Texas Commission on Environmental Quality

Developing An Emissions Estimation Tool For El Paso Border Crossings

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DEVELOPING AN EMISSIONS ESTIMATION TOOL FOR EL PASO BORDER CROSSINGS

REVIEW DRAFT

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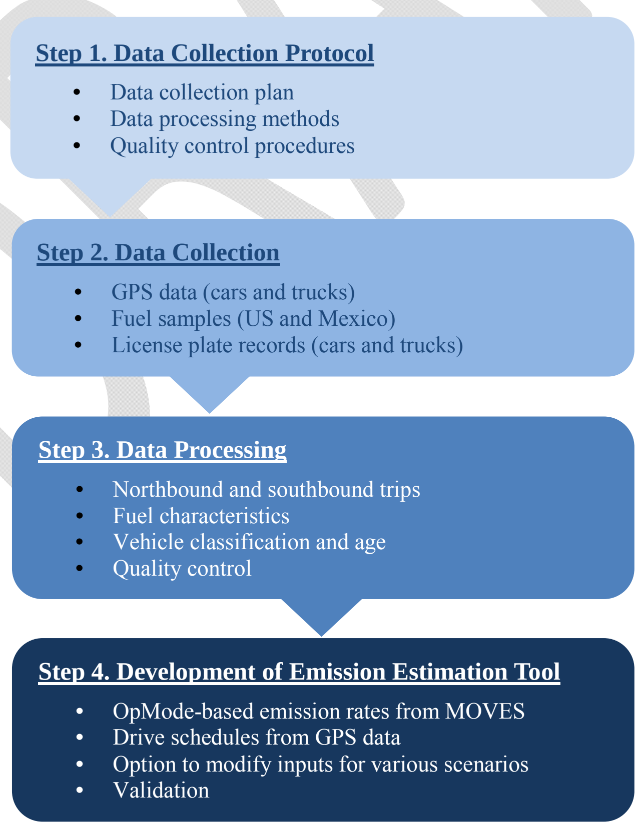
EXECUTIVE SUMMARY

Although border crossing traffic contributes a significant portion of emissions at various border crossing bridges along the U.S.-Mexico border, there is currently no standard methodology to estimate their portion of the on-road mobile source inventory. This is specifically important for nonattainment areas on the border such as El Paso.

Texas A&M Transportation Institute (TTI) researchers developed a methodology to specifically estimate the emissions produced at border crossings. TTI researchers used the U.S. Environmental Protection Agency's (EPA) MOtor Vehicle Emission Simulator (MOVES) model to develop the emissions rates and construct the tool. The EPA developed MOVES to estimate emissions from mobile sources. However, because the national average driving patterns used in MOVES fail to represent the special driving patterns of vehicles crossing the border, researchers developed a methodology to estimate emissions specifically for border crossing conditions. Global Positioning System (GPS) units were used to collect second-by-second vehicle activity data. These data along with other relevant information obtained from a series of data collection efforts at a sample of El Paso-Juarez border crossing locations were incorporated into the emissions estimation tool.

The border emissions estimation tool is established as a stand-alone Microsoft Excel® tool. The TTI research team used a four-step process to develop the border crossing emissions estimation tool. The following graphically presents this process.



Step 1 consisted of developing required processes and procedures including a detailed data collection plan, data processing methods, and quality control procedures. The team began with a review of the literature and available data sources. The required data elements and available data were identified. This information combined with the local knowledge of the TTI El Paso staff was used to develop the data collection plan. The data collection plan focuses on collecting data on three critical parameters deemed necessary for the emissions estimation tool; i.e., vehicle activity data, border crossing fleet composition, and fuel characteristics. The research team also identified and developed necessary data processing methodologies based on the previous work by the research team. Finally, a detailed quality assurance and quality control (QA/QC) plan was developed documenting various elements of the data collection and processing steps and required QC procedures for different data element and procedures.

In Step 2, the research team executed the data collection plan for a sample of border crossing bridges in the El Paso- Juarez Regions; i.e., the Bridge of the Americas (BOTA) and Ysleta-Zaragoza Bridge. GPS units were used to collect second-by-second speed and location data for a sample of light- and heavy-duty vehicles engaged in the border crossing activity.

The GPS data collection process included two parallel efforts — planned data collection on pre-defined routes for light-duty vehicles and normal vehicle activity for heavy-duty vehicles (HDVs). The first data collection effort consisted of a TTI staff member driving a GPS-equipped vehicle on a predefined route along the target network (i.e., border crossings) during a set period of time. The HDV data collection effort consisted of recruiting drayage fleet vehicles to record their normal border crossing activities during an extended period of time. Each vehicle was equipped with an assembly of three GPS units.

To obtain information on the vehicle fleet mix for vehicles crossing the border crossing bridges, the research team performed an extensive vehicle license plate data collection effort at the two target border crossing locations. Where the vehicle license plate was not available or was not unique, i.e., some drayage trucks, the vehicle identification number (VIN) was collected. Different forms were developed, one for the passenger vehicles, and one for the commercial vehicle lanes. Because the international bridges are closely monitored by the U.S. Customs and Border Patrol (CBP), permission was obtained from CBP to collect data on the bridges. The research team also obtained permission to collect the data for commercial vehicles from the Texas commercial vehicle inspection stations. A total of 11,143 unique vehicle crossings were recorded in this effort.

To determine fuel characteristics, gasoline and diesel fuel samples were collected from various gas stations in El Paso and Juarez. The research team used special containers for the fuel sampling. A sample size of five samples of each fuel type was collected from each area; i.e., 20 fuel samples. All the fuel samples were sent to the Southwest Research Institute (SwRI) for laboratory testing.

In Step 3, the research team processed the data obtained from the previous step and performed a series of quality control checks in the process. The license plate and VIN data in the database were divided into separate databases based on the vehicle type and vehicles' country of registration. All of the Texas vehicles were separated into one database while the Mexico vehicles were separated into passenger and commercial vehicles data sets. The Texas

Department of Motor Vehicles (TxDMV) processed the Texas vehicles data set and provided the research team with the required information on each vehicle. The data set of Mexico passenger vehicles were processed by Chihuahua's Recaudador de Rentas in the same manner. The commercial vehicles' dataset was sent to the Mexican federal agency the Secretaría de Comunicaciones y Transportes. In all instances, the vehicle type information of make, model, and model year was obtained for each individual vehicle. These data were used to generate the default age distribution profiles for different vehicle types in the estimation tool.

The results of the laboratory testing were used to prepare the fuel input tables for MOVES. The data processing and analysis of GPS data were conducted per the following general steps.

1. Quality control and validation of raw data – This step involved examining the speed and location data from the GPS units to determine their validity, and identify errors and outliers in the data. The faulty information was filtered out and a database of verified unprocessed data was established. Multiple error detection criteria were developed for this step.
2. Data processing – This step consisted of merging information from the three GPS units in each assembly, extracting micro-trips, and categorizing them by the target area, road classification (highway/freeway or arterial/local), average speed bin, and type of area (urban or rural). A Geographic Information System (GIS) application was used for this purpose.
3. Data analysis and drive schedule development – The processed data were analyzed according to a drive schedule selection algorithm that the research team developed to identify and extract border crossing trips.

The research team used all the information obtained in the previous steps to develop a Microsoft Excel®-based emissions estimation tool. The estimation methodology is based on MOVES' underlying; i.e., calculations are all based on operating mode (opMode) bins. The border crossing drive schedules were first translated into opMode bin distributions and stored in data table. The research team then used MOVES to extract emissions rates for each opMode bins for different vehicle types and based on various parameters such as season, fuel type, and time of day. In total, researchers ran MOVES 2010b for 400 different sets of conditions. The following is a summary of these conditions:

- 2 Locations – El Paso | Ciudad Juarez;
- 2 Seasons – Summer | Winter;
- 2 Fuel Types – Gasoline | Diesel;
- 3 Vehicle Types – Passenger Cars | Passenger Trucks | Combination Short-Haul Trucks;
- 4 Time-Periods – AM Peak | Midday | PM Peak | Overnight;
- 7 Pollutants – THC | CO | NOx | CO_2 | PM_{10} | $PM_{2.5}$ | PM-EC;
- 25 Analysis Years – 2010 to 2035; and
- 31 Vehicle Ages – 0 to 30+ years-old.

These emissions rates along with other data elements were implemented into an Excel-based emissions estimation tool for border crossings. The tool combines the calculated operating mode distribution with the emissions rates obtained from MOVES, the user-supplied volume data, and the default time-periods to generate estimates of emissions for the target scenario. The tool calculates separate emissions for each set of conditions (i.e., season, time-period, location, traffic direction, vehicle type, vehicle model year, fuel type, and pollutant) and sums these calculations to produce the total emission estimates.

The resulting border crossing emissions estimation tool enables users to quickly prepare and execute emissions estimation runs for a variety of conditions and scenarios. While the emissions estimation tool is based on the field data collected in El Paso-Juarez area, the structure of the estimation process is independent from the data and thus, can be easily updated using local emissions rates and vehicle activity data for other locations.

CHAPTER 1
INTRODUCTION

The El Paso area is currently in nonattainment for particulate matter (PM_{10}) and on the verge of being in nonattainment for carbon monoxide (CO) emissions. It will likely fall into nonattainment for ozone as well, as the U.S. Environmental Protection Agency (EPA) recently proposed more stringent ozone standards. Although cross border truck traffic produces a significant portion of these emissions, there is currently no methodology to estimate their portion of the on-road mobile source inventory.

With this in mind, Texas A&M Transportation Institute (TTI) researchers developed a methodology to estimate the emissions produced at border crossings. Data used in this effort were obtained from El Paso-Juarez border crossings. They also established this methodology in a Microsoft Excel® tool to help ensure that the cross-border vehicle activity can be calculated easily for different purposes. This methodology will directly assist the El Paso area agencies, and potentially other border location agencies, in accurately measuring the impact of cross-border vehicle activity and emission control strategies and incorporating these impacts in their decision making processes.

Researchers used the EPA's MOtor Vehicle Emission Simulator (MOVES) model extensively to develop the emission rates and construct the tool. The EPA developed MOVES to estimate emissions from mobile sources. However, because the national average driving patterns used in MOVES fail to represent the special driving patterns of vehicles crossing the border, researchers developed a methodology to estimate emissions specifically for border crossing conditions. Geographic Positioning System (GPS) units were used to collect second-by-second vehicle activity data. These data along with other relevant information obtained from a series of data collection efforts at a sample of El Paso-Juarez border crossing were incorporated into the emission estimation tool.

CHAPTER 2
BACKGROUND AND LITERATURE REVIEW

This chapter presents the findings of literature review covering existing information on the target study area, border crossing vehicle activity, and emissions characteristics of vehicle at border crossings.

El Paso Area Conditions

There are six border crossings in the El Paso region. The Bridge of the Americas (BOTA), Ysleta-Zaragoza, and Santa Teresa crossings handle both commercial and passenger vehicles, while the Paso Del Norte, Stanton, and Fabens-Caseta crossings handle only passenger vehicles. The area features up to 44 passenger lanes and 17 commercial lanes, although many of the inspection booths are under-staffed and, depending on the time-of-day, may not be open. Furthermore, some lanes are only available to registered vehicles – the FAST program is for commercial vehicles, and the SENTRI program is for passenger vehicles.

People cross the border for a number of reasons, including work, school, shopping, and medical services. Over 7.5 million pedestrians and 20,000 buses crossed the border in 2009, and nearly 13 million passenger vehicles and 650,000 commercial vehicles crossed northbound into the U.S. in 2010. Many of the trucks that cross the border are short-haul drayage trucks, which are often used to transfer trailers between long-haul trucks on either side of the border. In El Paso, short-haul drayage trucks typically make 4-to-6 individual crossings per day.

The Mexican vehicle fleet is much older than the American fleet. About 55 percent of the Mexican drayage fleet is model year 1993 or older, and about 25 percent is older than model year 1980. Vehicle age can significantly impact emissions, as trucks that were made before 1993 typically lack automatic fuel injection and computer controls designed to reduce emissions and improve fuel economy.

Existing Research

The TTI research team reviewed the most salient emission estimation methods (i.e., MOVES model) and associated components (i.e., drive schedule development) used for similar studies. The following paragraphs describe a Cambridge Systematics study in detail and summarize a number of additional studies that researchers considered.

***Cambridge Systematics 2011 Study* (*1, 2*)**

In 2011, Cambridge Systematics estimated emission rates for a variety of traffic conditions and lanes based on data obtained from the BOTA and Ysleta-Zaragoza border crossings in El Paso. This study was conducted for the Federal Highway Administration (FHWA) and was intended to develop an approach to estimate emission rates for the U.S.-Mexico border crossings. The study considered volatile organic compounds (VOC) oxides of nitrogen (NO_x), CO, $PM_{2.5}$, PM_{10}, ammonia (NH_3), sulfur dioxide (SO_2), and atmospheric carbon dioxide equivalent (CO_2e) emissions.

Approach/Methodology

A major component of the Cambridge Systematics study was to develop MOVES operating mode profiles to simulate different congestion conditions. The study applied MOVES at the project level, rather than at the county or national level, and considered three types of vehicle behavior — stop-and-go queuing, creeping queues, and uncongested operation. Stop-and-go queues are heavily congested (i.e., storage lanes) and experience average speeds of less than 1 mph, creeping queues are slightly less congested (i.e., roadway segment feeding stop-and-go queue) and experience average speeds around 5 mph, and uncongested operation, which typically occurs on roadway segments leading up to queues, experience speeds ranging from 25-to-35 mph. The study also considered "off-network" vehicle activity, including extended truck idling and vehicle starts that occur off of a road network.

The Cambridge Systematics researchers based the development of the operating mode profiles on a microsimulation model in VISSIM for the BOTA and Ysleta-Zaragoza ports of entry, which Cambridge Systematics had previously developed for the Texas Department of Transportation (TxDOT) as part of the El Paso Regional Ports of Entry Operations Plan. They developed 21 links to represent the three types of vehicle behavior (described in the previous paragraph) and seven different lane types:

1) Northbound FAST Trucks;
2) Northbound Unladen Trucks;
3) Northbound Laden Trucks;
4) Southbound Trucks (all types);
5) Northbound Autos;
6) Northbound SENTRI Autos; and
7) Southbound Autos (all types).

To estimate idling emissions and off-network emissions, they developed two additional links. Link average speeds were based on the microsimulation models and adjusted to the lowest allowable speed for MOVES. Because MOVES can only be run for one hour of any given year (at the project level), the Cambridge Systematics methodology established representative run specifications for hours of the day, days of the week, and months of the year. Runs were thus performed for January and July, for the AM peak, mid-day, PM peak, and overnight for 2010, 2015, 2025, and 2040. Figure 1 provides an example of the estimated emissions results.

The study was conducted partially to determine how results could be applied to other locations, and researchers investigated the following input parameters:

- Activity Information (vehicle volumes, types, and payloads);
- Infrastructure Information (traffic and lane conditions);
- Combustion conditions due to ambient temperature and humidity;
- Engine power adjustments for road grade and elevation;
- Off-network traffic activity;
- Additional vehicle profile detail (age, registration, model); and

- Directional similarity or difference (northbound versus southbound).

In addition, freight traffic was the study's primary concern, rather than passenger vehicle activity. Different values and parameters for each port of entry in the border region are reported in the tables included in Task 3E of the technical memo. Based on the characteristics of the El Paso port of entry, the following were determined to be the most similar:

- Laredo, TX;
- Hidalgo, TX;
- Calexico East, CA;
- Nogales, AZ;
- Brownsville, TX; and
- Otay Mesa, CA.

The largest ports of entry that were significantly dissimilar to El Paso include Lukeville, Sasabe, Naco, Roma, Columbus, and Presidio. Analysis of these locations would likely include significant re-calculations.

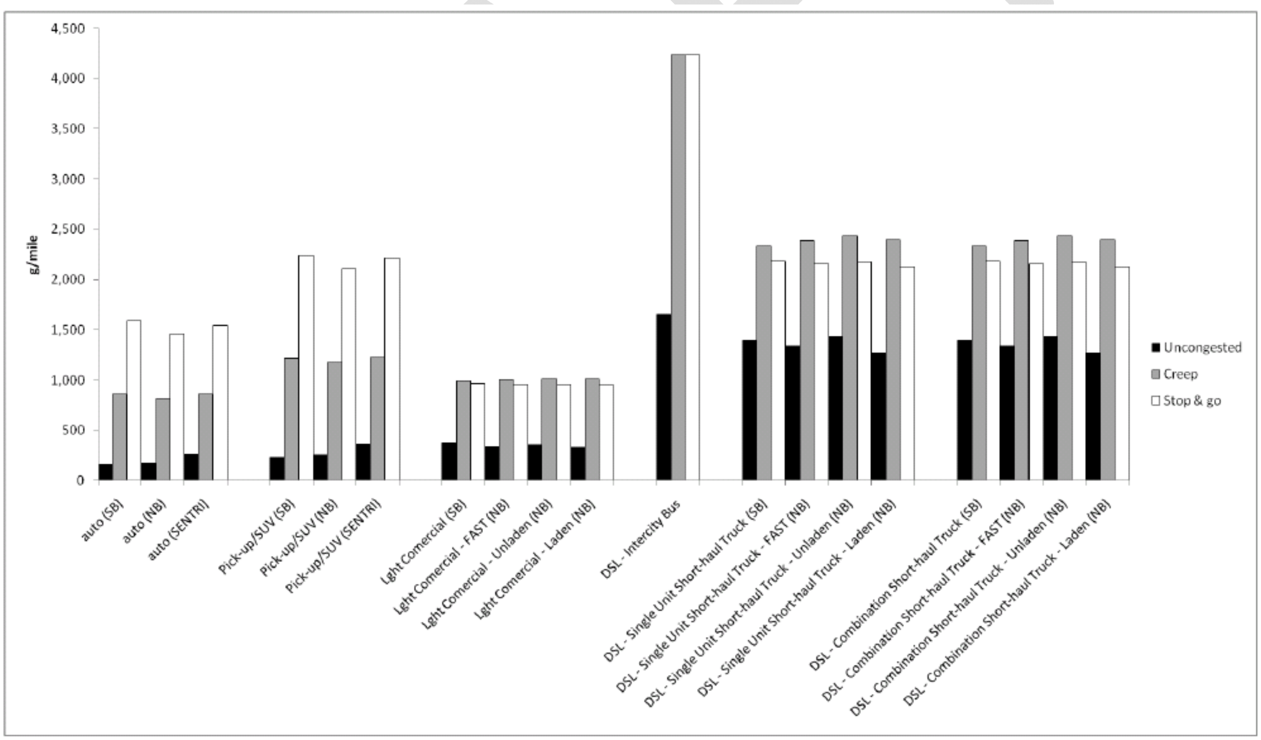


Figure 1. Sample CO_2 Emissions from the Cambridge Systematics Study.

Data Sources/Assumptions
The following paragraphs and Table 1 describes the data sources and assumptions that Cambridge Systematics used to conduct the study. These paragraphs list the data sources and assumptions by their respective MOVES inputs.

Link and Link Source Type - Links are the roadway segments in the transportation network, and they include specifications for the road type (i.e., arterial or freeway), average speed, link length, link volume, and link grade. The link source type is the portion of the link's volume counts by source type (or vehicle type). A number of these inputs were available from the Cambridge Systematics project that was conducted for TxDOT, the City of El Paso, and the El Paso Metropolitan Planning Organization. All commercial trucks crossing at BOTA and Ysleta-Zaragoza were modeled as short-haul trucks based on a 2005 TTI study which found that a majority of the trucks crossing at the two POEs were short-haul trucks. Cambridge Systematics calculated the proportion of MOVES source types based upon this 2005 TTI study and an EPA technical guidance document entitled *Population Mapping from MOBILE6.2 Vehicle Types to MOVES Source Types*. The Cambridge Systematics team did not provide these data in the methodology documentation. They based the U.S. passenger vehicle type proportions on the El Paso County vehicle type distribution information, which the TCEQ uses for the county emissions inventory. Mexican passenger vehicles' were distributed based on a 2009 study for the Monterrey Metropolitan Area. A 50 percent split between U.S.-registered and Mexican-registered passenger vehicles was assumed. Based on a U.S. DOT RITA study, the split for commercial trucks, passenger vehicles, and buses was 6.7 percent, 93.1 percent, and 0.2 percent, respectively. As this indicates, buses were included in this analysis and were assumed to be MOVES source type 41 (or intercity bus).

Operating Mode Distribution - Operating modes specify the drive cycles, which include second-by-second speed and acceleration information. Cambridge Systematics used PTV Visum, a microsimulation model, to estimate vehicle-specific power (VSP) profiles for three types of queues: stop-and-go, creeping, and uncongested movements. They also used the Visum model to develop second-by-second speed, acceleration, and location cycles, as well as average speed data by vehicle type and vehicle weight (i.e., Northbound FAST trucks, Northbound Unladen trucks, Northbound Laden trucks, Southbound All trucks, Northbound autos, Northbound SENTRI Autos, and Southbound All autos).

The Cambridge Systematics researchers calibrated the model outputs by using border-crossing vehicle counts, which they obtained from Customs and Border Protection (CBP) and the City of E Paso Toll Plaza for Ysleta-Zaragoza. They calibrated hourly demand model outputs against CBP reported hourly wait times for automobiles, regular trucks, and FAST trucks; they calibrated queue lengths against queue diagrams drawn by the study team on major approaching roadways. Note that they used average speeds for buses, rather than operating mode distribution. It was assumed to be the same average speed as for trucks.

Age Distribution - The Cambridge Systematics team obtained the age distributions for light commercial and short-haul trucks from the Texas Department of Safety. To account for the fact that the same model year Mexican truck has higher emission rates than the U.S. equivalent, they developed a separate age distribution for Mexican trucks by shifting the age to make the trucks 'older.' The study team subsequently calculated a weighted combined age distribution for U.S. and Mexican trucks crossing at BOTA and Ysleta-Zaragoza. They based the age distribution for U.S. passenger vehicles on El Paso County data that the Texas Commission on Environmental Quality (TCEQ) developed for the On-Road Mobile Sources MOVES Emissions Inventory.

They based the age distribution for Mexican passenger vehicles on a 2004 study of the Mexico City passenger vehicle fleet.

Fuel Formulation - The team used separate fuel formulations for U.S. vehicles and Mexican vehicles. For the U.S., they used the default MOVES fuel formulations for El Paso. The Material Safety Data Sheet provided by PEMEX for on-road diesel revealed a higher Reid Vapor Pressure for Mexican fuel, which could lead to higher VOC emissions. It was assumed that 78.1 percent of the fuel purchased by trucks was purchased in Mexico and that passenger vehicle operators purchased fuel in their country of origin. Furthermore, based upon the 2004 Mexico City study, it was assumed that 0.6 percent of the passenger vehicles registered in Mexico used diesel fuel.

Meteorology and Inspection/Maintenance Programs - The meteorology data is comprised of average hourly temperature and relative humidity data. Inspection/Maintenance (I/M) programs establish the type of inspection and maintenance programs, who they apply to, how often the vehicles are tested, and the compliance rate. For both Mexico and the U.S., the Cambridge Systematics researchers used El Paso County meteorological data inputs, which the TCEQ developed. For I/M programs, they combined I/M program data for both countries. They used Ciudad Juarez I/M program data for Mexico and El Paso data for the U.S.

Issues/Concluding Remarks

Cambridge Systematics produced tables that list the data required to run MOVES to estimate emissions at border crossings on the U.S.-Mexico border. These tables reference the available data sources, the need for obtaining the data to ensure robust model results, the process for obtaining missing data, and the cost considerations. TTI researchers developed Table 2 from the Cambridge Systematics tables included in Technical Memorandum 3F.

Table 1. Data Sources for Cambridge Systematics Study

<table>
<tr><th>Data Type
(MOVES Inputs
Requiring Data)</th><th>Mixed Car
Lanes</th><th>POV
Lanes</th><th>Mixed Truck
Lanes</th><th>Regular Commercial
Lanes</th><th>FAST
Lanes</th></tr>
<tr><td>Vehicle Types/Weight
(Inputs: Links, Link Source Type)</td><td colspan="2">• 2011 El Paso Regional Ports of Entry Operations Plan study.
• U.S. passenger vehicles: TCEQ 2008 data (El Paso County).
• MX passenger vehicles: data from a 2009 study of the Monterrey Area (National Institute of Ecology).
• Buses: U.S. DOT RITA 2010 data (0.2% traffic). All intercity buses.</td><td colspan="3">• 2011 El Paso Regional Ports of Entry Operations Plan study.
• 2010 Data from the Texas Department of Public Safety.
• Data from a 2005 Texas Transportation Institute study.</td></tr>
<tr><td>Age Groups, Vehicle Registration
(Inputs: Age Distribution)</td><td colspan="2">• U.S. passenger vehicles: TCEQ 2008 data (El Paso County).
• MX passenger vehicles: data from a 2004 Mexico City study International Sustainable Systems Research Center). Adjust age distribution to account for different emissions standards.</td><td colspan="3">• 2011 El Paso Regional Ports of Entry Operations Plan study.
• 2010 Data from the Texas Department of Public Safety. Adjusted age distribution to account for different emissions standards.</td></tr>
<tr><td>Traffic Count (by Hour)
(Inputs: Links, Link Source Type)</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td></tr>
<tr><td>OpMode Distribution Peak
(Inputs: OpMode)</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td></tr>
<tr><td>OpMode Distribution Off-Peak
(Inputs: OpMode)</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td></tr>
<tr><td>Wait time (by Hour)
(Inputs: Off-network)</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td><td>Cambridge Systematics</td></tr>
</table>

Diesel versus Gasoline (Inputs: Fuel Supply)	• U.S. fuel mix: TCEQ 2008 data (El Paso County) for gasoline/diesel mix. • MX fuel mix: data from a 2004 Mexico City study International Sustainable Systems Research Center): 0.6% of cars are diesel. • Fuel market share: assume U.S. vehicles buy fuel in the U.S. and MX vehicles buy fuel in Mexico. The team will compare the U.S./MX fuel mix and determine if an AVFT (Alternative Vehicle Fuels and Technologies) input is required to account for the difference in diesel fractions. • Buses fuel mix: diesel only.	• HDV fuel mix: use data from a 2005 Texas Transportation Institute study (provides the distribution of gasoline versus diesel vehicles). • Fuel market share: use data from a 2006 study from the Institute of Transportation Studies at the University of California, Davis (78.1% of the fuel is purchased in Mexico).
Fuel Types (Inputs: Fuel Supply, Formulation)	• U.S. fuel: TCEQ 2008 data (El Paso County) for gasoline/diesel formulations. • MX fuel: create a new MOVES fuel formulation (gasoline) to account for higher RVP standards in the summer. Based on data from the Mexican Fuel Standards (Norma Official Mexicana Nom-086-Semarnat-Sener-Scfi-2005). Diesel is similar based on sulfur level in standards.	• U.S. fuel: TCEQ 2008 data (El Paso County) for diesel formulations. • MX fuel: Diesel is similar based on sulfur level in standards. Add a caveat in documentation about ultralow sulfur diesel not being available yet in all MX stations. Emissions modeling done according to standards.
Inspection and Maintenance (Inputs: I/M programs)	• U.S. passenger vehicles: TCEQ 2008 data (El Paso County). • MX passenger vehicles: data from the I/M program for the city of Juarez (programa de verificacion vehicular de emisiones para el Municipio de Juárez 2011-2013). • Compared inspection procedures and created a combined I/M program for U.S./MX vehicles (most likely, adjustment of compliance ratios since it is not possible to "create new" I/M programs, unlike fuels).	• Not Applicable: I/M programs do not impact trucks; thus MOVES does not model I/M programs for trucks.
Temperature/Humidity (Inputs: Meteorology)	• TCEQ 2008 data (El Paso County) for meteorological data.	

Table 2. Data Gaps in Running MOVES for Border Crossing Emissions Estimates.

Data Category	Data Description	Existing Data Source	Existing Source Availability and Contact	Degree of Importance	Process to Obtain	Cost Considerations
Links and Link Source Type						
Links (all link information is specific to each Port of Entry by direction):						
Vehicle volumes by hour, by season, by source type, and vehicle type (MOVES source types or HPMS classes)	Hourly average day vehicle volumes by source type (MOVES source types include: passenger cars, passenger trucks, intercity buses, light-commercial truck, single short-haul, single long-haul, combination short-haul, and combination long-haul trucks) by season (winter and summer) and by vehicle type (FAST trucks, unladen trucks, laden trucks, autos, SENTRI autos)	Traffic counts from toll operators or Customs officials, recent manual traffic counts or border crossing surveys, regional travel demand model data, State/Local HPMS VMT data	Traffic counts are usually available, although detail by vehicle type usually not available. Survey data either not recent or insignificant sample sizes. State/Regional or Local data available through DOT, DPS, MPO, or county/city agencies.	High	1. Automated traffic counts 2. Manual traffic counts with video for quality confirmation	1. Roadway sensors/tubes would provide axle and weight data, but still need extensive manipulation to break vehicles into classes and requires permits to install equipment 2. Manual field counts require multiple staff and use of video collection (through repurposing existing cameras or setting-up new)
Average peak and off-peak delay	Total number of vehicles processed by hour (peak and off-peak) by direction by vehicle type and lane type (NB FAST trucks, NB unladen trucks, NB laden trucks, SB trucks, NB autos, NB SENTRI autos, SB autos) or average time spent in delay (creeping queue + stop-and-go queue)	CBP average wait time data, previous survey/data collection programs	CBP wait time are estimates and addresses NB only, survey and data collection needs to consider both NB and SB delays at outbound and inbound inspection points	High	1. Interviews of border toll booth operators and/or U.S. and Mexican customs officials supported with multi-day field review 2. Bluetooth or RFID electronic signature data collection	1. Scheduling and conducting interviews, multiple staff and field visits required 2. Number of border crossings, detail of study (ie number of data collection points), setup of communications equipment

Data Category	Data Description	Existing Data Source	Existing Source Availability and Contact	Degree of Importance	Process to Obtain	Cost Considerations
General information regarding physical layout of border crossing	Border approach link capacities (facility type, # of lanes) and border crossing link capacities (# of lanes, # of booths, average # of booths open (peak and off-peak), queue lane lengths)	Aerial photography, CBP and Mexican Customs information, recent border operation plans or surveys	Information available through publically accessible high-res aerial photography and CBP and Mexican Customs information. Recent operations planning or engineering/operations projects with border crossing schematics/engineering drawings.	High	Web search	Free access, labor cost involved with interpreting and summarizing border layout characteristics
Average roadway grades	Average grade for border crossing links	Available through border crossing planning/design documents, or topographic maps/GIS data	Border crossing operator, publically accessible GIS data	Medium	Additional interviews with border operator to confirm grades as well as other physical characteristics of the border noted in above row	Minimal costs - conducting phone interviews

Data Category	Data Description	Existing Data Source	Existing Source Availability and Contact	Degree of Importance	Process to Obtain	Cost Considerations
Source Type:						
County of origin/ registration and age distribution by source type	Trucks - truck make, model year, state or country of registration, and total border crossing count, Passenger vehicles - regional vehicle type age distribution	Registration data supporting conformity/SIP analysis	Registration data supporting conformity/SIP analysis from State DEQ/DEP or MPOs, Mexico National Institute of Ecology	Medium - High	Vehicle type/country of origin survey with license plate reader tied to VIN number and registration data	Manual survey effort requires staff time and approval from Customs officials, license plate readers require staff time in the field, data interpretation, and arrangement with registration data holders to obtain age information
Operating Mode Distribution –						
Share of travel by speed bin and vehicle type for three operating modes (uncongested, creeping queue, stop-and-go queue) for peak and off-peak periods	Daily or hourly vehicle volumes, when taken in context with the infrastructure (number of lanes/type of lanes, number of booths/type of booths) and the hours of operation at the POE, can establish an estimate of the extent of delay and average queue lengths for each lane type at the border crossing. Queue lengths by vehicle type, combined with link grades are a critical component of operating mode distribution.	Data from in-vehicle instrumentation recording second-by-second operations	Only available if studies have been conducted	Medium	1) Calculation/ assumptions based on average delay and queue length information 2) Vehicle instrumentation and collection program	1) Minimal cost, technical staff time only 2) Arrangements with vehicle operators/owners, purchasing of instrumentation equipment, interpreting data

Data Category	Data Description	Existing Data Source	Existing Source Availability and Contact	Degree of Importance	Process to Obtain	Cost Considerations
Off Network –						
Average extended idling time (wait time)	Trucks stopping and restarting, and idling for inspections are accounted for as off-network - MOVES estimates emissions rates based on soak time (i.e., a specific start emission rate was developed for each specific soak, or idling time). Average wait time at each border inspection by direction supports this MOVES estimate	CBP, Mexican Aduana information on share of vehicles receiving secondary inspections and time to clear inspections	Likely institutional/ security barriers to obtaining data from customs officials	High	Could be obtained through a detailed license plate survey that times vehicles as they proceed through multiple inspection points. Field data collection - 3+ staff per direction to record license plates at multiple points (primary inspection, secondary inspection, clear all inspections)	Staff needs and obtaining permission from border crossing operator/Customs to collect data
Other Inputs –						
Inspection and maintenance program information (for areas with such a program)	13 Border Crossings are in areas with current SIPs. SIP provide requirement details for federal I&M programs. California has separate, more stringent I&M requirements.	US EPA SIP Report Website (by state)	http://www.epa.gov/air/urbanair/sipstatus	High	Download from website	Free access, labor cost involved with accessing and interpreting SIPs and related technical documentation

Data Category	Data Description	Existing Data Source	Existing Source Availability and Contact	Degree of Importance	Process to Obtain	Cost Considerations
Fuel formulation and supply data (seasonality, RVP, ULSD, etc…)	13 Border Crossings are in areas with current SIPs. SIPs provide details for locally required federal fuel formulation. Federal and state requirements for non-SIP areas available from separate state and EPA sources. California has separate, more stringent fuel formulation standards. Mexico national and regional fuel formulation requirements are available from Instituto Mexicano del Petróleo	US EPA SIP Report Website (by state), Instituto Mexicano del Petróleo	http://www.epa.gov/air/urbanair/sipstatus	High	Download from website	Free access, labor cost involved with accessing and interpreting SIPs and related technical documentation
Meteorology information (temperature and humidity by AM, midday, PM, overnight) and by season (winter & summer)	Detailed (hourly temp, humidity and wind) localized meteorology required for SIP modeling available for SIP areas. Similar detailed regional meteorology (generally at 12km x 12km resolution) available for all locations from regional air pollution models (e.g., CMAQ, CAMx, CalPuff)	US EPA Support Center for Regulatory Atmospheric Modeling (TTN/SCRAM) Mexican data is available through National Institute of Ecology or other local sources	http://www.epa.gov/ttn/scram/aqmindex.htm http://www.imp.mx/	High	Download standardized meteorogical data from website for individual models	Freely downloadable data; labor cost involved with accessing data and preparing for use in border crossing project

Data Category	Data Description	Existing Data Source	Existing Source Availability and Contact	Degree of Importance	Process to Obtain	Cost Considerations
Model Validation –						
Criteria pollutant ambient monitoring data	In 2011 there were 259 monitors (197 US, 62 Mexico) within 20 miles of border, including CO (30 monitors), lead(14), ozone (57), PM2.5 (29, none in Mexico), PM10 (61), SO2(19), NO2(31). Not all border crossings are near monitors. Yearly data available from 1990 (# monitors vary by year)	US EPA AirData website data clearinghouse (US and Mexico data)	http://www.epa.gov/airdata/ad_maps.html	Low	Download from website	Free access, labor cost involved with accessing and interpreting data and documentation
Outcomes of existing air quality studies in border regions (i.e., SIP related data and models)	13 Border Crossings are in areas with current SIPs. Pollutants covered by SIP vary by border crossing, include ozone, CO, PM10, and SO2.	US EPA SIP Report Website (by state)	http://www.epa.gov/air/urbanair/sipstatus	Low	Download from website	Free access, labor cost involved with accessing and interpreting SIPs and related technical documentation
Pollutants of concern for each POE by region based on nonattainment data	Pollutants covered by SIP vary by border crossing, include ozone, CO, PM10, and SO2. PM2.5 is also of high concern (no yet completed SIPs in region include PM2.5)	US EPA SIP Report Website (by state)	http://www.epa.gov/air/urbanair/sipstatus	High	Download from website	Free access, labor cost involved with accessing and interpreting SIPs and related technical documentation
Air Pollution Non-Attainment Status	8 US areas with border crossings are currently designated as non-attainment areas for ozone, CO, PM10 and/or SO2 .	US EPA SIP Report Website (by state)	http://www.epa.gov/air/urbanair/sipstatus	Low	Download from website	Free access, labor cost involved with accessing and interpreting non-attainment designation and related technical documentation

***Arizona Department of Transportation (ADOT) 2008 Study* (*3*)**

In 2008, ADOT conducted a cost evaluation of using heavy-duty remote sensing equipment to test cross-border truck emissions. The study considered HC, CO, NO_x, $PM_{2.5}$ (including Black Carbon [BC]), PM_{10}, and SO_2 emissions.

Approach/Methodology

The research team evaluated the feasibility of installing and maintaining heavy-duty remote sensing technology to test truck emissions at a land port of entry. They also recommend potential sources to fund ongoing program maintenance. The study presents cost estimates for each equipment alternative, including capital investment costs, as well as five years of operation and maintenance costs. Finally, they compared labor costs for contract work versus hiring employees, citing that it may be difficult to attract highly skilled employees to the remote border locations.

The study referred to a variety of remote sensing data collection literature. It also used data for the Nogales land port of entry and cost data for remote sensing equipment.

Issues/Concluding Remarks

To determine if this program merits investment at this time, it is recommended that ADOT partner with the Arizona Department of Environmental Quality (ADEQ). ADEQ may already have plans for dealing with air quality issues at the Nogales POE, and the two agencies may be able to coordinate efforts and possibly share costs for equipment and staffing.

***Texas A&M Transportation Institute (TTI) 1997 study for Texas Department of Transportation (TxDOT)* (*4*)**

In 1997, TTI investigated highway and vehicle pollutant levels along Texas border towns for TxDOT. The study considered CO, VOCs, NO_x, ozone, and PM_{10} emissions.

Approach/Methodology

This study applied three major types of analyses to four highly active border counties in Texas and recommended a plan of action to address concerns. One analysis investigated overall vehicle emissions and presented emissions inventories for each county. This analysis also considered the contribution of Mexican vehicles to the emissions scenario in each county. The next analysis assessed the amount of delay and idling, for all vehicles, at international bridges. It also estimated the proportion of vehicles that were Mexican. They combined data sources to generate county-level aggregation estimates, meaning the data did not represent bridge-specific estimates. The final analysis projected increased vehicle traffic to evaluate the potential of each county becoming a nonattainment area. It emphasized carbon monoxide violations caused by delay and idling at ports of entry.

TTI used the following data to quantify mobile source emissions:

- Vehicle Miles of Travel (VMT) – Highway Performance Monitoring System (HPMS) records;
- Fleet composition – from county registration data and field data;
- Speeds – El Paso County survey data;

- Operating mode fractions – El Paso travel survey data and EPA default values; and
- Annual mileage accumulation – EPA default values.

TTI used the following data to estimate county level bridge emissions:

- Queue length and delay data;
- Distribution of registration and vehicle classification – developed from field data; and
- County level vehicular border crossing data.

They used Continuous Air Monitoring System (CAMS) data to evaluate the potential of each county becoming a nonattainment area.

Issues/Concluding Remarks
Vehicle registration data and Mexican VMT data were from Laredo only, which affects the analysis. More refined bridge delay data could improve the study as well. Also, CAMS stations were sparsely represented, which was not ideal.

Health Effects Institute (HEI) 2011 Study **(*5*)**
In 2011, HEI investigated exposure to toxic vehicle emissions at the Peace Bridge border crossing in Buffalo, New York. The study considered mobile source air toxics (MSATs), including VOCs, polycyclic aromatic hydrocarbons (PAHs), nitrogenated PAHs (NPAHs), PM_{10}, $PM_{2.5}$, and ultrafine particles (UFPs).

Approach/Methodology
The HEI researchers measured concentration levels for a number of air toxics that are typically emitted in the exhaust of diesel and gasoline vehicles. They chose three fixed sites for both continuous monitoring and integrated sampling. One site was primarily a directly downwind site, one site was primarily a directly upwind site, and the third site was a less directly downwind site. The study featured a mobile monitoring component as well. Staff members carried air monitoring equipment and GPS units while following four different routes in the neighborhoods near the bridge.

The research team used the following data to analyze air toxics near the bridge:

- Meteorological data from a weather station – including one-minute values of wind direction, wind speed, temperature, humidity, rainfall, and pressure;
- Real-time continuous monitoring data – from integrated samplers at three fixed sites;
- Mobile monitoring data – from backpack monitors following four defined routes; and
- Hourly car and truck counts – from the Peace Bridge Authority.

Issues/Concluding Remarks
The study concluded that the area downwind of the bridge is a hot spot for air toxics, although the MSATs levels that they reported were not high in comparison to measurements made in other U.S. locations. The study also revealed that high concentrations of air toxics near the bridge were especially dependent on wind direction. The results provide a wealth of comparative data on air toxics. This study includes important innovations and contributions to data collection

methods and study design for hot spot research. The results show that researchers need to consider meteorological conditions, such as wind direction and wind speed, when selecting sampling sites for the analysis of potential hot spots.

***Transportation Northwest Regional Center (TransNow) 2011 Study* (*6*)**
In 2011, TransNow investigated the operational efficiency of several ports of entry on the U.S.-Canada border in the state of Washington. The study considered truck idling emissions.

Approach/Methodology
The TransNow researchers used survey data from three different years to analyze three ports of entry. More specifically, they used a new data collection that was based on survey efforts from two previous years. They improved the data collection by including a survey that dispatchers used, which captured information on the logistics of border crossing trips, including origins and destinations, commodities carried (or empty trucks), facility types at transaction points, and the scheduling demands of the trip.

One of the study's primary objectives was to describe near-border operations and identify potential approaches to reduce miles driven by empty trucks. Another objective was to improve the understanding of near-border operations and logistics and identify barriers to reducing wait times. The study also sought to improve the understanding of the connection between border crossing time and primary processing time. Finally, the study investigated the impact of ACE electronic manifest filing on primary processing and primary processing time.

The research team used the following sources:

- 2001 data collection of driver surveys;
- 2006 data collection of driver surveys; and
- 2009 data collection of driver surveys and online dispatcher surveys.

Issues/Concluding Remarks
One of the key challenges in this study was to identify the features unique to the Blaine, WA port of entry that make modeling the port of entry so challenging.

***University Transportation Research Center (UTRC) 2009 Study* (*7*)**
In 2009, the UTRC investigated the development and improvement of advanced modeling tools used to analyze transportation emission hotspots. The study considered CO, $PM_{2.5}$ (including BC), and PM_{10} emissions.

Approach/Methodology
Gaussian plume dispersion models (of line sources) struggle to accurately simulate the impact of complex roadway networks (found in urban environments) on air quality. This is largely due to their inability to address the wide range of turbulent mixing processes near roadways. They also fail to account for chemical reactions and physical dynamics, such as condensation, coagulation and deposition.

This study presents two alternative advanced modeling tools that are designed to analyze mobile emission hotspots. The first is a multi-link dispersion model (MLDM) based on AERMOD, which is a dispersion model developed by the EPA to model particulate matter. The researchers applied the MLDM to a study area in the South Bronx where asthma rates in children have been linked to exposure to diesel particulate matter. They used travel demand models and Geographical Information Systems (GIS) to develop a detailed vehicle emissions inventory that included emissions for individual road links. The second model, a computational fluid dynamics (CFD) based approach, models CO gradients by calculating the turbulence created by road embankment, road surface thermal effects, and roadside structures. These turbulence calculations include vehicle-induced turbulence (VIT) and road-induced turbulence (RIT).

Running the CFD-VIT-RIT model at the neighborhood level required the following data inputs:

- U.S. Geological Survey (USGS) Digital Elevation Model (DEM) with 10-m resolution;
- Observational meteorological data, including on-site (i.e., directly measured temperature, relative humidity, wind direction, and wind speed), surface, and upper air data (i.e., temperature, dew point, wind direction, wind speed, cloud cover, cloud layer(s), ceiling height, visibility, current weather, and precipitation amount at surface level) – they obtained the surface and upper air data from the nearest National Weather Service (NWS) monitoring station;
- Link-level road network data – from a travel demand forecasting model;
- Traffic activity data – from real-time traffic video and a travel demand forecasting model;
- Emissions factors from MOBILE6.2 and BC emissions factors from SPECIATE (version 4.0);
- Point emissions data from the 2002 National Emission Inventory (NEI) – the speciation profiles for those sources were acquired from SPECIATE; and
- Roadside monitoring of BC data – from 2004 study.

The UTRC research team obtained the following data inputs from field measurements to run the CFD-VIT-RIT model at the neighborhood level:

- Temperature (°C);
- Relative humidity (%);
- Solar zenith angles (°)[50];
- Wind velocity (m s-1);
- Wind direction to highways (°);
- Wind deviation (°);
- Stability class;
- Traffic volume (vehicles min-1);
- Heavy-duty truck percentage; and
- Upwind CO concentration (ppm).

Issues/Concluding Remarks
The AERMOD model that researchers used was not able to simulate line sources. They resolved this issue by dividing road links into multiple segments that were modeled as area sources.

University of Tennessee (UT) and Oak Ridge National Laboratory (ORNL) 2007 Study **(*8*)**
In 2007, researchers with UT and ORNL investigated diesel truck idling $PM_{2.5}$ hotspot emissions at an intersection in Knoxville, TN.

Approach/Methodology
The intersection, which experiences 20,000 heavy-duty trucks on interstate I-40 every day, has three large truck stops where up to 400 trucks can have idling engines at night. Previous studies have measured high levels of $PM_{2.5}$ near the interchange, which often exceed National Ambient Air Quality Standards (NAAQS). This study investigated the relative $PM_{2.5}$ contributions from the regional background, local truck idling, and trucks on the interstate.

The research team used the following data to conduct the study:

- Background $PM_{2.5}$ air monitoring data;
- Ambient PM air monitor data – from installed monitors;
- PM data – from continuous monitors;
- Meteorological data, including hourly average wind speed, wind direction, standard deviation of wind direction, solar intensity, temperature, humidity, and rainfall – from continuous monitors; and
- Traffic data – from manual observation counts, pneumatic road tube traffic counters, and side-fired radar traffic counters (Remote Traffic Microwave Sensor [RTMS] automatic traffic counters).

Issues/Concluding Remarks
This study showed that the high levels of $PM_{2.5}$ are due to the overnight truck idling, rather than through traffic, which confirmed the findings of other studies showing the significance of truck idling emissions. This significance is relevant to border crossings.

More research is needed to better identify the characteristics that cause certain projects to produce high levels of emissions, which often create hot spots and need project level analyses. This research should identify the pollutants that should be considered, the distance from the project that should be analyzed, and meteorological conditions and times of day that are most at risk.

Texas A&M Transportation Institute (TTI), Clean Air Technologies Inc., and Oak Ridge National Laboratory (ORTM) 2007 Study **(*9*)**
In 2007, TTI, Clean Air Technologies Inc., and ORTM researchers sought to develop an approach for estimating the emissions from idling trucks at the U.S-Mexico border. The study considered mobile source air toxics (MSATs) and diesel PM.

Approach/Methodology
The study investigated truck idling at the Bridge of Americas and the Zaragoza/Ysletta bridge, which are the two major commercial crossings between El Paso and Ciudad Juarez. Ambient temperatures are assumed to affect heavy-duty truck emissions, and large numbers of trucks can lead to air quality hot spots. The research team focused on emissions from idling Mexican trucks. More specifically, they analyzed MSAT emissions, in hot weather conditions, from nine Mexican truck types that are common to those ports of entry spanning twenty different model years.

The research team used the following data to carry out the study:

- Engine data for each of the nine truck types tested; and
- MSATs sampling data, from diluted exhaust, for high and low speed idling with the air conditioner on and off.

Issues/Concluding Remarks
Real-time, portable instrumentation may be needed to best quantify MSATs emissions from in-use trucks over their drive cycles.

California Air Resources Board (CARB) and San Diego County State Implementation Plan
CARB and San Diego County plans for the San Diego-Tijuana border crossing considered CO and ozone emissions.

San Diego County has been in nonattainment for CO and ozone in the past, and CARB and San Diego County developed plans to address the problems. These plans include emissions inventories, emission control strategies, reasonably available control measures (RACMs), attainment demonstrations, contingency measures, and new source reviews.

The state implementation plans include the following data:

- Motor vehicle emissions estimates;
- Air quality data; and
- Emissions inventory data.

Texas Commission on Environmental Quality (TCEQ) State Implementation Plan
TCEQ plans for the El Paso-Ciudad Juarez border crossing considered CO, ozone, and PM emissions.

El Paso County has been in nonattainment for CO and ozone in the past and is currently in nonattainment for PM_{10}. TCEQ developed state implementation plans to address these problems. These plans provide a wealth of information, including attainment statuses, ozone design values, air quality history, emissions inventories, planning activities, air quality plans, emission control strategies, RACMs, attainment demonstrations, and contingency measures.

The state implementation plans include the following data:

- Motor vehicle emissions estimates;
- Air quality data; and
- Emissions inventory data.

CHAPTER 3
METHODOLOGY

This chapter documents the process that the TTI research team used to develop the border crossing emission estimation tool. Researchers used the following four-step process to develop the border crossing emission estimation tool:

Figure 2. Methodology for Developing the Border Crossing Emissions Estimation Tool.

The following sections cover these steps.

DATA COLLECTION

The research team developed and executed a data collection protocol based on related literature and the research team's previous experiences. The majority of the data collection protocol was documented in the project's Quality Assurance Quality Control (QA/QC) Project Plan submitted to the sponsor in January of 2013.

Data Collection Technologies

GPS technology is the best candidate for collecting speed and location data required for this study. GPS data have already been used to develop MOVES' default drive schedules.

The research team focused on identifying the GPS data logger that meets the requirements of this study. The GPS unit used for collecting vehicle activity data is the QStarz BT-Q1000eX Xtreme Recorder.[1] Figure 3 shows the QStarz BT-Q1000eX unit. The Xtreme Recorder is based on MTK II chipset with a sensitivity of -165 dbm. The unit has the capability of recording speed and position data on a second-by-second basis (1Hz) as well as 5Hz and has a memory capacity for 64 hours of observation on the 1-Hz mode.

Figure 3. QStarz BT-Q1000eX unit and its extended battery pack.

The QStarz unit is equipped with a vibration detector that enables the option of deactivating the unit if no motion is detected for 10 consecutive minutes. This option is crucial to conserve battery power by deactivating the recorder when no activity is detected. The power for the data logger is provided by a rechargeable lithium-ion battery similar to ones used by Nokia cell phones capable of powering the unit for one week under normal urban driving conditions. The original battery life is extended by soldering an additional battery pack onto the original unit.

Recorded data from the GPS units were downloaded from the equipment into an electronic text file which can be read into Microsoft Excel, SAS or other statistical software packages. The GPS data from the field tests were downloaded on the TTI office computers and backed up onto TTI's network server. TTI will keep both field records as well as electronic data on a computer.

Duration of GPS Data Collection

The battery capacity and data logger's memory size are the main limiting factors for the duration of data collection. The research team has performed a limited number of beta testing with the

[1] BT-Q100eX Users Manual, http://www.qstarz.com/download/BT-Q1000eX Users Manual.pdf.

selected data loggers to determine the optimal duration for each category of vehicles. The results of this beta testing suggested that a two-week period will provide the necessary amount of data. This estimated time is usually lower for long-haul vehicles since they tend to drive more in a short period of time.

Test Vehicles and Data Collection Process

The data collection process includes two parallel efforts – planned data collection on pre-defined routes for light-duty vehicles and normal vehicle activity for heavy-duty vehicles (HDVs). The first data collection effort consists of a TTI staff member driving a GPS-equipped vehicle on a predefined route along the target network (i.e., border crossings) during a set period of time. This includes driving during peak and off-peak periods.

The HDV data collection effort consists of recruiting fleet vehicles to record their normal border crossing activity during an extended period of time. The research team has developed a standardized methodology for gathering and storing information collected using GPS data loggers that monitor second-by-second movement. Figure 4 shows an overall outline of the data collection methodology.

Three GPS data loggers were sent through the mail or hand-delivered to the participants. Installing three units as opposed to one unit in each vehicle helps to ensure accuracy in the case that one unit is malfunctioning or providing erroneous data. A set of instructions accompanied the devices providing instructions on how to place and activate the data loggers (Appendix A). In the majority cases, a TTI staff with previous experience with GPS unit installation delivers and installs the units on target vehicles.

Typically, the devices will be set in the driver-side storage compartment (as shown in figure in Appendix A) to ensure that the vibration detector starts recording whenever the vehicle door is opened, which is usually at the beginning of a trip. If the vehicle does not have driver-side storage compartment, the loggers can be placed in vehicle's glove box or another secure location inside the cabin. The data loggers will be returned after two weeks when the power supply for the unit is expected to be completely drained.

Information from each of the three data loggers were downloaded onto a central server and given a unique identifier that will not trace the data back to the original participant. The spreadsheets from each of the three devices will be merged into one document that were labeled with variables describing unit number, date of initial activation, and type of vehicle observed. Only researchers assigned to the project will be given access to the secure files on the server.

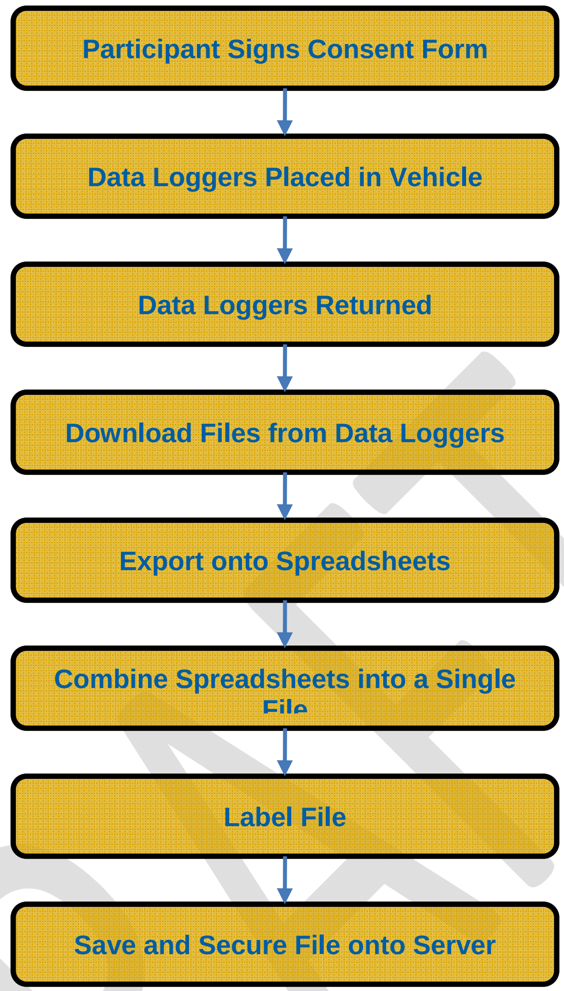


Figure 4. Data Collection Process Flowchart.

GPS Data from Heavy-Duty Drayage Trucks

Drayage vehicles on the international border are short-haul trucks that typically receive freight transferred from long-haul trucks and simply cross the international bridges several times daily carrying shipments back and forth. Nearly all of the drayage fleets in the El Paso-Ciudad Juarez border region operate out of Mexico and they typically use older diesel trucks. This task involved installing GPS units into 10 drayage trucks at the Servicio de Transporte Internacional y Local S.A. de C.V. (STIL) company which operates out of Ciudad Juarez, Mexico. Sets of three QStarz GPS units were installed into each of the ten drayage vehicles for approximately two weeks.

The El Paso-based members of the research team contacted the owners of the STIL Company which had previously helped them on a separate study. Their cooperation was requested for installing the GPS units in their vehicles for a two-week period. TTI staff delivered the 10 sets of three bundled GPS units along with instructions about how to install them and how to verify their functioning. Because the STIL trucks were in transit during regular business hours, the STIL lot manager was put in charge of installing the units, securing them in place, and confirming their operation. After 13 days the GPS units were retrieved, and all of the information from the GPS units was downloaded.

Collection of License Plate Data

To determine information about the vehicle fleet mix for vehicles crossing the international bridges, an extensive data collection effort was performed to sample the fleet. The information that ultimately was necessary for this study was the make, model, and model year for each vehicle. Different approaches were considered regarding how to collect these data. After it was confirmed that all of the vehicle type information could be obtained through vehicle registration information at the respective agencies in both the U.S. and Mexico, the research team decided that using the vehicle license plates would be the most efficient and effective method for gathering the data. Where the vehicle license plate was not available or was not unique, i.e., drayage trucks, the vehicular identification numbers (VIN) were collected. The data collection process involved two stages:

1. Collecting license plate numbers or VIN from vehicles on paper forms; and
2. Initial quality control and data entry into an excel data file.

These records were entered into a spreadsheet and stored on TTI computers. All hardcopy records including field data logs and fuel characteristics information are kept at TTI El Paso office per requirements of Texas A&M System record Retention Schedule.[2]

The first stage of the data collection was to document a sample of vehicles crossing the international bridges by collecting a unique identifier for the vehicles (either their license plate number or the VIN). These identifiers would later be used to obtain vehicle type information. This was done for both passenger and commercial vehicles. For passenger vehicles, a sample was gathered by license plate numbers one lane at a time. A sample was gathered for each type of lane, whether regular; express; or ready lanes. A set of tasks was needed to complete the vehicle samples. These tasks included:

- Prepared data collection sheets;
- Scheduled and trained temporary workers for the data collection;
- Requested permission from the CBP and the Texas vehicle inspection stations to collect data on the international bridges; and
- Performed data collection at Zaragosa international bridge and the BOTA.

Data Collection Sheets

The research team developed a series of data collection forms that were used in gathering the data. Different forms were created, one for the passenger vehicle lanes, and one for the commercial vehicle lanes. Columns were created for the country, the state, and the license plate number. For commercial vehicles, a descriptive column indicated whether the truck was a single

[2] TAMUS Record Retention Schedule; available online at http://www.tamus.edu/assets/files/legal/pdf/System-Records-Retention-Schedule-Dec2012.pdf.

unit or tractor trailer type of vehicle. The amount of vehicles that would be documented was estimated, and the data collection sheets were printed and bound together into data collection booklets (see Figure 5).

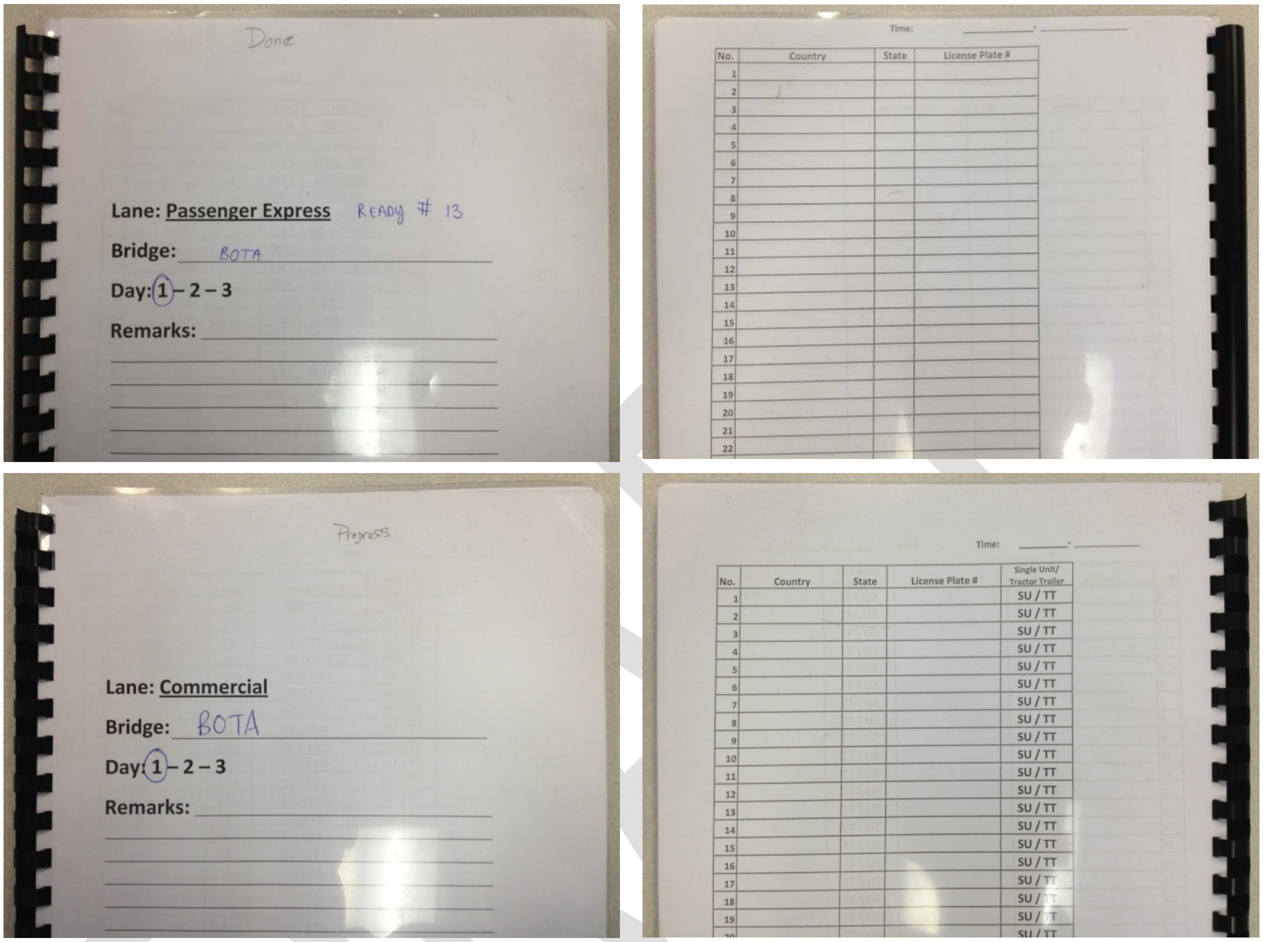


Figure 5. Data Collection Booklets.

Scheduling and training temporary workers for the data collection

The next step in the data collection effort was to hire a group of temporary workers to conduct the field work. A set of six temporary workers were contracted. The workers participated in a 1.5 hour training session where all of the details of the data collection effort were discussed. They were familiarized with the data collection booklets, and the overview of the effort was discussed with them. The workers were told that they were to perform about 7.5 hours of data collection per day. Each worker would be assigned to a particular lane, be it commercial or passenger. They would write down each license plate number for every vehicle that passed through the lane. This was possible because each vehicle would have to stop for an inspection by the CBP or the Texas state vehicle inspection station. If a license plate was not available, then a VIN would be documented, though this occurred only for commercial vehicles.

Often at the bridges, the CBP closes lanes and these changes are not predictable. If a lane were to close while a worker was gathering data there, they were instructed to move to another lane.

They would then document the lane switch in the booklets. They were instructed to write down the time session for each data gathering session (generally 1.5-2 hours each). They were also instructed to write down any relevant notes if for example a vehicle was a motorcycle, or if it was missing a license plate and a VIN could not be obtained.

Obtaining The Required Permissions

Because the international bridges are closely monitored by the CBP, permission was requested from them to collect data on the bridges. A formal letter was written to CBP explaining the project and the data collection. CBP requested the names, dates of birth, and social security numbers of all of the people that would be on the bridges collecting data, and they passed these through a security clearance. After everyone was cleared, the team was given the go ahead from CBP, and they provided contact numbers for the managing officers that were to be at the bridges on the scheduled days.

The research team also requested permission to collect the data for commercial vehicles from the Texas commercial vehicle inspection stations. These stations are located on the bridge crossing route after the CBP facilities for commercial traffic. Permission was granted without any obstacles and the data collection schedule was coordinated with their commanding officers.

Data Collection at the Ysleta- Zaragoza Bridge and the BOTA

Collecting license plate numbers and VINs from vehicles was conducted on the two most important international bridges on the El Paso-Ciudad Juarez border. These bridges are the Ysleta-Zaragoza international bridge, and the BOTA. For each bridge, three weekdays and one weekend day were scheduled for data collection. A graduate student was in charge of managing the temp workers on-site. Data collection was planned to run from 7 a.m. to 11:30 a.m., then from 1 p.m. to 4 p.m., for a total of 7.5 hours each day. Workers would stand near the inspection booths, and count each vehicle as it passed through (Figure 6).

On the Ysleta-Zaragoza Bridge, the single commercial vehicle lane and four lanes of passenger vehicles were counted. The passenger vehicle lanes consisted of two regular lanes, one dedicated commuter lane (DCL), and one Ready Lane. DCLs are lanes that are used by pre-approved, low-risk travelers that undergo a background checks for quicker border crossing. Ready Lanes are dedicated lanes for travelers using Western Hemisphere Travel Initiative (WHTI)-compliant, Radio Frequency Identification (RFID)-enabled documents for quicker border crossing. On the BOTA, the single commercial vehicle lane four lanes of passenger vehicles were counted. These were two regular lanes, and two Ready Lanes.

For the commercial lane counting, it was discovered that many of the trucks from states other than Chihuahua did not have license plates that were unique identifiers. The Texas state inspectors assisted the team with this problem and requested the VIN for each commercial vehicle that had this issue (Figure 7).

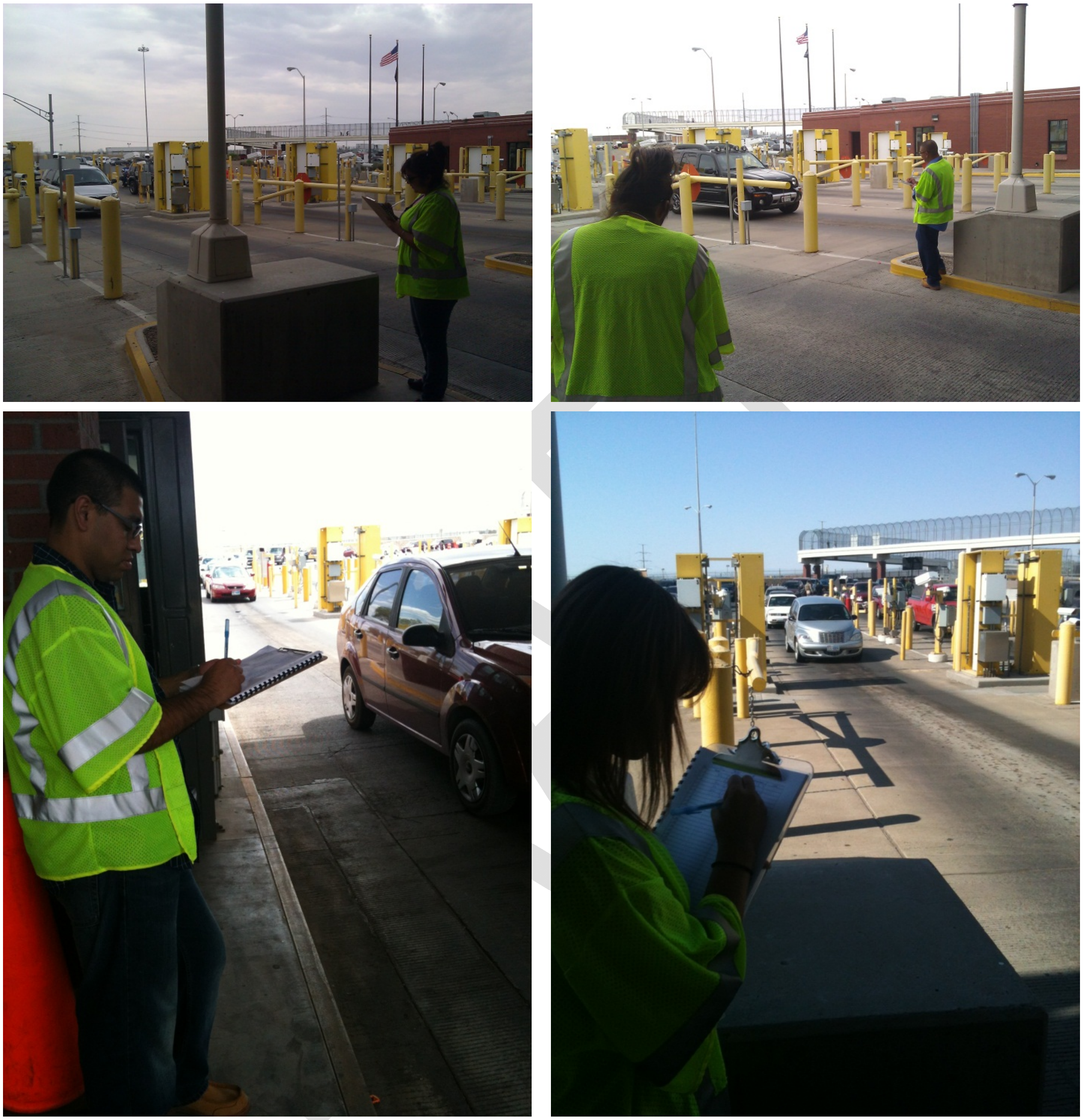


Figure 6. Data Collection for Passenger Vehicles.

Figure 7. Data Collection for Commercial Vehicles.

Entering Collected Data into an Excel Database

A student was charged with the task of manually entering the data into an Excel® spreadsheet database. The database included columns with the information of the vehicle type (commercial or passenger), license plate, the country of origin, the state, along with information about the bridge, the lane that the vehicle was in, and the data collection date and time block, along with any special notes. This transferring process underwent some quality control procedures such as performing random checking of the accuracy of the data transfer.

Fuel Characteristics

MOVES uses fuel characteristic in the emissions estimation calculations. Gasoline and diesel fuel samples were collected from various gas stations in El Paso and Juarez. The research team used special containers for the fuel sampling. A sample size of five samples of each fuel type was collected from each area; i.e., 20 fuel samples. All the fuel samples were sent to the Southwest Research Institute (SwRI) for laboratory testing. Table 3 and Table 4 show the fuel analysis results for all the samples.

Table 3. Diesel Fuel Analysis Results.

			Sample 2	Sample 4	Sample 6	Sample 8	Sample 10	Sample 12	Sample 14	Sample 16	Sample 18	Sample 20
			Juarez Diesel	Juarez Diesel	Juarez Diesel	Juarez Diesel	Juarez Diesel	El Paso Diesel	El Paso Diesel	El Paso Diesel	El Paso Diesel	El Paso Diesel
			Triumfo de la Republica	*Triumfo de la Republica*	*Blvd. Gomez Morin*	*Triumfo de la Republica*	*Blvd. Gomez Morin*	*Exxon*	*Circle K*	*Valero*	*Chevron*	*Shell*
			Results	Results	Results	Results	Results	Results	Results	Results	Results	Results
D4052s	API Gravity		37	37.1	37.3	37.1	39.8	37.5	37.3	40.5	37.1	36.6
	Specific Gravity		0.8399	0.8391	0.8383	0.8392	0.826	0.8374	0.8381	0.8229	0.8394	0.8416
	Density at 15°C	grams/L	839.4	838.7	837.9	838.7	825.6	837	837.7	822.5	839	841.1
D5453	Sulfur	ppm	5.8	6	6	6.2	5.8	3.5	3.6	4.5	6.5	5.7
D86	Distillation											
	IBP	degF	312	316	325	328	321	321	331	342	325	322
	10%	degF	389	389	391	387	386	383	387	397	391	397
	50%	degF	506	506	504	501	498	482	487	495	509	523
	90%	degF	627	632	633	630	631	584	590	592	629	636
	FBP	degF	673	681	685	685	686	631	632	640	683	680
	Recoverd	mL	97.5	97.3	97.6	98	98	98.2	97.6	98.5	98.1	98
	Residue	mL	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4
	Loss	mL	1.1	1.3	1.1	0.6	0.7	0.4	1	0.1	0.6	0.6
D976	Cetane Index		49.9	50.1	50.2	49.5	53.8	47.6	48	54.5	50.5	51.4
EN14078	FAME Content by IR	volume %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	5.4

Table 4. Gasoline Fuel Analysis Results.

			Sample 1	Sample 3	Sample 5	Sample 7	Sample 9	Sample 11	Sample 13	Sample 15	Sample 17	Sample 19
			Juarez Reg	Juarez Reg	Juarez Reg	Juarez Reg	Juarez Reg	El Paso Reg	El Paso Reg	El Paso Reg	El Paso Reg	El Paso Reg
			Triumfo de la Republica	*Triumfo de la Republica*	*Blvd. Gomez Morin*	*Triumfo de la Republica*	*Blvd. Gomez Morin*	*Exxon*	*Circle K*	*Valero*	*Chevron*	*Shell*
			RESULTS	RESULTS	RESULTS	RESULTS	RESULTS	RESULTS	RESULTS	RESULTS	RESULTS	RESULTS
D5191	RVP	psi	8.59	7.94	8.49	8.17	7.91	6.83	6.73	6.74	6.17	6.47
D1319	FIA (Oxygenate-Free Basis)											
	Aromatic	%	24	24.5	22.3	23.1	22.6	37.4	36.6	37.3	33.1	32.5
	Olefins	%	12.9	11.8	12.9	12.2	13.1	1.4	1.7	2.1	6.4	7.4
	Saturate	%	63.1	63.7	64.8	64.7	64.3	61.2	61.7	60.6	60.5	60.1
D1319	FIA (Corrected Total Basis)											
	Aromatic	%						33.7	33.0	33.6		
	Olefins	%						1.3	1.5	1.9		
	Saturate	%						55.2	55.6	54.6		
D3606EPA	Benzene	Vol%	0.58	0.4	0.57	0.6	0.39	0.55	0.54	0.53	0.84	0.86
	Toluene	Vol%	4.41	4.82	4.46	5.38	4.48	11.18	10.93	11.01	11.02	11.18
D5453	Sulfur	ppm	100.4	101.4	106.4	95	113.3	4	5.7	5.8	16.5	17.3
D5599	Oxygen and Oxygenates											
D5599	DIPE	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	ETBE	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	EtOH	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	10.12	10.25	10.18	<0.1	<0.1
	iBA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	iPA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	MeOH	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	MTBE	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	nBA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	nPA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	sBA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	TAME	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	tBA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	tPA	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Total Oxygen	Wt%	<0.1	<0.1	<0.1	<0.1	<0.1	3.51	3.56	3.53	<0.1	<0.1
D86	Distillation											
	IBP	deg F	93	93	90	91	91	110	103	106	99	96
	5%	degF	114	116	112	116	115	131	132	131	135	129
	10%	degF	126	129	125	130	128	139	140	140	154	150
	15%	degF	135	139	135	140	138	144	145	145	168	165
	20%	degF	144	149	144	150	148	149	150	149	179	177
	30%	degF	165	169	165	172	168	157	158	156	199	198
	40%	degF	189	193	189	196	192	180	189	186	215	215
	50%	degF	214	218	215	219	217	225	228	225	229	229
	60%	degF	237	240	239	240	240	244	246	245	241	242
	70%	degF	262	264	263	263	264	261	263	262	257	257
	80%	degF	294	295	296	293	297	282	283	282	277	277
	90%	degF	334	337	337	331	335	309	310	310	304	305
	95%	degF	359	361	359	359	360	329	331	332	331	331
	FBP	degF	406	405	410	410	415	376	372	374	377	377
	Recoverd	mL	97.4	96.8	97.7	97.7	97.3	97.5	98.5	97.4	98	97.4
	Residue	mL	0.7	0.8	0.6	0.7	0.6	0.7	0.6	0.9	0.6	0.6
	Loss	mL	1.9	2.4	1.7	1.6	2.1	1.8	0.9	1.7	1.4	2
D86	E200	--	44.42	42.91	44.23	41.64	43.39	42.94	41.89	42.24	30.56	30.89
	E300	--	81.42	81.2	81.18	81.86	80.79	87.08	86.62	87.4	88.37	88.18

Quality Control

With regard to general GPS data, the output of GPS equipment is routinely checked for potential problems by performing a visual investigation of the location data (coordinates) overlaid on standard road maps prepared for the equipment. A set of quality control data filtering methods have been developed to identify problems with speed and acceleration data (see Appendix B).

Border crossing visual observation data were collected in the form of vehicle license plate numbers. The quality control on this dataset consisted of checking each individual record with the registration data from Texas and Mexico and verifying the existence of a valid record.

The outputs of the estimation tool are compared to default values of MOVES. This provides a level of quality control by ensuring that the results are within an acceptable range based on the default MOVES results. The acceptable range will be determined as part of the emission estimation tool development task.

GPS units are routinely tested before and after each session of data collection to ensure that they work properly and all their critical settings are correct. The maintenance of the equipment is performed periodically and according to the manufacturer's specification.

DATA PROCESSING AND DRIVE SCHEDULE DEVELOPMENT

This section explains the data processing step for GPS information and license plate observations.

License Plate Data

The first step for processing the license plate and VIN data was to divide up the database into separate databases that could be provided to the different government agencies to request the vehicle type information of make, model, and year. This task was performed using the data filtering tool in Excel®. All of the Texas vehicles were separated into one database. Then, all of the Mexico vehicles were separated into another database, and later the Mexico commercial vehicles were separated into a third database. The column headings in the Mexico databases were also translated into Spanish.

The Texas Department of Motor Vehicles (TxDMV) was initially contacted to confirm that they could provide the make, model, and year information from license plate numbers. They confirmed that it was feasible. Normally, this costs a few dollars per license plate, but a special request was made for a waiving of the fee being that this was a state-sponsored research. The fee waiver was granted.

After the database was prepared, the Texas license plate numbers database was converted into a text file with only a two digit code for the year and the license plate numbers. Within a few weeks, they returned the database as an Excel® spreadsheet with the information of the year, the make, the body type, and the VIN. Later, a request was made to the TxDMV to confirm the meaning of the body type codes that they provided. They provided a document that defines all of their body type codes, and this information was later used to determine what MOVES vehicle type code would be used.

The ability to obtain the vehicle type information from Mexico was initially confirmed by telephone. After the data was in hand, a formal request was made to the Mexican state agency the Recaudador de Rentas for the vehicle type information of make, model, and year for all collected Mexican vehicles. A written letter was prepared and signed, and emailed to the agency, along with the database of all Mexican vehicles. After a few weeks, the data was returned with the year, make, model, body type, and vehicle class information. However, the Recaudador de Rentas did not return any information for commercial vehicles. They informed the research team that they did not have these data and subsequently referred the researchers to the Secretaría de Comunicaciones y Transportes.

A formal request was made to the Mexican federal agency the Secretaría de Comunicaciones y Transportes for the vehicle type information of make, model, and year for the remaining Mexican commercial vehicles. A written letter was prepared and signed, and emailed to the agency, along with the database of the Mexican commercial vehicles. The data were returned with the year, make, and vehicle class information for the commercial vehicles after a few months.

After all of the vehicle type data were returned from the government agencies, these data were placed back into the original database. This was performed for two reasons: primarily, so that the documented time of crossing would be available for each vehicle. Secondarily, this was done so that all of the data could be quality-checked. After the new database was merged into the original dataset, data quality metrics were generated.

Table 5 shows data quality metrics about the complete set of vehicle data collected. Table 6 shows data quality metrics for the passenger or light-duty vehicles. Table 7 shows data quality metrics for the commercial or HDVs. Table 8 shows counts of vehicles based on the state of origin of their license plate for light-duty vehicles for each country. Table 9 shows the same information for HDVs. The research team calculated the age distribution of each vehicle type according to age categories of the MOVES mode. Table 10 shows these results.

Table 5. Data Quality Metrics for All Vehicles Documented

Total number of Vehicles	11,143	
Normal Observations	10,522	94.4%
Code Yellow – Incomplete data for heavy duty	35	0.3%
Code Red - Missing or incorrect data for light-duty vehicles	586	5.3%

Table 6. Data Quality Metrics for Light-Duty Vehicles

	Number of Light-Duty Vehicles				
			Mexico	USA	N/A
100.0%	Total	7,947	4,400	3,493	54
92.6%	Normal	7,361	4,020	3,302	39
7.4%	Code Red	586	380	191	15

Table 7. Data Quality Metrics for HDVs

	Number of HDVs				
			Mexico	USA	N/A
100.0%	Total	3,196	3,154	5	37
98.9%	Normal	3,161	3,126	3	32
1.1%	Yellow	35	28	2	5

Table 8. States of Origin for Light-Duty Vehicles

Mexican States	Number of Vehicles	U.S. States	Number of Vehicles
Baja California	3	Arizona	6
Chihuahua	4,343	Arkansas	1
Coahuila	9	California	9
DF	9	Colorado	18
Durango	5	Illinois	1
Hidalgo	1	Kansas	2
Jalisco	4	Michigan	2
Mexico	1	Montana	1
Morelos	1	Nebraska	1
Nuevo Leon	7	Nevada	6
San Luis Potosi	1	New Mexico	122
Sinaloa	1	North Dakota	1
Sonora	3	Ohio	1
Tamaulipas	2	Oklahoma	5
Zacatecas	2	Pennsylvania	1
		South Carolina	2
		Texas	3,309
		Utah	1
		Virginia	1
		Washington DC	2
		Wyoming	1
Total Mexico	**55.7%**	**Total USA**	**44.3%**

Table 9. States of Origin for HDVs

Mexican States	Number of Vehicles	U.S. States	Number of Vehicles
Chihuahua	2,697	Texas	5
Distrito Federal	442		
Durango	1		
Nuevo Leon	6		
Total Mexico	**99.8%**	**Total USA**	**0.2%**

Table 10. Age Distribution of the Observed Vehicles, August 2012.

	Mexican Vehicles (Registered in Mexico)			U.S. Vehicles (Registered in the U.S.)		
Age	**Passenger Cars**	**Passenger Trucks**	**Freight Trucks**	**Passenger Cars**	**Passenger Trucks**	**Freight Trucks***
0	0.4%	0.2%	1.7%	0.0%	0.1%	N/A
1	7.0%	2.9%	1.8%	4.8%	2.0%	N/A
2	4.9%	2.5%	0.9%	3.4%	3.4%	N/A
3	4.1%	1.7%	0.2%	4.1%	3.5%	N/A
4	3.6%	2.0%	0.4%	4.1%	2.4%	N/A
5	3.6%	3.6%	1.9%	6.7%	5.4%	N/A
6	5.0%	4.8%	1.9%	7.9%	7.2%	N/A
7	5.9%	4.1%	2.5%	7.9%	6.7%	N/A
8	7.0%	5.1%	3.1%	6.9%	8.0%	N/A
9	5.0%	5.8%	3.3%	6.1%	8.6%	N/A
10	4.6%	5.7%	2.6%	4.6%	8.2%	N/A
11	6.8%	9.8%	4.0%	5.2%	8.2%	N/A
12	7.0%	6.8%	5.4%	5.8%	6.9%	N/A
13	8.3%	7.5%	7.9%	5.8%	5.7%	N/A
14	5.3%	8.4%	11.4%	4.9%	4.9%	N/A
15	4.3%	4.7%	9.3%	4.3%	4.4%	N/A
16	4.3%	6.6%	6.5%	2.3%	3.6%	N/A
17	2.9%	3.8%	7.3%	2.5%	1.6%	N/A
18	3.3%	3.7%	8.8%	1.0%	2.0%	N/A
19	1.6%	2.5%	5.6%	1.4%	1.8%	N/A
20	1.4%	2.0%	5.6%	1.9%	1.2%	N/A
21	1.0%	1.4%	2.0%	0.7%	0.9%	N/A
22	0.9%	0.8%	1.1%	0.3%	0.5%	N/A
23	0.2%	0.7%	1.2%	0.4%	0.5%	N/A
24	0.6%	0.7%	0.8%	0.9%	0.3%	N/A
25	0.2%	0.5%	0.6%	0.4%	0.4%	N/A
26	0.1%	0.3%	0.4%	0.4%	0.3%	N/A
27	0.1%	0.4%	0.6%	0.4%	0.4%	N/A
28	0.2%	0.2%	0.5%	0.6%	0.2%	N/A
29	0.0%	0.1%	0.1%	0.1%	0.2%	N/A
30+	0.2%	0.8%	0.2%	4.3%	0.5%	N/A

* Only five U.S. trucks were observed.

GPS Data

The data used for the border crossing drive schedule development were all collected using the data collection methodology developed by the research team. The team examined the other sources of data including previous TTI studies. This investigation showed that that these data do not meet the quality and quantity required for this task. Specifically, GPS units proposed for the data collection in this project are of higher quality and sensitivity than those used in previous studies. Furthermore, three GPS units were used on each vehicle to increase the precision and fidelity of the data. The use of three GPS units was approved by the project director (PD).

The data processing and analysis of this task was conducted per the following general steps:

1. Quality control and validation of raw data – This step involved examining the speed and location data from the GPS units to determine their validity, and identify errors and outliers in the data. The faulty information was filtered out and a database of verified unprocessed data was established. Multiple error detection criteria were developed for this step.
2. Data processing – This step consisted of merging information from the three GPS units in each assembly, extracting micro-trips, and categorizing them by the target area, road classification (highway/freeway or arterial/local), average speed bin, and type of area (urban or rural).
3. Data analysis and drive schedule development – The processed data were analyzed according to a drive schedule selection algorithm that the research team developed to identify and extract border crossing trips.

The following sections cover these steps and the extracted border crossing drive schedules.

Quality Control and Validation of Raw Data

After downloading the data from the GPS units, the quality of data was checked to detect errors in speed data and missing speed values. This process was performed separately for all three data loggers of the same assembly.

The major step in this exercise was checking the speed differences between each two consecutive observations; i.e., instantaneous acceleration or deceleration rates. The maximum attainable acceleration rate of a vehicle under a certain driving condition or load is limited mechanically by two factors: friction coefficient between the pavement and vehicle tires, and the available power from the engine. Friction coefficient is the dominant factor in lower speeds while the engine power is the limiting factor at higher speeds. The MOVES model's documentation suggests the following thresholds for the acceleration/deceleration values:

- An upper limit of 14 mph/s for acceleration; and
- A lower limit of −10mph/s for deceleration.

While these two criteria filter out the most extreme outliers, they are not sufficient to detect and eliminate all the errors in the data; specifically the ones with high acceleration rates at higher speeds. As previously mentioned, the upper limit of the attainable acceleration drops as the speed of the vehicle goes up; i.e., an observation with a high acceleration rate at a high speed is not possible for regular vehicles even though the acceleration rate values stay within the above limits. The deceleration maneuver on the other hand is made by braking, which is only governed by the effective friction coefficient between tires and the pavement. However, a high deceleration rate is usually associated with near crash or very aggressive driving, which are not the desired driving conditions for a representative drive cycle. To partially address these concerns, the EPA used the following two additional criteria for light duty vehicles established based on the VPS values for each second of speed observations:

- An upper limit of 62.5 kW/Mg for positive VSP values; and
- A lower limit of kW/Mg for negative VSP values (deceleration).

The research team examined the collected data based on the above criteria. It was found that these thresholds are not sufficient to detect all suspected data for heavy- and medium-duty vehicles. Researchers then developed a method based on the accumulative distribution of the positive accelerations. Different percentiles were calculated for positive acceleration observations grouped by their speed values. A 99 percentile value was found to provide satisfactory results with regards to filtering out suspected high accelerations; therefore, the acceleration rate corresponding to the 99 percentile was chosen as the upper limit of valid acceleration values used in this study. All the observations with an acceleration value higher than these limits were dropped from the database. Table 11 shows the upper threshold (99 percentile value) resulted from this approach.

After applying the above criteria to the light-duty vehicles, the research team observed that there are still observations with marginally high acceleration values. Since these suspicious observations are technically valid, it was decided to treat them as noisy valid data points. A data smoothing method was applied to these observation points to cancel the noise. This noise cancellation was applied to observations with an acceleration rate higher than 8 mph/s at speeds over 15 mph. A simple three-point average was used for this purpose.

Table 11. Upper Threshold of Accelerations for Heavy-Duty Vehicles.

Vehicle Type/Area/Area Type	0-25 mph	25-50 mph	>50 mph
	Maximum Acceleration Rate (mph/s)		
Heavy Duty/El Paso/Urban	3.8	2.7	2.3

Data Processing

The data processing consisted of the following processes:

- Merge data from the 3 GPS units of an assembly (Appendix C);
- Perform quality control and validation on the merged data; and

- Determine locations and roads, and extract and label border crossing trips.

Each participating vehicle was equipped with an assembly of three GPS units — A, B, and C. Information from each of the three data loggers was downloaded into a separate file. To merge this information to create a single data set for each vehicle, the speed, and coordinates information for each second of data set were averaged for the three separate files. Following are the details of this process.

Details of the process used to merge data from the three GPS units are provided in Appendix C. After merging the information and creating a single data file for each vehicle, a quality control was performed on the observations to detect and correct any error that may have resulted from the merging process. The criteria used for this purpose were generally the same as the ones used in the validation step process above. As the result, a new data files is created that contains the validated data. The details of this process are covered in Appendix D.

The focus of this study is emissions emitted from vehicles at border crossings. Therefore, the border crossing trips need to be extracted from the entire GPS data. To achieve this, the research team first assigned the location information of each second of the data using a GIS application. A GIS process for map-matching data specific to border crossings was developed. Required steps were implemented to define the country, crossing, and direction of travel for each observation. Specifically, the variables defined whether the observations had occurred within:

- U.S. or Mexico (for country);
- BOTA or Ysleta-Zaragoza Bridge (for border crossing); and
- Northbound or Southbound (for direction of travel).

ArcGIS was used as the software application to apply the model, by using discrete polygons to define the additional elements. Each observation within the data was map-matched to discrete polygons, which denoted the geographic limits that defined the variables. In other words, a point-to-polygon approach was used as the basic approach, with an identity tool being used within ArcGIS to apply the critical steps of the model.

Separate polygons were created for the northbound and southbound lanes of travel. The boundaries of the northbound and southbound polygons were drawn by using the outline of the roadway. The ends of the polygons were selected by looking at the queues associated with the worst peak for each direction of a crossing. Additional consideration was given to crossings with loading zones and separate facilities for trucks (in the case of the Zaragoza crossing). A FHWA memorandum on Emissions and Border Wait-Time (1) for the U.S.-Mexico Border near El Paso, Texas was used as the reference for defining the polygons. Figure 8 and Figure 9 show the polygons that were used to define the direction of travel.

Larger polygons were drawn to outline variables associated with country and individual crossings. Two distinct shapes were created for the area bounded by Mexico and the U.S. Observations that fell in either shape were labeled as having occurred within that country. A similar methodology was used to define the border crossing location for each observation, if it was nearby, with a specific buffer outlined for the Zaragoza and BOTA crossings.

Figure 8. Bridge of the Americas Crossing (NB = RED, SB = BLUE).

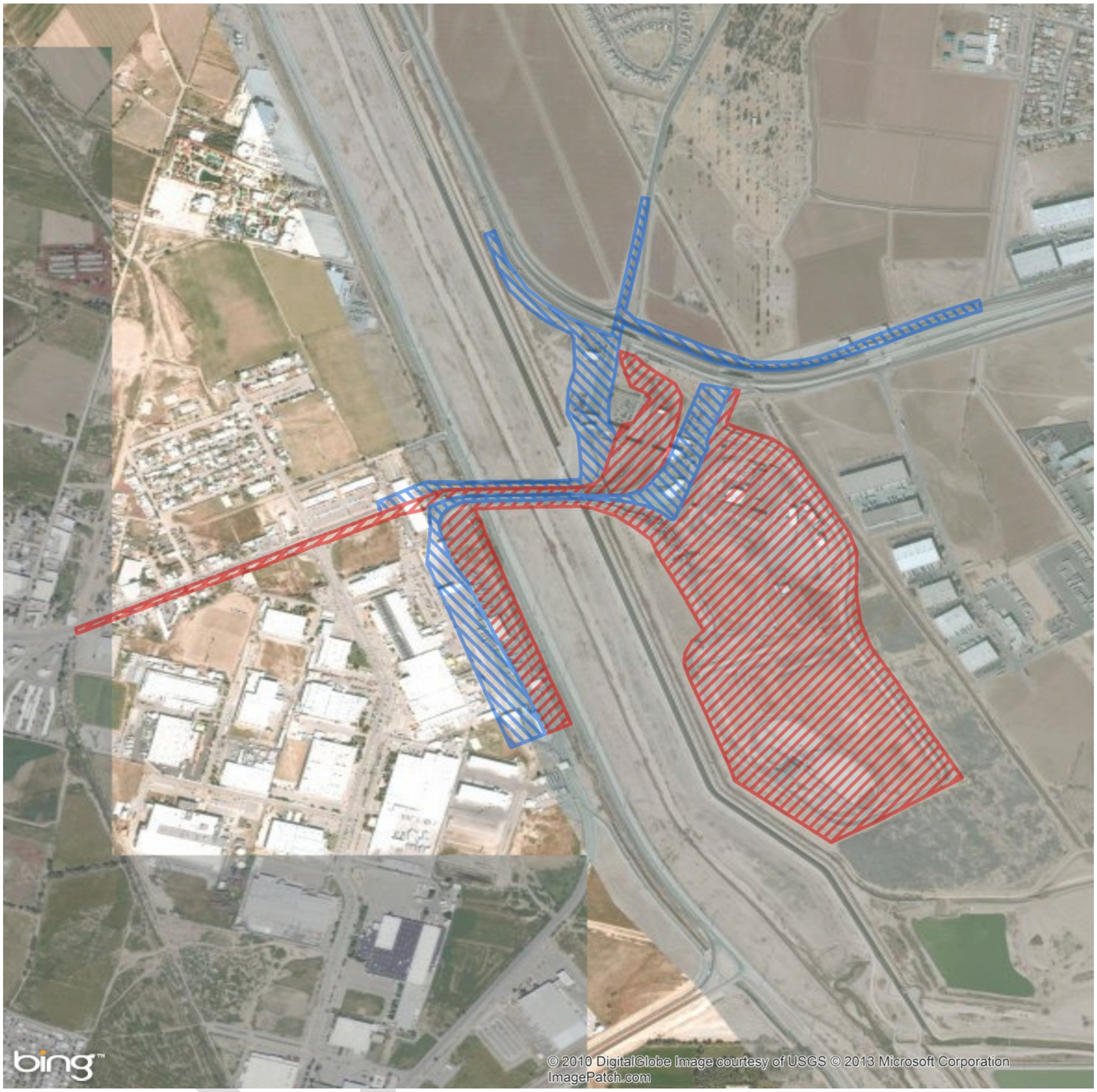


Figure 9. Zaragoza Crossing (NB = RED, SB = BLUE).

Note: The Zaragoza Bridge had two separate bridges: one for light-duty vehicles and another for commercial traffic. Light-duty vehicles used the bridge on the western side of the crossing and commercial traffic used the eastern side of the crossing.

The results of the above GIS processing were used to extract border crossing trips. A border crossing trip was defined a continuous series of observations beginning when a vehicle crossed into the predefined polygons as shown in Figure 8 and Figure 9 and ending when crossing out of the polygon on the other side of the border. Each trip was assigned a unique trip label. This trip label contains information regarding the location (border crossing), vehicle type (light- or heavy-duty), and direction (southbound or northbound). Table 12 shows a summary of the border crossing travel distances for BOTA and Ysleta-Zaragoza port of entries (POEs).

Table 12. Border Crossing Travel Distances for BOTA and Ysleta-Zaragoza POEs.

	Vehicle Type	Traffic Direction	Approach	Border Crossing Travel Distance
BOTA	Passenger Vehicles	NB	Single Approach	1.1 mi
		SB	Single Approach	0.9 mi
	Freight Trucks	NB	Single Approach	1.1 mi
		SB	Single Approach	0.9 mi
Ysleta-Zaragoza	Passenger Vehicles	NB	Single Approach	0.9 mi
		SB-1	SH375 N Frontage Road	0.8 mi
		SB-2	S Zaragoza Road	0.8 mi
		SB-3	SH375 S Frontage Road	1.1 mi
	Freight Trucks	NB	Single Approach	1.1 mi
		SB	Single Approach	1.2 mi

All the extracted trips were included in an Excel data file. A summary table of the database was created to describe the key statistics of each border crossing trip. The summary table of the trips includes the following key information:

- Average speed;
- Date and time;
- Start point information, including location, time, and speed; and
- End point information, including location and time, and speed.

The date, begin time and end time information were used to determine the time of the day and the days of the week for each trip. According to the time of the day, the trips are categorized to four groups, AM peak, mid-day, PM peak, and overnight. The use of these time periods is based on the approach recommended by EPA for PM quantitative hot spot analysis. Table 13 demonstrates the hours used for each time period in this study.

Table 13. Time of the Day

Time of the day	Actual Time Duration
AM Peak	06:00 to 09:00
Mid-Day	09:00 to s16:00
PM Peak	16:00 to 19:00
Overnight	19:00 to 06:00

During the data processing, it was found that the start and end points of the trips are not at the same location. There are two reasons for this: first, multiple entrances to the bridges and secondly, test drivers turning around before the start point for the other direction. Because the calculations in the estimation tool are based on the operating mode distributions, the impact of the different entrances is minimal.

The second type of differences, i.e., turning around midway, has potentially a larger impact because it changes the operating mode (opMode) distribution and average speed of the trip. This issue happened only for the light-duty vehicles because the drivers did not fully follow the instructions. The research team decided to fix this issue to be able to use the entire data set. To accomplish this, these trips were divided into two sections: pre-border crossing trips (part I) and border crossing trips (part II). The end point of the part I is the beginning point of part II. All the trips have a complete part II section while a minority of trips misses a portion of part I section. For each trip with incomplete portion section I, an average opMode distribution and average speed was calculated based on the complete trips. These averages were then added to the incomplete trips. A Visual Basic macro was developed to calculate operating mode distributions from the speed profiles. MOVES dafualt values were used for vehicle types 21 (passenger cars), 31 (passenger trucks) and 61 (short-haul heavy-duty trucks) in this macro. Table 14 through Table 17show a summary of the corrected border crossing average speeds.

Table 14. BOTA Light-Duty Average Speed Summary.

Time of Day \ Day of Week		Average Speed (mph)					
		Weekday			Weekend		
		Average	Max	Min	Average	Max	Min
AM Peak	**NB**	1.5	2.2	0.9	-	-	-
	SB	8.4	13.1	5.5	-	-	-
Mid-Day	**NB**	2.1	5.1	0.7	1.6	2.2	1.2
	SB	7.4	15.1	2.0	4.6	6.9	3.3
PM Peak	**NB**	1.5	2.7	0.8	1.1	1.4	0.7
	SB	3.8	5.1	2.7	3.4	3.6	3.2
Overnight	**NB**	0.9	0.9	0.9	-	-	-
	SB	7.1	15.5	2.3	-	-	-

Table 15. Ysleta-Zaragoza Light-Duty Average Speed Summary.

Time of Day \ Day of Week		Weekday Average	Weekday Max	Weekday Min	Weekend Average	Weekend Max	Weekend Min
		Average Speed (mph)					
AM Peak	**NB**	5.9	10.1	2.2	1.9	2.8	0.7
	SB	6.4	8.5	4.3	8.6	15.2	5.0
Mid-Day	**NB**	1.5	2.7	0.9	3.4	6.0	0.8
	SB	8.7	12.2	4.1	6.7	9.5	4.6
PM Peak	**NB**	1.4	1.9	0.8	3.1	5.5	1.3
	SB	3.0	3.0	3.0	6.6	10.1	2.6
Overnight	**NB**	3.2	8.6	0.8	-	-	-
	SB	5.2	10.9	1.1	7.0	10.8	1.3

Table 16. BOTA Heavy-Duty Average Speed Summary.

Time of Day \ Day of Week		Weekday Average	Weekday Max	Weekday Min	Weekend Average	Weekend Max	Weekend Min
		Average Speed (mph)					
AM Peak	**NB**	-	-	-	-	-	-
	SB	-	-	-	-	-	-
Mid-Day	**NB**	1.9	1.9	1.9	-	-	-
	SB	5.6	12.0	0.4	3.6	3.6	3.6
PM Peak	**NB**	8.5	8.5	8.5	-	-	-
	SB	3.0	3.3	2.7	-	-	-
Overnight	**NB**	-	-	-	-	-	-
	SB	7.0	15.5	0.8	-	-	-

Table 17.Ysleta-Zaragoza Heavy-Duty Average Speed Summary.

Time of Day \ Day of Week		Weekday Average	Weekday Max	Weekday Min	Weekend Average	Weekend Max	Weekend Min
		Average Speed (mph)					
AM Peak	**NB**	-	-	-	-	-	-
	SB	-	-	-	-	-	-
Mid-Day	**NB**	5.3	13.3	0.5	4.8	5.9	3.6
	SB	6.6	9.9	3.8	-	-	-
PM Peak	**NB**	6.2	10.1	2.8	-	-	-
	SB	4.6	7.2	0.3	-	-	-
Overnight	**NB**	5.2	11.5	0.9	-	-	-
	SB	5.2	7.5	2.5	-	-	-

DEVELOPMENT OF EMISSION ESTIMATION TOOL

This section describes the approach that the research team used to develop the border crossing emission estimation tool. The process consisted of the following steps:

- Obtaining emission rates for each opMode bin from MOVES; and
- Develop the emission estimation tool in a spreadsheet environment.

Extracting OpMode-Based Emission Rates

This segment describes the overall approach and MOVES parameters and inputs that researchers used to extract the required emissions rates from the MOVES model. These emissions rates are specific to the El Paso-Ciudad Juarez border crossings.

Approach

The EPA developed MOVES to estimate emissions for mobile sources. MOVES estimates emissions based on second-by-second vehicle activity data, which is a fundamental characteristic of the model. However, vehicle activity is unique at border crossings (i.e., excessive stop-and-go conditions for an extended period of time), and the default second-by-second driving patterns used in MOVES fail to represent this activity because they are based on normal roadways. The TTI research team resolved this issue by extracting operating mode emissions rates, rather than average speed emissions rates, and applying them to the border-crossing-specific vehicle activity data explained in the previous section.

Normally, MOVES is used to produce emissions rates or inventories by average speed (i.e., vehicle type 21 produces X grams of emissions per mile if traveling at 25 mph) for running-exhaust emissions. Exhaust emissions are defined as the on-road emissions produced after the engine and control systems have stabilized at operating temperature (*10*). However, emissions rates are not unique to average speeds themselves. Instead, they are the product of emissions rates unique to 23 different operating mode bins (opMode bins) – i.e., the different states that vehicles experience while operating. To calculate the emissions rate for an average speed, MOVES uses the average speed's drive cycle, or its second-by-second speed profile, to generate the average speed's operating mode distribution – i.e., the percentage of the total vehicle activity that occurs in each operating mode. MOVES applies bin-specific emissions rates to this opMode distribution and then sums them to produce the emissions rate for the target average speed. This is why different drive cycles could produce different emissions rates for the same average speed.

Thus, to obtain emissions rates that were independent of the default drive cycles, researchers obtained emissions rates for each running opMode bins. The next section expands on how researchers used these opMode-specific emissions rates to develop emissions estimation tool for the El Paso-Ciudad Juarez border crossings.

MOVES Parameters and Inputs

To account for a number of necessary local and temporal-specific factors such as climate, fuel, and fleet composition changes, researchers used batch files to run MOVES 2010b for 400 different sets of conditions. The run specification parameters and inputs considered most relevant are listed below.

Run Specifications – Scale — Researchers ran MOVES at the project level for every run. This level has the highest level of flexibility and lets the user to control almost all aspects of the process including the detailed vehicle activity data. To simplify the runs, the inventory option was selected. The next section describes how the results were used to produce opMode-based emissions rates.

Run Specifications – Time Spans — For every run, researchers ran MOVES for a one-hour time span, for one day, for one month, and for one year. A one-hour time span is the shortest time-period for which MOVES can estimate emissions. Note that the hour of the day, the day of the week, and the month that researchers selected did not affect the results because the research team supplied inputs for the factors that these conditions affect (i.e., climate, fuel, and fleet composition). The selected analysis year did impact a number of inputs though (i.e., vehicle model years, fuel supply), so researchers selected the appropriate year for each run, which included ever year from 2010 to 2035.

Run Specifications – Geographic Bounds — Researchers ran MOVES for El Paso County in Texas. Although they provided data for most of the factors that the location affects (i.e., climate, fuel, I/M program), they did not provide a barometric pressure value. Thus, the run used the default value for El Paso, which is stored in the MOVES database.

Run Specifications – Vehicles/Equipment — Researchers ran MOVES for passenger cars (vehicle type 21), passenger trucks (vehicle type 31), and combination short-haul trucks (vehicle type 61). Because all the parameters were the same for vehicle type 61 for both El Paso and Ciudad Juarez, it was unnecessary to include combination short-haul trucks in the runs for both locations, as it would have produced identical results.

Run Specifications – Road Type — The research team ran MOVES for the urban unrestricted access road type because it better represents the stop-and-go driving patterns of the border crossing. This likely did not affect the results, however, because the emission estimation process uses the opMode distributions that were developed based on the collected GPS data.

Run Specifications – Pollutants and Processes — Table 18 displays the pollutants included in the MOVES runs. The "pollutants of primary concern" are the pollutants included in the developed emissions estimation tool. Note that a number of these pollutants' emissions estimates are dependent upon the emissions estimates of the "additional required pollutants." The research team ran MOVES for the running-exhaust process only.

Table 18. Pollutants Included in MOVES Runs.

Pollutants of Primary Concern			Additional Required Pollutants	
		MOVES ID		*MOVES ID*
THC	Total Gaseous Hydrocarbons	1	-	-
CO	Carbon Monoxide	2	-	-
NOx	Oxides of Nitrogen	3	-	-
CO_2	Carbon Dioxide	90	Total Energy Consumption	91
PM_{10}	Particulate Matter <10 µm - Total	100	PM_{10} - Organic Carbon	101
			PM_{10} - Elemental Carbon	102
			PM_{10} - Sulfate Particulate	105
PM_{10}-EC	PM_{10} - Elemental Carbon	102	-	-
$PM_{2.5}$	Particulate Matter <2.5 µm - Total	110	$PM_{2.5}$ - Organic Carbon	111
			$PM_{2.5}$ - Elemental Carbon	112
			$PM_{2.5}$ - Sulfate Particulate	115

Inputs – Age Distribution, Links, Link Source Type, and Operating Mode Distribution — Researchers provided age distribution, links, link source type, and operating mode distribution inputs that enabled them to produce emission rates from total emissions resulted from the inventory mode. To accomplish this, they used a separate one-mile link (road segment) for each set of conditions.

Each link had one vehicle type and one operating mode. To account for different model years, they assigned 31 vehicles to each link (31 model years) and established an equal age distribution. This would equate to 31 vehicles per link and one vehicle per model year, but MOVES applies a fuel market share factor to volume data. This fuel market share factor defines the percentage of vehicles that use a given fuel type based on a number of factors, including vehicle type and model year. When this factor was below 100 percent, it reduced the total number of vehicles, so researchers adjusted the results accordingly to ensure that there were 31 vehicles per link and one vehicle per model year. Finally, they established a 100 percent opMode distribution, meaning each vehicle operated in its link-specific operating mode for the entire trip. This allowed researchers to obtain the total emissions produced in an hour by each model year of a vehicle type for a single opMode bin.

Inputs – Fuel Formulations and Fuel Supply — Researchers used the same set of fuel formulation data obtained from the fuel samples discussed in the previous section for each analysis year. This consisted of four total fuel types:

1) A gasoline fuel type for El Paso in the summer;
2) A gasoline fuel type for El Paso in the winter;
3) A gasoline fuel type for Ciudad Juarez in both the summer and winter; and
4) A diesel fuel type for both locations and seasons as the diesel for both locations were practically the same.

Inputs – I/M Coverage — The research team obtained and used the inspection/maintenance (I/M) coverage data that is used for official emission inventory analyses. Note that researchers adjusted the affected model years appropriately, but the I/M program coverage itself did not change. This consisted of two total I/M programs:

1) An I/M program coverage table for El Paso that was developed by TTI for TCEQ for regional emissions inventories; and
2) An I/M program coverage table for Ciudad Juarez obtained from a report on Ciudad Juarez's vehicle fleet.[3]

Inputs – Meteorology — Researchers used the same set of meteorology data for each location and analysis year. The meteorology data is comprised of both an average temperature and an average relative humidity. The hourly meteorology data was developed by TCEQ for official emissions inventory purposes. The research team used a weighted average approach to calculate a traffic weighted average temperature and relative humidity for each of the periods of the day. This consisted of eight total meteorology conditions:

1) A summer temperature and relative humidity for the A.M. peak period (6 .a.m. to 9 a.m.);
2) A winter temperature and relative humidity for the A.M. peak period (6 a.m. to 9 a.m.);
3) A summer temperature and relative humidity for the midday period (9 a.m. to 3 p.m.);
4) A winter temperature and relative humidity for the midday period (9 a.m. to 3 p.m.);
5) A summer temperature and relative humidity for the P.M. peak period (3 p.m. to 9 p.m.);
6) A winter temperature and relative humidity for the P.M. peak period (3 p.m. to 9 p.m.);
7) A summer temperature and relative humidity for the overnight period (9 p.m. to 6 a.m.); and
8) A winter temperature and relative humidity for the overnight period (9 p.m. to 6 a.m.).

By running MOVES, researchers obtained operating mode emission rates (in grams per hour) for the following conditions:

- 2 Locations – El Paso | Ciudad Juarez;
- 2 Seasons – Summer | Winter;
- 2 Fuel Types – Gasoline | Diesel:
    - Note that researchers assumed that 100 percent of combination short-haul trucks use diesel fuel. This was consistent with the field observations;
- 3 Vehicle Types – Passenger Cars | Passenger Trucks | Combination Short-Haul Trucks;
- 4 Time-Periods – AM Peak | Midday | PM Peak | Overnight;
- 7 Pollutants – THC | CO | NOx | CO_2 | PM_{10} | $PM_{2.5}$ | PM-EC;
- 25 Analysis Years – 2010 to 2035; and
- 31 Vehicle Ages – 0 to 30+ years-old.

[3] Ciudad Juárez (2011), Dirección General De Ecología Y Protección Civil, Programa de verificación vehicular de emisiones para el Municipio de Juárez 2011-2013.

Validating Emission Rates

To ensure that researchers could use operating mode emissions rates to accurately develop emissions rates for the El Paso-Ciudad Juarez border crossings, they ran MOVES separately, with average speed inputs and operating mode distribution inputs, and compared the results. The research team ran MOVES with an average speed input first because MOVES records the operating mode distribution used during each run. They exported the resulting operating mode distribution and used it to rerun MOVES with an operating mode distribution input, rather than an average speed input. Researchers repeated this process with a number of different average speeds and the subsequent operating mode distributions.

For combination short-haul trucks, both the average speed input and operating mode distribution input based runs produced identical results for every pollutant. For passenger cars and passenger trucks, the two approaches produced identical results for CO_2, PM_{10}, PM_{10}-EC, and $PM_{2.5}$, but they produced different results for CO, NO_x, and total hydrocarbons (THC); these results varied by as much as 30 percent. The TTI research team could not diagnose why these results were different and has reached out to the EPA in an attempt to resolve the issue. This is an important topic of interest that researchers are working to resolve.

Develop Emission Estimation Tool

This section describes the methodology developed to estimate emissions for the El Paso-Ciudad Juarez border crossings. The section also covers how the developed Microsoft Excel® tool uses this methodology, along with user-supplied inputs, to produce emissions estimates for the vehicle activities at the border crossings.

Calculate Operating Mode Distributions

The emissions rates obtained from MOVES represent the amount of pollutants that a vehicle emits while operating in a single mode for an entire trip. However, on-road vehicles do not operate in a single mode for an entire trip, so the tool calculates the percentage of time of a given trip that a vehicle spends in each opMode bin, which is known as the operating mode distribution, for the second-by-second speed data.

Two Potential User-Supplied Inputs

Users can either supply second-by-second speed data or average speed data in the estimation tool. The tool uses slightly different methods to calculate operating mode distributions for each option, although both methods use second-by-second speed data to calculate emissions rates for each vehicle type (i.e., passenger cars, passenger trucks, and freight trucks) and traffic direction (i.e., southbound and northbound).

If the user supplies second-by-second speed data, the tool simply calculates the operating mode distribution for these data, which the following paragraph describes. If the user supplies average speed data, the tool uses the second-by-second speed data for border crossing trips explained in the previous section. Note that researchers calculated the average speeds and operating mode distributions for these El Paso-Ciudad Juarez data before incorporating them into the tool. To use these second-by-second data for the user-supplied average speeds, the tool selects and uses the operating mode distributions for the two sets of speed data whose average speed is closest to the user-supplied average speed. A linear interpolation is used for this purpose. To ensure that this process works, the tool requires users to enter average speeds within a certain range.

Calculate Acceleration and Vehicle Specific Power (VSP) Characteristics

To determine the operating mode distributions, the tool must calculate vehicle specific power (VSP) values for passenger cars and passenger trucks and scaled tractive power (STP) values for combination short-haul trucks. Operating mode bins are defined by instantaneous speed and VSP – the "tractive power exerted by a vehicle to move itself and its cargo or passengers" (*10*) or the related concept STP, which is scaled differently (*11*). The tool uses the method used in MOVES to calculate the acceleration and VSP or STP. As Equation 1 indicates, this method estimates VSP or STP in terms of speed and acceleration. It accounts for road grade as well, although Equation 1 does not show this; the tool assumes a road grade of zero. To determine the acceleration values, the tool simply calculates the changes in speed between each second. Table 19 displays the 23 running-exhaust operating mode bins, as well as the parameters that define them. Note that there are multiple operating modes within each range of speeds.

$$P_{V,t} = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{m}$$

Equation 1 (*10*)

Where:

- $P_{V,t}$ = vehicle-specific power (VSP) (kW/metric ton);
- $_t$ = speed at time $_t$ (m/sec);
- a_t = acceleration (m/sec^2);
- m = mass (metric ton); and
- A, B, and C = coefficients representing rolling resistance (kW sec/m), rotational resistance (kW sec^2/m^2), and aerodynamic drag (kW sec^3/m^3).

Table 19. MOVES Operating Modes for Running-Exhaust Operation (*10*).

Operating Mode	Operating Mode Description	Vehicle-Specific Power (VSP_t, kW/metric ton)	Vehicle Speed (v_t, mi/hr)	Vehicle Acceleration (a_t, mi/hr-sec)
0	Deceleration/Braking			$a_t \leq -2.0$ OR ($a_t < -1.0$ AND $a_{t-1} < -1.0$ AND $a_{t-2} < -1.0$)
1	Idle		$-1.0 \leq v_t < 1.0$	
11	Coast	$VSP_t < 0$	$1 \leq v_t < 25$	
12	Cruise/Acceleration	$0 \leq VSP_t < 3$	$1 \leq v_t < 25$	
13	Cruise/Acceleration	$3 \leq VSP_t < 6$	$1 \leq v_t < 25$	
14	Cruise/Acceleration	$6 \leq VSP_t < 9$	$1 \leq v_t < 25$	
15	Cruise/Acceleration	$9 \leq VSP_t < 12$	$1 \leq v_t < 25$	
16	Cruise/Acceleration	$12 \leq VSP_t$	$1 \leq v_t < 25$	
21	Coast	$VSP_t < 0$	$25 \leq v_t < 50$	
22	Cruise/Acceleration	$0 \leq VSP_t < 3$	$25 \leq v_t < 50$	
23	Cruise/Acceleration	$3 \leq VSP_t < 6$	$25 \leq v_t < 50$	
24	Cruise/Acceleration	$6 \leq VSP_t < 9$	$25 \leq v_t < 50$	
25	Cruise/Acceleration	$9 \leq VSP_t < 12$	$25 \leq v_t < 50$	
27	Cruise/Acceleration	$12 \leq VSP < 18$	$25 \leq v_t < 50$	
28	Cruise/Acceleration	$18 \leq VSP < 24$	$25 \leq v_t < 50$	
29	Cruise/Acceleration	$24 \leq VSP < 30$	$25 \leq v_t < 50$	
30	Cruise/Acceleration	$30 \leq VSP$	$25 \leq v_t < 50$	
33	Cruise/Acceleration	$VSP_t < 6$	$50 \leq v_t$	
35	Cruise/Acceleration	$6 \leq VSP_t < 12$	$50 \leq v_t$	
37	Cruise/Acceleration	$12 \leq VSP < 18$	$50 \leq v_t$	
38	Cruise/Acceleration	$18 \leq VSP < 24$	$50 \leq v_t$	
39	Cruise/Acceleration	$24 \leq VSP < 30$	$50 \leq v_t$	
40	Cruise/Acceleration	$30 \leq VSP$	$50 \leq v_t$	

Calculate Emissions

To calculate the emissions, the tool combines the calculated operating mode distribution with the emission rates obtained from MOVES, the user-supplied volume data, and the default time-periods. The following list defines these four factors:

- Operating Mode Distribution – percentage of the total vehicle activity that occurs in each operating mode;
- Emission Rates – for each operating mode, the amount of pollutants emitted by a single vehicle over a given period of time (i.e., grams of pollutant per vehicle per hour);
- Volume Data – total number of vehicles for a given period of time; and
- Time-Periods – the user supplies data for four different times of day:

    - AM Peak: 6 a.m. to 9 a.m. (3 total hours);
    - Mid-Day: 9 a.m. to 3 p.m. (6 total hours);
    - PM Peak: 3 p.m. to 9 p.m. (6 total hours); and
    - Overnight: 9 p.m. to 6 a.m. (9 total hours).

The tool calculates separate emissions for each set of conditions (i.e., season, time-period, location, traffic direction, vehicle type, vehicle model year, fuel type, and pollutant) and sums these calculations to produce the total emission estimates. First, it calculates the operating mode distributions for the user-supplied speed data, as described previously. Then, it applies these operating mode distributions to the activity during each time period to determine the amount of time spent in each operating mode. To produce the emissions estimates, the tool then applies these "time spent in each operating mode" values to the operating mode emissions rates, which represent the amount of pollutants that a vehicle emits over a given period of time (i.e., grams of pollutant per vehicle per minute). Finally, the tool multiplies these emissions estimates by the total number of vehicles and sums the operating modes.

Validating Emission Estimation Model

To ensure that the research team successfully incorporated both the emission rates and emission estimating methodology into the Microsoft Excel® tool, they ran MOVES and the tool for the same conditions and compared the results.

Table 20 displays the results from one of the runs. Note that the THC, CO, and NO_x emissions in Table 20 are grey for the passenger car and truck vehicle types because, except for combination short-haul trucks, MOVES results were not consistent with the estimation tool. Table 20 indicates that there was otherwise no difference between the tool results and MOVES results.

Table 20. Sample Results Validating the Emission Estimation Tool.

Vehicle Type	Fuel Type	Pollutant	Results: Tool	Results: MOVES	Results: Tool/MOVES
Passenger Car	Gasoline	*THC*	*0.52*	*0.61*	*86%*
		CO	*9.34*	*10.36*	*90%*
		NOx	*0.83*	*0.93*	*89%*
		CO_2	450.46	450.46	100%
		PM_{10}	0.01	0.01	100%
		$PM_{2.5}$	0.01	0.01	100%
		PM-EC	0.00	0.00	100%
	Diesel	*THC*	*0.07*	*0.07*	*100%*
		CO	*0.38*	*0.38*	*101%*
		NOx	*0.46*	*0.46*	*101%*
		CO_2	215.85	215.85	100%
		PM_{10}	0.06	0.06	100%
		$PM_{2.5}$	0.06	0.06	100%
		PM-EC	0.02	0.02	100%
Passenger Truck	Gasoline	*THC*	*1.38*	*1.46*	*95%*
		CO	*17.57*	*19.44*	*90%*
		NOx	*1.32*	*1.54*	*86%*
		CO_2	570.56	570.56	100%
		PM_{10}	0.02	0.02	100%
		$PM_{2.5}$	0.02	0.02	100%
		PM-EC	0.00	0.00	100%
	Diesel	*THC*	*1.24*	*1.23*	*100%*
		CO	*6.34*	*6.27*	*101%*
		NOx	*6.61*	*6.76*	*98%*
		CO_2	592.91	592.90	100%
		PM_{10}	0.50	0.50	100%
		$PM_{2.5}$	0.49	0.49	100%
		PM-EC	0.19	0.19	100%
Freight Truck	Diesel	THC	1.48	1.48	100%
		CO	6.78	6.78	100%
		NOx	21.53	21.53	100%
		CO_2	1,769.55	1,769.55	100%
		PM_{10}	1.13	1.13	100%
		$PM_{2.5}$	1.10	1.10	100%
		PM-EC	0.56	0.56	100%

CHAPTER 4
CASE STUDY APPLICATIONS

A couple of case study applications were developed to demonstrate the application of the emissions estimation tool for the quantification of emissions at border crossings. The first case study provides projections of emissions at the border crossing for different analysis years. The second case study demonstrates how the tool can be used to estimate the impact of a strategy focusing on replacing old drayage trucks with new ones.

CASE STUDY 1: FUTURE TRENDS OF EMISSIONS AT A BORDER CROSSING

This case study demonstrated how future trends of emissions at a border crossing can be easily estimated in one run. Users can choose up to five analysis years for a single run; in this case 2010, 2015, 2020, 2025, and 2035. Table 21 shows the traffic data for each year. Corresponding average speeds for each time period of day is shown in Table 22. Note that all the values shown here are for demonstration purpose only and do not reflect the reality. The default age distributions which is based on the 2012 observation at El Paso-Juarez border crossings were used in this case study. All northbound values were assumed to be the same as values for southbound inputs.

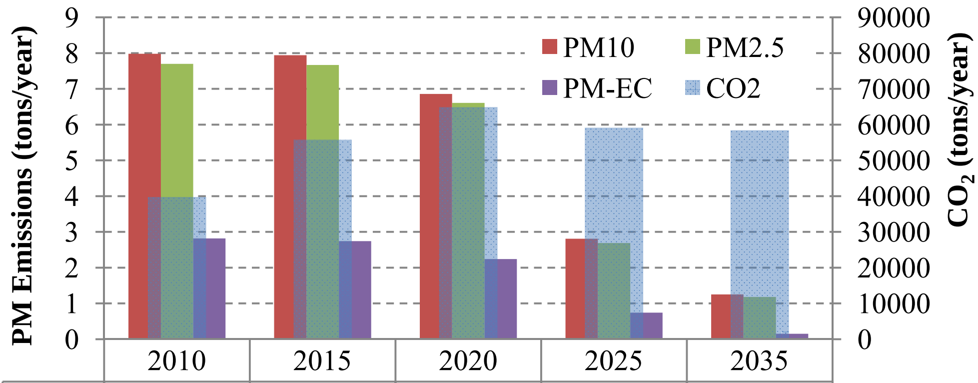
Table 21. Traffic Volumes Used in Case Study 1.

	Daily Traffic (veh/day)				
Vehicle Type	**2010**	**2015**	**2020**	**2025**	**2035**
Passenger Cars	8,000	10,000	11,000	12,000	14,000
Passenger Trucks	8,000	10,000	11,000	12,000	14,000
Freight Trucks	2,000	2,200	2,500	2,800	3,500

Table 22. Average Speeds Used in Case Study 1.

	Average Speed (mph)				
Time of Day	**2010**	**2015**	**2020**	**2025**	**2035**
AM Peak (6am to 9am)	8	7	7	8	8
Midday (9am to 3pm)	5	4	3.5	4	5
PM Peak (3pm to 9pm)	5	4	3.5	4	5
Overnight (9pm to 6am)	8	7	7	8	8

Figure 10 shows the results of this case study in graphical format. It took less than five minutes to enter the data and run the estimation.

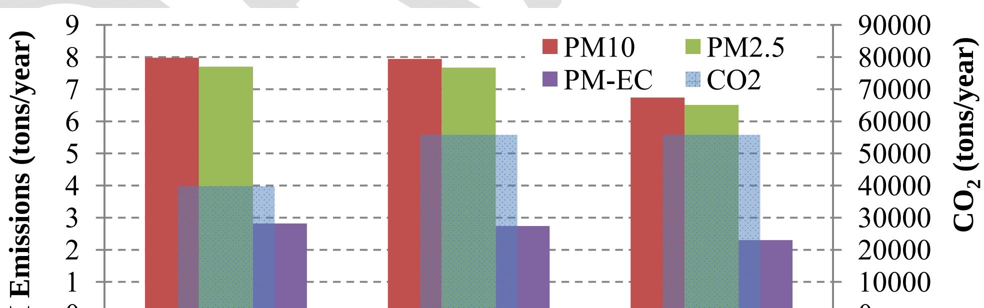


	2010	2015	2020	2025	2035
PM10	7.98	7.94	6.86	2.81	1.25
PM2.5	7.70	7.67	6.61	2.69	1.18
PM-EC	2.82	2.74	2.24	0.74	0.15
CO2	39788	55775	64991	59155	58416

Figure 10. Total Annual Emissions from All Vehicle Types - Case Study 1.

CASE STUDY 2: EMISSIONS IMPACTS OF A DRAYAGE TRUCK REPLACEMENT PROGRAM

Case study 2 demonstrates how the estimation tool can be used to investigate the impact of a very aggressive drayage replacement programs in El Paso-Juarez region. To investigate this case, it is assumed that as a result of this replacement program, 36 percent of drayage trucks will be 5 years-old or newer compared to 6.9 percent from the current trend. All the other parameters are the same as case study 1. Because age distribution is fixed for a single run, two runs were necessary for this investigation. Figure 11 shows the results for this case study.



	2010 Baseline	2015 Current Age Dist.	2015 After Replacement
PM10	7.98	7.94	6.74
PM2.5	7.70	7.67	6.51
PM-EC	2.82	2.74	2.30
CO2	39788	55775	55792

Figure 11. Total Annual Emissions from All Vehicle Types - Case Study 2.

CHAPTER 5
CONCLUSIONS AND FINDINGS

This research developed a spreadsheet-based emission estimation tool for border crossing activities in El Paso-Juarez region. A large scale data collection effort was performed to provide the necessary data for this estimation tool. The following are the main findings and implications of this research.

- Light-duty passenger vehicles and heavy-duty drayage trucks comprise the majority of the traffic activity at the border crossings in El Paso-Juarez region and are important sources of emissions in the region.
- This study examined and developed estimation procedures for three vehicle types according to MOVES vehicle classifications: passenger cars (source type 21), passenger trucks (source type 31), and combination short-haul trucks (source type 61). These vehicle types represent the majority of the vehicular activity at the region's border crossings.
- A four-step process was formulated to develop the border crossing emission estimation tool. The four steps are: data collection protocol development, conducting field data collection, processing the field data, and analysis of data and developing the estimation tool.
- The researchers used the information from review of the literature and available data sources to identify the required data elements and available data sources. This information combined with the local knowledge of the TTI El Paso staff was used to develop the data collection plan.
- The data collection plan focused on collecting data on three critical parameters deemed necessary for the emission estimation tool; i.e., vehicle activity data, border crossing fleet composition, and fuel characteristics. The research team also identified and developed necessary data processing methodologies including a detailed QA/QC plan.
- The research team executed the data collection plan for two border crossing bridges in El Paso- Juarez Regions: BOTA and Ysleta-Zaragoza Bridge. GPS units were used to collect second-by-second speed and location data for a sample of light- and heavy-duty vehicles engaged in the border crossing activity. To obtain information on the vehicle fleet mix for vehicles crossing the border crossing bridges, the research team performed an extensive vehicle license plate data collection at the two target border crossing locations. A total of 11,143 unique vehicle crossings were recorded in this effort. To determine fuel characteristics, a total of 20 gasoline and diesel fuel samples were collected from various gas stations in El Paso and Juarez. All the fuel samples were sent to SwRI for laboratory testing.
- The research team processed the collected data performed a series of quality control checks in the process. Vehicles' information was obtained from the TxDMV and Mexico state and federal agencies using the license plate and VIN records. The vehicle information included make, model, and model year was obtained for each individual vehicle. These data were used to generate the default age distribution profiles for

different vehicle types in the estimation tool. The results of the laboratory testing were uses to prepare the fuel input tables for MOVES.

- The data processing and analysis of GPS data were conducted per a three-step process: quality control and validation of raw data, data processing and categorizing the information according to key parameters, and data analysis and drive schedule development.
- The research team used all the information obtained in the previous steps to develop a Microsoft Excel®-based emission estimation tool. The estimation methodology is based on MOVES' underlying processes; i.e., calculations are all based on opMode bins.
- Researchers used MOVES to extract emission rates for each opMode bins for different vehicle types and based on various parameters such as season, fuel type, and time of day. In total researchers ran MOVES 2010b for 400 different sets of conditions.
- The opMode-based emissions rates along with other data elements were implemented into a simple user-friendly spreadsheet-based emissions estimation tool for border crossings. The tool combines the calculated operating mode distribution with the emissions rates obtained from MOVES, the user-supplied volume data, and the default time-periods to generate estimates of emissions for the target scenario. The tool calculates separate emissions for each set of conditions (i.e., season, time-period, location, traffic direction, vehicle type, vehicle model year, fuel type, and pollutant) and sums these calculations to produce the total emission estimates.
- The research team conducted a series of validation runs comparing the outputs of the tool with results of MOVES. The results indicate that there are discrepancies for NO_x, CO, and THC emissions from gasoline vehicles. The research team is working with EPA staff to determine what is causing this problem. Once the source of discrepencies identified, the emissions rates tables in the tool will be updated.
- The resulted border crossing emissions estimation tool enables the users to quickly prepare and execute emissions estimation runs for a variety of conditions and scenarios. While the emission estimation tool is based on the field data collected in El Paso-Juarez area, the structure of the estimation process is independent from the data and thus can be easily updated using local data for other locations.

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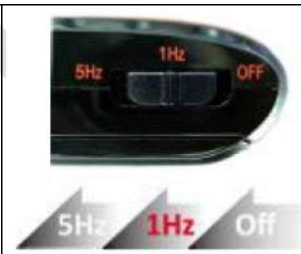
APPENDIX A: INSTALLATION INSTRUCTIONS FOR GPS UNITS

1) You must have received three GPS units that are tied together. If you have not received three (3) units, immediately contact TTI researchers at (512) 467-0946 or mfarzaneh@tamu.edu.

2) Turn on the GPS units by pushing the mode switch located on the side of the unit to the right. Put the mode switch on **1Hz** (middle position). The 5Hz option (leftmost position) is blocked on all units.

	**Mode Switch on 1Hz**	

3) Confirm that ***ALL*** the units are functioning – both a blue symbol and an orange symbol should light up. The orange symbol will blink when receiving information from the GPS satellite system. The units will beep when they first acquire GPS location data from the system.

4) Place the active GPS unit in the driver-side door storage compartment of your vehicle, taking care to place it in such a way that it will not become buried under other items in the compartment.

If your vehicle does not have a door storage compartment, place the units in the glove box or a secure place inside the cabin of the vehicle. The units should be placed in a way that does not pose any danger to the driver; e.g., block the driver's view, etc.

5) Leave units in the "ON – 1Hz" position and in the secure location until the end of the research experiment period.

6) Upon completion of the research experiment, remove the GPS units from your vehicle, turn off the unit, and return the unit to the researcher in the pre-addressed box that was provided with the unit.

Return Address:

Texas Transportation Institute
Center for Air Quality Studies
1106 Clayton Lane, Suite 300E
Austin, TX 78723
(512) 467-0946

APPENDIX B: INITIAL QUALITY CONTORL OF GPS DATA

The following are the other processes used in the data quality control.

1. Create a NEW_SPEED variable that:
    a. Checks each record to see if the SPEED variable is less than 0.2. If SPEED is less than 0.2, then record a value of 0.0 for the NEW_SPEED variable in the same record.
    b. Convert SPEED from a base unit of kilometers per hour (kph) to miles per hour (mph).

    In summary:
    IF(SPEED < 0.02, NEW_SPEED = 0, NEW_SPEED = SPEED * 0.621371192)

2. Create a TIME_CHECK variable that:
    a. Indicates whether the difference in LOCAL_TIME between consecutive records in a dataset is one second. YES = one second difference. NO = greater than a one second difference.
    b. Note: The process will truncate the first second (or record) of any trip because there is either no speed (at the beginning of the dataset) or the beginning of a new series of movements from the vehicle.

    In summary:
    LOCAL_TIME_α = Value of LOCAL_TIME for preceding record, listed directly before
    LOCAL_TIME_β = Value of LOCAL_TIME for current record

    IF(LOCAL_TIME_β – LOCAL_TIME_ α > 1 second, TIME_CHECK = “NO”, TIME_CHECK = “YES”)

3. Create an ACCEL_CHECK variable:
    a. Similar to the process with TIME_CHECK, but checking different variables using a different threshold.
    b. NEW_SPEED from the preceding record will be checked.
    c. The threshold is the absolute value of 15 mph/sec.

    In summary:
    NEW_SPEED_ α = Value of NEW_SPEED from preceding record
    NEW_SPEED_ β = Value of NEW_SPEED from current record

    IF(ABS(NEW_SPEED_ α – NEW_SPEED_ β) > 14, ACCEL_CHECK = “NO”, ACCEL_CHECK = “YES”)

4. Create a HEAD_CHECK variable:
    a. Similar to TIME_CHECK and ACCEL_CHECK.
    b. HEADING will be checked from the preceding record.
    c. The threshold is 30 degrees.

In summary:
HEADING_ α = Value of HEADING from preceding record
HEADING_ β = Value of HEADING from current record

IF(ABS(HEADING_ α – HEADING_ β) > 30, HEAD_CHECK = “NO”, HEAD_CHECK = “YES”)

APPENDIX C: MERGING INFORMATION FROM 3 GPS UNITS

1. Create a series of CHECK_SPEED variables in the new merged spreadsheet.
    a. Compare the differences with NEW_SPEED for every record with the same LOCAL_TIME and LOCAL_DATE across all the three spreadsheets within the same Excel file.
    b. Make a series of IF statements to test the validity of each of the three data loggers.
    c. A resulting value of 1 indicates the NEW_SPEED value to be true, 0 is false.

    In summary:

    Create CHECK_SPEED_A; CHECK_SPEED_B; and CHECK_SPEED_C

    NEW_SPEED_A = NEW_SPEED from Data Logger A

    NEW_SPEED_B = NEW_SPEED from Data Logger B

    NEW_SPEED_C = NEW_SPEED from Data Logger C

    CHECK_SPEED_A = IF(ABS(NEW_SPEED_A – NEW_SPEED_B) > 2 AND ABS(NEW_SPEED_A – NEW_SPEED_C) > 2, CHECK_SPEED_A = 0, CHECK_SPEED_A = 1)

    CHECK_SPEED_B = IF(ABS(NEW_SPEED_B – NEW_SPEED_C) > 2 AND ABS(NEW_SPEED_B – NEW_SPEED_A) > 2, CHECK_SPEED_B = 0, CHECK_SPEED_B = 1)

    CHECK_SPEED_C = IF(ABS(NEW_SPEED_C – NEW_SPEED_A) > 2 AND ABS(NEW_SPEED_C – NEW_SPEED_B) > 2, CHECK_SPEED_C = 0, CHECK_SPEED_C = 1)

2. Create a SUM_CHECK_SPEED variable.
    a. This variable will be used in a later step to assess every record by LOCAL_DATE and LOCAL_TIME against a pre-established threshold.
    b. Sum the CHECK_SPEED_A; CHECK_SPEED_B; and CHECK_SPEED_C variables.

    In summary:

    SUM_CHECK_SPEED = SUM(CHECK_SPEED_A; CHECK_SPEED_B; CHECK_SPEED_C)

3. Create a MOD_AVG_SPEED variable.
    a. This variable will average the speeds that are deemed to be valid for every record with the same LOCAL_DATE and LOCAL_TIME within a single Excel file.
    b. The threshold will be set as SUM_CHECK_SPEED = 2; or a date and time with at least two recorded speeds that are valid.

In summary:
MOD_AVG_SPEED = X
if SUM_CHECK_SPEED = 3
then X = AVG(CHECK_SPEED_A; CHECK_SPEED_B; CHECK_SPEED_C)
else

if SUM_CHECK_SPEED = 2 & CHECK_SPEED_A = 1 & CHECK_SPEED_B =1
then X = AVG(CHECK_SPEED_A; CHECK_SPEED_B)
else

if SUM_CHECK_SPEED = 2 & CHECK_SPEED_B = 1 & CHECK_SPEED_C =1
then X = AVG(CHECK_SPEED_B; CHECK_SPEED_C)
else

if SUM_CHECK_SPEED = 2 & CHECK_SPEED_A = 1 & CHECK_SPEED_C =1
then X = AVG(CHECK_SPEED_A; CHECK_SPEED_C)
else X = "NO"

4. Create a new spreadsheet that averages key variables from the three separate datasets. One record will be shown, as averaged, for every date and time of observation.
   a. Do not include records with the same date and time if they meet the following conditions:
      i. TIME_CHECK = NO
      ii. ACCEL_CHECK = NO
      iii. HEAD_CHECK = NO
      iv. MOD_AVG_SPEED = NO
   b. The following variables should be seen in the merged dataset:
      i. UNIT_NO
      ii. LOC_INSTALL
      iii. VEH_CODE
      iv. LOCAL_DATE
      v. LOCAL_TIME
      vi. LONGITUDE
      vii. LATITUDE
      viii. MOD_AVG_SPEED

APPENDIX D: VALIDATION OF MERGED DATA

1. Create a TIME_CHECK_2 variable in the new dataset that will check the consecutiveness of recorded times with the averaged dataset.
   a. Similar to the previous TIME_CHECK variable.
   b. If the difference in LOCAL_TIME from the preceding record is one, then TIME_CHECK_2 = “YES”, if not then TIME_CHECK_2 = “NO”.

   In summary:
   LOCAL_TIME_α = Value of LOCAL_TIME for preceding record, listed directly before
   LOCAL_TIME_β = Value of LOCAL_TIME for current record

   IF(LOCAL_TIME_β – LOCAL_TIME_ α > 1 second, TIME_CHECK_2 = “NO”,
   TIME_CHECK_2 = “YES”)

2. Create an ACCEL_CHECK_2 variable in the new dataset that will check the validity of speed between continuous records in the averaged dataset.
   a. Similar to the previous ACCEL_CHECK variable.
   b. If the difference in MOD_AVG_SPEED from the preceding record is less than the absolute value of 15, then ACCEL_CHECK_2 = “YES”, else ACCEL_CHECK_2 = “NO”.

   In summary:
   MOD_AVG_SPEED_ α = Value of MOD_AVG_SPEED from preceding record
   MOD_AVG_SPEED_ β = Value of MOD_AVG_SPEED from current record

   IF(ABS(MOD_AVG_SPEED_ α – MOD_AVG_SPEED_ β) > 15, ACCEL_CHECK_2
   = “NO”, ACCEL_CHECK_2 = “YES”)

3. Create another new dataset that accounts for this iteration of quality control measures.
   a. Do not include records if they meet the following conditions:
      i. TIME_CHECK_2 = NO
      ii. ACCEL_CHECK_2 = NO
   b. The following variables should be seen in the new dataset:
      i. UNIT_NO
      ii. LOC_INSTALL
      iii. VEH_CODE
      iv. LOCAL_DATE
      v. LOCAL_TIME
      vi. LONGITUDE
      vii. LATITUDE
      viii. MOD_AVG_SPEED