ANALYSIS OF BLUETOOTH AND WI-FI TECHNOLOGY TO MEASURE WAIT TIMES OF PERSONAL VEHICLES AT ARIZONA-MEXICO PORTS OF ENTRY

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Abstract

This study documented an analysis of Bluetooth and Wi-Fi technology to measure wait times and delay of personal vehicles at the Arizona, United States – Sonora, Mexico Ports of Entry. The objective of the analysis was to identify the technology with the higher penetration rate and assess the suitability of permanent technology implementation at Arizona-Mexico Ports of Entry (POE).

The Arizona Department of Transportation (ADOT), Office of P3 Initiatives and International Affairs selected Lee Engineering to analyze the penetration rate of Anonymous Re-Identification (ARID) technology to measure wait time of U.S. and Mexico bound personal vehicles at 6 (six) United States-Mexico Ports of Entry (POEs) in Arizona. The purpose of this study is for ADOT and stakeholders to have an understanding of ARID data collection technology, validity of measuring wait time at POEs, and recommendations on which POEs to install permanent ARID technology, in priority order.

Lee Engineering and Crossborder Group collected travel time and traffic volumes in June and July of 2015. A pilot field study was conducted to analyze ARID Bluetooth and Wi-Fi technologies, and it was determined that the Wi-Fi technology was more successful in match identification for this application.

The results of this study identified the average penetration rate, average delay per vehicle, and average vehicle-hours of total delay of each Port of Entry. These findings were used to assess the suitability of future permanent ARID installation and prioritize implementation based on observed delay, annual volumes, and the ability of the devices to measure data. The method used to determine the prioritization order could be recreated to evaluate future permanent installation at other POEs or high traffic event areas.

Introduction

Robust travel time data collection is possible using Bluetooth™ or Wi-Fi technology that matches anonymous MAC addresses from discoverable electronic devices (e.g., smart phones) to determine travel time along a roadway segment. Several hundred data points can be collected, and analyzed in real-time, each day. Anonymous Re-Identification (ARID), a term coined for local Arizona agencies, is commonly used for this technology and is inclusive or either Bluetooth™ or Wi-Fi technology.

The purpose of this study is to analyze the penetration rate of ARID technology to measure wait time of U.S. and Mexico bound personal vehicles at 6 (six) United States-Mexico Ports of Entry (POEs) in Arizona. The Ports of Entry included in this study are provided in **Table 1**.

Table 1. Arizona – Mexico Ports of Entry[1]

Port of Entry	City/Town	Operating Hours	Total Volume of Personal Vehicles Entering the U.S. in 2014 (Jan-Dec)
San Luis I	San Luis	24 Hours	3,028,042
DeConcini	Nogales	24 Hours	3,286,532
Mariposa	Nogales	6 AM to 10 PM	
Raul Hector Castro	Douglas	24 Hours	1,571,929
Lukeville	Lukeville	6 AM to 12 AM	316,429
Naco	Naco	24 Hours	298,368

Data Collection

Travel time and traffic volume data was collected in June and July of 2015 to evaluate the penetration rate (sampling rate) of Bluetooth or Wi-Fi anonymous re-identification technology at the six Arizona-Mexico POEs. Prior to field deployment, field visits were conducted at the six POEs along the Arizona-Sonora border to assess specific site location options and potential limitations for the deployment of video volume data collection and ARID technology equipment. Site locations were identified based on several factors including the availability of existing poles or parking areas for security, strength of cellular communications network, and traffic flow. The ease of installation, travel time between sites, avoiding holidays, and the overall project schedule was also considered. Traffic volumes were obtained using video technology. To estimate the number of passenger vehicles only, trucks were removed from the volume counts.

ARID travel time data collection devices developed by Post Oak Traffic Systems were used to collect travel times. The equipment included a deep cycle gel cell battery, data processing device, Bluetooth or Wi-Fi antenna, and cellular modem inside a Pelican hardcase. The pelican hardcase and an example deployment are shown in **Figure 1**.

Figure 1: ARID Deployment

Cellular communication allowed for monitoring and processing the ARID device data in real-time and alerted data collection staff to tampering, theft, or malfunction. If cellular service was not available at a deployment location, the data was stored within the device for upload to a computer and post-processing. The off-site data processing matched MAC addresses recorded by the ARID readers, which were later used to estimate sample size of wait times of personal vehicles entering and exiting the United States.

A pilot field test of the ARID technology was performed using Bluetooth™ and Wi-Fi to evaluate the functionality of the two technologies. The pilot field test served as the method of identifying the most appropriate technology for the six POEs in the study and was conducted for three hours on June 16th at the DeConcini Port of Entry. The Bluetooth and Wi-Fi ARID devices were deployed at the same time on opposite sides of the roadway to record the same vehicle flow. Interference between the Bluetooth and Wi-Fi ARID devices was not evident. The pilot field test concluded that Wi-Fi yielded 4-5 times greater valid matches at the DeConcini POE, therefore Wi-Fi technology was selected for use at the six Ports of Entry. The southbound Wi-Fi and Bluetooth match data, collected at the DeConcini POE during the pilot field test, is shown in **Figure 2**.

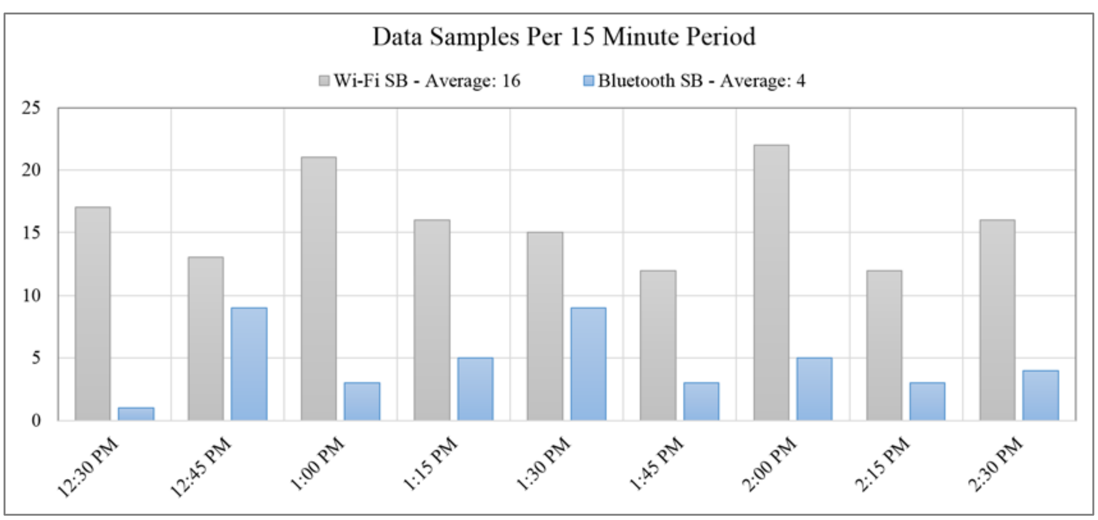

Figure 2: Pilot Study Results, DeConcini Port of Entry, Southbound

Field equipment was deployed for at least two operating days at each POE; however, some of the observation hours were excluded due to POE operating hours or device adjustment time. The adjustment period occurs primarily during installation, when the ARID device requires time to equilibrate and begin identifying valid matches.

<u>Methodology</u>

The purpose of the analysis was to determine whether ARID devices deployed at each Arizona-Mexico Port of Entry could collect a sufficient sample size of passenger vehicle travel time matches, compared to the total volume of passenger vehicles, to confidently estimate wait times of U.S. and Mexico bound personal vehicles. The method in which crossing time, wait time, and delay are calculated are described in this section, along with a description and analysis from one of the six POEs.

Penetration Rate Calculation:

The penetration rate is similar to sampling rate, which is essentially the number of unique devices detected by the ARID technology divided by the traffic volume for the same time period. The team used the following formula to calculate the penetration rate.

$$\text{Penetration Rate (\% of traffic)} = \frac{\#\ of\ unique\ devices\ detected\ (devices\ per\ hour)}{traffic\ volume\ (cars\ per\ hour)}$$

The penetration rate was calculated using a comparison of the ARID Wi-Fi data to the collected video data, which captured the volume of personal vehicles.

Crossing Time, Wait Time and Delay Calculations:

Crossing time and wait time can be measured using multiple ARID devices along border crossing segments. Crossing time, as it applies to this study, is defined as the time required for passenger vehicles to pass by the first ARID device, proceed through the check point, and pass by a second ARID device. Wait time describes a smaller component of crossing time, where the time is measured from the first ARID device to a second ARID device located at the border check point station. To accurately measure crossing time and wait time at a Port of Entry in both queuing directions using ARID technology, three device installation positions are required. The configuration of devices to determine wait time and crossing time are shown in **Figure 3**. When ARID devices are permanently implemented at a Port of Entry, three devices should be installed to accurately measure both the crossing time and wait time in the entering and exiting U.S. directions.

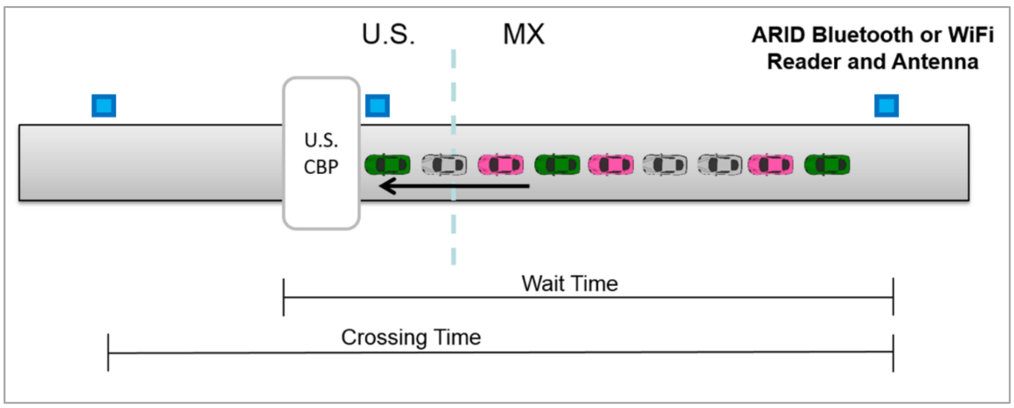

Figure 3: Wait Time and Crossing Time Diagram at a Port of Entry

The wait time, delay, and vehicle delay are estimated using the formulae described in **Table 2**.

Table 2: Wait Time, Delay, and Vehicle Delay Formulae

Measure	Units	Formula
Wait Time	seconds	Crossing Time (seconds) - time required at free flow condition from check point to downstream ARID device (seconds)
Delay	hours	Wait Time (hours) - time required at free flow condition (hours)
Vehicle Delay	vehicle-hours	Delay of each vehicle (hours) x Number of vehicles

Case Study Data Collection: DeConcini Port of Entry

The DeConcini Port of Entry connects Nogales, Arizona with Nogales, Sonora, and operates on a 24-hour basis, seven days a week. The primary access roadways to the POE are Interstate 19 Business (Grand Avenue) in Arizona and Mexican Federal Highway 15 in Sonora. **Figure 4** and **Table 3** describe the study area, device deployment locations, and data collection segments.

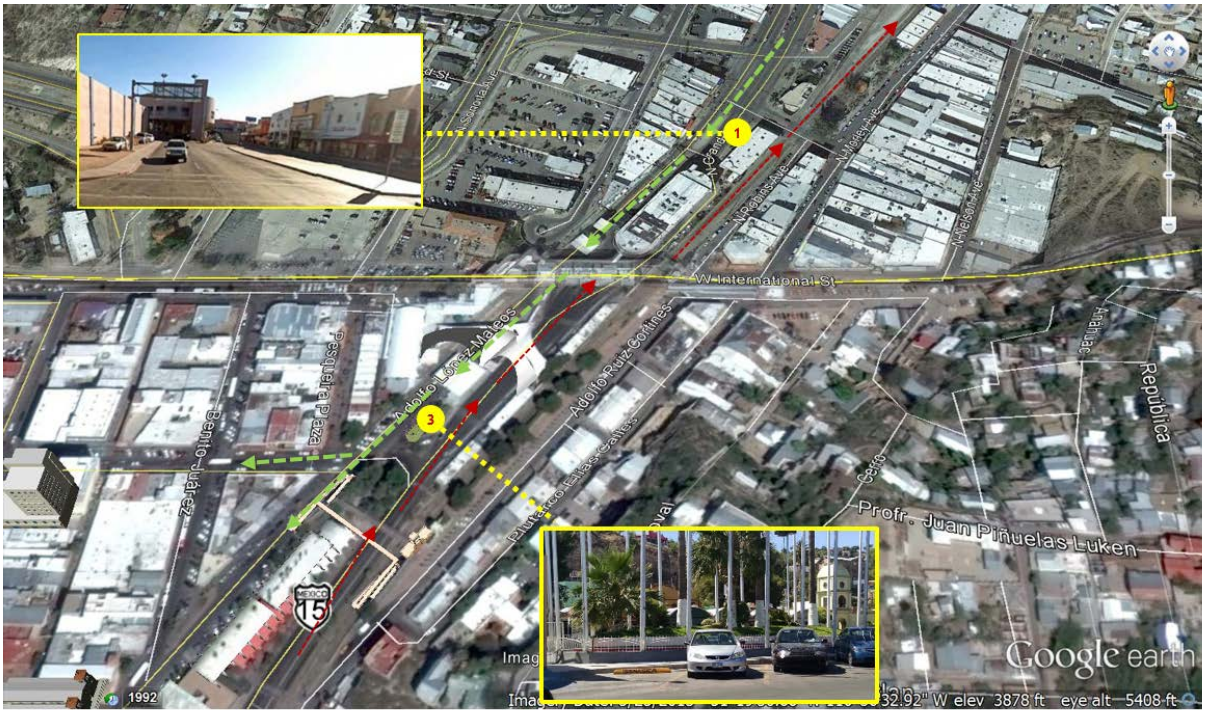

Figure 4. DeConcini Port of Entry, Aerial View and Device Position Location

Two ARID devices were deployed at the DeConcini Port of Entry; one located in Arizona (Position 1) and one located in Sonora (Position 3). Using this configuration, there is one northbound segment (3-1) and one southbound segment (1-3) available for Wi-Fi matching. A video camera was deployed at Position 1 with the ability to count northbound and southbound personal vehicle counts. A summary of the collected data is shown in **Table 3** and **Figure 5.**

Table 3. DeConcini Port of Entry, Data Collection Segment Information

ARID Device Data Collection Locations		
Position 1	Mounted on ADOT sign structure southeast of the intersection of Grand Ave and Park.	
Position 3	Located in the INDAABIN managed median "flag park" between the northbound and southbound lanes of Adolfo Lopez Mateos.	
Segments Evaluated Using ARID Technology		
SB	1 → 3	Nogales, Arizona (US) → Nogales, Sonora (MX)
NB	3 → 1	Nogales, Sonora (MX) → Nogales, Arizona (US)
Miovision Data Collection Location		
Mounting Location: Position 1		
Segments Evaluated Using Miovision Technology		
SB	1 → 3	Nogales, Arizona (US) → Nogales, Sonora (MX)
NB	3 → 1	Nogales, Sonora (MX) → Nogales, Arizona (US)

DeConcini Port of Entry Nogales, Arizona / Nogales, Sonora

ARID Wi-Fi Data Summary
Data Collected from June 16 - 18, 2015

Northbound — MX to US (3-1)	
Travel Time Samples Collected:	
Total Samples	3117
Hours Analyzed	44
Average Matches Per Hour	72

Southbound — US to MX (1-3)	
Travel Time Samples Collected:	
Total Samples	2258
Hours Analyzed	44
Average Matches Per Hour	52

Miovision Video Data Summary
Data Collected from June 16 - 18, 2015

Northbound — MX to US - At Position 1, Reflecting (3-1)	
Travel Time Samples Collected:	
Total Samples	12148
Hours Analyzed	50
Average Vehicles Per Hour	245

Southbound — US to MX - At Position 1, Reflecting (1-3)	
Travel Time Samples Collected:	
Total Samples	4363
Hours Analyzed	50
Average Vehicles Per Hour	88

Figure 5. DeConcini Port of Entry, Summary of ARID Wi-Fi and Miovision Data

Data Analysis and Results

The travel time and traffic volume data was collected for at least two days at each Port of Entry. The rate at which the ARID device successfully matches a unique vehicle at two locations, or the penetration rate, was determined for the 6 POEs. The average vehicle delay was also determined using the segment length and the travel time measured by the multiple ARID sensors. A case study of the DeConcini Port of Entry demonstrates the analysis and results of one of the six POE locations.

Case Study Results: DeConcini Port of Entry

During the three day data collection period at the DeConcini POE, both the Miovision video and ARID technologies indicated greater traffic volumes in the northbound direction (vehicles entering Arizona). The penetration rate was also greater in the northbound direction. **Figures 5** and **6** describe the relationship between the total number of vehicles and the quantity of vehicles detected by Wi-Fi matching at the DeConcini Port of Entry in the northbound and southbound directions, respectively.

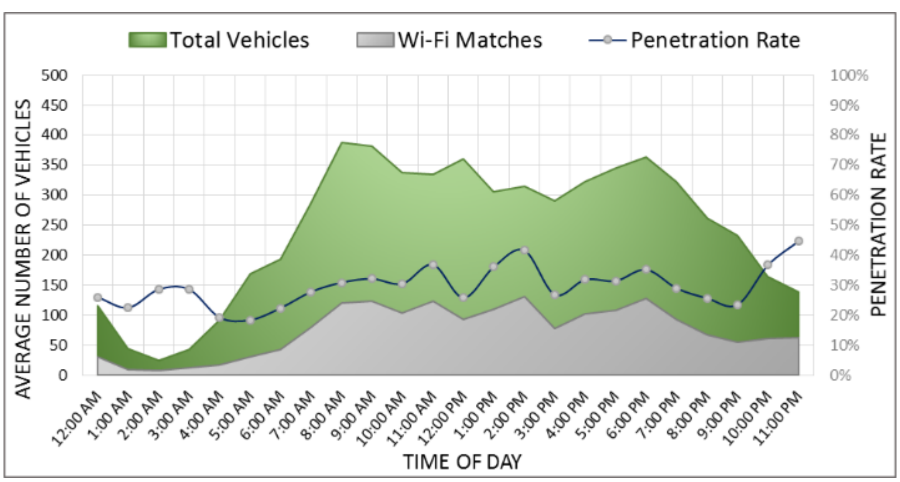

Figure 6. DeConcini Port of Entry, Quantity of Total Vehicles and ARID Wi-Fi Matches Observed in the Northbound Direction (3-1)

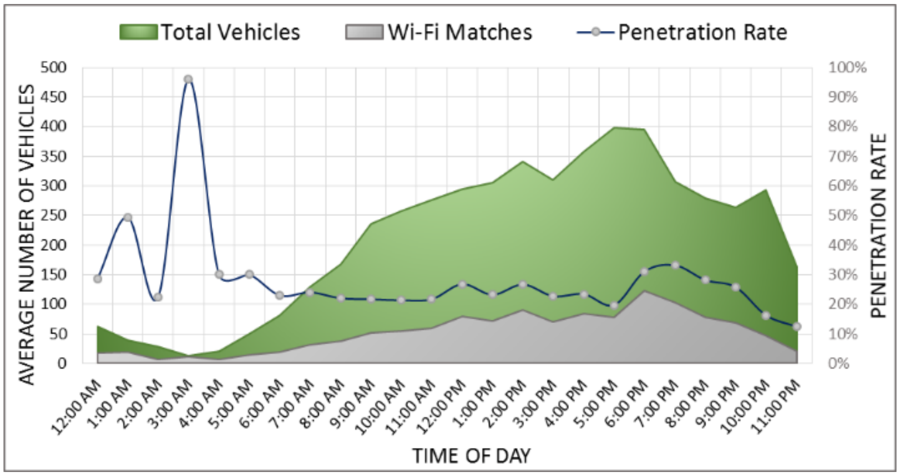

Figure 7. DeConcini Port of Entry, Quantity of Total Vehicles and ARID Wi-Fi Matches Observed in the Southbound Direction (1-3)

In both the northbound and southbound direction, the Wi-Fi matches follow the same moving trends as the total hourly vehicle volume averages. These findings indicate that the equipment operated successfully and consistent vehicle samples were evaluated in the analysis (same location, days, time periods, etc.) The average daily penetration rate was determined to be 30.6% in the northbound direction and 24.5% in the southbound direction.

The average delay per vehicle in the northbound and southbound directions was 2.89 minutes and 0.78 minutes, respectively. The delay was determined by calculating a baseline travel time during free flow conditions, and then calculating the additional travel time, or delay. The collective average vehicle delay was 303 vehicle-hours per day and 70 vehicle-hours per day, in the northbound and southbound directions, respectively.

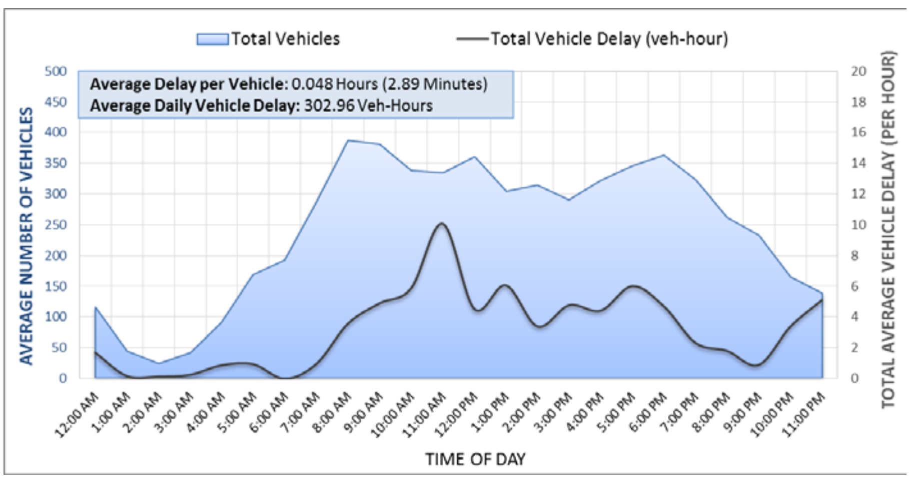

Figure 8. DeConcini Port of Entry, Average Delay of Northbound Vehicles Entering the U.S. (3-1)

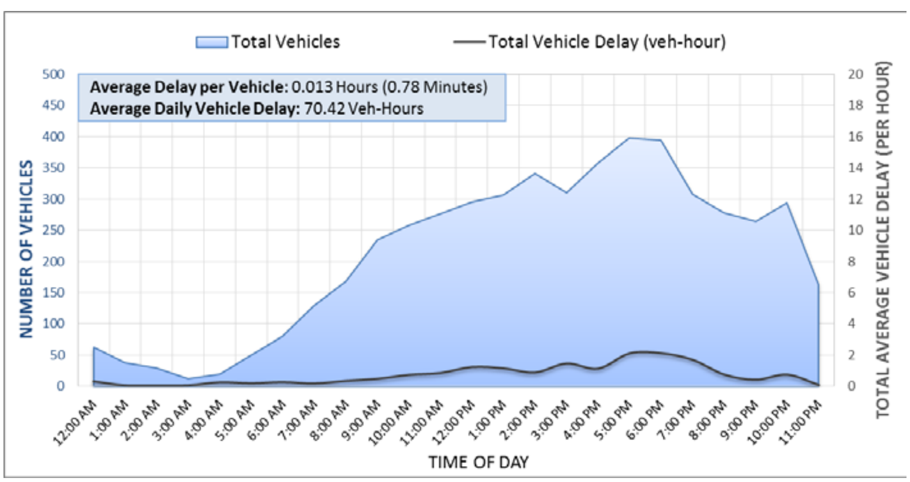

Figure 9. DeConcini Port of Entry, Average Delay of Southbound Vehicles Exiting the U.S. (1-3)

Average Daily Vehicle Delay

The average daily vehicle delay (ADVD) is a measure that considers wait time, delay, and total quantity of vehicles. The ADVD is the sum of delay experienced by the average number of personal vehicles observed at each Port of Entry as part of this study.

The results of the ADVD analysis is consistent with average delay per vehicle trends. In all cases, the delay experienced by vehicles waiting to enter the U.S. is greater than those exiting the U.S. Naco and Lukeville POEs have the lowest volumes of the Ports of Entry, and they also have the lowest average delay per vehicle.

Table 4. Port of Entry Vehicle Delay Summary

	Port of Entry	Average Vehicle Waiting Time (seconds)	Segment Length (mi)	Average Speed (mph)	Average Delay Per Vehicle (Minutes)	Average Delay Per Vehicle (Hours)	Average Daily Vehicle Delay (Veh-Hours)
San Luis	Exiting U.S.	174	0.25	5.0	0.77	0.013	128.6
DeConcini	Entering U.S.	340	0.18	2.0	2.89	0.048	303.0
	Exiting U.S.	168	0.18	4.0	0.78	0.013	70.4
Mariposa	Entering U.S.	610	0.33	2.0	5.46	0.091	238.2
	Exiting U.S.	114	0.35	11.0	0.96	0.016	42.0
Raul Hector Castro	Entering U.S.	229	0.20	3.0	2.39	0.040	209.1
	Exiting U.S.	163	0.20	4.0	1.76	0.029	197.7
Lukeville	Exiting U.S.	60	0.14	8.0	0.53	0.009	3.9
Naco	Entering U.S.	82	0.17	7.0	0.72	0.012	4.9
	Exiting U.S.	61	0.17	10.0	0.28	0.005	3.8

Note: Data shown is representative of days sampled as part of this study only

Permanent Installation of ARID Devices for Measuring Travel Time at POEs

The prioritization of ARID devices at the Ports of Entry is based on the volume of personal vehicles, the success of the ARID data collection, the average delay, and possible implementation constraints. The annual volume of personal vehicles at each Port of Entry is described in **Table 1**. The success of the ARID data collection is reflected in the penetration rate, or the percentage of total vehicles that are identified using Wi-Fi matching. A summary of the penetration rate results are provided in **Table 5.** The penetration results should be interpreted with caution, and the sample size should be considered. The unusually large penetration rates at the Lukeville and Naco Ports of Entry are due to the low volumes at these locations. The lower the sample size is, the greater the risk of inaccurate results. Bias can be created at low sample sizes with multiple devices and signals from a single vehicle, or if there is a large volume of trucks mixing with passenger vehicles. Both of these scenarios will create a large quantity of Wi-Fi matches in comparison to the actual volume of personal vehicles. A statistical analysis was conducted as part of this study to validate the match data. The results of the analysis concluded that a sufficient sample size of data was collected at all Port of Entry locations, with the exception of the Mariposa POE, to estimate border crossing times with 95% confidence. The low sample sizes at Mariposa POE were likely caused by the deployment location or technology interference.

Table 5: ARID Wi-Fi Penetration Rate Summary

	Port of Entry	Penetration Rate (%)
San Luis	Exiting U.S.	21.0%
DeConcini	Entering U.S.	30.6%
	Exiting U.S.	24.5%
Mariposa	Entering U.S.	5.7%
	Exiting U.S.	2.4%
Raul Hector Castro	Entering U.S.	25.8%
	Exiting U.S.	32.0%
Lukeville*	Exiting U.S.	64.5%
Naco*	Entering U.S.	53.5%
	Exiting U.S.	27.8%

**Note: The high penetration rates should be interpreted with caution due to the low traffic volumes at these POEs*

Excluding the low volume POEs, the penetration rate analysis showed the greatest device success (in descending order) at the Raul Hector Castro, DeConcini, San Luis, and Mariposa Ports of Entry. In terms of the most significant average annual vehicle delay, the POEs are ranked as follows: DeConcini, Mariposa, Raul Hector Castro, San Luis, Lukeville, and Naco. The delay analysis and the ARID success evaluation both conclude similar results in terms of prioritization. The DeConcini and Mariposa POEs are recommended to be implemented together with highest priority due to the observed vehicle delay, combined annual vehicle volume of 3,286,532, and close proximity in location (1.4 miles) allowing them to serve as alternate routes to each other. The list of recommended ARID device implementation locations is shown in **Table 6**.

Table 6: Prioritization of Future ARID Device Installation

Rank	Port of Entry	Disposition
1	DeConcini / Mariposa	Recommended for simultaneous ARID implementation, with further evaluation of sensor location at the Mariposa POE due to low penetration rates observed for this study
2	Raul Hector Castro	Recommended for ARID implementation
3	San Luis	Recommended for ARID implementation
4	Lukeville	Not recommended due to low volumes, unless peak periods are a concern
5	Naco	Not recommended due to low volumes, unless peak periods are a concern

The success of the ARID technology to determine wait times of personal vehicles at POEs depends on the type of vehicles crossing through the port of entry, the amount of probe vehicles (sample size), the proximity of the ARID device to vehicle flow, and any possible interference of nearby devices operating on the same radio spectrum. The planning level design and construction cost for a single, stand-alone permanent ARID device is approximately $28,000.

Principal Findings

This study evaluated the capabilities and limitations of using ARID technology to estimate wait times of U.S. and Mexico bound personal vehicles. The analysis concluded the following:

- The ARID technology was successful in identifying unique vehicle matches between two locations across the border, which allowed for crossing time data collection and wait time, delay, and average speed analysis.
- The pilot study of ARID travel time data collection using Wi-Fi technology resulted in higher penetration rates for the Port of Entry study application than using Bluetooth technology.
- ARID travel time data collection using Wi-Fi technology resulted in higher penetration rates for this Port of Entry study application than other Arizona deployments on freeways and urban arterial roadways within the past year.
- Of the four POEs with data both entering and exiting the U.S., three had higher ARID penetration rates of passenger vehicles entering the U.S.
- ARID (Wi-Fi) technology collects enough valid data to estimate border crossing times with 95% confidence, with the exception of the Mariposa POE in the northbound direction. This is due to low penetration rates at the Mariposa POE, which may have been related to deployment location or technology interference.
- The highest average individual vehicle delay entering the U.S. was observed at the Mariposa POE (5.46 minutes).
- The DeConcini POE has the greatest estimated average daily vehicle delay (303 vehicle-hours).
- The results of the study allowed for the prioritization of future permanent ARID installation at the six Ports of Entry based on:
    - ARID technology identification and matching rate
    - Average delay
    - Annual average vehicle volume
    - Constraints of device installation
    - Proximity to alternate routes

[1]Source: U.S. DOT, Research and Innovative Technology Administration, Bureau of Transportation Statistics, based on data from the Department of Homeland Security, U.S. Customs and Border Protection, Office of Field Operations.