 minutes on average, and the peak hours are from 6 p.m. until 12 a.m., being 25 minutes on average. Off-peak wait times are 15.4 minutes on average for weekdays.

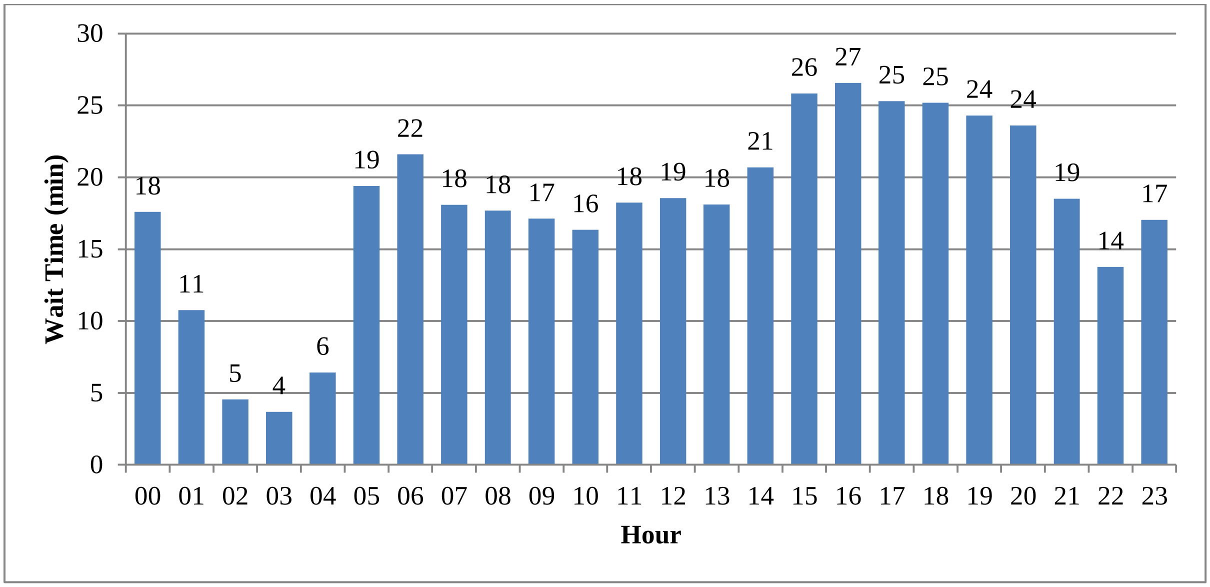


Figure B-80. POV Standard Average Wait Times for Different Hours during Weekdays at Ysleta.

Weekend wait time peak is from 12 p.m. to 11 p.m. being over 38 minutes on average. Off-peak wait times are averaged to 22 minutes, and the average wait times during weekends are 26 minutes.

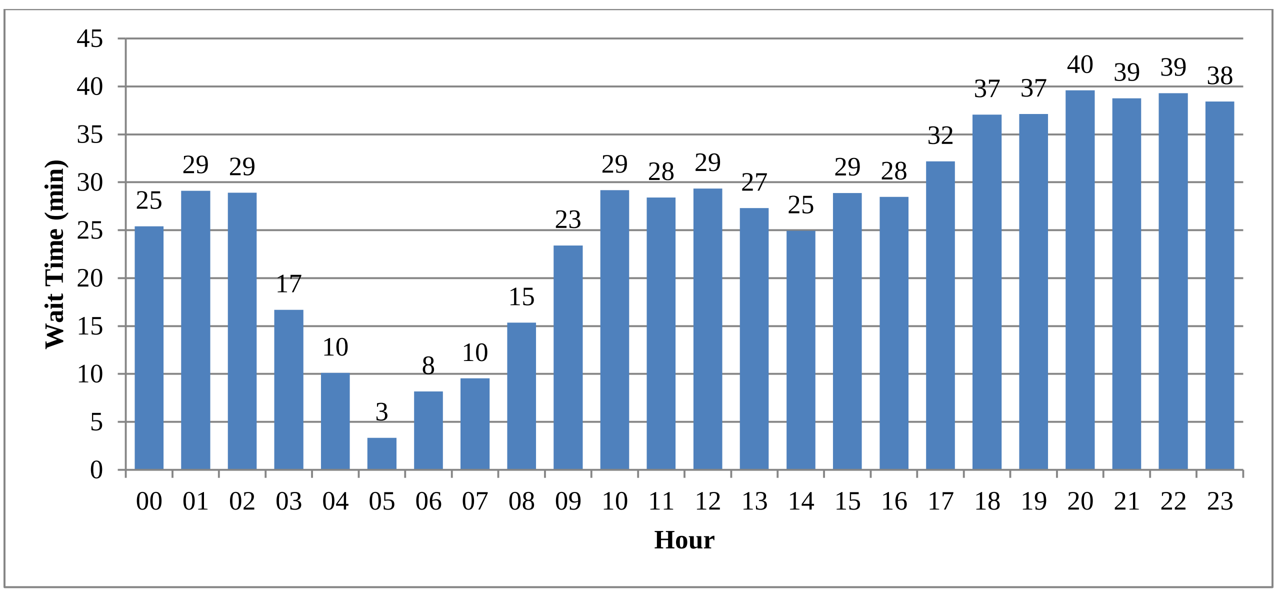


Figure B-81. POV Standard Average Wait Times for Different Hours during Weekends at Ysleta.

Table B-84. POV Standard Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Ysleta.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	17.87	18:00–00:00	25.13	15.45
Weekend	26.21	12:00–23:00	38.37	22.15

6.6.1.3 Regression and Correlation – POV Standard – Ysleta

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.32 and 0.21, respectively. However, wait time is negatively correlated with cycle time with correlation coefficient of −0.43. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being open as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.49). Further, as cycle time increases, wait time decreases. It is feasible that that officers may be spending more time for inspection when wait time is low than when wait times are longer. This is evidenced by negative correlation between volumes and cycle times (being −0.75), meaning that as the border crossing becomes more crowded, officers are probably working faster. As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.55). Table B-85 presents the correlation matrix.

Table B-85. POV Standard Correlation Matrix at Ysleta.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00			
Cycle Time	−0.75	1.00		
Number of Lanes	0.49	−0.55	1.00	
Wait Time	0.32	−0.43	0.21	1.00

Table B-86 and Table B-87 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.08 min, and each additional lane opened increases wait time by 2.5 min. Additional second of cycle time increases wait time by 0.05 min. This equation explains border process in 71 percent of cases (value of adjusted R square in Table B-87). In other words, this equation explains the variability (fits) of the 71 percent of data provided by CBP. The remaining 29 percent are not explained by this particular equation.

Table B-86. POV Standard Regression Coefficients at Ysleta.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0758	0.0066	11.5556	2.61E-29
Cycle Time	0.0502	0.0085	5.9444	3.67E-09
Number of Lanes	2.5080	0.2442	10.2691	9.74E-24

Table B-87. POV Standard Regression Statistics at Ysleta.

Regression Statistics	
Multiple R	0.8409
R Square	0.7071
Adjusted R Square	0.7057
Standard Error	15.3909
Observations	1162

6.6.2 POV Ready Analysis – Ysleta POE

Vehicle volumes vary between 10 and 340 veh/h, having a mean of 156 veh/h and deviation of 57 veh/h. Cycle time ranges between 42 and 172 seconds, while the mean is 73 seconds and standard deviation is 18 seconds. Number of lanes open is between 1 and 5, and the mode is 4, meaning that 4 lanes are open in most cases. Wait time is between 1 and 89 minutes, and its mean value is over 18 minutes. Table B-88 shows detailed statistical characteristics.

Table B-88. POV Ready Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Ysleta.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	156.50	73.39	2.66	18.37
Standard Error	1.50	0.47	0.04	15.00
Median	157.00	70.32	3.00	15.00
Mode	121.00	81.00	4.00	5.00
Standard Deviation	56.69	17.86	1.18	14.21
Minimum	10.00	42.45	1.00	1.00
Maximum	340.00	171.92	5.00	89.00

6.6.2.1 Volume Analysis – POV Ready – Ysleta

Figure B-82 presents average hourly volumes for different days of the week. The volumes are significantly higher on weekends (167 veh/h and 172 veh/h) in comparison to weekdays (between 144 veh/h and 161 veh/h).

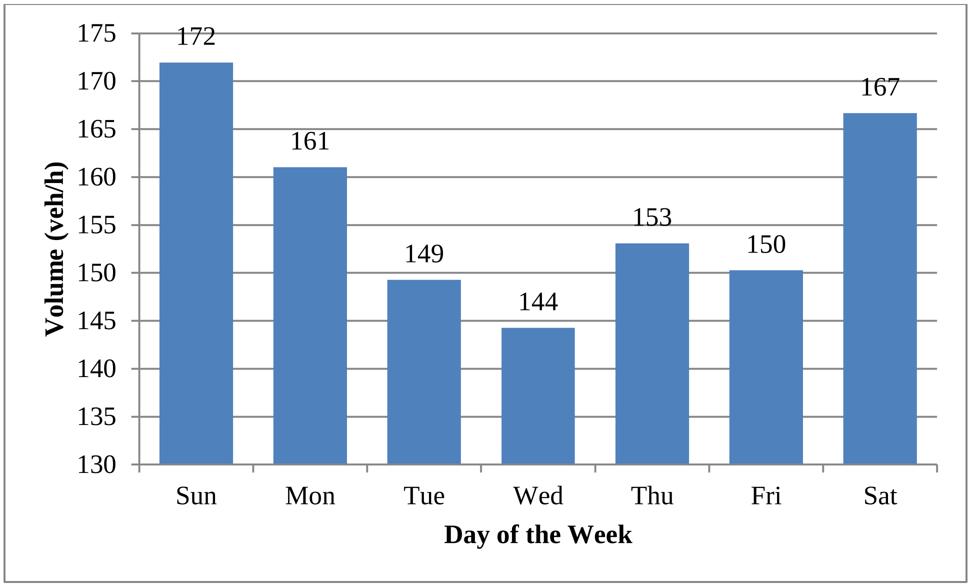


Figure B-82. POV Ready Average Hourly Volume for Each Day of the Week at Ysleta.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-83 and Figure B-84, respectively. It can be concluded from Figure B-83 that the highest number of vehicles crossing the border from Monday to Friday occurs between 7 a.m. and 4 p.m. being over 140 veh/h and having a maximum value of 237 veh/h.

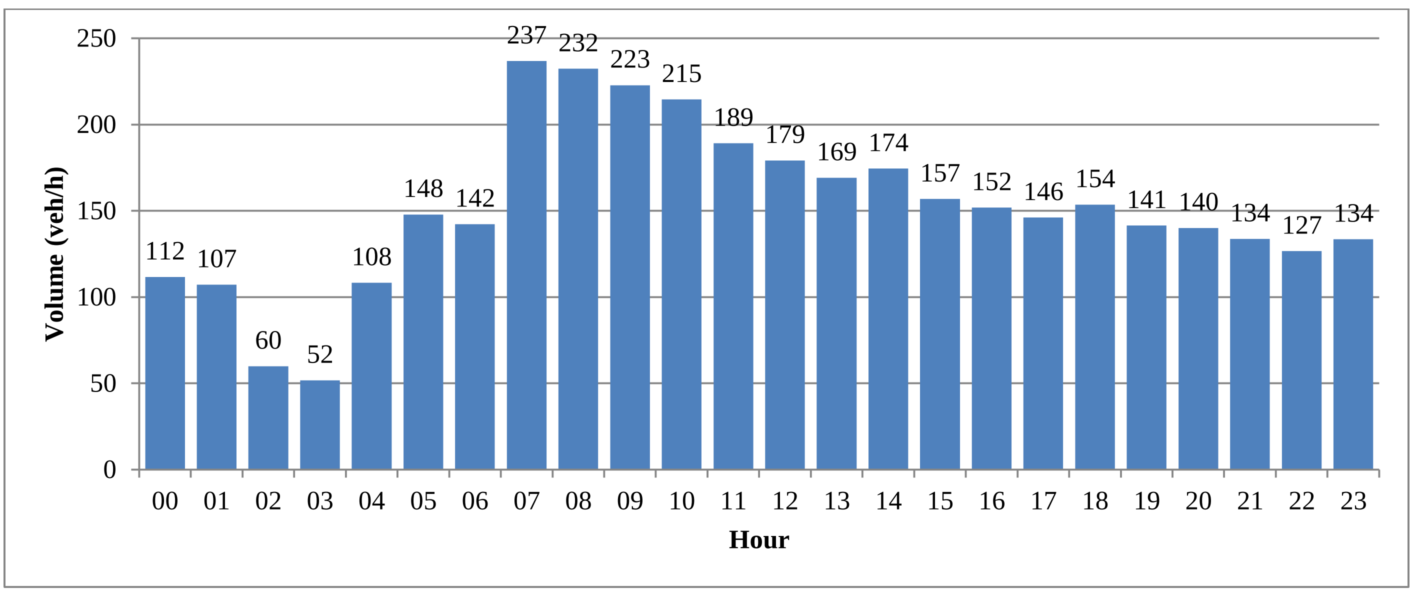


Figure B-83. POV Ready Average Volume for Different Hours of Weekdays at Ysleta.

Figure B-84 displays vehicle volumes for different hours of the weekends. Weekend volumes have peak hours from 12 a.m. to 6 p.m and maximum value of 215 veh/h.

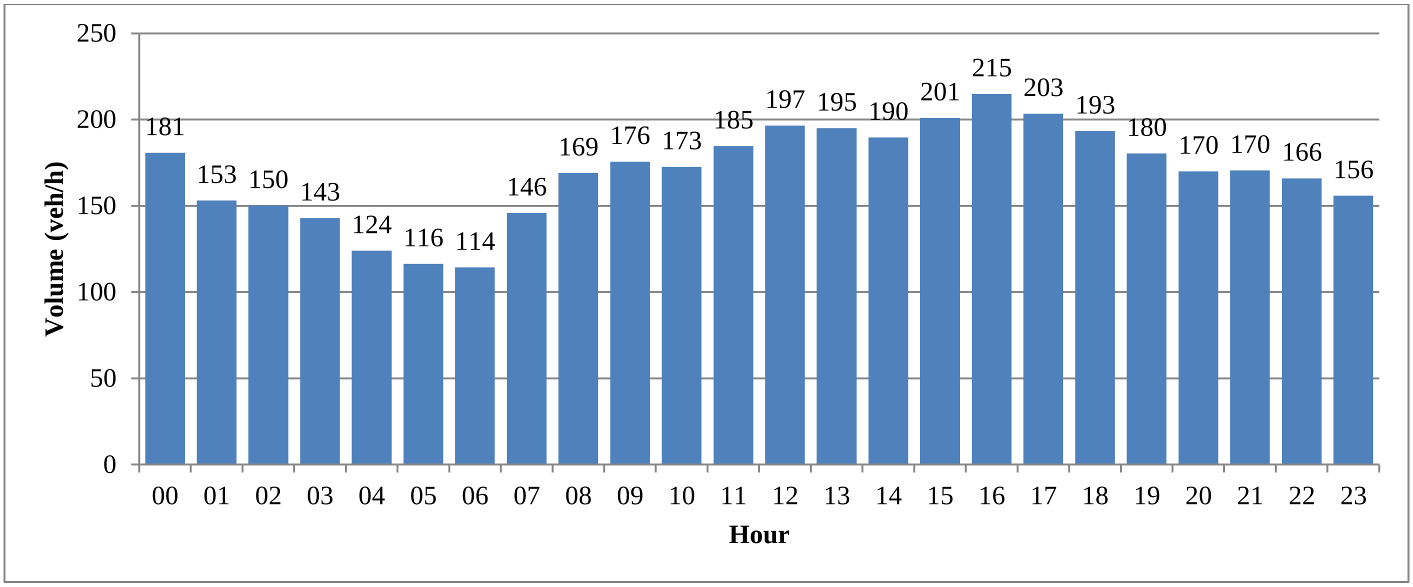


Figure B-84. POV Ready Average Volume for Different Hours of a Weekend at Ysleta.

6.6.2.2 Wait Time Analysis – POV Ready – Ysleta

Figure B-85 presents average wait time analysis and suggests that vehicles wait significantly longer on Sundays in comparison to other days of the week. The shortest wait times are on Thursdays, being 13 minutes, and longest are 26 minutes on average on Sundays.

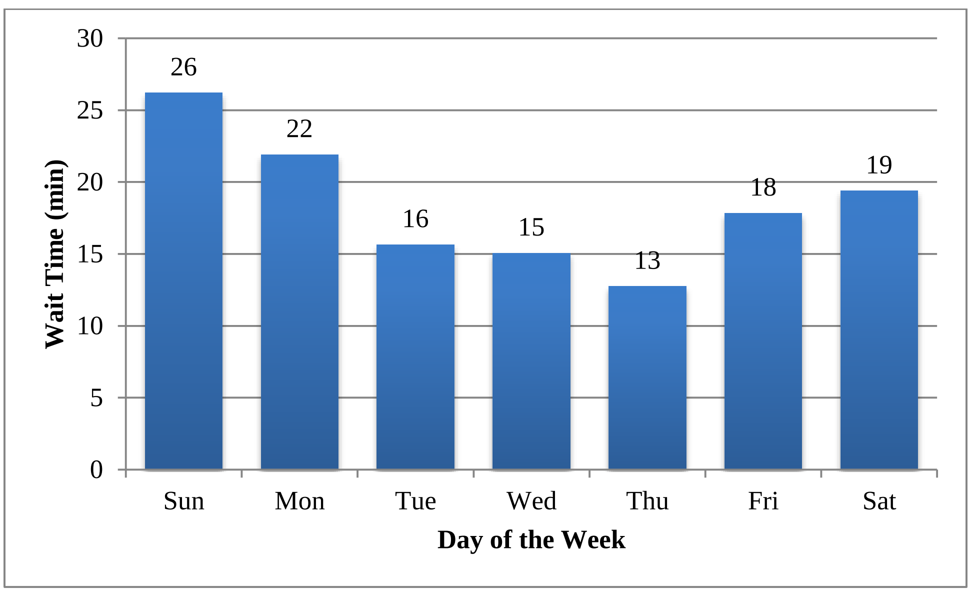


Figure B-85. POV Ready Average Wait Times for Different Days of the Week at Ysleta.

Figure B-86 represents average wait times during weekdays for different hours of the day, while Figure B-87 is for weekends.

Table B-89 summarizes the findings from both.

Average wait times on weekdays are almost 15 minutes on average, and the peak hours are from 3 p.m. until 9 p.m., being 20.7 minutes on average. Off-peak wait times are 12.4 minutes on average for weekdays.

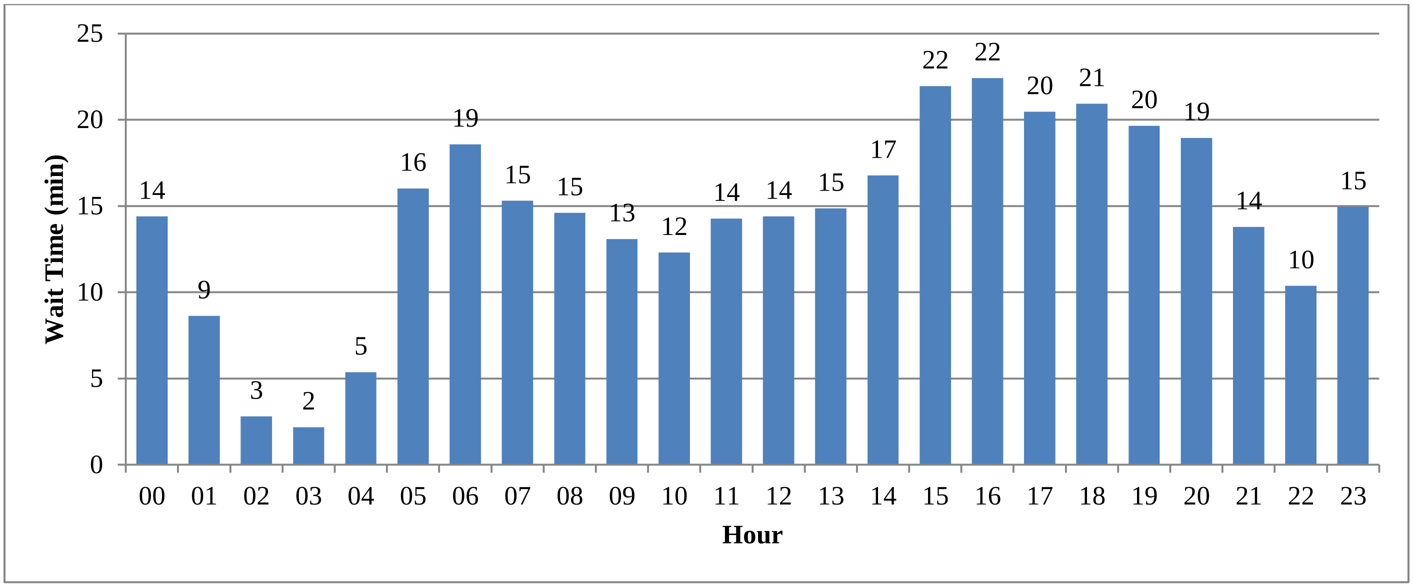


Figure B-86. POV Ready Average Wait Times for Different Hours during Weekdays at Ysleta.

Weekend wait time peak is from 6 p.m. to 12 a.m. being over 32 minutes on average. Off-peak wait times are close to 18 minutes on average, and the average wait times during weekends are 21.4 minutes.

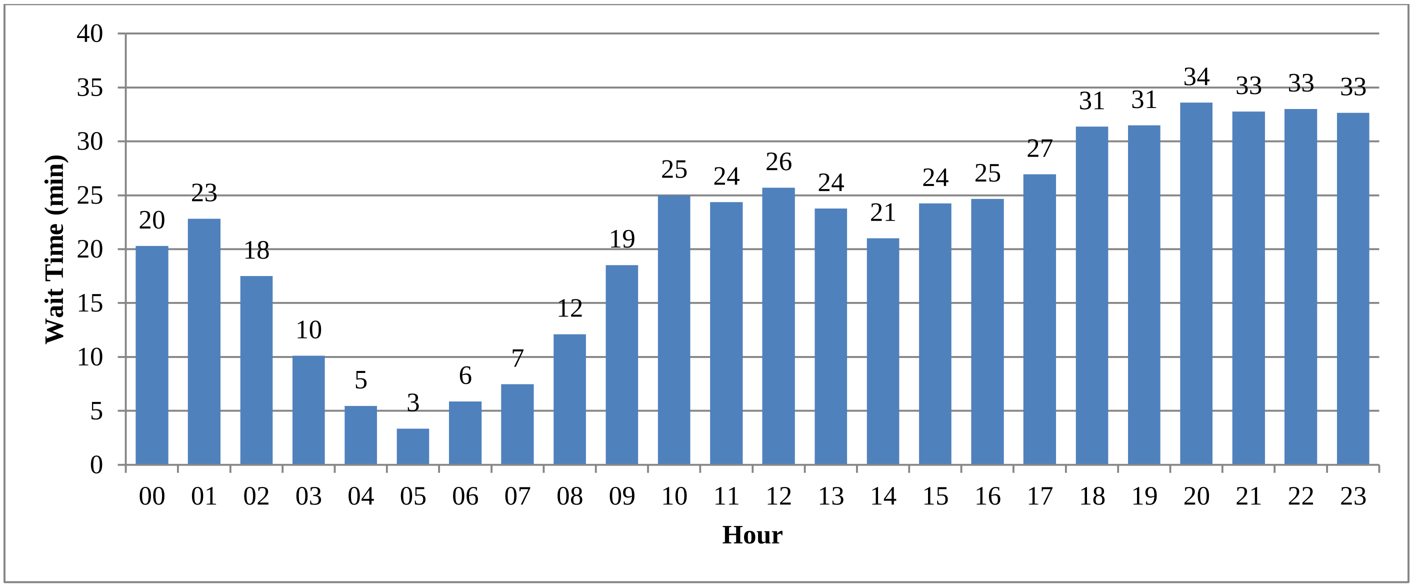


Figure B-87. POV Ready Average Wait Times for Different Hours during Weekends at Ysleta.

Table B-89. POV Ready Distribution of Peak Hours during Weekdays and Weekends and Average Wait Times at Ysleta.

	Average Wait Time (min)	Peak Hours	Peak Hours Wait Time (min)	Off-Peak Wait Time (min)
Weekdays	14.46	15:00–21:00	20.73	12.37
Weekend	21.42	18:00–00:00	32.47	17.73

6.6.2.3 Regression and Correlation – POV Ready – Ysleta

Wait time is positively correlated with volume and number of open lanes, having correlation coefficients of 0.24 and 0.27, respectively. However, wait time is negatively correlated with wait time with correlation coefficient of −0.23. This shows that as volume and number of open lanes increases, wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being open as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. As volume increases, additional lanes are being opened (correlation factor is 0.64). Further, as cycle time increases, wait time decreases. It is feasible that that officers may be spending more time for inspection when wait time is low than when wait times are longer. This is evidenced by negative correlation between volumes and cycle times (being −0.61), meaning that as the border crossing becomes more crowded, officers are probably working faster. As volumes increase, more lanes are open, but officers are still trying to be more efficient when processing vehicles (correlation factor is −0.25). Table B-90 shows the correlation matrix.

Table B-90. POV Ready Correlation Matrix at Ysleta.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00			
Cycle Time	−0.61	1.00		
Number of Lanes	0.64	−0.25	1.00	
Wait Time	0.24	−0.23	0.27	1.00

Table B-91 and Table B-92 explain regression between wait times (dependent variable) and independent variables (vehicle volumes, cycle times, and number of open lanes). Each additional vehicle increases wait time by 0.06 min, and each additional lane opened increases wait time by 2.2 min. Additional second of cycle time increases wait time by 0.045 min. This equation explains border process in 65 percent of cases (value of adjusted R square in Table B-92). In other words, this equation explains the variability (fits) of the 65 percent of data provided by CBP. The remaining 35 percent are not explained by this particular equation.

Table B-91. POV Ready Regression Coefficients at Ysleta.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0564	0.0075	7.5062	1.13E-13
Cycle Time	0.0447	0.0106	4.2301	2.50E-05
Number of Lanes	2.2049	0.4310	5.1156	3.60E-07

Table B-92. POV Ready Regression Statistics at Ysleta.

Regression Statistics	
Multiple R	0.8043
R Square	0.6468
Adjusted R Square	0.6455
Standard Error	13.8157
Observations	1287

6.6.3 POV SENTRI Analysis – Ysleta POE

Vehicle volumes vary between 1 and 396 veh/h, having a mean of 217 veh/h and deviation of 67 veh/h. Cycle time ranges between 26 and 300 seconds, while the mean is 82.4 seconds and standard deviation is 15 seconds. Number of lanes open is either 1 or 2, and the mode is 1, meaning that 1 lane are open in most cases. Wait time is between 1 and 15 minutes, and its mean value is 1.4 minutes. Table B-93 shows detailed statistical characteristics.

Table B-93. POV SENTRI Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Ysleta.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	217.43	82.39	1.47	1.37
Standard Error	2.09	0.46	0.03	1.00
Median	224.00	81.29	1.00	1.00
Mode	277.00	180.00	1.00	1.00
Standard Deviation	67.01	14.84	0.50	1.14
Minimum	1.00	26.00	1.00	1.00
Maximum	396.00	300.00	2.00	15.00

6.6.3.1 Volume Analysis – POV SENTRI – Ysleta

Figure B-88 presents average hourly volumes for different days of the week. The volumes are significantly higher on Saturdays (237 veh/h on average) in comparison to other days of the week (between 209 veh/h and 221 veh/h).

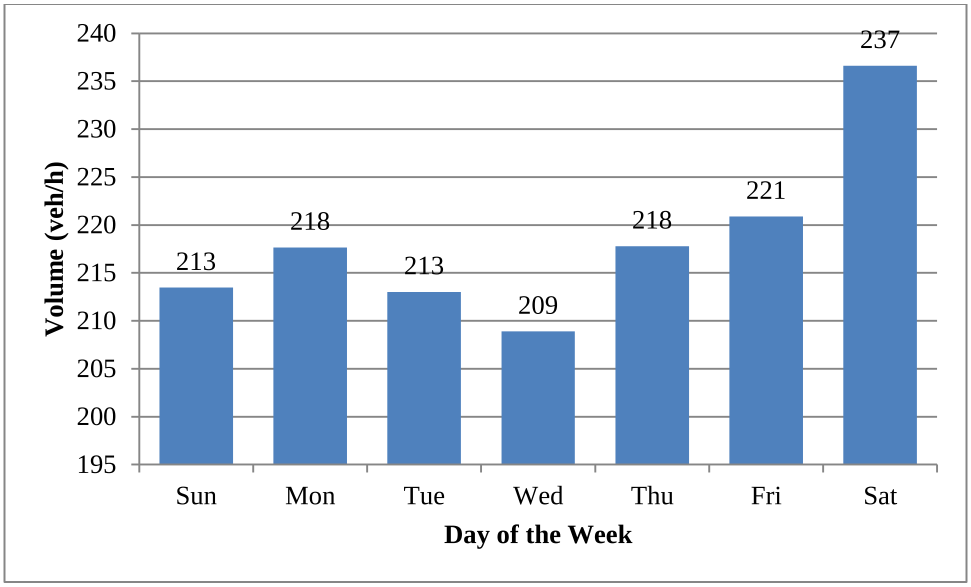


Figure B-88. POV SENTRI Average Hourly Volume for Each Day of the Week at Ysleta.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-89 and Figure B-90, respectively. It can be concluded from Figure B-89 that the highest number of vehicles crossing the border from Monday to Friday occurs between 7 a.m. and 10 a.m. being around 280 veh/h and having a maximum value of 290 veh/h.

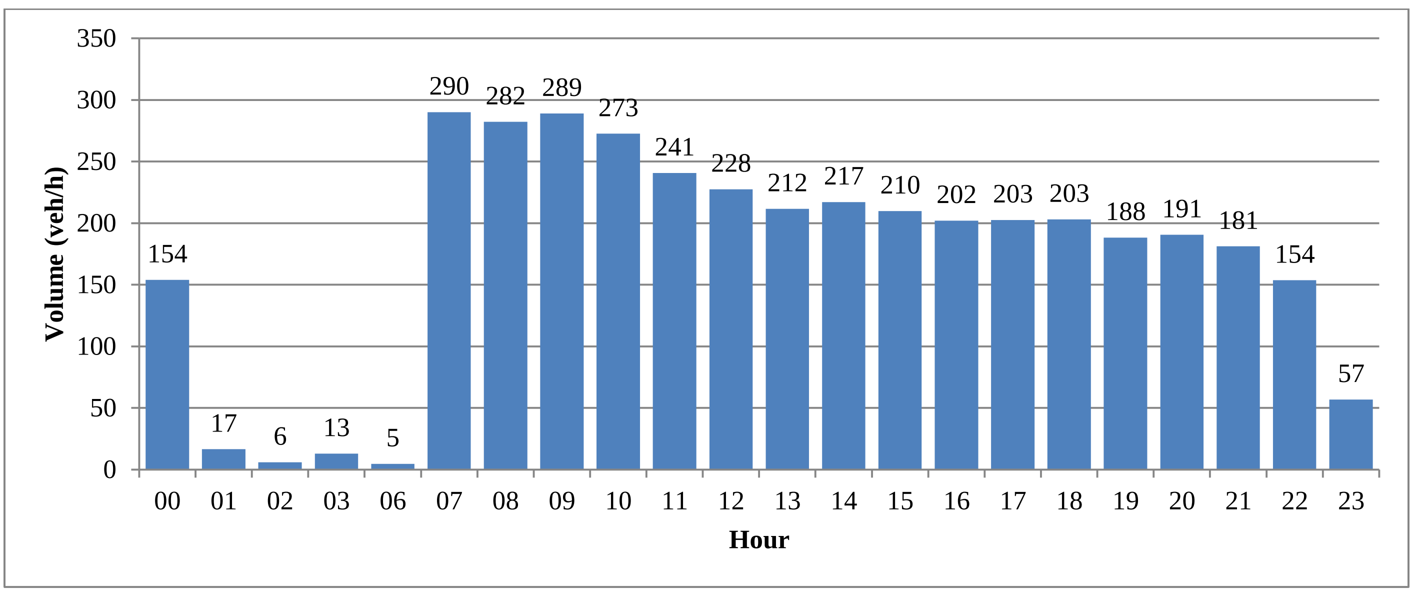


Figure B-89. POV SENTRI Average Volume for Different Hours of Weekdays at Ysleta.

Figure B-90 displays vehicle volumes for different hours of the weekends. The spread of volumes is relatively similar to the weekdays one. Values are relatively consistent from 7 a.m. until midnight, being between 190 veh/h and 268 veh/h.

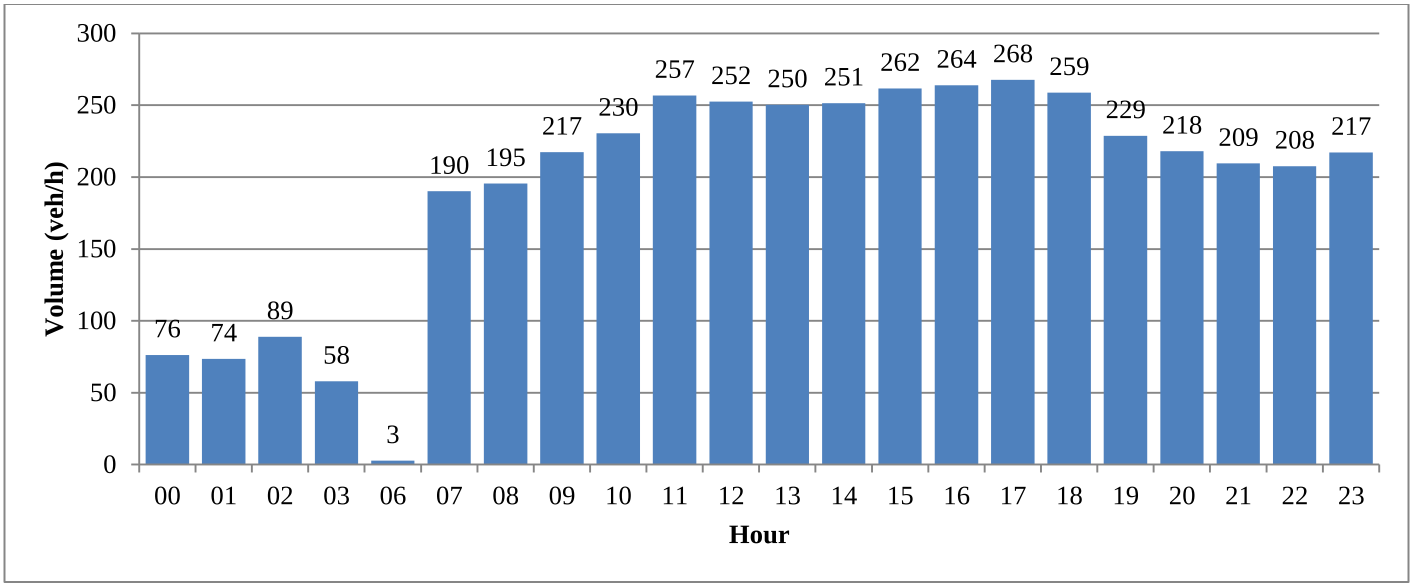


Figure B-90. POV SENTRI Average Volume for Different Hours of a Weekend at Ysleta.

6.6.3.2 Wait Time Analysis – POV SENTRI – Ysleta

Average wait time is very low during entire week, being either 1 or 2 minutes, on average. Figure B-91 presents it.

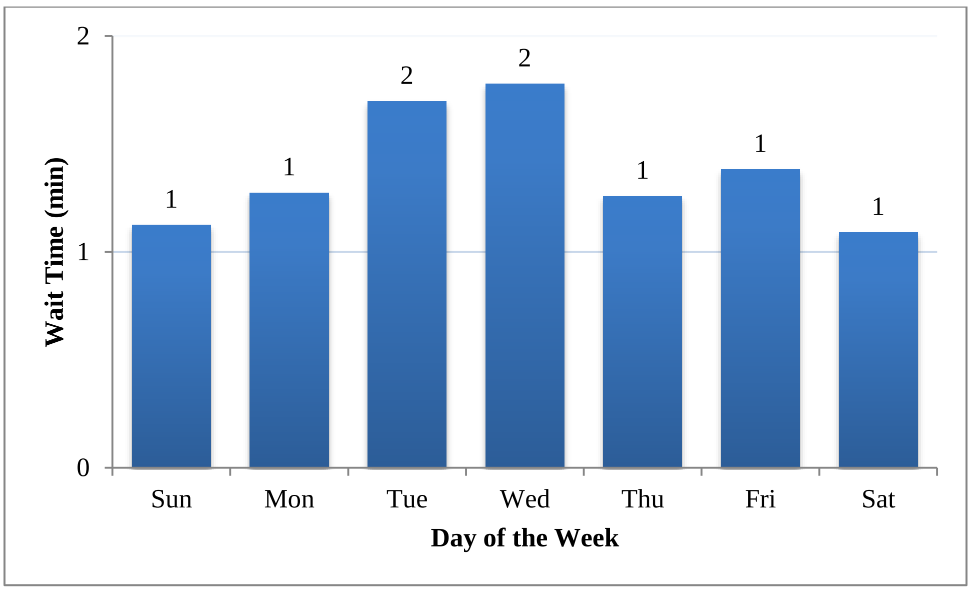


Figure B-91. POV SENTRI Average Wait Times for Different Days of the Week at Ysleta.

6.6.3.3 Regression and Correlation – POV SENTRI – Ysleta

Wait time is positively correlated with number of open lanes, having correlation coefficients of 0.19. However, wait time is negatively correlated with cycle time with correlation coefficient of −0.06. This shows that as number of open lanes increases wait time also increases. Although wait time–number of lanes correlation is counterintuitive, lanes are being open as wait time increases, so this can be explained by insufficient lanes available when wait times reach the peaks. Volume does not influence wait time. But, as volume increases, additional lanes are being opened (correlation factor is 0.32). Table B-94 presents the correlation matrix.

Table B-94. POV SENTRI Correlation Matrix at Ysleta.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.33	1.00	-	-
Number of Lanes	0.32	−0.06	1.00	-
Wait Time	0.01	−0.06	0.19	1.00

Table B-95 and Table B-96 explain regression between wait times (dependent variable) and independent variables (cycle times and number of open lanes). Each additional lane opened increases wait time by 0.59 min. Additional second of cycle time increases wait time by 0.006 min. This equation explains border process in 60 percent of cases (value of adjusted R square in Table B-96). In other words, this equation explains the variability (fits) of the 60 percent of data provided by CBP. The remaining 40 percent are not explained by this particular equation.

Table B-95. POV SENTRI Regression Coefficients at Ysleta.

	Coefficients	Standard Error	t Stat	P-value
Cycle Time	0.0058	0.0012	4.8631	1.36E-06
Number of Lanes	0.5874	0.0645	9.1069	5.28E-19

Table B-96. POV SENTRI Regression Statistics at Ysleta.

Regression Statistics	
Multiple R	0.7749
R Square	0.6004
Adjusted R Square	0.5989
Standard Error	1.1276
Observations	910

6.6.4 COV Standard Analysis – Ysleta POE

Vehicle volumes vary between 1 and 185 veh/h, having a mean of 86 veh/h and deviation of 33 veh/h. Cycle time ranges between 46 and 256 seconds, while the mean is 91 seconds and standard deviation is 21 seconds. Number of lanes open is between 1 and 5, and the mode is 3, meaning that 3 lanes are open in most cases. Wait time is between 1 and 55 minutes, and its mean value is 17.3 minutes.

Table B-97 shows detailed statistical characteristics.

Table B-97. COV Standard Basic Statistics for Volume, Cycle Time, Number of Lanes, and Wait Time at Ysleta.

	Volume (veh/h)	Cycle Time (s)	Number of Lanes	Wait Time (min)
Mean	86.00	91.05	3.24	17.27
Standard Error	1.19	0.74	0.07	12.00
Median	90.00	89.60	3.00	12.00
Mode	93.00	88.03	3.00	10.00
Standard Deviation	33.25	20.60	0.94	12.77
Minimum	1.00	45.73	1.00	1.00
Maximum	185.00	256.29	5.00	55.00

6.6.4.1 Volume Analysis – COV Standard – Ysleta

Figure B-92 presents average hourly volumes for different days of the week. The volumes are significantly lower on Saturdays (72 veh/h) in comparison to other days of the week (between 83 and 92 veh/h).

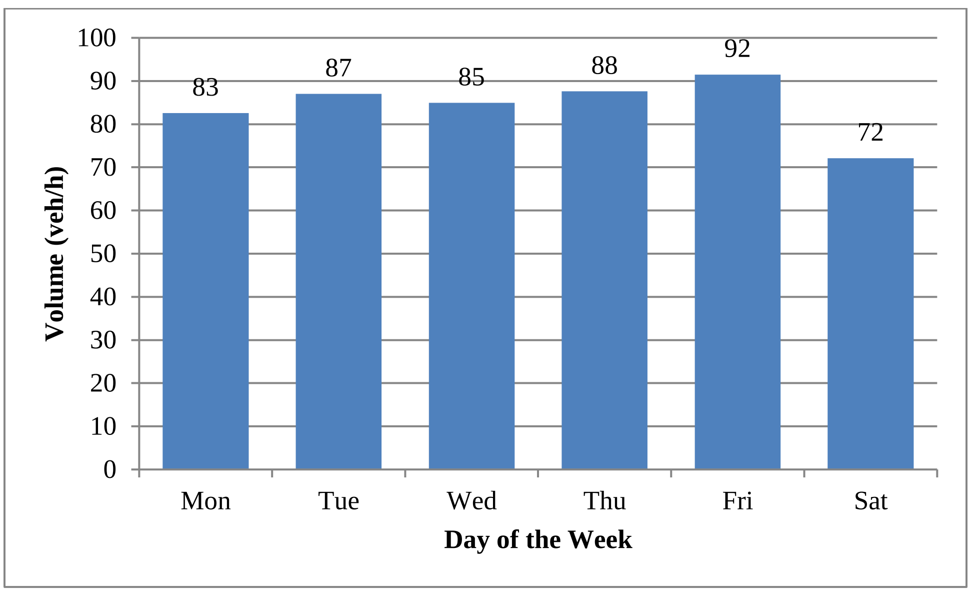


Figure B-92. COV Standard Average Hourly Volume for Each Day of the Week at Ysleta.

Average hourly volume for each hour of the day during weekdays and weekend are presented in Figure B-93 and Figure B-94, respectively. It can be concluded from Figure B-93 that the number of vehicles crossing the border from Monday to Friday is consistent between 7 a.m. and 6 p.m. being around 100 veh/h and having a maximum value of 114 veh/h.

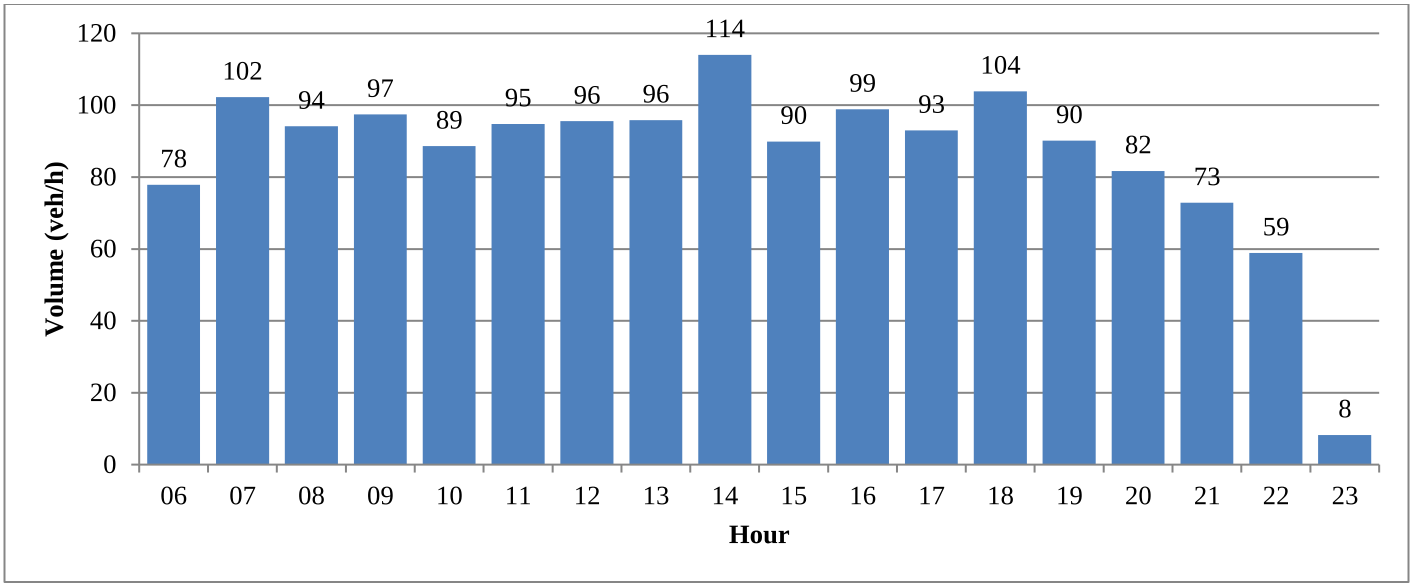


Figure B-93. COV Standard Average Volume for Different Hours of Weekdays at Ysleta.

Figure B-94 displays vehicle volumes for different hours of the weekends. The data are recorded only from 8 a.m. until 4 p.m., so the average peak hours are inconclusive.

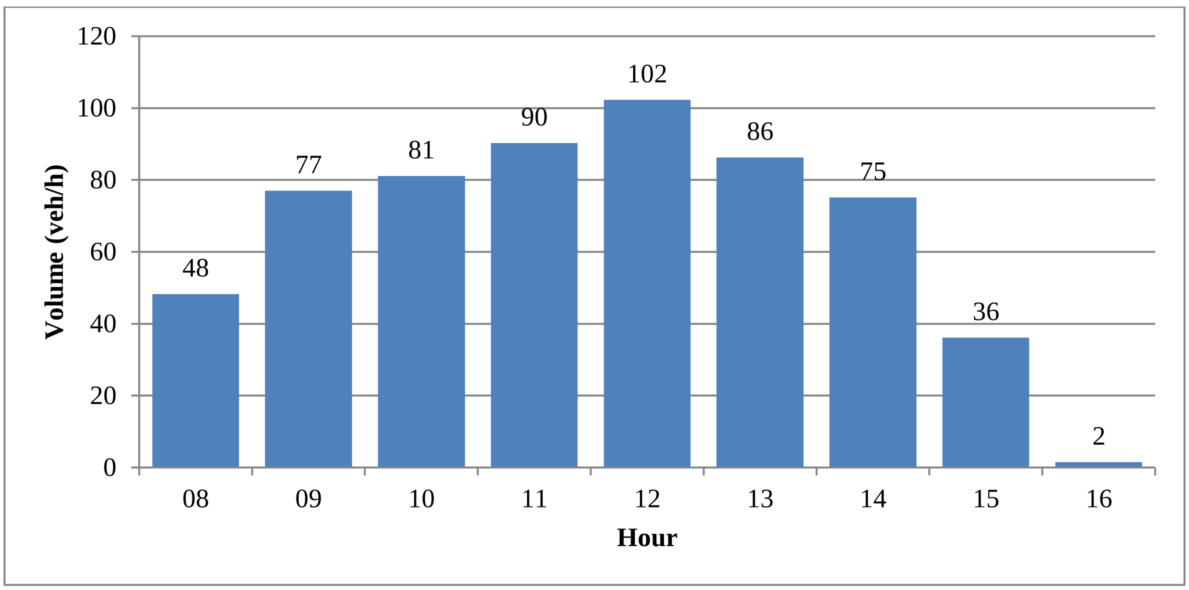


Figure B-94. COV Standard Average Volume for Different Hours of a Weekend at Ysleta.

6.6.4.2 Wait Time Analysis – COV Standard – Ysleta

Figure B-95 presents average wait time analysis and suggests that vehicles wait longer on Tuesdays (22 minutes), in comparison to other days of the week (between 15 and 18 minutes).

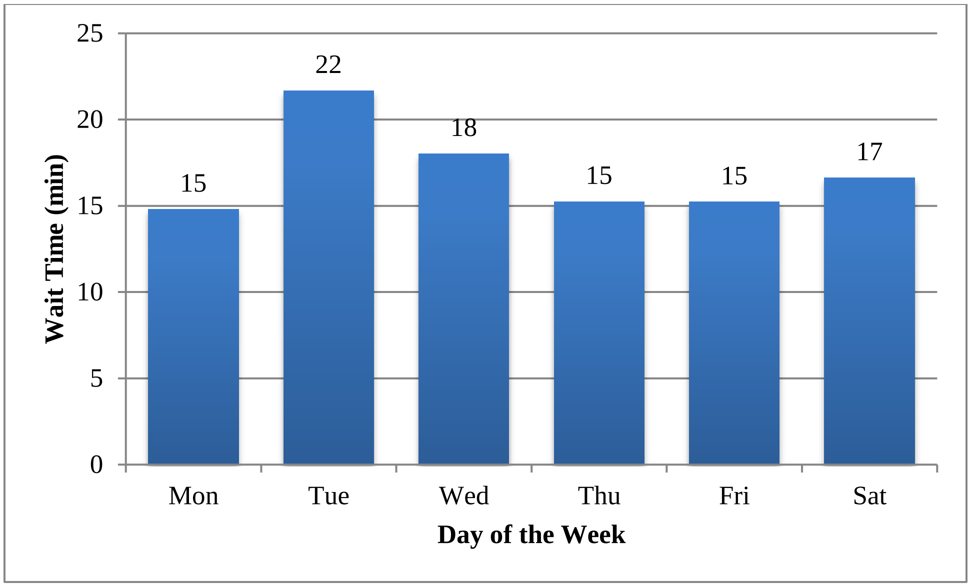


Figure B-95. COV Standard Average Wait Times for Different Days of the Week at Ysleta.

Figure B-96 represents average wait times during weekdays for different hours of the day, while Figure B-97 is for weekends. Weekday wait times remained the same at 20 minutes between 9 a.m. and 11 p.m., so a definite peak hour could not be determined.

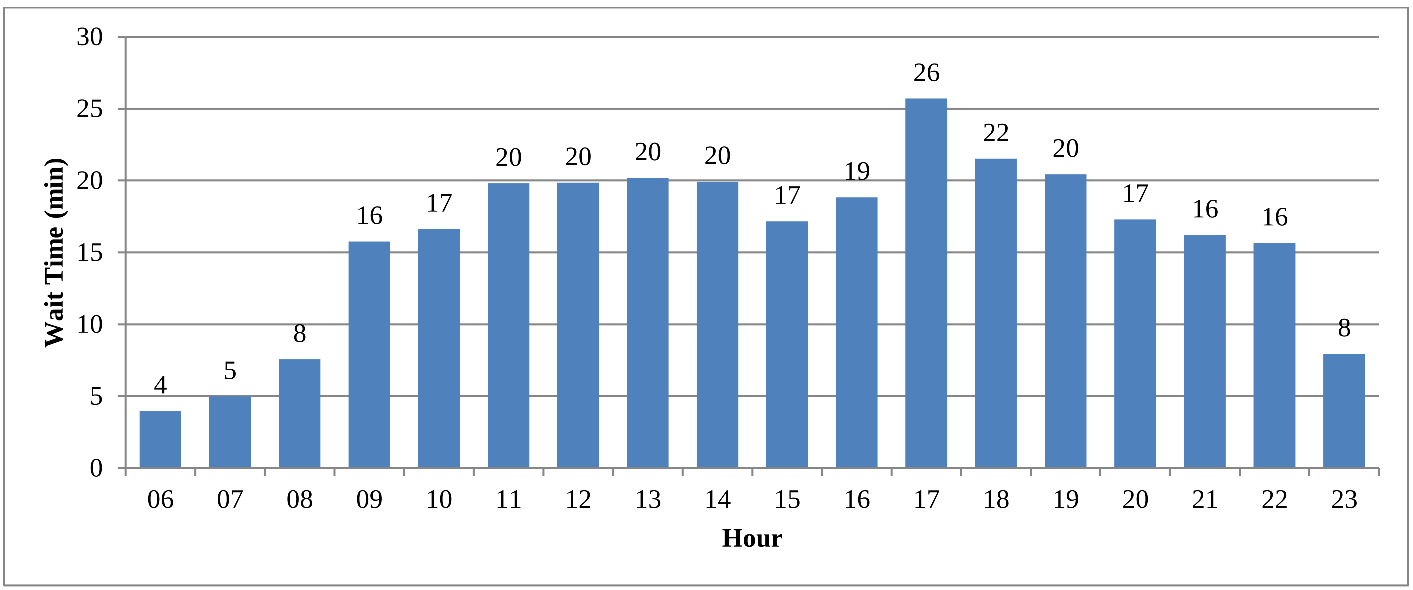


Figure B-96. COV Standard Average Wait Times for Different Hours during Weekdays at Ysleta.

Weekend peak hours cannot be determined as well, since data are recorded only from 8 a.m. until 5 p.m.

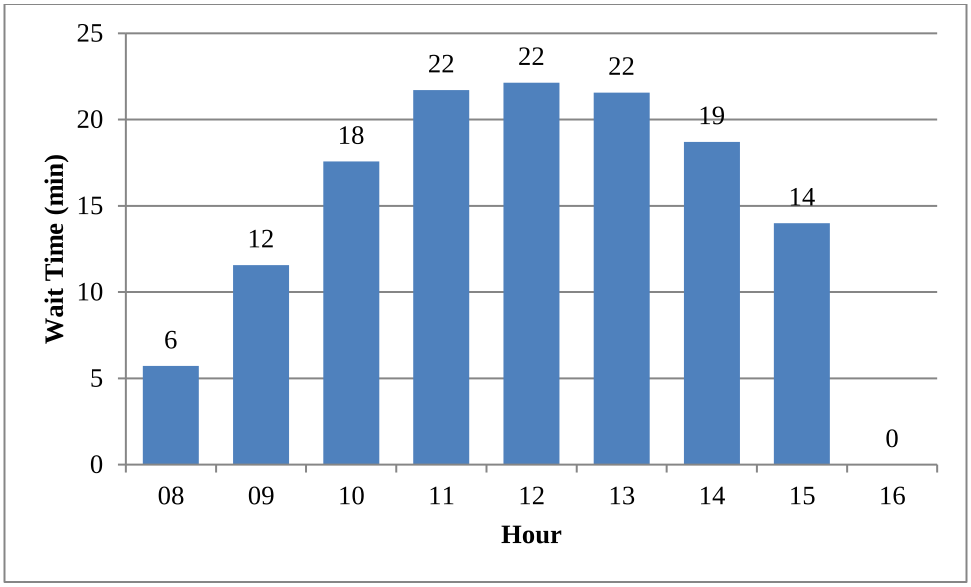


Figure B-97. COV Standard Average Wait Times for Different Hours during Weekends at Ysleta.

6.6.4.3 Regression and Correlation – COV Standard – Ysleta

Wait time is positively correlated with volume, cycle times, and number of open lanes, having correlation coefficients of 0.29, 0.25 and 0.19, respectively. Volumes are negatively correlated with cycle times (correlation factor is −0.21), meaning that as the border crossing becomes more crowded, officers are probably working faster. When volume increases, additional lanes are being opened (correlation factor is 0.37). Table B-98 presents the correlation matrix.

Table B-98. COV Standard Correlation Matrix at Ysleta.

	Volume	Cycle Time	Number of Lanes	Wait Time
Volume	1.00	-	-	-
Cycle Time	−0.21	1.00	-	-
Number of Lanes	0.37	0.16	1.00	-
Wait Time	0.29	0.25	0.19	1.00

Table B-99 and
Table B-100 present regression between dependent variable (wait time) and independent variables (vehicle volume and cycle times). Each additional vehicle increases wait time by 0.1 min, and additional second of cycle time increases wait time by 0.103 min. This equation explains border process in 70 percent of cases (value of adjusted R square in
Table B-100). In other words, this equation explains the variability (fits) of the 70 percent of data provided by CBP. The remaining 30 percent are not explained by this particular equation.

Table B-99. COV Standard Regression Coefficients at Ysleta.

	Coefficients	Standard Error	t Stat	P-value
Volume	0.0960	0.0105	9.1771	4.65E-19
Cycle Time	0.1031	0.0103	9.9914	4.27E-22

Table B-100. COV Standard Regression Statistics at Ysleta.

Regression Statistics	
Multiple R	0.8372
R Square	0.7009
Adjusted R Square	0.6991
Standard Error	11.7516
Observations	719

APPENDIX C – VEHICLE TRAVEL TIME ESTIMATION TECHNOLOGY ASSESSMENT

T.3.1 Developing a Concept of Operations for an Innovative System for Measuring Wait Times at Land Ports of Entry

Vehicle Travel Time Estimation Technology Assessment

Prepared for the

BTI Institute
Borders • Trade • Immigration
A Department of Homeland Security Center of Excellence

By:

Juan Carlos Villa
(Principal Investigator)

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Melissa Tooley, Ph.D., PE

Texas A&M Transportation Institute

10/13/2016

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1 INTRODUCTION AND SCOPE

1.1 PROJECT OVERVIEW AND ORGANIZATION OF THE DOCUMENT

Border wait times at land ports of entry (POEs) are an important measurement of port performance, trade, and regional competitiveness. A reliable and systematic method of measuring border wait times is needed in order to make better construction, planning, and operations decisions at land POEs. As technologies become more pervasive and more functional, there is a need to enhance the systems to take advantage of emerging technologies such as connected vehicle (CV), automated vehicle, Wi-Fi, global positioning system (GPS), and near field communication.

This document presents the results of a review of literature on various technologies that were identified as currently being used or that could be used in the future to measure vehicle travel time at POEs. The objective of this technology assessment is to identify potential technologies that could be used in the border crossing measurement system Concept of Operations (ConOps) document. The ConOps lays the foundation necessary to design an enhanced wait time system at the POEs in a later project phase.

After conducting an analysis of potential technologies to be used for border crossing time measurement, researchers found the following technologies are currently used to measure border wait time:

- Inductive loop detectors.
- Bluetooth® (BT).
- Radio frequency identification (RFID).

The emerging technologies that were identified to have potential to be used for travel time measurement in the future are:

- GPS.
- CVs.

CVs include several technologies that have been grouped under the connected vehicle concept.

This document includes a brief description of each technology, followed by an analysis of strengths, weaknesses, opportunities, and threats (SWOT). The final section of the documents summarizes the analysis with a SWOT table.

2 SWOT ANALYSIS

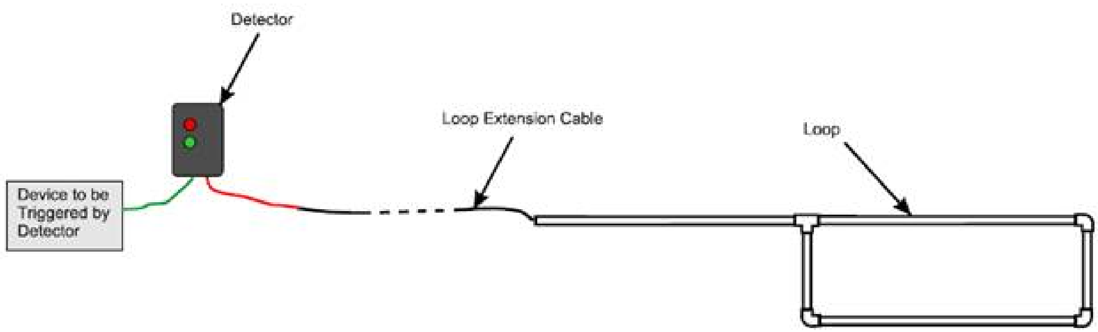
A SWOT analysis was conducted to determine if the technologies can support the needs assessed previously and the parameters influencing border wait times. The SWOT analysis considered the technology's functional capabilities, market trends, deployment costs, and maturity.

2.1 CURRENT EMPLOYED TECHNOLOGIES

2.1.1 Inductive Loops

2.1.1.1 Background

Inductive loop detectors comprise electronic circuitry that operates in conjunction with a loop (wire coil). Turns or loops of isolated wire are placed under each lane of the roadway paralleled to the roadway surface. The two ends of the loop wire are connected to the loop extension cable, which connects to the vehicle detector. The detector powers the loop and creates a magnetic field in the area surrounded by the loop. The resonant frequency is established and remains constant as long as there are no vehicles in the loop area. When a large metal object (vehicle) moves over the loop, resonant frequency increases, and the detection is made. Figure C-1 presents an inductive loop vehicle detector system (*1*).



Source: Doug Marsh/Marsh Products, Inc.

Figure C-1. Inductive Loop.

Inductive loop detectors were employed at Blaine-Pacific Highway and Douglas (Peace Arch) border crossings for passenger cars in 2003 and at the Sarnia, Ontario–Port Huron border crossing for both privately owned and commercial vehicles in 2008 (*2*). However, the concern remained on the queue length measurement. Loop detectors are able to detect the vehicle if it is above the loop, and can approximately calculate wait time from that point only. The time the vehicle has already spent in line is not integrated in the total wait time (*3*).

2.1.1.2 Strengths

The main function of loop detectors is to detect the presence of vehicles. The data obtained from the loop detector include traffic volumes, vehicle speeds, occupancy, and vehicle length information (*4*). Being invented 50 years ago, this technology is very mature. Therefore, this technology is well known and broadly used. Additionally, no on-board equipment is needed and the installation and maintenance costs per detector are relatively low (*5*). Also, if sufficient numbers of detectors are installed with the right spacing, samples of volume and speed measurements can be relatively high.

2.1.1.3 Weaknesses

Loop detectors do not capture traffic conditions between detectors (e.g., speed), additional calculations have to be made in order to gain sufficient insight in traffic condition (*6*). Unstable traffic conditions, which occur at the borders, raise a concern about high errors. Therefore, large numbers of detectors are needed in order to improve measurement accuracy.

Existing models for travel time measurement are applicable only with dense spacing of detectors (typically 500 m). However, detector malfunction occurrence can increase the spacing and significantly deteriorate accuracy, especially under congested conditions (*7*). Therefore, one of the biggest disadvantages of inductive loops usage is reduced reliability; approximately 25 percent of installed detectors will fail every year (*8*). The main reasons for failure are improper installation or pavement deterioration (*9*). If the failure occurs, entire lanes need to be closed in order to perform maintenance, which causes additional vehicle delays.

2.1.1.4 Opportunities

Characteristics of loop detectors measurement (high sample size and low accuracy) offer the possibility to merge it with complementary technologies and improve its performance. The studies confirmed that merging data from two or more sources might enhance the wait time measuring system. Probe data and data fusion techniques offer a new strategy that can fill the information gap, without deploying additional loop detectors. For example, one of the probe data collection technologies is GPS, which is currently employed on several border crossings. GPS is recognized as a technology with potential to supplement information about queues and provide more accurate wait time measurements (*3*).

Probe vehicle data (such as BT, Wi-Fi, GPS, RFID) have sufficient spatial coverage and combined with a good temporal sampling of loop detectors can increase border wait time measurement accuracy. For instance, one study analyzed fusion techniques for BT and loop detector data, and the results show that the combined results will be more accurate than the most accurate estimate of the independently used technology (*10*). Another report confirmed that data fusion techniques can significantly improve accuracy in congested traffic conditions, even if low percentage of probe vehicles is available (*11*).

When loop detectors are combined with GPS probe data, more information can be extracted regarding traffic status then either method individually (*12*). Taking advantage of these hybrid data would increase efficiency of the wait time measuring system and decrease costs of installing additional loop detectors, at the same time.

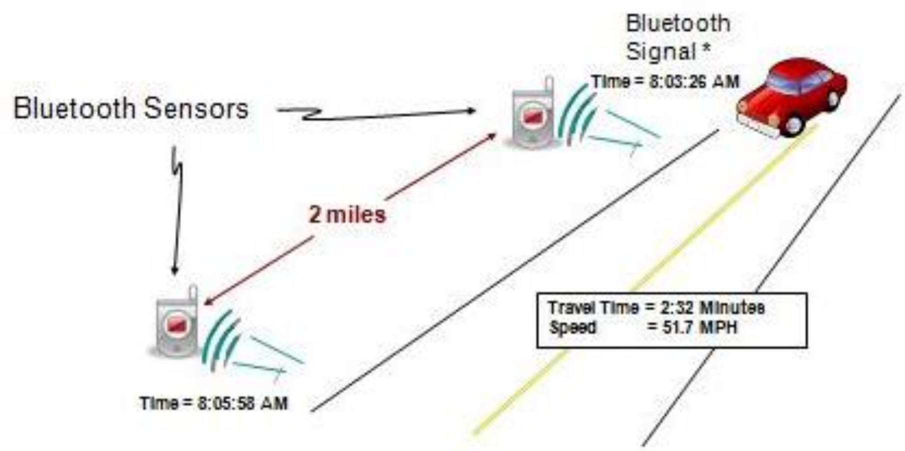
2.1.1.5 Threats

One study indicated that better travel time accuracy and coverage can be obtained when fusing existent loop detectors with relatively small amount of GPS data (penetration rate of 0.2 percent), than by doubling the number of loop detectors (*13*). Therefore, implementation of loop detectors has lower value added in comparison to implementation of more innovative technologies.

2.1.2 Bluetooth

2.1.2.1 Background

BT is a wireless technology that allows radio frequency communication between BT-enabled devices. The procedure of BT application for border wait time measurement is straightforward. On-board electronic device with enabled BT, broadcasts its unique media access control (MAC) address (tag) in order to communicate with other devices within range. A BT sensor located by the road records MAC addresses and detection time for each detectable BT device in the vehicle. In order to determine travel time for the particular in-vehicle device two detections are required, conducted by two distanced sensors. These BT sensors detect tag and time stamp for the device in discoverable mode. Wait (travel) times are calculated by subtracting recorded times. The vehicle average speed is derived from travel times across this road segment. Figure C-2 illustrates the detection process by BT sensors.



Source: Traffax Inc.

Figure C-2. BT Detection.

2.1.2.2 Strengths

The BT technology, being on the marker for over 20 years, is included in various electronic devices such as: mobile phones, computers, tablets, headsets, car navigation systems, etc. Being highly available technology on the market and low on cost, travel time measurement systems based on BT communication can be greatly used. Additional advantages of BT systems over more conventional methods are cost-effectiveness, easy implementation, relatively large quantities of data that can be collected, and almost absent privacy violation. Also, one of the advantages is that specific software on motorists' devices is unnecessary.

2.1.2.3 Weaknesses

The disadvantages include complex algorithms required for accurate output report, and the fact that crowded borders may have lack of room for BT sensors' installment due to physical geometry and queue existence (*14*).

In order to determine wait time at the border, a sample of vehicles detected needs to be representative. The average travel time of a sample is generalized to the entire population crossing the border at the particular period of time. Thus, the same BT devices need to be detected twice, and quantity of these detections needs to allow truthful general travel time approximation. Sufficient quantity and high accuracy of detection pairs would provide good estimates of border wait times. Depending on the duration of time that the on-board device resides in the detection area, that device may be detected once, several times, or not at all. If a vehicle travels too fast, and is not detected by the BT sensor, it will not be in the sample, and as a result, its travel time will be overlooked and data loss will occur. Deficiency of detecting faster moving vehicles leads to the overestimation of a travel time. Therefore, acquiring proper sample size and output accuracy are closely related.

Reliable detection distance of BT sensors reaches up to 328 ft (100 m). This range can be reduced if a lower gain antenna is used. Antenna's features impact detection zone's size and shape. The larger detection zone provides greater sample. On the other hand, it can also cause multiple detections of the same device, causing a decrease in accuracy level.

Inquiry time represents the time BT sensor scans range of channels in order to find discoverable BT devices. The inquiry phase requires up to 10.24 seconds (*15*). For example, the vehicle traveling at 60 mph through the maximum detection radius will be measurable for only 3.4 seconds and the 25 mph vehicle will be in range for 8.2 seconds. Consequently, lower speeds allow larger probability of BT device detection. Additionally, only a maximum of eight detections could be detected within each inquiry window (*16*). Furthermore, the travel time estimate is less accurate if the detection event is farther from the sensor (*17*).

2.1.2.4 Opportunities

Technology advancement and wider exploitation of BT devices can increase probability of detectable devices' existence in vehicles crossing the border. Reports show that 92 percent of U.S. adults own a cell phone, 68 percent own a smartphone device, and 45 percent a tablet computer (*18*). In 2016, on average consumers own almost four BT integrated products (*19*). It is estimated that 40 percent of devices in North America have enabled BT (*20*). BT is expected to remain the standard wireless connection in vehicles and is anticipated to rise by 41 percent from 2012 to 2018 (*21*). BT sends information faster and uses less power as technology advances. The consequence might be higher accuracy of border crossing wait time data through BT.

Stevanovic et al. concluded that MAC readers are more reliable at lower traveling speeds (*22*). Accurate border wait times are generally more important for congested conditions, in comparison to free-flow conditions and situations when the queue is not formed. BT has higher probability of performing well in crowded environments, such as border crossings. The report on

BT performance evaluation in a work zone suggests that congestion in the work zone increased number of pairs detected (*23*).

The characteristics (speed and strength) of the transmitting device impact the reaction time to the sensor's connection inquiry. However, technology advancement continuously provides faster and more powerful BT devices, capable to fulfill the demands. Also, BT shows the high potential to be used as a complementary method for wait time estimation along with other technologies (*24*).

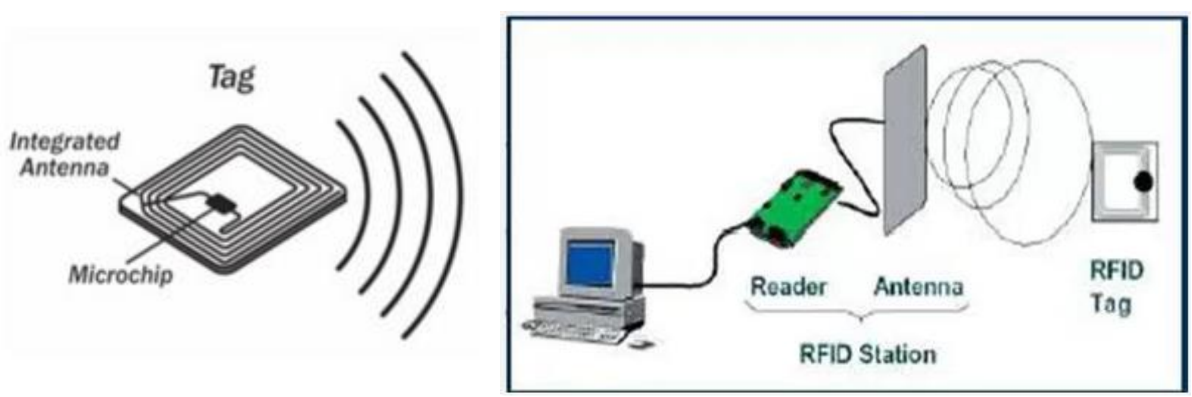
2.1.2.5 Threats

The main threat of the BT application for wait time measurement is the fact that this technology has low sample rates. Although advancement of technology might provide higher accuracy and algorithm advancement, penetration rate is relatively low, and consequently, accuracy decreases. Research conducted by Vo summarized literature review on penetration rate (percentage of vehicles containing discoverable BT device) to be less than 10 percent and match rate being around 2 percent (*25*). Therefore, BT application might be greatly endangered by the supplemental technologies' market penetration. For example, Wi-Fi has an inquiry time of only 8 milliseconds. The data collection rate of Wi-Fi MAC address is almost 10 times theoretically and 8 times empirically bigger than BT. Hence, application of Wi-Fi connection allows detection at a much quicker rate (*26*).

2.1.3 RFID

2.1.3.1 Background

RFID is an automatic vehicle identification technology that uses electromagnetic fields for tag identification and tracking. The system consists of reader, antennas, and tags. A RFID tag, consisting of a microchip and antenna, is located inside the vehicle. Figure C-3 shows a reader unit, mounted above traffic lanes, which contains a transmitter/receiver and antenna.



Source: BarcodesInc. Com; Krazytech.com

Figure C-3. RFID Tag and RFID System.

A reader generates an electromagnetic field, so when the tag passes through the electromagnetic zone, it detects the reader's activation signal. The tag receives the signal sent by the reader's antenna and the tag's activation is conducted. Once activated, the tag receives commands from the reading unit and responds by sending requested data stored on the chip—its serial number, location, or other specific information. The time when the RFID tag is read is also recorded. Subtracting times of two RFID readings would display the wait time information.

RFID is used at NEXUS, SENTRI, and FAST programs at border crossings for commercial vehicles. This is due to relatively high percentage of CVs crossing the border already have RFID transponders (tags).

2.1.3.2 Strengths

RFID technology has been available for over 40 years, but its commercial application began to escalate only recently, as its price persistently decreased. The main advantage of RFID application in travel time measurement is that the data collected are very precise. This technology has been recognized as one of the most appropriate to support a system that automatically measures freight border wait times (*9*). Further, advantages include an easy implementation, high accuracy, low operating cost, and ability to be simultaneously used with sensors (*27*).

2.1.3.3 Weaknesses

The main concern is that RFID requires a relatively high investment for roadside infrastructure. Additionally, the occurrence of reader collision and tag collision is a drawback. Reader collision takes place when two readers read the same tag at the same time, and tag collision when a reader unit attempts to read multiple chips within its range simultaneously. The results are multiple detection and data loss. Anticollision algorithms are created to eliminate this (*28*).

2.1.3.4 Opportunities

RFID-based vehicle identification can be a valuable supplement to GPS data, since currently used GPS has a limitation of being inaccurate and loss of signal. Additionally, RFID has low operating costs and sufficient accuracy (*29*).

2.1.3.5 Threats

Although RFID has been greatly improved over the years, certain challenges remain: connection loss and collisions among simultaneous transmissions of data. The solution would be use of advanced antennas, implementation of active RFID (battery-powered), and development of reliable MAC protocols for the RFID sensor network (*30*).

Because RFID's high initial investment, this technology has been used to measure wait time of commercial vehicles on U.S.-Mexico border since high percentage of trucks already carry transponders, so initial investment is somewhat reduced. On the other hand, distribution of transponders to motorists would be expensive even though roadside hardware cost may be justified.

2.2 EMERGING TECHNOLOGIES

2.2.1 GPS

2.2.1.1 Background

A probe (floating) vehicle is a vehicle that has an on-board data collection device that observes traffic conditions and collects traffic data. Most common probe vehicles are equipped with GPS. GPS is a satellite-based navigation system that was originally meant for military use; however, it has been available to the public for over 30 years.

A GPS receiver in a vehicle determines its coordinates at multiple locations while moving. The combination of vehicle's location at regular time intervals provides the data to calculate border wait time (*2*). Estimation of travel time with GPS allows excellent spatial coverage and the technology advancement promises growing availability of data. Raising number of individuals travels with GPS-enabled mobile phones capable of providing location information, making GPS more accessible than before (*31*). According to the International Telecommunication Union, number of mobile phone active users is 86 percent in developed countries. Particularly in the United States, every 100 habitants of the United States own 110 mobile phones on average (*32*).

The data that can be acquired from GPS devices available on the market include velocity and position on a regular basis.

2.2.1.2 Strengths

The key advantage of GPS is the fact that its deployment does not require infrastructure to be purchased, deployed, or maintained, which significantly lowers the operating costs (*33*). Hence, the technology promises a growing availability of data, high accuracy, and a wide geographical coverage.

2.2.1.3 Weaknesses

The main concern on GPS use is insufficient number of GPS-equipped vehicles and consequently, privacy and low accuracy of the gathered wait time information. For example, for passenger vehicles, privacy is a huge concern. However, aggregated data can be used to show traffic status, but cannot determine wait time. Websites such as INRIX, Google Maps, and Bing Maps can show traffic status at border crossings. Although this information is based on GPS location of mobile devices, they cannot be matched after vehicles have crossed the border to estimate wait times.

Several studies have defined the desirable penetration rate for this system. The field experiment suggests that 2–3 percent penetration rate is required for highly accurate estimation of results (*34*). Studies that used simulations proposed minimal penetration rate between 1 and 5 percent to guarantee the information integrity (*35*) (*36*) (*37*). The simulation study conducted by Zhan and Zhang reveals that the same accuracy data will be obtained when smaller penetration rate is used under congested conditions in comparison to lighter traffic conditions (*38*). This conclusion might be beneficial when a border crossing is congested. The study by Vandenberghe et al. aimed at penetration rate of 1 percent, sample interval of 10 sec, and a transmission interval of

30 sec. The results would provide accuracy in both congested and normal conditions (*39*). Similar study of minimal penetration rate has not been performed in border crossing environment for either commercial or passenger vehicles.

2.2.1.4 Opportunities

In 2015, a new breakthrough was made in terms of GPS improvement. Enhanced reliability of the GPS system provides centimeter positioning accuracy even in challenging environments (*40*). An internal navigation system combines data from GPS and an internal measurement unit. By joining these two, the GPS location accuracy will increase and the internal measurement unit will deliver data to reach continuous high rates (*41*). However, until now, the main issue was the requirement of powerful computers to combine these data sets. This was not cost-effective for use in cell phones and cars (*42*). But, simplification of the required algorithms for accurate GPS position calculation allows even GPS systems in mobile devices to complete the calculation (*43*). The research team basically created a new set of algorithms that reduce the complexity of the required calculations. One of the leading researchers, Jay Farrell, states that this discovery "will improve location services accessed through mobile phones and other personal devices, without decreasing their cost" (*44*). This innovation would allow existence of very accurate navigation systems in every cell phone, tablet, or car. This would significantly improve the sample rate of the wait time measurement system and provide accurate information on vehicles' positions and speeds. Consequently, wait times will be evaluated in a precise manner.

2.2.1.5 Threats

This technology does not offer a backup system for instances when it goes down. Since the system relies on satellite signals from space, they can be easily blocked, jammed, or compromised. Signals can be affected from solar flares, satellite malfunctions, by interference either intentional or unintentional, to name a few (*45*). Substitute technologies could emerge to incorporate the backup system.

2.2.2 Connected Vehicles

2.2.2.1 Background

In 1999, the United States Federal Communications Commission allocated 75 MHz of wireless spectrum denoted as the 5.9 GHz band to be dedicated for dedicated short range communication (DSRC) in intelligent transportation system (ITS) technology, particularly for CV usage. DSRC is a reliable and efficient two-way wireless communication capability that allows very high data transmission (*46*). Similarly, CVs are defined as vehicles that communicate via DSRC between a system onboard and another system not onboard (*47; 48*).

This type of vehicle autonomously collects information about its own location and speed, and stores them in the on-board unit in the vehicle. These data can be connected and wirelessly transferred to each other (vehicle to vehicle [V2V]), to infrastructure and roadside sensors (vehicle to infrastructure [V2I]), and to other road users such as pedestrians and bicyclists (V2X) (*48*). This way, data on location and speed, and consequently on border wait times, becomes available for manipulation (*49*).

For example, a basic safety message (BSM) is a data package that can be transmitted from DSRC-equipped vehicle, and among others, includes: identification, vehicle position, speed, and heading information. The BSM is frequently broadcasted (10 times per second) and provides real-time information.

From its beginning to the present, CV technology has been in focus by both government and industry. They continuously seek to evaluate it and improve its capabilities. For instance, the U.S. Department of Transportation (USDOT) is interested in CV technology due to its potential for vastly improved vehicle safety (*48*). In 2015, USDOT announced the selection of three CV deployment sites in the Connected Vehicle Pilot Deployment Program (*50*). The Connected Vehicle Pilot Deployment Program seeks to spur innovation among early adopters of CV application concepts, using best available and emerging technologies (*51*). The three pilot sites include: using CV technologies to improve safe and efficient truck movement along I-80 in southern Wyoming; using V2V and V2I to improve vehicle flow and pedestrian safety in high-priority corridors in New York City; and deploying multiple safety and mobility applications on and in proximity to reversible freeway lanes in Tampa, Florida (*50*).

CVs are a promising and emerging technology for border wait time measurements that are able to share vehicle information over a wireless network. The appendix presents a detailed description of the CV technology.

2.2.2.2 Strengths

Both the vehicle and the road use for DSRC technology has advantages of being fast, secure, reliable, and unlikely to experience interference in message transmission (*52*). DSRC provides a wider detection rage than the other technologies previously mentioned, with approximately 300 m of detection range. CVs provide better interaction between vehicles and road infrastructure to increased safety, better mobility, and lower environment impact (*53*).

2.2.2.3 Weaknesses

The technology is not yet mature, however its potential in benefiting mobility and safety is clear. CVs rely on a tight integration of sensing, communication, and computing in order to maintain a fast, secure, and reliable system (*52*). Hence, roadside equipment and infrastructure deployment would be needed, which is no different than other technologies currently deployed.

2.2.2.4 Opportunities

According to the BI Intelligence report, the connected-car market is expected to grow 10 times faster rate than the overall car market (*54*). General Motors declared at the Mobile World Congress that their plans to install high-speed wireless connections on all of its vehicles would start in 2015 (*55*). It is forecasted that 75 percent of vehicles will be capable of internet connectivity by 2020 (*56*). The USDOT’s National Highway Traffic Safety Administration decidedly took action to enable communication between vehicles (*30*). USDOT CV technologies are recognized to have a potential to improve border operations (*57*).

Olia et al. tested the influence of CVs’ market penetration rate in Paramics traffic microsimulation software. The researchers concluded that drivers would experience decreases in travel time by 37 percent when only 50 percent CVs are in the flow in comparison to the flow consisted of all non-CVs. In addition, the existence of CVs decreases average travel time for non-CVs, as well. The reason for this is the fact that CVs take less congested routes, allowing non-CVs to benefit from it. Divergence across alternative routes decreases the congestion on the key routes that non-informed drivers usually take (*58*). Similarly, existence of CVs at the border crossings would create much more balanced demand among POEs.

According to the American Association of State Highway and Transportation Officials report, incorporation of CVs has the potential to reduce costs relative to deployment of older technologies, and if a driver is capable of gathering all needed information from on-board CV devices, older technologies will become obsolete. With the detailed information on vehicles crossing the border, wait times can be predicted based on queue length estimate, travel time between points, and number of inspection booths open (*55*).

2.2.2.5 Threats

The sharing of data information between CVs and road infrastructure has led to concerns about personal privacy (*59*). Since, the connected vehicular program has been the focus as an effort of the federal government (*60*). As a result, the USDOT is committed to ensure that CVs technology preserves personal privacy and protects against unauthorized access (*59*).

3 SUMMARY OF SWOT ANALYSIS

Table C-1 summarizes the SWOT analysis of currently employed and new technologies as an automated measurement system at border crossings.

Table C-1. SWOT Analysis of Automatic Measurement Systems.

	Inductive Loop Detectors	**BT**	**RFID**	**GPS**	**CVs**
Strengths	Mature technology High temporal sampling No on-board equipment required Low installation costs per detector Low maintenance costs per detector	Mature technology Cost-effective Easy implementation Almost absent privacy violation	Mature technology Precise data collected Easy implementation Low operating cost Can be simultaneously used with sensors	Wide geographical coverage High data availability Low operating cost Potentially high accuracy	Reliable Efficient Fast Secure No interference in message transmission
Weaknesses	High errors Low reliability	Complex algorithms required Low sample rate Overestimation of travel time Multiple detections High inquiry time and low number of maximum detections	High investment for roadside infrastructure Multiple detection Possible data loss	Insufficient number of GPS-equipped vehicles Privacy concern	Technology still in development Roadside equipment and infrastructure deployment Licensing fees
Opportunities	Fusion techniques	Performs well in crowded environments Technology advancement- more powerful devices Can be used as a complimentary method	Performs well for fright wait time measurement at the border	Low penetration rate is sufficient Increased accuracy	Market growth Lower congestion at border crossings Wait time forecast
Threats	Substitute products	Low penetration rate Low match rate Substitute technologies perform better (e.g., Wi-Fi)	Low penetration rate for POVs Insufficient technology for wait time measurement	Substitute technologies	Privacy concern

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5 APPENDIX. CONNECTED VEHICLE TECHNOLOGY DETAILED DESCRIPTION

5.1 CONNECTED VEHICLE SYSTEM ARCHITECTURES

The CV system architecture is, at a high level, a system for exchanging data bidirectionally between transportation system field equipment, mobile users, vehicle systems, and transportation system center users. Transportation field equipment is typically located at or near the roadway, and may include traffic signal controllers, access controls, or ITS field equipment such as dynamic message signs, count or vehicle detection (speed) stations, highway advisory radio stations, surveillance stations, and other related equipment.

Vehicle systems include sensors and various types of user interfaces such as displays, audio interfaces, and such. Mobile users interact directly with the transportation field equipment through the normal use of the transportation system—driving on a roadway, observing a traffic signal—and (if they are in a vehicle) interact with the vehicle systems through the vehicle's user interface equipment. A mobile user's primary interests are to get through the transportation system safely and efficiently. Transportation information system users are any other users that may need information about the roadway or transportation system state or about vehicles on the roadway. These users are typically responsible for managing and maintaining the roads or may be other users with an interest in information about the transportation system, such as users planning trips. Figure C-4 illustrates this overall system.

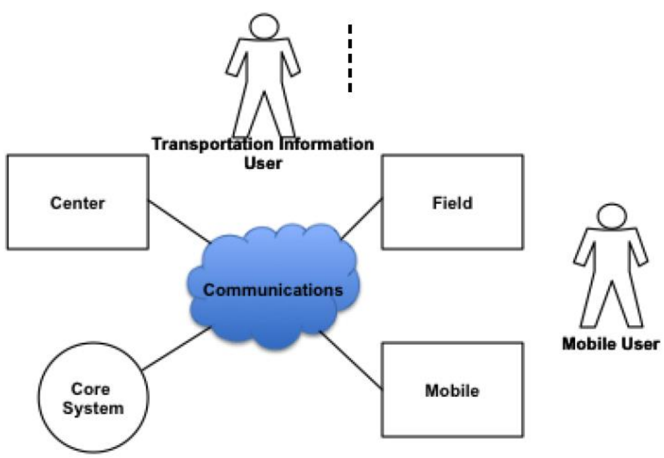

Figure C-4. Top Level View of CV System.

This system is the same as the overall system described in the core system architecture and the Connected Vehicle Reference Implementation Architecture documentation, although here it is focused on the mobile, field, and center elements of that architecture since these are the parts that actually carry out the steps of CV applications.

While it is included here for completeness, the core system does not play a role in the applications discussed in this report. The core system ConOps does not describe the applications treated in this report, and the core system requirements apply to elements within the core system (in support of the core system functions described in the ConOps), but these do not apply to the mobile, field, and center elements described here since these elements are outside the core system boundary.

The CV system sits within the existing transportation system. The mobile, field, and center elements of the system shown above actually include elements that are part of the CV system and elements that lie outside the CV system. Vehicles (mobile), traffic signal controllers and signals (field), and traffic management centers (center) exist today without the CV system. As the CV system emerges, it will include new elements for each of these component areas. A key aspect of the system deployment will be the implementation of the interfaces between these new CV elements and the existing elements in the transportation system. The CV system diagram is shown in Figure C-5.

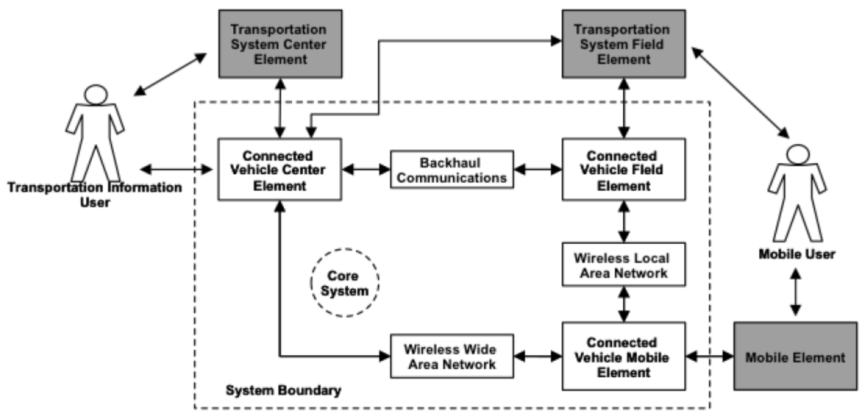

Figure C-5. CV System Diagram.

To support this separation between existing elements and their CV counterparts, the diagram has adopted some slightly refined terminology. For example, in a DSRC-based system, the CV Field Element is also known as a roadside unit (RSU) and the CV Mobile Element is known as the on-board unit. In general, the CV mobile element is located in a vehicle, so CVs may refer to a CV mobile element even if the mobile element were a user's smartphone. There will always be a wireless connection to a mobile element.

As shown in the diagram above, the mobile element of the CV system may communicate with the field element using a wireless local area network (WLAN). The WLAN supports communications over a limited range in the area local to the field element. In most currently envisioned implementations of the CV system, the WLAN element is implemented using DSRC. However many studies have examined other ways of implementing this element (e.g., Wi-Fi, BT, or long-term evolution [LTE] Direct), so it is referred to here by its more generic term.

Through this connection the mobile element can receive information from the field element. This information may originate at a center element (e.g., a traffic management center) and be provided to the field element over the backhaul link, or it may originate from transportation field equipment co-located with the CV field equipment (e.g., a signal controller providing signal information to a roadside DSRC unit). The mobile element may also provide data to the center element via the field elements (again over the backhaul link), or it may also exchange data (bidirectionally) directly with the center element using a wireless wide area network (WWAN) such as cellular/LTE network.

The WWAN is so named because it facilitates communication over a long range, so the mobile element can communicate with the remotely located center element(s) over a large geographic region. Other technologies for implementing the WWAN element include satellite and WiMAX, although generally cellular/LTE is the dominant approach.

This system diagram above is general and technology-agnostic, but it also represents the two primary current CV approaches: local two-way communication using DSRC and remote two-way communication using cellular/LTE. Other communication paths may be possible, but from a technical perspective these two approaches are representative and further discussion is generally limited to these concepts (see Communications Elements below for further discussion).

5.2 CV DATA NEEDS AND STANDARDS

CV data needs include data needed by CVs from other nearby CVs (V2V data), data needed by the center elements from CVs (V2I data), and data needed by CVs from the roadway (strictly speaking, infrastructure to vehicle [I2V data], but commonly referred to as V2I data). V2I is used in this report for both directions of communication except where this direction is important to understanding the system.

V2V data generally consist of kinematic data from nearby vehicles that will enable a receiving vehicle to understand the current state of the transmitting vehicle and to project its trajectory a few seconds into the future so as to assess potential conflicts.

V2I data include data describing road and traffic conditions observed by the vehicle along sections of road traveled at some earlier time. These data are sent from a vehicle to an RSU using the local wireless link and are generally passed from the RSU to the center element over the backhaul communications link. These data may also be provided directly to the center element by the vehicle using the wide area link (e.g., via cellular). V2I data may also include V2V messages that may be received by an RSU (where the CV is transmitting V2V data in the vicinity of an RSU).

V2I data also include data generally associated with the roadway on which the vehicle is or will likely be traveling. These data may be transmitted locally from RSUs to vehicles in the local vicinity of the RSU (i.e., in range of the wireless local link) or may be transmitted to the vehicle directly by the center element using the wide area wireless link. Some of these data may originate locally from transportation field equipment co-located with the RSU (for example, traffic signal data), and some may be provided to the RSU through its backhaul link by the center element.

Data provided to the vehicle may be relevant at the *current location* or at a *potential future location* of the vehicle. For example, it is not necessary to deliver curve speed warning information to the vehicle at or near the curve in question. Since curve speed information is relatively static over time, it can be delivered at a remote location (for example, where it is convenient to locate an RSU) and then activated when/if the vehicle reaches the curve. Information that has a higher time criticality must be delivered when the vehicle is closer to the location to which the information relates. Traffic signal timing information, for example, generally needs to be delivered when the vehicle is relatively close to the intersection.

The data communications between vehicles and infrastructure are sent as discrete messages. These messages are typically structured as pre-defined sets of data corresponding to particular parameters. These sets may be fixed in size (i.e., a fixed number of data bits) or they may be variable in size, in which case they are preceded by an indication of the length of the subsequent data set. For current CV applications, the SAE J2735 standard defines messages for many of these types of information. These are listed in Figure C-6 in relation to the type of communication (V2V, V2I, or I2V) to which they relate.

	V2V	V2I	I2V*
Basic Safety Message Part 1	✓	✓	
Basic Safety Message Part 2	✓	✓	
Emergency Vehicle Alert	✓		
Common Safety Request	✓		
Probe Vehicle Data		✓	
Signal Request Message		✓	
Roadside Alert			✓
Traveler Information			✓
MAP Data			✓
Probe Data Management			✓
Signal Phase and Timing			✓
Signal State Message			✓
NMEA Corrections			✓
RTCM Corrections			✓

* I2V here is commonly referred to as V2I data. It is denoted I2V here to illustrate the direction of transmission

Figure C-6. Representative SAE J2735 Messages and Communication Modes.

The messages defined in the current SAE J2735 standard partially meet the application needs, but there are issues beyond the scope of this analysis that are yet to be addressed. A significant opportunity presented by the CV system is to obtain data from mobile (vehicle-based) sensors that would otherwise be provided by infrastructure sensors that are limited in coverage. A single infrastructure communications point can then gather information on what is happening at multiple points along miles of roadway, albeit with some delay. This provides a very cost effective means of creating a general situational awareness of the transportations system status.

Some of the messages above, in particular the Probe Vehicle Data message, are intended for this purpose.

The J2735 standard provides a technical description of the potential messages and the data they may contain, but does not guarantee that data elements will actually be available or that messages would be delivered. The BSM Part 1 is currently the only message widely agreed to be transmitted. A more complete data needs discussion necessarily extends beyond what *can* be transmitted to what *will* be transmitted, but this is largely a policy issue outside the scope of this document. Nonetheless, many of the applications described in this document require data beyond the BSM Part 1, and the availability of those applications is linked to availability of data.

The collection of probe data poses significant privacy issues, especially where a mandate is considered. For data collected using wide area communications, the carrier knows who is sending the data, and so the data must be reliably separated from its source. In the case of local area communications, the data must be stored on the vehicle until the vehicle reaches a suitable RSU, and it must then be encrypted during transmission so that an eavesdropper cannot link the transferred data to a physically observed vehicle.

A potential solution to the privacy concern would be to enlist a third-party who does not know where the data are coming from (either via wide area or local area communications) to process the data packets. The carrier (WAN or LAN) may know the origin of packets, but cannot open the contents. Since this third-party would have access to the data, it is likely they could build a successful business model and help to finance the overall deployment, but many policy issues surround this concept.

5.3 MOBILE ELEMENT COMPONENTS

5.3.1 Embedded Vehicle Terminals

Figure C-7 shows a typical embedded vehicle terminal. This implementation includes an interface that enables the collection of various vehicle data that can then be sent over the local or wide area links. Depending on the implementation, this interface may be a bidirectional gateway allowing authorized input of data to the vehicle, or it may be a one-way data reporting gateway.

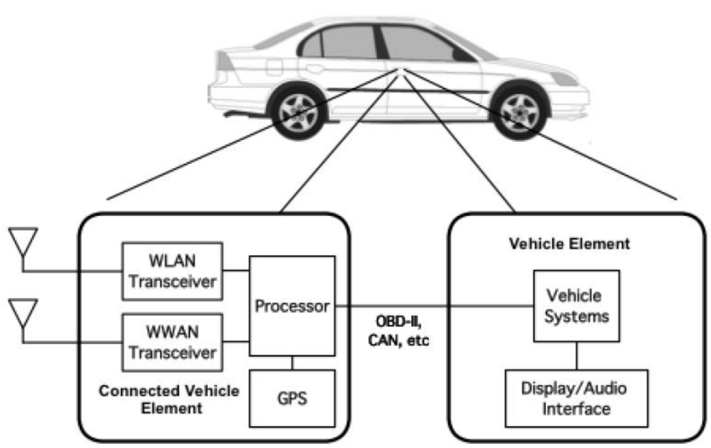

Figure C-7. Embedded CV Terminal Example.

The CV element is typically supported by a host processor that runs various CV applications and includes a location capability such as GPS. In general, an embedded system will be implemented such that the CV functions are integral with other vehicle elements. They are shown here as separate to preserve the CV system boundary. In general, embedded vehicle implementations will be exclusively controlled by the vehicle original equipment manufacturers (OEMs).

5.3.2 Aftermarket Vehicle Terminals

Aftermarket vehicle terminals are similar to embedded terminals except that they depend on post-production installation in the vehicle and will typically include a dedicated user interface. Depending on the origin of the terminal, the vehicle interface may include extensive vehicle data (for example, if the aftermarket device is OEM approved), or it may be limited to data available through the vehicle's on-board diagnostics connector. Systems without access to OEM data are likely to be limited in functionality due to the lack of access to sensors generally available within a vehicle. Figure C-8 illustrates a typical aftermarket implementation.

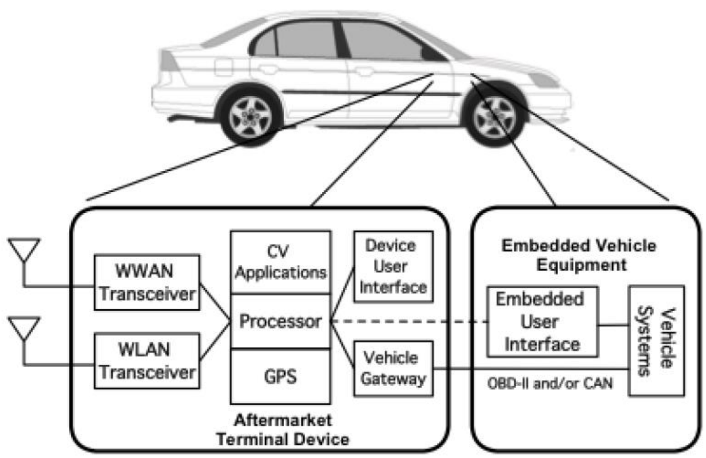

Figure C-8. Aftermarket CV Example.

In addition to variations in the vehicle interface, it is expected that some advanced implementations may also take advantage of specialized user interface technologies such as MirrorLink© or other systems that allow third party devices to access a user interface provided by the manufacturer embedded in the vehicle (shown notionally as a dashed line in the figure). This approach is attractive since it assures a high quality user interface that complies with OEM safety objectives but does not depend on the long vehicle product development cycle, so it can support a changing various aftermarket terminal implementations. However, these systems have not yet been proven in the marketplace.

5.3.3 Portable Consumer Electronic Terminals

Portable or nomadic CV terminals are likely to be based on smartphones. The devices may connect to vehicle systems through a gateway using BT MirrorLink© or other serial protocols. Like aftermarket devices, they may use a dedicated device user interface or may use a user interface embedded in the vehicle. Consumer electronic CV devices may also be used by pedestrians, wheelchairs, cyclists, motorcyclists, and other non-motor vehicle users. It is also likely that many consumer electronic–based devices, especially initially, will not support a CV WLAN connection (i.e., DSRC). These devices will generally use a cellular data connection and may support Wi-Fi, but these links will only provide access to and transactions with a CV center element, not connected to vehicle field equipment. It is possible that over time these devices may also support direct local connections to CV field equipment using DSRC, although no consumer electronics manufacturers have announced any such products.

5.3.4 V2I Communications

In general, CV communications between CV mobile elements and field elements are carried out using DSRC/WAVE technology, and communications directly between CV mobile elements and center elements are carried out using cellular/LTE. These are discussed in more detail below. There are other communications systems that could also be used, but generally these are not seen as particularly viable for CV applications and are outside the scope of this discussion.

5.3.5 DSRC WAVE Communications

DSRC is a form of 802.11 (Wi-Fi) that does not involve any association process between the terminals and the base station. (DSRC systems are *not* interoperable with other Wi-Fi systems, but they are based on most of the same underlying standards). It operates in a frequency band between 5.85 GHz and 5.925 GHz. Unlike Wi-Fi, in which the operating channel is selected at the time of association, DSRC also allows terminals to dynamically switch between channels, so the entire allocated frequency band can be used by any mobile terminal. The other two key differences between DSRC and Wi-Fi are in the upper layers of the protocol. For DSRC, this is known as the Wireless Access in Vehicular Environments (WAVE) protocol. WAVE identifies two network layer protocols, the WAVE Short Message Protocol (WSMP) and IPv6, which are discussed below.

5.3.5.1 WAVE Short Message Protocol

The WSMP provides a simple means for sending a short (single packet) message (WAVE Short Message [WSM]) to other terminals in the local area. It is primarily intended for broadcast communication to any and all terminals in range, and as a result it uses a different type of addressing. Instead of addressing a message to a particular network element (i.e., a network address), WSMP addresses messages according to the type of service they are associated with. This enables a receiving terminal to deliver a received message to those applications that are associated with the referenced service. While it is also possible to send a message to a specific terminal (known as unicast), this requires that the target terminal has already sent a broadcast message (so that the transmitting terminal can learn its network address, known as a MAC address). In general, most WSM transmissions are broadcast since they relate to all terminals in the immediate proximity of the transmitter.

The WSM is limited in size because the entire message, including all of the headers and security information, must fit into the specified maximum transmission unit. While the maximum transmission unit size can be changed, this requires coordination and/or discovery by the communicating terminals, so typically the default value of 1500 bytes is used.

WSMP is primarily a local protocol. That is, it is not routable using conventional network protocols, so it is intended to serve applications that are local to the transmitting radio.

5.3.5.2 Internet Protocol

For transactions involving larger amounts of data than can be supported by WSMP, or for transactions where the recipient is not local to the DSRC terminal (e.g., a remote service provider connected to the fixed provider terminal by a backhaul network), the DSRC system supports the well-known Internet Protocol (IP), specifically, the IPv6 protocol. IP transactions are only supported on the undesignated DSRC service channels and are forbidden in the 802.11p Standard on the control channel. Unlike WSMP, IP enables the sender to send messages that are larger than a single packet. The IP protocol segments the original messages into smaller packets and sends these, and they are then reassembled at the receiving end to recover the original file.

In order to send an IP packet, a terminal must have an IP address. This is easily accomplished for fixed terminals where the IP address is established when the network is formed. For mobile terminals, this is not so simple. Because the terminal is mobile, it is not likely to remain in contact with any given access point for very long, and as a result, if it were to have a fixed IP address, the routing information for each access point would be in constant flux, and would generally be hopelessly out of date all the time. In addition, it would then be possible to geographically track any terminal by tracking the IP address. It is not practical to use dynamic host configuration protocol (DHCP) (which is typically used by Wi-Fi hotspots) to assign IP addresses because the vehicles are entering and leaving a given hot spot at a relatively fast rate, and servicing the high volume of DHCP requests would be overwhelming. IPv6 addresses this problem by using a different sort of IP address. In operation, the mobile terminal can adopt a portion of the roadside unit’s IP address and thereby create an IP address that is valid while the vehicle is in the radio footprint of the RSU.

5.3.6 Cellular Communications

Cellular systems are widely available and, driven by various consumer devices (smartphones, tablet computers, etc.), the cellular industry has been substantially expanding cellular capacity and coverage over the past 20 years. The most recent advancement in cellular technology is known as LTE. This technology effectively combines the benefits of Global System for Mobile Communications and Code Division Multiple Access systems in a highly flexible and wideband IP-based system. While LTE is able to deliver very high data rates to fixed users, the highest achievable future LTE (LTE Advanced) data rate for moving users is 100 Mbps. In practice, however, because of user capacity limitations and interference, this is typically substantially lower.

Still, LTE is a rapidly evolving technology that is specifically intended to provide high data rates to mobile users. LTE and the various previous versions of the cellular standard have been managed by the 3rd Generation Partnership Project (3GPP) since 1998. The 3GPP specification releases occur about every 2 years or so. Because the standard is so widely used, there is substantial attention paid to backward compatibility, so in most cases new features that extend performance can be used without rendering earlier systems obsolete. The current standard, known commonly as 4G, is expected to evolve as discussed briefly below (e.g., see LTE-Direct).

LTE is an all IP network. The cell areas are generally large, and each terminal is assigned an IP address when it joins the network. Various schemes have been developed to enable terminals to maintain IP connectivity with remote servers as they move from cell site to cell site. As a result LTE is very well suited to connecting mobile terminals to remote servers. Contacting mobile terminals over the IP network is somewhat more complex, although mechanisms for this have been developed.

Unlike DSRC, LTE currently provides no provision for one mobile terminal to communicate directly with another nearby mobile terminal or a local data source (e.g., a system that might be connected to an RSU to provide localized data). With LTE, all communications currently must go through the cellular system carrier's back haul network (a network that connects the cell site to the carrier's back office systems, and generally, to the Internet) and must include an IP address. An emerging addition to the 3GPP specifications (Release 12) is a system known as LTE-Direct. This system will allow communication directly between LTE terminal devices. It uses a concept known as proximate discovery that allows LTE terminals to announce the services they have to offer to other terminals in the local area. These announcements can then lead to one terminal providing information to other terminals in the area. The technology has not been widely used as yet, but it may provide an LTE-based mechanism for V2V and V2I communications.

5.4 COMMUNICATIONS SECURITY

The CV security system is aimed at ensuring three basic objectives: privacy, authenticity, and robustness through certification. The basic structure of the security system is designed to provide assurance of the confidentiality of private message traffic, the authenticity of public message traffic, and the anonymity of private generators of public messages.

5.4.1 Privacy

Because the CV system includes messages relating to location and speed of mobile users, it has been generally agreed that it is necessary to protect the privacy of the mobile user population (to avoid, for example, using the system to enforce traffic laws, and to prevent tracking of the movements of individuals based on their transmitted messages). Privacy is not necessarily needed or desired for public sector users and/or equipment, and generally both public and private field elements do not require anonymous certification since they are stationary.

For private sector mobile users, privacy is addressed in two ways: anonymity and confidentiality. Anonymity is achieved by excluding any sort of identifying information in publicly transmitted messages, and by assuring that there is no publicly available linkage between the user's identity and any of the message content. In addition, when identifying information is passed through the system to trusted service providers (for example, to execute a payment transaction or to request services from a subscriber based service), the system provides mechanisms to encrypt this information so that only the intended recipient can access this information. This process uses conventional encryption techniques.

To assure anonymity, the CV system uses a special security credentialing process for private users. This process assures that the security credentials themselves do not provide a mechanism for tracking or identifying the users. This system has some shortcomings outside the scope of this analysis that are yet to be addressed.

5.4.2 Authenticity

To provide assurance that received messages are authentic, the CV system employs a digital signing system based on conventional public key cryptography systems. In this approach, each message includes a digital signature and a certificate. To generate a signature, a digest of the message is generated using some agreed-upon algorithm. This digest is essentially a small subset of the data that forms the message, generated by a hashing algorithm. The resulting digest is then encrypted using the sender's private key. The certificate includes other information relating to the permissions of the sender. For example, an RSU certificate might include the authorized location or jurisdiction for the RSU to avoid issues with the RSU being physically moved to a different location.

The certificate also includes a digital signature that is provided by a trusted third party, known as a certificate authority. This signature allows the receiving party to verify that the certificate is legitimate.

The signature, the sender's certificate and, if appropriate, the certificate authority signature on the sender's certificate are appended to the message; the sender's certificate includes the sender's public key so that the receiver can decrypt the signature. Once decrypted, the receiver can compare the decrypted signature to the same data generated from the received message (using the same agreed upon algorithm for generating the digest). If the two resulting files match, then the receiver can be assured that the message was sent by the holder of the certificate, the holder of the certificate is endorsed by the certificate authority, and the message was not somehow altered in transit.

This process is the same for both public and private users, except that the certificates used by public users are not necessarily anonymous, so the certificate and/or the message itself may include identifying information (e.g., the organization responsible for generating the message).

5.4.3 Certification

The originator must be certified by the certificate authority to send signed messages. In general, the originator is assumed to be the transmitting terminal. For CV mobile equipment, the originator would be the WLAN or WWAN device; for CV field equipment, it would be the WLAN device (e.g., RSU); and for CV center elements, it would be the server originating the message. It is generally assumed that backhaul communication between the center elements and the field elements is secured using conventional network security methods, so a message provided by the center element to a field element for transmission would be provided through whatever secure backhaul system the agency had implemented, and the message transmitted over the WLAN (DSRC) link would be signed by the sending device.

There has been a great deal of industry attention applied to the process of certifying private mobile terminal equipment. This is primarily a result of the need for anonymity and the desire to prevent tracking of private mobile terminals through the security credentials. The process for certification of public sector mobile equipment and both public and private field equipment is much simpler since it can be based on conventional public key cryptography certification processes. Field equipment is inherently trackable and non-anonymous (since it is generally licensed, and is located at a known place), so it does not require anonymous certification.

5.4.4 Other Security Elements

The entire security system and its management has been the topic of extensive development effort over the past few years. Currently, the threats addressed by the security system focus primarily on false messages and resulting false positive application actions (generally false warnings). Issues associated with the number of certificates used in vehicles, the process of identifying bad actors (misbehavior detection), the process of removing those bad actors, and the scope of this sort of problem (i.e., the size of the revocation list) are all key concerns to which interim approaches have been developed.

There are open questions about the ability of the system to withstand attacks and about the threat model that the system is designed to protect against. For example, the current assumptions about the scale of misbehavior and the resulting scale of certificate revocation are either so low as to suggest that the security system may not be all that necessary (i.e., the security system is imposing heavy overhead to avoid a problem that will almost never be seen), or are so large that the current design will be unable to cope with the load (i.e., creating a large number of misbehaving vehicles will cause the security system to fail). In addition, the fact that a vehicle terminal has certificates does not by itself assure that the terminal has not been tampered with in some way. Recent studies have indicated that in addition to false messages, attacks where the terminal is injected with malware are feasible. Such an attack could find its way inside the existing security system (so malware messages would be signed and appear legitimate), and could extensively subvert system operations.

Security is a moving target and will likely undergo extensive evolution over time.

5.5 BACKHAUL

The CV environment includes mobile terminals, field terminals, and center terminals. Mobile terminals are typically vehicles, while field terminals, when they are used, are typically radio terminals located along the roadway (typically called roadside equipment, or RSU). Center facilities include traffic management centers and other road authority/agency back office facilities, and remote service providers.

Conventional CV architectures assume that field equipment and center facilities are connected by a communications link. This is typically called a backhaul network. In these systems, the center can send information to field terminals (e.g., messages to be transmitted by the field terminal) and the field equipment can send information back to the center facility. The information sent back to the center facility may be status information about the field terminal, or it may be local information on other field equipment such as signal controllers that are attached to the field terminal. It may also be information received from nearby mobile terminals and forwarded to the center by the field terminal.

Some CV architectures may not use field equipment. In this case, communications between the mobile terminals and the center facilities would be over a wide area network. While this could be considered a backhaul link, for purposes of this project it is not included. WWAN connections to mobile terminals are discussed in section 5.1 of this report.

APPENDIX D – MILESTONE 2 REPORT: DEVELOPING A CONCEPT OF OPERATIONS FOR AN INNOVATIVE SYSTEM FOR MEASURING WAIT TIMES AT LAND PORTS OF ENTRY

T.3.1 Developing a Concept of Operations for an Innovative System for Measuring Wait Times at Land Ports of Entry

Milestone 2 Report: Concept of Operations for Next Generation Wait Times System at Land Ports of Entry

Prepared for the

CBTIR
CENTER FOR BORDERS, TRADE, AND IMMIGRATION RESEARCH

A DHS Center of Excellence led by the University of Houston

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Submitted on **08/16/2016**

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1 INTRODUCTION AND SCOPE

1.1 PURPOSE OF THE CONCEPT OF OPERATIONS

A Concept of Operations (ConOps) is a scientific and consensus-based process initially developed by the Department of Defense. Its sole purpose is to capture the high-level needs and requirements of stakeholders of a system under consideration. A ConOps clearly identifies the needs and requirements for a new or revised system, as well as the high-level functional design of a new or upgraded system that meets the needs of the stakeholders. For the project discussed in this document, a key stakeholder is the United States Customs and Border Protection (CBP), and the related ConOps includes the high-level design of enhancements to the existing wait time and traffic management system in use at land ports of entry (POEs).

1.2 INTENDED AUDIENCE OF THE DOCUMENT

The ConOps presented in this document provides a high-level overview of the who, what, where, and how of the existing wait time and traffic management system and identifies the high-level requirements for an enhanced system. This ConOps does not apply to any particular POE; it focuses on how the enhanced system should fulfill the needs of CBP. However, the ConOps does include scenarios that may be unique to one or more POEs in order to exemplify how the enhanced system would work at a specific POE.

1.3 CONTENTS AND ORGANIZATION OF THE DOCUMENT

The contents of this document are organized according to Institute of Electrical and Electronics Engineers (IEEE) Standard 1362-1998 (*1*). The standard is used to develop a ConOps for an existing system that requires improvement or changes. Chapter 1 describes the purpose and intended audience of this ConOps document, as well as the project overview and scope. Chapter 2 describes the current high-level border crossing process for commercially operated vehicles (COVs) and privately operated vehicles (POVs). The border crossing process is different for COVs versus POVs, as well as for U.S.-bound and Mexico-bound vehicles. Chapter 3 outlines the justification for improvement of current wait time systems and nature of changes recommended by this ConOps. Chapter 4 describes the high-level architecture of the proposed or enhanced wait time measurement system along with other value propositions for CBP. Chapter 5 describes how the enhanced system would operate at a real POE, and Chapter 6 provides a summary of the impact that the enhanced system would have at POEs.

1.4 PROJECT OVERVIEW AND SCOPE

The vast majority of people and goods entering, exiting, and traversing the U.S. land borders represent lawful travel and trade. These flows are a main driver of U.S. economic prosperity. Estimating wait times of COVs and POVs entering the United States at land POEs is an important performance measure. CBP has specific border wait time parameters that need to be met; currently, CBP measures border wait times inconsistently throughout land POEs and requires field officers to spend time performing these activities.

Border wait times at land POEs are an important estimation of port performance, trade, and regional competitiveness. A reliable and systematic method of measuring border wait times is needed in order to make better construction, planning, and operations decisions at land POEs.

Currently, CBP officers estimate wait times in a non-scientific way with different criteria on a POE-by-POE basis. CBP officers have to dedicate time to collect information on border wait times to populate CBP's website and mobile application—time that could be spent performing border inspection activities at the POEs.

At the majority of POEs, CBP uses visual and random surveys of drivers to get a sense of queue length and estimate wait times. At smaller POEs, this method may be adequate. However, at larger POEs with high traffic volumes, visual methods significantly underestimate the wait times because the end of the queue may not be visible to CBP officers. CBP has determined that it needs to move away from visual and anecdotal methods and gather wait time data scientifically.

In recent years, technologies such as Bluetooth®, wireless fidelity (Wi-Fi), magnetic loops, and radio frequency identification (RFID) have been deployed at a select few POEs to estimate wait times of U.S.-bound COVs and POVs. These deployments have been successful in estimating wait times using ubiquitous electronic devices such as mobile phones and transponders. However, these deployments cannot be used for purposes other than wait time estimation. Because these deployments measure travel time between fixed locations and use algorithms to estimate wait times, they are unsuitable for activities such as approach management, inspection lane management, and queue determination. These systems are also based on after-the-fact estimations of travel time from a small sample of vehicles crossing the border.

CBP has an opportunity to develop an enhanced system that takes advantage of emerging technologies such as connected vehicles, automated vehicles, and global positioning systems (*2*). Current systems also need to be enhanced by adding new capabilities, such as queue prediction, approach management, and lane management. These new technologies have the potential to significantly improve the accuracy of wait time estimates because they are sensitive to variables such as queue length and lane closures. They also have the potential to integrate wait time estimation with approach management, queue estimation, and lane management.

Enhancing the existing system by adding new capabilities requires an understanding of CBP's current and future needs for port operation and planning; understanding these needs was key to the success of this research project.

The main goal of this project was to develop a ConOps for enhancing the border wait time estimation system for commercial and passenger vehicles at land POEs. Except for the case of wait time estimation and traffic management of vehicles, it was not the intent of this project to alter or reinvent systems and functions currently deployed and/or planned by CBP concerning pre-clearance, security screening, etc.

2 CURRENT BORDER CROSSING PROCESS AND SYSTEMS

This chapter describes the border crossing process for U.S.-bound COVs and POVs. It describes how CBP screens and inspects COVs and POVs crossing the international border. It also describes special pre-clearance programs that are currently available at the land POEs.

2.1 CURRENT BORDER CROSSING PROCESS

2.1.1 U.S.-Bound Commercial Vehicle Crossing Process

The typical northbound border crossing process requires a shipper in Mexico to share shipment data with both Mexican and U.S. federal agencies, prepare both paper and electronic forms, and use a drayage or transfer tractor to move the goods from one country to the other. Once the shipment is at the border with the drayage or transfer tractor and an authorized driver, the process flows through three main potential physical inspection areas: Mexican export lot, U.S. federal compound, and/or U.S. state safety inspection facility.

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

There are several international crossings along the US-Mexico border that are tolled. Tolls are collected in Mexico for northbound traffic and in the United States for southbound traffic. Toll collection is manual (cash) and electronic. All of the crossings along the Texas-Mexico border are bridges that cross the Rio Grande River, and most of them are tolled. Before crossing into the United States, commercial vehicles pay tolls and proceed to the U.S. federal compound.

At the primary inspection booth, the driver of the truck presents identification and shipment documentation to the processing agent. The CBP officers at the primary inspection booth use computer terminals to cross-check the basic information about the driver, vehicle, and cargo with information sent previously by the carrier via the CBP’s Automated Cargo Environment electronic manifest (e-Manifest). The CBP officer then makes a decision to refer the truck, driver, or cargo for a more detailed secondary inspection of any or all of these elements, or alternatively releases the truck to the exit gate.

The e-Manifest is electronically submitted by motor carriers and enables CBP to pre-screen the crew, conveyance, equipment, and shipment information before the truck arrives at the border. This practice allows CBP to focus its efforts and inspections on high-risk commerce and to minimize unnecessary delays for low-risk commerce.

A secondary inspection includes any inspection that the driver, freight, or conveyance undergoes between the primary inspection and the exit gate of the U.S. federal compound. Personnel from CBP usually conduct these inspections, which can be done by physically inspecting the conveyance and the cargo or by using non-intrusive inspection equipment (such as x-rays).

Within the compound, several other federal agencies have personnel and facilities to perform other inspections when required.

2.1.2 Commercial Border Crossing Pre-clearance Program

The Free and Secure Trade (FAST) program is in operation at most of the major land border crossings. Its objective is to offer expedited clearance to carriers that have demonstrated supply chain security and are enrolled in the Customs-Trade Partnership against Terrorism (C-TPAT) program. The FAST program allows U.S.-Canada and U.S.-Mexico partnering importers expedited release for qualifying commercial shipments.

For a shipment to be considered a FAST shipment, it needs to comply with very specific regulations. The shipper in Mexico, the carrier that is transporting the cargo across the border, and the driver all have to be C-TPAT certified.

The time required for a typical Mexican export shipment to make the trip from the yard, the distribution center, or the manufacturing plant in Mexico to the exit of the state safety inspection facility depends on the number of secondary inspections required, number of inspection booths in service, traffic volume at that specific time of day, and shipment eligibility for FAST.

2.1.3 Mexico-Bound Commercial Vehicle Crossing Process

The southbound commercial vehicle crossing process has only one inspection station by the Mexican Customs Agency. The process in Mexico is a red-light/green-light decision in which a loaded commercial vehicle is randomly selected for a secondary inspection if it gets a red light. Empty vehicles cross with no need to stop at the Mexican Customs booths. The Mexican Customs Agency uses weigh-in-motion technology to measure the weight of commercial vehicles at the POE to make red-light/green-light decisions.

Recently, CBP has started to perform random manual inspections on the U.S. side of the border for commercial vehicles crossing into Mexico, aiming to identify illegal shipments of money and weapons. The border crossings are not designed for southbound commercial inspections on the U.S. side of the border; consequently, these inspections have created congestion.

2.1.4 U.S.-Bound Passenger Vehicle Crossing Process

On the Mexican side of the border, passenger vehicles are required to pay tolls at those crossings that have tolls, usually the international bridges. Tolls are paid manually or via electronic collection systems. Once passenger vehicles pay the toll, if necessary, they proceed to the U.S. federal compound, where they go through primary and sometimes secondary inspections. At the primary inspection booths, CBP officers must ask the individuals who want to enter the country to show proper documentation, such as proof of citizenship, and state the purpose of their visit to the United States. Additionally, during this stage of the process, a query on the Interagency Border Inspection System is executed to review the past records of violations that the traveler(s) may have. If necessary, the vehicle is sent to secondary inspection.

At the primary inspection booth, license plate readers and computers perform queries of the vehicles against law enforcement databases that are continuously updated. A combination of electric gates, tire shredders, traffic control lights, fixed iron bollards, and pop-up pneumatic bollards ensures physical control of the travelers and their vehicles.

At the secondary inspection station, a more thorough investigation is performed concerning the identity of an individual and the purpose of his or her visit to the United States. During this step, individuals may also have to pay duties on their declared items. Upon completion, access to the United States is either granted or denied.

2.1.5 Passenger Vehicle Border Crossing Pre-clearance Program

Similar to the FAST program for commercial vehicles, the Secure Electronic Network for Travelers Rapid Inspection (SENTRI) program provides expedited CBP processing for pre-approved, low-risk travelers at the US-Mexico border. Applicants must voluntarily undergo a thorough biographical background check against criminal, law enforcement, customs, immigration, and terrorist indices; a 10-fingerprint law enforcement check; and a personal interview with a CBP officer.

Once an applicant is approved, he or she is issued a document with the RFID that will identify his or her record and status in the CBP database upon arrival at the border crossing. A sticker decal is also issued for the applicant’s vehicle or motorcycle. SENTRI users have access to specific, dedicated primary lanes into the United States. Dedicated SENTRI commuter lanes exist at the Otay Mesa, El Paso, San Ysidro, Calexico, Nogales, Hidalgo, Brownsville, Anzalduas, Laredo, and San Luis POEs on the US-Mexico border.

When an approved international traveler approaches the border in the SENTRI lane, the system automatically identifies the vehicle and the identity of its occupant(s) by reading the file number on the RFID card. The file number triggers the participant’s data to be brought up on the CBP officer’s screen. The data are verified by the CBP officer, and the traveler is released or referred for additional inspection.

Participants in the program wait for much shorter times than those in regular lanes waiting to enter the United States. Critical information required in the inspection process is provided to the CBP officer in advance of the passenger’s arrival, therefore reducing the inspection time. The program helps ease traffic congestion, but it is still not widely utilized.

A READY Lane is a dedicated primary vehicle lane for travelers entering the United States at land border POEs. Travelers who obtain and travel with a Western Hemisphere Travel Initiative (WHTI)–compliant, RFID-enabled travel document receive the benefits of utilizing a READY Lane to expedite the inspection process while crossing the border. The U.S. passport card, the SENTRI card, the NEXUS card, the FAST card, the new enhanced permanent resident green card, and the new border crossing card are all RFID-enabled documents.

RFID technology allows information contained in a wireless tag to be read from a distance, enabling officers to process travelers more quickly, reliably, and accurately. The driver stops at the beginning of the lane and makes sure each passenger has his or her card out. The driver slowly proceeds through the lane, holds all cards up on the driver’s side of the vehicle, and stops at the officer’s booth.

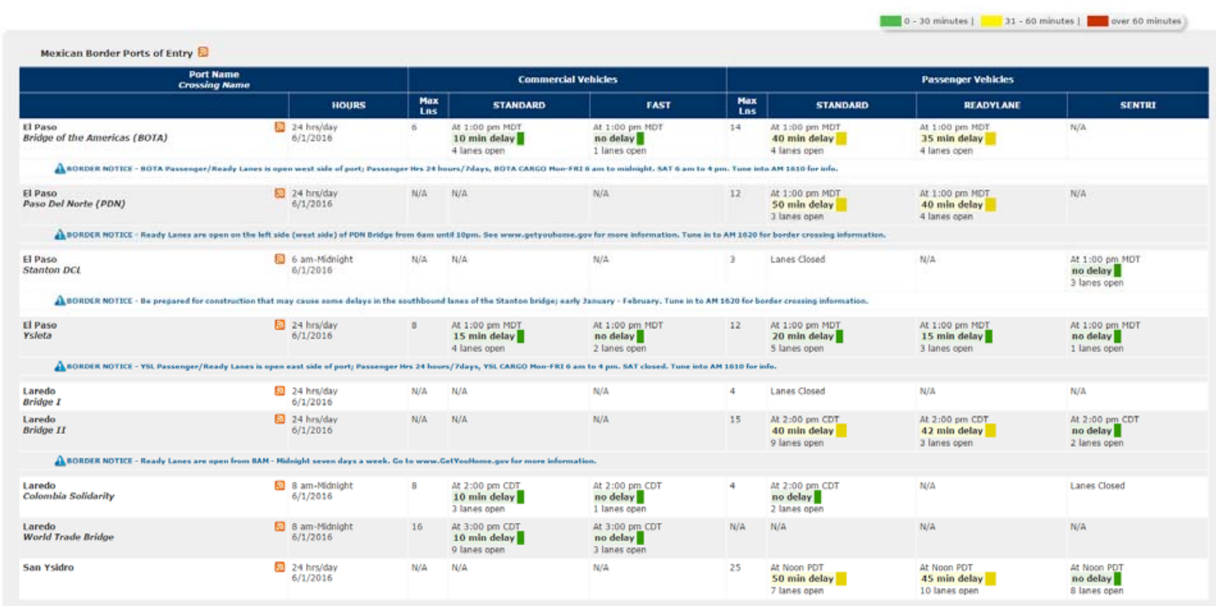
2.1.6 Mexico-Bound Passenger Vehicle Crossing Process

Unless POVs that enter Mexico are tolled on the U.S. side, POVs entering Mexico do not go through rigorous processing compared to U.S.-bound POVs. Typically, wait times of vehicles entering Mexico are very small. Vehicles do have to go through weigh in motion and may be subject to random checks by Mexican law enforcement officers.

2.2 CURRENT TOOLS AND THEIR LIMITATIONS

Wait time information assists motorists and travelers with making efficient travel-related decisions—before starting the trip, en route, and while waiting to cross the border. Wait time is also one of the key indicators of performance of a land POE. Archived wait time data help operators, planners, and policy makers make informed decisions to improve operation of the POE. Long wait time is detrimental to the operation of a POE in many ways. It undermines the attractiveness of the port among travelers and negatively affects the economic competitiveness of the region and the environment surrounding the port.

CBP provides wait time and other associated information (e.g., lane openings and closures) to the traveling public via its website, as shown in Figure D-1. CBP monitors wait times to optimize its resources so that wait time is under acceptable conditions. At the majority of POEs, CBP uses visual and random surveys of drivers to get a sense of queue length and estimate wait times. At smaller POEs, this method may be adequate. However, at larger POEs with high traffic volumes, visual methods significantly underestimate the wait times because the end of the queue may not be visible to CBP officers.



0 - 30 minutes | 31 - 60 minutes | over 60 minutes

Mexican Border Ports of Entry

Port Name *Crossing Name*		Commercial Vehicles			Passenger Vehicles			
	HOURS	Max Lns	STANDARD	FAST	Max Lns	STANDARD	READYLANE	SENTRI
El Paso *Bridge of the Americas (BOTA)*	24 hrs/day 6/1/2016	6	At 1:00 pm MDT **10 min delay** 4 lanes open	At 1:00 pm MDT **no delay** 1 lanes open	14	At 1:00 pm MDT **40 min delay** 4 lanes open	At 1:00 pm MDT **35 min delay** 4 lanes open	N/A
BORDER NOTICE - BOTA Passenger/Ready Lanes is open west side of port; Passenger Hrs 24 hours/7days, BOTA CARGO Mon-FRI 6 am to midnight. SAT 6 am to 4 pm. Tune into AM 1610 for info.								
El Paso *Paso Del Norte (PDN)*	24 hrs/day 6/1/2016	N/A	N/A	N/A	12	At 1:00 pm MDT **50 min delay** 3 lanes open	At 1:00 pm MDT **40 min delay** 4 lanes open	N/A
BORDER NOTICE - Ready Lanes are open on the left side (west side) of PDN Bridge from 6am until 10pm. See www.getyouhome.gov for more information. Tune in to AM 1620 for border crossing information.								
El Paso *Stanton DCL*	6 am-Midnight 6/1/2016	N/A	N/A	N/A	3	Lanes Closed	N/A	At 1:00 pm MDT **no delay** 3 lanes open
BORDER NOTICE - Be prepared for construction that may cause some delays in the southbound lanes of the Stanton bridge; early January - February. Tune in to AM 1620 for border crossing information.								
El Paso *Ysleta*	24 hrs/day 6/1/2016	8	At 1:00 pm MDT **15 min delay** 4 lanes open	At 1:00 pm MDT **no delay** 2 lanes open	12	At 1:00 pm MDT **20 min delay** 5 lanes open	At 1:00 pm MDT **15 min delay** 3 lanes open	At 1:00 pm MDT **no delay** 1 lanes open
BORDER NOTICE - YSL Passenger/Ready Lanes is open east side of port; Passenger Hrs 24 hours/7days, YSL CARGO Mon-FRI 6 am to 4 pm. SAT closed. Tune into AM 1610 for info.								
Laredo *Bridge I*	24 hrs/day 6/1/2016	N/A	N/A	N/A	4	Lanes Closed	N/A	N/A
Laredo *Bridge II*	24 hrs/day 6/1/2016	N/A	N/A	N/A	15	At 2:00 pm CDT **40 min delay** 9 lanes open	At 2:00 pm CDT **42 min delay** 3 lanes open	At 2:00 pm CDT **no delay** 2 lanes open
BORDER NOTICE - Ready Lanes are open from 8AM - Midnight seven days a week. Go to www.GetYouHome.gov for more information.								
Laredo *Colombia Solidarity*	8 am-Midnight 6/1/2016	8	At 2:00 pm CDT **10 min delay** 3 lanes open	At 2:00 pm CDT **no delay** 1 lanes open	4	At 2:00 pm CDT **no delay** 2 lanes open	N/A	Lanes Closed
Laredo *World Trade Bridge*	8 am-Midnight 6/1/2016	16	At 3:00 pm CDT **10 min delay** 9 lanes open	At 3:00 pm CDT **no delay** 3 lanes open	N/A	N/A	N/A	N/A
San Ysidro	24 hrs/day 6/1/2016	N/A	N/A	N/A	25	At Noon PDT **50 min delay** 7 lanes open	At Noon PDT **45 min delay** 10 lanes open	At Noon PDT **no delay** 8 lanes open

Figure D-1. Snapshot of CBP's Website Showing Wait Times at Land POEs.

CBP has determined that it needs to move away from visual and anecdotal methods and gather wait time data scientifically. Before vehicles reach CBP's primary booth, Mexican Customs screens U.S.-bound vehicles. Thus, CBP feels that the wait time of vehicles in Mexico is not entirely its problem. While this is certainly true at POEs where distance between Aduanas and CBP may be several miles (e.g., Pharr-Reynosa International Bridge), there are other crossings where the distance between CBP Primary and the Mexican toll booth or inspection is relatively short. Crossings outside Texas do not require to cross the Rio Grande, so the distance could be very short.

In recent years, technologies such as Bluetooth, Wi-Fi, magnetic loops, and RFID have been deployed at a select few POEs, as illustrated in Figure D-2 and Figure D-3, to estimate wait times of U.S.-bound COVs and POVs. These deployments have been successful at estimating wait times using ubiquitous electronic devices such as mobile phones and transponders. However, these deployments cannot be used for purposes other than wait time estimation. Because these deployments measure travel time between fixed locations and use algorithms to estimate wait times, they are unsuitable for activities such as approach management, inspection lane management, and queue determination.

Figure D-2. RFID Technology–Based System to Estimate Wait Times of COVs at Ysleta-Zaragoza Port of Entry (Source: Texas A&M Transportation Institute [TTI]).

Figure D-3. Bluetooth Technology–Based System to Estimate Wait Times of POVs at Ysleta-Zaragoza Port of Entry (Source: TTI).

2.3 EXISTING OPERATIONAL CONSTRAINTS

Deployment of crossing and wait time estimation systems based on RFID technology is expensive. They run more than $200,000 per POE,[1] not including costs related to distribution and administration of transponders. Bluetooth- and WiFi-based systems are relatively cheap but have privacy and low sampling issues. Magnetic loops in pavements have high maintenance costs and can incur delay to the traveling public during maintenance.

None of these technology-based systems are systematically integrated with CBP's internal systems that manage primary inspection lanes. CBP officers anticipate queue length and wait times using visual methods and then use this information to decide which and how many inspection lanes to open or close. This practice may result in longer wait times due to inadequate open lanes during lengthier queues.

At most POEs, CBP has designated FAST (for commercial vehicles) and READY (for passenger vehicles) lanes. CBP has the ability to process FAST or READY vehicles in any standard lanes, as well. CBP has at some POEs deployed signs above inspection areas, as shown in Figure D-4. Traffic close to the areas is well separated according to which documentation travelers have. However, farther upstream, travelers can be mixed since there are no message signs upstream in Mexico.

Figure D-4. Lane Management with Dynamic Signs at a CBP Primary Inspection Facility (Source: CBP).

[1] Based on previous experience at POEs in the Texas/Mexico border.

3 JUSTIFICATION FOR AND NATURE OF CHANGES

This chapter describes why and how the current system needs to be modified for wait time estimation and traffic management. The results from this analysis drive the requirements of a proposed new system.

3.1 MOTIVATION OF CHANGES

The efficiency and effectiveness of the current wait time system will increase significantly if changes mentioned in this ConOps are implemented at land ports of entry. The desired changes will not only reduce wait times but also improve management of vehicles approaching POEs, allocation of resources at inspection facilities, and customer service. However, for the system to reach its full potential, large penetration of connected vehicles is required. The next-generation system is expected to provide the following benefits:

- **Improved accuracy of wait time information—**The estimates of end-of-queue location and how the queue is progressing will improve short-term prediction of wait times. At the same time, the enhanced system can transmit wait time directly to vehicles based on their location relative to CBP's facility.
- **Enhanced approach lane management—**At many POEs, vehicles enrolled in different types of pre-clearance programs mix together because they do not know which approach lane leads to which inspection lane at the CBP facility. This is especially true when queues extend beyond static signs that separate vehicles. If the enhanced system knows queue lengths of, for example, FAST and standard trucks and if queues of standard truck lanes are much longer than FAST lane queues, then roadside sensors can suggest that standard trucks move to the FAST lanes to reduce the overall queue length.
- **Improved efficiency of resource allocation at inspection facility—**With better estimation of queue lengths and how queues are progressing against time, CBP can make better decisions about allocating resources at its primary facility in order to reduce wait time.
- **Improved customer service—**Long wait time has always been a major complaint of motorists crossing the border. While CBP can play a limited role in controlling the demand, it can provide a better customer experience by implementing a system that is more sensitive to queues forming at the back and reduces wait time.
- **Improved pre-clearance—**While connected vehicle technology is designed to be anonymous, motorists can opt in and register their SENTRI/NEXUS or FAST vehicles to work with the connected vehicle devices. This arrangement allows these vehicles to send, via roadside sensors, "I'm here" messages to CBP, which can then perform screening even before the vehicle has reached the CBP primary booth. This capability allows vehicles to minimize interaction with CBP officers and reduces time to process them.

3.2 JUSTIFICATION OF CHANGES

At present, CBP officers estimate queue visually using nearby landmarks as a reference for distance. The officers then use length of queue as a basis to open/close inspection lanes and post wait times. However, at some POEs during peak hours and special events, queue can extend beyond officers' field of vision. This condition results in underestimation of wait times as well as number of lanes that should be opened.

CBP estimates wait times using random surveys of drivers or visible queue length, or a combination. CBP officers ask random drivers when they approach the inspection lane about how long they had to wait. The drawback of this approach is that wait times from random surveys are gathered after the fact and are not indicative of what is happening upstream from the queue. Thus, surveys can be biased, especially during peak periods.

Existing technologies such as Bluetooth, RFID, and WiFi measure travel times between fixed locations where vehicles are identified using mobile or transponder IDs. Travel times between static locations are calculated as vehicles pass by these locations. Using the most recent travel times, expected and actual wait times are estimated. Expected wait times (EWTs) are wait times that motorists can expect when they join the end of the queue. Actual wait times (AWTs) are wait times that motorists actually experience. EWT is determined using short-term prediction models based on AWTs. These technologies unfortunately cannot directly measure queue length and how the queue is progressing.

Loop detectors measure speed and volume of vehicles at fixed locations using in-pavement electromagnetic loops. This technology uses inflow and outflow models to determine EWT and AWT. However, loop detectors are expensive to install. Another drawback of loops is that travel lanes may have to be closed during maintenance.

No POEs provide in-vehicle and individualized warnings about wait times. Technologies mentioned in the previous paragraphs are not designed for two-way communication. This ConOps assumes that individualized warnings about wait time provided directly to motorists will significantly improve service to motorists if they can be informed about wait times before and after they have joined the queue.

At present, CBP's signs that separate inspection lane types are available at its facilities only. At some POE facilities that process COVs, there are static signs that separate FAST and non-FAST vehicles farther upstream. However, they are static signs. Motorists and drivers do not know where lanes separate until they see the signs. Better approach management is feasible if lane assignment can be provided to motorists inside the vehicles in real time. In-vehicle warning is a much better information delivery method than static or dynamic message signs at fixed locations upstream of inspection booths. This ConOps assumes that an in-vehicle information delivery method will result in better utilization of approach lanes.

The ConOps also assumes that the next-generation wait time and traffic management system should be able to measure changing queue lengths, lane openings and closures at a CBP inspection facility, and wait times. Wait time is much more sensitive to the number of inspection lanes open. At present, this integration happens manually. However, the ConOps contends that queue measurement, approach lane management, inspection lane assignment, and wait time estimation should be fully integrated.

3.3 DESCRIPTION OF DESIRED HIGH-LEVEL CHANGES

Desired high-level changes for the next-generation wait time estimation and traffic management system are as follows:

- The wait time estimation system should be based on speed snapshots and location breadcrumbs of vehicles when they approach the end of the queue and are in the queue. This approach is a shift from traditional methods, which measure travel times of individual vehicles between fixed locations. However, wait times measured by this approach can be augmented with travel times between fixed locations in order to verify and calibrate wait time estimation models. For vehicles approaching the end of the queue, the system should estimate wait time based on their locations and the types of pre-clearance programs (FAST, SENTRI, NEXUS) they are enrolled in or eligible for (e.g., READY). Such notifications should be sent as in-vehicle messages unique to individual vehicles.
- The system should directly measure the length of the queue and its progression in real time. Queue length and progression should be integrated with wait time estimation and inspection lane management processes. Based on the queue forming on the other side of the U.S. border and the number of lanes currently open, the system should trigger warnings to open more lanes or close lanes.
- The system should notify vehicles approaching the end of the queue about which lane they ought to use based on their locations and the types of pre-clearance programs they are enrolled in or eligible for. Such notifications should be sent as in-vehicle messages unique to individual vehicles.
- CBP should be able to perform advanced screening of vehicles after they enter the queue and before they reach the CBP primary booth. However, those vehicles have to be enrolled in the SENTRI/NEXUS program and opt in for advanced screening.

Figure D-5 shows the existing method (upper chart) and desired changes (bottom chart) for wait time and overall traffic management at land ports of entry. The upper chart illustrates how existing wait time deployments receive identification of vehicles at static locations. This information is processed to estimate expected wait time and broadcast as generalized information (i.e., not tailored to vehicle location).

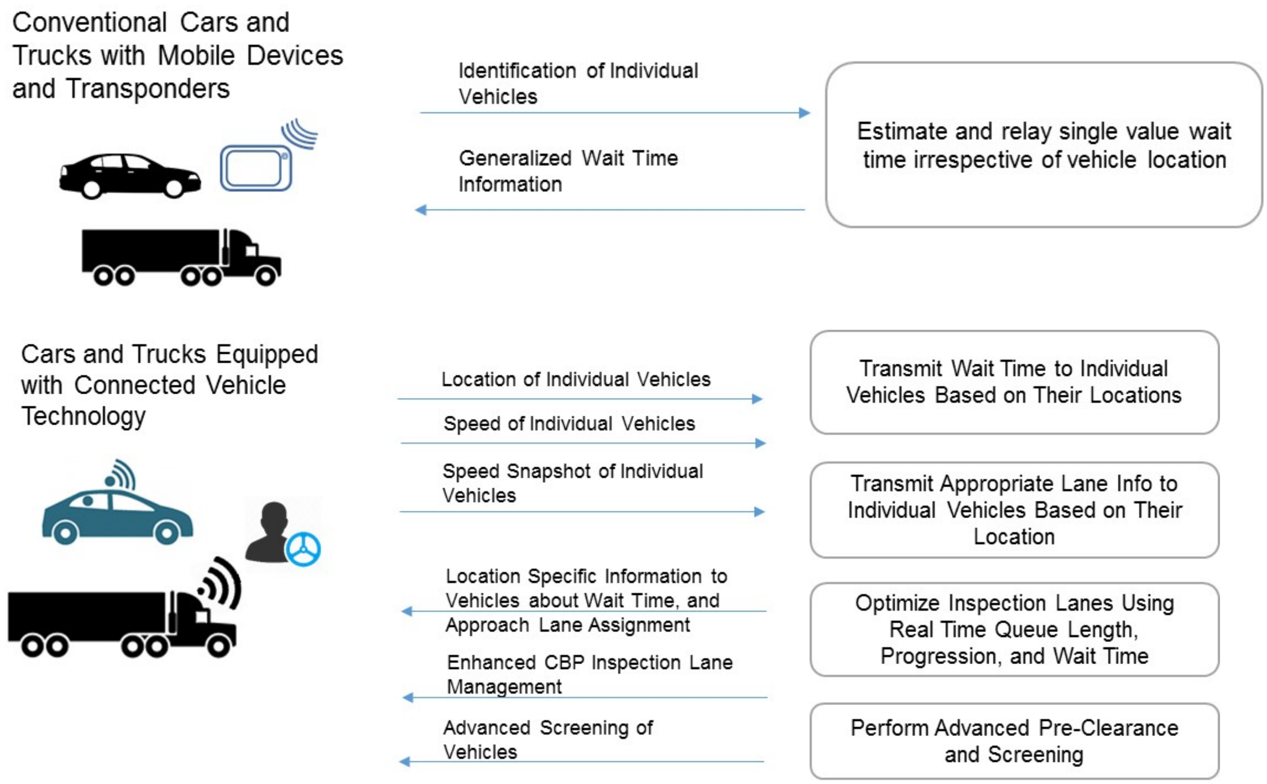


Figure D-5. Existing Method (Upper Image) and Desired Changes (Lower Image) for Wait Time and Overall Traffic Management at Land POEs.

4 CONCEPTS OF THE PROPOSED SYSTEM

This chapter provides an overview of the proposed changes to the wait time estimation and traffic management system and key considerations for its design. It includes key components of the proposed system and describes the changes in operations.

4.1 HIGH-LEVEL SYSTEM ARCHITECTURE

The next-generation wait time and traffic management system concept uses the power of connected vehicle technology including roadside and onboard devices integrated with internal systems to provide location and CBP program wait time information directly to individual vehicles. Thus, based on their location relative to CBP's primary inspection facility, vehicles receive individualized wait times rather than a single wait time broadcast to all.

The system sends in-vehicle messages to drivers to change lanes if they are in the wrong approach lane. The system also measures location and progression of queue more efficiently than existing technologies. This information is crucial to estimate wait times and manage inspection lanes at CBP (and Aduana).

By design, connected vehicle technology does not identify in-vehicle devices (or onboard units). However, motorists can opt in by registering their in-vehicle devices with the relevant authorities or information providers. By opting in, motorists can receive individualized messages about wait times and appropriate approach lanes based on the pre-clearance program in which they are enrolled.

The architecture is based on dedicated short range communication (DSRC) technology as a means to communicate (exchange data payload) between in-vehicle and roadside sensors. DSRC is a two-way short- to medium-range wireless communications capability that permits very high data transmission critical in communications-based active safety applications. In Report and Order FCC-03-324 (*3*, *4*), the Federal Communications Commission (FCC) allocated 75 MHz of spectrum in the 5.9 GHz band for vehicle safety and mobility applications.

The architecture assumes that a significant portion of vehicles in the traffic mix will have DSRC-enabled devices either installed as an aftermarket device or embedded within the vehicle. Vehicles with such capability are called connected vehicles. Because the DSRC technology allows two-way low-latency communication, roadside sensors can continuously exchange data with connected vehicles.

Figure D-6 illustrates how connected vehicles communicate with roadside sensors spatially and strategically distributed along approaches and at a CBP facility. Connected vehicles transmit location and speed snapshots to roadside sensors spread around the CBP facility and along the roadway approaching the facility. These data are transmitted to a centralized service, which then estimates wait times, queue lengths, queue progression, and approach lane assignment. Roadside sensors then transmit the information back to individual vehicles based on their current location.

In the illustration shown in Figure D-6, roadside sensors send messages to vehicles (shown in red) enrolled in the SENTRI program to move from the right lane to the left lane since right lanes are designated for SENTRI vehicles. The roadside sensors also send wait times to vehicles based on their current location. Thus, as vehicles get closer to the CBP facility, their wait time decreases. The system also provides wait times for SENTRI/NEXUS lanes to vehicles enrolled in such programs. Vehicles not enrolled in SENTRI (shown in black) do not receive lane-specific information, but they do receive location-specific wait times at pre-defined intervals.

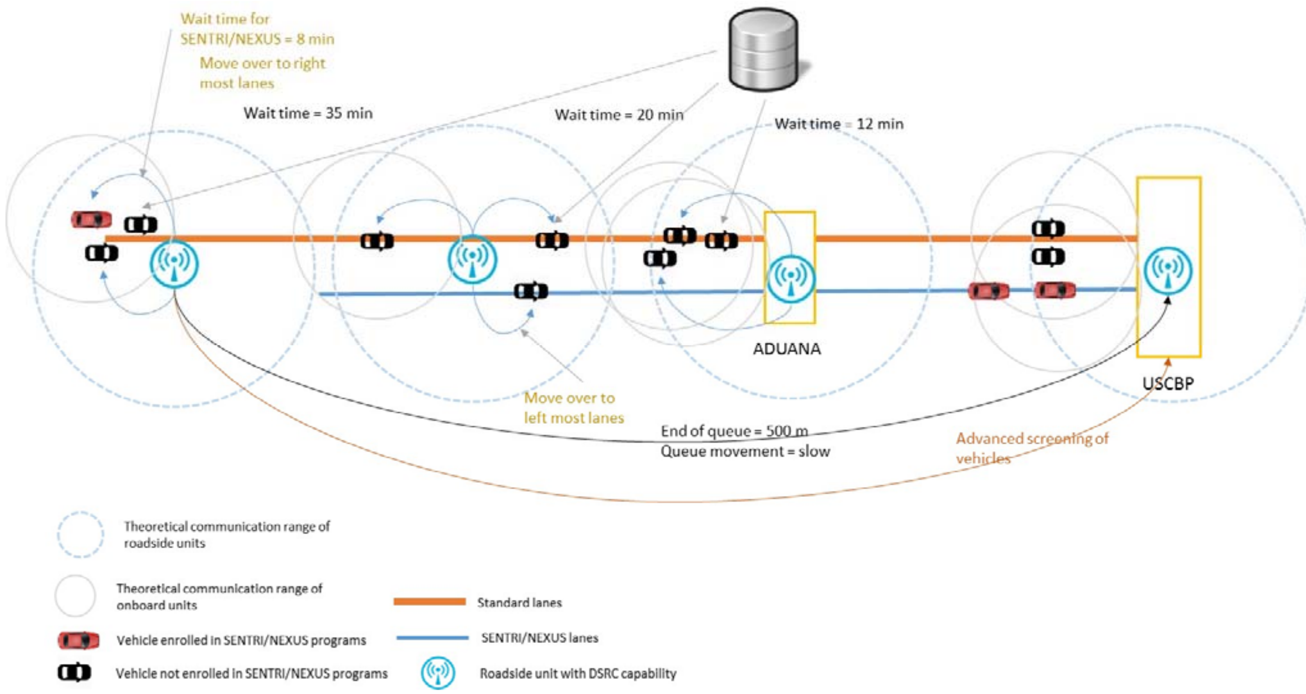


Figure D-6. High-Level Overview of the Enhanced System.

Figure D-7 shows the high-level logical modules in the enhanced system. These modules perform domain-level functions and communicate with other modules as needed. The module recognizes the fact that in the interim, there will be a mix of connected and non-connected vehicles with and without DSRC capabilities. However, non-connected vehicles may have existing technology such as Bluetooth, RFID, and WiFi. These vehicles can still be identified by roadside sensors to determine travel time between static locations to estimate wait time and complement the enhanced system by providing calibration parameters.

Ultimately, in the future, the majority of vehicles will have connected vehicle technology embedded in them. The connected vehicles transmit location and speed data to the central database via roadside sensors. The database then reallocates all or parts of the data to various modules, which then estimate queue lengths, wait times, etc., and sends the information back to vehicles using the same roadside sensors.

Vehicles without connected vehicle technology can receive broadcast information about wait times using roadside displays, web-based tools, mobile apps, etc. However, the information drivers receive will not be customized for their current location because the system cannot transmit data directly to conventional vehicles using Bluetooth or WiFi or mobile phones without significant latency.

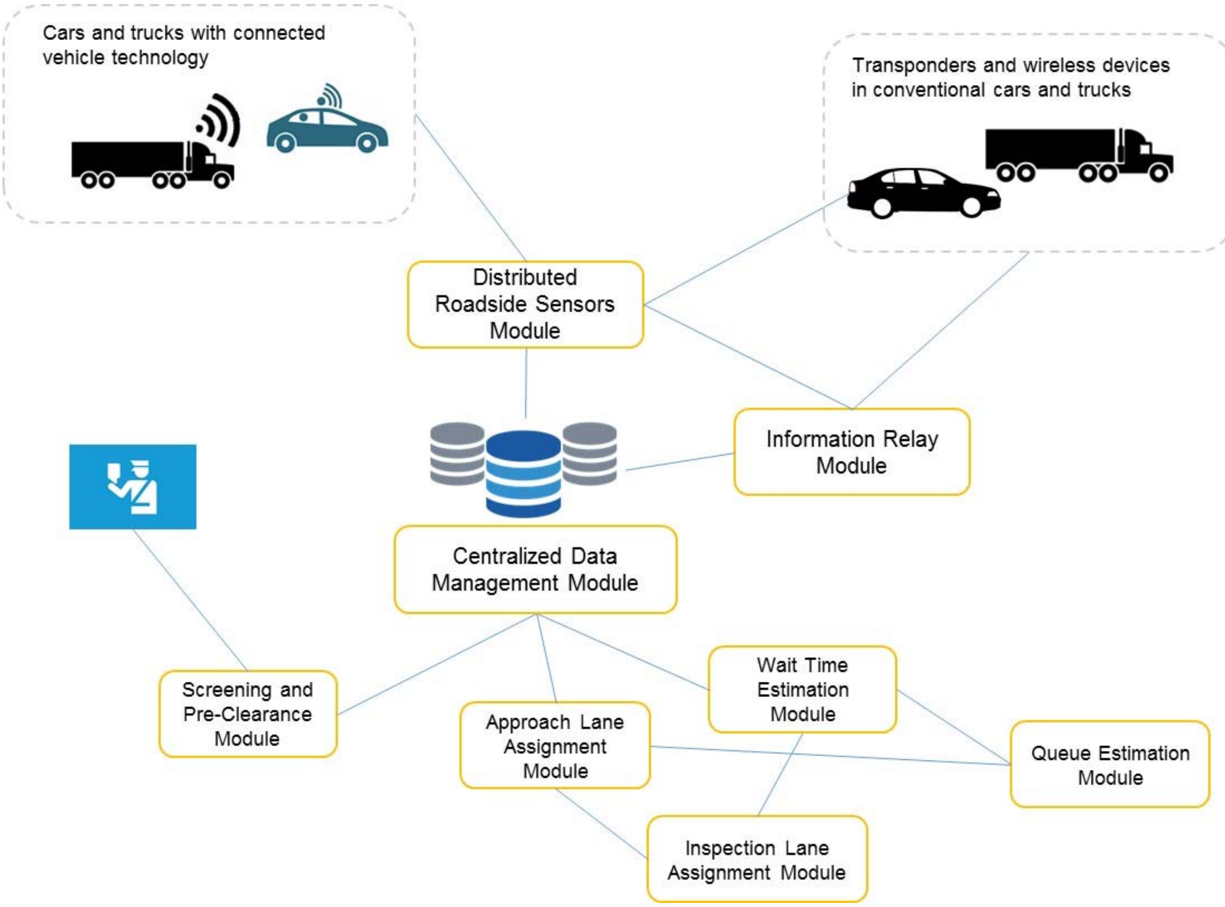


Figure D-7. High-Level Overview of the Individual Modules in the System.

4.2 MAJOR SYSTEM MODULES AND REQUIREMENTS

The enhanced system includes eight logical modules. These modules have to work in a collaborative environment in real time in order to function properly as a system. Figure D-8. Interactions between Modules to Provide Wait Times to Connected and Conventional VehiclesFigure D-8 shows how individual modules interact with each other to estimate queue length and wait time and relay the information to vehicles. Figure D-9 illustrates the data exchange between modules to perform lane assignment functions to warn vehicles to use the right lanes while approaching POEs. Both figures show high-level data messages received and transmitted between the modules and on to vehicles approaching POEs.

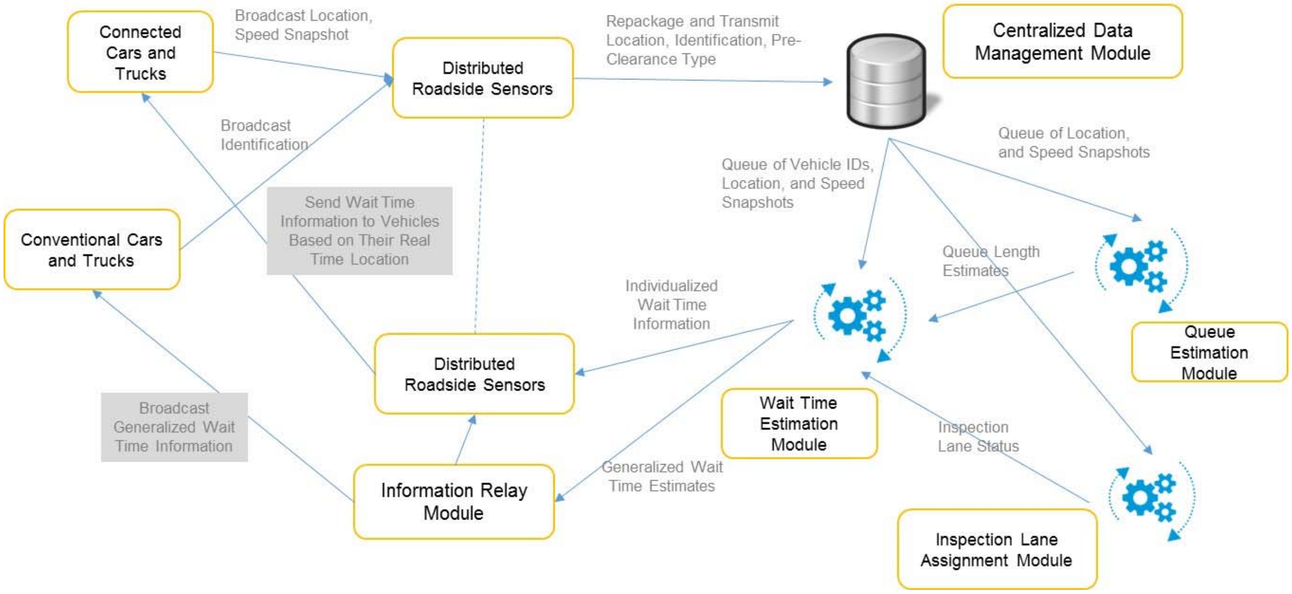


Figure D-8. Interactions between Modules to Provide Wait Times to Connected and Conventional Vehicles.

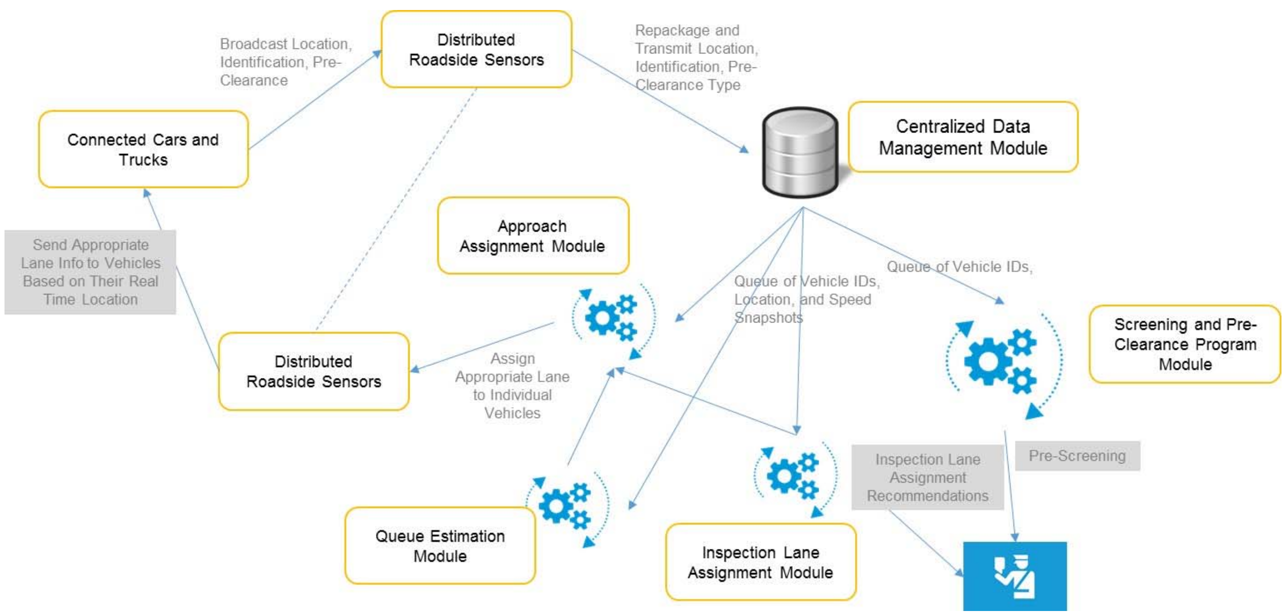


Figure D-9. Interactions between Modules to Provide Lane Assignments to Connected Vehicles.

4.2.1 Distributed Roadside Sensors Module

Depending on the physical layout of POEs, the locations of roadside sensors have to be laid out to ensure minimal obstruction to the line-of-sight coverage. Physically, these sensors may be installed to work independently from one another. However, this module ensures that the sensors properly function to transmit data from vehicles to the information relay module.

In the enhanced system, connected vehicles send basic safety messages (BSMs) and probe data messages (PDMs) to roadside sensors when they come within communication range (approximately 300 meters) of each other. A BSM includes current location (i.e., latitude, longitude) and speed, among other information. Transmission rates of BSMs from onboard units are typically 10 times per second unless congestion control algorithms prescribe a reduced rate. PDMs include a snapshot of a vehicle's speed recorded over a short time period.

The sensors then send the data packets to a centralized data management module for further processing. It is not clear if existing Long-Term Evolution (LTE) and future 5G technology can transmit data packets between the two locations. Otherwise, such transmission will have to take place using a wide area network (WAN) or fiber optics. Roadside sensors that detect connected cars can be installed on existing utility poles alongside Bluetooth and RFID readers, where already deployed.

Roadside sensors may also be deployed to read MAC IDs and transponder IDs from conventional vehicles. Radios deployed in the sensors to detect Bluetooth and WiFi signals from vehicles are different from radios that communicate with connected vehicles with DSRC capabilities. Both radios can be installed in a single roadside sensor unit and send data to the central module in single or multiple data packets.

4.2.2 Centralized Data Management Module

Connected vehicles transmit data packets to roadside sensors every 10 milliseconds or more, depending on configuration of onboard devices. BSMs may arrive in much shorter frequencies than PDMs since PDMs are by design configured to be less frequent than BSMs. Hundreds of vehicles approaching a POE, especially during congested conditions, may generate large amounts of small data packets at a very high frequency. Roadside sensors may be configured to perform limited data verification and cleaning before transmitting to a centralized data management module.

The module is also responsible for receiving identification information from conventional vehicles equipped with traditional technology such as Bluetooth and WiFi. The size of data packets from a connected vehicle will be bigger than the simple ID from conventional vehicles because both BSMs and PDMs have more attributes and are designed to send data to roadside sensors at a much higher frequency than Bluetooth or WiFi sensors.

The module then archives, prunes, and geospatially clusters the data (both from connected and conventional vehicles) before retransmitting them to other modules for queue estimation, wait time, etc. The module also receives results from other estimation/assignment modules and archives and retransmits the data to vehicles via the information relay module.

4.2.3 Information Relay Module

The key function of the information relay module is to broadcast information to connected vehicles via roadside sensors and to broadcast information to conventional vehicles via traditional media such as websites, mobile apps, and roadside display signs. The module receives messages to be broadcast to vehicles from the central database management module. It utilizes rule-based methods to broadcast messages to vehicles based on their relative location to the CBP primary inspection booth. This module does not receive data from connected vehicles.

4.2.4 Queue Estimation Module

The queue estimation module utilizes a combination of speed snapshots (from PDMs) and location (from BSMs) to estimate the location of the end of the queue and its speed of progression. Speed snapshots include the speed of vehicles taken over a few milliseconds of time stored in the device at pre-defined intervals. The accuracy of queue length estimation depends on a statistically significant number of vehicles transmitting the PDM data at the same time. The module receives PDM and BSM data from the centralized data management module. As shown in Figure D-8, it then sends the end of the queue and its progression information to the wait time estimation module since queue location is critical information for estimating wait time. Although not shown in Figure D-8, CBP officers may benefit from knowing where the queue is and how quickly or slowly it is moving. This might help the officers verify that their actions to address long wait times (e.g., opening additional lanes) are working.

4.2.5 Wait Time Estimation Module

Location breadcrumbs from vehicles can be used to determine travel times between roadside sensors. That information can be complemented with queue progression information and the number of inspection lanes open to increase accuracy of wait times. The wait time estimation module estimates wait times for vehicles based on their locations relative to the CBP primary inspection booth. The module sends geospatially clustered wait times to the information relay module, which sends data to individual roadside sensors and then to vehicles directly.

4.2.6 Approach Lane Assignment Module

Most motorists know which lane to stay in while approaching a POE. At some POEs, there are signs that suggest motorists use certain lanes depending on which pre-clearance program they are enrolled in. At some POEs, there are separate lanes for POVs and COVs. However, when the queue is exceptionally long and extends beyond static signs, the traffic can mix. The approach lane assignment module requires that motorists send some kind of identification information to the system in order to track vehicles as they move downstream toward the CBP primary booth. The identification information should include a unique ID number, whether it is a POV or a COV, and the pre-clearance program the motorist is enrolled in. Using the ID and real-time location of vehicles, the module can send a message to the vehicles' onboard units about which lane they should be in.

4.2.7 Inspection Lane Optimization/Assignment Module

This module optimizes the number of lanes that should be open at the CBP primary inspection booth in response to current wait time and queue length. The module takes in as input the wait time and queue length information as well as the queue progression estimate to determine the number of lanes to open. The module can factor in policy constraints such as minimum and maximum number of lanes that can stay open for different shifts during the day. The officers can perform what-if scenarios, such as how many lanes should be opened at the current condition to reduce wait time from 45 to 30 minutes.

4.2.8 Screening and Pre-clearance Module

Because roadside sensors can communicate with vehicles several thousand feet beyond the border, CBP can identify motorists and perform screening before they reach the CBP primary inspection booth. However, the system needs to consider the fact that connected vehicle technology utilizes the privacy by design concept, which means onboard devices can be identified only temporarily (for a few minutes) using a public key. Whether these public keys will be shared with law enforcement agencies is still unresolved. Nonetheless, CBP can design a program whereby motorists can opt in and receive a CBP-specific static unique ID of onboard devices. When those devices come within the range of a roadside sensor, they transmit their ID along with BSMs and PDMs to CBP.

4.3 ASSUMPTIONS AND CONSTRAINTS

Adequate market penetration of connected vehicles will be necessary to maximize the benefit of deploying the enhanced system at POEs. However, it is unclear what “adequate” means. One thing is certain: market penetration of connected vehicles will rise exponentially once the National Highway Transportation Safety Administration (NHTSA) makes a rule on the subject, possibly in 2017. NHTSA is expected to make it mandatory for all new passenger cars and light trucks to have connected vehicle technology built in. It is unclear about the scope of such a rule in terms of types of applications that should be built into vehicles.

A significant portion of POVs and COVs that enter the United States from Mexico are vehicles sold in Mexico. Therefore, there is a possibility that market penetration of connected vehicles in Mexico may significantly lag that of the United States. However, CBP can get rid of original transponders that it distributes to COVs and replace them with DSRC-capable devices. At present, doing so is unfeasible because of the high cost of DSRC-capable devices.

Auto manufacturers are heavily marketing connected car services, which include infotainment, roadside assistance, and other safety features. This service primarily works off 4G/LTE connections between vehicles and service providers. Some industry experts believe that 5G and further improvements in wireless technology may outdate the need for DSRC technology in connected vehicles. Thus, cellular technology advancements can change the picture entirely and may make the need to install roadside devices with DSRC technology unnecessary.

4.4 PERFORMANCE AND QUALITY REQUIREMENTS

This section discusses technical performance needs that may be considered when assessing and evaluating the system. The topics considered here may form the basis for later work on building engineering requirements and specifications for the system.

4.4.1 Capabilities and Performance

The system must be able to support a wide range of operational scenarios and applications. It must be capable of capturing data accurately and reliably across this range of conditions. Placement of roadside sensors may vary depending on the operational type and location of deployment. The reading range of devices may vary depending on obstruction, height of installation, antenna type, etc.

4.4.2 Vehicle Speed and Location

Communication between roadside and onboard devices must happen at all relative speeds. These devices must be within range of each other long enough to transfer the required data. Data transfer rates of the technology must be high enough to support the transfer of payload between devices. Onboard devices send location and speed snapshots at pre-defined frequencies to roadside sensors.

4.4.3 Transmit/Receive Range

The required range for the communications channel will vary depending on the specific border crossing operation type. The transmit/receive range needs must also be balanced by the need for selectivity if it is desirable to identify the lane that a vehicle is traveling in.

4.4.4 Message/Data Size and Rate

As discussed above, the maximum message or data size and the minimum rate at which that data can be sent over the data link are important so that the data can be sent in time to support the application. Data retries due to error rates and/or data collisions must be factored into the calculation in such a way that the identification can be transmitted reliably given the range and vehicle speeds for the application.

4.5 OPERATIONAL REQUIREMENTS

4.5.1 Staffing Needs

Consideration should be given to the staffing required to operate and maintain the system. The technology should require minimal staffing needs for operation of the equipment. The system should automatically detect when a truck is in range, query the truck for an identifier, and process the identifier within the database to determine the related truck information. In normal operation, the only requirement for staff should be to assess the data presented and make a decision on whether to inspect the vehicle. Consideration should be given to the need for preventive maintenance and routine management of the system.

4.5.2 Power

In-vehicle components must operate on power available in the vehicle and the environment, such as 12V DC, integral battery, solar power, or no external power. Passive RFID tags operate from power supplied by the reader. For components with integral batteries, consideration must be given to the trade-off between replacing batteries and having permanent batteries that last the life of the device. For example, battery life may need to be at least one year if a battery can be removed and replaced or five years if it is not replaceable. Roadside equipment may be powered by municipal power, but it is preferable to operate as many components as possible using batteries recharged from renewable resources such as solar cells.

4.5.3 Health and Safety

All equipment should protect the health and safety of operators and maintainers. In-vehicle components should not require the vehicle occupant to interact directly with the device while the vehicle is moving. Roadside equipment should protect personnel from exposure to high-voltage electrical or high-power radiated signals. Readers for universal electronic truck identification should meet the performance and safety requirements for roadside hardware used on the National Highway System, such as those identified at http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/.

4.6 SECURITY REQUIREMENTS

4.6.1 Authorized Access

The system should detect and prevent non-authorized personnel and/or subsystems from interfacing with the system.

4.6.2 Resistance to Removal or Tampering

Field hardware should be installed permanently in the field in such a way that it is resistant to removal, replacement, or tampering. At the same time, the field equipment should be easily accessible to authorized personnel for maintenance purposes.

4.6.3 Identifier Verification

The truck identification system should include an automated means for verifying its accuracy (i.e., that the identifier is on the correct truck). This verification may require an independent reader system that compares the identifier to other information in the truck identification record, such as license plate.

4.6.4 Installation Method and Location

The identifier should be designed to be quickly, permanently installed or mounted on all power units in a standard location that can be reliably read by the roadside equipment. While ease of installation is important, the technology should be installed in a permanent manner such that its removal will destroy its functionality and minimize tampering.

4.7 ENVIRONMENTAL RESISTANCE AND DURABILITY

Environmental conditions to be considered for onboard and off-board equipment include extremes in temperature, humidity, wind, snow, rain, dust, sand, salt, fog, vibration, shock, electromagnetic interference, petroleum exposure, oils and lubricants, fungus, and lightning. The in-vehicle technology should comply with applicable Society of Automotive Engineers (SAE) and industry standards for onboard equipment exposed to the rigors of commercial vehicle operation throughout its service life, such as the Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks) (J1455). Similarly, the roadside equipment should comply with applicable industry standards for roadside and stationary equipment exposed to the rigors of outdoor service.

4.8 SUPPORTABILITY

4.8.1 Availability and Reliability

The system should be capable of automatically operating continuously without operator intervention. The operational availability of the system should be specified, typically in terms of percent time available, and meet the needs of the application. Reliability should be specified, typically in terms of mean time between failure and availability.

4.8.2 Maintainability

The system should have a built-in test function to validate that the system is operating within normal parameters. The maintainability of the system should be specified in terms of mean time to repair.

4.8.3 Portability and Transportability

The universal electronic truck identification system should support portable readers installed permanently or temporarily on mobile enforcement vehicles or in small trailers. It should support handheld readers, which interface with laptop computers. It should also support transportable units that can be setup quickly on the roadside and remain operable using vehicle or generator power.

4.8.4 Expandability and Extensibility

The system should be upgradeable to allow for application of repairs when failures occur and to allow for new functionality to be programmed into the system.

4.8.5 Logistics Constraints

Roadside readers and other equipment should be installed permanently, should be transportable, and should be able to be installed by experienced roadside equipment contractors.

5 OPERATIONAL SCENARIOS

This chapter describes how the system would operate/behave under hypothetical scenarios, what users would do during typical and extraordinary circumstances, and what user services and functions would be provided/not provided during these scenarios. Operational scenarios are demonstrated in this chapter by describing how the enhanced system would operate at a typical POE with both POV and COV movement including separate lanes for pre-clearance programs such as SENTRI and FAST. This chapter also describes how the system would operate under extraordinary conditions such as POE closure and system failure.

5.1 YSLETA-ZARAGOZA PORT OF ENTRY

The Ysleta-Zaragoza POE is located in El Paso, Texas. The POE processes both U.S.- and Mexico-bound traffic (both POVs and COVs). The POE went through recent upgrades to its commercial facility in order to accommodate increasing demand of COVs entering the United States from Mexico.

The passenger vehicle bridge at the POE has five lanes: two southbound lanes, two northbound lanes, and one SENTRI or dedicated commuter lane. The commercial bridge has four lanes: two southbound and one northbound lane, and one northbound FAST lane. Plans are underway to increase the number of lanes without increasing the bridge width. The redesign will allow the commercial bridge to accommodate two southbound lanes, two northbound lanes, and one dedicated FAST lane.

The POE is open 24 hours for standard POVs, but for SENTRI vehicles, it is open from 6 a.m. until midnight. For COVs, the POE is open from 8 a.m.–4 p.m. (Monday to Saturday). In 2015, approximately 261,000 trucks entered the United States from Mexico, averaging 1,000 trucks a day. In the same year, approximately 4.3 million POVs entered the United States, including 885,000 via the SENTRI program.

The POE is equipped with a Bluetooth technology–based system to measure wait times of both U.S.- and Mexico-bound POVs. It is also equipped with an RFID technology–based system to measure wait times of U.S.-bound COVs. Both systems were implemented in 2014 and funded by the Texas Department of Transportation and Federal Highway Administration.

Both systems were designed and deployed by TTI. The agency still runs and maintains the system. Estimated and archived wait times are relayed to the public via the following website: https:\\bcis.tamu.edu. Bluetooth and RFID sensors individually transmit device identification numbers (MAC ID and transponder ID) to TTI's server in El Paso. Algorithms in the server calculate those IDs along with timestamps into travel time between sensors and estimate expected and actual wait times.

Bluetooth sensors consist of a Bluetooth radio to sense signals from mobile devices in POVs, a cellular modem to transmit data to TTI's server, a data logger, and a power supply. RFID sensors consist of transponder readers, directional antennas, a communication path, and a power supply.

Figure D-10 shows existing locations of Bluetooth sensors to measure wait times of both U.S.- and Mexico-bound POVs. It also shows that DSRC sensors can be added at the same location as Bluetooth sensors in order to share a power supply and communication path. Shaded orange polygons show the feasible coverage area of DSRC radios. Actual coverage will have to be measured at the sight since it is affected by line of sight and nearby buildings. Based on coverage and layout of the POE, seven DSRC sensor locations (shown within orange circles) would be adequate to measure wait times and queue propagation as well as send direct messages to POVs.

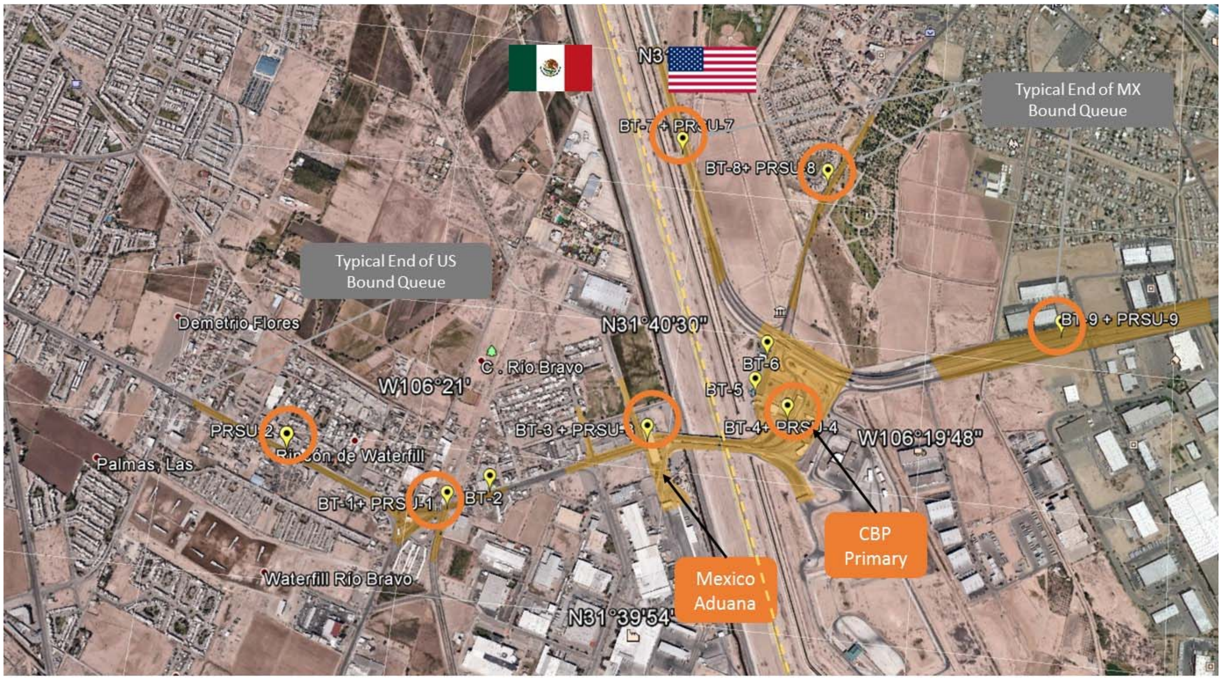


Figure D-10. Aerial Image of Ysleta-Zaragoza POE Showing Existing Locations of Bluetooth Sensors and Potential Locations of DSRC Sensors.

Similarly, Figure D-11Figure D-10 shows existing locations of RFID sensors to measure wait times of U.S.-bound COVs. It shows that DSRC sensors can be added at the same location as RFID sensors in order to share a power supply and communication path. The blue circles show the feasible coverage area of DSRC radios. Actual coverage will have to be determined at the site since the coverage is affected by line of sight and nearby buildings. Based on coverage and layout of the POE, four DSRC sensor locations (shown within blue circles) would be adequate to measure wait times and queue propagation as well as send direct messages to COVs.

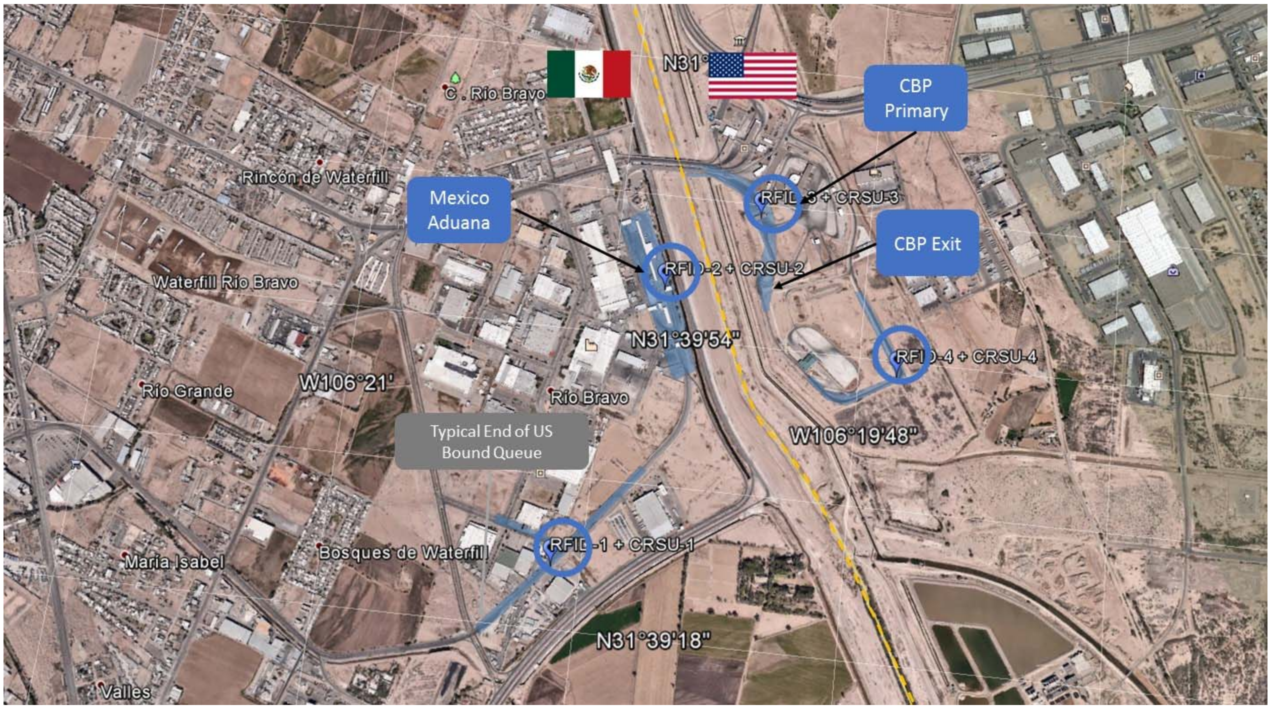


Figure D-11. Aerial Image of Ysleta-Zaragoza POE Showing Existing Locations of RFID Sensors and Potential Locations of DSRC Sensors.

At the moment, it is unclear if individual DSRC sensors would be able to handle payload (both transferring and receiving) to a central server or cloud via cellular connections. Perhaps future versions of 4G/LTE connections may be able to handle the data transfer. If not, then these sensors can be connected to a central server or cloud via WAN or fiber optics. Connections via WAN are feasible; however, connecting individual sensors with fiber optics will be cost prohibitive. It is feasible to collect information from individual sensors using WAN and then transmit data to a central server. The benefit of locating a server inside the CBP facility is that it can be connected to other field systems such as an overhead LED display that shows standard, SENTRI, and READY lanes as well as other locally operated CBP systems.

5.2 NORMAL OPERATION

In normal operation, the central server would continuously gather probe and BSM data from vehicles' DSRC radios, process them, and send wait time and other relevant information back to vehicles. The system would require minimal or no human intervention for normal operation.

5.3 ABNORMAL QUEUE LENGTH

One of the system's goals is to measure the location of the beginning of the queue and to ensure that wait time (and queue length) stays within an acceptable range for the POE. However, situations can arise when the beginning of the queue might be abnormally farther to the south and out of reach of the first DSRC sensor in Mexico. In this situation, the system would underestimate the wait time, at least for vehicles at the end of the queue. When the queue is unusually long, vehicles in the middle of the queue progress much slower than usual and can be detected by other DSRC sensors. Even though it might be difficult to accurately estimate the wait time, CBP officers can be warned that the queue is progressing much slower than usual.

5.4 CLOSURE OF A POE

Although extremely rare, complete shutdown of a POE with short notice can occur due to security situations. Depending on time of day and presence of vehicles already entering the queue, estimating wait time and relaying it to vehicles would be fruitless, especially in a situation where CBP does not know when it will reopen the POE. The system can relay a message to vehicles saying that the POE is temporarily closed and advise them to go to another POE.

Once CBP decides to reopen the POE, then the officers can use the system to monitor how quickly the queue is progressing based on the number of inspection lanes open and make decisions to open more lanes to move the queue faster.

5.5 COMPONENT FAILURE

Component failure typically occurs in the form of a lost connection between DSRC sensors and a central server. A well-programmed system should be able to handle and quickly respond to situations when one or more field sensors go offline and lose connection with the server. These failures not only impact how to bring those systems back online but also how queue length and wait time estimation algorithms adjust themselves in those situations. Estimation algorithms will need to have exceptions built in. If all components fail, the system should be able to relay “wait time not available” message to vehicles.

6 SUMMARY OF IMPACT

This chapter describes operational impacts of the enhanced system on CBP. This information will allow CBP to prepare for the changes that will result from the new system and plan for impacts.

6.1 OPERATIONAL IMPACTS

The enhanced system will have an impact on CBP's field operation where it is deployed. In order to achieve the benefits from the system, CBP officers will have to continuously use the system (i.e., monitor queue progression and wait time, take action by opening/closing more lanes, and relay information to vehicles). If the system is designed to learn from actions taken by the officers, then constant use of the system is even more critical for its improvement.

6.2 ORGANIZATIONAL IMPACTS

CBP officers will require training in using the enhanced system, especially regarding how to utilize the information generated by the system and react. However, interaction with the system will have to be governed by clearly outlined policies and practices. For example, what should the officers do if the system shows wait times have exceeded the maximum threshold? CBP should have clear policies about what kind of automated and manual messages need to be sent to vehicles.

6.3 IMPACTS DURING DEPLOYMENT

Most likely, CBP will outsource deployment of the enhanced system to a private contractor. The contractor will need access to CBP facilities in order to install DSRC sensors. Typically, sensors can be installed on different types of vertical elements such as utility poles and walls. Because the footprint of the sensors is minimal, there is no need to close inspection lanes or any part of the facility during installment.

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