Measuring Cross-Border Travel Times for Freight:
Otay Mesa International Border Crossing

Final Report

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U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

In October 2008 The Federal Highway Administration contracted a study team to conduct a two-part study to assess technology for the measurement of travel times for trucks through the Otay Mesa international border crossing into the US. The primary goal was to evaluate the ability of one of two technologies to accurately record travel times through the border zone.

The specific objectives of the project were to:

- Assess the effectiveness of a technology for automated capture of travel time for vehicles crossing the border.
- Gather historical travel time data over the period of one year.

The results of the work are summarized in this Final Report.

Electronic copies of these documents are available from FHWA.

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Background

Cross border movement of people and goods is a vital part of the North American economy. Accurate real-time data on travel times along the US-Mexico border can help generate a range of tangible benefits covering improved operations and security, lower costs for travelers (both personal and commercial, reduced environmental impacts, reduced negative impacts on adjacent communities, and, of course, increased economic activity for both countries.

Congestion creates delays that result in wasted fuel and exacerbate noise and air pollution for communities adjacent to the crossings. Accurate travel time data can provide considerable benefits to the people that use the crossing, and the entities that are charged with managing it and the adjacent transportation network. It can:

- Help travelers make more informed decisions regarding which crossing to use and when to use it, thus saving time and fuel and making it less likely they will encounter congestion delays;

- Help operators, including transportation agencies, customs and immigration agencies, and private crossing operators, make more informed operating decisions such as the assignment of staff (e.g., from secondary inspection to primary inspection), or the opening of additional toll or inspection lanes to accommodate surges in demand;

- Support improved planning both along the border and for the transport network that provides access through Mexico and the US. Planning decisions would include facility design or layout modification that would ease the congestion at a particular crossing;

- More convincingly make the case for needed improvements in areas such as infrastructure upgrades and increased staffing, it can be a powerful planning aid for transportation and compliance agencies, as well as businesses;

- Be a very helpful means to educate border crossing users of the benefits of engaging in better planning, and those associated with expedited crossing programs.

The current quality of data on border crossing delays is mixed. Border agencies often rely on visual observations of the vehicle queue or a manual data collection process (driver surveys or time-stamped cards) to provide an estimate of total wait time. Unfortunately, these approaches

are costly, inconsistent over time and from location to location, and do not take advantage of existing technology to monitor traffic movement.

In October 2007 The Federal Highway Administration initiated a three-part assignment to assess technology for the measurement of travel times for trucks through the Otay Mesa international border crossing into the US. The primary goal was to evaluate the ability of one of two technologies to accurately record travel times through the border zone. The three parts of the study were to:

- Examine two candidate technologies for installation and testing at the Otay Mesa crossing, and recommend one for testing;

- Conduct an assessment of the suitability of the selected technology to provide accurate border crossing travel time data; and

- Gather one-year's worth of travel time data at the crossing to establish a historic database for future use.

The Otay Mesa crossing is a truck-only crossing between the US and Mexico south of San Diego, California. At the onset of the project the port served an average of 2,500 vehicles per day inbound into the US. Over the last several decades, the crossing has seen an increase in the amount of traffic, and as a result, the amount of time necessary to cross into the US has been perceived to have increased for the average trucker. Rather than assess the accuracy of that perception, this project was focused on evaluating the ability of a technology solution to accurately measure the time it takes a truck to pass through the border.

The first part of the project involved the comparative examination of two candidate technologies. These technologies were:

- **Automatic License Plate Recognition (ALPR).** ALPR applications seek to identify, catalog, and track individual truck movements using optical image capture and re-identification. ALPR systems record a combination of registered license plates and USDOT numbers, use optical character recognition (OCR) to resolve images into strings of characters, store these character strings in a central database, and compare them to subsequently captures and resolved character strings in order to re-identify individual vehicles.

- **Global Positioning System (GPS).** GPS applications, particularly in the form of commercial feet management systems, are becoming more commonplace. Motor

carriers typically rely upon such systems to locate individual trucks in order to more effectively manage dispatch operations, and to provide "visibility" regarding shipment status to customers. GPS systems rely upon a long-used navigational technique called triangulation to locate assets.

Based on a careful examination of functional characteristics, deployment requirements, long-term potential for viability, and options related to business models for gaining access to the data, it was determined that GPS technology would be used for this project.

The second part of the project was to capture data over an extended period in order to determine whether it was of sufficient quantity and quality to determine travel time. This task consisted of ongoing statistical analysis of weekly data files provided by a third-party data provider. As additional data was received, it was processed and analyzed, and stored both raw and processed data in a database for future use.

The final component of the project was the archiving for future use of one year's worth of GPS data and associated travel time calculations.

Stakeholder input was an essential component of the success of the project during both the design and execution of the technology assessment. Because it was important to gain national, international and local insight into the operations at the Otay crossing, the study team conducted stakeholder sessions in the San Diego / Otay Mesa area. The sessions were designed to communicate the objectives of the study, to discuss the various information needs of the stakeholders, and to provide information regarding the progress of the study. These stakeholders included motor carriers, and Federal, State, and local agencies from both sides of the border.

The stakeholder sessions offered the study team some valuable insights into the challenges faced by users and administrators at the border. They allowed for a much more comprehensive understanding of not only the conditions as they exist, but also regarding what might be done to improve them.

Stakeholders provided some useful ideas regarding what would be a potential set of functional requirements for any border travel time measurement solution. Table ES-1 contains a brief summary of important input. Most notably, the stakeholders offered information regarding their needs, and the functional requirements that a system that provides travel time information might be expected to meet.

Table ES-1. Stakeholder Input Summary

Stakeholder Group	User Needs (Northbound)
FHWA	Provide leadership in the area of automated cross border travel time measurement by testing a technology to provide better quality data, to facilitate better transportation operations in the border region
Motor Carriers	Gain access to real-time cross-border total travel time to assist in dispatching and routing decisions and in providing information to customers
State and Local Transportation Agencies	Historic travel time data for the assessment of overall system performance and real-time data for use in traffic operations and transportation system management
US/MX Customs	Historic and real-time data to assess needs for modifications to crossing infrastructure and to assist in managing resources and facilities during daily operations

Findings

Technology Assessment

Based on a combination of stakeholder preferences for access to real-time data, as well as the need to establish a focused localized data source, the study team recommended that the best GPS-based alternative for this test was one that included a third-party provider. Stakeholders strongly supported this approach, and the study team procured the services of Calmar Telematics to capture, process, and deliver fleet GPS data for the study.

Data acquisition requirements were broadly prescribed to the data provider. The key requirements were that the sample size be sufficient to adequately characterize travel times and that the participating carriers allow unrestricted access to all available GPS data generated by trucks passing through the Otay Mesa crossing into the US.

In order to meet the requirement for truck GPS data, the data provider needed to identify and recruit motor carriers to participate in the project. The data provider chose to address this requirement by recruiting three carriers that regularly travel the Otay crossing. Initially, the carriers were chosen because they already possessed vehicles with GPS data systems installed.

The data initially provided by the carriers that agreed to participate was generated by devices affixed to semi-trailers. While the position data provided by these systems has proven reliable over a number of years, it became clear as the test progressed that the reporting frequency the carriers had negotiated with the data provider was not sufficient for measuring travel time over such a short distance. Rather than incur the costs associated with increasing the frequency of reports, the participating carriers opted to upgrade their GPS units to devices that are installed in the tractor (as opposed to trailers) and provide a higher reporting rate. The carriers purchased and installed a total of 175 units in trucks.

Crossing Statistics

During the test the study team obtained data from CBP that indicated that the average daily US-bound vehicle count between January 2009 and February 2010 was between 1,900 and 2,400.

In order to assess whether the fleets participating in the project were providing an adequate percentage of overall trips, the study team examined the GPS data to identify two different types of trips. The first was "total trips." For this category, any appearance of multiple points from the same truck within the dataset for a given two-hour period was considered a trip. This was true regardless of where the points were located, as long as they were within the travel time measurement zone (defined as the distance between the point at which stakeholders indicated that trucks typically begin to queue up to cross and the point where trucks exit the California Highway Patrol commercial vehicle inspection station downstream of the US Customs import processing facility), and indicated US-bound movement. The second trip type was "crossed trips." The study team considered a trip a crossed trip if a truck was identified as having been on both sides of the border during an individual trip, and headed US-bound. Hence, the group of total trips included all crossed trips, plus any additional trips for which points could not be identified on one side of the border or the other.

Figure ES-1 contains a plot of the data gathered during the test from January 2009 through March 2010. It illustrates the number of trips for which data was captured during each month.

Figure ES-1. Otay Mesa Data Trips – January 2009 through March 2010
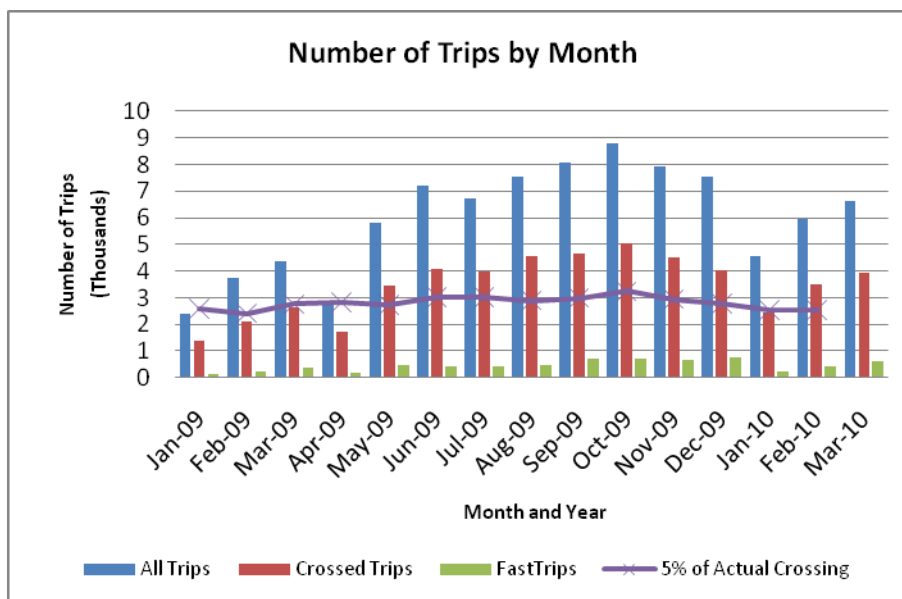
As the data indicate, the number of crossed trips consistently fell between three and five percent of all trips through the border. Based on these figures, the study team felt confident it could rely upon the data from crossed trips to characterize travel time through the crossing.

Border Travel Time Findings

To facilitate calculating border crossing travel time across the full measurement zone and for portions of the trip, the trip length was segregated into a series of consecutive travel zones, or districts, ten in all. The districts were utilized for determining the portion of the total trip travel time that was accumulated on the approach to the US customs primary inspection facility. Figure ES-2 shows the calculated travel times through the measurement zone by the day of the week (DoW) for all trips, trips conducted by trucks participating in the FAST (Free and Secure Trade)[1] expedited processing program, and trucks that were not required to pass through the US Customs secondary inspection facility, over the period of a year.

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[1] The Free and Secure Trade (FAST) program was established and is operated by US Customs and Border Protection, Mexican Customs, and Canada Border Services Agency as a means to expedite the movement of safe, legal trade movements among the three North American countries. It relies on the comprehensive screening and validation of supply chain security.

Figure ES-2. Calculated Travel Time Values by Day of the Week
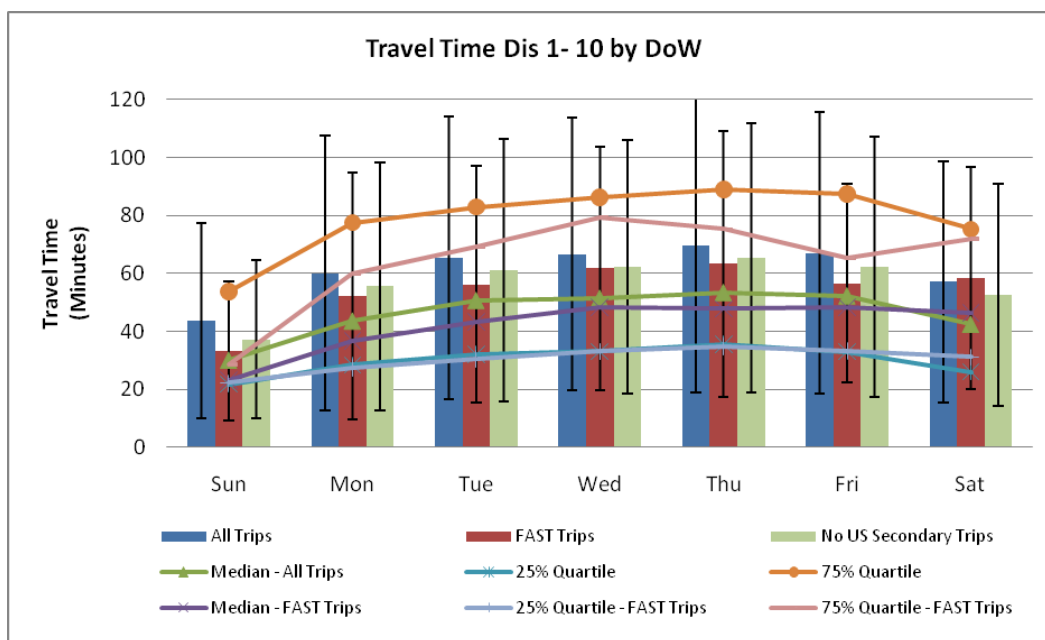
The travel time values calculated from the data indicate that the mean measured travel time across the entire measurement zone for Mondays through Saturdays was approximately 67 minutes. Sundays, which see very limited traffic, showed a mean travel time value of just over 43 minutes. The data suggests that travel times are longest on Thursdays and Fridays, where mean values are approximately 70 minutes.

The data also indicates that FAST trips—at least those that could be identified definitively—take less time for all days except Saturdays. Differences range from values of 15 percent lower on Mondays for FAST trips to just over 10 percent lower on Thursdays.

Among the more notable characteristics of the data is the very large value associated with the standard deviation from the mean (illustrated in the figure by the vertical black lines). The values calculated from the data indicate that the standard deviation ranged from 61 percent to 81 percent of the mean. These values suggest that the carriers that participated in the study experienced very wide fluctuations in travel times. Fluctuations of this magnitude are indicative of low travel time reliability, a characteristic that makes it difficult for border users to anticipate how long a border crossing trip might take.

Because it is less prone to the influence of outliers, the study team also calculated median travel time values for each day of the week. The data indicated that the median values were 15 to 30

percent lower than the mean values, which would place the median travel time for Mondays through Saturdays between 42 and 53 minutes.

The upward bias in mean travel time values is revealed further through the identification of 25% and 75% quartile values. These values form the upper and lower limits of observed travel times for the middle 50% of all observed trips. A comparison of the portions of the standard deviation range outside the middle 50% to those inside reveals that more of the deviation interval lies to the upper side of the range.

The root cause of the high degree of travel time variability is not known for certain. However, the study team suspects that several factors may contribute to it. Fluctuations in demand volume, the opening and closing of primary screening lanes, the proportion of trucks participating in the FAST expedited screening program, variations in screening actions undertaken by US CBP can affect travel time.

Travel time values were also calculated and reviewed on a month of year (MOY) and time of day (TOD) basis. Some of the characteristics of these datasets are summarized in Table ES-2.

Table ES-2. MOY and TOD Data Characteristics

Analysis Timeframe	*Characteristics*
Month of Year (MOY)	Mean and median travel time values peaked in the March-April 2009 and September-October 2009 timeframes. According to CBP crossing statistics, the September-October 2009 period was the busiest period.
	The mean travel times for FAST trips were lower than the overall average for all but three of the months: January 2009, April 2009, and January 2010.
	The monthly data is consistent with the daily data in that they show that the median travel time is consistently lower than the mean, and that the middle 50% of trips fall to the lower end of the standard deviation range.
Time of Day (TOD)	For the TOD data, because the number of points was exceedingly small, all trips identified as having started between 12 AM (when the border closes) and 6 AM were excluded from the dataset. The study team did this because it did not have confidence in the values provided.
	Because the border does not open until 8 AM local time, the high travel time values reported between 6 AM and the opening of the border suggest that some vehicles are queuing in advance in order to ensure earlier entry into the US.
	The increase in volume seen in the peak afternoon/evening travel period does not translate into longer travel times. This is likely due at least in part to higher staffing levels during those periods.

Data Validation

At the conclusion of the data collection period, the study team contacted carriers that participated in the project to gain some perspective on their operations, and to gather information related to their typical crossing experience. The principal objective was to validate the border crossing travel time findings.

The study team first sought feedback regarding the mix of loaded to unloaded trips and FAST to non-FAST trips for each carrier. The intent was to assess the ability of the GPS devices to discern the various trip types. The participating carriers indicated FAST trip frequencies of between 75 and 90 percent of all northbound trips. This is in contrast to the GPS data that indicated that approximately 30 percent of trips were FAST trips. While neither carrier offered detailed records to indicate that these figures were close to actual numbers, the implication is clear that the use of GPS data to isolate FAST trips was not an accurate method at the Otay Mesa crossing, where vehicles conducting FAST trips are physically separated by a significant distance from non-FAST and empty trips for only a short period. Separation of paths of travel is essential if GPS data is to be relied upon for differentiating trip types.

The study team also sought feedback from the carriers regarding whether their drivers encounter a high degree of travel time variability (i.e., a low level of travel time reliability) when crossing into the US. Representatives from both carriers concurred that there is, in fact, significant variability, and that the degree seen in the data could be accurate.

Finally, the study team asked the carriers about the value they perceive GPS-based technology systems have with respect to their operations. Both carriers indicated that they routinely use the tracking and tracing functions as a means to meet business needs of customers, and both use the data on a continual basis.

Conclusions

Based on the observed results from the full data collection period, the study team is able to draw a number of conclusions regarding the use of truck fleet GPS data for the measurement of travel time across international border crossings, both in general terms and in terms specific to the Otay Mesa Crossing.

With respect to the primary goal, the devices and the processing methods employed to capture and analyze the GPS data succeeded. There are, however, some considerations that must be taken into account as border stakeholders contemplate its use on a regular basis.

First, the figures reflected in this report are based on a marginally representative sample. While the number of trips and their distribution throughout the day consistently exceeded the three to five percent threshold commonly required for probe vehicle-based traffic monitoring, the carriers that participated are similar to only a portion of those that cross the border. Both carriers are highly reputable companies that are C-TPAT[2] qualified, and conduct a significant portion of their cross-border trips as FAST trips. As such, the test sample was not random, and may not be representative of the general population.

The second consideration that must be taken into account is the size and placement of the measurement zone. At the onset of the project, carriers indicated to the study team that queues often extend to the Bellas Artes/Calle Doce intersection. However, the data gathered during the test suggests that traffic often flowed quite freely from there to the sorting gate upstream of the Mexican Customs Export screening point.

The implication is that care should be taken in deciding at what point the border crossing travel time clock should start. It is worthwhile to consider beginning measurement of an individual trip after a vehicle has reached the end of the queue waiting to cross. The time from that point until the crossing is completed is probably of more value to a border user.

Finally, consideration must be given to the implications associated with the large values of standard deviation, and the differences between the mean and median values seen in the data. This level of variability does present particular challenges in formulating accurate values for current travel time, such as might be used in a traveler information system.

This is important because high levels of variability in the data can make it difficult to accurately characterize travel time fluctuations associated with non-recurring congestion, which has a profound effect on travel time reliability. A larger number of vehicles, spread across a more diverse set of carriers, should improve the data and lower the degree of variability. From a statistical standpoint, as the sample size increases, the proportion of outliers and their influence on the mean values should diminish. It is not clear at this point the threshold at which that might occur to an acceptable degree.

It is important to remember that some degree of variability will continue to exist simply due to factors such as variations in the proportion of vehicles participating in secure supply chain

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[2] C-TPAT (Customs-Trade Partnership Against Terrorism) is a supply chain security assessment program, participation in which is required in order to access FAST processing lanes.

operations (such as the C-TPAT and FAST programs), fluctuations in the total number of vehicle crossing during a given period, the number of empty trucks versus loaded trucks passing through the crossing, and the application of various enforcement actions.

The capture and use of real-time—or more accurately, near real time—data presents a set of challenges that were not completely addressed during the project, but the experience offers some useful insights. The information exchange and processing mechanisms employed for the project would not be suitable as deployed solutions. These mechanisms would need to be replaced with appropriate communications and processing tools and protocols in order to be usable for applications that rely upon timely information processing, such as traveler information systems that might inform border users of current conditions.

The data model that the data provider applied to access motor carrier data—seeking to obtain it directly from the carriers—is different from that which is typically seen from other fleet data providers. This approach presents both benefits and challenges. One potential benefit is that, because the carrier already owns the data for its fleet, and only its fleet, it may be willing to grant access to the data for a modest sum. Further, by working directly with the carrier while agreeing to protect sensitive information from distribution, a data provider could structure its data agreements to allow for the re-use of information for multiple purposes without incurring additional cost.

Perhaps the most significant challenge to this approach is that which was encountered during the recruitment of carriers for participation in this project. The data provider was forced to endure a lengthy courtship process before the carriers finally agreed to grant access to their data. Ultimately, the carriers became more receptive as they recognized that the devices are useful for other functions, as well. Nonetheless, the level of time and effort necessary to execute agreements with the carriers indicates that this should be factored in whenever GPS fleet data is sought.

Even with the level of variability demonstrated in the data gathered during this project there appears to be significant value associate with GPS fleet data. GPS devices can easily provide data for other movements, and the data processed to quickly multiply its planning and operations value.

For instance, the data provider already possesses raw GPS data for Mexico-bound movements at the Otay crossing. This means that with the completion of some processing logic, travel time for southbound trucks during the same period could be calculated without additional data

collection. Further, raw GPS data has already been recorded for movements both within the areas adjacent to and those beyond the Otay border zone. This data could be used not only for travel time calculation, but also for the identification of origins and destinations and route selection. This also underscores the importance of carefully considering the terms of any data agreement to ensure that the maximum value can be obtained.

Finally, modern fleet GPS devices are becoming both more affordable and more capable, opening up additional opportunities to capture valuable information. One example is the capture of device from a vehicle's engine data bus, which would include such information as throttle position, travel speed and fuel use by location. This has potential value for the identification of locations where excessive idling is occurring—important data for carriers to establish mechanisms to improve fleet fuel efficiency and for agencies to examine the potential environmental value of infrastructure upgrades.

Recommendations

While a significant amount of information was captured during the project, the study team recommends that a series of actions be undertaken to establish a complete service for the various potential users of GPS data. These actions will increase the likelihood that the data obtained from a GPS-based system offers the appropriate value and usability to enable the cost of deployment to be spread over a broad set of stakeholders. The team's recommendations are offered below, along with an explanation of the value associated with exercising each of them

Recommendation #1: Use a Larger Number of Reports.

While the rule of thumb threshold of three to five percent of the total population was successfully reached during the project, the data suggests that a larger population of GPS-equipped trucks could significantly enhance the dataset by reducing the effect of outlier trips on the mean travel time value. The relationship between sample size and variability is not known, but an increase in the number of units to 300 (at the same crossing frequency) should yield definitive evidence of it. Of course, such action would need to be balanced against the cost of the additional devices, and the expected value of the (presumably) more precise data.

Recommendation #2: Increase the Variety of Carrier Participants.

The carriers that participated in the project indicated that the overwhelming majority of their US-bound trips are FAST trips. At the very least, that means that the samples gathered for this project under-represent non-FAST trips. If a GPS data solution is to be deployed in a production

setting, the team suggests that the trucks from which GPS data is collected conduct non-FAST trips into the US at a representative frequency.

Recommendation #3: Examine Secondary Uses for Data.

The measurement of travel time for vehicles entering the US represents only a small portion of the value to be extracted from GPS data. These devices are typically on when the vehicle is running, offering the opportunity to examine movements, origins and destinations, idling points, and various travel delays throughout a vehicle's duty cycle. Those entities that adopt GPS-based systems should examine these and other secondary uses for the data in order to realize its full value. For instance, a significant volume of data was captured during the project regarding southbound movements, but it was not analyzed because it fell outside the scope of the project. At this point, the value and usefulness of this data is unknown.

Recommendation #4: Use Extended Data Collection to Reinforce Calculations & Diminish Variability.

Much in the way that an increase in the number of trucks using the crossing should reduce variability and enhance confidence in the data, so too should the capture of data over a long period of time. Doing so will likely lend stability and reduce variability in historical travel time data, thereby reducing the effects of outliers. Additionally, external factors such as the level of economic activity will also affect the figures. Collecting data over an extended period offers the opportunity to examine the effects.

Recommendation #5: Examine and Test Near Real Time Data Use.

Although GPS-based traffic monitoring solutions are being used in other locations on a real-time basis (e.g., I-95 Corridor Coalition), the usefulness and usability of similar data in the border environment is still largely unknown. The approach used for this project offers an opportunity to examine whether enough value can be extracted to affect agency and carrier decisions during the course of everyday operations. This could be accomplished through a continuation of data acquisition and analysis activities, with the participation of and interaction with users who have access to a near real time data feed.

Recommendation #6: Pursue Transfer of Data Acquisition Oversight and Funding to State/Local Agencies, Customs Agencies, or Others.

It is understood that FHWA does not have an ongoing operations function at international border crossings, and that its primary role is the conduct of research and support for deployment of solutions that enhance the nation's transportation system. Hence, the funding and use of systems that measure border travel time are the purview of border management agencies, agencies with responsibility over local transportation infrastructure, and the border user community. The results of this project establish the viability of GPS technology for travel time measurement. They also present an opportunity to explore how a transition to a production solution might take place through the leveraging of carrier relationships established during the test, the expansion of data coverage to a comprehensive geographic scale, and the examination of opportunities for secondary data uses.

1 Project Background

Cross border movement of people and goods is a vital part of the North American economy. Accurate real-time data on travel times along the US-Mexico border can help generate a range of tangible benefits covering improved operations and security, lower costs for travelers (both personal and commercial, reduced environmental impacts, reduced negative impacts on adjacent communities, and, of course, increased economic activity for both countries.

Congestion creates delays that result in wasted fuel and exacerbate noise and air pollution for communities adjacent to the crossings. Accurate travel time data can help travelers make more informed decisions regarding which crossing to use and when to use it, thus saving time and fuel and making it less likely they will encounter congestion delays. Just as travelers save time and fuel, these savings will be passed on to local communities.

Accurate travel time data can also help operators, including transportation agencies, customs and immigration agencies, and private crossing operators, make more informed operating decisions such as the assignment of staff (e.g., from secondary inspection to primary inspection), or the opening of additional toll or inspection lanes to accommodate surges in demand. Such data also can support improved planning both along the border and for the transport network that provides access through Mexico and the US. Planning decisions would include facility design or layout modification that would ease the congestion at a particular crossing.

Further, accurate and timely delay information is a useful public policy tool. Not only can it more convincingly make the case for needed improvements in areas such as infrastructure upgrades and increased staffing, it can be a powerful planning aid for transportation and compliance agencies, as well as businesses. These data can also be a very helpful means to educate border crossing users of the benefits of engaging in better planning, and those associated with expedited crossing programs.

The current quality of data on border crossing delays is mixed. Border agencies often rely on visual observations of the vehicle queue or a manual data collection process (driver surveys or time-stamped cards) to provide an estimate of total wait time. Unfortunately, these approaches are costly, inconsistent over time and from location to location, and do not take advantage of existing technology to monitor traffic movement.

In October 2007 The Federal Highway Administration tasked the team of SAIC and Delcan to conduct a three-part assignment to assess technology for the measurement of travel times for trucks through the Otay Mesa international border crossing into the US. The primary goal was to evaluate the ability of one of two technologies to accurately record travel times through the border zone.

The ultimate objective for the project was to put in place an automated system that had the potential to provide data of sufficient value and reliability to become a long-term solution for border stakeholders, and replace the labor-intensive and imprecise manual methods currently in use. By facilitating the deployment of a system at Otay Mesa, FHWA hopes to provide leadership in the effort to produce information that can support improvements in operations at border crossings, and to demonstrate the viability of such systems for implementation at other locations.

The three parts of the study were to:

- Examine two candidate technologies for installation and testing at the Otay Mesa crossing, and recommend one for testing;

- Conduct an assessment of the suitability of the selected technology to provide accurate border crossing travel time data; and

- Gather one year's worth of travel time data at the crossing to establish a historic database for future use.

The Otay Mesa crossing is a truck-only crossing between the US and Mexico south of San Diego, California. At the onset of the project the port served an average of 2,500 vehicles per day inbound into the US. Over the last several decades, the crossing has seen an increase in the amount of traffic, and as a result, the amount of time necessary to cross into the US has been perceived to have increased for the average trucker. Rather than assess the accuracy of that perception, this project was focused on evaluating the ability of a technology solution to accurately measure the time it takes a truck to pass through the border.

1.1 Study Part I – Comparative Technology Examination

The first part of the project involved the comparative examination of two candidate technologies. The FHWA directed the study team to catalog the relative capabilities and potential shortcomings of each, and recommend one for implementation and use during the test. These technologies were:

Automatic License Plate Recognition (ALPR). ALPR applications seek to identify, catalog, and track individual truck movements using optical image capture and re-identification. ALPR systems record a combination of registered license plates and USDOT numbers, use optical character recognition (OCR) to resolve images into strings of characters, store these character strings in a central database, and compare them to subsequently captured and resolved character strings in order to re-identify individual vehicles. Travel time can then be calculated directly for individual vehicles using the time elapsed between sequential successful "reads." ALPR systems typically consist of cameras mounted either along the roadside or on elevated structures (a pole, for example), tied to a central processor through various communications media. Each camera requires a power source and data transmission capability, and depending upon the configuration, OCR processing may take place at the camera location or at the central processing system.

Global Positioning System (GPS). GPS applications, particularly in the form of commercial feet management systems, are becoming more commonplace. Motor carriers typically rely upon such systems to locate individual trucks in order to more effectively manage dispatch operations, and to provide "visibility" regarding shipment status to customers. GPS systems rely upon a long-used navigational technique called triangulation to locate assets. GPS-based systems come in different forms. Among the most common types used for commercial trucking are transceivers that transmit data through the cell phone network or via satellite to report location and time information. The location and time stamp information from successive system reports can then be used to travel time.

These technologies and the methodology used to compare their characteristics for use at Otay Mesa are discussed in detail in Section 2.1. During this process, the study team consulted with local and national stakeholders to examine key functional characteristics and the operating environment at the crossing. These activities are described in detail in Section 2.2.

1.2   Study Part II – Technology Viability Assessment

Once the technology was selected, the study team oversaw its deployment at the Otay Mesa crossing and captured travel time data at volumes significant enough to provide the opportunity to examine the output of the selected system to determine its viability as a travel time data source.

This critically important portion of the project involved several significant activities, which are detailed in Sections 2.3 and 2.4 of this report.

1.3   Study Part III – Compilation of Historical Travel Time Data

Once the technology was selected and deployed, the study team captured data to catalogue average travel times for a period of one year. This was done to capture historical data that could be used for a variety of purposes, including as a basis of comparison for assessing future delays. Detailed information regarding how the study team accomplished this activity is provided in Section 2.5.

The remainder of this report details the approach, findings, conclusions, and recommendations formulated during the project.

2 Project Approach

As discussed in the previous section, the project consisted of three major parts: data comparative technology examination, a technology viability assessment, and the compilation of historical travel time data. These three parts were accomplished through the execution of five activities, as described below.

2.1 Technology Assessment

The primary focus of the technology assessment was to determine which of the two technology options, ALPR or GPS, was best suited for testing at the Otay Mesa crossing. The intent of the assessment was not to imply that one technology was superior to the other with respect to the capture of border crossing travel time. Rather, it was intended to determine whether either technology would function adequately under the conditions as they exist at the Otay crossing, and whether there was a significant opportunity to learn about the capabilities of a particular technology.

This activity was accomplished by comparing functional characteristics, and assessing the degree to which these characteristics might affect the ability of the technology to function in the Otay Mesa crossing environment. The assessment also included a review of potential business models for gaining access to the travel time data, and the implications of choosing between a capital investment approach and a data purchase agreement approach.

In completing this task, the study team examined documentation regarding the two technologies, and conferred with representatives from providers of both types of technologies. Additionally, the study team solicited cost estimates from both providers for the instrumentation and support services associated with establishing a travel time data feed at the crossing.

The study team then completed a comprehensive examination of options, and provided to FHWA a recommendation regarding which technology to deploy. The results of these activities are provided in Section 3 of this report.

2.2 Stakeholder Coordination

At the onset of the project, FHWA and the study team recognized the importance of gaining appropriate national, international and local insight into the operations at the Otay crossing, from the perspective of the agencies and users. The team conducted two separate stakeholder sessions in the San Diego / Otay Mesa area—one at the start of the project, and one after the

system had been selected and data was being gathered. The Study Team designed these sessions to:

- Communicate the objectives of the study and the objectives of the US DOT Federal Highway Administration (FHWA) in collecting a baseline, historic, cross-border travel time data set;

- Gather information related to the cross-border journey to better understand how and when these data should be collected;

- Summarize the needs of the stakeholders and potential uses of these data;

- Provide updates about the study as it progressed; and

- Assess the importance of providing real-time data to various stakeholders in the future.

Stakeholders from the following groups were invited to attend the sessions:

- Cross-border motor carriers, freight forwarders, and logistics companies;

- State and local transportation agencies from the San Diego and Tijuana, Mexico (MX) region, including Caltrans, the San Diego Association of Governments (SANDAG), the state of Baja California, and the Instituto Municipal de Investigación y Planeación de Ensenada (IMIP);

- US and MX customs staff from the Otay Mesa port of entry - US Customs and Border Protection (CBP) and MX Aduana;

- US and MX federal transportation agencies - FHWA and MX Secretaría de Comunicaciones y Transportes (SCT).

The input received from stakeholders is detailed in Section 3 of this report.

2.3   Technology Deployment

The two different technologies required very different deployment paths and present different infrastructure approaches. By nature of its design, ALPR requires the installation of devices at fixed locations on both sides of the border. It then relies upon this fixed infrastructure to detect and decipher visual images of license plates, which are required for all vehicles operating in the

US. Hence, ALPR requires nothing be done on the part of the border user (other than maintain a legible license plate).

In contrast, GPS requires the installation of GPS devices in vehicles, which places some burden on the vehicle owner to support the travel time measurement infrastructure. The remainder of this infrastructure (typically) consists of the satellite owner (in this case the US Department of Defense), and the vendor that receives, processes, and forwards data from the devices.

Based upon the analysis of technology options, the FHWA concurred with the recommendation to deploy GPS for this project. This required the selection of the GPS data provider, Calmar Telematics, and the execution of a subcontract to procure their services. Once the contracting was completed, the data provider then proceeded to negotiate data access agreements with candidate carriers.

2.4 Technology Testing

The third, and primary, activity was the capture of data over an extended period in order to determine whether it was of sufficient quantity and quality to determine border crossing travel time. This task consisted of ongoing statistical analysis of weekly data files provided by Calmar. As additional data was received, the study team processed and analyzed it, and stored both raw and processed data in a database for future use.

The study team then examined the data within the context of known border operating conditions and conferred with the motor carriers that participated in the project. Sections 3 and 4 of this report contain the results of the testing and the conclusions drawn from the travel time data.

2.5 Data Archiving

The final component of the project was the archiving for future use of one year's worth of GPS data and associated travel time calculations. The study team has created and will transfer to FHWA files containing both the GPS data as provided by the data provider, and the processed data as used to calculate border crossing travel time.[3]

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[3] Interested parties can obtain the data referenced in this report by sending an e-mail to: FreightFeedback@dot.gov.

3   Results and Findings

3.1   Crossing Characteristics

The Otay Mesa International Border Crossing is a truck-only crossing connecting the San Diego, California metro area with the city of Tijuana in the Baja California Peninsula. The Otay port of entry (POE), coupled with the adjacent San Ysidro crossing that serves automobile traffic, represents a key international trade transportation link. With more than 1.4 million truck crossings per year, the Otay Mesa Port of Entry is the largest commercial crossing in the California/Mexico border and handles the second highest volume of trucks and third dollar value of trade among all U.S./Mexico land border crossings.[4] The satellite image in Figure 1 illustrates the location of the crossing.

Figure 1. Satellite Image of Otay Mesa Border Crossing Location
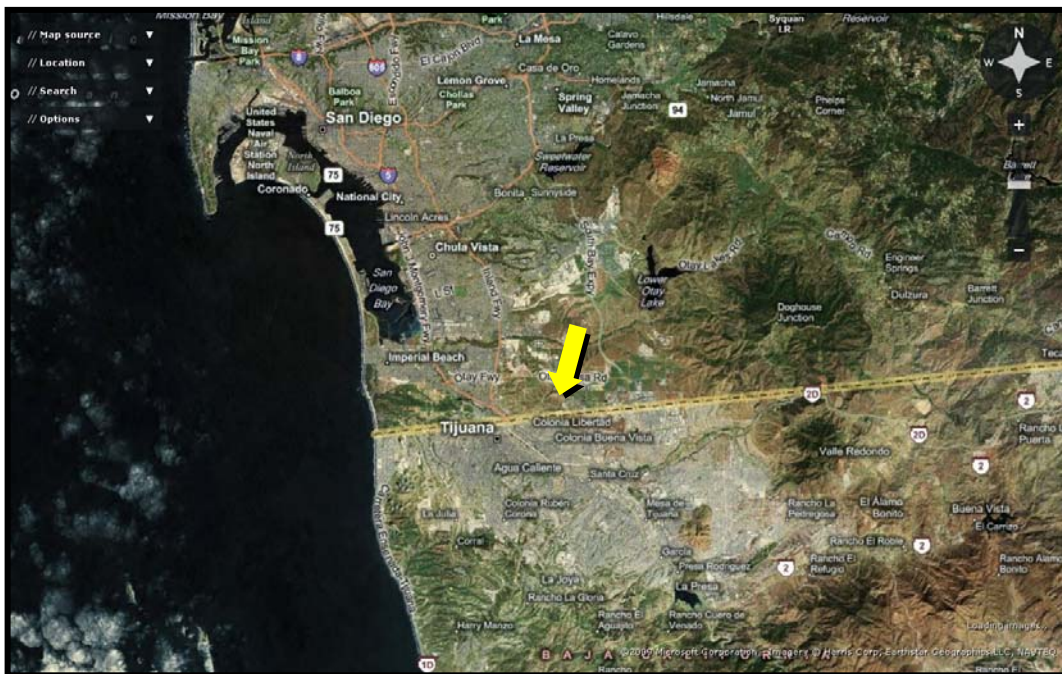
At the onset of the project, US Customs and Border Protection (CBP) staff at the Otay Mesa commercial crossing reported processing approximately 2,500 trucks per day during peak season, which runs from October through December. Figure 2 shows the actual volume of

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[4] Otay Mesa Chamber of Commerce, http://www.otaymesa.org/ab_otay/port_of_entry.html.

trucks that crossed through Otay Mesa into the US during the period between January 2009 and February 2010.[5] As the figure indicates, the 2009 peak occurred in October, during which a total of nearly 65,000 trucks crossed from Mexico.

Figure 2. Otay Mesa Truck Crossings – January 2009 – February 2010
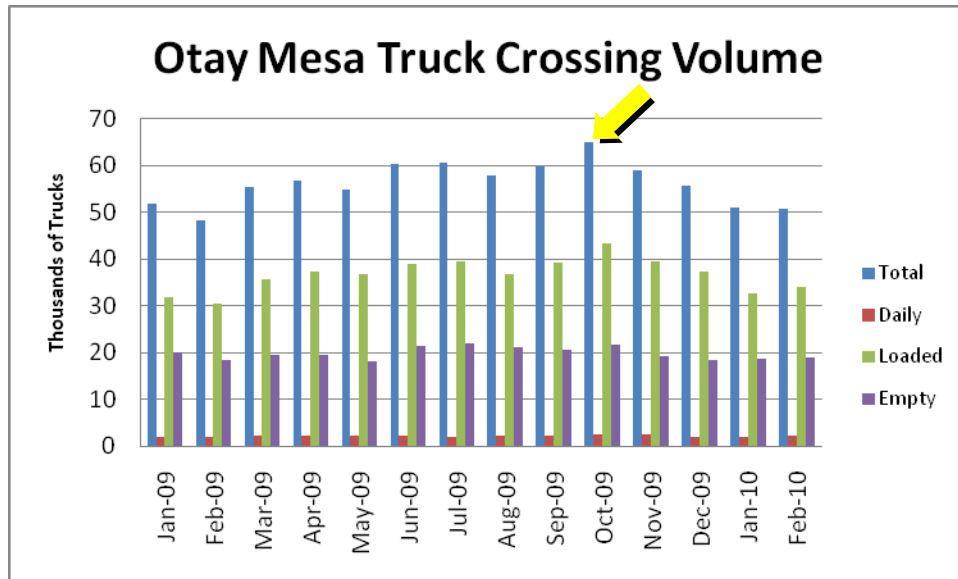
According to motor carriers, during the peak period each individual truck makes between 1.4 and 2 cross-border "turns" daily. The current layout of the Northbound crossing (from MX to the US) provides 1 FAST (Free and Secure Trade)[6] lane, 2 laden lanes for general cargo, and 1 lane for empty trucks. This configuration starts at the "sorting gate" on the Mexican side of the crossing (see Figure 2), which is approximately 1.55 miles from the MX (Mexican) export facility and approximately 2 miles from the entry to the US Customs compound. FAST lanes process approximately 15 percent of total Northbound traffic (approximately 375 trucks per day during peak season). About one-third of Northbound movements are empty movements that cannot use FAST.

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[5] Based upon data obtained from CBP at the Otay Mesa Port of Entry.

[6] The FAST (Free and Secure Trade) program was established by the US CBP to facilitate expedited screening at US border POEs. It requires an entire supply chain to apply for and obtain certification under the Customs-Trade Partnership Against Terrorism (C-TPAT), a program that seeks to ensure that every portion of a supply chain complies with certain minimum security assurance criteria.

Otay Mesa is primarily a maquila crossing, where merchandise parts are shipped Southbound into the Tijuana area to be assembled and shipped Northbound into the US for delivery to distribution centers and retail stores. A substantial portion of peak season movements consist of electronics being shipped to the US for the Christmas holiday season. Motor carriers and US and MX customs staff note that traffic volume during this period is such that trucks crossing the international border often wait up to three hours. The second quarter (April to June) is the least busy from a truck volumes perspective, according to CBP staff, who indicate that wait times during this period are often 1 hour or less. Quarters 1 and 3 are moderately busy.

Border stakeholders report that Friday is the often busiest day at the crossing (more so during peak season), followed by Thursday, Monday/Tuesday, and Wed (in order of demand). Weekend hours and truck movements are more limited and represent some hazardous materials and Customs-Trade Partnership Against Terrorism (C-TPAT) movements only.

Motor carriers attending stakeholder sessions identified Northbound queues and respective border crossing travel times to characterize the Northbound movement. Figures 3 and 4 show the Northbound travel pattern. Figure 3 shows the approach from Mexico; Figure 4 includes customs facilities on both sides of the border as well as the California Highway Patrol (CHP) commercial vehicle safety inspection facility.

Figure 3. Google Earth Map of Northbound Access to Otay Crossing - MX

Mexican and US inspection facilities are shown in Figure 4 and are labeled as follows:

> A – Mexican Export Lot

> B – US Federal Inspection Facilities

> C – CHP: State Inspection Facility

The road connecting the MX sorting gate to MX customs serves is the location of the physical border.

Figure 4. Google Earth Map of Northbound Access to Otay Crossing (MX/US Customs Facilities and CHP Inspection Facility
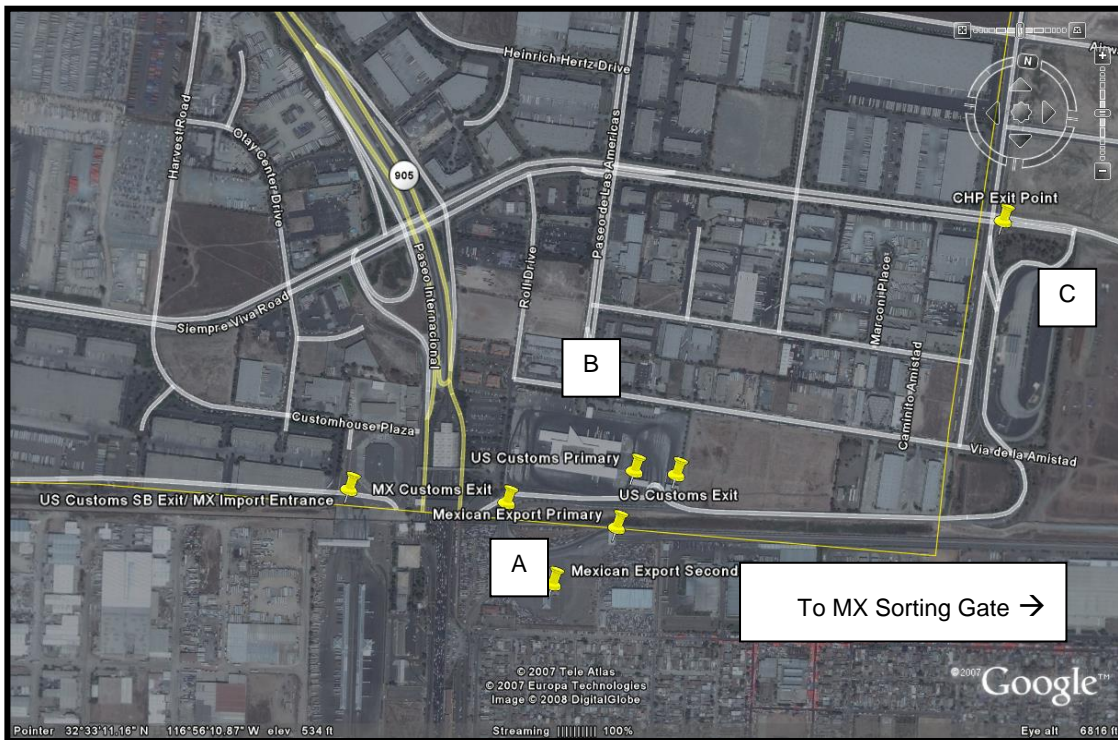
During the stakeholder sessions, trucking company representatives and state and local government officials expressed interest in obtaining border travel time information across several distances:

- From the beginning of the queue at Calle Doce and Bellas Artes, through MX and US customs, to the exit of the CHP inspection facility. Motor carriers noted that this

characterizes a complete cross-border trip. Additionally, from the intersection of Calle Doce and Bellas Artes, the travel time would likely extend beyond 3 hours.

- From the beginning of the queue to the MX sorting gate. In peak season, the cross-border queue often extends beyond Calle Doce and Bellas Artes. In off-peak, the MX sorting gate often marks the end of the queue.

- From the start of the queue to/through MX customs. A measure from the start of the queue to MX customs and then a measure of the time to traverse MX customs was of interest to both Aduana and US Customs and Border Protection (CBP) staff.

- At the exit of MX customs to/through US customs primary, allowing for a measure of wait times to enter customs as well as a measure of the time to traverse primary inspection. CBP officials noted that waits to traverse secondary inspection should not be included.

- From the exit of US customs primary to the exit of the CHP facility, with the CHP facility marking the end of the cross-border journey.

Table 1 summarizes the distances between these points of interest.

Table 1. Distances between points of interest identified by stakeholders

	Measurement Segment	*Distance - Miles*
Image 1	Bellas Artes at Calle Doce to MX Sorting Gate	**0.5**
Image 2	MX Sorting Gate to MX Customs Primary	**1.55**
	MX Customs Primary through MX Customs Exit	**0.2**
	MX Customs Exit to US Customs Primary	**0.3**
	US Customs Exit, through CHP inspection, to CHP Exit	**0.65**
	Total Distance (Estimated) Northbound	**3.20**

Generally speaking, the roadway infrastructure between the Bellas Artes/Calle Doce intersection and the exit from the CHP safety facility has limited access, and at certain locations, has restrictive geometry. At the northern end of Calle Doce, the roadway turns 90 degrees to the left, and truck drivers are presented almost immediately with the sorting gate. Immediately downstream of the sorting gate the empty and FAST lanes are separated from the standard lanes by barriers. Trucks must then traverse the entire length of the roadway between the

sorting gate and the MX export compound (a distance of approximately 1.55 miles) in this configuration.

Upon arrival at and processing through the MX export facility, FAST trucks, which are in the leftmost lane, are routed south around the MX export secondary facility single-file, following a path just inside the perimeter of the compound. Empty trucks and non-FAST loaded trucks follow a route directly eastward to the exit at the northwest corner of the compound. The three truck types come together at this point, but remain in separate lanes—FAST trucks and bobtails (trucks without trailers) stay in a single lane to the left, loaded non-FAST trucks remain in the two middle lanes, and empty trucks stay in the lane to the right. An overhead view of the MX export compound is provided in Figure 5.

Figure 5. Satellite Image of Trucks Passing Through the Mexican Customs Export Compound
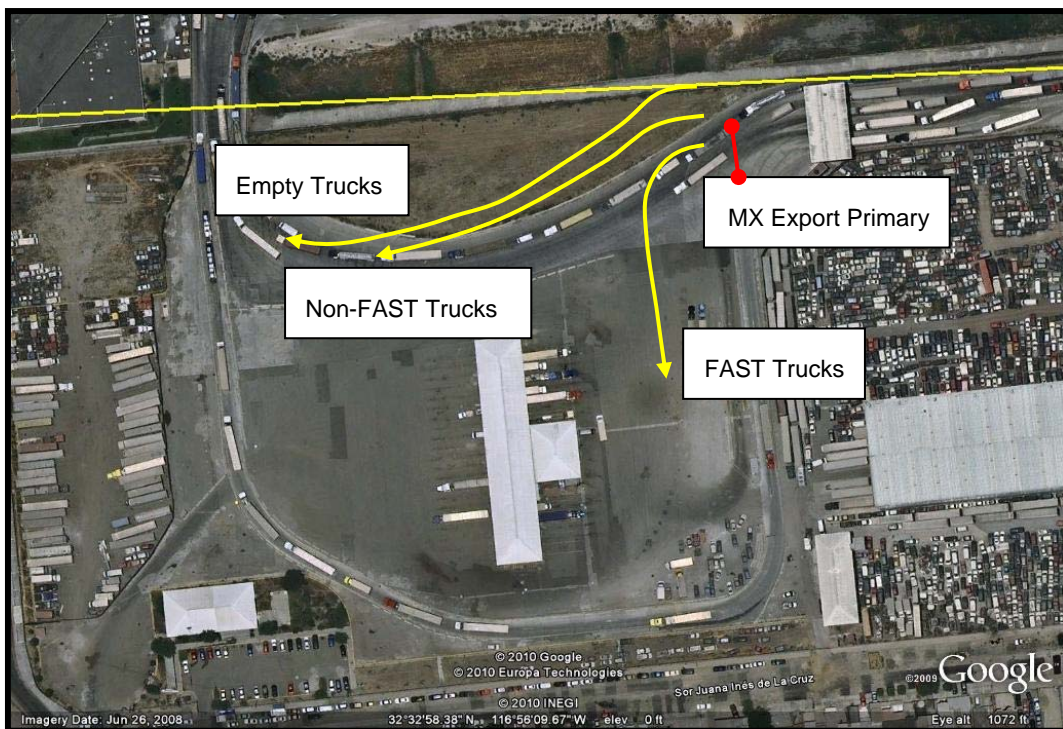
Once they pass across the border, trucks queue for entry processing into the US. Figure 6 contains an image of the US CBP entry processing facility. As the image shows, empty trucks follow a path parallel to the border from west to east, and do not enter the CBP compound. These vehicles are processed at a separate gate, at which CBP has an x-ray portal and a CBP officer stationed.

All other trucks must pass through the CBP primary screening facility and enter the US compound. FAST trucks are directed to the leftmost lanes. The two left lanes are dedicated to FAST traffic, and additional lanes can be used for FAST traffic as needed. Loaded trucks and bobtails must use one of the seven lanes to the right.

Figure 6. Satellite Image of Trucks Passing Through the US Customs Entry Compound
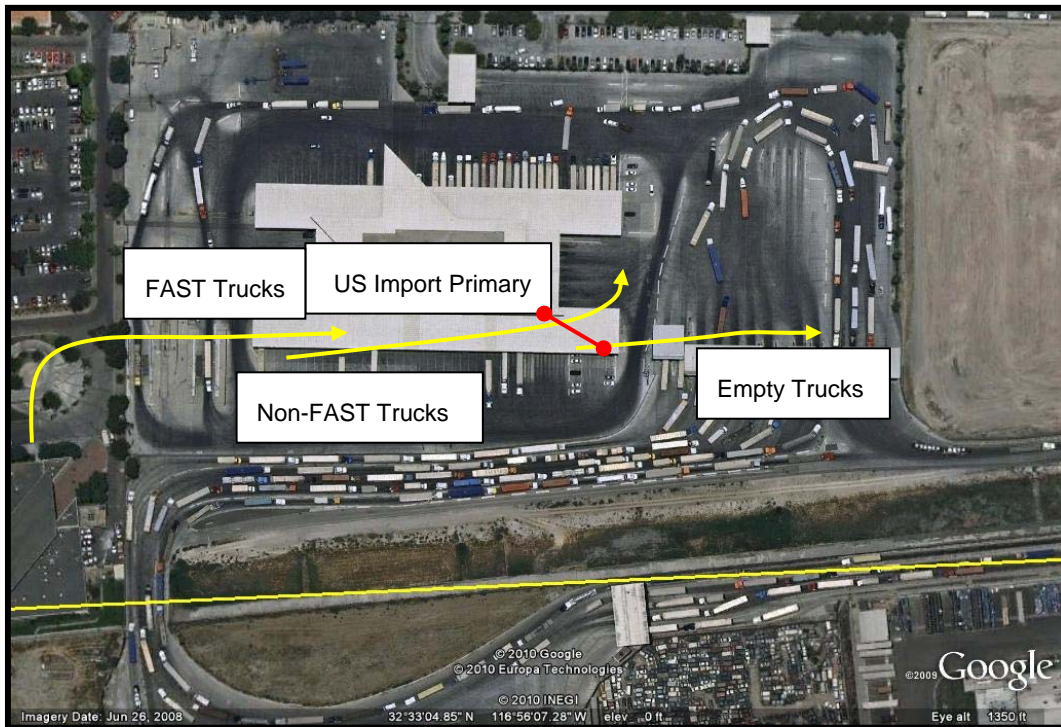
Once inside the US compound, trucks may be directed to do one of four different things:

- Proceed to the compound exit at the southeast corner of the compound by executing a u-turn near the northeast corner of the compound;

- Proceed to the secondary inspection facility at the center of the compound for further examination of cargo, paperwork, or driver credentials;

- Proceed in a loop around the secondary inspection facility to one of two x-ray screening portals on the west side of the compound; or

- Proceed straight ahead and form lines four abreast (called blocking) and await canine screening.

Which activity a given vehicle may be directed to complete is a function of a combination of screening practices employed by US CBP. Some of these actions may be directed as a result of

specific screening outcomes, while others are random in nature. At the conclusion of screening activities, all vehicles must merge with other traffic to exit at the southeast corner of the compound, and then merge with empty vehicles onto a single-lane access road leading to the CHP screening facility.

The final leg in the US inbound trip is the conclusion of commercial vehicle safety screening at the CHP facility. The facility, shown in a satellite image in Figure 7, has low speed and stationary vehicle weighing capabilities, and a full commercial vehicle inspection facility.

Figure 7. Satellite Image of the CHP Screening Facility
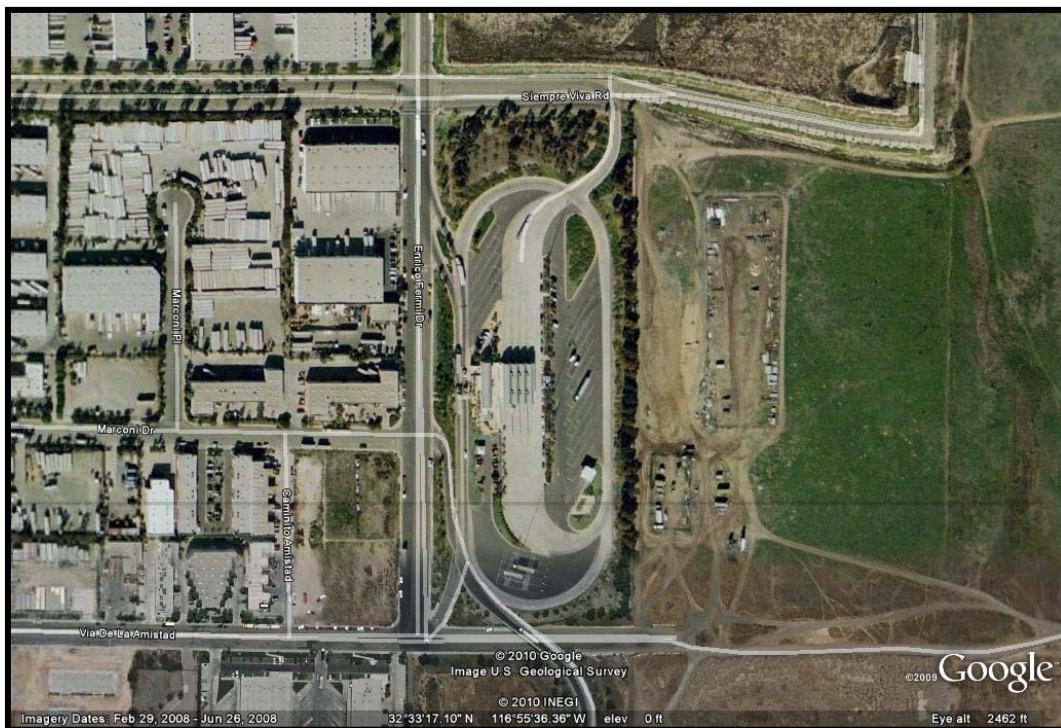
Trucks enter the southern end of the facility, and proceed along its western side through weigh scales. Vehicles and drivers that pass weight and credentials screening can exit the compound at its northwest corner onto northbound Enrico Fermi Drive. Vehicles that must undergo inspections are directed around the inspection facility in the center of the compound, and enter the covered inspection bays from the south. Once inspections are completed, vehicles can exit at the northeast corner of the compound onto Siempre Viva Road, either eastbound or westbound. Most vehicles head west from that exit.

Once the US bound crossing process is complete, trucks either complete their trip at one of the many warehouse facilities in the vicinity of the Otay crossing, or they continue west on Siempre Viva Road to Highway 905, which intersects with Interstate 805, Interstate 5, and Highway 125.

During the period of the test and data collection, the traffic volume at the Otay Mesa crossing dropped significantly from its daily average of 2,500 trucks. According to statistics provided by the CBP, the average daily volume ranged from just over 1,600 to approximately 2,000 trucks per day, with the average staying between 1,800 and 2,000 per day between June and November 2009. This reflects a drop of approximately 20 percent. The implication is that a smaller total number of trips by participating trucks would be required to meet the desired three to five percent of total truck trips.

3.2   Stakeholder Session Results

The stakeholder sessions offered valuable insights into the challenges faced by users and administrators at the border. They allowed for a much more comprehensive understanding of not only the conditions as they exist, but also regarding what might be done to improve them. While each stakeholder session was tailored to the specific groups represented, the general format for each session was as follows:

1. Project Overview: the Study Team delivered basic project information summarizing the Otay Mesa test.

2. Stakeholders were shown a live a Google Earth map to facilitate a discussion among participants to gain a "day in the life" overview of border workings from their perspective. The discussion was tailored to the stakeholder session attendees, and included a facilitated discussion of stakeholder observations regarding travel time through the Otay Mesa crossing, including:

- How often are delays experienced?

- Where do the delays occur (start and end)?

- Are there delays in both directions?

- Are there any patterns worth noting (e.g., changes based on days of week, other periods)?

3. Stakeholders then took part in a facilitated discussion of border travel time information needs of the stakeholder group. This included summarizing the needs identified at Sessions 1 and 2 to state, local, and federal transportation agencies and customs representatives.

4. The Study Team led a summary of the proposed technologies to be tested: GPS and ALPR.

5. Stakeholders were then asked to look forward and offer thoughts on what the future holds for the crossing, including increases in trade traffic and how these may be related to information needs and/or any facility and technology programs planned or underway that might affect this project and potential future deployment.

6. The sessions closed with a request for each stakeholder group to identify a representative to be part of a Technical Working Group. This group was to be utilized for any follow-up questions and/or to review proposed technologies or deployment locations.

In addition to the information presented in earlier sessions regarding the operations at the crossing, stakeholders provided some useful ideas regarding what would be a potential set of functional requirements for any border travel time measurement solution. These are provided in Table 2.

Table 2. User Needs/Functional Requirements Summary

Stakeholder Group	User Needs (Northbound)	Characteristics	Functional Requirements
FHWA	Measure a total cross border travel time from the beginning to the end of the queue; need historic data for planning applications	Without isolating any one agency, measure a cross-border travel time from beginning to end of queue	End of queue is likely the longest end point in peak season; measuring "too close" to the border will cause bias; travel times can be determined at two instrumented points, but load type may require additional analysis and/or another instrumented location
Motor Carriers	Real-time cross-border total travel time is of great interest for providing information to customers; GPS technology has implications for C-TPAT	Queues often back up to Calle 12 and Bellas Artes (peak season); queues usually reach the MX sorting gate; the exit of the CHP facility marks the end of the cross-border trip	Measure from the start of the queue at Calle 12 and Bellas Artes to a common point outside of CHP inspection, at the intersection of Enrico Fermi Drive and Siempre Viva Road; alternatively, measure at both CHP exit gates)

Stakeholder Group	User Needs (Northbound)	Characteristics	Functional Requirements
State and Local Transportation Agencies	For transportation systems operations, it is unlikely that historic or real-time data will affect procedures; however, any data of interest to customers will be incorporated into regional ITS	Real-time data will be utilized in the regional 511 system; data could be integrated into PeMS[1]	Data requirements for PeMS integration will be explored; any data would be used and no one technology is preferred over another
US/MX Customs	Customs and Aduana are interested in intermediary measures; CBP notes that a measure of exiting MX gate through US primary is needed; must normalize for secondary inspections	Aduana is interested in measures from the beginning of the queue to/through MX customs; US CBP is interested in the total travel time and time to/through MX customs, but primarily in the time from exiting MX customs to/through US customs primary inspection	Requires multiple measurement points; FAST, laden, and empty moves should be differentiated End of queue (1); MX sorting gate (2) to differentiate load type; entry to MX export lot (3); exit of MX export lot (4); entry to US primary (5); exit of US primary (6); common point outside of CHP facility (7 or 8)

1. PeMS – California's Freeway Performance Measurement System: The PeMS project is conducted and maintained by the University of California at Berkeley with cooperation from the California Department of Transportation (Caltrans), California Partners fro Advanced Transit and Highways, and Berkeley Transportation Systems. This statewide database collects historical and real-time freeway data from freeways in the State of California in order to compute freeway performance measures.

3.3   Technology Selection

ALPR

Automatic license plate recognition is a specialized application of digital cameras to detect the presence of individual vehicles. License plate recognition is used for traffic management, weigh-in-motion commercial vehicle inspections, security, parking, and border control, as well as for toll collection and violation tracking. London's congestion pricing program, for example, uses license plate recognition to charge a fee to vehicles that enter central London during peak hours. Toronto's Highway 407 uses ALPR applications to toll system users whose vehicles are not equipped with radio frequency identification (RFID) toll transponders. The tolling system

uses an ALPR system to capture vehicle license plate numbers. From there, optical character recognition (OCR) software is used to identify the plate numbers for billing the toll at a higher rate.[7]

ALPR-based travel time measurement systems work by electronically recording the front or rear license plates of vehicles as they pass mounted ALPR cameras or "out-stations." Once a vehicle passes an out-station, the system resolves the image into a string of alphanumeric characters and transmits the resulting string to an "in-station." This data transfer may happen via wired connection or wirelessly. After a vehicle passes two out-stations, the system then calculates the travel time between them.

ALPR technology is widely deployed in both the US and Mexico. ALPR vendors interviewed for this study also confirm the use of ALPR in Mexico for security applications. Intelligent Imaging Systems,[8] for example, works closely with the City of Tijuana and states in the Mexican interior; Devices provided by imaging system supplier PIPS Technology are also widely deployed in Mexico. Both technologies can also detect license plates from various Mexican states.

ALPR applications for travel time measurement are not as widely deployed as the security and enforcement applications; however, ALPR can provide an accurate measurement of travel times between fixed locations provided that the cameras have an appropriate sight angle to read the license plates and that the license plates themselves are not too damaged or dirty for the camera to collect a "good read." ALPR can work both during the day and at night and is not dependent upon carrier participation. ALPR can theoretically collect data from the total vehicle population, up to the successful read rate. However, because an unimpeded visual line of sight to each plate is required to capture a complete image, sufficient space between commercial vehicles is needed. This may be a problem at congested border locations where nose-to-tail operations are common.[9] Further, the security of ALPR infrastructure is of concern since roadway geometry and other factors may dictate that it must be mounted in areas outside of controlled-access facilities.

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[7] FHWA Public Roads. May 2005. http://www.tfhrc.gov/pubrds/05may/10.htm.

[8] http://www.intelligentimagingsystems.com/

[9] It is important to note that USDOT numbers are not unique to individual trucks, but are typically used as a secondary source of verification in the absence of an unobscured license plate number.

The most likely business model for deploying ALPR in Otay Mesa is to purchase ALPR equipment from an ALPR vendor and install two out-stations and one in-station to collect a total cross-border travel time. These installations would be located at the beginning and end of queue as detailed in the Task 1 Stakeholder Summary and would be permanent installations. Additional temporary installations could be utilized to collect a sample of information at various intermediate points. For example, such an installation would be necessary to capture data points at locations such as the exit of MX customs, the entrance to the US primary booths, or one for the FAST lanes entering US Customs. This temporary installation would then be used to collect representative sample of "average day" data that could be applied to extrapolate travel times by type of movement or between various points. This could be accomplished within the FHWA's budget for this study; however, funding for equipment maintenance and replacement past the equipment warranty, or to address vandalism would need to be identified and programmed for each installation.

GPS

GPS data are becoming more commonplace as a solution to collecting travel time information where fixed devices (including sensors and ALPR) cannot provide the same levels of area-wide coverage. Section 1201 of the Safe Accountable Flexible Transportation Equity Act – A Legacy for Users (SAFETEA-LU) has encouraged regional GPS deployments to collect traffic data. Section 1201 established the Real-Time System Management Information Program and encourages states to "monitor, in real-time, the traffic and travel conditions of the major highways" and to share data with local governments and travelers alike.[10]

Because of deployment, maintenance, and operations expenses associated with fixed travel time data collection technologies (such as loop detectors, fixed sensors, and even ALPR), GPS and other types of probe data (including cellular probe data) provide a cost-effective solution and can cover an entire metropolitan region.

Large-scale probe-based travel time data are currently being collected in Baltimore, MD; Missouri – statewide; San Francisco, CA; New York State; and at the northern border (among other locations nationwide). In Baltimore and Missouri, ITIS Holdings Plc. in partnership with Delcan is collecting probe data from the cellular phone network and from GPS-equipped commercial vehicles. In San Francisco, researchers at the University of California Berkeley

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[10] SAFETEA-LU Section 1201, as summarized in Federal Register Vol. 72, No. 198, Monday, October 15, 2007.

have partnered with Nokia to test using GPS-enabled mobile phones to provide traffic information. Perhaps the largest GPS-based deployment to date is on the I-95 Corridor, from New Jersey to North Carolina, where INRIX was recently awarded a multi-year, multi-million dollar contract to provide travel time and speed data from more than 750,000 GPS-equipped vehicles.[11]

GPS-equipped vehicles are often used to calculate "ground truth" travel time estimates to evaluate the accuracy of travel times collected via fixed sensors. This technique is used to validate regional congestion information by the Baltimore Metropolitan Council, for example.[12]

GPS units can provide a continuous source of location information with an infinite number of measurement points; however, reporting cycles of equipment and vendors often dictate when a measurement is taken. Many carriers, for example, choose to have in-vehicle units send location information every 15 to 30 minutes as a means to manage the overall communications costs associated with such systems. Vendors transmitting location information on the cellular data network (Nextel, for example) may collect location information every 2-5 minutes.[13] While older GPS units may not provide enough accuracy to detail lane-by-lane travel times, studies by the Institute of Transportation Engineers (ITE) and the Texas Transportation Institute (TTI) among others validate the accuracy of GPS-based traffic data.[14]

The FHWA is also engaged in GPS-based travel time measurement on a national scale. In work conducted under a project entitled "Freight Performance Measurement: Travel Time in Freight-Significant Corridors," the FHWA has been examining the use of GPS systems to calculate the average speed for trucks on specific road segments.[15] The speeds of multiple trucks are then aggregated to determine average speed on a road segment. These measured speeds are then

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[11] "Inrix to Deliver Real-Time Traffic Information for I-95 Corridor." GPS Daily.
http://www.gpsdaily.com/reports/INRIX_To_Deliver_Real_Time_Traffic_Information_For_I_95_Corridor_999.html

[12] Delcan for the Baltimore Multimodal Traveler Information System Business Model.

[13] Delcan for the Baltimore Multimodal Traveler Information System Business Model.

[14] Addressing Issues with GPS Data Accuracy and Position Update Rate for Field Traffic Studies, Institute of Transportation Engineers, ITE Journal. Feb 2003; Travel Time Studies with Global Positioning and Geographic Information Systems: An Integrated Methodology, Texas Transportation Institute. 1998.

[15] http://ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/fpmtraveltime/index.htm#travel

used to calculate travel time reliability along various routes. This same GPS data is being used to assess border crossing time at 15 US/Canada ports of entry.

At the Otay Mesa border, a number of different deployment options were considered for cross-border travel time measurement using GPS data. A key study objective was to utilize a deployment option and business model that could be sustained over time and have a high likelihood of adoption after the test was completed. These options are shown in more detail in Table 3, which discusses the characteristics of and the risks associated with each of four different deployment models.

Table 3. GPS Data Collection – Deployment Model vs. Risk

Deployment Model	Time to Implement	Historic Data Collection	Real-Time Data Collection	Contractual Agreements	Hardware	Software	Ownership	Future Operations	Cost	Risk
Collect GPS data by deploying units in trucks	6 months for deployment followed by 1 year for data collection	Baseline data will be analyzed over time	Real-time data demonstration may require additional funding	Will require contracts with carriers; if carriers are paid for participation; contract oversight will be time-consuming and costly	Will require hard-mount GPS units in trucks; hand-held units may not provide accurate data, but could be considered	Will require basic algorithms to analyze data	FHWA will own baseline data and equipment after test conclusion	A continuation of this model is unlikely to be sustainable over time due to time spent facilitating arrangement with carriers and operations/ maintenance of equipment	Short-term costs are moderate, but carrier issues and project budget translate to high risk; additionally, long-term model not sustainable	High
Purchase GPS data from vendors (no carrier involvement)	6-12 months for agreements followed by 1 year for data collection	Baseline data will be analyzed over time	Real-time data demonstration may require additional funding	Contracts with multiple vendors will be difficult to arrange; vendors may be unwilling to participate	No additional hardware; will use systems already deployed	Will require basic algorithms to analyze data	Baseline dataset will be public, but additional data use will require renegotiation with vendor	Likely to be sustainable over time if vendors are willing to participate; privacy concerns add risk	Short-term costs are moderate; risks are high due to privacy issues; better model involves carriers directly	High
Carrier request GPS data from vendor to be exported to Study Team	6 months for data stream followed by 1 year for data collection	Baseline data will be analyzed over time	Real-time data demonstration may require additional funding	Will require contracts with carriers; if carriers are paid for participation; contract oversight will be time-consuming and costly	No additional hardware; will use systems already deployed	Will require basic algorithms to analyze data	Baseline dataset will be public, but additional data use will require renegotiation with carriers and vendors	Likely to be sustainable over time; however, maintaining contracts with carriers will be time consuming	Data collection costs are likely initially low, but may increase over time	Med

Deployment Model	Time to Implement	Historic Data Collection	Real-Time Data Collection	Contractual Agreements	Hardware	Software	Ownership	Future Operations	Cost	Risk
Collect travel time information from third-party provider (e.g. Calmar, Inrix)	3-6 months for initial data stream, followed by 1 year of data collection	Baseline data will be analyzed over time	Real-time data demonstration may require additional funding	Will require agreement with third-party provider	No additional hardware; will use systems already deployed	No additional software for baseline data	Baseline dataset will be public, but additional data will require third-party provider	Sustainable- if third-party providers stay in business; cost may initially rise, then adjust to market conditions	Data collection costs are likely initially low for a "test;" provider may increase cost after test deployment	Low/ Med

The options for collecting GPS data from commercial vehicles crossing the international border at Otay Mesa are highlighted in Table 3 and summarized below. Because GPS equipment is largely a carrier-based asset, the business models must involve cross-border motor carriers in a way that is acceptable for their businesses. While the following deployment models are all potential methods of collecting GPS-based data, some make more sense than others in the case of the Otay Mesa deployment, where options with lower risk and greater likelihood of adoption are preferable.

Option 1: Deploy GPS units in trucks to collect baseline travel time data and validate technology. This would require purchasing GPS units and software to collect and aggregate these data as well as coordination with carriers for participation agreements. While this model is technically possible, its feasibility is doubtful. In addition to the expenses associated with device purchase and use, many larger carriers already have GPS-equipped vehicles and may be unwilling to participate. Additionally, the validity of the data may be in question, since the GPS equipment could be easily disconnected if it is deemed not valuable to business operations, if a driver feels it is intrusive, or if external parties become aware of its presence in vehicles. Government-owned GPS devices would also require FHWA-sponsored operations and maintenance, which would significantly complicate the contractual process. Table 3 summarizes this model as: *Low feasibility, high risk.*

Option 2: Purchase GPS data directly from vendors. Acquiring data directly from vendors provides a means to streamline GPS data collection. This method does not include purchasing any propriety information about the carriers themselves, only access to aggregated GPS data not segmented by carrier or carrier type. While some third-party providers have had success in purchasing data from GPS vendors, Delcan's experience in the US suggests that probe data that are provided from vendors or cellular phone carriers, while robust, are difficult to procure due to contracting and privacy issues. While carrier privacy would not be violated, carriers may perceive a privacy breach and question vendor rights in selling data. Table 3 summarizes this model as: *Low feasibility, high risk* for the purposes of this study; however, other initiatives may find success for this model with larger budgets and longer timeframes.

Option 3: Purchase GPS data directly from carriers and/or carriers request data feed from vendor. This business model will likely provide more success than working with the vendor. Three large carriers attending the Otay Mesa sessions have already agreed to provide GPS

data for the test. These carriers, by agreeing to participate, would also likely share business characteristics (fleet size, FAST/CTPAT certified, empty movements, etc), which could be used to help statistically differentiate the travel times of the laden, FAST, and empty movements traversing the border.   At the same time, contracting and data access issues will be more time consuming not only for the test, but for the FHWA over the long-term if the data stream is to be maintained. Finally, there is some concern that outside parties may not trust the data obtained directly from motor carriers, since carriers may be reticent to provide complete datasets directly to a government entity. Table 3 summarizes this model as: *Medium feasibility, but high risk* due to the high involvement of the FHWA in contracting with carriers.

Option 4: Purchase GPS data from a third party provider. Calmar Telematics and Inrix provide these services, among others.   As third-party providers, they contract with the carriers and/or owners to collect GPS data either directly from the fleet's IT department or from the vendor. Fleets will ask vendors to push data to the third party provider, and the third party will then provide data for that specific carrier. Third party providers may pay between $20 and $100 per vehicle per year directly to the carriers. It should be noted that the payments are based on market conditions, where heavily congested urban areas often demand higher payments to carriers as third parties have more success reselling data in these areas. Calmar is currently providing data on the New York State Thruway and at the northern border Peace Bridge. Inrix was recently awarded a contract to provide data along the I-95 Corridor and provides data in cities nationwide.

To meet the project objectives, a GPS deployment strategy that utilizes a third-party provider (Option 4) was selected.

Acquiring GPS data from a third-party provider is not without risk, however, and data "ownership" issues must be addressed. The dissemination of raw GPS data is more likely to be restricted by the carrier or by the third party because of the issues associated with collecting, using and maintaining these data. In this case, the customer agency might have full rights to review the analyzed data and travel times and to disseminate summary information, but the raw data would likely have certain limitations for use outside of agency activities and may not be available directly to the agency. This was not a significant concern during the test, but may introduce more complex contracting language under deployed conditions.

Additionally, third-party providers may provide GPS data, which they purchase directly from motor carriers, for a greatly reduced cost for the purposes of the test. However, the cost of these data may increase (or decrease) based on coverage and market conditions. Delcan's experience with probe data shows that deployment costs may initially increase after the initial test period until they adjust for market conditions and/or a larger business to the third party is realized.[16]

Both GPS and ALPR were considered for deployment at Otay Mesa and were evaluated against the following User Requirements for technology deployment as detailed in the Task 1 Stakeholder Sessions. A summary comparison of ALPR and GPS for each User Requirement is shown in Table 4, with the primary User Requirements of:

- Total cross-border travel times (historic data);

- Total cross-border travel time with FAST, empty, and laden movements differentiated;

- Real-time information on delay; and

- Measures of travel times between multiple points within the US and MX Customs compounds.

It should be noted that not all user requirements could be addressed with this initial technology deployment; however, each technology and its potential to provide these capabilities was addressed in detail as shown in shown in Table 4.

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[16] Delcan for the Baltimore Multimodal Traveler Information System Business Model.

Table 4. Functional Requirements / Technology Implications Summary

User Needs (Northbound)	GPS	ALPR
Total cross border travel time (historic) from the beginning to the end of the queue	GPS data can be used to provide a total cross-border measurement of travel times within FHWA's budget. GPS risks are related to carrier commitments to participate; however, carriers were eager to participate in the stakeholder session conducted in January 2008 and in follow-up contacts with stakeholders.	ALPR can be used to provide a total cross-border measurement of travel times within FHWA's budget. ALPR risks include safety and security of the ALPR equipment. The specific location of ALPR camera at beginning of queue has yet to be determined
Total cross-border travel time with FAST, laden, and empty moves differentiated	GPS data for each movement type may be differentiated using fleet characteristics and geo-fencing. This requires additional analysis and estimation using statistics.	Travel times will be estimated based on statistical distributions of trip types within the total sample. CBP crossing data, if provided, can enhance this analysis.
Real-time wait information: total travel time, FAST, laden, and empty	GPS data can be used to collect data on the approach to, as well as within, the customs compound and can provide real-time travel time information.	The total travel time using ALPR can be reported in real-time, but only after the truck passes both the first and last reader locations.
Travel time information between multiple points within the MX and US customs compounds	GPS data for multiple measurement points can be differentiated using geofencing, provided the location sampling frequency is high enough to capture a truck as it passes through a geofenced area (e.g., CBP secondary). This requires additional statistical analysis.	ALPR data for multiple measurement points can be collected using portable ALPR stations at temporary points. This requires additional analysis and estimation for segments not measured. Alternatively, could relate plate reads to CBP records showing crossings by individual trucks, if access to such data is permissible.
Data/ infrastructure ownership	GPS equipment will not be owned by the FHWA; raw GPS data may not be owned or even accessible to the FHWA. As a risk, carriers can choose to terminate data access at any time, but would lose revenue	FHWA will own both the infrastructure and the raw data, but will also be responsible for maintenance of the physical assets, which include at least two camera/antenna/power "out station" assemblies, and one "in station" to receive transmitted data.
Safety, security, and maintenance	No issues associated with safety and security - many GPS deployments by carriers support C-TPAT programs; however, maintenance of contracts with carriers is required.	Safety and security of ALPR infrastructure is primary concern. Life span of equipment is 3-5 years; more information is needed to assess useful life under rugged border conditions. Potential security risk from theft or damage to fixed infrastructure.
Long-term viability	Carrier commitments will likely change over time. For long-term viability, a third party can best address carrier contracts, where business models provide incentives to add more carriers and data-related service offerings.	Historical precedent exists regarding ability of agencies to support long-term maintenance, security, and life-span of equipment. Trends in state-of-practice suggest in the long-term, fixed infrastructure for travel time measurements will likely be replaced by probe technologies.
Stakeholder support	Stakeholders support sharing or selling of GPS data based on feedback obtained during January 2008 stakeholder sessions and follow-up phone calls/ emails.	Initial cost of infrastructure along with maintenance and security issues are sources of high stakeholder concern. Cameras near border may add additional privacy concerns for carriers.
Information beyond borders	Could potentially track trip origin, destination, and routes for more robust analysis. Could provide data for FHWA's freight travel time data base. Southbound data can be added at no additional deployment cost.	Could provide travel times with other ALPR sites from same vendor with additional software. Extension of geographic measurement window or addition of southbound data would require additional installations.

Additionally, the following "other considerations" for deployment are documented in Table 4:

- Data and/or infrastructure ownership;

- Safety, security, and maintenance;

- Long-term viability of the technology;

- Stakeholder support for deployment; and

- Potential for a richer dataset "beyond" the border and/or on the southbound approach.

In summary, GPS data provide a robust stream of multiple data points. The continuous nature of the data allows for analysis of travel times for different segments of the cross border trip. Southbound information can also be added without additional deployment costs. The study team recommended a third-party provider approach to help mitigate risks from carrier involvement and data contracts; however, the provision of the data from the carriers was still the largest risk for GPS deployment. The January stakeholder sessions helped identify carriers who were willing to participate in this task. Stakeholders strongly supported GPS applications.

ALPR deployment can provide a concrete measure of the total cross-border travel time provided that the infrastructure can be mounted in a safe and secure location that is within range to read commercial license plates. Temporary ALPR stations can provide additional estimates of travel times for segments of the trip within the MX and US Customs compounds. Because the FHWA would be responsible for maintenance of ALPR infrastructure, safety and security is a significant risk.

3.4 Technology Deployment

Once the decision was made to go forward with a GPS-based deployment, data acquisition requirements were broadly described to the data provider. The key requirements were that the sample size be sufficient to provide the required volume of data to adequately characterize travel times and that carriers would need to allow unrestricted access to all available GPS data generated by trucks passing through the Otay Mesa crossing.

Prior research indicates that, in order to accurately characterize travel times on a roadway network, between three and five percent of the total vehicle population must provide GPS data

on a regular basis.[17] With a typical daily volume of 2,500 truck trips at the Otay crossing, this equates to between 75 and 125 truck trips daily.

In order to meet these requirements for truck GPS data, the data provider needed to identify and recruit motor carriers to participate in the project. The data provider's operating model involves the acquisition of GPS data directly from the carriers, as opposed to other vendors that obtain data from fleet management system providers. Though for business confidentiality reasons the data provider did not fully disclose the reasons for adopting this model, they did indicate a preference for dealing directly with the owners of the data, as opposed to negotiating agreements with system or service providers.

The data provider chose to address this requirement by recruiting three carriers with trucks that regularly travel the Otay crossing. Initially, the carriers were chosen because they already possessed vehicles with GPS data systems installed. This approach is taken for two primary reasons. First, because the carrier has ultimate ownership rights to the data, they can grant access directly, without requiring the approval of any additional party. Second, carriers are typically open to receiving modest compensation, since they incur no additional expense and can recoup a portion of their investment in fleet management systems and services.

The primary drawback of this approach is that individual agreements must be negotiated and maintained with each carrier. This proved especially challenging for this project. While the carriers from whom the data provider acquires GPS data are primarily US-based fleets—many that are located in the northeast US—many of those that use the Otay crossing are co-owned by families that have operations on both sides of the border. Hence, the nature of negotiations was somewhat unique, as compared to that which the data provider is accustomed. The result was that it took somewhat longer to negotiate agreements than might otherwise be required in a non-border environment.

Initial data received from the equipped trucks indicated that many of the trucks that appeared in the measurement zone did so only once or twice during a given trip, often on the Mexican side of the border before reaching US CBP primary inspection. This level of data was deemed by the team to be insufficient to reliably measure travel time in the Otay border zone.

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[17] Ferman, Martin A., Dennis E. Blumenfeld, Xiaowen Dai, "An Analytical Evaluation of a Real-Time Traffic Information System using Probe Vehicles," Journal of Intelligent Transportation Systems, 9:1, 23-34. Available at: http://dx.doi.org/10.1080/15472450590912547.

Initially, the GPS data provided by the carriers that agreed to participate was generated with a trailer-tracking system called SkyBitz. While the position data provided by these systems has proven reliable over a number of years, it became clear as the test progressed that the reporting frequency was not sufficient for measuring travel time over such a short distance. Skybitz systems typically report position every 30 minutes, plus provide additional reports when vehicles begin moving, or stop for a predetermined period of time.

Because the existing carrier agreements with SkyBitz did not generate data with enough frequency to provide a sufficient number of data points within the border travel time measurement zone, and because the participating carriers often move trailers that are not equipped with SkyBitz devices, To address this, the participating carriers opted to upgrade their GPS units. These units, provided by LocJack, are designed to be installed in the tractor. The units capture position data every two to three minutes, and forward reports within 10 minutes. Going this route meant that the opportunity existed to also capture the movement of unequipped trailers and bobtail trucks (trucks without trailers attached).

Carriers utilized the compensation provided to them through their data agreement with the data provider to purchase and install a total of 175 units in trucks. The devices were installed and brought on line during the February to April timeframe in 2009. The carriers purchased these units at a price of $350 per unit, and subscribed to data services at a cost of $17 per month. Once the units were installed, the data provider was granted access to data feeds by the carriers.

While the study team was not a party to the specific terms and conditions of the agreements between the data provider and the carriers, the terms included a provision to provide anonymous data to the study team, and by extension to the FHWA, for all US-bound truck trips occurring within the area in the immediate vicinity of the crossing, and all data points falling within the measurement zone, for a period of one year. This was agreed upon by the carriers in return for the provision of data from the GPS units.

3.5 Trip Statistics

As previously discussed, the average daily truck traffic volume at the beginning of the test was expected to be approximately 2,500 trips per day. Using the general rule of thumb that between three and five percent of the vehicle total needs to provide probe data in order to accurately characterize travel times, this places the desired number of daily trips by equipped vehicles between 75 and 125.

In actuality, during the test the total vehicle counts were consistently lower than the 2,500 figure. CBP provided data that indicated that the average daily US-bound vehicle count. Table 5 shows the total (including loaded and empty) truck counts by month, plus the daily averages for the period from January 2009 through February 2010.

Table 5. Truck Counts at Otay Mesa – US Inbound

Month	Truck Counts			
	Total	*Daily**	*Loaded*	*Empty*
January 2009	51,766	1,922	31,787	20,099
February 2009	48,205	2,040	30,501	18,465
March 2009	55,285	2,126	35,758	19,527
April 2009	56,709	2,181	37,242	19,467
May 2009	54,790	2,107	36,778	18,012
June 2009	60,191	2,314	38,851	21,321
July 2009	60,550	2,047	39,560	21,862
August 2009	57,821	2,224	36,682	21,141
September 2009	59,743	2,298	39,094	20,649
October 2009	64,848	2,402	43,236	21,612
November 2009	58,879	2,355	39,545	19,334
December 2009	55,638	2,059	37,207	18,389
January 2010	51,020	1,962	32,504	18,516
February 2010	50,816	2,201	33,884	18,945

*Based on Mon-Sat. Sundays were excluded because trip counts are very small.

According to port officials at Otay Mesa, approximately one third of the total laden shipments are FAST trips.

In order to assess whether the fleets participating in the project were providing an adequate percentage of overall trips, the study team examined the GPS data to identify two different types of trips. The first was "total trips." For this category, any appearance of multiple points from the same truck within the dataset for a given two-hour period was considered a trip. This was true regardless of where the points were located, as long as they were within the travel time measurement zone, and indicated US-bound movement. The second trip type was "crossed trips." The study team considered a trip a crossed trip if a truck reported its position at least once on each side of the border during an individual trip. Hence, the group of total trips included all crossed trips, plus any additional trips for which points could not be identified on one side of the border or the other.

Figure 8 contains a plot of the data gathered during the test from January 2009 through March 2010. It illustrates the number of trips for which data was captured during each month. The acronym MOY represents month of the year.

Figure 8. Otay Mesa Data Trips – January 2009 through March 2010
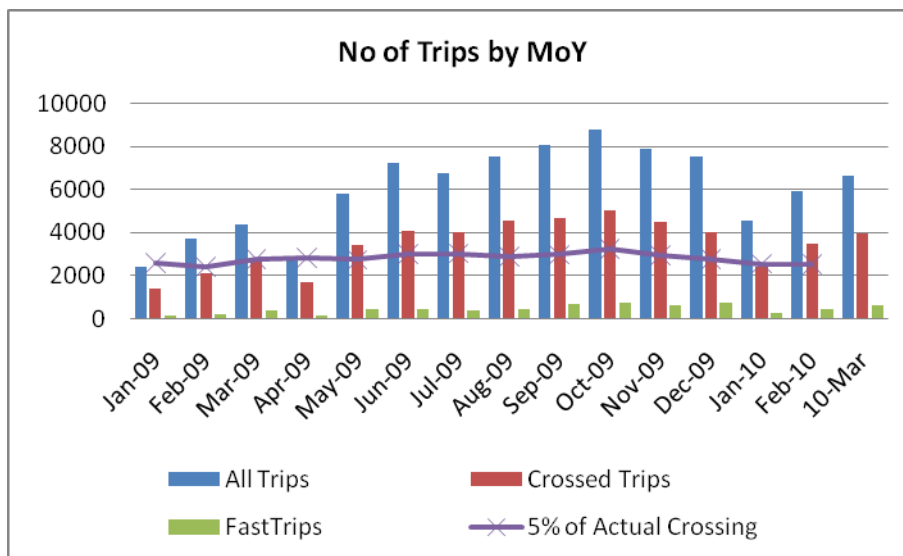
As the data indicate, the number of crossed trips for which GPS data was collected consistently fell between three and five percent of the total trips through the border as reported by CBP.[18] Based on these figures, the study team was confident it could rely upon the data from crossed trips to characterize travel time through the crossing. The alternative would have been to attempt to construct composite travel times from the totality of the captured trips. The team considered this unnecessary and therefore did not attempt it.

As the graph shows, the number of trips that the team was able to identify as FAST trips was very small. The FAST trips generally equated to between 10 and 18 percent of the total crossed trips on a monthly basis, with just under 13 percent over the duration of data collection. The team arrived at these figures by creating a "geofence"[19] around the portions of the MX customs compound through which only FAST trucks travel. This was accomplished using TransCAD, overlaying all of the points on the map grid for the crossing, and identifying individual truck GPS data points that fell within the area. A graphical depiction of this geofenced area is provided in Figure 9.

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[18] CBP had not released statistics for March 2010 as of the writing of this report, so the 5 percent value could not be determined for that period.

[19] A Geofence is a virtual perimeter on a geographic area using a location-based service, so that when a telemetry device enters or exits the area a notification is generated. (Source: Wikipedia - http://en.wikipedia.org/wiki/Geofence).

Figure 9. Illustration of Geofence Used to Identify FAST Trips
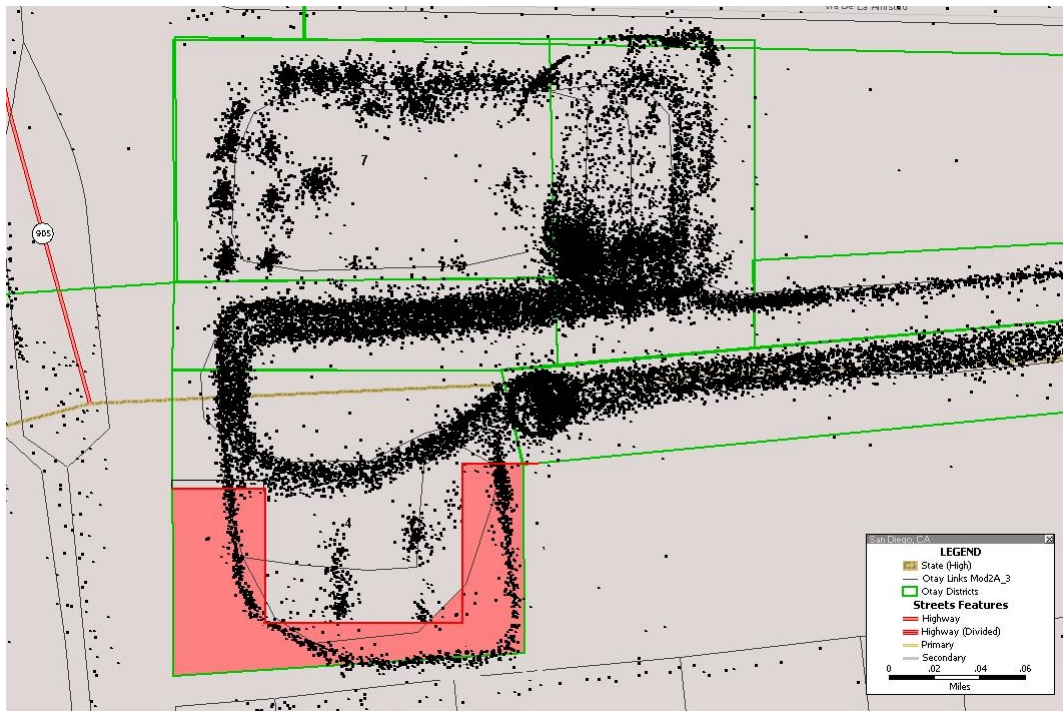
The study team designated the area indicated in red as the most likely opportunity to isolate trucks completing FAST trips. The small black dots superimposed over the image represent individual GPS data points received from participating trucks. As the image indicates, there is a distinct separation in traffic flow. However, based upon the figures cited by the carriers regarding the percentage of trips conducted as FAST trips, the method clearly resulted in under-reporting.

By contrast, the study team was confident that the method was appropriate for the identification of vehicles that passed through secondary inspection, which includes the screening of vehicles by x-ray units on the western end of the US customs compound. Vehicles directed to secondary for x-ray screening pass along the upper perimeter of the compound from east to west, then turn south to pass through one of two x-ray units. Travel speeds are typically low through this area, and every truck must come to a stop during the x-ray screening process. The result is that vehicles directed to complete this screening can be expected to report multiple times while in secondary.

The team also analyzed crossing data by day of the week (DOW) and time of day (TOD). Figures 10 and 11 illustrate the distribution of trips for these parameters.

Figure 10. Otay Mesa Data Trips by Day of the Week
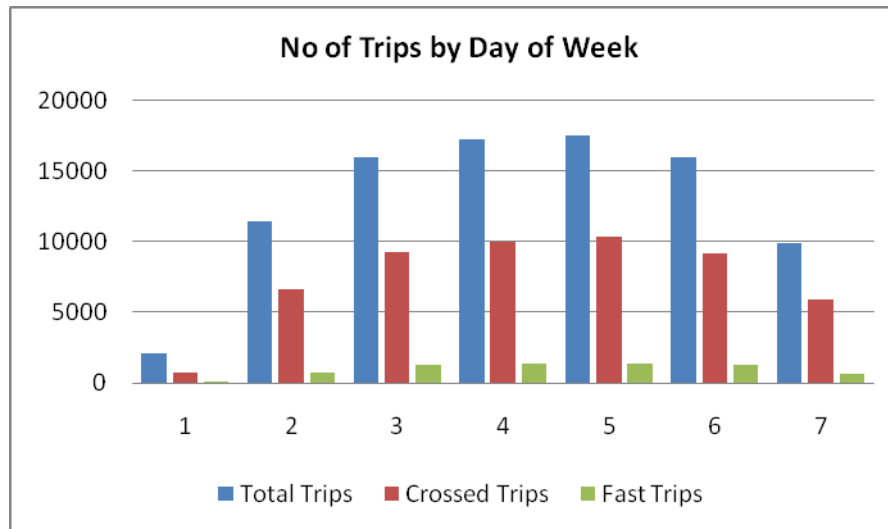
In Figure 10, the days of the week start with Sunday, which is designated as day 1, and end with Saturday, which is day 7. As the data indicate, Wednesdays and Thursdays were the busiest days, while very little traffic crossed on Sundays. With the exception of Sundays, the number of crossed trips captured for each day type was consistently above 500, with values approaching or exceeding 1000 trips for all days from Tuesday through Friday.

The data illustrated in Figure 11 requires more explanation. The crossing itself is closed between midnight and 8 AM. However, there are two phenomena that result in the appearance of trips during those hours. The first is that trips that begin late at night, and include processing through US customs primary prior to the midnight closure must still complete the trip through customs and the CHP inspection facility. This phenomenon likely accounts for most of the trips reported until the 4 AM low point. The second phenomenon, which likely accounts for most of the trips between 5 and 8 AM, is the queuing of trucks awaiting the opening of the border. In any case, the data for the period from 3 AM up until 6 AM is very sparse, and are not considered reliable.

Figure 11. Otay Mesa Data Trips by Time of Day
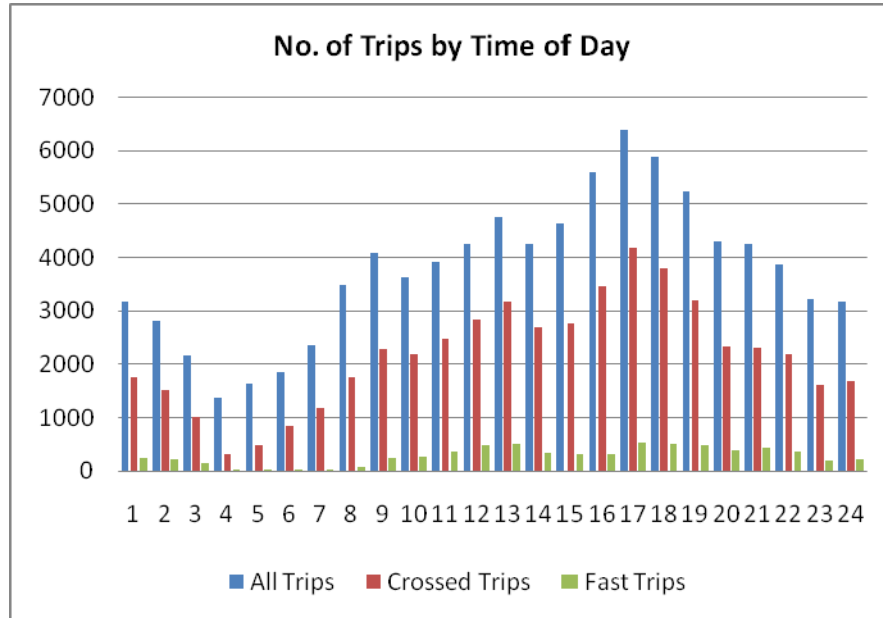
3.6 Border Travel Time Data

The accumulation and processing of individual GPS data points is a multi-step process. GPS data from the units used during this test is similar to data that would be forwarded from other GPS devices. The units transmit numerical values for latitude and longitude, along with a time stamp (in Greenwich Mean Time – GMT) and a unit identifier. Each of these points is then translated into a position on a roadway grid (see Figure 9 above), along with a direction of travel, and from that data vehicle speed and travel time can be calculated.

For this project, both the data provider and the study team ran calculations on the data, with the data provider conducting initial filtering and mapping, the forwarding it to the study team for analytical computation. At the onset of the data collection effort, the data provider created a set of geo-registered spaces that represented segments of the trip through the Otay crossing. These spaces, which are referred to as "districts," are shown as segments outlined in green polygons in the illustration in Figure 12, which also contains data from one empty vehicle trip through the border (dark blue dots) and one FAST truck trip (light blue dots).

The purpose of this was to allow for the consideration of partial trips in the overall calculation of travel time through the measurement zone. It was initially intended to accommodate the infrequent reporting intervals of the Skybitz devices. When the LocJack devices were brought

on line, these districts simply became convenient mechanisms for observing partial-trip travel times, and to identify whether trucks were completing FAST trips or were unloaded.

Figure 12. Sample Otay Mesa GPS Data in Districts
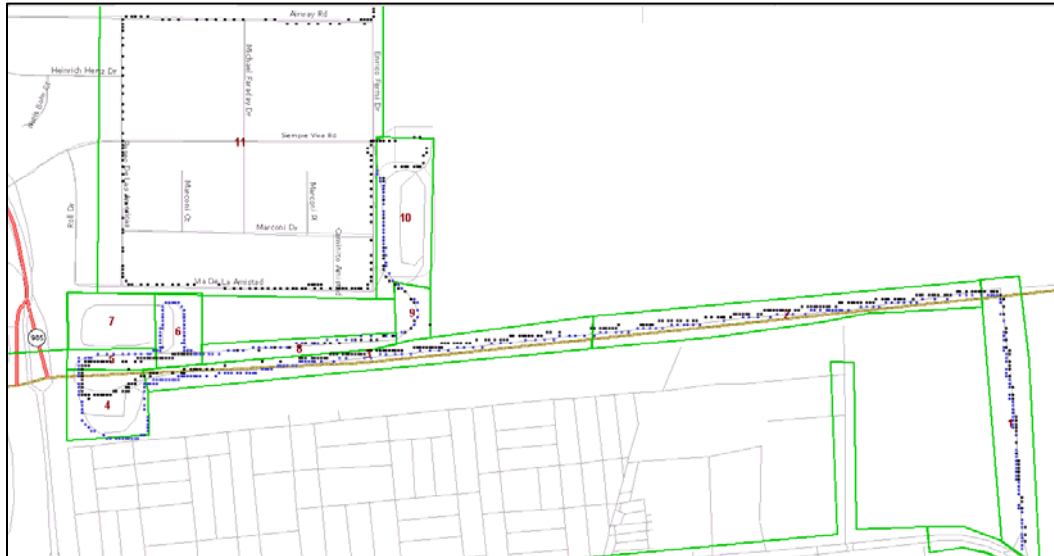
For the purposes of understanding the translation of individual GPS points into travel time calculation parameters, it is useful to review the data manipulation sequence used during the project. The following sequence of actions took place for the data captured during the test:

Data Processing Sequence

1. Data is collected from units:
   a. If the carrier has a database, Calmar applies a tool (created by them) that polls the carrier database, translates the GPS data into XML[20] format, and then sends it to Calmar using encrypted TCP/IP.[21]

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[20] Extensible Markup Language (XML) is a simple, very flexible text format derived from SGML (ISO 8879). Originally designed to meet the challenges of large-scale electronic publishing, XML is also playing an increasingly important role in the exchange of a wide variety of data on the Web and elsewhere. (Source: W3C - http://www.w3.org/XML/)

[21] The set of communications protocols used for the Internet and other similar networks. It is named from two of the most important protocols in it: the Transmission Control Protocol (TCP) and the Internet Protocol (IP), which were the first two networking protocols defined in this standard. (Source: Wikipedia - http://en.wikipedia.org/wiki/Internet_Protocol_Suite)

    b. If a carrier uses the provider website (rather than its own database), Calmar accesses the XML or .csv[22] feeds through the website with a tool they created

2. GPS data is fed into a "threshold database," which contains all raw data

3. Calmar applies routines to process the GPS data and store in a "national database."

    a. Assigns a token ID to each GPS point.

    b. Strips specific vehicle identifiers, replacing them with a weeklong artificial identifier

    c. Snaps individual GPS points to the roadway grid using a routine written by Calmar,[23] and the Navteq database shape file

4. Snapping results – the results of the snapping routine are rows in a database file with the following headings:

    a. roadID – node to node breakdowns

    b. linkNum – segment of road

    c. DistToSeg-Ft – perpendicular distance from an individual GPS point to roadway segment

    d. DistFrom_Ft – distance from projected point (point location on link) to beginning of segment

    e. Method – internal reference identifier that helps to sort dataset and understand characteristics of subsets of the dataset

5. Labels are applied to different SensorStatus points (also labeled as "Reason"), based on what is and isn't known (start, stop, breadcrumb,[24] etc.)

6. GPS data is picked from the database using a specific area of interest defined as a box defined by lat/long corner points. For this project, this is defined as a rectangular area that fully encompasses all of the roadway segments that constitute the measurement zone.

7. Outliers are identified and excluded by analyzing for unreasonable speeds between successive points.

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[22] csv – Comma Separated Values – a file type often used to transfer data among various applications where individual values are separated by commas.

[23] Calmar uses its own proprietary geo-location tuning logic to improve upon the precision found in standard commercial mapping products, which Calmar considers insufficient for accurate travel time measurement. This was the case with the telemetry data acquired during the project.

[24] "Breadcrumb" is a term that is often used to identify points that are recorded at regular intervals by a telemetry unit as a vehicle is moving

8. GPS data is fed into a GIS[25] where it is associated with a selected area or district bounded by a geo-registered space. Then a geospatial overlay is superimposed over the dataset to bind the area/district identifier to the GPS data.

9. A series of geospatial transforms is applied:

   a. The district of interest in which an individual point resides is associated with the underlying link structure as well as the GPS – i.e., a district ID is assigned. If the point is not in a district, the district identifier is a null.

   b. Export GIS data that has been snapped to a district of interest into a statistical analysis package.[26]

   c. Within the statistical analysis package, data parsing modifies the dataset to add useful characteristics (e.g., day of week, month, etc.), and to sort by different criteria.

   d. The system then tries to identify logical trip chain endpoints using elapsed time between consecutive points from an individual vehicle. Elapsed time clock (time between consecutive GPS points from the same vehicle) is reset to zero when a vehicle reappears in the dataset after having been absent for more than 6-1/2 hours.

   e. Single points are tossed out if there is not another data point within the districts within the 6-1/2 hour window.

10. The refined output is placed into a data file to facilitate the calculation of travel times.

Many of the individual actions within this sequence required manual triggering of calculations or processing. As such, it is not likely to be useful for anything other than examination of data after the fact.

For the purposes of analyzing the data generated during the test, the study team fed the data into Excel and compiled statistical summaries of travel time. Because the travel time measurement zone was defined as the full distance between the Bellas Artes/Calle Doce intersection to the exit of the CHP facility (see Figures 3 and 4), the travel times were initially calculated to reflect that distance.

As described above, to facilitate calculating travel time across the full measurement zone and for portions of the trip, the trip length was segregated into a series of consecutive travel zones, or districts. The data provider formulated a set of eleven travel districts and provided the GIS

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[25] GIS – Geographic Information System. A GIS is a system that allows for spatial placement and analysis of telemetry points. For this project, Calmar utilized Manifold, while Delcan used TransCAD.

[26] For this project, Calmar used SAS, while Delcan used a SQL database and a set of analytical algorithms.

shapefile to the study team for use during data collection and analysis. The image in Figure 13 shows all of the districts.

Figure 13. Otay Mesa Travel Time Measurement Districts

This was initially done to accommodate the compilation of travel time using portions of trips as reported by vehicles using the Skybitz solution, which, as was indicated previously, reports relatively infrequently. Ultimately, this became unnecessary. However, the districts were still utilized for determining the portion of the total trip travel time that was accumulated on the approach to the US customs primary inspection facility.

Based on the original definition of the measurement zone, the travel time calculation consisted of the total time elapsed between the first appearance of a truck GPS data report within district 1 and the last report within district 10. Using this approach, the study team concluded that there was a risk that the calculated travel time would be underreported, since conceptually speaking, a truck GPS unit could travel two to three minutes into the trip before issuing an initial report, and could then issue its last report two to three minutes before leaving the measurement zone on the US side. Ultimately, the team concluded that little could be done to correct for this and that given the typical travel times calculated, it would have a minimal effect.

The charts in Figures 14, 15, and 16 show the calculated border travel time values for the trips observed during the test period, by day of the week, month of the year, and time of day. In each

of the figures, travel time is presented in seconds, and the data is segregated to show all trips, and FAST trips.

Figure 14. Calculated Travel Time Values by Day of the Week (Dist 1 – 10)
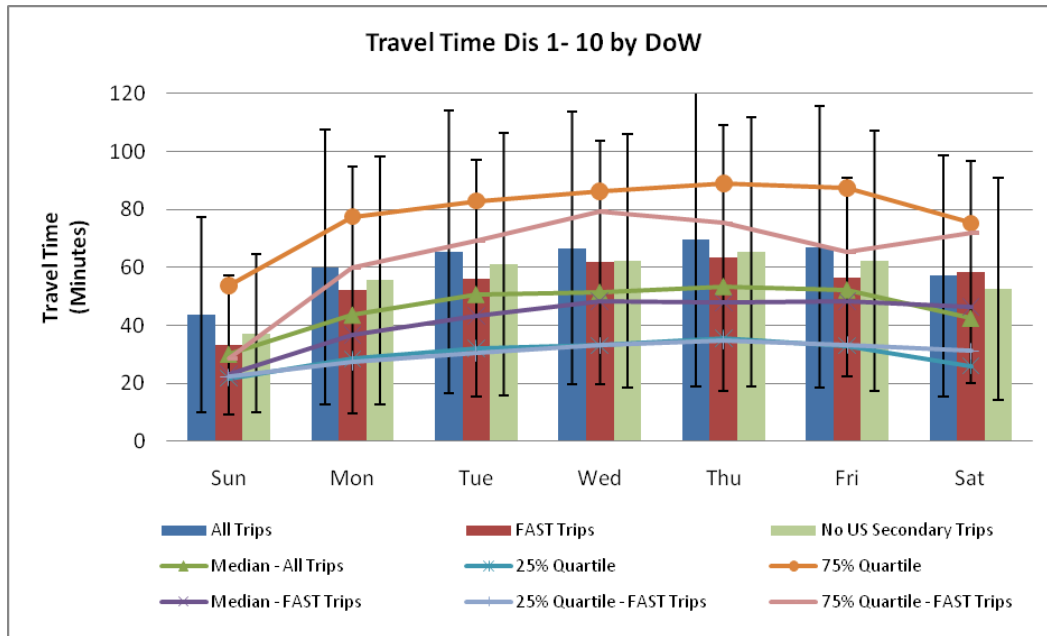
The vertical red, blue and green bars indicate mean travel time for all crossed trips, all FAST trips, and all trips for which the truck did not pass through secondary inspection, respectively. The vertical black interval lines represent the calculated standard deviation values for each mean value. The green line with intervals designated by triangles represents the median travel time for all trips, and the purple line with intervals designated by x's represents the median travel time value for FAST trips. Finally, the remaining lines represent the 25% and 75% quartile values for all trips and FAST trips.

The values presented in Figure 14 indicate that the mean measured travel time across the entire measurement zone for Mondays through Saturdays was between 60 and 70 minutes. Sundays, which as stated previously see very limited traffic, showed a mean travel time value of approximately 43 minutes. The data suggests that average travel times are longest on Thursdays and Fridays. The data corresponding to Figure 14 is provided in Table 6, which shows mean border travel time values and standard deviation values by day of the week.

Table 6. Mean District 1 – 10 Travel Times by DOW

	Day of Week	All Trips		FAST Trips		Non-Secondary Trips	
		Mean Travel Time 1-10	Stdev	Mean Travel Time 1-10	Stdev	Mean Travel Time 1-10	Stdev
Day 1	Sun	44	34	33	24	37	27
Day 2	Mon	60	47	52	43	55	43
Day 3	Tue	65	49	56	41	61	45
Day 4	Wed	67	47	62	42	62	44
Day 5	Thu	70	51	63	46	65	47
Day 6	Fri	67	48	57	34	62	45
Day 7	Sat	57	42	58	38	52	38

One notable characteristic in the dataset is that FAST trips—at least those that could be identified definitively—take less time for all days except Saturdays. Differences range from values of 15 percent lower on Mondays for FAST trips to just over 10 percent lower on Thursdays. This does not include Sundays, where differences are negligible and crossing numbers are very low. Saturday data suggests that FAST trips take an average of 2 percent longer. However, given the low level of confidence associated with the identification of FAST trips using the GPS data, this value cannot be considered significant.

Also notable within the data is the very large value associated with the standard deviation from the mean. The values calculated from the data indicate that the standard deviation ranged from 61 percent to 81 percent of the mean. These values suggest that the carriers that participated in the study experienced very wide fluctuations in travel times.

Because the standard deviation values were so high, the study team was concerned that a small number of trips with inordinately high or low travel times were potentially influencing the values to a high degree. This is not uncommon for datasets where the sample is non-random, and where there are extenuating circumstances that may influence the outcome, such as variability in enforcement methods. In the case of travel times, vehicles that are delayed for extended periods, or that queue in advance of the opening of the border, may influence the data to such an extent that the mean values are biased to the high side. Because it is less prone to the influence of outliers, the study team also calculated median travel time values for each day of the week. As Figure 13 shows, the median values were measurably lower than the mean values. The data indicated that the median values were 15 to 30 percent lower than the mean

values, which would place the median travel time for Mondays through Saturdays between 42 and 53 minutes.

The upward bias in mean travel time values is revealed further through the identification of 25% and 75% quartile values. These values form the upper and lower limits of observed travel times for the middle 50% of all observed trips. A comparison of the portions of the standard deviation range outside the middle 50% to those inside reveals that more of the deviation interval lies to the upper side of the range.

Figure 15 shows similar values for the crossing by month of the year between January 2009 and March 2010.

Figure 15. Calculated Travel Time Values by Month of the Year (Dist 1 – 10)
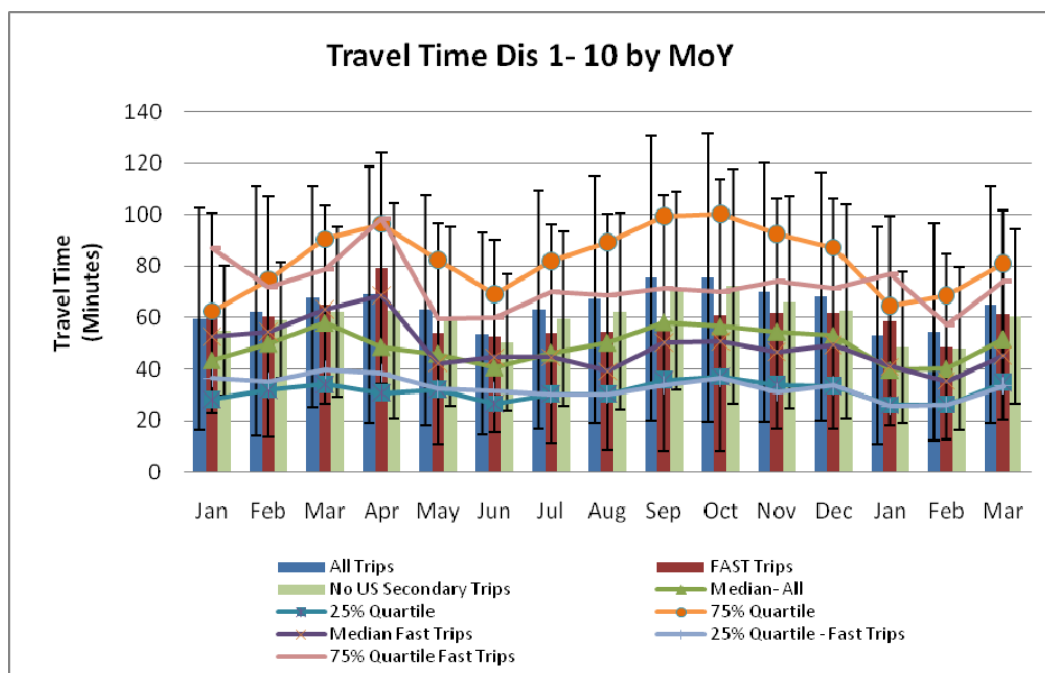
The travel time data characteristics for the months shown in the figure are consistent with those in Figure 14, with a few notable unique characteristics and observable differences. The first notable characteristic is that the mean and median travel time values peaked in the March-April 2009 and September-October 2009 timeframes.

According to CBP crossing statistics, the September-October 2009 period was the busiest period (see Table 5). This would seem to correlate with the increases in mean and median travel times. Interestingly, this is not the case with the March-April peak travel time values. The CBP crossing volume data indicates that the June-July 2009 timeframe was busier than the March-April 2009 time period. Unfortunately this is not explainable directly from the data.

The monthly data also indicates that the mean travel times for FAST trips were lower than the overall average for all but three of the months: January 2009, April 2009, and January 2010. Finally, the monthly data is consistent with the daily data in that they show that the median travel time is consistently lower than the mean, and that the middle 50% of trips fall to the lower end of the standard deviation range. Table 7 contains a summary of the mean and standard deviation values by month.

Table 7. Mean District 1 – 10 Travel Times by MOY

	Month and Year	All Trips		Fast Trips		No US Secondary Trips	
		Mean Travel Time 1-10	Stdev	Mean Travel Time 1-10	Stdev	Mean Travel Time 1-10	Stdev
Month 1	Jan-09	60	43	62	32	55	39
Month 2	Feb-09	62	49	60	34	59	47
Month 3	Mar-09	68	43	65	28	62	39
Month 4	Apr-09	69	50	79	58	63	45
Month 5	May-09	63	45	54	35	61	43
Month 6	Jun-09	54	39	53	35	50	37
Month 7	Jul-09	63	46	54	42	60	42
Month 8	Aug-09	67	48	54	39	62	46
Month 9	Sep-09	75	55	58	38	71	50
Month 10	Oct-09	76	56	61	39	72	53
Month 11	Nov-09	70	50	62	44	66	45
Month 12	Dec-09	68	48	62	41	62	45
Month 13	Jan-10	53	42	59	46	48	41
Month 14	Feb-10	54	42	49	35	48	36
Month 15	Mar-10	65	46	61	47	60	41

Finally, Figure 16 illustrates the travel time data broken out by time of day.

Figure 16. Calculated Travel Time Values by Time of Day (Dist 1 – 10)
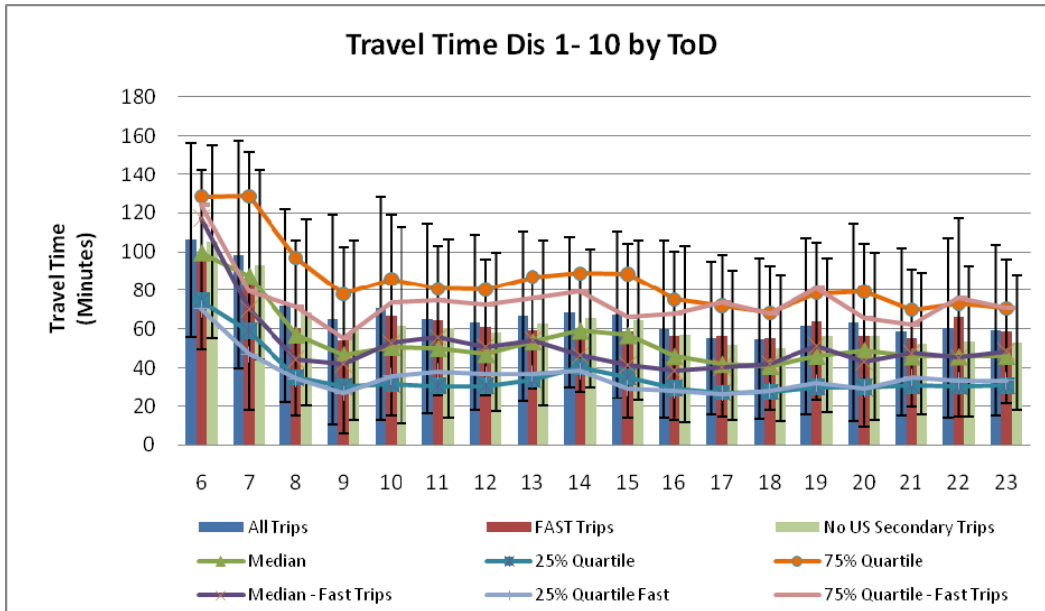
The time of day (TOD) dataset reflects the total travel time experienced by vehicles based upon the hour of the day when they first appeared in the system. For example, the value shown for hour 19 indicates that the mean travel time is approximately 62 minutes for trucks that first entered the measurement zone at 7 PM local time.

The more notable characteristics of the TOD dataset are as follows. First, because the number of points was exceedingly small, all trips identified as having started between 12 AM (when the border closes) and 6 AM were excluded from the dataset. The study team did this because it did not have confidence in the values provided. Second because the border does not open until 8 AM local time, the high travel time values reported between 6 AM and the opening of the border suggest that some vehicles are queuing in advance in order to ensure earlier entry into the US.

This would explain why travel times are longer for those vehicles, despite the fact that lower numbers of vehicles are processed in the early hours than in the peak volume hours between 4 PM and 7 PM (see Figure 11). Interestingly, the increase in volume seen in the peak afternoon/evening travel period does not translate into longer travel times. This is likely due at least in part to higher staffing levels during those periods.

Table 8 contains a summary of the mean and standard deviation values by time of day.

As was indicated previously, the travel time values presented to this point included the entire trip through the measurement zone from the Bellas Artes/Calle Doce intersection all the way

through the exit of the CHP inspection facility. The study team and FHWA selected this as the measurement zone because it reflects the total border crossing as experienced by the truckers. While this is likely to be the most useful measurement zone, the nature of the GPS data suggests that it may be useful for the examination of portions of the trip, as well. This might be useful to isolate factors that may contribute to overall travel time, such as infrastructure geometry and overall facility capacity.

Table 8. Mean District 1 – 10 Travel Times by TOD

	Time	All Trips		Fast Trips		No US Secondary Trips	
		Mean Travel Time 1-10	Stdev	Mean Travel Time 1-10	Stdev	Mean Travel Time 1-10	Stdev
Hour 0	12:00 AM	60	48	54	36	53	39
Hour 1	1:00 AM	53	32	56	30	47	26
Hour 2	2:00 AM	48	38	43	24	45	37
Hour 3	3:00 AM	87	0	41	0	81	64
Hour 4	4:00 AM	123	0	91	0	123	65
Hour 5	5:00 AM	124	0	35	0	120	52
Hour 6	6:00 AM	106	50	96	46	105	50
Hour 7	7:00 AM	99	59	85	67	93	49
Hour 8	8:00 AM	72	50	60	45	69	48
Hour 9	9:00 AM	65	55	54	48	59	47
Hour 10	10:00 AM	71	58	67	52	62	51
Hour 11	11:00 AM	65	49	64	38	60	46
Hour 12	12:00 PM	63	45	61	35	58	41
Hour 13	1:00 PM	67	44	59	30	63	43
Hour 14	2:00 PM	69	39	59	31	66	36
Hour 15	3:00 PM	67	43	59	45	65	42
Hour 16	4:00 PM	60	46	57	44	57	46
Hour 17	5:00 PM	55	40	56	42	52	39
Hour 18	6:00 PM	55	42	55	37	50	38
Hour 19	7:00 PM	61	46	64	41	57	40
Hour 20	8:00 PM	63	51	57	47	56	43
Hour 21	9:00 PM	59	44	55	36	52	37
Hour 22	10:00 PM	60	46	66	51	54	39
Hour 23	11:00 PM	59	44	59	37	53	35

In order to examine the efficacy of partial trip travel time measurement, the study team also analyzed the data to calculate the travel time from the beginning of the measurement zone to the exit from the US Customs primary inspection facility. This facility is represented as zone 6 in

the dataset (see Figure 11). Hence, the travel time for this measurement zone would include the time elapsed between the first time a vehicle reported in zone 1 through the last time it reported in zone 6. The result of this analysis is illustrated in Figures 17 through 19.

Figure 17. Calculated Travel Time Values by Day of the Week (Dist 1 – 6)
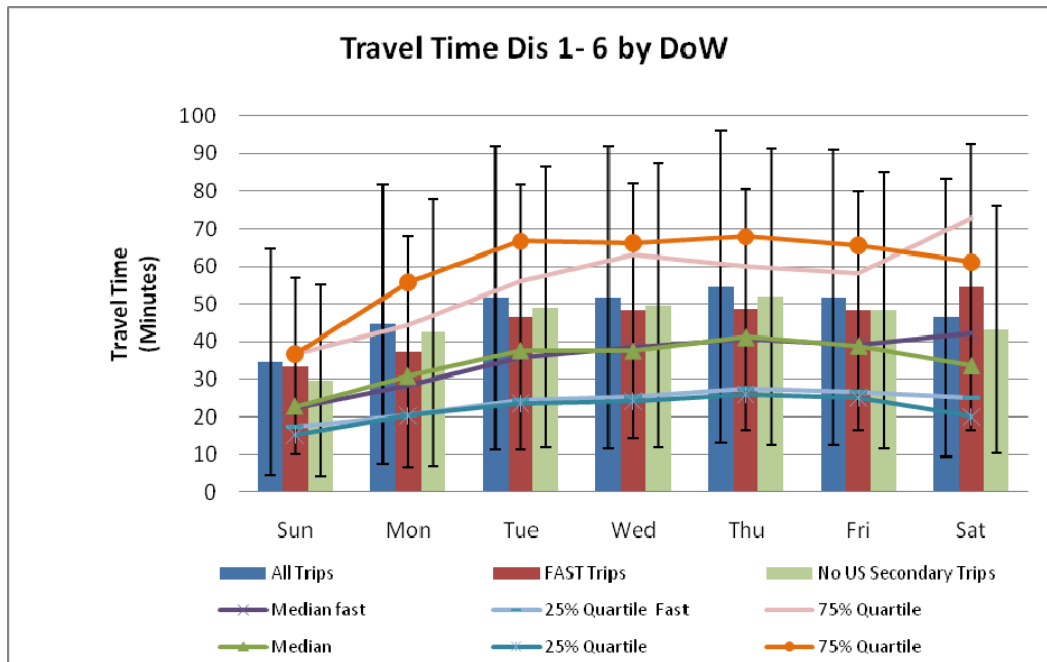
The most immediately identifiable characteristic is that the mean and median travel time values for the district 1 – 6 dataset are consistently approximately 75 to 80 percent of the district 1 – 10 values. This indicates that approximately three-quarters of the total travel time is spent queuing for and processing through US Customs primary inspection. The second notable characteristic is that the standard deviation is a slightly higher percentage of the mean, averaging from three to ten percentage points higher than those for the district 1 – 10 values. This suggests that travel time variability is more dependent upon the portion of the trip between the beginning of the measurement zone and the exit of the US compound than those portions afterwards. This is a reasonable result given the variety of screening actions that may be taken by CBP.
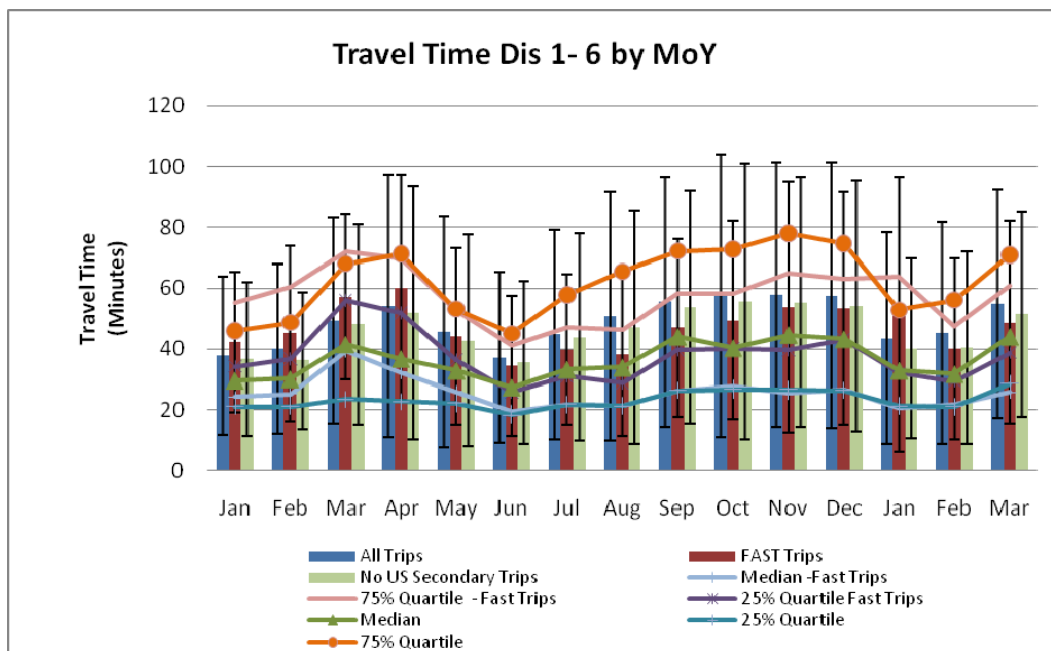
The data corresponding to Figure 17 is provided in Table 9, which shows mean border travel time values and standard deviation values by day of the week.

Table 9. Mean District 1 – 6 Travel Times by DOW

	Day of the Week	All Trips		FAST Trips		Non-Secondary Trips	
		Mean Travel Time 1-6	Stdev	Mean Travel Time 1-6	Stdev	Mean Travel Time 1-6	Stdev
Day 1	Sun	35	30	33	24	30	25
Day 2	Mon	45	37	37	31	42	35
Day 3	Tue	52	40	47	35	49	37
Day 4	Wed	52	40	48	34	49	38
Day 5	Thu	54	41	49	32	52	39
Day 6	Fri	52	39	48	32	48	37
Day 7	Sat	46	37	55	38	43	33

The data shown in Figure 18 indicates these findings are consistent when the travel times are examined by month of the year.

Figure 18. Calculated Travel Time Values by Month of the Year (Dist 1 – 6)

The data corresponding to Figure 18 is provided in Table 10, which shows mean border travel time values and standard deviation values by day of the week.

The data shown in Figure 19 indicates these findings are consistent when the travel times are examined by time of day.

Table 10. Mean District 1 – 6 Travel Times by MOY

	Month and Year	All Trips		Fast Trips		No US Secondary Trips	
		Mean Travel Time 1-6	Stdev	Mean Travel Time 1-6	Stdev	Mean Travel Time 1-6	Stdev
Month 1	Jan-09	38	26	42	23	37	25
Month 2	Feb-09	40	28	45	29	36	22
Month 3	Mar-09	49	34	57	27	48	33
Month 4	Apr-09	54	43	60	37	52	42
Month 5	May-09	46	38	44	29	43	35
Month 6	Jun-09	37	28	35	23	36	27
Month 7	Jul-09	45	34	40	25	44	34
Month 8	Aug-09	51	41	38	27	47	38
Month 9	Sep-09	56	41	47	29	54	38
Month 10	Oct-09	57	47	49	32	56	46
Month 11	Nov-09	58	44	54	41	55	41
Month 12	Dec-09	58	44	53	39	54	41
Month 13	Jan-10	43	35	51	45	40	29
Month 14	Feb-10	45	36	40	30	40	32
Month 15	Mar-10	55	38	49	33	51	34

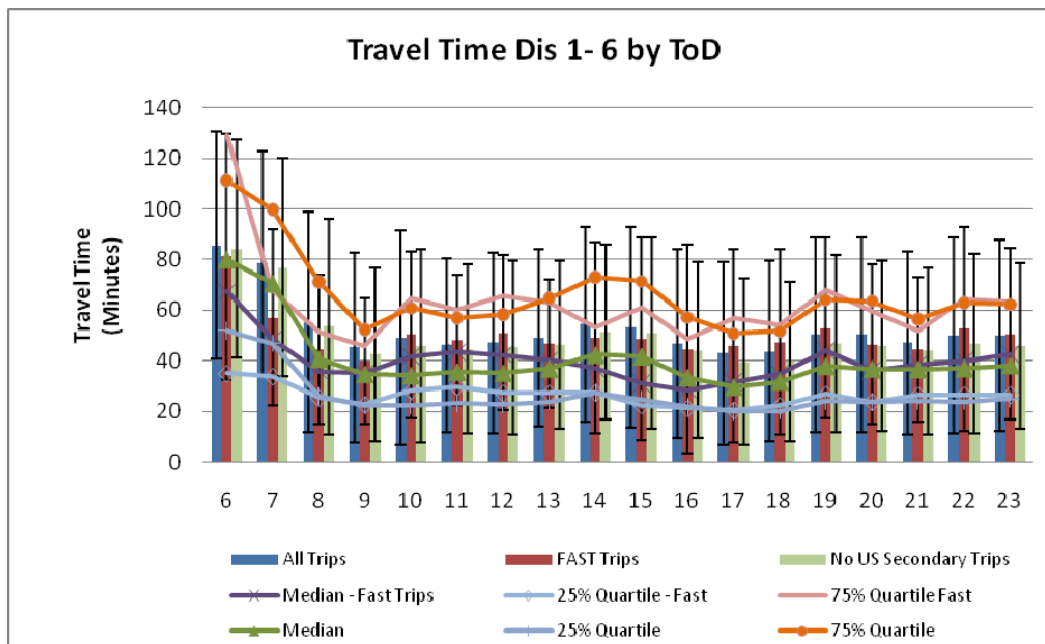**Figure 19. Calculated Travel Time Values by Time of Day (Dist 1 – 6)**

The data corresponding to Figure 19 is provided in Table 11, which shows mean border travel time values and standard deviation values by day of the week.

Table 11. Mean District 1 – 6 Travel Times by TOD

	Time	All Trips		Fast Trips		No US Secondary Trips	
		Mean Travel Time 1-6	Stdev	Mean Travel Time 1-6	Stdev	Mean Travel Time 1-6	Stdev
Hour 0	12:00 AM	46	35	43	28	42	31
Hour 1	1:00 AM	44	31	47	29	41	28
Hour 2	2:00 AM	38	31	36	24	35	29
Hour 3	3:00 AM	64	0	30	0	66	64
Hour 4	4:00 AM	108	0	61	0	110	59
Hour 5	5:00 AM	99	0	44	0	97	50
Hour 6	6:00 AM	86	45	81	49	84	43
Hour 7	7:00 AM	79	44	57	35	77	43
Hour 8	8:00 AM	55	43	45	30	54	43
Hour 9	9:00 AM	45	38	40	25	42	34
Hour 10	10:00 AM	49	43	50	33	46	38
Hour 11	11:00 AM	46	34	48	26	45	33
Hour 12	12:00 PM	47	36	51	30	45	34
Hour 13	1:00 PM	49	35	47	25	46	33
Hour 14	2:00 PM	54	39	49	38	51	35
Hour 15	3:00 PM	53	40	49	40	51	38
Hour 16	4:00 PM	47	37	45	41	44	35
Hour 17	5:00 PM	43	36	46	38	40	33
Hour 18	6:00 PM	44	36	47	37	40	32
Hour 19	7:00 PM	50	39	53	36	47	35
Hour 20	8:00 PM	50	38	46	32	46	34
Hour 21	9:00 PM	47	36	45	29	44	33
Hour 22	10:00 PM	50	39	53	40	47	36
Hour 23	11:00 PM	50	38	51	34	46	33

The root cause of the high degree of travel time variability is not known for certain. However, the study team suspects that several factors may contribute to it. Fluctuations in demand volume, the opening and closing of primary screening lanes, the proportion of trucks participating in the FAST expedited screening program, variations in screening actions undertaken by US CBP can affect travel time. For example, during the team members' visit to the crossing, they observed an operation termed "blocking" by CBP staff. In this operation, trucks that have passed through the US Customs primary inspection booth are directed to form several northbound lines inside the compound, and are held stationary until the lines are filled. Once the lines are filled, CBP staff performs canine screening of all of the stationary trucks by walking around all of the trucks.

Once the screening is complete the trucks are released in unison, whereupon they complete the u-turn to head south back through the exit of the compound and proceed on to the CHP inspection facility.

This activity is conducted on a periodic basis, at different times, and for obvious reasons is not announced in advance. Hence, while initial screening at the primary inspection booth may take no more than a minute, the trucks that are subjected to blocking are likely to encounter travel time increases of five to fifteen minutes, depending upon their position in line and the speed with which the canine screening can be completed. Given a mean travel time in the 60-minute range, such activities could easily result in measurable variations.

In order to gain a more complete perspective on the characteristics of the data set—and more importantly, develop a better understanding of the effects of outliers on the mean and median travel times—the team examined the frequency of occurrence of travel times within various "bands" or ranges. The results of this analysis are illuminating, and could have a significant effect on the methodology that should be applied when analyzing travel time data, particularly under near real time conditions.

The graph in Figure 20 depicts the cumulative distribution of travel times for trips from district 1 through district 10. As the image shows, 90 percent of all trips incurred a travel time of less than 133 minutes, and 90 percent of FAST trips took less than 100 minutes to complete. Figure 21 offers a slightly different view of the same data. It depicts the distribution of individual trips across the measurement zone by range of travel time.

These results suggest that is may be advantageous to examine the use of an arithmetic filtering process by which the trips with the longest travel times are removed from mean and median travel time calculations, thus yielding more meaningful values for the vast majority of crossing users.

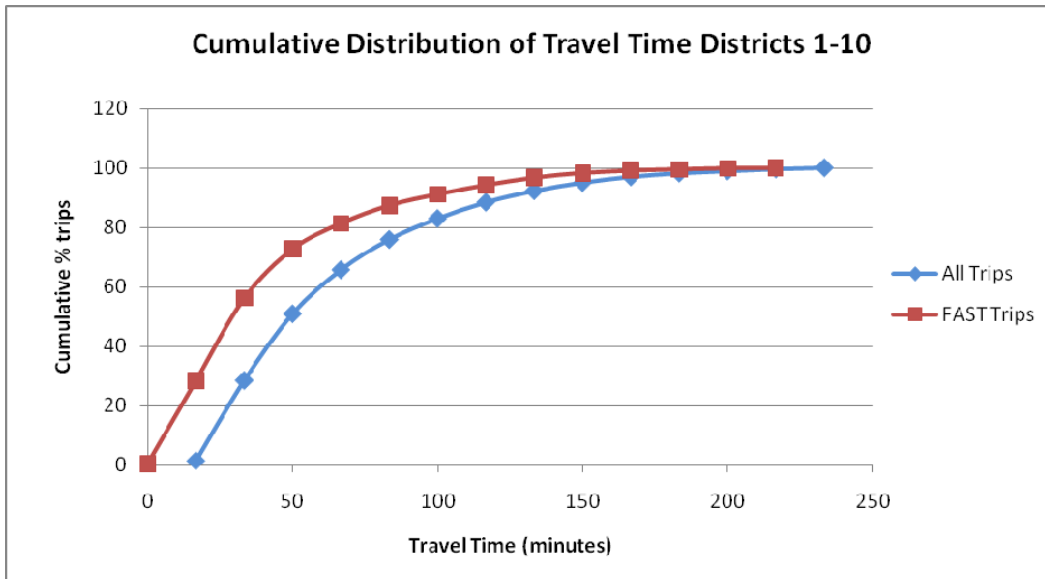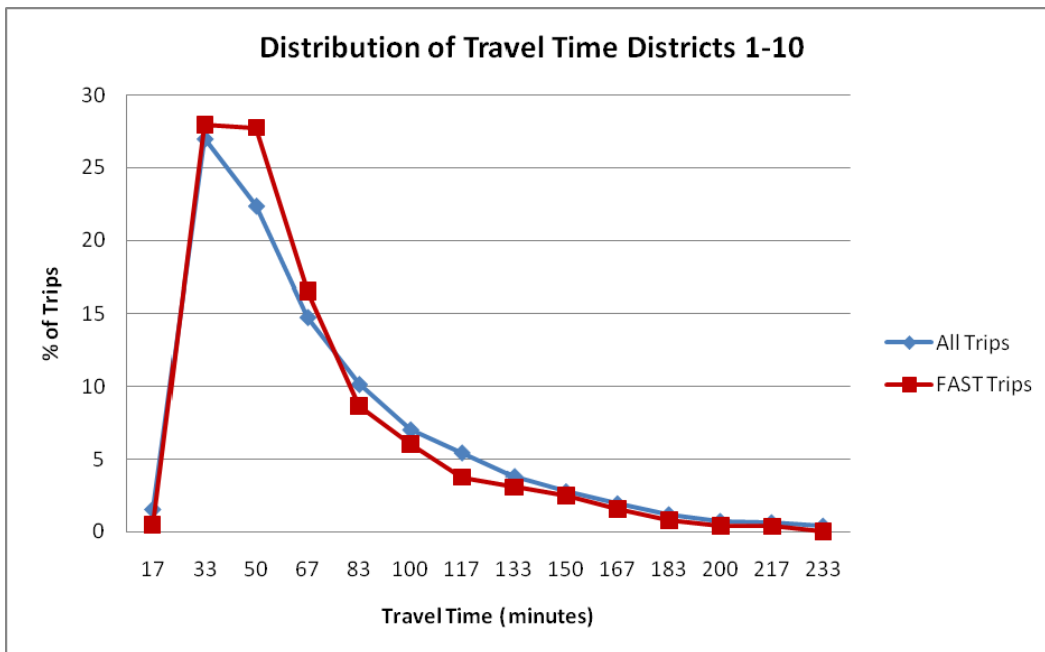**Figure 20. Cumulative Distribution of Travel Times (Dist 1 – 10)**

Figure 21. Distribution of Travel Times (Dist 1 – 10)

For completeness, the study team conducted similar analyses on the travel time data for trips from district 1 through district 6. The results of these analyses are presented in Figures 22 and 23. As can be seen in these graphs, the data profiles for the cumulative and individual trip travel

times follow a similar pattern, suggesting that trimming of higher travel times should also be possible for the trip from the beginning of the measurement zone to the exit of US primary.

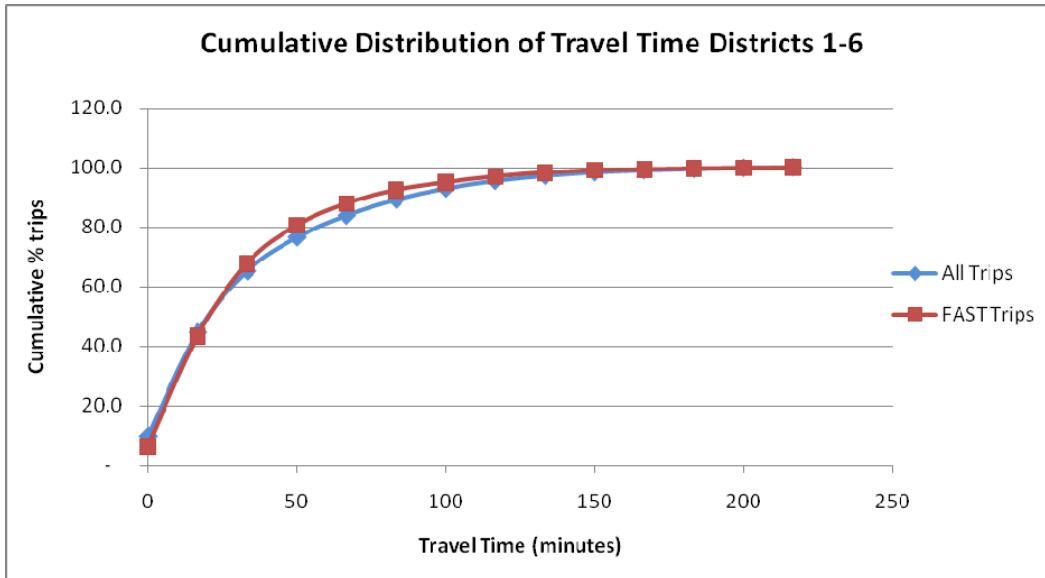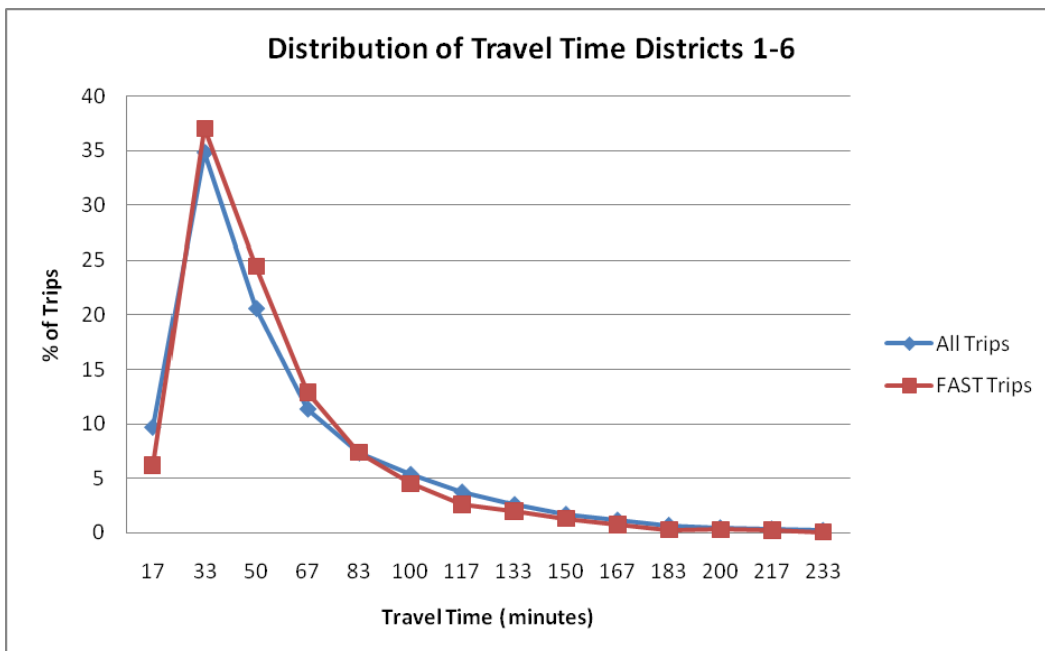**Figure 22. Cumulative Distribution of Travel Times (Dist 1 – 6)**

Figure 23. Distribution of Travel Times (Dist 1 – 6)

3.7 Motor Carrier Feedback

At the conclusion of the data collection period, the study team contacted the two carriers that participated in the project to gain some perspective on their operations, and to gather information related to their typical crossing experience. The principal objective was to ascertain whether the data accurately reflected the conditions they encounter when crossing into the US.

The study team first asked questions regarding the mix of loaded to unloaded trips and FAST to non-FAST trips for each carrier. The intent was to assess the ability of the GPS devices to discern the various trip types. As stated previously, trucks conducting FAST trips follow a path around the southern perimeter of the MX export compound before reaching the point where they actually cross the border and queue for entry into the US.

According to operations staff at the two carriers, the majority of US-bound trips are FAST trips. One carrier indicated that more than 90 percent of traffic was FAST trips, while the second carrier said approximately 75 percent of its US-bound trips were FAST trips. This is in contrast to the GPS data that indicated that approximately 13 percent of trips were FAST trips. While neither carrier offered detailed records to indicate that these figures were close to actual numbers, the implication is clear that the use of GPS data to isolate FAST trips is not an accurate method, at least as it was applied during the project. Further, because both carriers indicated that trucks completing FAST trips typically do not encounter queuing between MX export primary and the physical border, it is logical to conclude that the travel time within the MX export compound (district 4) is too brief to allow a large portion of the trucks to report.

The second major question the team asked the carriers was whether their drivers encounter a high degree of travel time variability when crossing into the US. As indicated previously, the recorded travel times showed a very high degree of variability, whether observing the data by time of day, day of week, or month of the year.

Representatives from both carriers concurred that there is, in fact, significant variability, and that the degree seen in the data could be accurate.[27] This feedback was, of course, anecdotal in nature. As such, it does not alone validate the travel time data. It does, however, lend credibility to them. The study team asked the carriers if they had an insight into why the level of variability might be so large. They both indicated that there are several factors that can contribute to it.

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[27] The carrier representatives were not shown specific numbers regarding variability. They were told, however, that the travel time might deviate by as much as 100 percent or more from the mean on a regular basis.

They suggested that travel time on days just before and just after holidays is typically unpredictable. They also stated that other factors such as significant law enforcement events—major drug interdictions, for example—can have a profound effect on screening practices, at least for a period of time.

Carriers also cited manufacturing-related events as contributors to travel time variability. Because the participating carriers do a significant amount of hauling for maquiladoras, production schedules and factory cutoffs can create spikes in volume. Finally, the carriers stated that systems problems—most notably those associated with managing the flow of documentation for US import—can slow things down. These may be systems operated by customs brokers and banks.

Both carriers cited all of the above conditions as contributing factors that complicate predicting the amount of time needed to cross.

Finally, the study team asked the carriers about the value they perceive GPS-based GPS systems have with respect to their operations. Both carriers indicated that they routinely use the tracking and tracing functions as a means to meet business needs of customers, and to satisfy shipment visibility requirements associated with compliance with C-TPAT. Both use the data on a continual basis.

4 Conclusions

Based on the observed results from the full data collection period, the study team is able to draw a number of conclusions regarding the use of truck fleet GPS data for the measurement of travel time across international border crossings, both in general terms and in terms specific to the Otay Mesa Crossing. These conclusions are offered in the sections that follow.

4.1 Data Validity

As discussed earlier in this report, GPS-based fleet tracking systems have been in commercial use for some time. They have gained the trust of users as an accurate means for locating assets for the purposes of managing operations and providing customers information about shipment status. As such, the team did not consider it necessary to examine the accuracy or measurement precision of the device used for the test. It is a commercially available solution that relies upon standard components and communications methods.

This test focused on the degree to which such devices can adequately characterize travel time on a specific roadway network through a commercial vehicle border crossing. The secondary goal was to assess the viability of GPS-generated travel time data as a means to support real-time traveler information.

With respect to the primary goal, the devices and the processing methods employed to capture and analyze the GPS data succeeded. The combination of reverse geo-coding, which is a commonly employed practice in the use of GPS-based roadway speed monitoring, and the segregation of the border trip into geo-coded segments has proven to be a viable method. There are, however, some considerations that must be taken into account as border stakeholders contemplate its use on a regular basis.

First, the figures reflected in this report are based on a marginally representative sample. While the number of trips and their distribution throughout the day consistently exceeded the three to five percent threshold commonly required for probe vehicle-based traffic monitoring, the carriers that participated are similar to only a portion of those that cross the border. Both carriers are highly reputable companies that are C-TPAT qualified, and conduct a significant portion of their cross-border trips as FAST trips. As such, the test sample was not random, and may not be representative of the general population. However, it is important to note that all FAST trips conducted by all carriers experience the same travel patterns, and occupy the same portions of

the infrastructure. In that regard, the figures shown here can be considered representative for all carriers with similar profiles.

The second consideration that must be taken into account is the location and length of the travel time measurement zone. At the onset of the project, carriers indicated to the study team that queues often extend to the Bellas Artes/Calle Doce intersection. However, the data gathered during the test suggests that traffic often flowed quite freely from there to the sorting gate upstream of the Mexican Customs Export screening point.

The implication is that care should be taken in deciding at what point the border crossing travel time clock should start. It is worthwhile to consider beginning measurement of an individual trip after a vehicle has reached the end of the queue waiting to cross. The time from that point until the crossing is completed is probably of more value to a border user.

In theory, if the first district is too short or is positioned at a point so far upstream that vehicles most often pass quickly through it then it is probably of little value. This was not an issue for the calculation of border travel time during this project, since the number of trips during which vehicles reported in District 1 was nearly identical to the number of reports recorded in District 2. This suggests that the size of District 1 was appropriate. As the number of vehicles providing GPS data increases, this becomes less of an issue, since those not reporting in the first district can be excluded without significantly compromising the dataset.

Alternately, if a lack of reports in the first district occurs with great frequency, it may be appropriate to forego the use of districts altogether and use a combination of vehicle speed data and data that shows the linear distance to defined landmarks—both of which can be obtained using GPS technology—to characterize the operating profile of each trip, rather than use a fixed measurement zone.

Finally, consideration must be given to the implications associated with the large values of standard deviation, and the differences between the mean and median values seen in the data. This level of variability does present particular challenges in formulating accurate values for current travel time, such as might be used in a traveler information system.

This is important because high levels of variability in the data can make it difficult to accurately characterize travel time fluctuations associated with non-recurring congestion, which has a profound effect on travel time reliability.

A larger number of vehicles, spread across a more diverse set of carriers, should improve the data and lower the degree of variability in much the same way. From a statistical standpoint, as

the sample size increases, the proportion of outliers and their influence on the mean values should diminish.

It is not clear at this point the threshold at which that might occur to an acceptable degree. The border environment, while similar to the greater roadway network in many ways, does have some unique characteristics. Most notably, it is very small in comparison to a freeway network around a metropolitan area, for example. In a border zone such as the Otay Mesa crossing, where the trip length is short, travel speeds are typically low, and there is a great deal of commercial clutter in the immediate vicinity, extra care must be taken when defining algorithms for assignment of points to roadway links, and in defining measurement zones that are appropriately sized. On an open roadway network, where speeds are generally higher under normal conditions and monitored roadways are more easily segregated in a GIS overlay, the same level of precision is not required.

It is important to remember that some degree of variability will continue to exist simply due to factors such as variations in the proportion of vehicles participating in secure supply chain operations (such as the C-TPAT and FAST programs), fluctuations in the total number of vehicle crossing during a given period, the number of empty trucks versus loaded trucks passing through the crossing, and the application of various enforcement actions, such as the blocking procedure discussed earlier.

As for the GPS device installed in the trucks of the participating carriers, it is expected that the performance was similar to that of a number of devices currently available commercially. The key performance specifications of the unit were the reporting accuracy and the recording and reporting frequency (3 minutes and less than 10 minutes, respectively). Any device that offers these specifications should suffice for the purposes of travel time reporting. It should be noted that the Otay crossing is located in an area that is largely devoid of features that could interfere with GPS signals, such as closely-spaced tall buildings. For that reason, the performance achieved at Otay may not be similarly achieved in locations where such conditions exist.

4.2   Data Applicability

As discussed above, the results of this project indicate that the applicability of the GPS data for historical analysis is clear. The current dataset has significant planning and analytical value. Using queue modeling techniques, border and transportation agencies should be able to easily examine and model the effects of various practices and configurations. They should also be able to examine real-world effects of such changes through before-after analysis of the data.

This should be of particular value for assessing infrastructure modifications and changes in staffing practices.

The capture and use of real-time—or more accurately, near real time—data presents a set of challenges that were not completely addressed during the project, but the experience offers some useful insights. First, the information exchange and processing mechanisms employed for the project would not be suitable as deployed solutions. The study team received the data via weekly FTP file exchanges, processed the data manually through TransCAD GIS software, and ran algorithms against a static database to derive travel time values. This would not be an acceptable solution for use of the data in near real time.

These mechanisms would need to be replaced with appropriate communications and processing tools and protocols in order to be usable for applications that rely upon timely information processing, such as traveler information systems that might inform border users of current conditions. These sorts of solutions—which use GPS data—are presently in use by various traffic data information providers. For example, INRIX uses GPS data as a component of its travel speed information services under a program it is conducting for the I-95 Corridor Coalition.[28]

In order for the Otay data to be made available for such purposes, three major actions would be necessary. First, the data from the fleets would need to be received as part of a live data feed. One popular method is the use of Extensible Markup Language (XML) connections through a web services environment. These sorts of feeds are relatively easy to establish, and offer flexibility for modification as necessary. Second, the association of individual points received from units with an underlying GIS would need to be automated. Again, this activity is becoming more commonplace. In fact, this is being done as part of a separate project with FHWA.[29] It involves the assignment of individual GPS data points (i.e., latitude, longitude, time stamp, travel heading, travel speed) to pre-defined roadway links, as designated by geo-coded base maps that are typically in use by state departments of transportation. Finally, the transfer of data back to a user (e.g., a DOT) would need to be automated. This could be accomplished in much the same way as the GPS data feed, using an XML data stream exchanged using web services.

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[28] Information available on I-95 Corridor Coalition website at:
http://www.i95coalition.org/i95/Projects/ProjectDatabase/tabid/120/agentType/View/PropertyID/107/Default.aspx

[29] The project is the Real Time Traffic Monitoring (RTTM) component of the Cross-Town Improvement Project (C-TIP). More information is available at: http://www.ctip-us.com/Ctip/home.htm

Each of these actions, as cited above, is relatively commonplace and none require extensive programming. The investment necessary to accomplish this would be modest, though it would certainly be contingent upon the technical sophistication of the entities performing the development and the end users.

The second major challenge associated with the use of the GPS data for real time or near real time operations is the interpretation and use of the data for decision-making purposes. As indicated previously, the data gathered for the Otay crossing over a one year period indicates a high degree of variability for travel time. The implication is that the establishment of a reliable baseline value for the "typical" travel time for a defined period is difficult. It is this baseline value that forms the basis upon which a determination can be made by a user whether current conditions warrant a change in border usage (e.g., a change in departure time or crossing location).

For instance, a user might determine that in order to affect their crossing decision the current travel time must exceed the baseline ("normal") value by 15 percent. That means that if the expected travel time is 60 minutes, the current travel time would need to reach 75 minutes for that user to decide to delay a trip until a later time period. Consequently, the user must trust that the values are accurate and reliable in order to have confidence in his/her decision. The level of variability in the data captured during the test suggests that this user scenario would be difficult to accommodate without some means to mitigate the effects of the variability.

Given this outcome, it is important to remember two things. First, there is no evidence to suggest that the data gathered during the project is not completely accurate. The data simply indicates that the identification of a reliable, precisely-defined mean (or median) value at the Otay crossing is difficult. Carrier input supports the conclusion that the degree of variability is accurate. Hence, this is not an indictment of the validity of GPS data. To the contrary, it appears to be evidence of its accuracy. As indicated above, this may become less of a concern as the volume of baseline data increases, and more stringent filtering can be applied to reduce the affect of outliers on the mean and median values.

Second, it is important to remember that there are few options for local carriers that use the crossing to apply the information in its current state. Carriers must use the Otay crossing since commercial vehicles are not permitted at San Ysidro, and the Calexico crossing is too far to the east to be of use for the local maquiladora traffic. Further, their delivery schedules—at least those of the carriers that participated in the project—are dictated by customers. Where real time or near real time data might be more useful is for the management of agency staff at border

inspection points, or for long-haul truckers that use the port while they are at points distant enough that allow them to re-route or re-schedule to avoid delays.

Ultimately, a larger penetration level of trucks, from a broader cross-section of the user population at the crossing, may have a beneficial effect on the level of variability by driving down the standard deviation.

4.3   Data Accessibility

The data model that was used to access motor carrier data for this project is one of several different approaches employed by GPS data providers. Many data providers obtain GPS data in use for roadway monitoring from the provider of the GPS device and/or service. The data provider for this project chose to seek it directly from the carriers. Ultimately, regardless of the source of the data, if it is generated by a carrier's vehicles, then it is the property of the carrier. As such, the carrier can do with it whatever it desires. Fleet GPS device and service providers may have to obtain permission from their carrier customers in order to re-use the data, as was the case for this project.

This approach presents both benefits and challenges. One potential benefit is that, because the carrier already owns the data for its fleet, and only its fleet, it may be willing to grant access to the data for a modest sum. Further, by working directly with the carrier while agreeing to protect sensitive information from distribution, a data provider could structure its data agreements to allow for the re-use of information for multiple purposes without incurring additional cost.

Perhaps the most significant challenge to this approach is that which was encountered during the recruitment of carriers for participation in this project. The data provider was forced to endure a lengthy courtship process before the carriers finally agreed to grant access to their data. Ultimately, the carriers became more receptive as they recognized that the devices are useful for other functions, as well. Nonetheless, the level of time and effort necessary to execute agreements with the carriers indicates that this should be factored in whenever GPS fleet data is sought.

4.4   Data Value

Even with the level of variability demonstrated in the data gathered during this project there appears to be significant value associated with GPS fleet data. It is important to remember that the nature of the GPS system is such that it continuously generates data, regardless of time or

location. Hence, the very same devices could easily be monitored for other movements, and the data processed to quickly multiply its planning and operations value.

For instance, the data provider already possesses raw GPS data for Mexico-bound movements at the Otay crossing. This means that with the completion of some processing logic, travel time for southbound trucks during the same period could be calculated without additional data collection. Further, raw GPS data has already been recorded for movements both within the areas adjacent to and those beyond the Otay border zone. This data could be used not only for travel time calculation, but also for the identification of origins and destinations and route selection. This also underscores the importance of carefully considering the terms of any data agreement to ensure that the maximum value can be obtained.

Finally, modern fleet GPS devices are becoming both more affordable and more capable, opening up additional opportunities to capture valuable information. One example is the capture of device from a vehicle's engine data bus, which would include such information as throttle position, travel speed and fuel use by location. This has potential value for the identification of locations where excessive idling is occurring—important data for carriers to establish mechanisms to improve fleet fuel efficiency and for agencies to examine the potential environmental value of infrastructure upgrades.

The key to accessing such data requires the definition of the appropriate levels of data access and use rights with the carriers or with service providers. This will require that significant attention is paid to the protection of carrier and driver identity, and restrictions pertaining to the use of the data for ancillary purposes, such as public sector analyses.

4.5   Data Business Model Options

The previous section discussed some of the conclusions associated with the various options for collection and use of GPS data. Obviously, this project was focused on the collection and analysis of a narrow segment of GPS data for the purposes of establishing the usefulness of GPS as a travel time measurement technology. It was also configured and priced accordingly, rather than might otherwise be appropriate for what might be considered a "production" solution.

In order to establish a more meaningful representation of what a customer body might incur for the implementation and operation of a GPS-based solution, the study team worked with Calmar to define and establish potential price ranges for a series of data packages. These are provided in Table 6 below.

The table highlights three different data packages, each containing different types and amounts of data, processed to different levels. Each package is described according to eight different characteristics:

- Content – this describes, at a high level, the data that will be made available by the vendor.

- Data Set Size – this reflects the approximate number of vehicles from which GPS data would be acquired.

- Geographic Scope – this defines the geographic area within which data will be collected.

- Potential Uses – this indicates a brief summary of some of the uses of the data, and what activities it might support.

- Potential Users – this contains a simplified list of potential consumers of the data, by type.

- Output – this defines the proposed format and delivery method for the dissemination of the data.

- Cost Range – this reflects an estimate of initial and ongoing costs associated with establishing and maintaining the proposed data feed.

- Time to Deploy – this offers an estimate of the time necessary to complete carrier recruitment, development of the data feed, and testing prior to deployment.

Table 6. Business Model Options

Data Package Characteristics	Data Package Type		
	Basic	Enhanced	Full
Content	Mildly processed data including basic historical travel time, and raw GPS data with filtering to remove outliers	Fully processed travel time data, plus data traces and files indicating origins and destinations	Fully processed travel time data, plus data traces and files indicating origins and destinations
Data Set Size	Approx. 200 trucks	Approx. 500 trucks	Approx. 1000 trucks
Geographic Scope	Area similar to project area, which includes a limited rectangular are that encompasses length of measurement zone, in both directions across border, along the entire distance of the California border with Mexico	Area that extends from the border, along the entire distance of the California border with Mexico, to the Los Angeles basin to the north, and (to the extent available) to the Ensenada area in Baja California	Area that extends from the border, along the entire distance of the California border with Mexico, to the Los Angeles basin to the north, and (to the extent available) to the Ensenada area in Baja California
Potential Uses	Establishment and refinement of historical travel time dataset to monitor changes over time due to various factors (e.g., facility alterations, operational procedure modification, affect of trade fluctuations, etc.)	Establishment and refinement of historical travel time dataset to monitor changes over time, plus information for route choice modeling and infrastructure investment planning, plus near real time data for integration with existing traveler information systems, for user decisions regarding facility staffing, traffic control, and trip planning	Establishment and refinement of historical travel time dataset to monitor changes over time, plus information for route choice modeling and infrastructure investment planning, plus near real time data for integration with existing traveler information systems, for user decisions regarding facility staffing, traffic control, and trip planning, provided via web site and/or wireless device notification
Potential Users	Planning organizations, customs agencies, shippers, carriers	Transportation system managers, planning organizations, customs agencies, shippers, carriers	Transportation system managers, planning organizations, customs agencies, shippers, carriers, border users
Output	Database file, updated monthly via ftp, plus basic graphical output similar to that produced for this project	Live XML (or similar) data feed suitable for supporting near real time operations and analysis, plus graphical summaries at regular intervals	Live XML (or similar) data feed suitable for supporting near real time operations and analysis, plus a fully functional user interface for interactive access to data
Cost Range	$10K to 12K per month	$40K to $60K plus $14K to $20K per month	$80K to $120K plus $16K to $25K per month
Time to Deploy	3 months	6-9 months	8-12 months

When viewing this information it is important to remember that the figures provided for price ranges are intentionally broad. This is necessary for two reasons. First, until detailed specifications are identified, precise estimates are impossible to make. Only after working with the potential customer can a data provider accurately establish pricing. Second, because this is a commercial venture for Calmar and other similar providers, sensitivity exists regarding the provision of specific pricing data in a public document such as this.

A few assumptions must be considered with regard to the data outlined in the table. First, all data feeds would include basic quality control/quality assurance (QA/QC) provisions (i.e., erroneous and redundant points would be removed), data would be tagged with and trip begin and end identifiers where GPS data patterns suggests such a case exists. Second, the data would primarily consist of latitude/longitude, date/time stamp, speed, link identification, and vehicle identification. Vehicle identification would be a sequentially applied anonymous number that would change daily, or upon some other user-defined criteria.

Finally, two limiting conditions would be placed on the data. Specifically, location information for carrier yards and other confidential locations (i.e., customer locations) would be removed, and activity within ports and rail yards would be excluded using geo-fencing. All locations would be designated as general originations/destinations.

As the information in the table implies, there appear to be ample opportunities to recoup the costs associated with the establishment and maintenance of fleet GPS data beyond that of simply generation of travel time values. Among the most immediately promising applications is the capture of transportation origin/destination data, which is of significant value for transportation planning purposes. Such data can be of use for establishing and validating travel demand models popular with planning staff, and can also offer significant insight into overall roadway usage patterns. Coupled with capabilities to connect to and extract information from engine control units (ECUs), this data could also be used to spatially examine truck operating speeds, idling, and emissions on the roadway network, allowing agencies and carriers to identify trouble spots and adjust investments and operations accordingly.

5   Recommendations

GPS and ALPR both provide potential value in applying the technologies at Otay Mesa; however the study team recommended that the FHWA choose GPS as the primary means of collecting travel time information at the crossing.   FHWA's limited budget made it possible to deploy only one technology and the study team concluded that GPS data would yield the most robust data set with less risk than that associated with ALPR deployment.

While a significant amount of information was captured during the project, the study team recommends that a series of actions be undertaken to establish a complete service for the various potential users of GPS data. These actions will increase the likelihood that the data obtained from a GPS-based system offers the appropriate value and usability to enable the cost of deployment to be spread over a broad set of stakeholders. The team's recommendations are offered below, along with an explanation of the value associated with exercising each of them.

Recommendation #1: Use a Larger Number of Reports.

While the rule of thumb threshold of three to five percent of the total population was successfully reached during the project, the data suggests that a larger population of GPS-equipped trucks could significantly enhance the dataset by reducing the effect of outlier trips on the mean travel time value. The relationship between sample size and variability is not known, but an increase in the number of units to 300 (at the same crossing frequency) should yield definitive evidence of it. Of course, such action would need to be balanced against the cost of the additional devices, and the expected value of the (presumably) more precise data.

Recommendation #2: Increase the Variety of Carrier Participants.

The carriers that participated in the project indicated that the overwhelming majority of their US-bound trips are FAST trips. At the very least, that means that the samples gathered for this project under-represent non-FAST trips. If a GPS data solution is to be deployed in a production setting, the team suggests that the trucks from which GPS data is collected conduct non-FAST trips into the US at a representative frequency.

Recommendation #3: Examine Secondary Uses for Data.

The measurement of travel time for vehicles entering the US represents only a small portion of the value to be extracted from GPS data. These devices are typically on when the vehicle is running, offering the opportunity to examine movements, origins and destinations, idling points, and various travel delays throughout a vehicle's duty cycle. Those entities that adopt GPS-

based systems should examine these and other secondary uses for the data in order to realize its full value. For instance, a significant volume of data was captured during the project regarding southbound movements, but it was not analyzed because it fell outside the scope of the project. At this point, the value and usefulness of this data is unknown.

Recommendation #4: Use Extended Data Collection to Reinforce Calculations & Diminish Variability.

Much in the way that an increase in the number of trucks using the crossing should reduce variability and enhance confidence in the data, so too should the capture of data over a long period of time. Doing so will likely lend stability and reduce variability in historical travel time data, thereby reducing the effects of outliers. Additionally, external factors such as the level of economic activity will also affect the figures. Collecting data over an extended period offers the opportunity to examine the effects.

Recommendation #5: Examine and Test Near Real Time Data Use.

Although GPS-based traffic monitoring solutions are being used in other locations on a real-time basis (e.g., I-95 Corridor Coalition), the usefulness and usability of similar data in the border environment is still largely unknown. The approach used for this project offers an opportunity to examine whether enough value can be extracted to affect agency and carrier decisions during the course of everyday operations. This could be accomplished through a continuation of data acquisition and analysis activities, with the participation of and interaction with users who have access to a near real time data feed.

Recommendation #6: Pursue Transfer of Data Acquisition Oversight and Funding to State/Local Agencies, Customs Agencies, or Others.

It is understood that FHWA does not have an ongoing operations function at international border crossings, and that its primary role is the conduct of research and support for deployment of solutions that enhance the nation's transportation system. Hence, the funding and use of systems that measure border travel time are the purview of border management agencies, agencies with responsibility over local transportation infrastructure, and the border user community. The results of this project establish the viability of GPS technology for travel time measurement. They also present an opportunity to explore how a transition to a production solution might take place through the leveraging of carrier relationships established during the test, the expansion of data coverage to a comprehensive geographic scale, and the examination of opportunities for secondary data uses.

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16. Abstract The Federal Highway Administration (FHWA) sought to examine the use of technology to support the automated collection of border crossing travel time data at the Otay Mesa international port of entry (POE), with the intent of gaining an understanding of the degree to which it might be usable for improving operations and planning at border crossings throughout the US. The study involved the deployment and use of Global Positioning System (GPS) devices to capture the movements of a sample of trucks passing through the Otay Mesa POE. The Otay Mesa POE is a truck-only crossing located between the US and Mexico south of San Diego, CA. The study examined the viability of the GPS technology approach, and resulted in the capture of historical travel time data over the period of one year.			
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