DEVELOPMENT OF EMISSIONS REDUCTION PROGRAM FOR HEAVY-DUTY TRUCKS OPERATING IN THE BORDER REGION

FINAL REPORT

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TTI Air Quality Program

ABOUT THIS REPORT

This work was performed by the Texas A&M Transportation Institute (TTI) in cooperation with the Texas Commission on Environmental Quality (TCEQ). The principal investigator for this study is Reza Farzaneh. The report authors include: Jeremy Johnson, Tara Ramani, and Robert Huch.

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DISCLAIMER

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EXECUTIVE SUMMARY

This report summarizes the findings from a study aimed at reducing diesel emissions from drayage trucks operating in the El Paso-Ciudad Juárez region on the U.S.-Mexico border. El Paso is one of the largest border crossings in the U.S., and receives large amounts of cross-border freight, mostly carried by heavy-duty drayage trucks. Drayage trucks have unique operational and emissions characteristics, and are a major source of emissions in border regions.

This study was conducted by the Texas A&M Transportation Institute (TTI) for the Texas Commission on Environmental Quality (TCEQ). It investigated the potential for reducing diesel emissions from drayage truck operations through the development and implementation of a driver training program. This program is aimed at heavy-duty drayage fleets operating in border regions. A case study was conducted for in the El Paso-Juárez region, where drivers were provided with training, and driving behavior data collected before and after the training to assess potential training benefits.

As a first step, the research team conducted an extensive literature review of information relevant to understanding drayage truck operations and emissions. Heavy-duty truck emissions reduction strategies, and the role of driver training and behavior were also investigated, and several existing driver training programs were reviewed. Following this, the TTI team developed a driver training program (available in English and Spanish versions) aimed specifically at drayage truck drivers. The training emphasized factors that were relevant to drayage operations, and on factors that were within a driver's control.

Following the development of the training program, a case study was undertaken to assess training program impacts. It involved an assessment of driver behavior before and after implementation of the training program. The assessment was performed by collecting driving data from a sample of trucks, each operated by a single driver before and after receiving the training. Global positioning system (GPS) units and portable activity measurement system (PAMS) were used for the data collection.

The analysis of GPS and PAMS data covered two aspects of driving behavior, namely analysis of idling events and analysis of acceleration patterns (as an indicator of aggressive driving). The findings indicated, overall, there were reduced idling levels and

acceleration levels that could potentially be attributed to the training program. Non-border facility idling of greater than a minute duration decreased by approximately 65 seconds (approximately 22%) after the training. Further, acceleration rates decreased over all speed ranges tested, with changes ranging from 3% to 11%. The findings indicated that overall, there were reduced idling levels and acceleration levels that could potentially be attributed to the training program. However, not all the trucks showed statistically significant improvements, and further research is needed to conclusively establish benefits of these programs.

In addition, emissions testing was conducted, and supplemented with data from emissions models, to establish representative emissions rates for heavy-duty drayage trucks. The findings from the analysis of idling and acceleration changes were then used along with emissions rates to identify potential emissions benefits from driver behavior training programs.

In conclusion, the findings from this study indicate that there is potential for effecting behavioral changes in drayage operators through a training program, with the associated emissions and fuel consumption benefits. Areas for future research include additional studies with expanded participants over a longer period of time, addressing idling at border crossing locations (which was considered to be non-discretionary for purposes of this analysis), and the investigation of incentive programs for drivers to improve effectiveness of training programs.

CHAPTER 1 - INTRODUCTION

BACKGROUND

El Paso, Texas, is a large city located on the border between the United States and Mexico, The El Paso area is part of a larger binational airshed called the Paso del Norte, which includes Ciudad Juárez in Mexico and Doña Ana County in New Mexico. Poor air quality is a prevailing concern in this region – El Paso is currently in violation of the federal National Ambient Air Quality Standards (NAAQS) for particulate matter (PM), classified as being in moderate nonattainment. The region is also in attainment-maintenance (i.e. was previously in nonattainment) for carbon monoxide (CO). Further, the area is also likely to be classified as a nonattainment area for ozone, per the 2015 standard, for which designations are still pending (*1,2*). Thus, air quality improvement and reduction of emissions is very important to the region.

El Paso is a gateway to large amounts of cross-border freight movement from Mexico to the United States, most of which is carried through drayage trucks. Previous studies conducted by the Texas A&M Transportation Institute (TTI) for the Texas Commission on Environmental Quality (TCEQ) have investigated the role of drayage traffic on emissions at the border. A project to develop an emissions estimation tool for cross-border traffic in the El Paso-Juárez area found that heavy-duty traffic crossing the border was a significant component of the total on-road mobile source emissions (3). Another TTI study conducted for TCEQ and the U.S Environmental Protection Agency (EPA) analyzed several emissions reduction strategies and technologies in terms of their potential applicability and effectiveness for drayage operations (4). The findings indicated the potential for driving behavior changes (i.e. "eco-driving") to result in emissions reduction from heavy-duty drayage truck operations.

PROJECT GOAL

The overall goal of this project is to reduce diesel emissions from drayage truck operations through the development of a driver training program aimed at heavy-duty drayage fleets operating in border regions. The main elements of the study are:

– Development of a training program focused on fuel reduction techniques for drayage operators;

- Implementation of a case study in the El Paso-Juárez region, where drivers were provided with training, and driving behavior data collected before and after the training to assess potential training benefits.

Project Approach and Tasks

The project began with a thorough literature review of emissions reduction techniques that are available and in use for heavy-duty truck operations, as well as other heavy-duty training programs that have been developed. The review then focused on specific techniques that would be applicable for the drayage operations, which are very different from long haul trucking operations. Using the results of the review, the TTI research team created a training program to teach operators techniques that would help to reduce emissions and fuel consumption from drayage operations. In order to determine the potential impact of the training, a case study was conducted, monitoring the driving characteristics of the drayage operators on a second by second basis both before and after they took part in the training. The data were analyzed to determine the potential benefits of the training, and the training program was finalized based on findings from the study and lessons learned.

Report Overview

Following this introductory chapter, Chapter 2 details the findings from a review of literature and the state of the practice. Chapter 3 discusses the development of the training program. This is followed by a description of the case study and results in Chapter 4, and findings and conclusions in Chapter 5.

CHAPTER 2 – LITERATURE AND STATE OF THE PRACTICE REVIEW

This section of the report details the findings from a review of current literature and the state of practice related to heavy-duty truck operations in the border region and an overview and evaluation of existing emissions reductions strategies for heavy-duty trucks. The review includes an overview U.S-Mexico cross-border freight, a review of drayage operations, activity and emissions characteristics, emissions reduction strategies for freight, and existing driver training programs.

U.S.-Mexico Cross Border Freight

Freight movement across the U.S.-Mexico border has increased rapidly in recent years. From 2005 to 2015 the total trade (including goods both exported to and imported from Mexico) has increased from just over $290 million in 2005 to just over $532 million in 2015 (*5*). Over the same time period trucks entering the U.S. at southern border crossings have increased by almost 1 million trucks per year (6). A large portion of the cross-border freight between the U.S. and Mexico occurs in Texas. Between the years of 2005 and 2015, a total of 54.34 million trucks crossed southern border ports of entry (POEs) into the U.S, out of which 36.97 million (68%) entered through POEs in Texas. Texas POEs are among the busiest along the southern border in terms of truck traffic, as shown below in Table 1. In 2016 alone just under 4 million trucks (3,967,238) entered the U.S. through Texas POEs (*6*).

Table 1: Southern Border POEs by Number of Truck Crossings in 2016 (*6*)

POE Name	Truck Crossings into U.S.	% of Total Mexico Border
Laredo, TX	2,083,964	35.9 %
Otay Mesa, CA	899,336	15.5%
El Paso, TX	763,868	13.2%
Hidalgo, TX	568,235	9.8%
Calexico East, CA	349,727	6.0%
Nogales, AZ	335,737	5.8%

There is a total of 28 POEs (including non-commercial POEs) in Texas along the border with Mexico, as shown in Figure 1 (*7*). Of these, 10 are capable of handling truck traffic. Table 2 lists the details of these POEs based on 2016 data, ordered from the busiest to the least used crossing.

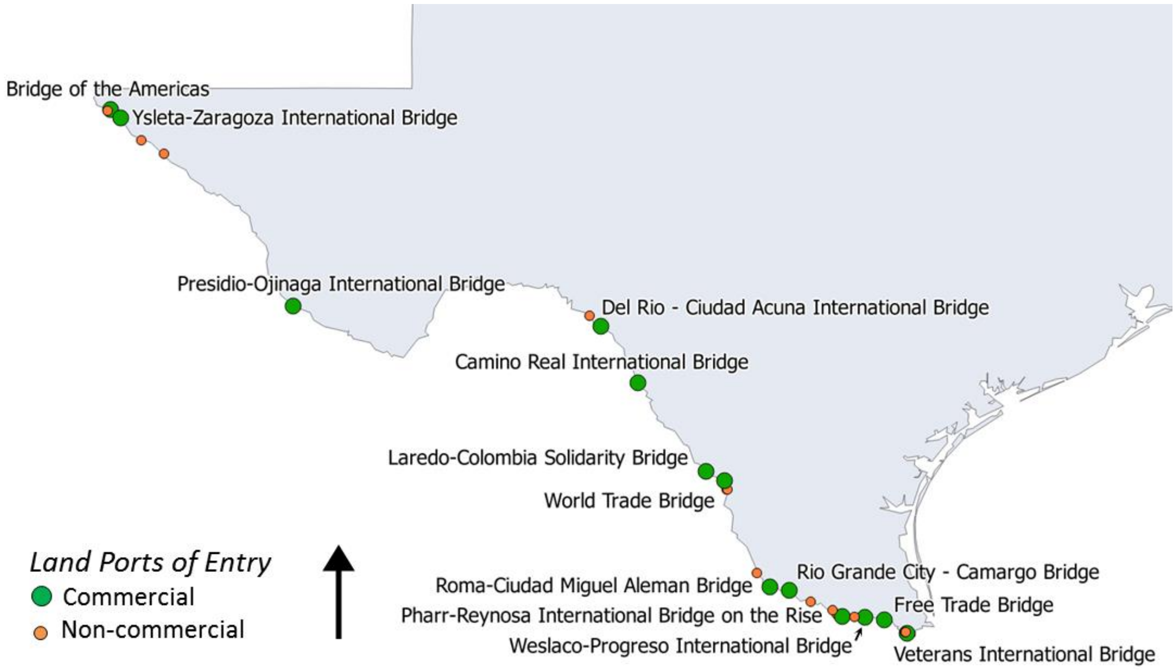


Figure 1: Texas/Mexico Border Vehicular Ports of Entry *(7)*

Table 2: Texas POEs Truck Crossings in 2016 (*6*)

POE Name	Truck Crossings into U.S.	% of Total Texas Crossings
Laredo	2,083,964	52.5 %
El Paso	763,868	19.3 %
Hidalgo	568,235	14.3 %
Brownsville	217,331	5.5 %
Eagle Pass	159,538	4.0 %
Del Rio	74,290	1.9 %
Progreso	48,983	1.2 %
Rio Grande City	35,996	0.9 %
Presidio	7,539	0.2 %
Roma	7,494	0.2 %
Fabens	173	<0.1%
Total	3,967,411	100%

EMISSIONS REDUCTION STRATEGIES FOR HEAVY-DUTY TRUCKS

The studies reviewed in previous sections indicate that drayage trucks generate a disproportionate amount of emissions near the border due to lengthy wait times at POEs, and the overall age of the drayage fleet relative to the long-haul fleet. There are a variety of strategies in relevant literature regarding emissions reductions from freight and heavy-duty vehicles. Several of the strategies may be applicable to drayage trucks. A summary of strategies outlined in reports by the Federal Highway Association and the Commission for Environmental Cooperation are included in Table 3 (*8, 9*) and discussed in further detail in the remainder of this section. These strategies can be broadly categorized as follows:

- Technological Strategies: which relate to modification of parts of the vehicle or its fuel.
- Operational Strategies: which relate to modification of the operation or functioning of the vehicles and its components.
- Transportation System Management Strategies: which relate to planning strategies that increase the efficiency of the transportation system through congestion mitigation or smart growth initiatives.

Table 3: Emissions Reductions Strategies for Freight (*8,9*)

Strategy	Sub-strategy	Examples
Technological Strategies	Alternative Fuels	Biodiesel Ethanol Emulsified Diesel Natural gas Propane Ultra-low sulfur diesel Hybrid and electric vehicles
	Retrofits	Diesel oxidation catalysts Diesel particulate filters NOx catalysts Selective catalytic reduction technology catalysts
	Repowering and Replacement	Replace vehicle with newer model year Replace engine for pre-2007 engine with emission controls Replace for alternate fuel or electric powered vehicle
	Vehicle Maintenance	Periodic Maintenance
	Engine and Vehicle Efficiency	Fuel efficient lubricants Tare weight reduction Aerodynamic improvements Reduced tire rolling resistance
Operational Strategies	Idle Reduction Strategies	An auxiliary power unit Automatic engine idle systems Truck stop electrification Advanced truck stop electrification Others: Security pre-clearance at POE, Improved logistics for shipments etc.
	Driving Behaviors	Driver training Incentive programs
	Optimizing Truck Routing	Optimize routing to reduce backtracking or empty miles Improve logistics Maximize cargo volume Minimize trailer weight
Transportation System Management Strategies	Infrastructure Improvements	Arterial signal coordination Grade Separations Truck-only lanes
	Land Use and Transportation Strategies	Zoning tools Regional visioning and scenario planning Freight-exclusive facilities Effective truck-use networks

Technological Strategies

Technological strategies to achieve emission reductions include the following measures: alternative fuels, retrofits, repowering and replacement, vehicle maintenance, and engine and vehicle efficiency (*10)*. Several of these technologies and strategies have been employed by agencies in Texas and beyond, for freight as well as for buses and other types of vehicles. TCEQ manages the Emissions Reduction Incentive Grants (ERIG) program which provides grant opportunities in support of the use of emissions reduction technologies (*11*).

Alternative Fuels

There are several alternative fuel technologies available that provide cleaner-burning options for freight vehicles. Use of alternative fuels has been shown to reduce fuel consumption and CO_2 emissions, which make up the majority of greenhouse gases (GHGs). These fuel options, listed in Table 4, include ethanol, biodiesel, natural gas, propane, ultra-low-sulfur diesel (ULSD), and hybrid and electric vehicles.

These alternative fuels have lower carbon emissions than fossil fuels. However, not all alternate fuels can successfully replace traditional fuels due to their efficiency. An additional obstacle to increased market acceptance of alternative fuels is the lack of refueling stations. The lack of availability is related to the high infrastructure costs associated with building new refueling stations. For trucking operators to switch to alternative fuels, there must be refueling facilities along key routes. At the U.S-Mexico border, a large number of drayage trucks operate within a well-defined region. This means that refueling stations located there could serve a high number of trucks. Setting up refueling stations at the POEs and along major freight corridors, may encourage and facilitate the of use alternative fuels along the cross-border region (*10*). TCEQ's Alternative Fueling Facilities Program (AFFP) provides grants for the construction or expansion of alternative fueling stations within the 83-county Clean Transportation Zone (*12*).

Table 4: Alternative Fuel Types

Alternative Fuel Type	Description
Biodiesel	A fuel manufactured from vegetable oils and animal fats. Found to reduce PM emissions by 10%, but can increase NOx by 2%. (*13*)
Ethanol	A renewable bio-based fuel can be combined with diesel to reduce emissions.
Emulsified Diesel	A combination of diesel fuel, water, and other additives. Reduces emissions of PM and NOX. (*13*)
Natural gas	Natural gas can be used to fuel off-road engines in the forms of compressed gas or liquefied gas. Natural gas can produce fewer greenhouse gas emissions and tailpipe emissions, such as hydrocarbons, NOX, carbon monoxide, and carbon dioxide. (*14*) However, due to its fossil fuel base, it is not as effective in reducing greenhouse gas (GHG) emissions as other alternative fuels (*10*).
Propane	Propane has a lower carbon content than traditional fuels, and can produce fewer greenhouse gas emissions and tailpipe emissions. (*15*) At California ports, several diesel yard tractors were converted to using propane. The propane tractors were found to produce less NOx and PM emissions by 80% (*10*).
Ultra-Low Sulfur Diesel (ULSD)	ULSD is diesel fuel with 15 parts per million or less sulfur. Emission reductions of ULSD alone vary depending on application, but ULSD enables or improves the performance of after treatment technologies, for example a PM filter. (*13*)
Hybrid and electric vehicles	Hybrid and electric can be used in medium-duty tractor trailers that operate primarily in urban areas. Hybrid and electric vehicles produce lower tailpipe emissions than traditional vehicles. Vehicles running completely on electricity have zero tailpipe emissions. (*16*)

Retrofits

This approach refers to addition of after-treatment devices to the vehicle to reduce emissions. The current after-treatment devices usually require ULSD. Some examples of these devices are: diesel oxidation catalyst (DOC), diesel particulate filter (DPF), NOx catalysts, and selective catalytic reduction (SCR) technologies. DOCs break down pollutants into less harmful particles using a chemical process. This process can reduce PM emissions by 20% to 50%. DPFs use high temperatures to break down the particles into less harmful components. The filters require the use of low sulfur fuel but can reduce PM emissions from 50% to 90%. NOx catalysts use a chemical process to break down harmful NOx emissions by 10% to 20%. SCR catalysts breaks NOx emissions down into water and nitrogen and are found to reduce NOx by 75% to 90%, and PM emissions by 20% to 30% (*8*).

Repowering and Replacement

Repowering consists of replacing an engine or vehicle with a newer model year. An older engine could be replaced for a completely new engine or an engine manufactured before 2007 with emission controls. This approach is effective when the equipment has a longer life-span than the engine does (*10*). Repowering can also mean converting equipment from diesel to electrical power or an alternative fuel, such as propane. It can also mean replacing a vehicle with an electric powered vehicle. This approach is most frequently used for equipment such as cranes and forklifts. Repowering could entail a complete replacement of the equipment, taking older models out of service (*10*).

Old freight equipment may be replaced for newer, more fuel-efficient versions. Replacement of older equipment has been found to result in lower maintenance costs, and improved fuel economy performance for fleet owners.

Vehicle Maintenance

Periodic maintenance of equipment ensures maximum performance and helps reduce emissions (8). Since vehicle maintenance practices are mostly voluntary, outreach- and education-based strategies by public agencies can help educate the public and fleet owners regarding best maintenance practices. TCEQ's AirChekTexas/Drive a Clean Machine program provides vehicle repair assistance to eligible drivers (*17*).

Engine and Vehicle Efficiency

Improving the efficiency of the engine can result in reduced emissions and fuel costs. This includes a variety of options as listed below:

- Reducing the loads on the truck
- Improving the efficiency of drivetrains (a system which connects the drive axles to the transmission) and avoiding energy losses
- Reducing emissions from the exhaust and climate controls (i.e., heat and air conditioning)

The loads on a truck refers to the force of acceleration needed to overpower inertia, the rolling resistance of the tires, aerodynamic forces, and the weight of the truck when travelling up slopes. Approaches to improve engine efficiency include curbing frictional and pumping losses, and improving thermodynamic efficiency (*9*). Border crossings are often congested due to high traffic volumes as well as delays caused by customs processing and inspection. This congestion means the speed of operation is generally low. Given these low speeds, addressing frictional losses may not lead to significant energy savings, but reducing thermodynamic and pumping losses may lead to some improvement (*9*). Improving thermodynamics means recapturing heat lost in the process of reducing vehicle speed by breaking, when rolling resistance increases and aerodynamic forces take hold. Pumping losses occur any time air or fuel is pumped to the cylinders and out the exhaust. Pumping losses can be minimized by reducing the energy loss that occurs during these processes.

Operational Strategies

Operational strategies relate to modifications in the way the vehicle is operated. These strategies include idle reduction, driver behaviors, and optimal route selection.

Idle Reduction Strategies

The most common strategy to improve system efficiency is reducing idling time. Idling occurs most extensively at truck stops and rest areas. Drivers will idle the truck in order to use appliances, condition the cabin temperature, or keep the engine at an optimum temperature. Using an engine for these purposes is inefficient and leads to unnecessary emissions and fuel consumption. Some of the technologies that can be used to reduce idling are:

- *Auxiliary power unit (APU):* Small diesel or battery powered system mounted externally on the truck cab to help power amenities and provide air conditioning in the cabin.
- *Automatic engine idle systems:* Systems that will stop and start the engine automatically according to specified cabin temperature or minimum battery voltage.
- *Truck stop electrification:* Permanent systems installed at truck stops which allow trucks to be plugged into a power source to run amenities, such as air conditioning while the engine can be turned off (*8*).

Many factors increase idling time for trucks. One of these factors, as discussed above, is idling time at truck stops. Studies estimate that trucks idle for 6 hours a night *(18)*. Reducing this time by 50% would decrease NO_x emissions by 156 tons per year in Dallas-Fort Worth *(8)*.

Idling also occurs when drivers are picking up or dropping off a shipment. In these instances, a truck may arrive to a destination where their cargo needs to be unloaded, but find that they must wait for someone to receive the cargo. In many cases the driver will simply leave the truck idling while they wait, leading to unnecessary emissions and fuel consumption. Enhancing communication and scheduling with logistics software may decrease wait times. Shippers may also provide docking stations with electricity or implement no-idling policies (*10*).

Congestion frequently causes delays, and idling, at POEs. In part, this congestion is due to time-consuming security and immigration procedures. Electronic pre-clearance may be an option to expedite the border-crossing process, and reduce idling time. Another option may be incorporating mandatory or voluntary truck stop electrification facilities at the border, which require trucks to access a parking area and turn off their engines until they are signaled to cross the border according to an appointment system (*19*). These facilities would reduce idling while providing drivers access to amenities and electricity.

Driving Behavior

Driving behavior also affects fuel economy. Limiting speed, number of stops, route taken, and shifting and acceleration techniques are all methods to reduce fuel consumption. Providing driver training, using electronic engine monitors to track driving behavior, and incentive programs may encourage more fuel-efficient driving behavior.

Optimizing Routing

Freight efficiency is defined as the amount of freight hauled per gallon of fuel used, so the fuller the trailer, the better overall efficiency. Out-of-route miles, and empty trips waste driving time and fuel, so optimizing truck routing can save a significant amount of fuel and money and reduce emissions. Some relevant strategies to optimize truck routing include:

- *Optimizing routing to reduce backtracking and empty miles:* Improving logistics by consolidating and coordinating shipments, for example, could limit the amount of empty mileage trucks accrue. Coordinating a full return load improves fuel productivity because it means the truck is not using fuel on an empty return load. In addition to reducing emissions, return loads increase profit for trucking companies (*10*).
- *Improving logistics:* Reducing shipment frequency means fewer trucks on the road, and consequently, reduced emissions. Decentralizing supply chain origins can also generate fuel savings by shortening the haul distance. Further, coordinating logistics locally allows for full use of current truck trips rather than adding more trips as it is easier to manage and maximize trips on a localized scale.
- *Maximizing cargo volume:* Increasing the use of longer/heavier trucks and longer trains means more cargo is transported in a single trip, which decreases the number of trips required to haul goods.
- *Minimizing trailer weight:* Lighter trailers may also result in improved fuel economy. According to a study conducted by the EPA, reducing 3,000 pounds for lightweight trucks could save 240 gallons of fuel annually and cut up to five metric tons of CO_2 (*20*).

All of the above mentioned strategies focused on improving operational efficiency could be successful near the border. Specifically, Intelligent Transportation Systems (ITS) and global positioning systems (GPS) could provide alternate routes in order to reduce idling time.

Transportation System Management Strategies

Transportation System Management (TSM) strategies include options to improve the overall efficiency of the transportation system. Strategies in this category include improving infrastructure and land use and transportation strategies.

Infrastructure Improvements

Roadway congestion increases the amount of time vehicles spend idling, which reduces efficiency and increases emissions. Alleviating congestion can reduce emissions from trucks. Some of the strategies to mitigate congestion include:

- *Arterial signal coordination:* Improving signal timing can optimize traffic flow, especially in areas with high truck traffic. Trucks lose time while stopped at a traffic signal, and must expend additional energy to break and then accelerate—a process that increases emissions.
- *Grade separations for roads and rail:* Grade separations are physical divisions in the road to avoid conflicts from traffic travelling in different directions. These are most often used in reference to railroads that cross highways. Separating these two lines of traffic means vehicles do not have to stop to let trains through. In this manner, traffic flow improves and emissions are reduced.
- *Truck-only lanes:* These lanes separate trucks from other vehicles in order to improve traffic flow and safety. A few states have incorporated this including California which has two "truck-only" lanes, and Louisiana, which included "truck-only" lanes in the Tchoupitoulas Corridor Improvements at the Port of New Orleans *(21)*. New Jersey also included a "dial-dual alignment" to the Turnpike, which creates an auto-only lane. The Southern California Association of Governments (SCAG) conducted a study, which found that these lanes are more feasible when:
    - There are more than 1,800 vehicles per lane per hour during peak traffic;
    - There are more than 1,200 vehicles per lane per hour during off-peak traffic;
    - At least 30% of traffic consists of trucks. (*21*)

Land Use and Transportation Strategies

Integrated land use and transportation planning can reduce vehicle-miles traveled and thereby vehicles emissions. Integrated planning accounts for the relationship between land use and transportation (e.g., understanding and accounting for the effects of transportation systems on land use development, and vice versa). While coordinating between land use and transportation across the border region with stakeholders and governments from two countries can be difficult, there are examples of successful cross-border agreements. The Northwest Ports Clean Air Strategy involved the cooperation of maritime ports and environmental agencies, for example (*9*).

Some of the land use and transportation strategies are listed below.

- *Zoning tools:* Zoning tools are used to preserve industry and limit freight impacts. The goal is to provide space for manufacturing where necessary infrastructure and adjacent land use already exists, as well as protect industries from pressures to change land use. (*22)*
- *Regional visioning and scenario planning: R*egional visioning and scenario planning sets goals for regional stakeholders and assists in common understanding across different levels of government. (*22*)
- *Freight-exclusive facilities:* The advantage of freight exclusive facilities is that they reduce the impacts of noise, light, and air quality issues associated with freight facilities on adjacent land uses. (*22*)
- *Effective truck-use networks: E*ffective truck-use networks assist trucks to avoid sensitive areas. They also link to truck routes in neighboring areas. (*22*)

Drayage Operations at the U.S.-Mexico Border

Drayage operations deal with freight movement from one site to an intermediate location, and not the final destination. Drayage operations are common when transporting goods from areas such as an international border POEs, inland ports, or intermodal freight facilities to another temporary location prior to being moved to its final destination. For cities that are on or located near one of these areas, such as El Paso, drayage activities can be a major component of the total freight traffic in the area (*23*).

Most of the trucks entering Texas from Mexico are drayage vehicles. The North American Free Trade Agreement (NAFTA) signed into law in the early 1990s, spurred the increase of trade (mostly in the form of truck freight) between the U.S. and Mexico. However, until recently, long-haul trucks from Mexico were prevented from operating outside a designated border zone. In 2015, a decision announced by the Federal Motor Carrier Safety Administration (FMCSA) opened up the opportunity for Mexican vehicles to apply for long-haul travel within the U.S. This opportunity follows the completion of 2 pilot programs, the last of which ended in October 2014, where Mexican trucking companies were allowed long-haul operations in the U.S. after meeting specific safety and other requirements (*24)*. Despite the changed regulations on long-haul operations of Mexican trucks, it is expected that the drayage system will prevail, at least in the short- and medium-term (*25)*. At the U.S.-Mexico border, most drayage vehicles bring the goods from Mexico and drop them at U.S. based warehouses, where long-haul trucks in the U.S. take the goods to their final destination.

Process of Drayage Operations

Drayage trucks entering the U.S. from Mexico are usually restricted to operating in an area around the border, in designated commercial zones that vary in distance from the border (*26*). A basic overview of the border crossing process from Mexico to the U.S. involving drayage operations is shown in Figure 2. Goods coming from Mexico to the U.S. are initially transported to a warehouse on the Mexican side of the border. Once at the warehouse the documents are filled out by a customs broker, who informs authorities in the U.S. and Mexico on details of the shipment, including the origin and final destination of the goods. Once approved, the goods are picked up by a Mexican drayage truck at the warehouse and are transported to the border port. There at Mexican customs, also called Aduanas, the goods are inspected before being allowed to cross the border. After crossing the border to the U.S. side, the goods are again inspected, this time by the U.S. Customs and Border Protection (CBP) agency (*23*). In addition to manual inspection, goods may also be subjected to secondary inspections, by a Vehicle and Cargo Inspection System (VACIS) or x-ray machine. Safety inspections are also conducted by FMCSA or other state personnel (*27)*. Once all inspections have been completed, the drayage driver exits the port and drops off the goods at a U.S. based warehouse, or other facility, to be picked up and taken to the final destination. The drayage truck then returns to Mexico, either with goods going back to Mexico or empty.

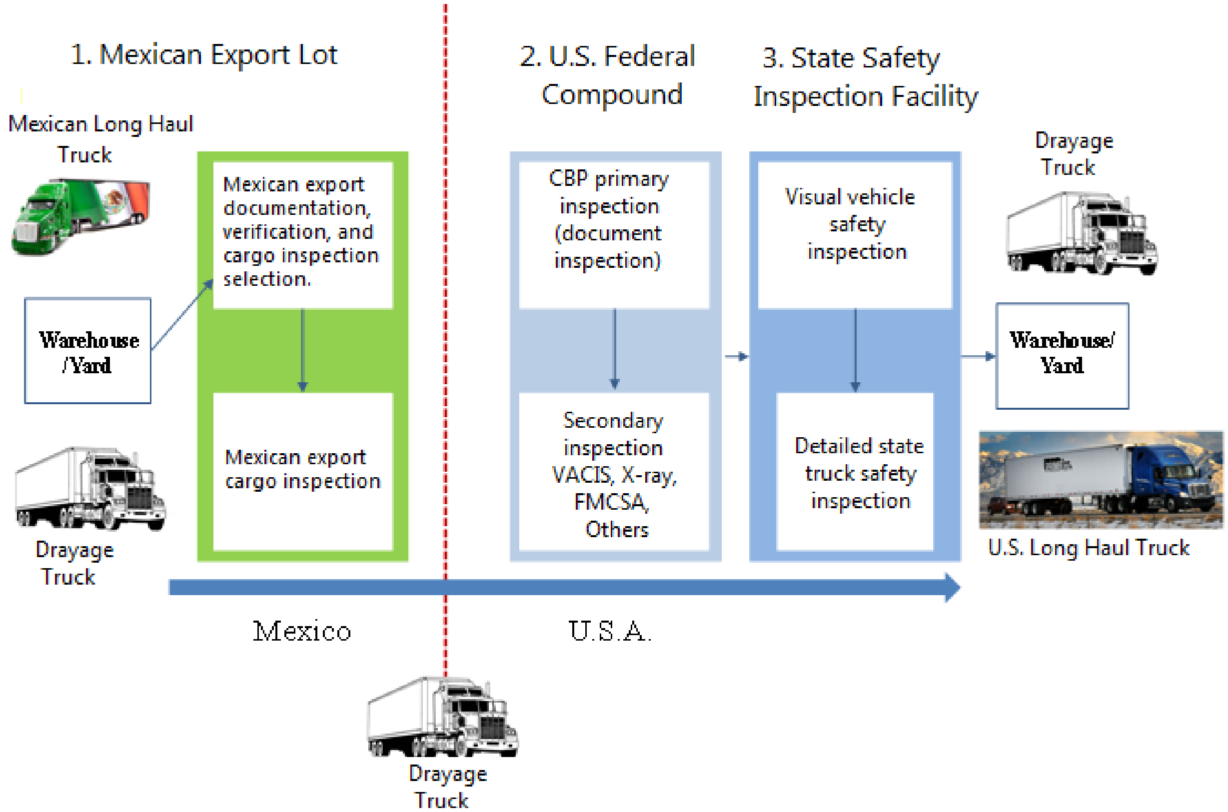


Figure 2: Border Crossing Process[1]

Drayage Fleet Characteristics

Since drayage trucks do not operate long distance trips, they are usually not held to the same standards of reliability and fuel efficiency as long-haul trucks. The drayage fleet is typically older than the long-haul fleet. In a 2013 study by Farzaneh et al., (*28*), a sample of 3,000 vehicles at the Bridge of the Americas (BOTA) and the Ysleta-Zaragoza Bridge in El Paso, Texas was studied to estimate emissions produced at border crossings. Of the sampled vehicles, 95% were registered in Mexico and only 5% from the U.S. The age distribution of these trucks (shown in Figure 3) indicates that majority of trucks are between 12 and 20 years old.

[1] Figure modified from FHWA, "Border-Wide Assessment of Intelligent Transportation System (ITS) Technology—Current and Future Concepts". http://ops.fhwa.dot.gov/publications/fhwahop12015/ch2.htm

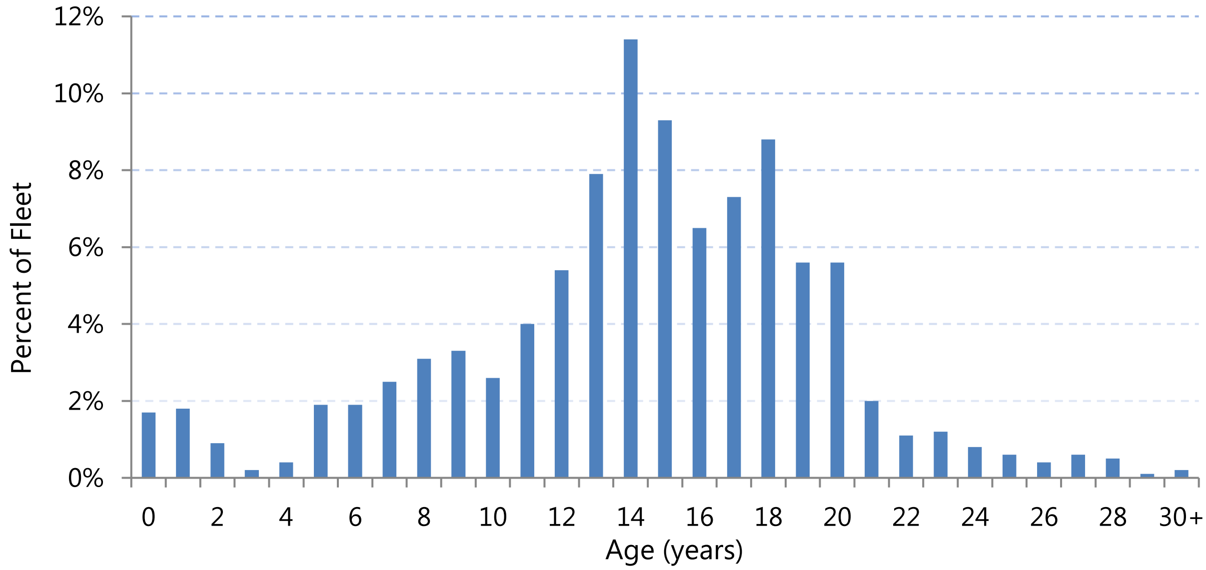


Figure 3: Age of Drayage Trucks in El Paso Region (*28*)

The same project used vehicle registration data to compare the age of the drayage fleet to the age of the short-haul and long-haul fleet. The resulting age distribution data from short-haul and long-haul trucks registered in El Paso are shown in Figure 4 and Figure 5 shows the age distributions for U.S. short-haul, long-haul, and drayage vehicles in 5-year categories. The data shows that the most common age range for drayage vehicles is between 15-19 years (37.5%), whereas U.S. short-haul and long-haul vehicles are newer, with the most common ranges being between 10-14 years (29.6%) in age for short-haul and between 5-9 years (25.98%) for long-haul vehicles.

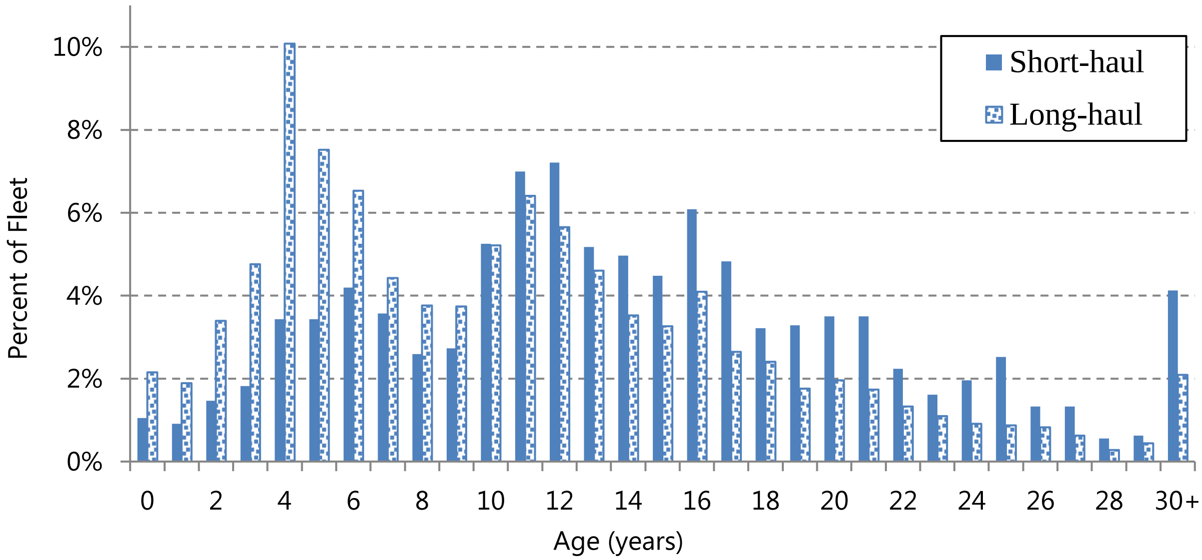
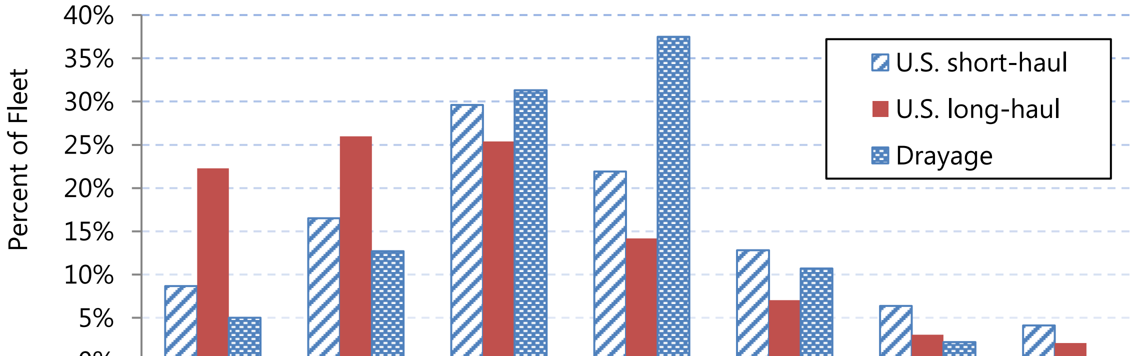


Figure 4: Age of Short and Long-Haul Heavy-Duty Vehicles in El Paso (*28*)



	0-4 years	5-9 years	10-14 years	15-19 years	20-24 years	25-29 years	over 30
U.S. short-haul	8.68%	16.52%	29.60%	21.90%	12.81%	6.37%	4.13%
U.S. long-haul	22.28%	25.98%	25.40%	14.17%	7.03%	3.06%	2.09%
Drayage	5.00%	12.70%	31.30%	37.50%	10.70%	2.20%	0.20%

Figure 5: Age Distribution of Heavy-Duty Trucks in El Paso-Juárez (*28*)

A 2005 survey on fleet mix at two bridge crossings in El Paso, Texas found that 89% of the surveyed trucks were large tractor-trailers (Class 8 vehicles), with the remaining 11% being smaller trucks (Class 5). The trucks ranged in model years from 1980-2005, with 75% falling in the 1991-2002 range. Over 20% of the vehicles were older than 15 years of age at the time of the survey (29).

A 2006 survey of drayage trucks coming across the southern border in Laredo on the U.S side. The study found 86% of the vehicles to be between 6 and 16 years old (30). Age distribution of drayage trucks based on the survey is shown in Figure 6.

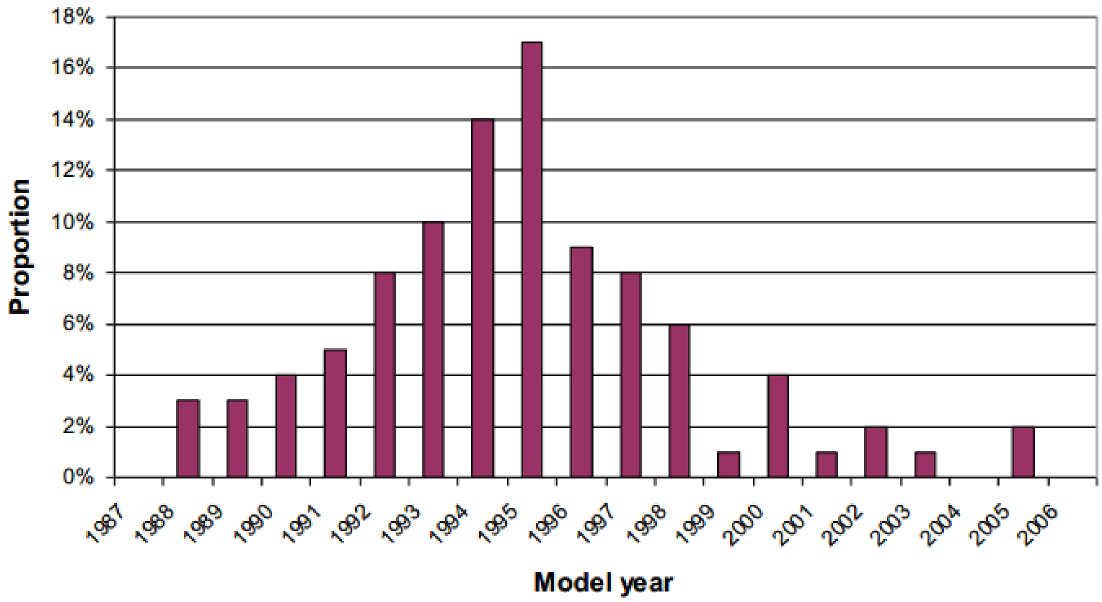


Figure 6: Drayage Trucks Age from 2006 Laredo Study (*30*)

A 2003 survey conducted by the University of California (UC)-Davis showed that only 8% of U.S-domiciled trucks sampled across the continental U.S. were over 10 years old (31), which is very different from the 75% of the Mexican-domiciled drayage trucks as found in the 2005 survey (*29*). Further, the UC-Davis survey indicated that 64% of U.S-domiciled trucks were four years old or newer. This disparity highlights the huge age differences between drayage vehicles operating in border crossings and the overall U.S. truck fleet.

A 2013 study by TTI for Mexico's Secretariat of Environment and Natural Resources (SEMARNAT) and the Border Environment Cooperation Commission (BECC) looked at the strategies to reduce PM emissions from trucks coming from Mexico to the U.S. The study also looked at the age of the fleet and found that half the trucks were model year (MY) 2000 and older, and 84% were MY2006 or older (32).

Drayage Truck Activity Characteristics

In addition to drayage vehicles' age, their operational characteristics also affect their overall emissions. These vehicles often face long and unpredictable wait times at the border, which leads to increased idling or creep-idling (i.e. moving slowly while in queue). TTI researchers used global positioning system (GPS) data collection to characterize the drive cycles of drayage trucks crossing the border (*29*). The research divided the trip into three sections: 1) entrance of Mexican customs through the U.S. customs primary inspection booth, 2) travel within the U.S. compound, and 3) travel through the safety inspection facility. The results found the trucks to idle[2] 63% and 72% of the time at the BOTA and Zaragoza border crossings, respectively, over the entire crossing process (*29*). Several other studies have characterized drayage truck activity with a view of estimating emissions – these studies are presented in the following section.

EMISSIONS CHARACTERISTICS AND IMPACTS OF DRAYAGE TRUCKS

The previously referenced TTI study also assessed the border crossing emissions profile of trucks at the El Paso-Ciudad Juárez border (*29*). Emissions testing using Portable Emission Measurement Systems (PEMS) was conducted on a total of 9 trucks from model years between 1985 and 1998. Results found the hydrocarbon (HC) emissions to be the highest for vehicles with the highest mileage, while oxides of nitrogen (NO_x), CO, and PM emissions were found to be higher for trucks with higher engine loads due to the use of air conditioning and higher idling speeds. The results also did not find any correlation between miles accumulated and NO_x emissions, or between idling and HC emissions. Of the nine trucks, two were found to have emissions rates higher than the EPA standards for the applicable model year. The total idling emissions for the BOTA and Zaragoza crossings were estimated to be 23.8 tons of NO_x, 3.1 tons of HC, 8.9 tons of CO, and 0.3 tons of PM annually.

In 2010, TTI researchers conducted a study that estimated base year and future year emissions for a freight corridor linking Mexico and Montreal. The highway corridor analyzed included the I-35 corridor passing through Laredo, Texas. The emissions estimates were based on past research and included PEMS data, emissions rates from the MOtor Vehicle Emissions Simulator (MOVES) emissions model, GPS data and vehicle age distribution data. The estimated annual emissions for the Laredo POE for 2035 were

[2] Total time includes idling and creep idling. In this study, idling was defined as being at a complete stop and creep idling was defined as traveling less than 5 mph and with acceleration or deceleration less than 0.5 mph/sec.

90 metric tons of NO_x, 200 metric tons of carbon-dioxide CO_2, 135 metric tons of carbon-monoxide CO, 68 metric tons of hydrocarbons HC, and 2.5 metric tons of particulate matter PM. These numbers are significant in relation to overall emissions on the corridor, from an emissions intensity perspective, which is attributable to congestion and border delays among other factors (33).

A study performed for the Federal Highway Administration (FHWA) estimated emissions rates for a variety of traffic conditions based on data obtained from the BOTA and Ysleta-Zaragoza border crossings in El Paso *(34)*. The study was focused on developing an approach for estimating emissions rates for border crossings between the U.S. and Mexico. The study considered volatile organic compounds (VOC), NO_x, CO, PM with 2.5 microns diameter or less ($PM_{2.5}$), PM with 10 microns diameter or less (PM_{10}), ammonia (NH_3), sulfur dioxide (SO_2), and atmospheric CO_2 equivalent (CO_2e) emissions for all types of truck movement at the border. The study considered different traffic conditions, including complete idling (< 1 mph), creep idling (< 5 mph), and uncongested operations (approximately 25-35 mph). Different traffic scenarios, and potential solutions to the congestions issue, were tested and used to model emissions using the MOVES model. The scenarios tested included free flow at the border with no delay, no action being taken, shifting private vehicles to faster SENTRI (Secure Electronic Network for Travelers Rapid Inspection*)* lanes,[3] and combining U.S. and Mexican cargo inspections. Results found that despite there being less commercial traffic at the bridge than passenger traffic, most of the $PM_{2.5}$ and NO_x emissions to be from the commercial trucks. Almost half of the emissions were from delay and queuing of traffic attempting to cross the border. The project made recommendations on how to reduce the emissions, including streamlining the inspection process and providing more parking to reduce the amount of idling.

In 2004, the NAFTA/Mexican Truck Emissions Overview from the California Air Resources Board (ARB) used data from various studies to estimate the emissions and air quality impact that Mexican trucks coming into the U.S., especially in California, would have. The study found that 66% of the trucks coming from Mexico were from before 1994, meaning they had no computer controls to reduce vehicle emissions that after 1994 and

[3] The Secure Electronic Network for Travelers Rapid Inspection (SENTRI) program is a trusted traveler program that allows private vehicles to use separate lanes at POEs for expedited processing. For more information see: http://www.cbp.gov/travel/trusted-traveler-programs/sentri.

newer trucks typically had. In addition, a quarter of the trucks were older than 1980 and were high emitters for NO_x and PM emissions. Another important note from the study was that Mexico did not follow U.S. standards, which require a 50% reduction in NO_x between model years 2004-2007 and a 90% reduction for model year 2007 and later. Mexico also does not require the use of ultra-low sulfur diesel fuel, which is mandated in the U.S. (35).

In a 2013 TTI study, researchers developed an emissions estimation tool for the El Paso-Cuidad Juárez border region in Texas, containing a rich dataset for the development of border crossing drive cycles for both light-duty and heavy-duty vehicles (*28*). The study installed 10 trucks with GPS data collection units for duration of two weeks. The study found that trucks crossed the border at different times of the day, days of the week, and in both directions. The study characterized the driving behavior of the drayage fleet using operating mode distributions, and these were built into the emissions estimation tool along with emissions rates from EPA's MOVES model.

Evaluation of Emission Reduction Strategies at Border Locations

Some emissions strategies have previously been piloted or implemented at border regions. These strategies include retrofitting, anti-idling, truck stop electrification, trusted traveler programs, and eco-driving (9).

Retrofitting

TTI analyzed the ability of two retrofit technologies, DOCs and DPFs, to reduce particulate matter (PM) from drayage trucks along the Laredo Port of Entry (POE) *(36)*. The study found substantial emission reduction with the DOCs. This conclusion was due, in part, to the fact that there is low availability of low-sulfur fuel, which is required by DPFs, in Mexico. This makes the use of DPFs limited when crossing the border into Mexico. Further, the study found installing DOCs in a fleet of 1700 trucks could reduce emission by 12 tons per year in the Laredo/Nuevo Laredo area.

SmartWay Program

The SmartWay® program was implemented in the U.S. in 2004 with the objective of reducing emissions through improved supply-chain environmental performance. The program is a partnership between the EPA, logistics companies, retailers and manufacturers, and other government agencies. The strategies to improve fuel efficiency include benchmarking operations, tracking fuel consumption, creating incentives to improve supply-chain fuel efficiency, driver training, and updating vehicle technology among others. In addition to the U.S, Mexico and Canada have their own versions of the SmartWay program.

TTI conducted an evaluation of SmartWay strategies that included the use of lighter trailers, modified driving behavior, and use of DOCs at the El Paso/Ciudad Juárez border. The study found the DOCs to result in total hydrocarbon (THC) and CO reduction, specifically for drayage trucks, of 78% and 53% respectively. Meanwhile, eco-driving and use of light-weight trailers strategies were found to provide minor decreases in THC and CO emissions. All strategies were found to reduce PM emissions (*4*).

Port of Entry Anti-Idling Programs

The British Columbia Ministry of Transportation and Infrastructure established an anti-idling program at the Washington/British Columbia border. In order to reduce the amount of time vehicles spend idling, a traffic signal was installed north of the U.S. Customs booth. When traffic is heavy, drivers stop at the light and turn off their engines. As vehicles ahead clear customs, the light turns green and vehicles can turn their engines on and advance. It is estimated that this system will reduce GHG emissions by 639,000 million kilograms a year. This type of program is likely applicable to other North American POEs (*9*).

The EPA launched the EModal Port Community System for Drayage through the SmartWay initiative, which establishes terminal appointments and removes delays due to fee payments and insufficient information. Terminal appointments reduce waiting time at terminal gates, thus reducing idling and emissions. These changes to the border crossing processes have the ability to reduce fuel consumption and pollution by 200 metric tons per year at the average port (*9*).

Another effort to reduce idling was launched by PierPass, a not for profit company, in 2005 at the ports of Los Angeles and Long Beach (*9*). The program involved the creation of five new work shifts a week and a new traffic mitigation fee paid by those who choose to move cargo during peak hours. Before the program was in place, 88% of containers were picked up during the first shift (8 am to 5 pm). After the program was implemented 50% of trucks picked up containers during the first shift and 50% did so during off-peak hours (*37*). Neither of these strategies have been implemented at land POEs, but have potential for success (*9*).

Trusted Traveler Programs

Border Trusted-Traveler Programs allow pre-approved, low-risk drivers to expedite travel through the use of dedicated lanes *(*38*)*. This system can speed-up the process of crossing the border, reducing congestion, idling time, and emissions. Those who are members of these programs are given radio security cards that allow them to access to a separate lane at border crossings. Some of these programs include:

- *Global Entry:* U.S. Customs and Border Protection program that, after a thorough background check and interview, allows pre-approved low-risk travelers expedited clearance through the border.
- *NEXUS:* Members are allowed to enter Canada and the United States using a specific lane. These privileges extend to land, air, and marine ports.
- *SENTRI:* Similar to NEXUS, SENTRI allows members to enter the United States and Mexico using a designated lane.
- *FAST (Free and Secure Trade Program):* A commercial clearance program that allows cargo to be processed via a separate lane when entering the U.S., Canada, or Mexico. There are 17 participating land POEs on the northern border, and 17 at the southern border (*9*).

These programs reduce emissions by allowing for faster processing at the border, thereby reducing idling time. Having fewer vehicles in a lane and using radio frequency identification cards allows inspectors to complete the process more quickly. For example, drivers enrolled in the NEXUS program at the Peach Arch Border Crossing in Washington accounted for 40% of traffic in 2013. This enrollment has saved an estimated 4,800 metric tons of CO_2 emissions (*9*).

Driver Behavior and Training

Eco-driving refers to the practice of taking into account environmental and economic benefits derived from consuming less fuel and reducing GHG emissions while driving.

Eco-driving training, or other similar forms of training, have been shown to change driver behavior and reduce fuel consumption, vehicle expenses, and emissions. (*39*, *40*)

Eco-driving training programs for drivers have been implemented in the U.S. (SmartWay), Canada (SmartDriver), and Mexico (Transporte Limpio), among others. Some trucking companies reported an estimated 44% to 49% reduction in emissions and fuel consumption after their drivers received eco-driving training (*9*).

The eco-driving component of the SmartWay program encourages behaviors such as reduced idling, lower speeds, and braking and accelerating smoothly. In addition to driver training, the EPA recommends installing electronic engine monitors to track driving behavior and implementing a driver incentive program to encourage fuel-saving behavior (*41*). In 2011, Con-way, a freight transportation company and a SmartWay member, reported reductions of 6 million gallons of diesel fuel and 134 million pounds of CO_2 emissions since 2008. Con-way achieved this reduction by lowering speeds from 65 to 62 mph for tractor trailers and from 70 to 65 mph for long-haul trucks (*40*).

SEMARNAT, Mexico's Ministry of the Environment and Natural Resources, is one of the entities responsible for conducting the "Transporte Limpio" program. The program trains drivers to modify driving behavior to reduce fuel consumption and lower emissions (*42*). The program is focused on training instructors and freight companies and has led to an estimated reduction of 634,486 tons per year in CO_2 emissions and a 17% reduction in fuel consumption (*43*).

Virage Simulation, a private company that develops driving simulators, was mandated by Quebec's government to create an eco-driving program for professional drivers of all types of vehicles. The program uses the VS600M truck simulator system, which models the inside of a truck cabin. It mimics vehicle behavior according to vehicle load and the effect of gravity when driving on a slope. The system also provides a range of engine performances, truck models, transmission configurations, differentials, and payloads. The training is delivered in several formats, including one day courses in groups of four, half day programs, one hour lessons, and 20 minute "express" sessions (*44*).

In the private sector, PHH GreenFleet® Driver training is an online program developed by the Environmental Defense Fund (EDF). The course aims to teach drivers how their behaviors affect fuel consumption and impact the environment. It presents a series of lessons on driving "green" and takes approximately 30 minutes to complete. The course is offered to PHH's employee drivers *(45)*.

While the number of companies participating in these programs is unknown, it is not likely that drayage carriers are heavily involved (9). Creating incentive programs for drayage carriers may offer an opportunity to further reduce emissions. Table 5 provides a summary of strategies provided in some of the major training programs to reduce emissions, developed by or for public agencies in North America.

Table 5: Driver Strategies for Emissions Reduction

Program/Publication	Provider/Author	Strategies
SmartWay *(38)*	U.S. Environmental Protection Agency	Use cruise control Coast when possible Brake and accelerate smoothly Progressive shifting Limit idling Drive at slowest speed possible
Transporte Limpio (Clean Transportation) *(39)*	SEMARNAT (Mexico's Ministry of the Environment and Natural Resources)	Use wide based tires Use advanced lubricants Regulate maximum speed Use automatic tire inflation systems Use efficiency control devices
Truck Driving Simulator Training Programs *(41)*	Virage Simulation (used by the Quebec government)	Basic to advanced level driver training in a truck simulator Focus on shifting, maneuvering in confined areas Advanced training includes energy efficient driver training and hazard perception
"Reducing the Carbon Footprint of Freight Movement through Eco-Driving Programs for Heavy-Duty Trucks" *(43)*	The National Center for Sustainable Transportation	Warm up and cool down engine per owner's manual Use moderate highway speed Maintain constant speed Accelerate and brake mildly Limit idling Inflate tires to manufacturer-recommended level

In addition, several other training programs, mostly from private sector sources, available online were also identified and reviewed, as shown in Appendix A. A review of the various training programs in existence showed that the information from the various sources and the recommended strategies were very similar to each other, and to those listed in Table 5. However, most of the strategies covered by the other major training programs are more focused on long-haul operations, which are the majority of heavy-duty truck traffic. The training developed for this project was focused on those strategies that pertained to short haul driving.

Summary

This chapter provided an overview of key topics and literature relevant to understanding drayage truck operations, emissions, emissions reduction strategies, and the role of driver training and behavior. Several existing driver training programs were reviewed, as the basis for the development of a training program specifically for drayage operations. The following chapter discusses the development of this training in further detail.

CHAPTER 3 - DEVELOPMENT OF DRIVER TRAINING PROGRAM

One of the main goals of this study was to develop and implement a driver training program for emissions and fuel reduction. This heavy-duty emission reduction training program was developed specifically for drayage truck driver behavior training. The training content was developed based on the review of literature and resources documented in Chapter 2. The content was developed to follow the typical driver behavior training programs seen from the examples; however, this training program was tailored for drayage operations. This chapter describes the process of developing this program, and provides an overview of the presentation developed.

Considerations for the Development of Training Program

The driver behavior training focuses on behavior that would benefit heavy-duty drayage truck drivers and generally includes the following considerations.

- Drayage operations are mostly, if not exclusively, local or short-haul routes.
- Drayage operations experience a high percentage of idling at warehouses and border crossings unlike typical long-haul operations.
- Drayage operations experience a higher percentage of urban stop-and-go driving than typical long-haul operations.

Unlike long haul operations, aerodynamics, top cruise speed, use of cruise control, sleeper cab power options, etc., do not likely play a significant role in drayage truck operations and therefore, were not emphasized. The training also focuses less on items that are generally outside of the driver's control, such as route selection or time of day. Therefore, emphasis was placed on anti-idling, smooth acceleration, shifting and gear selection, and maintenance.

Development of Training Program

The training content was developed based on the review of literature and resources documented in Chapter 2, and the additional sources listed in Appendix A. Table A in the appendix lists the additional on line driver-training sources that were used as a reference for developing driver recommendations for heavy-duty drayage operations.

Table B provides the additional sources from the EPA and TCEQ used for the background portion of the training. A draft version of the driver training was reviewed by the TCEQ on March 3rd, 2017. The initial driver training was conducted on May 12th, 2017 as part of the case study described in Chapter 4. The TTI team continued to make ongoing updates and enhancements to the training materials over the course of the project.

Overview of Training Presentation

The driver behavior training entitled "*Fuel Consumption and Emissions Reduction Study*" was prepared in both English and Spanish using Microsoft PowerPoint. The English version of the most up-to-date slides are provided in Appendix B (English) and Appendix C (Spanish)[4]. The general content and structure of the presentation is described in this section. This training does not attempt to instruct drivers how to drive, but raise driver awareness that how they drive can make a difference. The training provides drivers with information and techniques that can help them, and their company, save fuel, save money, and help improve air quality in the area. The stated purpose of the training is to work with international trucking companies to reduce fuel usage and diesel emissions in the border area. Recognizing that the reduction of fuel use and the reduction of emissions work together, the behavior training was presented to the drivers more as a way for drayage truck drivers and their companies to save fuel cost through their driving choices and behaviors rather than a way to reduce emissions. This approach was selected to make the training more relevant to drayage truck drivers and fleet owners.

The driver behavior training presentation provides drivers with the following.

- Purpose of the study:
    - The background information is provided to help drivers understand the air quality problem we are addressing and help them appreciate the importance of this training and study.

[4] Slides included in the report for reference purposes only. The PowerPoint versions include animations and other features, and are submitted as separate deliverables.

   - Structure of the study, including a description of the equipment used in the study. Data that will has been and will be collected and expectations of the study;
- Driver role in the study;
   - Duration of the study and expectations;
   - Driver behavior recommendations including:
   - Anti-idling;
   - Shifting and gearing;
   - Accelerating and braking;
   - Maintenance;
   - Speed and momentum;
   - Route selection;
- Questions and comment opportunity; and
- Contact information.

SUMMARY

One of the main goals of this study was to develop and implement a driver training program for emissions and fuel reduction. The training developed focuses on behavior that would benefit heavy-duty drayage truck drivers. Emphasis of the training was placed on anti-idling, smooth acceleration, shifting and gear selection, maintenance, and other items within the drayage drivers' control. Ongoing updates were made to the training materials during the course of the project, and English and Spanish versions of the training were developed and finalized as part of this project.

CHAPTER 4 - CASE STUDY OF TRAINING PROGRAM IMPACTS

A case study was conducted to determine the potential impact of the training on driver behavior, and resultant emissions and fuel consumption impacts. The overall approach to the case study involved the implementation of a "before and after" analysis of the driving patterns of drivers who were given the training. The basic steps involved were as follows:

1. Phase 1 ("Before") Data Collection - Collect baseline driving behavior data for a selected sample of drayage truck drivers. The data of interest include parameters that can be used for assessing driver behavior and emissions, such as speeds, idling, and acceleration rates.

2. Training Program Delivery - Conduct the driver training program for the selected drivers.

3. Phase 2 ("After") Data Collection - Collect driving behavior data for the same drivers after the driver training program.

The case study assessment framework is shown in Figure 7. In assessing differences in driver behavior, changes in driving patterns in terms of idling activity, and acceleration levels (as an indicator of aggressiveness while driving) were determined as being of greatest interest to the study, and were the focus of the analysis. Reducing discretionary idling, and reducing aggressive driving represent the most common behavioral changes that drayage drivers could easily implement to reduce emissions and fuel consumption. Drayage operators, especially those who drive fleet owned vehicles, may not be able freely apply some of the other techniques covered in the course. For instance, aspects such as route choice, pickup and delivery locations, or time of day may not be within the drivers' control. Similarly, border crossing wait times and traffic at those locations may also not be within the drivers' control. Thus, the data analysis focused on idling behavior and accelerating behavior, while assessing behavioral changes and program effectiveness.

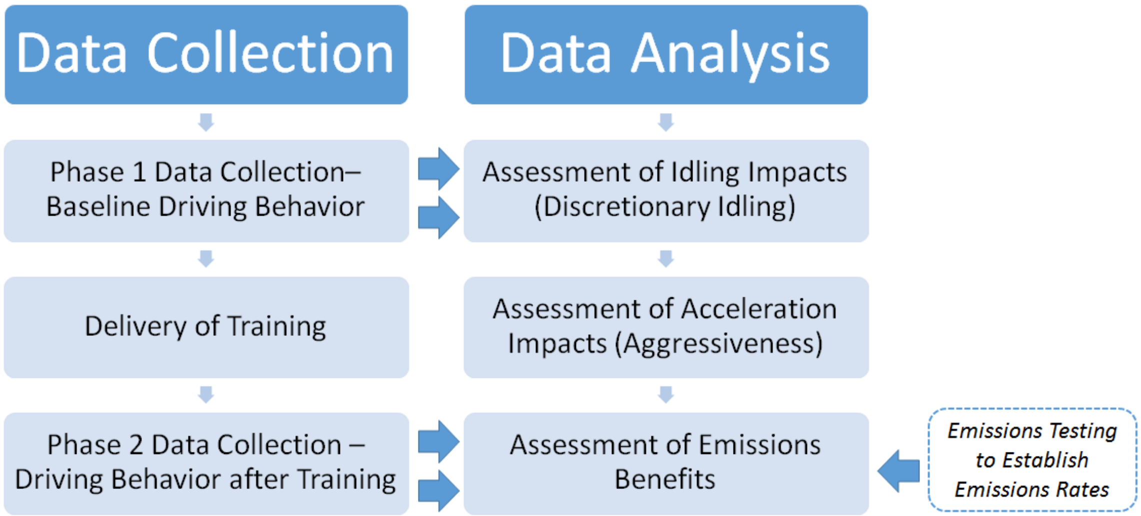


Figure 7: Flow Chart of Study Framework

Further, the estimation of associated changes in emissions and fuel consumption was done using emissions rates established from in-use emissions testing, supplemented by data from emissions models. The case study data collection, analysis and results are described in the remainder of this chapter.

Driver Recruitment and Training

Two drayage companies, based in Juárez and operating in the El Paso-Juárez region were recruited and agreed to participate in a data collection effort, as well as have their drivers take part the training program developed as part of the project. After the initial data collection, one of the companies terminated their participation in the study. The data analysis for the case study therefore only included one company for which both data collection phases were completed, though the additional collected data has been compiled and summarized by the research team. The training was delivered to a group of thirteen drivers from the participating company, including the drivers who served as participants for the driver behavior data collection. Following both data collection phases the data were analyzed, comparing the drivers' behavior before and after the training, to determine the impact on driving behavior[5].

Driver Behavior Data Collection

As mentioned previously, data were collected to establish potential differences in driver behavior (specifically idling activity and accelerations). Data collection was conducted using two types of technologies, GPS and Portable Activity Monitoring System (PAMS) devices. GPS devices provide locational information (GPS coordinates) of vehicles, which can be used to derive real-time speeds and accelerations. PAMS devices also record GPS information, but in addition also log information being reported by the vehicles engine over the controller area network (CAN) using the SAE J1939. The CAN data includes information such as vehicle speed, engine RPM, diagnostic codes, and many other pieces of information. The reasoning behind the use of two separate technologies is based on the cost and capabilities of each. The GPS data loggers are cheaper than the PAMS loggers, but only provide a small set of data, specifically speed and location. They also have a limited battery life and storage space, therefore are only able to log data for a limited time before requiring removal from the vehicles for downloading data and recharging batteries. The PAMS data loggers do not have these issues. They connect directly to, and are powered by, the test vehicle so there are no issues with battery life. The PAMS loggers also provide much more information, via the CAN data, than the GPS loggers. Another advantage of the PAMS loggers used for this project is the capability to transmit data via a cell network. The loggers connect and transmit each data file to a central server at the conclusion of each trop, removing the need to remove them from the vehicle to download the data. This also allows researchers to begin analyzing the data daily, instead of waiting until the end of the collection period. The drawback to the PAMS units are the cost, as they can be fifteen to twenty times more expensive than the standalone GPS unit. Thus, a combination of GPS units and PAMS units were used to allow for a larger sample of vehicles to be logged, with the PAMS units supplementing the data collected by GPS on selected trucks. The loggers used for this project were the QStarz BT-Q1000eX (GPS data logger) and the OBD Mini Logger™ (PAMS) from

[5] It was confirmed in discussion with the trucking companies that drivers were assigned to drive the same truck, thus the data collection for each truck represents the behavior of a single driver, before and after receiving the training.

HEMData as shown in Figure 8 and Figure 9 respectively. Both data loggers record data at a 1 Hz rate, i.e. on a second-by-second basis.

Figure 8: QStarz BT-Q10000eX Unit

Figure 9: HEMData PAMS Data Logger[6]

The Phase 1 data collection effort began on March 16th 2017, with the installation of 20 GPS data loggers, covering 2 different drayage companies. The Phase 1 GPS collection lasted for 2 weeks, and then the units were removed. The Phase 1 PAMS data collection effort began on April 20th 2017, with loggers being installed on 4 vehicles, all of which were from the same drayage company. On May 12th 2017, a training session was

[6] Picture from http://www.hemdata.com/products/dawn/obd-mini-logger.

conducted with 13 drivers. These drivers included the 4 driving the trucks with the PAMS installed, as well as other who previously had the GPS units in their vehicles. The training marked the end of the Phase 1 data collection, which included data for 615 trips[7] with the PAMS loggers, covering over 3100 miles of travel.

The Phase 2 data collection began on May 15th 2017, with the PAMS units on the same trucks as in Phase 1. After the training session, 10 GPS units were reinstalled on the same trucks they were on during Phase 1. Phase 2 data collection continued until June 8th 2017, when both the GPS and PAMS data loggers were removed. Information on the vehicles used in both phases of the study[8] is shown in Table 6. A second round of data collection and training was planned following the initial training,

Table 6: Test Vehicle Information

Truck ID	Data Type	Make and Model Year	Engine Size
DT01	PAMS and GPS	2006 International	10.8 L
DT02	PAMS and GPS	2007 Volvo	14.9 L
DT03	PAMS and GPS	2017 Freightliner	7.2 L
DT04	PAMS and GPS	2017 Freightliner	7.2 L
DT05	GPS	2016 Freightliner	7.2 L
DT06	GPS	2016 Freightliner	7.2 L
DT07	GPS	2006 International	10.8 L
DT08	GPS	2007 Volvo	14.9 L
DT09	GPS	2017 Freightliner	7.2 L
DT10	GPS	2017 Freightliner	7.2 L

Impact of Training Program on Driver Behavior

The goal of the study was to determine the impact the training course had on the drayage operators driving behaviors, and how that could affect the emissions of the drayage fleet. To determine the impact, the data from the Phase 1 and Phase 2 data collection efforts were compared to determine if the drivers' behaviors changed after

[7] The PAMS data loggers define a trip as the time between when the vehicle is keyed on until it is keyed off. Therefore, it is possible that a trip is recorded where the engine is never actually started. These trips were not factored into the analysis of the data.

[8] The Phase 1 data collection included two drayage companies. However, the second drayage company backed out of the project prior to the training and Phase 2 data collection. Therefore, only 10 vehicles from the first drayage company were included in the data analysis.

taking part in the training. As discussed at the beginning of the chapter, the analysis focused on behaviors that were within the drivers' control, namely reduced idling and less aggressive driving (defined by acceleration rates). This section describes the analysis of both behaviors and the impact the training had on each.

Impact on Idling Characteristics

The initial step in the analysis of the idling characteristics was to determine how to categorize and define idling events. It is not necessarily practical to eliminate all idling activities, i.e. all instances where the vehicle is stationary but has its engine running. For example, drivers must idle at traffic signals as well as in highly congested traffic. Drayage operators must also cross the border daily, which can lead to increased idling as they wait at border crossings. These types of idling events are largely unavoidable. Additionally, turning off the truck during short duration idling events, defined as less than a minute in the training program, may not provide any benefits due to the startup emissions and increased wear on the engine. Thus, the analysis of differences in idling behavior focused on idling events that were identified as being avoidable and longer than 1 minute in duration. To determine if an idling event was avoidable, the GPS location of each event was plotted on a map, to determine where the idling had occurred. Any idling event that took place either at the border crossing or on a roadway were not included in the data analysis.

To determine the impact the training had on the drivers the average duration of idling events was compared for Phase 1 and Phase 2. The actual number of trips, and days of data collection, varied between the phases, and so the number or frequency of idling events were not compared.

During the data analysis process, it was determined that only data for trucks installed with the PAMS units would be used, to provide an accurate analysis. Since the PAMS loggers are powered by the vehicle and record engine data, it is very easy to identify idling events based on the engine RPM data and vehicle speed. This ensured that a vehicle was only considered idling when the engine was actually running. Since the GPS loggers are triggered by vibration, and not tied to the engine being powered on, there was the potential the units to be triggered when a vehicle door was opened or closed, even if the engine wasn't running. Thus, the GPS data were not used in the analysis to avoid the risk of such events being considered as idling.

Analysis Results

The results for the idling were analyzed in two ways, first by looking at idling event location, and second by time of day. The first case looked at idling events at the locations of interest (i.e. idling of longer than 1 minute at non-border facilities and outside of the roadway network). Figure 10 and Figure 11 show the Phase 1 and Phase 2 locations of all idling events used in the analysis. As the figures show, a majority of the idling events occurred in the same locations for both phases of data collection. The types of facilities represented are the El Paso airport, offices, warehouses, parking yards, and stores.

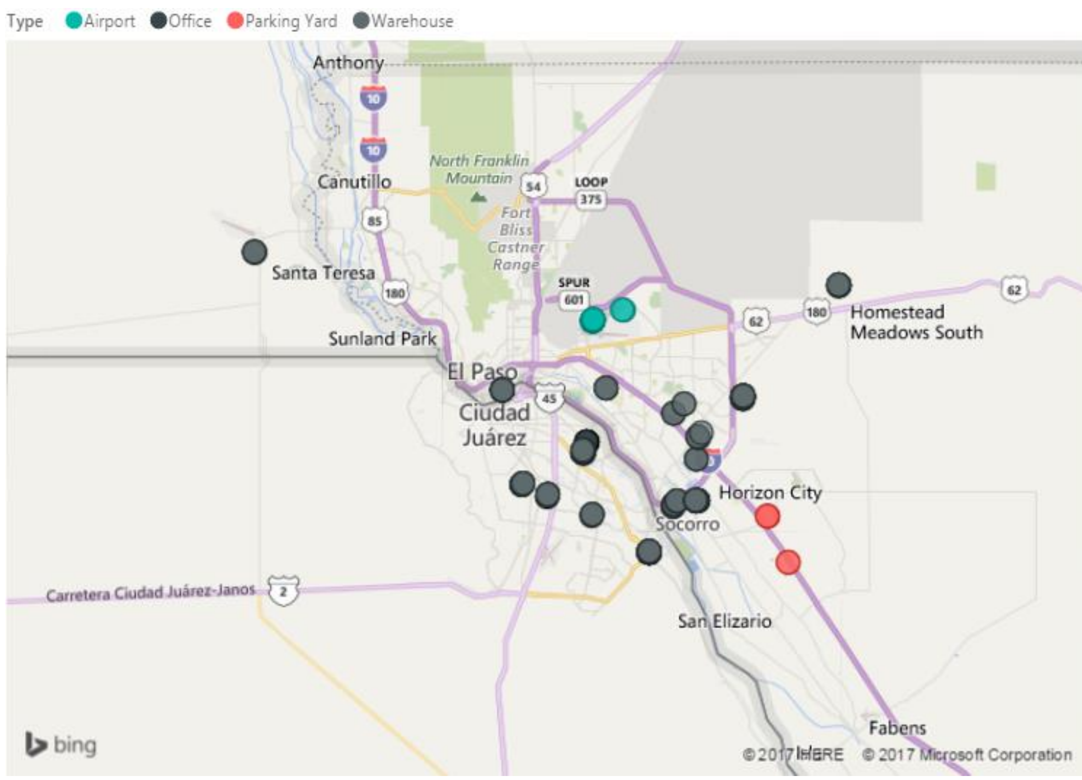


Figure 10: Location and Type of Idling Events: Phase 1

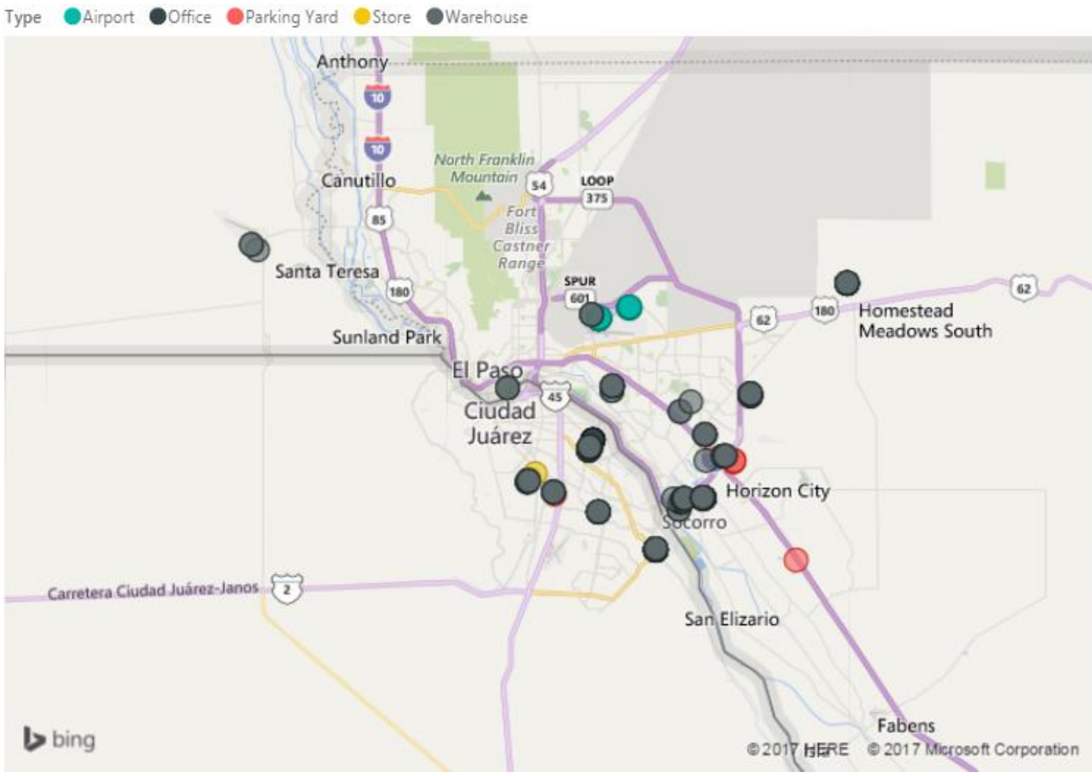


Figure 11: Location and Type of Idling Events: Phase 2

Table 7 and Figure 12 show the summary of the idling events from this analysis. Three of the four analyzed vehicles saw reductions in average idling durations after taking the training course. When the data from all four vehicles are combined the fleet had a reduction in duration of 12%, from 290 seconds to 256 seconds.

Table 7: Non-Border Facility Idling Events Summary

Truck ID	Before				After				Statistically Significant*
	Events	Average Duration (s)	Standard Deviation (s)	Max Duration	Events	Average Duration (s)	Standard Deviation (s)	Max Duration	
DT01	252	242.01	273.29	1,962	269	188	155.93	1,044	Yes
DT02	169	226.79	213.16	1,973	196	238.37	204.03	1,814	No
DT03	68	588.16	1,652.29	11,405	31	380.39	1,192.37	6,766	No
DT04	57	337.07	727.71	5,282	33	312.52	534.53	3,135	No
Total	546	290.34	672.36	11,405	529	255.7	358.43	6,766	No

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

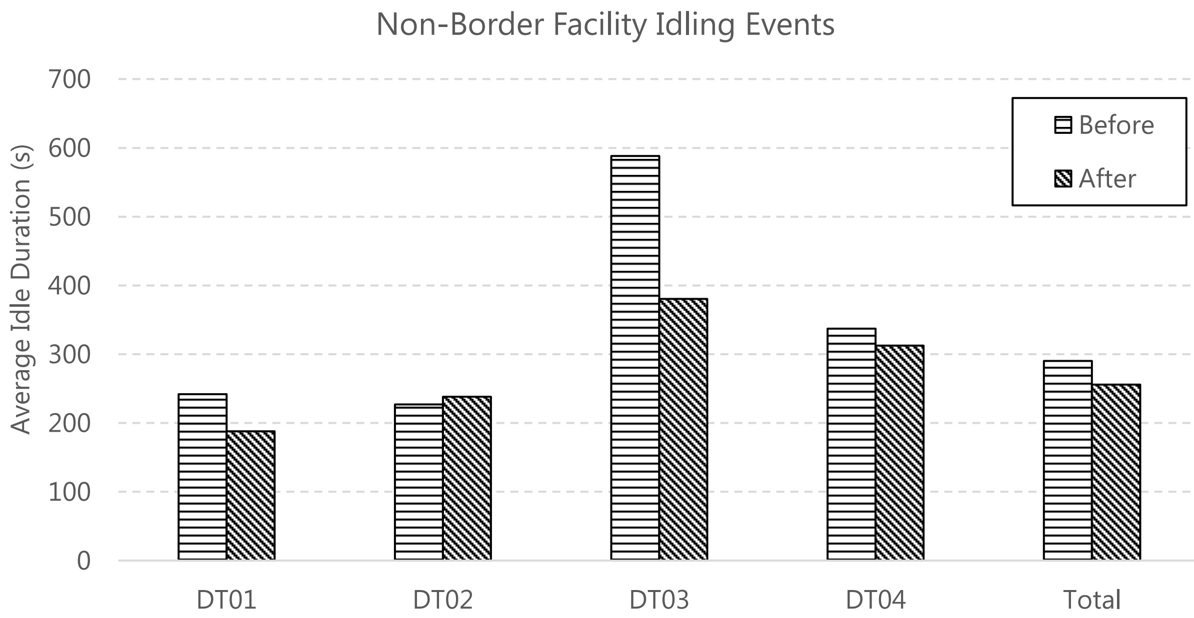


Figure 12: Non-Border Facility Idling Events

To determine if these differences were statistically significant a two-tail t-test was performed on the data. To conduct the t-test the data were log transformed, as the durations were found to follow a log-normal distribution. Figure 13 shows the distribution of the idle durations. The data from the t-test showed that only one truck showed a statistically significant reduction in average idle duration during Phase 2, i.e. after the training. This vehicle, DT01, reduced the average idling duration by almost a minute, or 22%, for 269 idling events when compared to Phase 1. Two other vehicles, DT03 and DT04, showed 35% and 7% reductions in average duration, although these were not statistically significant. A potential explanation for this is the outliers seen in the maximum idling durations of these two vehicles. Vehicle DT03 had a single event which lasted over three hours in Phase 1 and vehicle DT04 had an event just under ninety minutes. Vehicle DT02 showed a small (5%) increase in average idling time. The combined average idling event duration for the dataset as a whole was found to have decreased 12% after the drivers participated in the training.

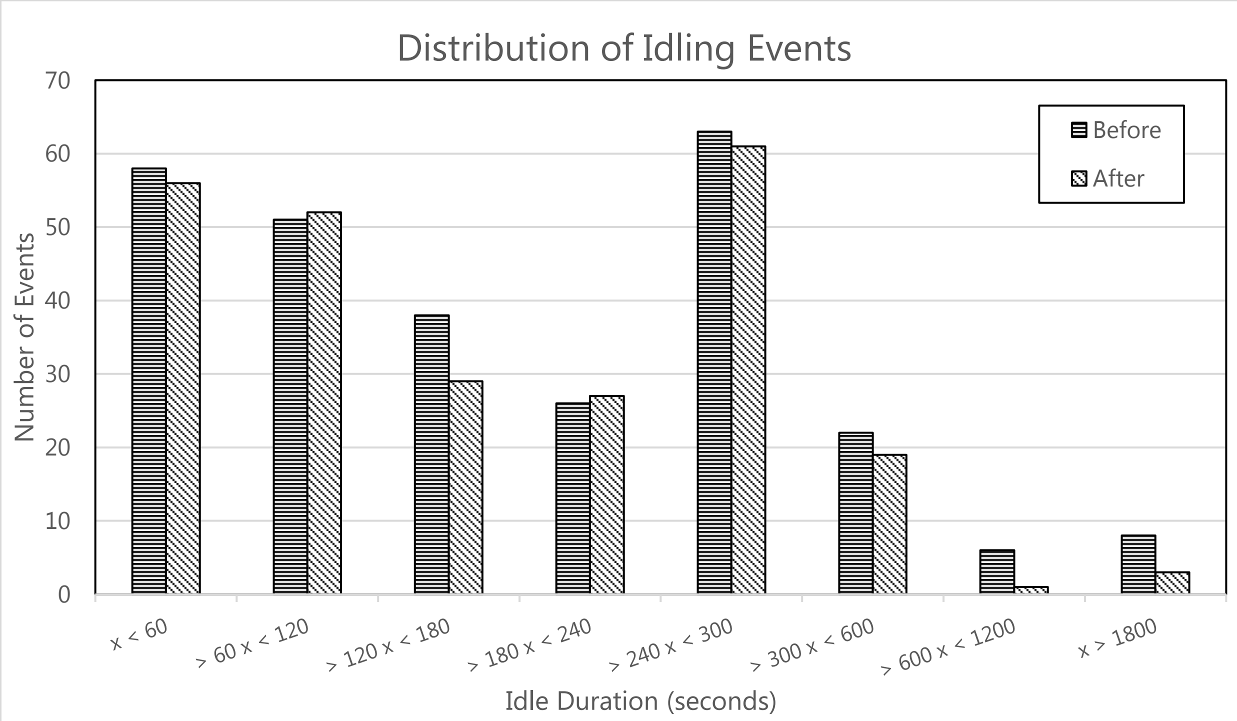


Figure 13: Distribution of Non-Border Facilities Idling Events

The second case considered for the idling analysis was to study idling events during different times of the day. Idling events from 6 AM-12 AM were classified as morning events, 12PM-7 PM as afternoon events, and 7 PM-6 AM as overnight events. The same criteria applied as the previous case, with only events longer than 1 minute occurring at non-border and non-roadway locations being considered. An additional factor, the country in which the idling took place, was also used in this analysis. The trucks began each day at their headquarters, located in Mexico, picking up deliveries to be taken to the U.S. Therefore, the number of events occurring during the times of day varied by the country. Mexico had a total of 407 idling events in the morning, compared to 108 in the U.S. In the afternoon, the numbers were more even, with 192 events in Mexico and 244 in the U.S. The overnight events were almost identical with 63 events in Mexico and 62 in the U.S. Figure 14 shows the Mexico idling events and Figure 15 shows the U.S. idling events.

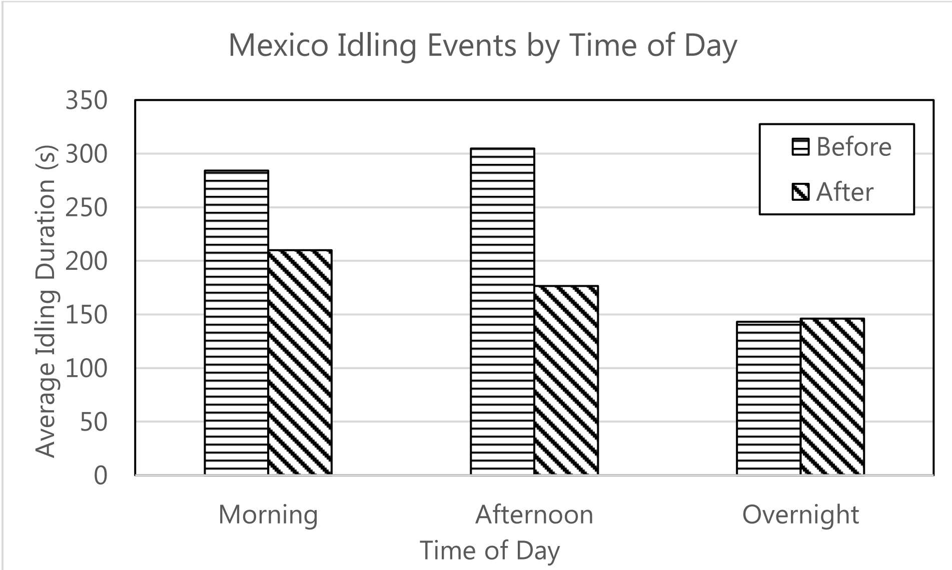


Figure 14: Mexico Idling Events by Time of Day

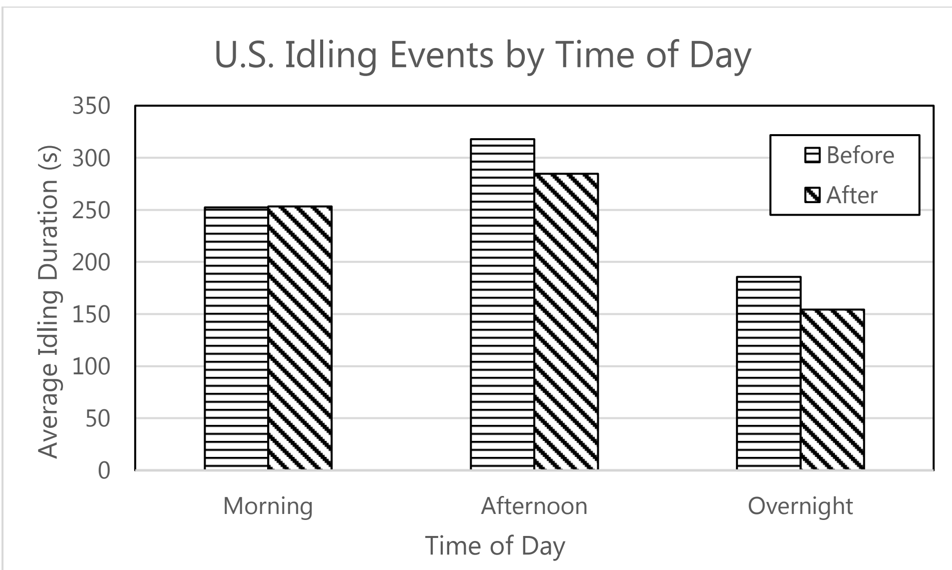


Figure 15: U.S. Idling Events by Time of Day

For the idling events occurring in Mexico both vehicle DT01, as well as the overall combined numbers, showed statistically significant improvement after the training for the morning time period. Table 8 shows the details of the morning idling events in Mexico. All four vehicles showed reduced average idling durations after the training, ranging from 7%-54%. Combining all the vehicles together reduced the average duration by 26%, from 284 seconds down to 210, a reduction of over 1 minute per event.

Table 8: Morning Idling Events in Mexico

Truck ID	Before				After				Statistically Significant*
	Events	Average Duration (s)	Standard Deviation (s)	Max Duration	Events	Average Duration (s)	Standard Deviation (s)	Max Duration	
DT01	91	304.29	386.40	1,962	95	201.92	187.44	1,044	Yes
DT02	79	242.66	148.24	755	95	220.04	136.63	735	No
DT03	14	517.79	1395.61	5,354	4	237.5	291.65	674	No
DT04	20	193.5	101.74	425	9	179.33	145.31	515	No
Total	204	284.21	453.62	5,354	203	210.1	165.14	1,044	Yes

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

No other time periods showed statistically significant reductions in idling durations. The afternoon time period in both the U.S. and Mexico were reduced by 10% and 42%, respectively, but neither were statistically significant. Morning events in the U.S. were almost identical before and after, as was the overnight average in Mexico. Overnight events in the U.S. did show a reduction of 17%.

Summary of Idling Differences

Overall, when considering the average duration of idling events, it can be seen that the results as a whole indicate reduced idling durations after the training. For non-border idling events, 3 of the 4 vehicles in the analysis saw a reduction in average idling duration, ranging from 7% to 35% reduction. While the results were statistically significant only in limited cases, the presence of potential outliers and the limited dataset should be taken into consideration. Another aspect of idling activities are operations at the border crossing locations. These events were not considered in the analysis, as they are seen as events that the drivers have no control over. However, idling events at the border accounted for over half (51.9%) of all idling events seen in both phases of the data collection. This emphasizes the importance of tackling border wait times and reducing idling and associated emissions in border regions.

Impact on Acceleration Characteristics

As with the idling, the initial step in the acceleration analysis was to define an acceleration event for purposes of the analysis. For this study an acceleration event was defined as five or more consecutive seconds of increasing speeds, with a total increase of at least 5 MPH over the entire event. During the events, slight decreases in speeds were allowed, as long as the speed was increasing again within 2 seconds. This was done to accommodate the vehicles shifting gears, when the speed could decrease slightly, or stay the same, while the driver released the gas pedal to shift. For the analysis, the acceleration events were grouped into 5 separate speed ranges. The ranges used of the analysis were:

- 0-10 mph,
- 10-20 mph,
- 20-30 mph,
- 30-40 mph, and
- 40-50 mph.

A single acceleration event could include data from multiple ranges, for instance an event that started from idle and ended at 45 MPH would have data that was included in each of the five ranges. However, only the data during the time when the event was in the associated speed range was used in the calculation for that particular range.

The focus of the analysis was to compare the acceleration rate (in mph per second), for each range. Further, for purposes of emissions assessment, the acceleration events were also classified into operating modes (opModes), as defined in the Motor Vehicle Emissions Simulator (MOVES) emissions model. MOVES is the EPA's mobile source emissions model, which looks at opMode bins, which are based on the instantaneous speed, acceleration, road grade, and road load for estimating second-by-second emissions (*46*). A Vehicle Specific Power (VSP) is calculated based on these inputs, which in combination with the instantaneous speeds describe the different opMode bins. Further details on the MOVES bins breakdown is included in the section on emissions impacts of the training program.

Part of the training program is focused on ways to reduce the aggressiveness of drivers, which can mean lower rates of acceleration. Unlike the idling data analysis which only relied on PAMS data, data collected using both the GPS and PAMS data loggers were used in the acceleration comparisons. This analysis therefore includes all ten vehicles listed in Table 6.

In comparing the acceleration data, the loading of an individual truck was not taken into account, since this data were not available. It was assumed that the data collected in Phase 1 and Phase 2 represented trucks under similar loading conditions. Truck load, however, was taken into account when calculating the emissions benefits of reduced acceleration rates during driving.

When data from all 10 vehicles are combined into a single data set, all 5 speed ranges showed statistically significant reduction in acceleration rates, as summarized in Table 9 through Table 13. As with the idling that comparison used a two-tailed t-test assuming lognormal distribution with a 95% confidence level. The acceleration rates for each range were between 3% and 11% lower during Phase 2, with the 20-30 MPH range showing the most improvement.

While overall the data were statistically significant for each range, the results for individual trucks varied between ranges. However, no trucks that had higher acceleration rates after the training were statistically significant. Of the 10 trucks tested, Unit DT02 seemed to have the most improvement, showing significant improvement of at least 8% for each of the speed ranges except the lowest range of 0-10 MPH.

Table 9: Acceleration Results (0-10 MPH)

Truck ID	Before		After		Percent Reduction	Statistically Significant*
	Events	Average Acceleration (mph/s)	Events	Average Acceleration (mph/s)		
DT01	780	0.923	899	0.862	7%	Yes
DT02	777	0.91	853	0.905	1%	No
DT03	294	0.952	134	0.936	2%	No
DT04	843	0.922	1057	0.895	3%	No
DT05	77	1.088	29	0.714	34%	Yes
DT06	79	0.92	77	0.94	-2%	No
DT07	70	0.977	166	0.903	8%	No
DT08	42	0.792	65	0.819	-3%	No
DT09	77	0.811	50	0.845	-4%	No
DT10	73	0.817	116	1.033	-26%	No
Total	3112	0.92	3446	0.893	3%	Yes

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

Table 10: Acceleration Results (10-20 MPH)

Truck ID	Before		After		Percent Reduction	Statistically Significant*
	Events	Average Acceleration (mph/s)	Events	Average Acceleration (mph/s)		
DT01	488	1.064	573	1.047	2%	No
DT02	308	0.988	362	0.907	8%	Yes
DT03	131	1.003	49	0.868	13%	Yes
DT04	349	0.948	453	0.857	10%	Yes
DT05	45	1.127	17	0.928	18%	No
DT06	50	1.036	52	1.053	-2%	No
DT07	37	1.036	70	0.836	19%	Yes
DT08	18	0.614	21	0.854	-39%	No
DT09	32	0.868	19	1.021	-18%	No
DT10	39	1.118	89	1.074	4%	No
Total	1497	1.008	1705	0.951	6%	Yes

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

Table 11: Acceleration Results (20-30 MPH)

Truck ID	Before		After		Percent Reduction	Statistically Significant*
	Events	Average Acceleration (mph/s)	Events	Average Acceleration (mph/s)		
DT01	509	0.982	533	0.933	5%	Yes
DT02	237	0.893	285	0.733	18%	Yes
DT03	107	0.859	44	0.749	13%	Yes
DT04	319	0.923	364	0.771	16%	Yes
DT05	46	0.993	18	0.814	18%	No
DT06	45	0.854	35	0.926	-8%	No
DT07	33	0.877	53	0.659	25%	Yes
DT08	13	0.436	27	0.682	-56%	No
DT09	22	0.836	16	1.022	-22%	No
DT10	35	0.978	72	0.905	7%	No
Total	1366	0.929	1447	0.83	11%	Yes

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

Table 12: Acceleration Results (30-40 MPH)

Truck ID	Before		After		Percent Reduction	Statistically Significant*
	Events	Average Acceleration (mph/s)	Events	Average Acceleration (mph/s)		
DT01	295	0.689	305	0.651	6%	No
DT02	195	0.599	188	0.535	11%	Yes
DT03	78	0.823	28	0.758	8%	No
DT04	148	0.745	195	0.684	8%	No
DT05	34	0.72	15	0.707	2%	No
DT06	29	0.667	18	0.622	7%	No
DT07	21	0.624	28	0.478	23%	Yes
DT08	9	0.406	14	0.559	-38%	No
DT09	10	0.637	7	0.8	-26%	No
DT10	26	0.768	41	0.74	4%	No
Total	845	0.688	839	0.635	8%	Yes

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

Table 13: Acceleration Results (40-50 MPH)

Truck ID	Before		After		Percent Reduction	Statistically Significant*
	Events	Average Acceleration (mph/s)	Events	Average Acceleration (mph/s)		
DT01	147	0.592	148	0.568	4%	No
DT02	86	0.564	101	0.46	18%	Yes
DT03	35	0.529	11	0.565	-7%	No
DT04	75	0.645	63	0.55	15%	Yes
DT05	7	0.484	10	0.483	0%	No
DT06	17	0.501	10	0.634	-27%	No
DT07	5	0.395	16	0.415	-5%	No
DT08	5	0.425	3	0.445	-5%	No
DT09	3	0.343	3	0.493	-44%	No
DT10	10	0.581	37	0.571	2%	No
Total	390	0.578	402	0.53	8%	Yes

** Two-tailed t-test, assuming lognormal distribution, at 95% confidence level*

Many of the trucks that saw higher acceleration rates during Phase 2 were trucks that tended to have fewer number of acceleration events overall, some as low as 3 events per category. Most of these trucks were those installed with GPS loggers, which had recorded fewer events overall than the trucks outfitted with PAMS. It is possible that these results were more affected by outliers than the trucks that had larger number of events recorded. When only taking into account the trucks with PAMS data loggers, only one truck in one speed range (truck DT03 in the 40-50 MPH range) showed an increase in acceleration rates. It is notable that this particular truck also had relatively lower number of recorded events compared to the other trucks equipped with PAMS due to the data logger having been unintentionally disconnected by the driver for part of the data collection period.

Assessment of Emissions Impacts

To determine the potential emissions benefits or impacts from the training, the research team conducted emissions testing on a sample truck to establish emissions rates for the vehicles. Where necessary, the emissions rates were supplemented with those from the MOVES model. The emission rates were used to calculate the potential reductions in emissions based on the collected data.

The emissions testing took place at TTI's Environmental and Emissions Research Facility (EERF), located on the RELLIS campus of Texas A&M University. The RELLIS campus includes a set of runways, approximately 1 mile long, which allow for driving vehicles without the interference of other vehicles. During the testing at RELLIS a sample truck was outfitted with Portable Emissions Measurement Systems (PEMS) capable of measuring both particulate matter (PM) and gaseous emissions, including carbon dioxide (CO_2) and oxides of nitrogen (NO_X). The fuel consumption rates are also calculated based on the emissions and the carbon balance method of estimate fuel consumption. Figure 16 shows the PEMS equipment in the test truck (gaseous PEMS on the left, PM on the right). The PEMS units also include a flow meter (seen in Figure 17) to measure the exhaust flow of the vehicle which allowed the benefits of the testing to be calculated by total weight of each pollutant.

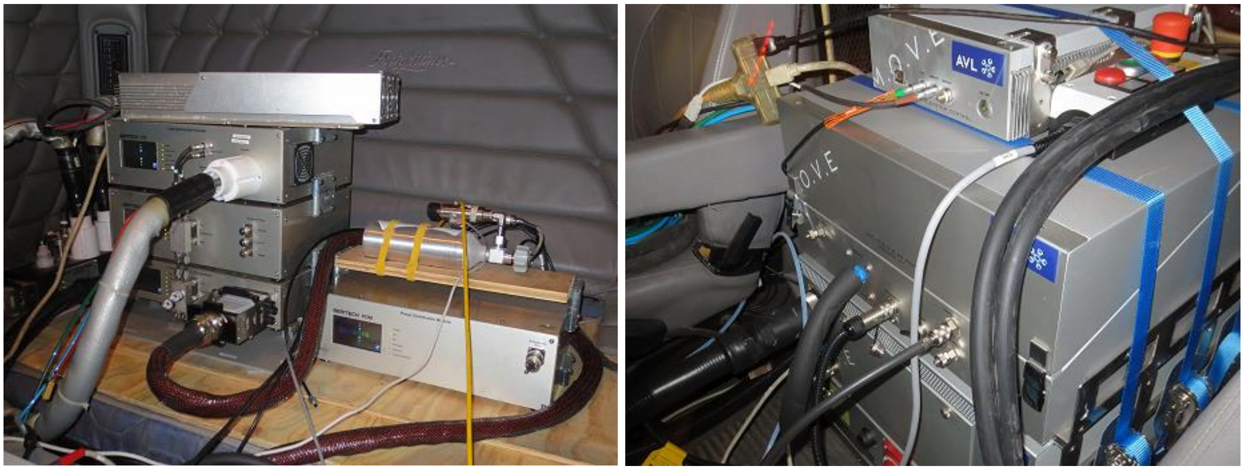


Figure 16: PEMS Equipment in Test Truck

The sample truck used for this study was a 2006 Freightliner Columbia. The model years of the trucks tested from the drayage companies varied from 1993 to 2017, with the median model year being 2007. The test truck was selected since it was representative of the median model year that was seen in the drayage fleets for this study. Figure 17 shows the test truck during the emissions testing.

Figure 17: Test Truck during Emissions Testing

As previously discussed the acceleration impacts of the training were calculated by breaking the second-by-second data into applicable MOVES bins[9]. Table 14 shows the speed and VSP combinations for each bin.

[9] Not all MOVES bins were used in this calculation, since the top speed considered for acceleration events was 50 MPH.

Table 14: MOVES Bins for Acceleration Comparison and Emission Rates

MOVES opMode Bin	Vehicle Speed (μ, mph)	Vehicle Specific Power (VSP)	CO2 (g/s)	NOx (g/s)	PM (g/s)	Fuel Consumption (gal/s)
0	Idle		2.468	0.031	0.0012	0.00037
11	0 ≤ μ < 25	VSP < 0	5.991	0.046	0.006	0.000555
12	0 ≤ μ < 25	0 ≤ VSP < 3	13.676	0.078	0.015	0.0013862
13	0 ≤ μ < 25	0 ≤ VSP < 6	22.390	0.093	0.017	0.0023105
14	0 ≤ μ < 25	0 ≤ VSP < 9	29.019	0.135	0.024	0.0030253
15	0 ≤ μ < 25	0 ≤ VSP < 12	32.076	0.179	0.0357	0.0036399
16	0 ≤ μ < 25	12 ≤ VSP	44.11	0.232	0.0358	0.0043
21	25 ≤ μ < 50	VSP < 0	5.016	0.022	0.005	0.001
22	25 ≤ μ < 50	0 ≤ VSP < 3	23.689	0.073	0.018	0.0023295
23	25 ≤ μ < 50	0 ≤ VSP < 6	31.231	0.108	0.019	0.0031875
24	25 ≤ μ < 50	0 ≤ VSP < 9	38.933	0.158	0.023	0.0039156
25	25 ≤ μ < 50	0 ≤ VSP < 12	43.176	0.204	0.026	0.0043439
27	25 ≤ μ < 50	0 ≤ VSP < 18	59.64	0.302	0.034	0.0047094
28	25 ≤ μ < 50	0 ≤ VSP < 24	83.49	0.389	0.049	0.0048882
29	25 ≤ μ < 50	0 ≤ VSP < 30	107.35	0.476	0.069	0.00049
30	25 ≤ μ < 50	30 ≤ VSP	131.21	0.2789	0.083	0.0051

The emissions and fuel consumption rates used in the calculations, and shown in Table 14, are a combination of the emissions rates measured during the testing at RELLIS, as well as emissions rates calculated using the MOVES model. Two sets of tests were conducted on the sample truck, one pulling an empty trailer and one pulling a trailer loaded with a load of approximately 30,000 lbs. of cargo. The loaded and empty rates, for each bin except for the idling bin, were then combined using a weighted average of the loaded and unloaded testing. According to the Bureau of Transportation Statistics[10], 64.5% of vehicles that crossed the border at El Paso in 2016 were loaded, while the other 35.5% were empty. The emissions rate were then weighted, based on these statistics, to give a single rate for each opMode bin. Due to the limited number of data points during the emissions testing, some bins had no emissions rates associated with them, mostly associated with the higher VSP bins. In order to fill in the missing rates the testing data were supplemented with data from a MOVES run using a typical 2006 truck operating in the El Paso region.

[10] https://transborder.bts.gov/programs/international/transborder/TBDR_BC/TBDR_BCQ.html

Idling Emissions

The data analysis on the driver behavior showed that there was a reduction in idling from the training. The emission rates for opMode bin 0 (i.e. idling) in Table 14 were used, along with the results from the analysis, to determine the potential emissions benefits from the reduced idling. To calculate the savings from reduced idling the data from truck DT01, in Table 7, was used. These were all idling events for truck DT01 which were not at the border. While DT01 was the only truck that saw a statistically significant reduction in average idling duration, the actual percentage reduction in idling was in the middle of the range seen for all trucks. It was therefore selected to be reasonable representation of the potential benefits of the training, and its data used for the calculation. DT01 had an average reduction of 22.3%, from an average of 242 seconds per idle event to 188 seconds. The average daily number of idling events for truck DT01 also went down, from 18/day to 15.8/day after the training. Using these results, and the emissions rates from opMode bin 0 in Table 14, the potential reduction in emissions from the idling is shown in Table 15. As the table shows, when considering the reduced duration and the fewer events, each pollutant is reduced over 31% daily. The table also shows the potential savings per month and years, based on an average of 20 workdays a month. The overall impact to the border area depends on the number of vehicles operating in the area that have taken the training. For the 10 vehicles that took the training as part of the project over 8,200 kg of CO_2, 100 kg of NO_x, and 4 kg of PM will be potentially removed from the region on an annual basis. This would translate to potential fuel savings of 1,220 gallons due to reduced idling.

Table 15: Potential Idling Emissions Reductions from Training

Pollutant	Rate (g/s)	Before			After			Daily Savings (g)	Monthly Savings (g)	Yearly Savings (g)
		Average Duration (s)	Total per Event (g)	Total Per Day (g)	Average Duration (s)	Total per Event (g)	Total Per Day (g)			
CO_2	2.468	242	597.25	10,750	188	463.98	7,330	3,419	68,380	820,560
NO_x	0.031	242	7.50	135.04	188	5.82	92.08	42.96	0.859	10.31
PM	0.0012	242	0.29	5.27	188	0.22	3.59	1.68	0.034	0.403
Fuel*	0.00037	242	0.09	1.61	188	0.07	1.10	0.51	10.2	122.4

** All reported fuel numbers are in gallons,*

Acceleration Emissions

For the duration of the study there were an average of 1,759 seconds of acceleration per vehicle per day[11] before and 1,652 per vehicle per day after the training. The breakdown of these daily averages is shown in Table 16. Based on the MOVES opMode bin breakdown from the data collection effort, and the emission rates in Table 14, the savings, per vehicle per day, are shown in Table 17. Based on the collected data the potential emissions savings from the reduced acceleration are 5.69 kg CO_2, 28.36 g NO_x, 3.89 g of PM, and 0.46 gallons of diesel. If the same number of working days per month and per year as the idling calculations are used, the monthly and yearly savings are as shown in Table 17.

Table 16: Per Vehicle Estimated Emissions from Acceleration Events

MOVES opMode Bin	Before					After				
	Data Points	CO_2 (kg)	NOx (g)	PM (g)	Fuel (gal)	Data Points	CO_2 (kg)	NOx (g)	PM (g)	Fuel (gal)
11	174	1.04	8.00	1.04	0.10	169	1.01	7.79	1.02	0.09
12	352	4.81	27.46	5.28	0.49	356	4.87	27.77	5.34	0.49
13	200	4.48	18.60	3.40	0.46	199	4.46	18.51	3.38	0.46
14	121	3.51	16.34	2.90	0.37	114	3.30	15.35	2.73	0.34
15	65	2.08	11.64	2.32	0.24	45	1.43	8.01	1.60	0.16
16	50	2.21	11.60	1.79	0.22	29	1.28	6.74	1.04	0.12
21	85	0.43	1.88	0.43	0.09	88	0.44	1.93	0.44	0.09
22	127	3.01	9.29	2.29	0.30	135	3.19	9.82	2.42	0.31
23	173	5.39	18.66	3.28	0.55	175	5.48	18.95	3.33	0.56
24	156	6.06	24.58	3.58	0.61	145	5.64	22.89	3.33	0.57
25	111	4.81	22.71	2.89	0.48	98	4.24	20.02	2.55	0.43
27	110	6.55	33.15	3.73	0.52	80	4.75	24.03	2.71	0.37
28	29	2.39	11.13	1.40	0.14	16	1.34	6.25	0.79	0.08
29	5	0.57	2.52	0.37	0.00	3	0.28	1.23	0.18	0.00
30	1	0.14	0.31	0.09	0.01	1	0.09	0.19	0.06	0.00
Total	1759	47.49	217.86	34.80	4.55	1652	41.80	189.49	30.91	4.09

[11] Based on data loggers that had a full day worth of data. If a logger did not have a full day worth of data, they were not counted in this average.

Table 17: Per Vehicle Potential Acceleration Emissions Reductions from Training

Pollutant	Potential Savings		
	Per Day	Per Month	Per Year
CO_2 (kg)	5.69	113.8	1,356.6
NO_x (g)	28.36	567.2	6,806.4
PM (g)	3.89	77.8	933.6
Fuel (gal)	0.46	9.2	110.4

SUMMARY

This chapter presented the results of the case study analysis, which involved an assessment of driver behavior before and after implementation of the training program. The findings indicated, overall, there were reduced idling levels and acceleration levels that could potentially be attributed to the training program. However, the limited data sample and resulting lack of a firm interpretation of statistical significance indicates that these findings are not conclusive. This chapter also discussed potential emissions benefits associated with the improvements in idling and accelerations observed in the study.

CHAPTER 5 – SUMMARY AND CONCLUSIONS

Emissions from drayage trucks operating in the U.S.-Mexico border region are important from an air quality perspective, and in light of growing freight movement between the two nations. This study focused on the use of driver training and behavioral changes as the means to reduce emissions from drayage truck operations. The study successfully developed a training program focused on fuel reduction techniques for drayage operators, and conducted a case study analysis by providing drivers with training and collecting driving behavior data before and after the training to assess potential benefits.

Key findings and conclusions from the study are as follows:

- From an idling behavior perspective, the data analysis indicated that overall, the average duration of idling events under consideration (i.e. non-border facility idling of greater than a minute duration) decreased by approximately 65 seconds (approximately 22%) after the training. The number of events per day were also reduced, from 18 to 15 per day.
- In terms of the aggressiveness of driving (assessed in terms of accelerations), average, acceleration rates decreased over all speed ranges tested, with changes ranging from 3% to 11%.
- While not all the results for individual trucks and the entire dataset were statistically significant, the relatively small datasets and presence of outliers should be taken into consideration in interpretation of results. Further data collection and testing could provide more conclusive benefits in terms of actual changes enforced.
- Finally, in terms of emissions and fuel consumption, potential benefits for a single truck, extrapolated from the study findings, considering both reduced idling and less aggressive accelerations, are potentially 2,160 kg of CO_2, 17.04 kg NO_x, 1.34 kg of PM, and 216 gallons of fuel per vehicle per year.

In conclusion, the findings from this study indicate that there is potential for effecting behavioral changes in drayage operators through a training program, with the associated emissions and fuel consumption benefits.

There are several areas for future research and investigation that can build on this study, including the following:

- *Investigating Driver Incentives and Enforcement Strategies:* The data analysis from this report shows that the training program can have impact on the drivers' behaviors, but that it was not effective for all the drivers. This could potentially be because the drivers themselves have no direct benefit to following the training program recommendations. The drivers may not be concerned with emissions, and the savings from reduced fuel consumption are generally going to be seen by the fleet operators, and not the drivers themselves. Thus, design and implementation of driver incentive programs in conjunction with the training can potentially result in greater adoption of desired driving behaviors. Alternative approaches, such as enforcement strategies to ensure compliance can also be similarly investigated.

- *Expanded Studies over Longer Duration:* Similar studies with larger participant numbers can help establish more robust conclusions regarding the benefits of training programs and their effectiveness. Further, assessing behavioral changes over time can also help identify whether the programs have a lasting effect, or whether drivers require refresher courses or periodic training to maintain the benefits.

- *Addressing Idling at the Border Crossings:* The data collection and analysis efforts found that a large number of idling events occur as the drivers are either waiting to arrive at the border facilities, or at the facilities while they wait to cross. Over 54% of all idling events occurred during border crossing activities. While this idling was considered to be non-discretionary for purposes of this analysis, it demonstrated that improvements to border wait times and idling could be an important areas to tackle for regional air quality improvements.

APPENDIX A – ADDITIONAL SOURCES FOR DEVELOPMENT OF DRIVER TRAINING

The following sources were used in preparation of the heavy-duty truck driver behavior training program.

Table A: Driver Training Information Sources

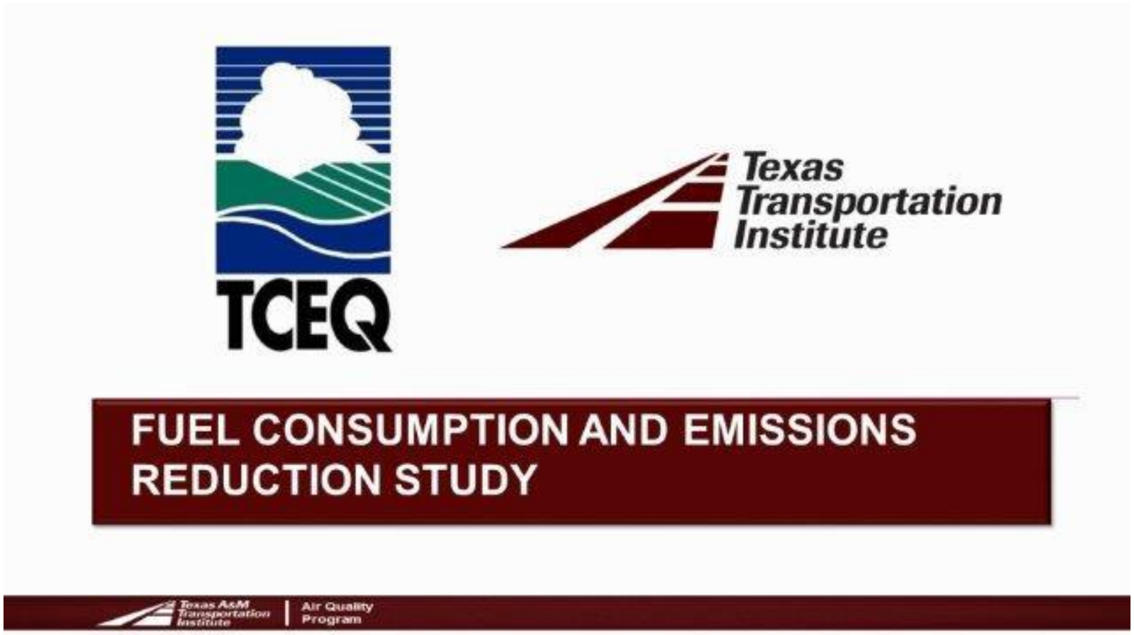
Title of Source	Provider	Web Address
The Role of Truck Drivers in Sustainability.	American Transportation Research Institute (ATRI)	http://atri-online.org/sustainable-driving-practices/
Estimating Truck-Related Fuel Consumption and Emissions in Maine: A Comparative Analysis for a 6-axle, 100,000 Pound Vehicle Configuration.	American Transportation Research Institute (ATRI) and Maine Department of Transportation.	Estimating Truck-Related Fuel Consumption and Emissions in Maine: A Comparative Analysis for a 6-axle, 100,000 Pound Vehicle Configuration,
Manage Your Semi-Truck's Fuel Use with These Tips.	Arrow Truck Sales	http://www.arrowtruck.com/blog/wp/index.php/manage-your-semi-trucks-fuel-use-with-these-tips/
Cummins MPG Guide, Secrets of Better Fuel Economy; The Physics of MPG.	Cummings, Inc.	https://cumminsengines.com/uploads/docs/cummins_secrets_of_better_fuel_economy.pdf
How to Get Great Fuel Efficiency	Detroit Diesel Corporation	https://www.demanddetroit.com/why-detroit/efficientdriving.aspx
Fuel Economy. Demand It All.	Detroit Diesel Corporation	http://www.westernstartrucks.com/_Assets/Brochures/Detroit-FuelEconomyBrochure.pdf
Modifying Driver Behavior – An Important Piece to Greening Your Fleet	Environmental Protection Agency (EPA)	https://www.epa.gov/smartway/modifying-driver-behavior-important-piece-greening-your-fleet
Fuel Economy 101	Fleet Owner.com	http://fleetowner.com/fuel_economy/fuel-economy-0701
Auxiliary Power Units – Reducing Carbon Emissions by Eliminating Idling in Heavy-Duty Trucks (photo credit)	Gereffi, G. & K. Dubay, Center on Globalization Governance and Competitiveness (November 2008)	https://commons.wikimedia.org/w/index.php?curid=10529325
Fleets Can Help Drivers Maximize Fuel Economy (Part 6 in HDV's Driver Dilemma series on the driver shortage)	Heavy Duty Trucking (HDT) Truckinginfo.com	http://www.truckinginfo.com/article/story/2015/06/fleets-can-help-drivers-maximize-fuel-economy.aspx

How to Improve Fuel Efficiency on the Road	Heavy Duty Trucking (HDT) Truckinginfo.com	http://www.truckinginfo.com/article/story/2013/06/how-to-improve-fuel-efficiency-on-the-road.aspx
121 Ways to Save Fuel	Heavy Duty Trucking (HDT) Truckinginfo.com	http://www.truckinginfo.com/article/story/2014/06/121-ways-to-save-fuel.aspx
Reducing the Carbon Footprint of Freight Movement through Eco-Driving Programs for Heavy-Duty Trucks	National Center for Sustainable Transportation and the University of California Riverside.	http://ncst.ucdavis.edu/wp-content/uploads/2014/08/06-24-2015-NCST_WP_Truck-eco-drivingFINAL.pdf
Improving Your Bottom Line through Fuel Economy	Peterson Power Systems, Inc.	http://209.236.123.92/training/articles/fuel-economy
Floating gears or using the double clutch technique – Which is better?	Raney's Inc. Heavy duty trucking parts and accessories.	http://blog.raneystruckparts.com/uncategorized/floating-gears-or-using-the-double-clutch-technique-which-is-better/
How Eco-Driving Impacts Fleet Fuel Economy	Sokolis Group Fuel Managment	http://blog.sokolisgroup.com/how-eco-driving-impacts-fleet-fuel-economy
Freight Vehicle Policy: Annex A of the Handbook 'Navigating Transport NAMAs' TRANSfer Project – Toward climate-friendly transport technologies and measures.	TRANSfer Project.org	http://transport-namas.org/wp-content/uploads/2014/05/P.-Freight-Vehicle-Policy.pdf
The Fuel-Efficient Truck Drivers' Handbook, Freight Best Practice Pocket Guide	United Kingdom Department for Transport	http://postconflict.unep.ch/humanitarianaction/documents/02_08-04_06-04_02-22.pdf
Eco-Driving Presentation (2014)	Wisconsin Clean Cities	http://www.wicleancities.org/projects/cmaq.php
40 Ways to Reduce Truck Fleet Costs	Work Truck Online	http://www.worktruckonline.com/article/story/2007/07/40-ways-to-reduce-truck-fleet-costs.aspx

Table B: Background Information Sources used in Driver Training

Title of Source	Provider	Web Address
Particulate Matter (PM) Basics; What is PM, and how does it get into the air?	Environmental Protection Agency (EPA)	https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM
Basic Information About Carbon Monoxide (CO) Outdoor Air Pollution	Environmental Protection Agency (EPA)	https://www.epa.gov/co-pollution/basic-information-about-carbon-monoxide-co-outdoor-air-pollution#What is CO
Geographical Texas Air Quality Monitoring Viewer (GeoTAM Viewer)	Texas Commission on Environmental Quality (TCEQ)	https://www.tceq.texas.gov/gis/geotam-viewer

APPENDIX B – FINAL TRAINING SLIDES (ENGLISH VERSION)



Fuel Consumption and Emission Study

Project Objective:

Work with International Trucking Companies to Reduce Fuel Usage and Diesel Emissions in the Border Area.

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Fuel Consumption and Emission Study

This Study is Part of a Larger, Over-all Strategy by TCEQ.

TCEQ

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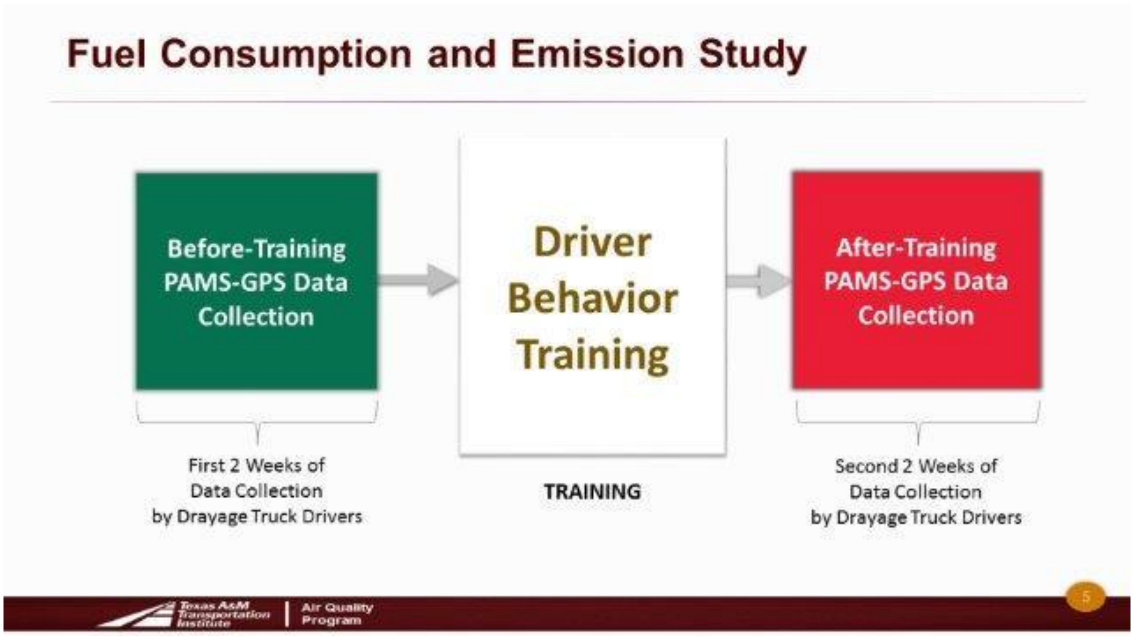
Fuel Consumption and Emission Study
Before-Training PAMS-GPS Data Collection
Driver Behavior Training
After-Training PAMS-GPS Data Collection
First 2 Weeks of Data Collection by Drayage Truck Drivers
TRAINING
Second 2 Weeks of Data Collection by Drayage Truck Drivers
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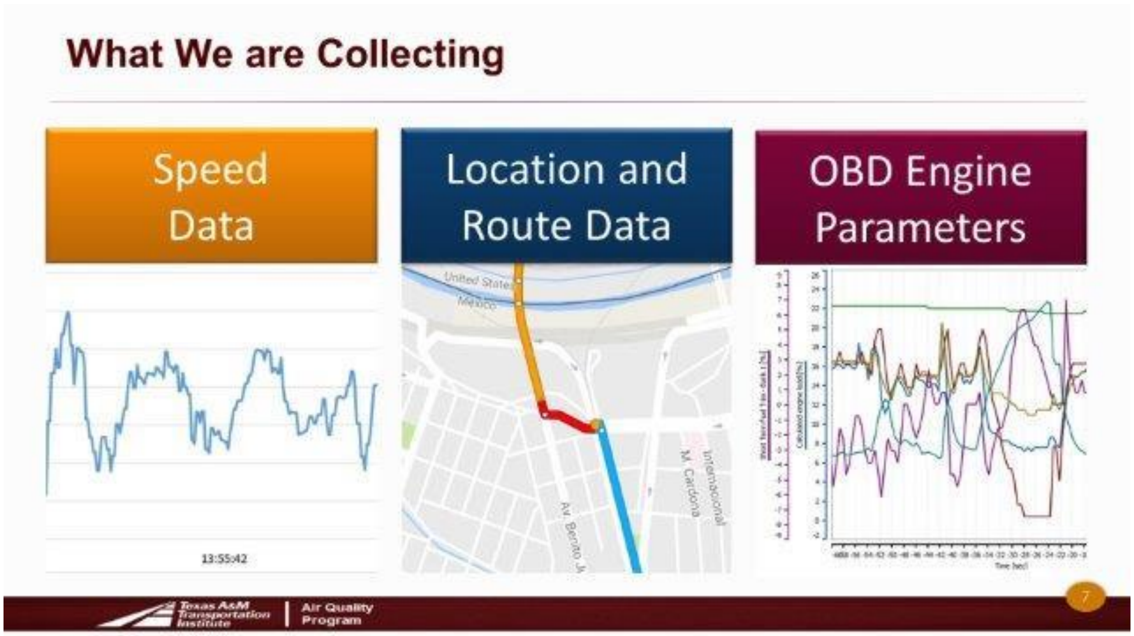
Portable Activity Measurement System (PAMS)
HEM Data
S/N 20188
Texas A&M Transportation Institute
Air Quality Program
6


What We are Collecting
Speed Data
Location and Route Data
OBD Engine Parameters
13:55:42
United States
Mexico
Internacional
M. Cardona
Texas A&M Transportation Institute
Air Quality Program
7


How the Data will be Used
Portable Emission Measurement System
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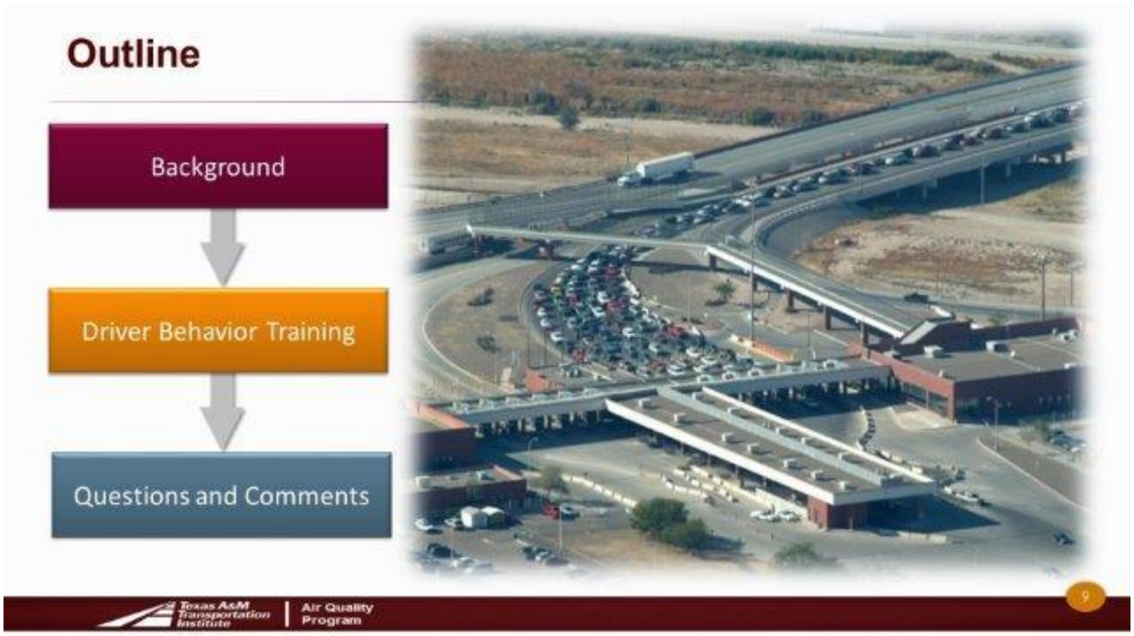
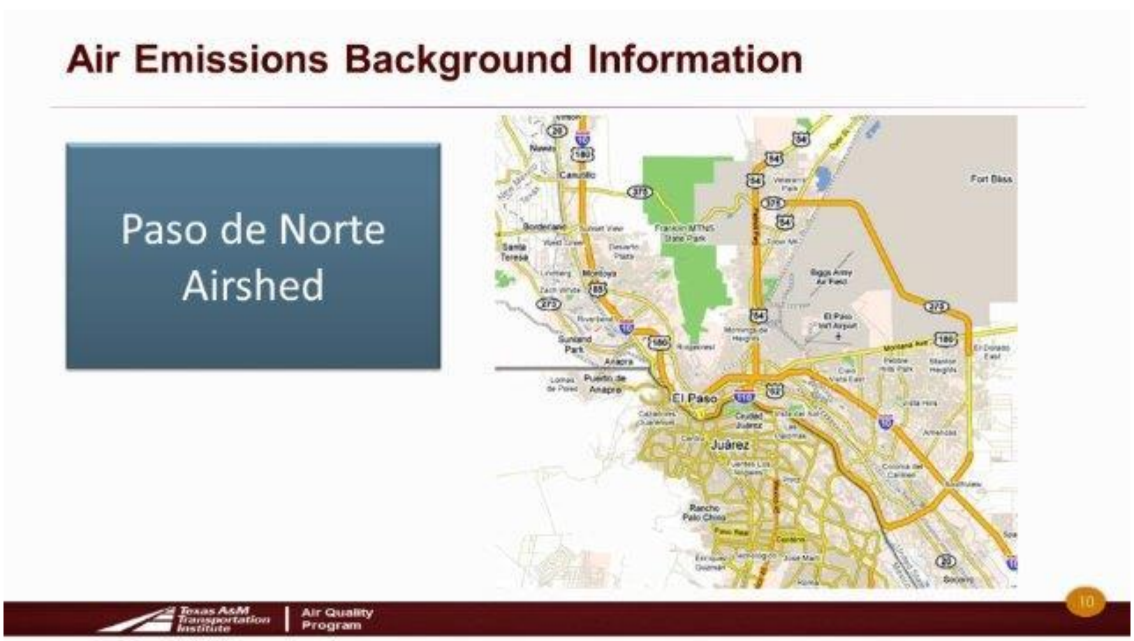
Air Quality Program
8


Outline
Background
Driver Behavior Training
Questions and Comments
Texas A&M Transportation Institute
Air Quality Program
9


Air Emissions Background Information
Paso de Norte Airshed
El Paso
Juárez
Fort Bliss
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10

Air Emissions Background Information

Particulate Matter

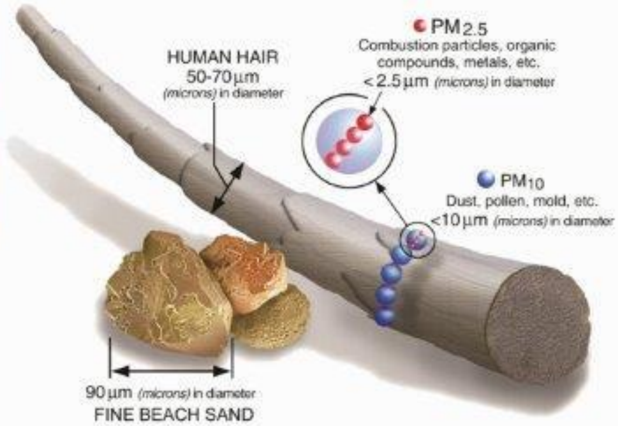

Illustration obtained from EPA's Particulate Matter (PM) Pollution website: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM

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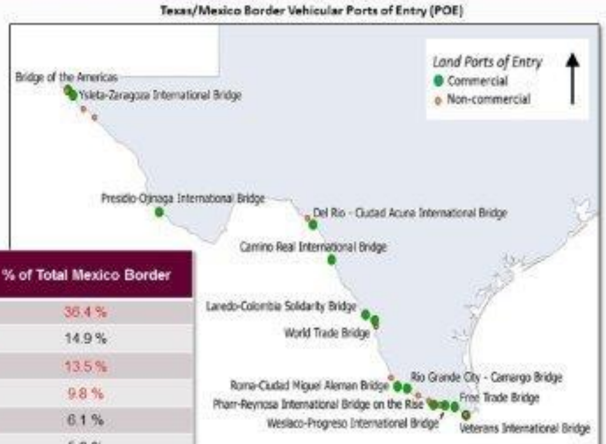
U.S – Mexico Cross Border Freight

Southern Border POEs by Number of Truck Crossings 2015

POE Name	Truck Crossings into U.S.	% of Total Mexico Border
Laredo, TX	2,015,773	36.4 %
Otay Mesa, CA	829,581	14.9 %
El Paso, TX	747,702	13.5 %
Hidalgo, TX	546,259	9.8 %
Calexico East, CA	337,474	6.1 %
Nogales, AZ	319,747	5.8 %

Texas/Mexico Border Vehicular Ports of Entry (POE)



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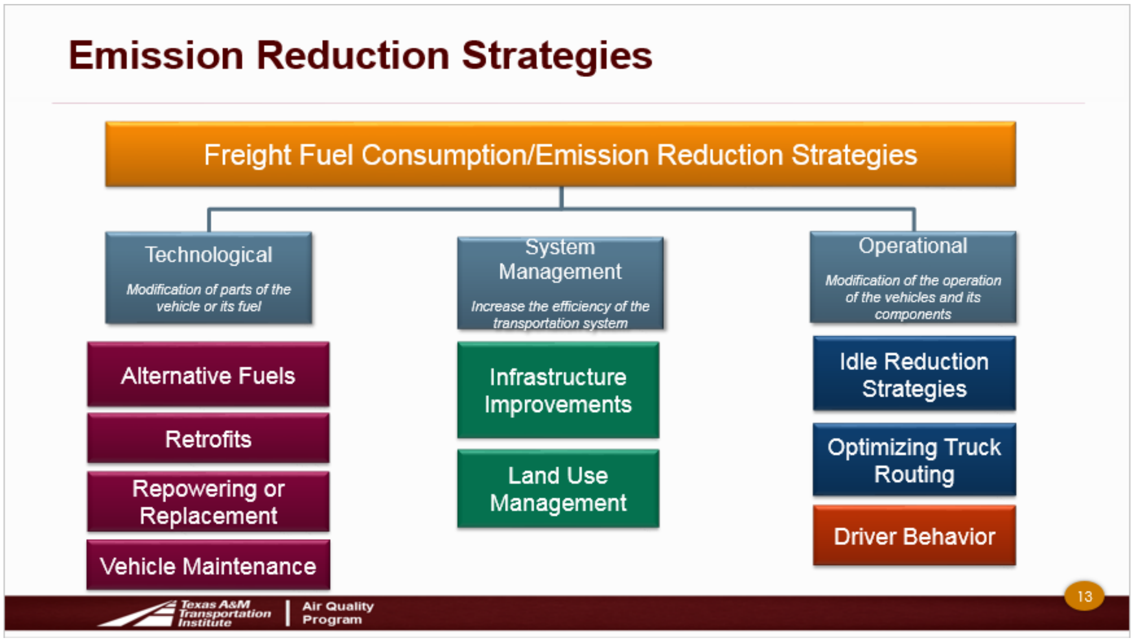
Emission Reduction Strategies
Freight Fuel Consumption/Emission Reduction Strategies
Technological
Modification of parts of the vehicle or its fuel
System Management
Increase the efficiency of the transportation system
Operational
Modification of the operation of the vehicles and its components
Alternative Fuels
Retrofits
Repowering or Replacement
Vehicle Maintenance
Infrastructure Improvements
Land Use Management
Idle Reduction Strategies
Optimizing Truck Routing
Driver Behavior
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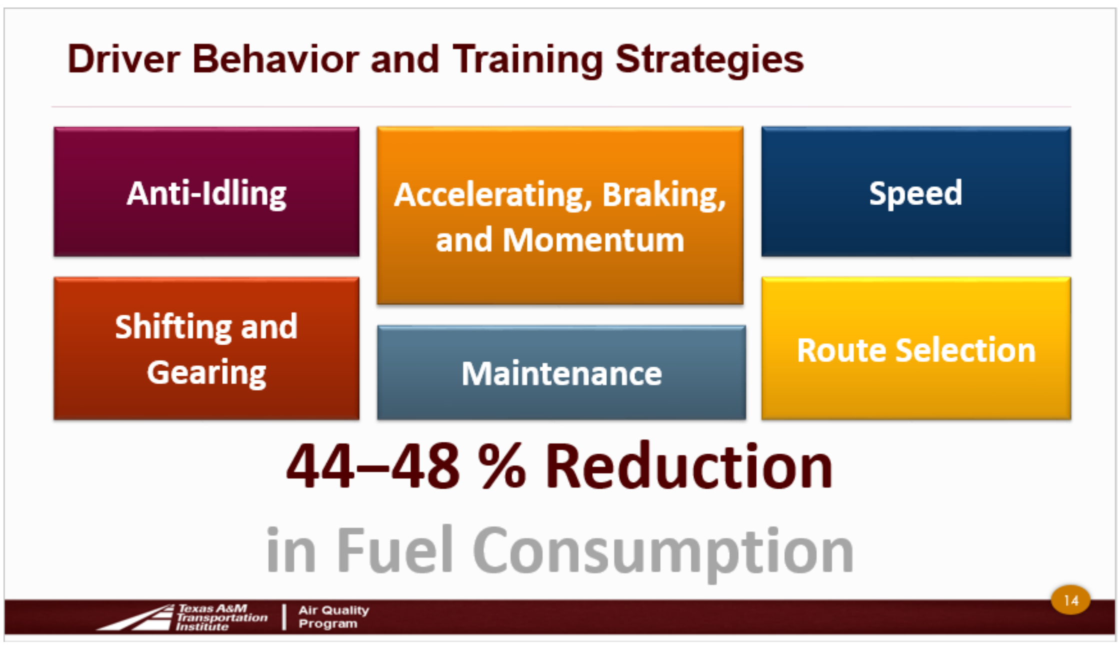
Driver Behavior and Training Strategies
Anti-Idling
Accelerating, Braking, and Momentum
Speed
Shifting and Gearing
Maintenance
Route Selection
44–48 % Reduction
in Fuel Consumption
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Driver Behavior and Training Strategies

How you drive matters.

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DRIVER BEHAVIOR STRATEGIES

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Driver Behavior Strategies
Anti-Idling
Speed
Shifting and Gearing
Maintenance
Accelerating, Braking, and Momentum
Planning Ahead
Other Techniques
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ANTI-IDLING STRATEGIES
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Anti-Idling Strategies

Drivers should consider turning off their engines if they have stopped for more than a minute

Anti-Idling Strategies

Limit warm up and cool down time

Anti-Idling Strategies

Use auxiliary power units (APUs) when available.

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Anti-Idling Strategies

For cab A/C and heat, choose the lowest idling speed possible (no higher that 800 rpm)

Table 9: Idle/PTO Fuel Consumption

Engine Speed (RPM)	Average Fuel Consumption (Gal/Hr)
650	~0.5
1000	~1.0
1200	~1.5

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Anti-Idling Strategies

Shut engine off whenever possible.

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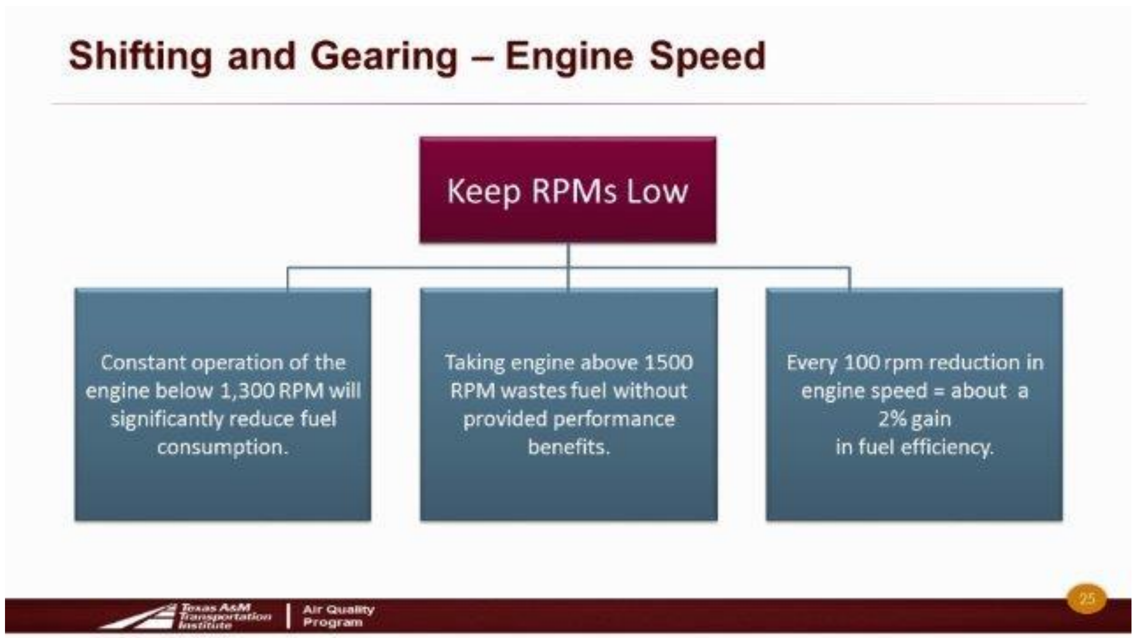
Shifting and Gearing – Engine Speed
Keep RPMs Low
Constant operation of the engine below 1,300 RPM will significantly reduce fuel consumption.
Taking engine above 1500 RPM wastes fuel without provided performance benefits.
Every 100 rpm reduction in engine speed = about a 2% gain in fuel efficiency.
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Shifting and Gearing
Limit Unnecessary Shifting
Shift Progressively and Efficiently
Keep RPM Low
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ACCELERATING, BRAKING, AND
MOMENTUM
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Accelerating
Don't Floor It!
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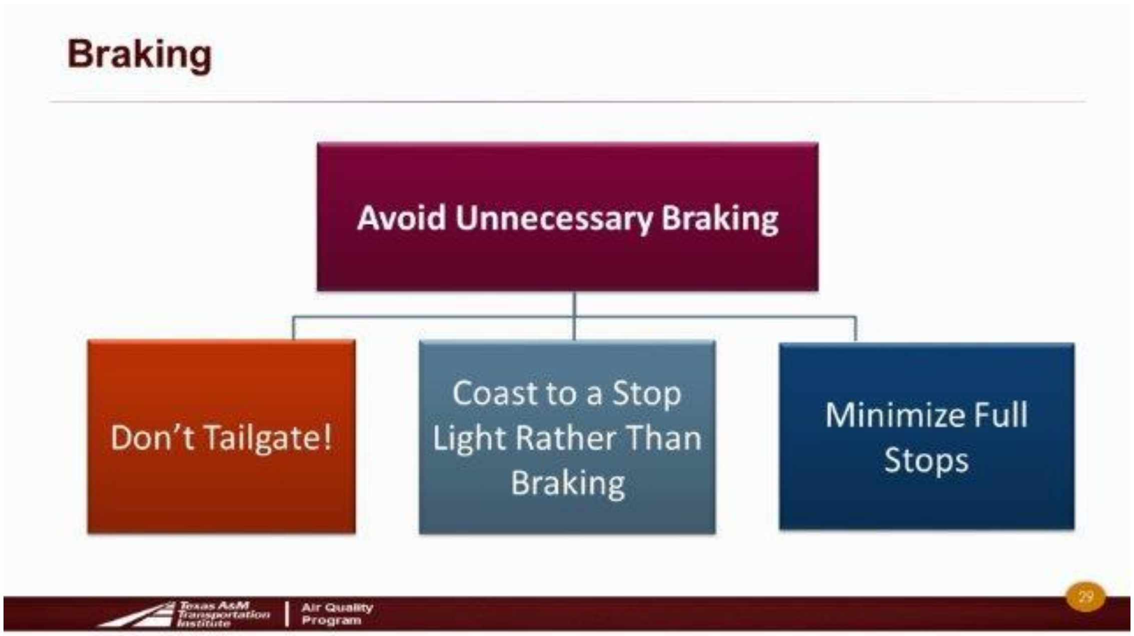
Braking
Avoid Unnecessary Braking
Don't Tailgate!
Coast to a Stop Light Rather Than Braking
Minimize Full Stops
Air Quality Program
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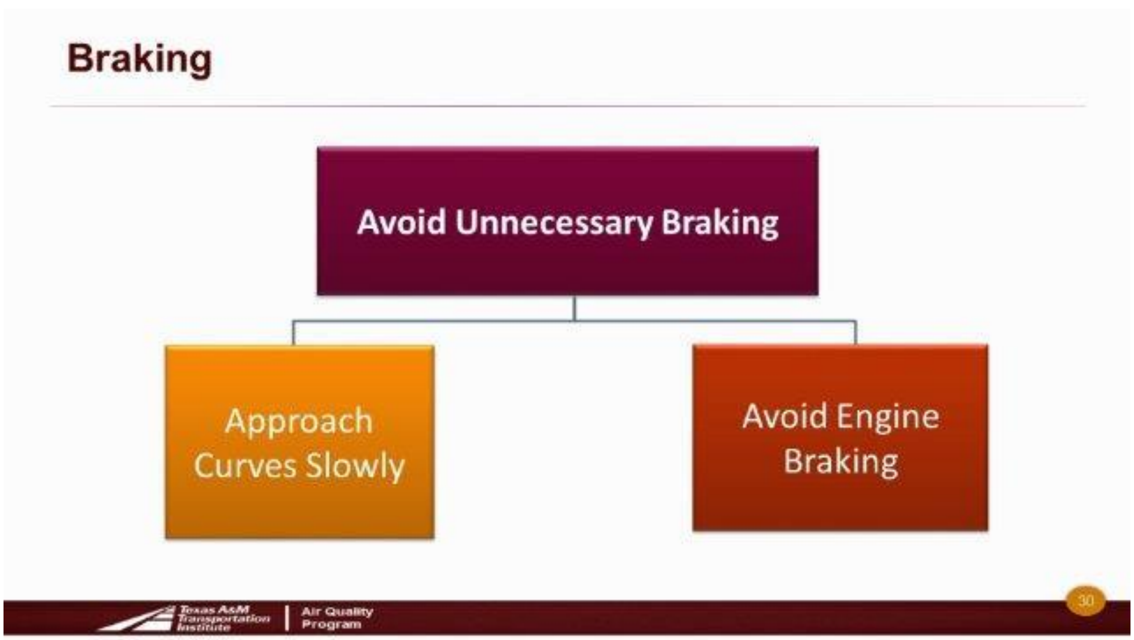
Braking
Avoid Unnecessary Braking
Approach Curves Slowly
Avoid Engine Braking
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Momentum
Slow Down and Stay Back to Maintain Momentum
In Rolling Terrain Allow Momentum to Carry Vehicle Over Short Grades
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Air Quality Program
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SPEED
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Air Quality Program

Speed

The Effects of Speed on Fuel Consumption of a Heavy Duty Truck Engine.

Metric Units

Speed (Km/h)	Distance (Km)	Fuel Used (Liters/h)	Fuel Consumption (Km/Liter)
Idling (at 480 rpm)	0	1.9	--
60	22.2	4.1	6.5
80	22.2	6.6	4.0
90	22.2	8.4	3.1

English Units

Speed (mph/kph)	Distance (miles)	Fuel Used (gal/hr)	Fuel Consumption (mpg)
Idling (at 480 rpm)	0	0.5	--
37	13.8	1.1	15.2
50	13.8	1.7	9.5
56	13.8	2.2	7.4

Tables modified from The Fuel Efficient Truck Driver's Handbook.

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Speed

The Effects of Speed on Fuel Consumption of a Heavy Duty Truck Engine.

Metric Units

Speed (Km/h)	Distance (Km)	Fuel Used (Liters/h)	Fuel Consumption (Km/Liter)
Idling (at 480 rpm)	0	1.9	--
60	22.2	4.1	6.5
80	22.2	6.6	4.0
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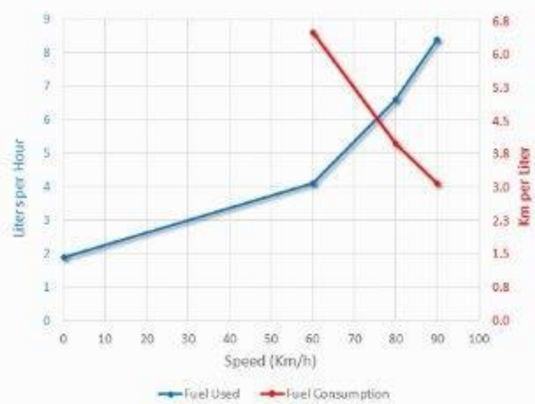
Tables modified from The Fuel Efficient Truck Driver's Handbook.



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Speed

The Effects of Speed on Fuel Consumption of a Heavy Duty Truck Engine.

English Units

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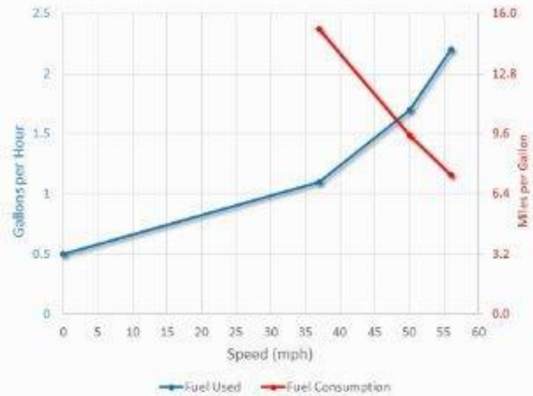
Idling (at 480 rpm)	0	0.5	--
37	13.8	1.1	15.2
50	13.8	1.7	9.5
56	13.8	2.2	7.4

Tables modified from The Fuel Efficient Truck Driver's Handbook.



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Speed – Cruise Control

Use Cruise Control When Appropriate

Manage Speed and Momentum According to Traffic and Weather Conditions

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TRUCK MAINTENANCE
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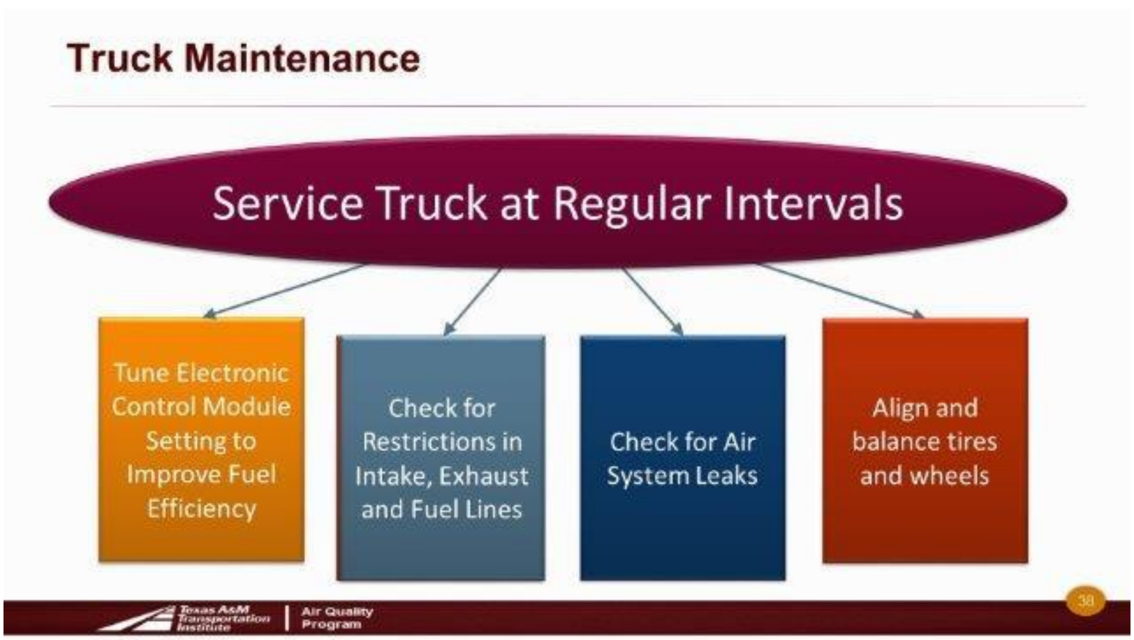
Air Quality Program


Truck Maintenance
Service Truck at Regular Intervals
Tune Electronic Control Module Setting to Improve Fuel Efficiency
Check for Restrictions in Intake, Exhaust and Fuel Lines
Check for Air System Leaks
Align and balance tires and wheels
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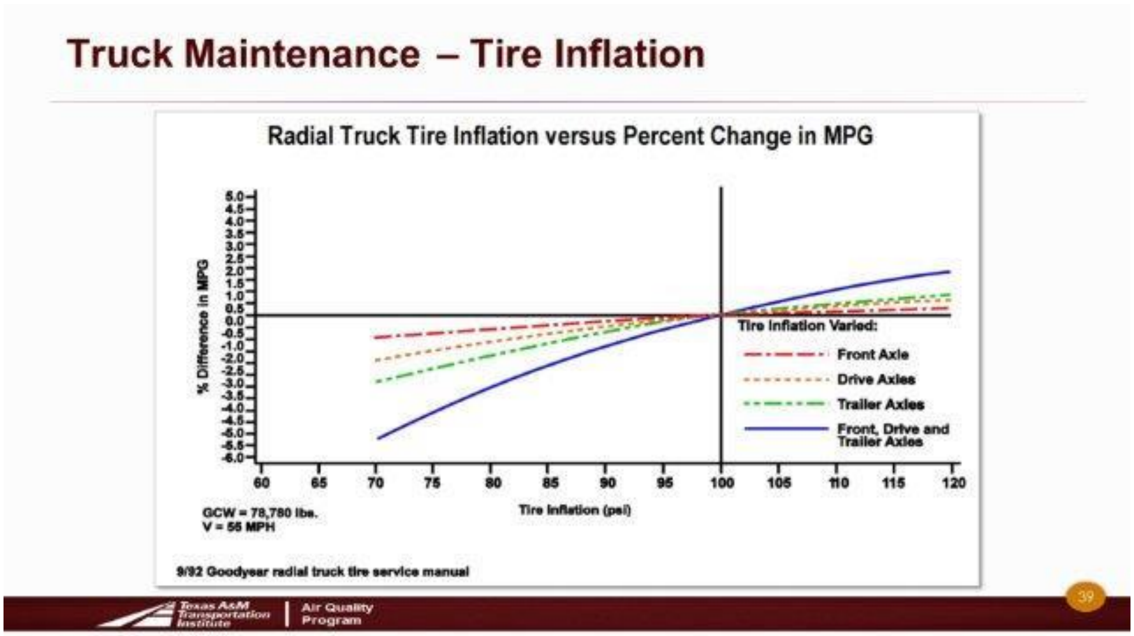
Truck Maintenance – Tire Inflation
Radial Truck Tire Inflation versus Percent Change in MPG
% Difference in MPG
Tire Inflation (psi)
Tire Inflation Varied:
Front Axle
Drive Axles
Trailer Axles
Front, Drive and Trailer Axles
GCW = 78,780 lbs.
V = 55 MPH
9/92 Goodyear radial truck tire service manual
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Truck Maintenance
Keep Tires Properly Inflated.
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PLANNING AHEAD
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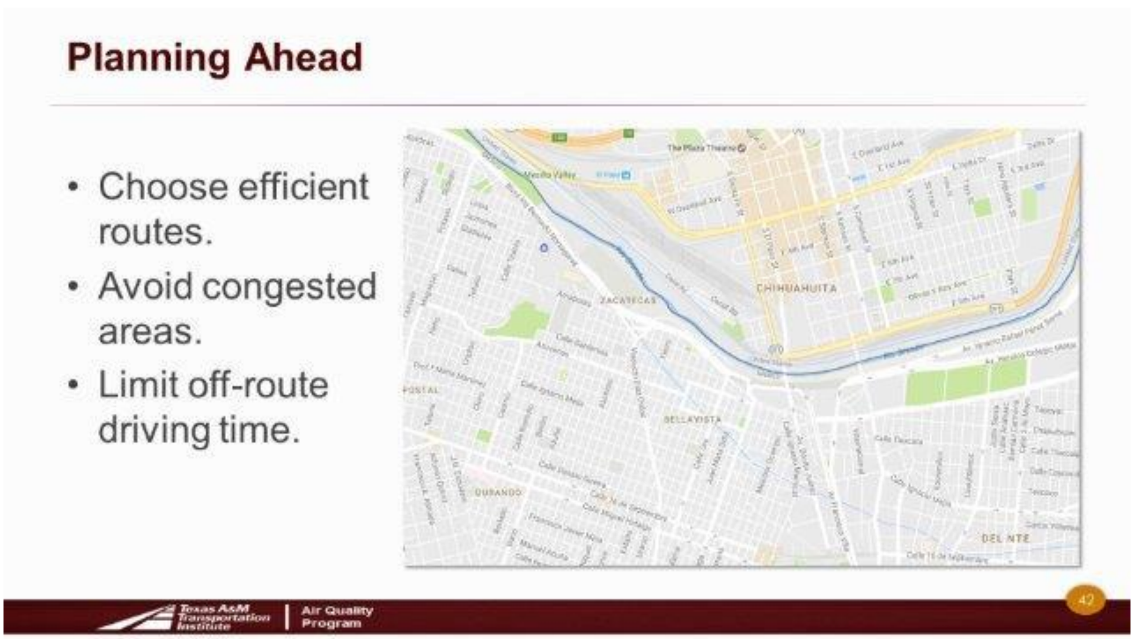
Planning Ahead
• Choose efficient routes.
• Avoid congested areas.
• Limit off-route driving time.
CHIHUAHUITA
ZACATECAS
BELLAVISTA
Texas A&M Transportation Institute
Air Quality Program
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Planning Ahead

- Use your high visibility

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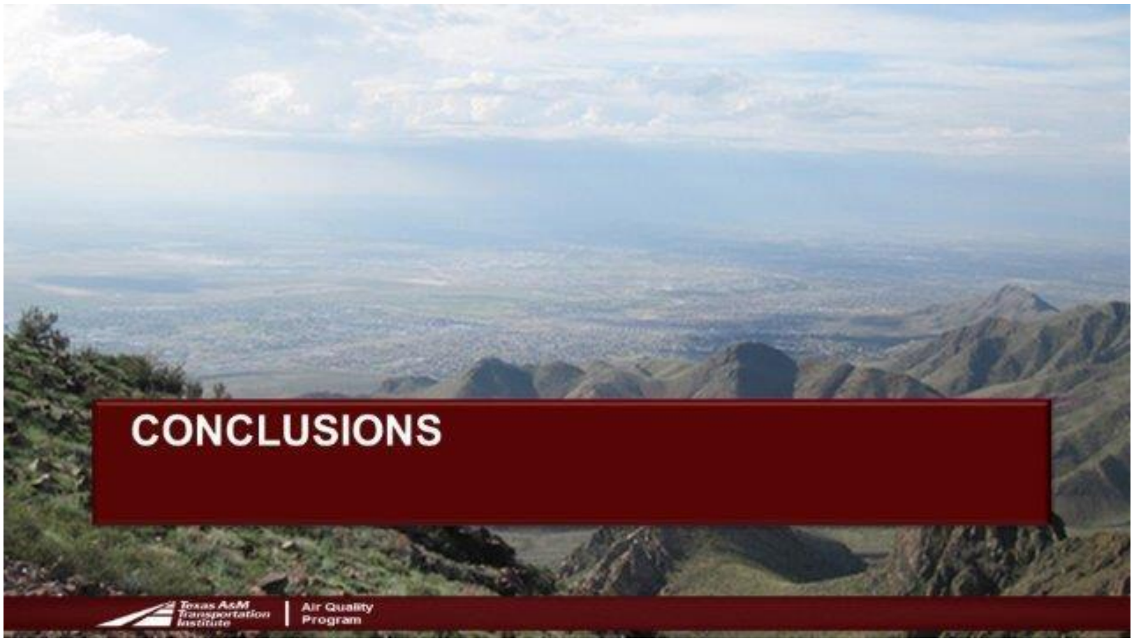
Other Techniques

- Minimize use of the A/C (when reasonable)

Other Techniques

Fuel = 30% of operating cost.

- Refuel in the morning or at night.
- Do not overfill the fuel tank.


CONCLUSIONS
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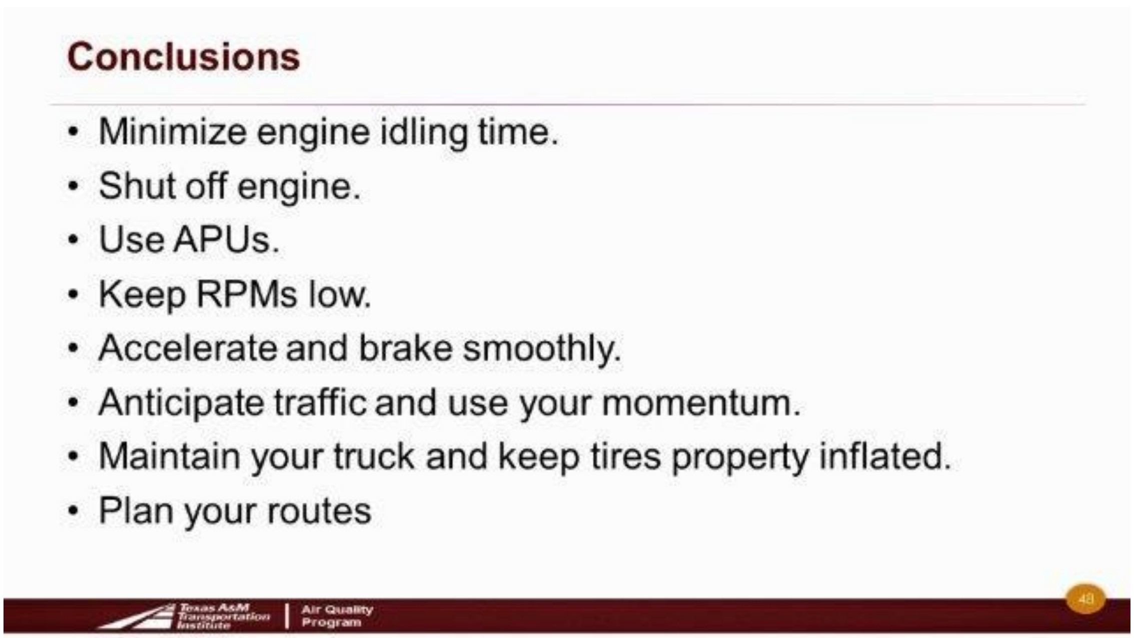
Conclusions
• Minimize engine idling time.
• Shut off engine.
• Use APUs.
• Keep RPMs low.
• Accelerate and brake smoothly.
• Anticipate traffic and use your momentum.
• Maintain your truck and keep tires property inflated.
• Plan your routes
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BIENVENIDOS A
WELCOME TO
MEXICO
CAMIONES - TRUCKS
THANK YOU!
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Air Quality Program


Questions and Comments
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Air Quality Program
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J-Johnson@tti.tamu.edu
Office: 979-862-7253
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APPENDIX C – FINAL TRAINING SLIDES (SPANISH VERSION)

Estudio sobre el Consumo de Combustible y Emisiones Ambientales

Objetivo del Proyecto:

Trabajar con Empresas de Transporte Internacionales para disminuir el consumo de combustible y las Emisiones Diesel en la Zona de la Frontera.

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3

Estudio sobre el Consumo de Combustible y Emisiones Ambientales

Este Estudio es Parte de una estrategia más grande y general de TCEQ.

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Estudio sobre el Consumo de Combustible y Emisiones Ambientales

PAMS-GPS Recolección de Datos antes de Capacitación → **Capacitación de Comportamiento del Conductor** → **PAMS-GPS Recolección de Datos después de Capacitación**

Primeras dos semanas de recolección de datos por conductores de camiones de translado

Capacitación

Segundas 2 semanas dde recolección de datos por conductores de camiones de translado

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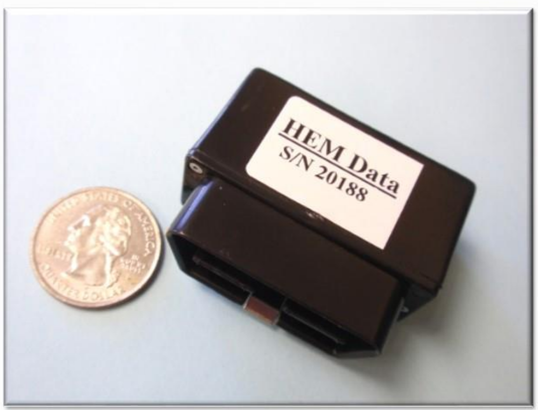
Sistema Portátil de Medida de Actividad (PAMS)



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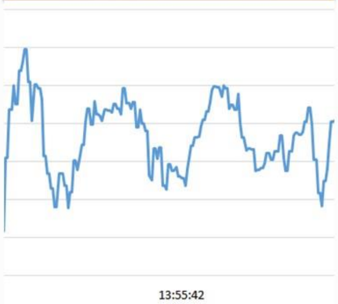
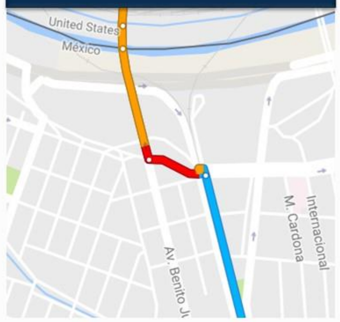
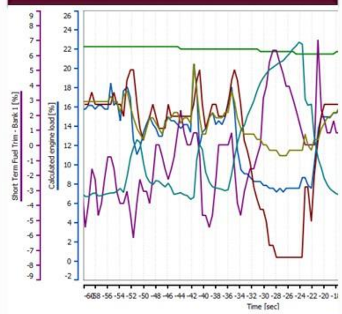
Lo que estamos grabando

Velocidad	Lugar y Ruta	Parámetros de Motor OBD







Como usamos los datos

Sistema Portátil de Medida de Actividad

Guión

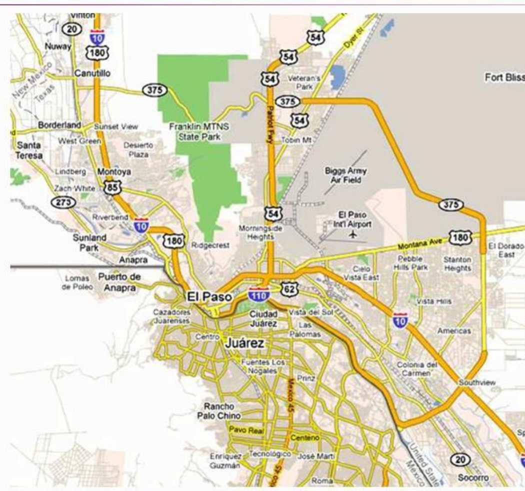
Contexto

Capacitación de Comportamiento del Conductor

Preguntas y Comentarios

Contexto de Emisiones Aéreas

Cuenca de Aire Paso de Norte



Contexto de Emisiones Aéreas

Material particulado

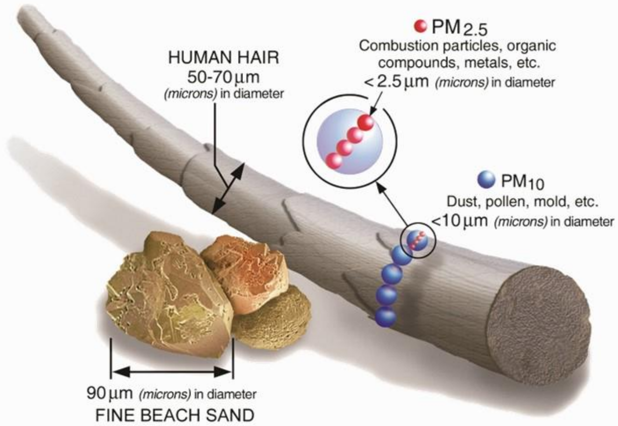


Illustration obtained from EPA's Particulate Matter (PM) Pollution website, https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM

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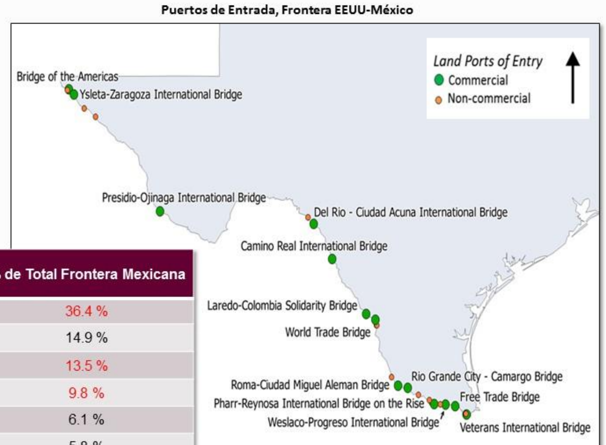
Carga Transfronteriza EEUU-México

Puertos de Entrada por Número de Camiones 2015

Puertos de Entrada, Frontera EEUU-México



Puerto de Entrada	Camiones Entrando EEUU	% de Total Frontera Mexicana
Laredo, TX	2,015,773	36.4 %
Otay Mesa, CA	829,581	14.9 %
El Paso, TX	747,702	13.5 %
Hidalgo, TX	546,259	9.8 %
Calexico East, CA	337,474	6.1 %
Nogales, AZ	319,747	5.8 %

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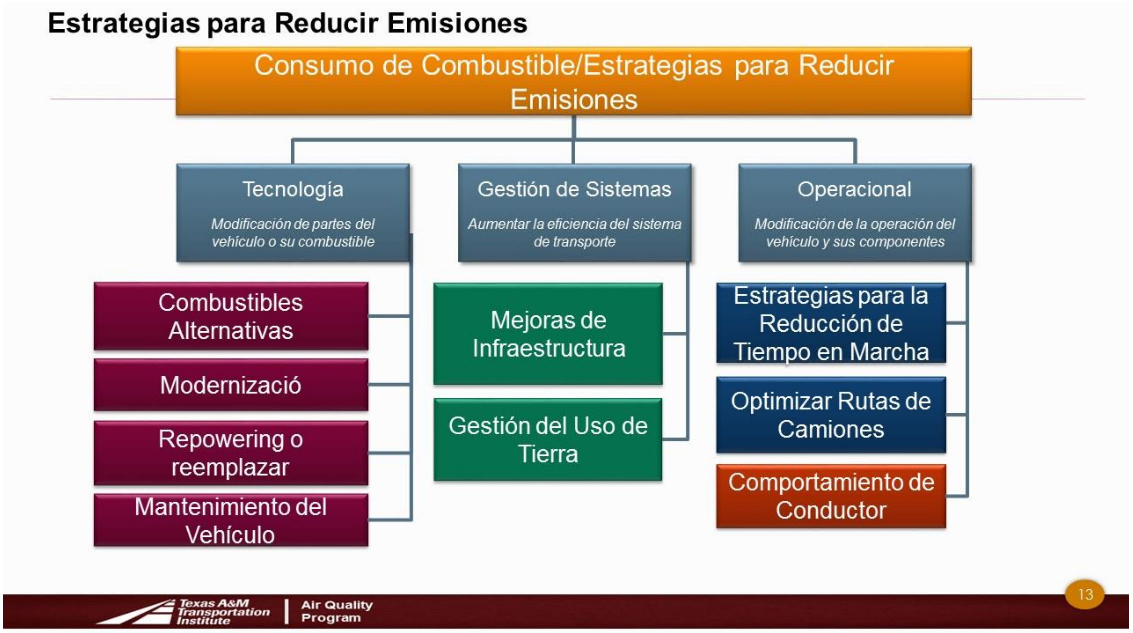
Estrategias para Reducir Emisiones
Consumo de Combustible/Estrategias para Reducir Emisiones
Tecnología
Modificación de partes del vehículo o su combustible
Gestión de Sistemas
Aumentar la eficiencia del sistema de transporte
Operacional
Modificación de la operación del vehículo y sus componentes
Combustibles Alternativas
Modernizació
Repowering o reemplazar
Mantenimiento del Vehículo
Mejoras de Infraestructura
Gestión del Uso de Tierra
Estrategias para la Reducción de Tiempo en Marcha
Optimizar Rutas de Camiones
Comportamiento de Conductor
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Comportamiento del Conductor y Estrategias para Capacitación
Reducción de Tiempo en Marcha
Acelerando, Frenando y Impulso
Velocidad
Cambios y Engranes
Mantenimiento
Seleción de Ruta
Reducción de entre 44 a 48% en consumo de combustible
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Comportamiento del Conductor y Estrategias para Capacitación

Como maneja es importante

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TCEQ

ESTRATEGIAS DE COMPORTAMIENTO DEL CONDUCTOR

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Estrategias de Comportamiento del Conductor
Reducción de Tiempo en Marcha
Velocidad
Cambios y Engranes
Mantenimiento
Acelerar, Frenar y Impulso
Planear con Anticipación
Otras Técnicas
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ESTRATEGIAS PARA REDUCIR EL TIEMPO EN MARCHA
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Estrategias para Reducer Tiempo en Marcha

Conductores deberían pensar en apagar el motor si paran por más de un minuto

Estrategias para Reducer Tiempo en Marcha

Limitar tiempo para calentar y enfriar

Estrategias para Reducir Tiempo en Marcha

Use unidades de energía auxiliaries (APUs) cuando posible

Estrategias para Reducir Tiempo en Marcha

**Para calefacción y aire acondicionado dentro de la cabina,
Elija el régimen de ralentí más bajo posible (no más de 800 rpm)**

Table 9: Consumo de combustible en ralenti/toma de fuerza

Régimen de motor (RPM)	Consumo de Combustible Promedio (Gal/Hr)
650	~0.5
1000	~1.0
1200	~1.5

Estrategias para Reducir Tiempo en Marcha

Apague el motor cuando sea posible

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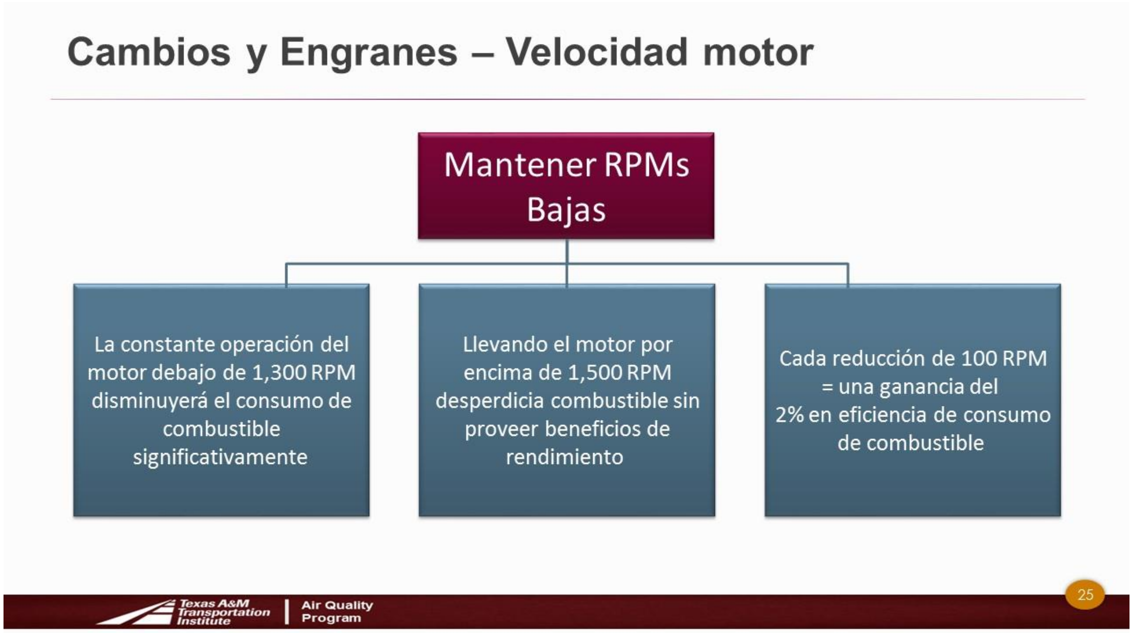
Cambios y Engranes – Velocidad motor
Mantener RPMs Bajas
La constante operación del motor debajo de 1,300 RPM disminuyerá el consumo de combustible significativamente
Llevando el motor por encima de 1,500 RPM desperdicia combustible sin proveer beneficios de rendimiento
Cada reducción de 100 RPM = una ganancia del 2% en eficiencia de consumo de combustible
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Cambios y Engranes
Limite Cambios Innecesarios
Haga Cambios de forma Progresiva y Eficiente
Mantenga RPM Bajas
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ACELERAR, FRENAR E IMPULSO
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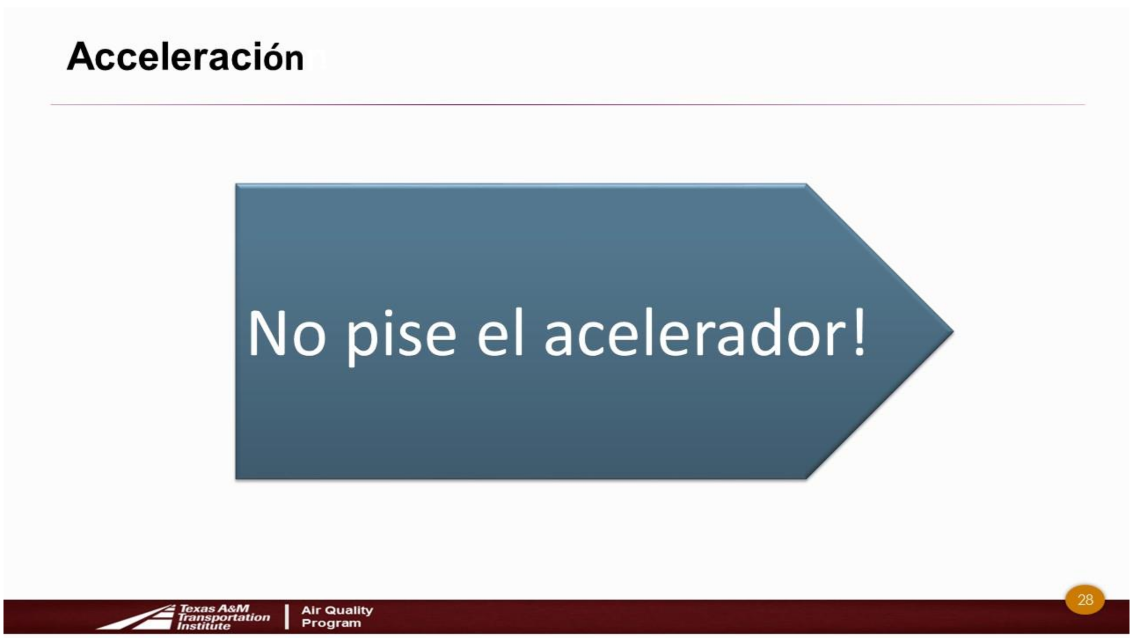
Acceleración
No pise el acelerador!
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Frenado
Evite Frenar Innecesariamente
Mantenga Distancia!
Pare por Inercia en vez de Pisar los Frenos
Minimiza Altos Completos
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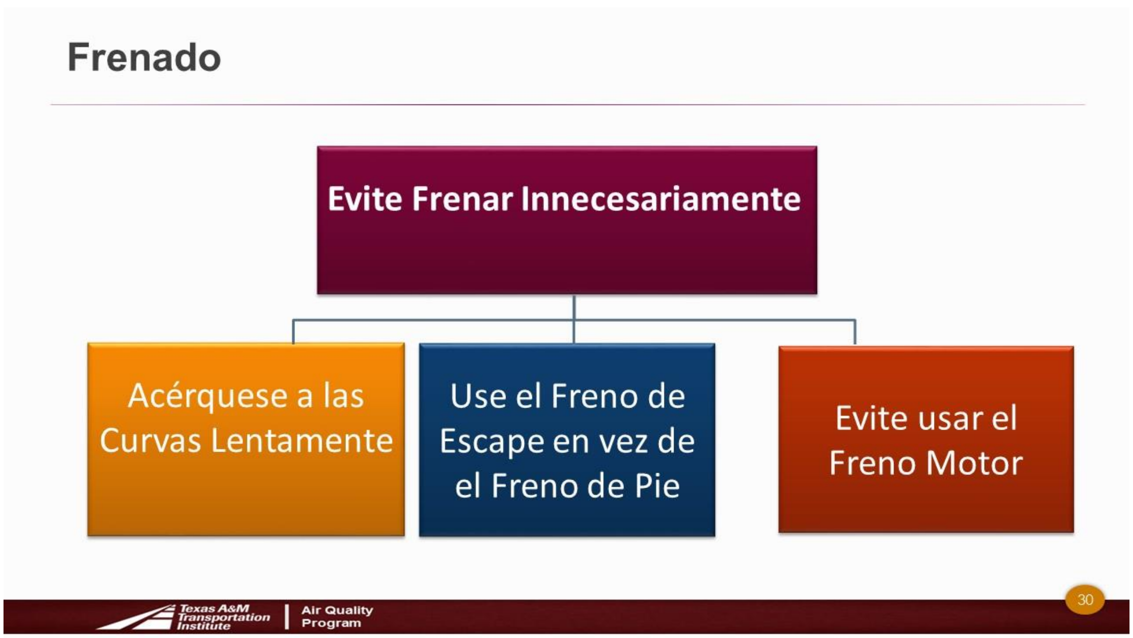
Frenado
Evite Frenar Innecesariamente
Acérquese a las Curvas Lentamente
Use el Freno de Escape en vez de el Freno de Pie
Evite usar el Freno Motor
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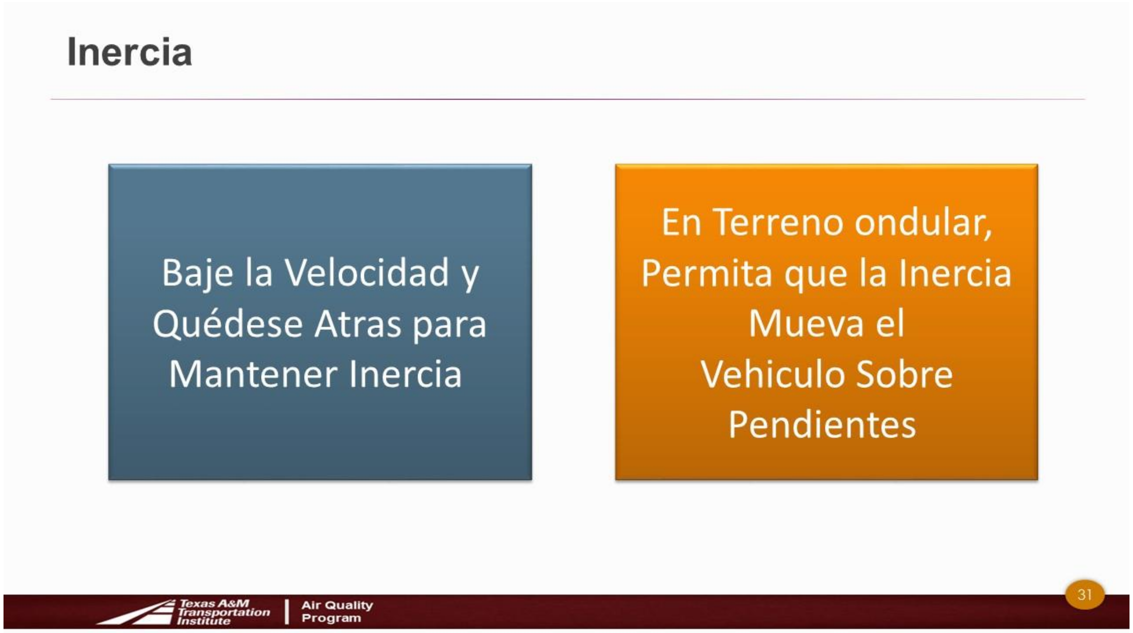
Inercia
Baje la Velocidad y Quédese Atras para Mantener Inercia
En Terreno ondular, Permita que la Inercia Mueva el Vehiculo Sobre Pendientes
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VELOCIDAD
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Velocidad

El efecto de velocidad sobre el consumo de combustible de motores de camiones pesados

Unidades Métricas

Velocidad (Km/h)	Distancia (Km)	Combustible utilizado (Litros/h)	Combustible consumido (Km/Liter)
En marcha (480 rpm)	0	1.9	--
60	22.2	4.1	6.5
80	22.2	6.6	4.0
90	22.2	8.4	3.1

Unidades Inglesas

Velocidad (mph/kph)	Distancia (millas)	Combustible utilizado (gal/h)	Combustible consumido (mpg)
En marcha (480 rpm)	0	0.5	--
37	13.8	1.1	15.2
50	13.8	1.7	9.5
56	13.8	2.2	7.4

Tablas modificadas de "The Fuel Efficient Truck Driver's Handbook."

Velocidad

El efecto de velocidad sobre el consumo de combustible de motores de camiones pesados

Unidades Métricas

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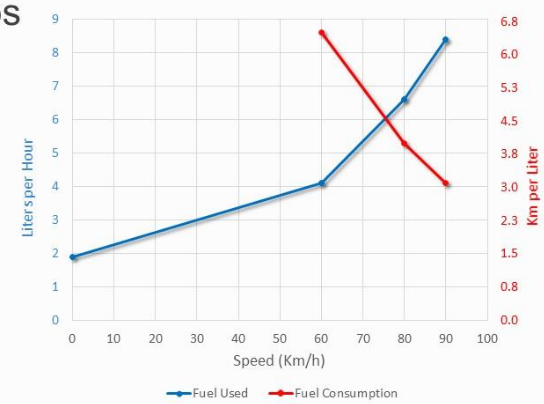
Tablas modificadas de "The Fuel Efficient Truck Driver's Handbook."



Velocidad – Control de Crucero

Use control de crucero cuando corresponda	Maneje su velocidad y impulso según el tránsito y clima

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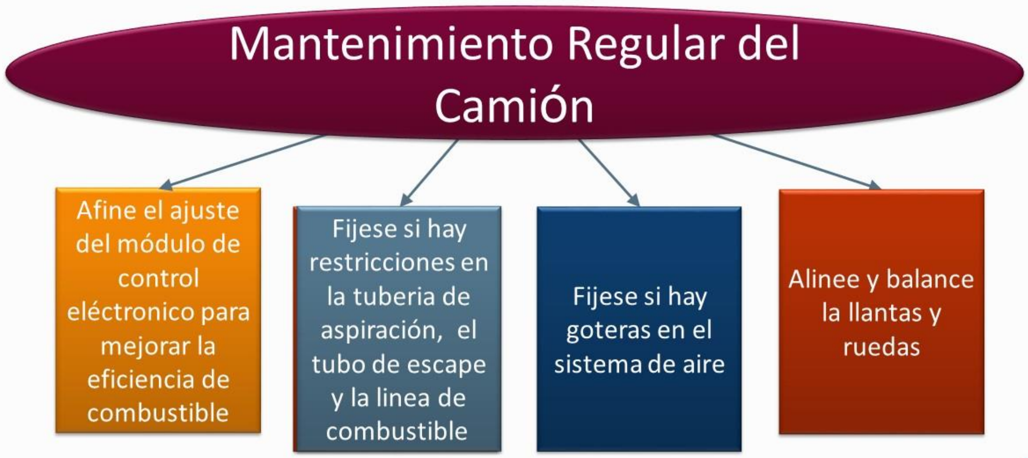
Mantenimiento del Camión



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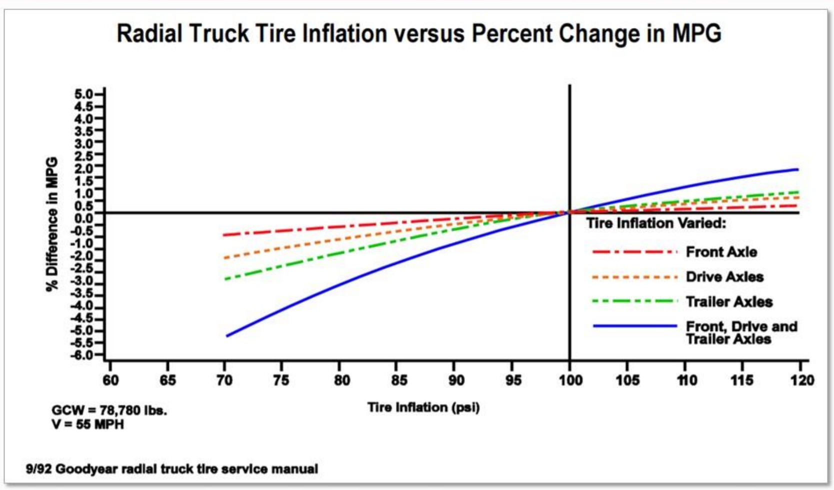
Mantenimiento del Camión – Inflación de Llantas



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Mantenimiento de Llantas

Mantenga las llantas suficientemente infladas

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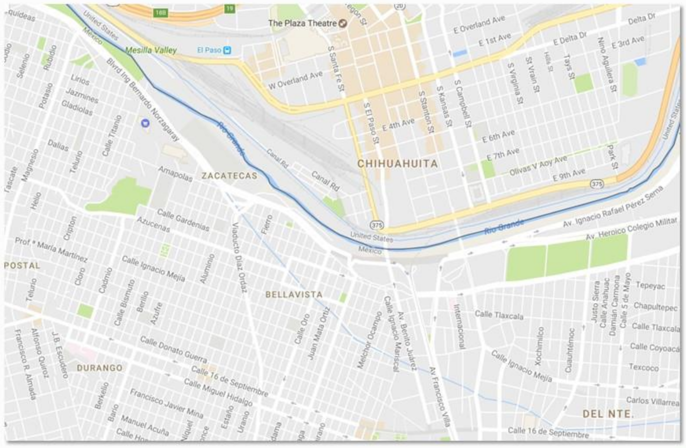
Planear con anticipación

- Elija rutas eficientes.
- Evite zonas congestionadas.
- Limite el tiempo de conducción fuera de la ruta.



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Planear con anticipación

- Use su alta visibilidad

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OTRAS TECNICAS
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Otras Tecnicas
• Minimizar uso del aire acondicionado
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Otras Tecnicas

Combustible= 30% del costo de operación.

- Llene el tanque a la manana o a la noche.
- No sobrellene el tanque de combustible.

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Conclusions

- Reduzca el tiempo en ralentí
- Apague el motor
- Use unidades de potencia auxiliar
- Mantenga las RPMs bajas
- Acelere y frene suavemente
- Anticipe tráfico y use su ímpetu
- Mantenga el camión y asegúrese que las llantas esten infladas
- Planee su ruta

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Preguntas y Comentarios

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REFERENCES

1. Texas Department of Transportation, *"Texas Air Quality Nonattainment or Attainment-Maintenance Areas and County--December 20, 2016",* Available at https://ftp.dot.state.tx.us/pub/txdot-info/env/toolkit/200-02-fig.pdf, Accessed July 2017.

2. Texas Commission on Environmental Quality, *"El Paso: Current Attainment Status",* Available at https://www.tceq.texas.gov/airquality/sip/elp/elp-status, Accessed July 2017.

3. TTI, *"Developing More Precise Emissions Estimates for Clean Air Act Compliance",* Available at https://tti.tamu.edu/2013/03/01/tti-on-the-border/#emissions-estimates, Accessed July 2017.

4. TTI. 2009. "SmartWay Applications for Drayage Trucks." Texas Transportation Institute. The Texas A&M University System, College Station, accessed August 2016.

5. United States Census Bureau, "Trade in Goods with Mexico". Available at http://www.census.gov/foreign-trade/balance/c2010.html, Accessed August 2016.

6. United States Department of Transportation, Bureau of Transportation Statistics, "Border Crossing/Entry Data", Available at http://transborder.bts.gov/programs/international/transborder/TBDR_BC/TBDR_BC_Index.html, Accessed June 2017.

7. The Center for Transportation Research, "Border Corridors and Trade Report," January, 2015.

8. Federal Highway Administration, "Effects of Freight Movement." Available at: http://www.fhwa.dot.gov/environment/air_quality/publications%20/effects_of_freight_movement/chapter04.cfm, accessed August 2016.

9. CEC, "Reducing Air Emission at Land Ports of Entry: Recommendations for Canada, Mexico and the United States." Available at: http://www3.cec.org/islandora/en/item/11656-reducing-air-pollution-land-ports-entry-recommendations-canada-mexico-and-united-en.pdf, accessed August 2016.

10. Federal Highway Administration, "Strategies for Freight Transportation-Related Emission Reduction / Air Quality Improvement Projects." Available at: http://ops.fhwa.dot.gov/publications/fhwahop10024/sect3.htm, accessed August 2016.

11. Texas Commission on Environmental Quality, "Emissions Reduction Incentive Grants (ERIG) Program." Available at https://www.tceq.texas.gov/airquality/terp/erig.html, Accessed August 2017.

12. Texas Commission on Environmental Quality, "Alternative Fueling Facilities Program (AFFP)." Available athttps://www.tceq.texas.gov/airquality/terp/ctt.html, Accessed August 2017.

13. The United States Environmental Protection Agency, "Retrofits and Cleaner Fuels." Available at: https://www3.epa.gov/region1/eco/diesel/retrofits.html#edf, accessed September 2016.

14. U.S. Department of Energy, Alternative Fuels Data Center, "Natural Gas Vehicle Emissions." Available at: http://www.afdc.energy.gov/vehicles/natural_gas_emissions.html, accessed September 2016.

15. U.S. Department of Energy, Alternative Fuels Data Center, "Propane Vehicle Emissions." Available at: http://www.afdc.energy.gov/vehicles/propane_emissions.html, accessed September 2016.

16. U.S. Department of Energy, Alternative Fuels Data Center, "Emissions from Hybrid and Plug-In Electric Vehicles." Available at: http://www.afdc.energy.gov/vehicles/electric_emissions.php, accessed September 2016.

17. Texas Commission on Environmental Quality, "AirCheckTexas Drive a Clean Machine – Vehicle Repair Assistance Program." Available at https://www.tceq.texas.gov/airquality/mobilesource/vim/vehicle_repair.html, Accessed August 2017.

18. Stodolsky, Frank, Linda Gaines and Anant Vyas, "Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks," Center for Transportation Research, Argonne National Laboratory, US DOE, June 2000. Available at: http://www.osti.gov/scitech/servlets/purl/771201, accessed August 2016.

19. US Environmental Protection Agency, Truck stop electrification and anti-idling as a diesel emissions reduction strategy at U.S.-Mexico ports of entry, 2009. Available at: https://www3.epa.gov/region9/climatechange/pdfs/TSE_Otay_report.pdf, accessed August 2016.

20. U.S. Environmental Protection Agency, SmartWay Transport Partnership. "Weight Reduction." Available at: https://www.epa.gov/sites/production/files/2016-06/documents/420f16028.pdf, accessed August 2016.

21. Southern California Association of Governments and KAKU Associates, "SR 60 Truck Lane Feasibility Study: Final Report," November 2000. Available at: http://www.freightworks.org/Documents/SR-60%20Truck%20Lane%20Feasibility%20Study.pdf, accessed August 2016.

22. Federal Highway Association, "FHWA Freight and Land Use Handbook," April 2012. Available at: http://ops.fhwa.dot.gov/publications/fhwahop12006/fhwahop12006.pdf, accessed September 2016.

23. Birt, A., Farzaneh, R., Johnson, J., Gu, C., Overmyer, S., Zietsman, J. Characterizing Drayage Activities and Emissions in the Laredo-Nuevo Laredo Airshed, Texas A&M Transportation Institute, March 2016.

24. Federal Motor Carrier Safety Administration, "United States to Expand Trade Opportunities with Mexico through Safe Cross-Border Trucking". Available at https://www.fmcsa.dot.gov/newsroom/united-states-expand-trade-opportunities-mexico-through-safe-cross-border-trucking, Accessed August 2016.

25. Birt, A., Ramani, T., Farzaneh, M., Zietsman, J. Gu, C., Emissions from Long-Haul Mexican Diesel Trucks in the Laredo-San Antonio Corridor, Texas A&M Transportation Institute, August 2015.

26. Harrison, R., N. Hutson, J. Prozzi, J. Gonzalez, J. McCray, and J. West (2009). The Impacts of Port, Rail, and Border Drayage Activity in Texas. Texas Department of Transportation Report No. FHWA/TX-09/0-5684-1. Center for Transportation Research, the University of Texas at Austin, Austin, TX. Available at: ttp://www.utexas.edu/research/ctr/pdf_reports/0_5684_1.pdf, accessed September 2016.

27. The Safety and Security of Transportation into the United States by Mexico-Domiciled Motor Carriers in Fiscal Year 2012 Annual Report, January 2014. Available at: http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/2012-Annual-Report-Safety-and-Security-Enclosure-FINAL-508.pdf, accessed August 2016.

28. Farzaneh, M., J. Zietsman, T. Fossett, J. Williams, and N. Wood (2013). Developing an Emissions Estimation Tool for El Paso Border Crossings. Texas A&M Transportation Institute, The Texas A&M University System, College Station, TX. Available at: http://pdnaq.org/PDN-ARP/TTI/Emissions_Border%20Crossings_Final%20Report_draft.pdf, accessed August 2016.

29. Zietsman, J., J. Villa, T. Forrest, and J. Storey (2005). Mexican Truck Idling Emissions at the El Paso-Ciudad Juárez Border. Southwest Region University Transportation Center Report No. SWUTC/05/473700-00033-1. Texas Transportation Institute, The Texas A&M University System, College Station, TX. Available at: http://swutc.tamu.edu/2005/11/03/473700-00033-1-report-abstract/, accessed August 2016.

30. Zietsman, J., M. Farzaneh, J. Storey, J. Villa, M. Ojah, D. Lee, and P. Bella (2007). Emissions of Mexican-Domiciled Heavy Duty Diesel Trucks Using Alternative Fuels. Sponsored by the Alamo Area Council of Governments. Texas Transportation Institute, The Texas A&M University System, College Station, TX. Available at: http://tti.tamu.edu/group/airquality/files/2010/11/Emissions-of-Mexican-Domiciled-Heavy-Duty-Diesel-Trucks-Using-Alternative-Fuels.pdf, accessed August 2016.

31. Lutsey, Nicholas P., Christie-Joy Brodrick, Daniel Sperling, Carollyn Oglesby (2004) Heavy-Duty Truck Idling Characteristics: Results from a Nationwide Survey. Transportation Research Record (1880), 29 – 38. Available at: http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id=252, accessed August 2016.

32. Texas A&M Transportation Institute (2013). Diseño de una Estrategia para Reducir Partículas como Parte del Programa Transporte Limpio. Accessed August 2016.

33. Greening North American Transportation Corridors – Challenges and Opportunities (2010). Prepared for the Commission for Environmental Cooperation. Texas Transportation Institute, Texas A&M University System, College Station, TX. Available at: http://www3.cec.org/islandora/en/item/4093-greening-north-american-transportation-corridors-en.pdf, accessed August 2016.

34. Cambridge Systematics, Inc. United States-Mexico Land Ports of Entry Emissions and Border Wait-Time White Paper and Analysis Template (2011). Available at: http://www.fhwa.dot.gov/planning/border_planning/us_mexico/publications/emissions_and_border/emsbrdr.pdf.

35. California/EPA – Air Resources Board (2004). NAFTA/Mexican Truck Emissions Overview. Available at: http://www.arb.ca.gov/enf/hdvip/bip/naftamextrk.pdf, accessed August 2016.

36. COCEF. 2014. "Strategy Design for Particle Reduction as Part of Clean Transportation [Diseño de una estrategia para reducir partículas como parte del Programa Transporte Limpio]." Colegio de la Frontera Norte. Accessed8 September 2014. www.cocef.org/proyectos/proyectos-de-frontera-2012/diseno-de-una-estrategia-para-reducir-particulas-como-parte-del-programa-Transporte-limpio, accessed August 2016.

37. Pier Pass, "Overview of PierPass and the OffPeak Program." Available at: http://www.pierpass.org/wp-content/uploads/2016/06/Overview-of-PierPass-and-OffPeak.pdf, accessed August 2016.

38. U.S. Customs and Border Protection, "Trusted Traveler Programs." Available at: https://www.cbp.gov/travel/trusted-traveler-programs, accessed August 2016.

39. Mark A. Symmons and Geoff Rose, "Ecodrive Training Delivers Substantial Fuel Savings for Heavy Vehicle Drivers," Proceeding of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 2009. Available at: https://www.researchgate.net/publication/229045713_ECODRIVE_TRAINING_DELIVERS_SUBSTANTIAL_FUEL_SAVINGS_FOR_HEAVY_VEHICLE_DRIVERS, accessed September 2016.

40. Ronal Killian, “Ecodriving: The Science and Art of Smarter Driving,” TR News 281, July-August 2012. Available at: http://onlinepubs.trb.org/onlinepubs/trnews/trnews281ecodriving.pdf, accessed September 2013.

41. U.S. Environmental Protection Agency, “Driver Training: A Glance at Clean Freight Strategies,” SmartWay. Available at: https://www.epa.gov/sites/production/files/2016-06/documents/420f16030.pdf, accessed August 2016.

42. Clean Air Institute, “National Initiative for Large-Scale Training on Ecodriving for Clean Transportation [Iniciativa Nacional de Capacitación Masiva en Conducción Ecoefficiente para un Transporte Limpio].” Available at: http://www.cleanairinstitute.org/conduccionecoeficiente/fase1/, accessed August 2016.

43. COEF, “Large-Scale Training Program on Ecodriving for Clean Transportation [Programa de Capacitacion Masiva en Conduccion Eficiente],” September 2013. Available at: http://www.cocef.org/noticias/noticias-de-la-cocef/programa-de-capacitacion-masiva-en-conduccion-eficiente#.V79TVaJ0zbQ, accessed August 2016.

44. Virage Simulation, “Truck Driving Simulation—VS600M.” Available at: https://viragesimulation.com/vs600m-truck-simulator/, accessed August 2016.

45. Environmental Defense Fund, “Green Driving Program Helps Optimize Fuel Economy and Reduce Emissions,” February 2009. Available at: https://www.edf.org/news/green-driving-program-helps-optimize-fuel-economy-and-reduce-emissions, accessed August 2016.

46. U.S. Environmental Protection Agency, “MOVES and Other Mobile Source Emissions Models”, Available at https://www.epa.gov/moves, Accessed July 2017.