Texas A&M Transportation Institute

Collection and Analysis of Vehicle Activity Data to Improve Transportation and Air Quality Planning

Final Report

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Air Quality Program

About this Report

This work was performed by the Texas A&M Transportation Institute (TTI) in cooperation with the Houston-Galveston Area Council (H-GAC), Port Houston (PH), and the Texas Department of Transportation (TxDOT). TTI contributors to this report include Reza Farzaneh, Jeremy Johnson, Tara Ramani, Rohit Jaikumar, Joe Zietsman, and Adam Meyer.

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EXECUTIVE SUMMARY

This project, Collection, and Analysis of Vehicle Activity Data to Improve Transportation and Air Quality Planning, was performed by the Texas A&M Transportation Institute (TTI) for the Houston-Galveston Area Council (H-GAC) and the Port Houston (PH).

The main objective of this study was to support H-GAC, PH, and other stakeholders in the application of vehicle activity data for transportation and air quality planning purposes. The project used Global Positioning System (GPS) data from trucks participating in H-GAC's Drayage Loan Program, along with data collection using Portable Activity Measurement Systems (PAMS).

PAMS data (on a second-by-second basis) were collected from a set of 39 trucks between April 2017 and April 2018. 31 trucks were DLP participants, and were heavy-duty diesel trucks operating in the HGB area, while the remainder were non-DLP trucks from local fleets, operating on compressed natural gas (CNG). The DLP participants in the study were also being tracked by H-GAC via GPS, through third party data providers. This vehicle activity data from GPS were available to H-GAC over an extended duration, and supplemented the PAMS data collected in the study.

Following collection of PAMS data and assembly of existing GPS data, TTI researchers conducted data analyses to provide insight into vehicle activities and emissions. The analysis included assessment of idling events (defined as vehicles having engines turned on without being in motion for a period of five minutes or more), activity (characterizing vehicle miles of travel and speeds), identification of trip origins and destinations (O/D), and geospatial analysis of O/D locations and port terminals visited. The PAMS data were also used to evaluate effectiveness of selective catalytic reduction (SCR) systems based on truck exhaust temperature, and to compare operational differences between CNG and diesel truck. Finally, the GPS and PAMS datasets for the DLP participant trucks were used to analyze differences between lower-resolution GPS data and higher-resolution PAMS data for assessing vehicle idling and activity. The data analyses were all conducted using an integrated data analytics tool (Microsoft Power BI), which allowed for data analysis, dashboarding, and mapping on a single platform.

The data analyses provided several insights into the vehicle activity, idling and emissions characteristics. Overall, the vehicles were found to operate at low speeds (average of 18 mph, with 63% of time spent at speeds below 10 mph). The vehicles also were found to idle for about 54% of the time, i.e. an average of 185 minutes of idling per vehicle per day. Over 90% of the DLP activities occurred between 6 AM and 7 PM, and on weekdays. Nearly half of all idling events were found to occur either at the vehicles' base of operations or inside port terminals.

For the DLP participant trucks, the comparison of GPS and PAMS data indicated that the GPS data corresponded well with PAMS data when used to analyze distances traveled over longer periods of time (such as on a monthly basis). The GPS data for shorter durations, however, did not correspond well to the PAMS data, and was also found to underrepresent idling time.

For the trucks that reported exhaust temperature, it was found that they operated nearly 60% of the time at temperatures below the optimal for SCR functionality. This indicates that NOx emissions reduction benefits from SCR may not be fully achieved by these trucks. Finally, the comparison of CNG and diesel vehicle operations indicate that the CNG vehicles operate at slightly lower speeds and travel slightly lower average distances than diesel trucks.

This study developed a methodology and analytics platform that was used to assess the activities and operations of drayage trucks in the HGB region, using PAMS and GPS data. There are several avenues to build on this research, including additional data collection from a larger sample of vehicles, further assessment of emissions impacts due to CNG vehicles and SCR functionality, and enhanced data collection and analysis pertaining to port-specific activities.

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CHAPTER 1: INTRODUCTION

BACKGROUND

The Houston-Galveston Area Council (H-GAC) currently operates a drayage loan program (DLP) which aims to reduce emissions, specifically of oxides of nitrogen (NOx), in the Houston-Galveston-Brazoria (HGB) nonattainment area. The target fleet for this program is drayage trucks, i.e. short-haul heavy-duty trucks that primarily operate in the Port of Houston area, moving goods short distances between the port and local destinations such as intermodal facilities.

Qualifying applicants to this program can receive low-interest loans that assist in the purchase of newer vehicles, to replace older trucks with higher levels of emissions. Compliance with the program is monitored on the basis of time spent in the HGB nonattainment area, to ensure that the emissions reductions from the cleaner truck operations benefit the region. As of the date of this report, there were 210 vehicles that are active in the DLP, with 22 others having completed their time required in the data monitoring phase of the program. To monitor the vehicles in the program, H-GAC relies on global positioning system (GPS) data loggers, which record vehicle locations over time, with the data used to report activity summaries to H-GAC. The GPS loggers installed on DLP participants are currently recording the data at 1- or- 2-minute intervals.

This dataset is unique in that it contains a complete record of multiple years of location and speed information of a relatively large number of trucks operating in the H-GAC area. In addition to compliance monitoring, this data also has the potential for use in other air quality planning and transportation planning applications, by providing insight into vehicle locations, origins, destinations and routes over time. Further, there is an opportunity to supplement this dataset with higher-resolution activity data collected through technologies such as Portable Activity Monitoring Systems (PAMS), to enable additional data analysis and investigation.

PROJECT GOAL AND APPROACH

The overall goal of this project is to support H-GAC, Port Houston (PH) and other stakeholders in the application of vehicle activity data (specifically drayage vehicle activity data) for transportation and air quality planning purposes. In addition to the existing H-GAC GPS dataset, the project also collected additional detailed vehicle activity data from a subset of vehicles in the DLP, as well as other heavy-duty vehicles that operate in the greater Houston area. This additional data were collected using PAMS units, which connect to the controller area network (CAN) bus of the vehicles and record both GPS and engine parameters at 1 Hz frequency, i.e., on a second-by-second basis.

In this study, the Texas A&M Transportation Institute (TTI) research team worked with H-GAC, PH, and TxDOT to identify the data applications of greatest interest to stakeholders. TTI then developed and applied analytical methodologies using the PAMS and GPS data, supplemented with information from other state and local datasets. TTI also used a Cooperative Research and Development Agreement (CRADA) with the Environmental Protection Agency's (EPA) National Vehicle and Fuels Emissions Laboratory (NVFEL), to leverage EPA's assistance and resources for data collection and analysis.

PROJECT TASKS

The project had five major tasks, as described below:

- Task 1: Project Initiation – This task included completion of contractual processes and kick-off activities. This included finalizing the priorities of the project in discussion with stakeholders and talking to fleets that were interested in participating in the project.
- Task 2: State of the Practice and Scoping – This task covered a review of existing data sources of relevance to the study, current practices of collecting vehicle activity data, especially in heavy-duty vehicles, and the applications of this data for transportation and air quality planning purposes. This information was used to scope the data analysis and inform subsequent tasks.
- Task 3: H-GAC GPS Data Acquisition and Processing – This task included the collection, acquisition, and processing of the current GPS data that was used by H-GAC for the tracking of the vehicles in the fleets.
- Task 4: PAMS Data Collection and Processing - This task involved the collection of the PAMS data on a subset of the vehicles in the DLP fleet, as well as other vehicles identified as being of interest to stakeholders.

- Task 5 – Data Analysis and Final Documentation – The final task was the data analysis, conducted in discussion with stakeholders, concurrently with Tasks 3 and 4, and report writing.

REPORT OVERVIEW

Following this introductory chapter, Chapter 2 provides a brief state of practice review, followed by the details on the data collected or acquired as part of the project (Chapter 3). Chapter 4 then provides a discussion of the data analysis and results, followed by conclusions and recommendations from the project (Chapter 5).

CHAPTER 2: STATE OF PRACTICE AND SCOPING

Before initiating data collection and analysis activities, the TTI team conducted a review the existing data sources relevant to this study, common data collection methods for obtaining vehicle activity data, and applications of this data for transportation and air quality planning purposes, to identify applications of greatest interest to stakeholders and to scope out the study. This chapter summarizes these findings.

EXISTING DATA SOURCES

There are several data sources related to heavy-duty vehicle activity data in the Houston region, as well as data that can be used in conjunction with information on vehicle activity to support transportation and air quality planning, and to characterize the emissions impact of drayage activities. Selected data sources of relevance to this study are described briefly below:

- <u>DLP Participants' GPS Data:</u> This data, introduced in the background section and detailed in Chapter 3, is used by H-GAC to monitor the activity of the vehicles in the DLP, and is the initial focus of this study. The GPS data set includes the vehicle location, speed and odometer readings at 1 or 2-minute intervals.
- <u>Travel Demand Model (TDM):</u> The TDM for the greater Houston area serves as the basis for regional transportation and air quality planning. The data and base files of the TDM, including traffic analysis zones (TAZs) boundaries for the area, were used to define the geographical regions in the data analysis.
- <u>Geographic Information System (GIS) Data for HGB Region:</u> GIS shapefiles were used which outlined the boundaries of the port terminals and H-GAC counties. These data were used in the geographical analysis of the raw and idling data activities from the vehicles included in the study.
- <u>Texas Department of Transportation (TxDOT) Road-Highway Inventory Network (RHINo):</u> This dataset, published annually by TxDOT, includes the complete road network map of the state of Texas, including attributes for each link such as functional class and annual average daily traffic (AADT) counts.
- <u>Freight Analysis Framework (FAF) Data:</u> The FAF is a dataset created through a partnership between the Bureau of Transportation Statistics (BTS) and the Federal Highway Administration (FHWA). The FAF merges data from numerous data

sources to provide freight movement data, by different modes of transportation, among states and major metropolitan areas (*1*).

- American Transportation Research Institute (ATRI) and INRIX Vehicle Probe Datasets: The main feature of these datasets is their large size and fine resolution, which includes location, time, and speed information for each vehicle in the sample. It must be noted that ATRI and INRIX data do not have any information on whether the engine is on or off, unlike PAMS data collected in this study.

VEHICLE ACTIVITY DATA COLLECTION METHODS

With technological advancements, emerging data sources from passive collection methods have shown promise in helping transportation professionals better understand vehicle activities. These data can provide more fine-grained information at high spatial and temporal resolutions, from large samples of vehicles at a lower cost. Sources of this data include PAMS data, GPS data, mobile network data, and cell phone GPS data. Of these, PAMS and GPS data have the greatest applicability to heavy-duty vehicles, while data from mobile networks and cell phones are commonly used as a means to identify personal travel patterns and origins and destinations to supplement traditional household travel surveys.

GPS devices can provide location and speed information of a vehicle through the utilization of satellites. Typically, GPS devices can record data up to 1 Hz, although there are devices that can record data more frequently, such as 10 times a second. A typical raw GPS data set includes the time, latitude, longitude, altitude, and the velocity of each record. Additional data, such as heading and a quantification of precision, are also reported by some GPS devices.

Since the start of the 80s, with the development of onboard diagnostic systems (OBD-II), different vehicular interfaces (VIs) were introduced to monitor different operating parameters, by reading and translating OBD-II requests and messages into a standard format. PAMS data loggers actively monitor the vehicles through the OBD-II, or other communication protocols, as the vehicles are in operation. Information that the PAMS loggers acquire includes engine and vehicle temperatures (engine, cooling system, exhaust), engine information (speed, load, throttle position, etc.), vehicle information (speed, distance traveled, etc.) and other parameters. Many PAMS loggers also combine GPS data along with the information being provided by the vehicle’s engine.

APPLICATIONS OF VEHICLE ACTIVITY DATA FOR TRANSPORTATION PLANNING AND AIR QUALITY ANALYSIS

There are several applications of vehicle activity data collected from GPS, PAMS, and other sources such as cellular phone records for transportation planning applications and air quality analyses in the literature. In the context of heavy-duty vehicle activity, applications seen in the literature can be broadly classified as:

- Origin-destination (OD) identification for travel demand modeling – this refers to the use of data collected from vehicle trips to identify origins and destinations for trucks. This information can be used for travel demand modeling purposes, including for developing OD matrices.
- Spatial and temporal characterization of truck trips - Utilizing location data from GPS records, truck activity can be used for spatial characterization of trips (identification of routes and corridors) or temporal characterization of trips (time of day, weekdays versus weekends, etc.).
- Idling characterization – Using GPS and PAMS/engine data to characterize idling behaviors of trucks, in terms of locations, duration, and other factors.
- Emissions estimation – Using activity data combined with emissions rates/emissions models to quantify emissions.

Table 1 provides examples from the literature of studies using vehicle activity data for these different applications. While these analyses can be conducted with GPS data, additional data from PAMS (such as engine operational characteristics) can be used for additional and supplementary analysis. For example, details of engine temperature and engine diagnostic codes can be used to assess the functioning of the engine and emissions reduction technologies such as Selective Catalytic Reduction (SCR) and Diesel Particulate Filters (DPF).

Table 1: Vehicle Activity Data Applications.

Application	Study Example References
OD Identification/Travel Demand Modeling	Huntsinger and Ward (2); Thakur et al, (3); Zanhani, et al. (4); Wang and Schrock (5); Fang, Xue, and Qui (6); Iqbal et al. (7); Colak, et al. (8); Rokib et al. (9); Li (10)
Spatial and Temporal Characterization of Truck Trips	Farzaneh et al. (11); Birt, et al. (12); Texas A&M Transportation Institute (13); Jackson et al. (14); Greaves and Figliozzi (15); Li, Guensler, and Ogle (16)
Idling Characterization	Huai et al. (17); Kahn et al. (18); Frey, Kuo, and Villa (19)
Emissions Estimations	Joumard, Jost, and Hickman (20); Rakha, Ahn, and Trani (21); U.S EPA (22); Pelkmans et al. (23); Jackson et al. (14); Sun and Ban (24); Sun et al (25); Jaikumar et al. (26)

POTENTIAL APPLICATIONS OF DLP ACTIVITY DATASET

Prior to initiating this study, the analyses of interest to stakeholders based on the DLP activity dataset included: identification of origins and destinations for the drayage trucks, identification of routes, driving characteristics such as speeds and vehicle miles traveled (VMT), spatial and temporal distribution of trips, idling characteristics and SCR/DPF functionality, and emissions associated with drayage activities. Based on discussion with stakeholders and the available resources, the analysis in this study was narrowed to the following key elements:

- Trip analysis, including identification of origins and destinations,
- Idling analysis,
- Geospatial analysis, including activities within ports terminals, counties, and for TAZs,
- VMT including by day of the week, time of day, roadway types, and other categories, and
- Emissions analysis of drayage activities.

SUMMARY

This chapter provided an overview of data sources, data collection methods, and example applications of vehicle activity data for transportation planning and air quality analysis purposes. H-GAC's DLP dataset, combined with other data sources such as PAMS data, can be used for a range of applications. After reviewing the literature and discussing with key stakeholders, the study scope was narrowed to focus on a few key elements. The next chapter provides further details on the study design and the key elements.

CHAPTER 3: STUDY DESIGN AND DATA COLLECTION

As previously discussed, one of the study goals were to leverage the existing GPS data being collected for transportation and air quality planning purposes; since this data is of relatively lower resolution (i.e., 1 or 2-minute interval), these data were used as a supplement to the higher-resolution PAMS data collected from a sample of drayage trucks. These datasets were then used to answer study questions and to compare the GPS and PAMS datasets in terms of the quality of the GPS data being collected at the lower resolutions.

STUDY DESIGN

The study design is shown in Figure 1. The data sources include the existing (GPS) and new (PAMS) data collected for this study. As the data was collected, it was processed and subjected to a thorough quality assurance/quality control (QAQC) process and was then analyzed based on the project approach as described in chapter 1.

The data processing and QAQC for this project focused mainly on the PAMS data. The GPS data, being reported by the different service providers, was analyzed as reported. The PAMS data processing began with a download of the data from a server. The PAMS devices used in this project transmit the data back to a central server each time the truck turns off (thereby creating a new file). After the data was sent to the server, the research team downloaded the data on a daily basis. The first step in handling the data was to use the data logger software to create a .csv file for each trip. These trip files contained the raw data as reported by the PAMS device. After processing the data, the QAQC process was run on the files in the batch mode. The data was checked for invalid records (i.e., speeds over 100 MPH) and missing data. Any data that was invalid or missing was marked as such. Additional entries in the data, such as the speed in MPH (miles per hour) was converted to meters/second, geographical data of each data point (port terminal or county), and other parameters as needed, was also added at this time. The data was then imported into single files, so the analysis could be completed. Summary files, which included information on each trip the vehicles made, were also created during the QAQC process.

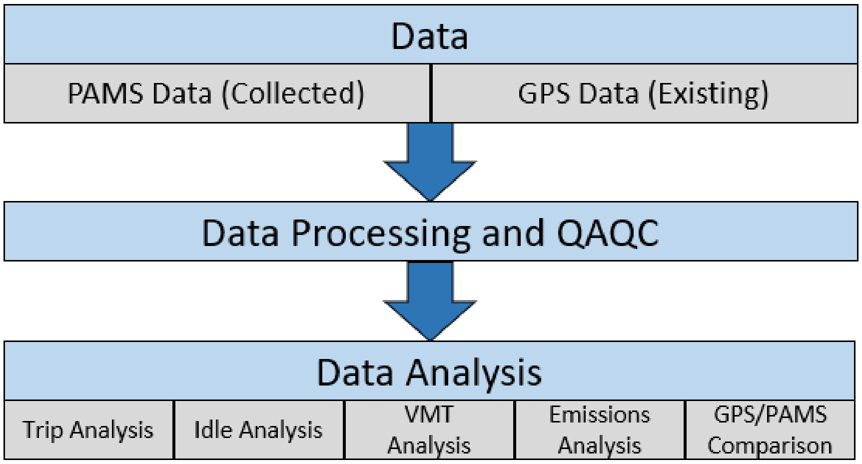


Figure 1. Study Data Flow Chart.

DATA SOURCES

The following provides a summary of the data sources used in this study.

GPS DATA

Currently, all the vehicles in the DLP are monitored for compliance by using GPS data loggers installed on the vehicles. The GPS data loggers are maintained and operated by different service providers, depending on the fleet, which led to some differences in the data reported by the different service providers.

All raw GPS data used in this report is collected on a 1-minute or 2-minute interval. For all service providers used in this project, each raw data point contained the date and time stamp, current odometer reading, GPS coordinate location, and the vehicle ID. Other data reported by some providers included the instantaneous speed, average and max speeds, and the direction of travel.

Although all providers collected the data on a 1-minute or 2-minute interval, some providers did not allow the raw data to be downloaded or accessed for analysis purposes. For those fleets that do not allow the raw data to be accessed, the research team relied on reports, available for download that further characterized the driving characteristics of the vehicles. For this project two reports were utilized for the analysis, an idle report and a summary report, which each of the service providers made available. Like the raw data, the reports varied slightly from each service provider. Each of the idle reports included the time of each idle event, the duration of the event, and the location (either a GPS coordinate location or a landmark location, such as corporate headquarters for the fleet). The minimum time reported for each service provider varied, from 1-minute to 5-minutes. The summary reports included the distance traveled per trip, which was used by the research team to compare the daily distance reported by both the GPS and PAMS data.

PAMS DATA

Unlike the GPS data, which varied based on the provider, the PAMS data collected was all done using the same data loggers, and therefore all the data collected was similar. The PAMS data was collected using the OBD data logger from HEM data, which is shown below in Figure 2. The data logger connects to the vehicle's CAN bus and collects the engine data, along with the GPS data via an integrated GPS chip, on a second-by-second basis. The amount, and specifics, of data that is being reported by the CAN bus varied by the vehicle manufacturer and resulted in thousands of parameters. For this project, the data loggers were configured to only record a set number of available parameters, which were chosen based on previous data collection efforts conducted by the research team, as well the EPA and others. There were 203 potential parameters that were recorded as part of the project, including information such as engine speed, engine load, engine temperatures, vehicle distance, vehicle speed, and others.

Figure 2. HEM Data OBD Data Logger.

In addition to logging the data, the HEM data loggers also have the capabilities to transmit the data, via cellular services, back to a central server where the data could be retrieved without the need to continuously visit the vehicles and pull data off the data loggers. Figure 3 shows one of the HEM data loggers installed on a vehicle during the data collection.

Figure 3. HEM Data Logger Installed on Vehicle.

DATA COLLECTION AND ASSEMBLY

PAMS DATA COLLECTION

A total of 39 vehicles were part of the PAMS data collection efforts for this project. The vehicles were selected by contacting fleets within the DLP who volunteered to be part of the data collection effort. The data collection lasted for just over 1 year, from April 12, 2017, through April 26, 2018. During the collection, over 81 million data points were collected, which covered over 22,500 hours of operation and approximately 413,000 miles of travel. Table 2 outlines the summary of the data collection for each of the vehicles in the effort. Most of the vehicles (31) that were part of the PAMS data collection were part of the DLP fleet: however, 8 vehicles that were monitored were from a non-DLP fleet that operates both compressed natural gas (CNG) and diesel vehicles. Half of these were CNG fueled and half were diesel-fueled vehicles. The selection of the non-DLP vehicles was done in order to allow the researchers to analyze the difference between the operation of CNG and diesel fuels. No fleets in the DLP operated both types of vehicles; therefore the non-DLP fleet was contacted and agreed to participate in the data collection. The data from these 8 vehicles are excluded from the analysis except for the comparison of the CNG versus diesel operations.

Table 2. Summary of PAMS Data Collection.

Vehicle ID	Days Active	Total Miles	Total Operating Time (Hours)	Average Speed (mph)
001	41	11,352.5	354.6	32.02
002	50	7,497.6	330.8	22.67
022*	111	17,099.8	621.7	27.51
036	54	3,687.6	348.8	10.57
042*	107	8,024.6	750.1	10.70
072	13	2,065.8	86.4	23.91
074	29	5,174.8	220.1	23.30
078	15	3,700.1	107.1	34.55
080	7	127.3	10.1	12.55
118	102	12,476.6	835.4	14.94
119	139	13,886.85	1,060.4	13.10
120	168	19,149.4	1,403.0	13.65
121	129	18,829.6	959.7	19.62
122	154	18,035.2	1,258.3	14.33
132*	65	9,319.3	447.4	20.83
420	85	13,531.3	681.2	19.87
438	119	24,446.7	980.7	24.93
439	107	25,787.5	921.9	27.97
445	24	1,889.8	80.5	23.47
447	82	15,550.4	659.6	23.58
652*	88	12,066.5	518.2	23.29
816	54	6,408.4	436.3	14.69
822	79	9,155.1	613.7	14.92
824	71	12,882.8	623.2	20.67
826	73	7,234.5	527.6	13.71
832	79	10,010.3	618.7	16.18
834	80	9,017.9	622.8	14.48
837	70	6,418.5	443.2	14.48
838	67	5,510.7	402.4	13.69
839	80	9,725.7	498.4	19.51
840	60	9,872.5	506.5	19.49
841	30	3,378.1	196.8	17.17
861	76	8,094.7	510.1	15.87
863	74	9,636.5	591.0	16.30
867	81	11,591.0	622.1	18.63
892*	99	9,157.9	980.7	9.34
942*	84	19,362.8	579.8	33.4
952*	109	8,799.6	563.7	15.61
992*	104	12,990.9	591.2	21.98

* Vehicles part of the CNG/Diesel fleet that are not included in the main data analysis.

GPS DATA ASSEMBLY

As mentioned previously, the GPS data used in this study was from existing data being collected on all DLP participant trucks, by H-GAC through third party service providers, who provide this data in different formats. The data for the relevant trucks (trucks for which PAMS data were collected) were assembled, quality checked, and compiled for analysis.

SUMMARY

This chapter describes the overall study design and the collection of PAMS data and assembly of GPS data required for the data analysis. PAMS data were collected from a total of 39 vehicles, over a year starting in April 2018, and GPS data being collected by H-GAC's third-party service providers were assembled for the same set of trucks. The data were compiled, processed, quality-checked and prepared for data analysis. The data analysis and results are discussed in the next chapter.

CHAPTER 4: DATA ANALYSIS

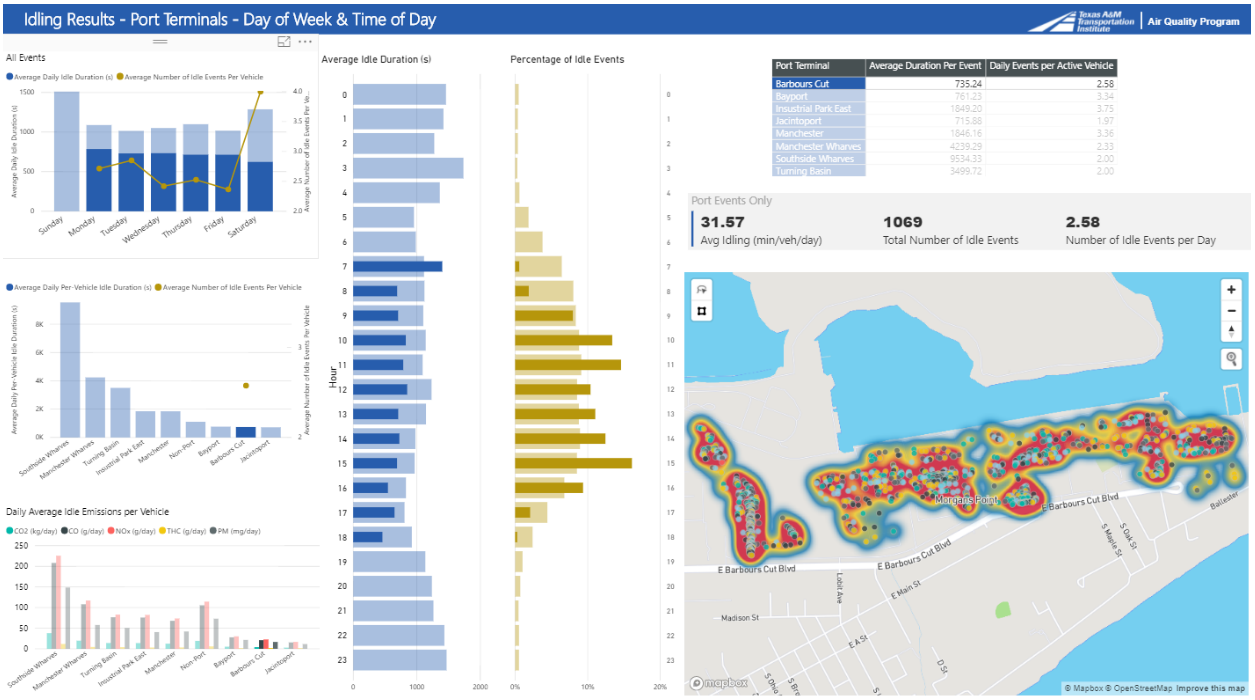
After completing the data collection, the TTI research team began the analysis of the data. This chapter gives an overview of the data analysis and results obtained.

DATA ANALYSIS

The data analysis performed focused on the following major areas:

- **Idle Analysis:** The idling analysis focused on idling events of the vehicles, defined as any event that the vehicles were running, but did not move, for a minimum of 5 minutes.
- **Vehicle Activity Analysis:** The VMT analysis looked at the daily VMT for each vehicle, including the VMT by day of the week and hour of the day
- **Emissions Analysis:** The emissions analysis focused on the daily emissions resulting from operations of the monitored vehicles that are part of the DLP, including the emissions from port-related activities.
- **Trip Analysis:** The trip and OD analysis focused on the trip and OD characteristics for geographical areas, including counties, TAZs, and port terminals.
- **Geospatial Analysis:** The research team performed a geospatial analysis on the trips, their associated OD locations, and idle events by port terminals, Counties and TAZs in the H-GAC area. This analysis helped the team to visually interpret the distribution and concentration of the trips and idle events within the study area.
- **Effectiveness of SCR Technology**: The research team performed sensitivity analysis to evaluate the effectiveness of the SCR system based on the temperature of the exhaust.
- **Comparison of CNG vs. Diesel Operations**: This analysis focused on the operational differences, within a fleet, of vehicles fueled by CNG vs diesel fuel.
- **Comparison of GPS and PAMS data:** The final analysis looks at the difference between the second-by-second PAMS data that is collected and the 1 to 2 minute interval data that the GPS units are reporting. The comparison focused on the difference in the reported total distance traveled, as well as the difference in estimated idling between the two methods.

The research team used an integrated data analytics tool (Microsoft Power BI) to prepare and process the activity data, estimate emissions, analyze and visualize the resulted estimates. In addition to its data processing and analysis functions, the interactive visual dashboarding and mapping capabilities of Power BI enabled the research team to perform quality control, examine multiple scenarios, and isolate and evaluate the impacts of specific combinations of parameters. The research team developed multiple data evaluation and visualization dashboards for this purpose. Figure 4 shows one of the dashboards that were developed by the research team. As shown in the figure, the research team could evaluate the idling activity and emissions changes by the port facility, day-of-week, and time-of-day. Users can select and filter any of the parameters present on the dashboard by clicking and selecting the value on a chart. A file containing the all the data analytics dashboards developed during this study is being submitted along with the report. All the analysis that are listed above have accompanying dashboards that contain the data discussed in the report.



Port Terminal	Average Duration Per Event	Daily Events per Active Vehicle
Barbours Cut	735.24	2.58
Bayport	761.23	3.34
Insustrial Park East	1849.20	3.75
Jacintoport	715.88	1.97
Manchester	1846.16	3.36
Manchester Wharves	4239.29	2.33
Southside Wharves	9534.33	2.00
Turning Basin	3499.72	2.00

Port Events Only

31.57 Avg Idling (min/veh/day)

1069 Total Number of Idle Events

2.58 Number of Idle Events per Day

Figure 4. Screenshot of Interactive Dashboard.

The remainder of this chapter focuses on the results from the data analysis in the areas listed above. Since this project is focused on vehicle activity in the H-GAC area, only activities that occurred in one of the 8 H-GAC counties (Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, or Waller) were considered during the analysis. The counties that make up the HGB non-attainment area are shown in Figure 5

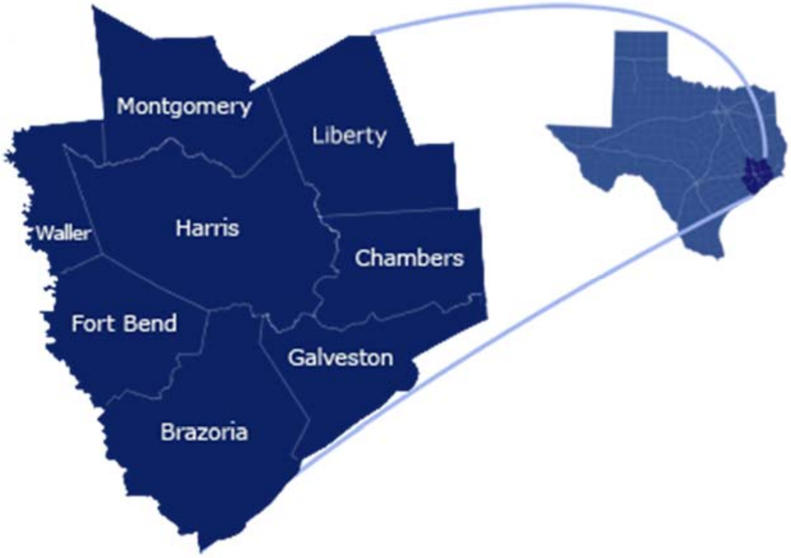


Figure 5. HGB Non-Attainment Area[1].

IDLE ANALYSIS

The first step in analyzing the idling characteristics of the vehicles in the PAMS data collection efforts was to define an idle event. For the purposes of this analysis, an idle event is defined as any time the vehicle was on (i.e., engine was running), but not moving (i.e., zero mph speed) for a minimum of 5 consecutive minutes. The PAMS data collection recorded 18,721 total idling events, over 5,555 hours of idling.

DAY-OF-WEEK

Table 3 gives the comparison of the idling events by day-of-week. On average, each vehicle had 10.25 idle events per day with an average duration of 17.81 minutes, for a total of 182.45 minutes of idle time per day.

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[1] Image from Texas Commission on Environmental Quality, https://www.tceq.texas.gov/airquality/sip/hgb.

Table 3: Idling Events by Day of Week.

Day of Week	Average Idle Event Duration (minutes)	Daily Events per Vehicle
Sunday	25.20	5.43
Monday	18.15	10.63
Tuesday	19.21	11.09
Wednesday	17.53	10.52
Thursday	18.33	10.59
Friday	16.97	10.51
Saturday	21.46	5.18
Average	17.81	10.25

Weekends have a longer average idle duration with fewer idle events per vehicle compared with the weekdays resulting, in shorter overall idle time. This trend is graphically presented in Figure 6.

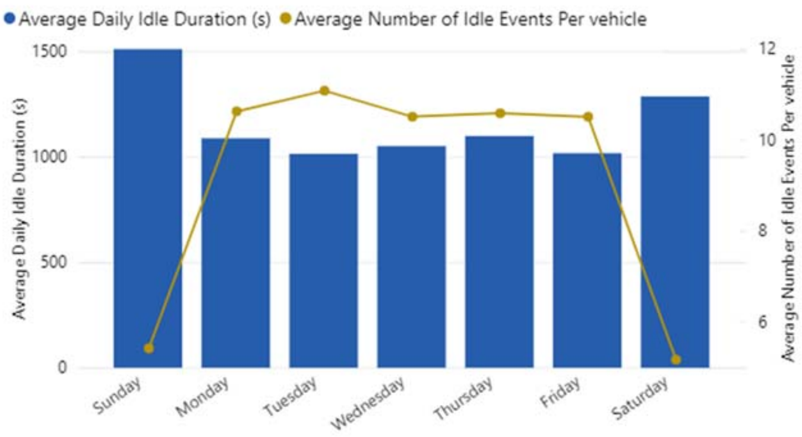


Figure 6. Distribution of Idling Activity by Day-of-Week.

TIME-OF-DAY

Figure 7 shows the distribution of the average duration of idle events and percentage of idle events by time-of-day for an average day. Events are categorized by the hour when the idle event starts. Most of the idle events occurred between the hours of 6 AM and 6 PM, with peak activity occurring from 11AM-12PM. Unlike the distribution of events where most events occur during the 6 AM – 6 PM hours, the average duration of events was found to be reversed, with events that occur during the other hours of the day (7 PM – 5 AM) generally lasting longer. The average idle event during the 7 PM – 5 AM hours is 1,240 seconds, where the average duration during the 6 AM – 6 PM hours is 1,055 seconds, a difference of just over 3 minutes per event.

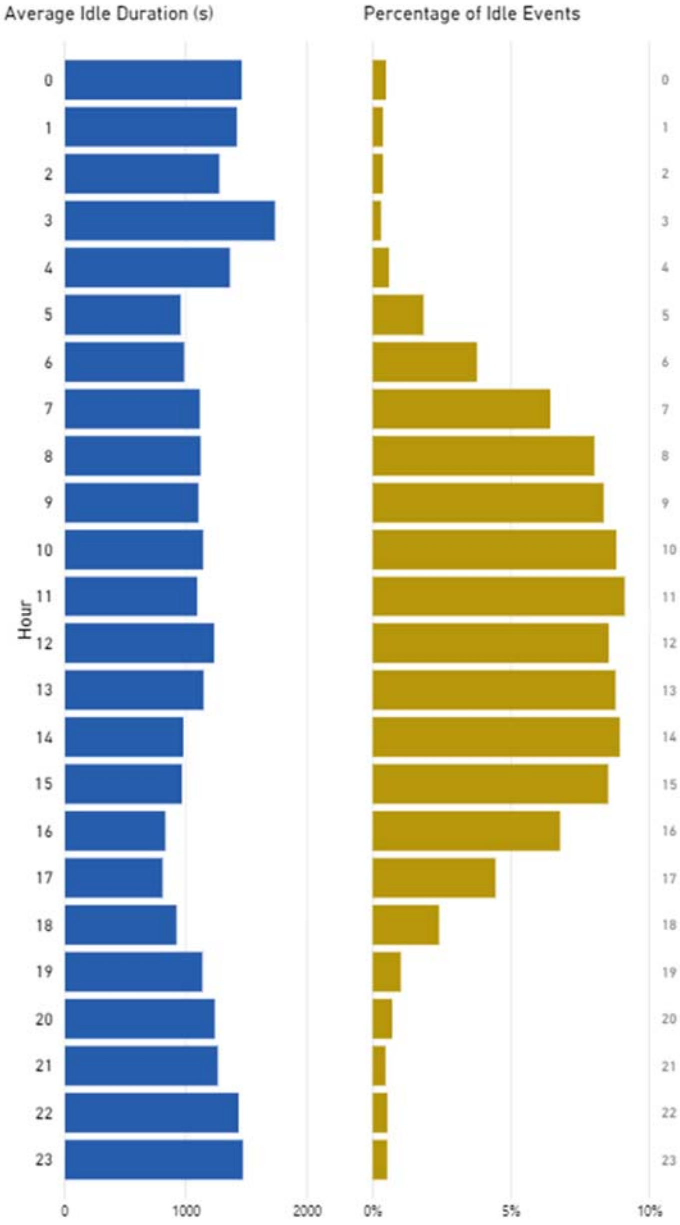


Figure 7. Hourly Distribution of Duration of Idle Events.

The activities over the day are grouped into four periods, that includes morning peak (6 AM-10 AM), midday (10 AM-3 PM), evening peak (3 PM-8 PM) and overnight period (8 PM-6 AM). Figure 8 shows the distribution of idle activities for these four periods. The longest average idle duration was obtained for the overnight period, compared with the shortest duration obtained for the evening peak time. In terms of the average number of idle events per vehicle, midday period was found to have the highest and the lowest being observed for the overnight period. Combining both metrics of average idle duration and idle events, the midday period was found to have the highest total idle duration.

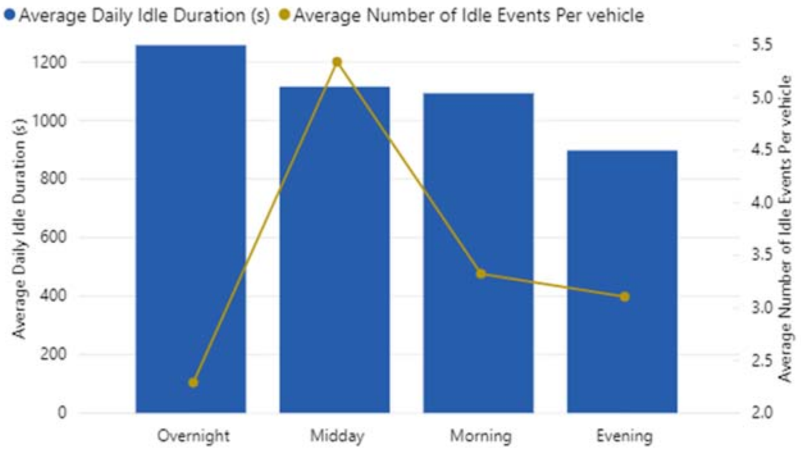


Figure 8. Summary of Idling Activities by Time Period.

Figure 9 summarizes key points from the idling analysis. The overall truck activities resulted in an emission inventory of 4.4 million of NO_x emissions. In terms of the split between different emission processes (running exhaust, brake and tire wear, etc.), idling accounted for 11% of the total emission inventory, which translated to 482,000 grams of NO_x. Comparison of idling in different areas revealed that trucks on average idle for 71.9% time during port activities compared to 50.2% overall, which includes the port activities.

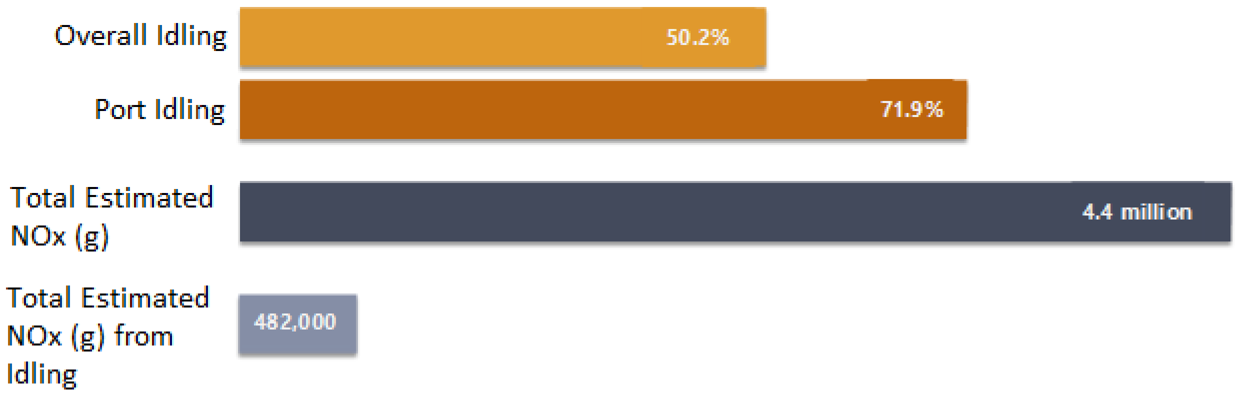


Figure 9. Summary of Idling Analysis.

VEHICLE ACTIVITY ANALYSIS

The data collection effort recorded PAMS data from 316,125 miles of operation, covering 17,513 hours, from the drayage vehicles. The VMT data obtained is classified by facility types as shown in Figure 10. Higher estimates of VMT were obtained from rural-arterial followed by urban-freeway. Urban-arterial and rural-freeways were the least traveled road types. Figure 11 shows the speed distribution for the same road types, with the highest average speeds of 57.7mph and 47.1 mph recorded on the rural and urban-freeways. The arterial speeds were much lower, at just over 30 MPH for rural-arterials and 10 MPH for urban arterials.

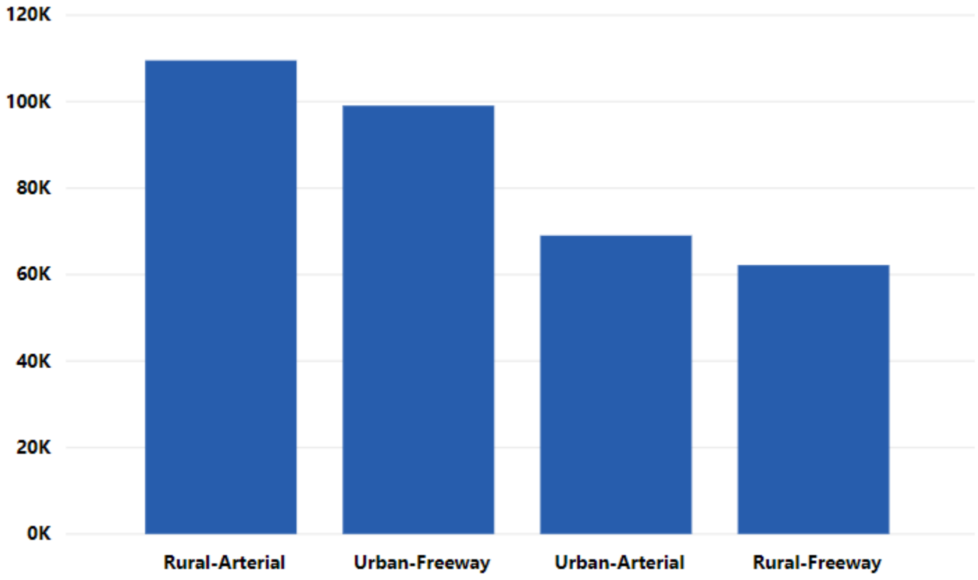


Figure 10. Distribution of VMT by Road Type.

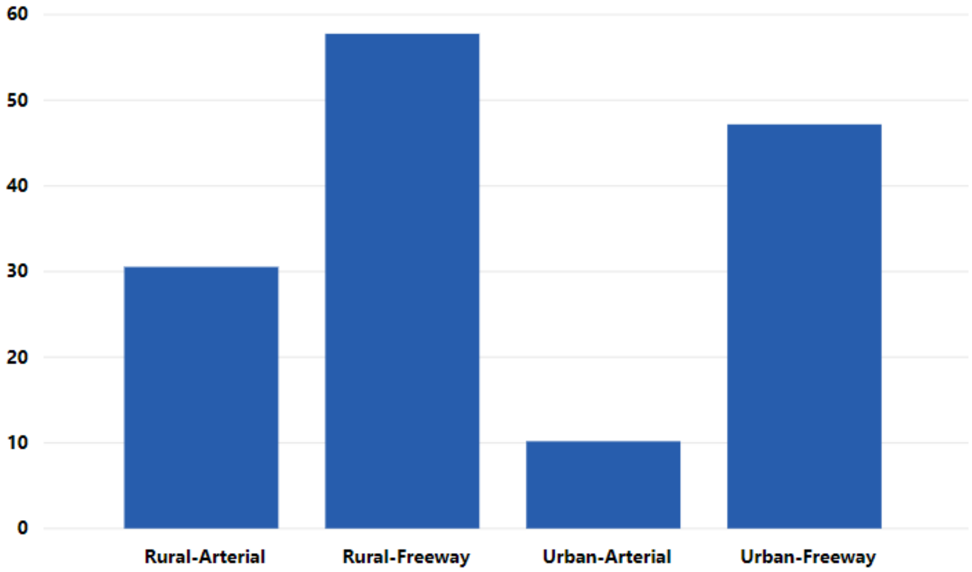


Figure 11: Average Speed by Roadway Type.

Figure 12 shows the speed distribution by speed range for all observations recorded during the data collection process. The vehicles spent an average of 63% of their time in the 0-10 mph speed range, leading to the average speed of 18.05 MPH. It must be noted that the 0-10 mph speed range covers idling and low-speed driving such as stop-and-go conditions.

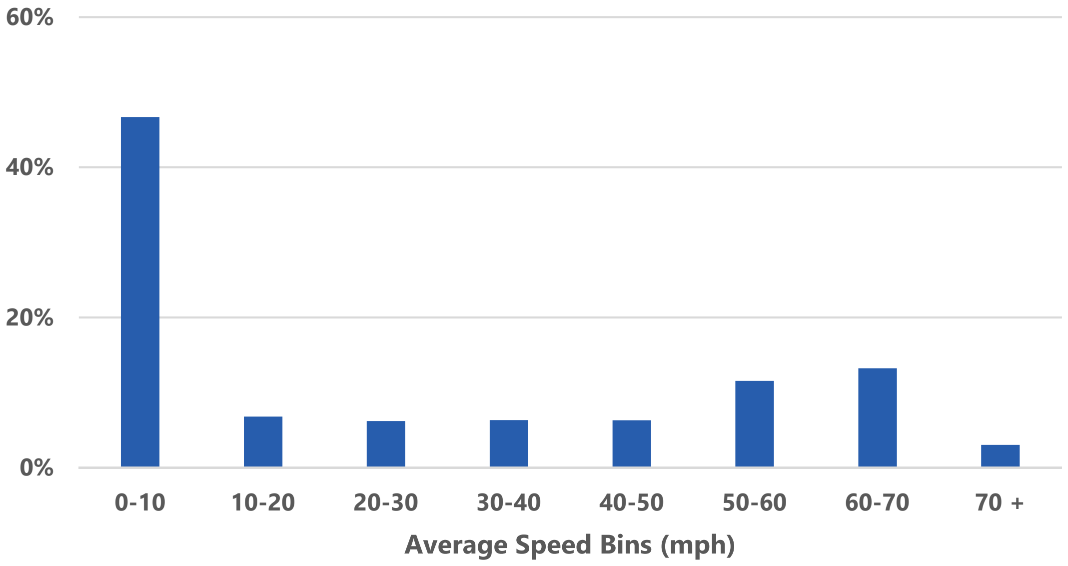


Figure 12. Speed Observation Distribution by Speed Range

Table 4 shows the vehicle activity daily averages for each day of the week in terms of the distance traveled, and average speed. Based on the vehicle activities, pollutant emissions were calculated that are also included in Table 4. In order to calculate the total emissions from the vehicles, the researchers used emissions rates from the EPA MOtor Vehicle Emission Simulator (MOVES) model, the preferred emissions modeling platform for a range of regulatory and research purposes. EPA has mandated the use of MOVES for all official air quality estimations in the United States, with the exception of California. MOVES provides a suitable platform for analysis of emissions because it is a modal-based model that estimates emissions based on a unique combination of modes (or bins) that represent vehicle operating conditions and vehicle characteristics. MOVES uses 40 drive cycles to model a wide range of possible driving patterns and their resultant emissions. The latest version of MOVES, MOVES2014a version was used for this study. Details of how the rates were calculated can be found in Appendix A. The rates were applied to each second of data recorded by the PAMS, and the total daily emissions of the vehicles were then calculated. As seen in Table 4, vehicle activity is found to peak during mid-week (Tuesday to Thursday) and is associated with higher emission estimates compared to the weekend with lower activity and thereby emissions. Average vehicle activity of 135.23 miles was found to emit an average of approximately 219 kg of CO_2, 395 g of CO, 1,113 g of NO_x, and 45 g of $PM_{2.5}$ per day of operation, Table 5 has the same set of data, broken down by the hour of the day. Over the course of a day, peaking in the vehicle activity occurs during hours 9 AM to 3 PM that leads to higher emission estimates compared to other periods in the day.

Table 4. VMT and Emissions Daily Per Vehicle

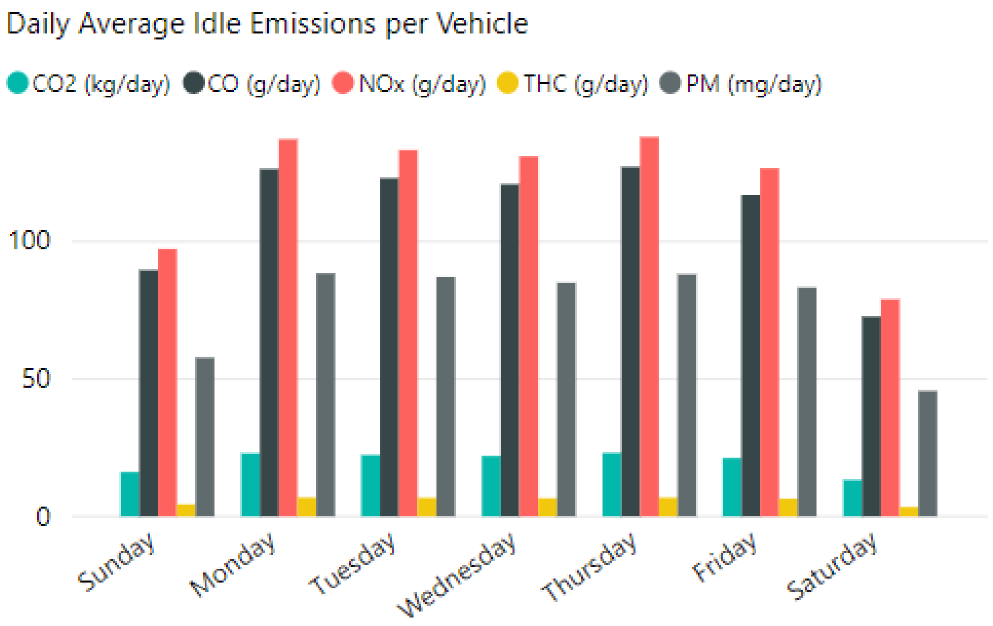
Day of Week	Distance (Miles)	CO_2 (kg)	CO (g)	NOx (g)	PM2.5 (g)	Average Speed (MPH)
Sunday	53.36	115.86	220.13	594.04	22.34	15.67
Monday	134.24	215.81	392.90	1097.37	44.23	17.37
Tuesday	143.41	229.60	411.55	1166.32	47.47	18.28
Wednesday	140.85	223.88	406.29	1137.59	46.434	17.709
Thursday	147.98	238.33	422.17	1210.60	48.96	18.83
Friday	139.46	223.23	402.03	1133.88	46.42	18.10
Saturday	73.99	150.37	260.90	765.17	29.72	19.55
Average	135.23	219.04	394.19	1,113.16	45.12	18.05

Table 5: VMT and Emissions Hourly Per Vehicle

Hour of Day	Distance (Miles)	CO2 (kg)	CO (g)	NOx (g)	PM2.5 (g)	Average Speed (mph)
0	0.39	0.88	1.90	4.56	0.19	12.05
1	0.44	0.97	1.95	4.96	0.21	14.36
2	0.34	0.75	1.51	3.84	0.15	14.10
3	0.33	0.72	1.38	3.70	0.14	15.53
4	0.63	1.29	2.23	6.63	0.25	20.31
5	1.91	3.80	6.42	19.51	0.72	21.96
6	5.08	9.74	16.15	50.69	2.00	24.85
7	7.09	14.12	25.05	73.69	2.90	20.08
8	9.29	18.57	33.56	96.78	3.97	19.27
9	11.21	18.76	34.76	98.02	3.98	18.43
10	12.76	18.77	33.89	94.09	3.80	17.47
11	12.24	19.96	35.26	100.03	3.99	18.45
12	11.13	18.44	33.68	92.60	3.65	16.84
13	11.05	17.98	32.89	90.30	3.58	16.72
14	11.23	18.26	33.02	91.54	3.71	17.37
15	10.52	17.04	30.51	85.87	3.53	17.16
16	9.07	14.68	26.18	73.68	3.18	17.40
17	7.17	10.54	18.45	52.64	2.36	18.07
18	5.30	5.36	9.56	26.99	1.12	17.42
19	3.53	2.85	5.07	14.41	0.56	17.55
20	2.27	1.81	3.34	9.30	0.37	17.59
21	1.09	1.46	2.73	7.48	0.30	17.09
22	0.66	1.20	2.42	6.17	0.25	14.23
23	0.51	1.11	2.26	5.70	0.23	13.84

EMISSIONS ANALYSIS

Idling of drayage vehicles is a major contributor of emissions to the HGB area. Figure 13 shows the average daily emissions per vehicle (top) and average emissions per idle event (bottom) by week-of-day. For the average daily emissions, it is important to note that the numbers are based only on vehicles that were active during that day of the week. The average vehicle emits approximately the same amount during each weekday, and the emissions from each idle event are also similar for each weekday. However, while the daily average emissions per vehicle is lower on the weekend, the average emissions per idle event are higher during the weekend compared to weekdays, due to the idle events have longer average durations during the weekend (seen in Figure 6).



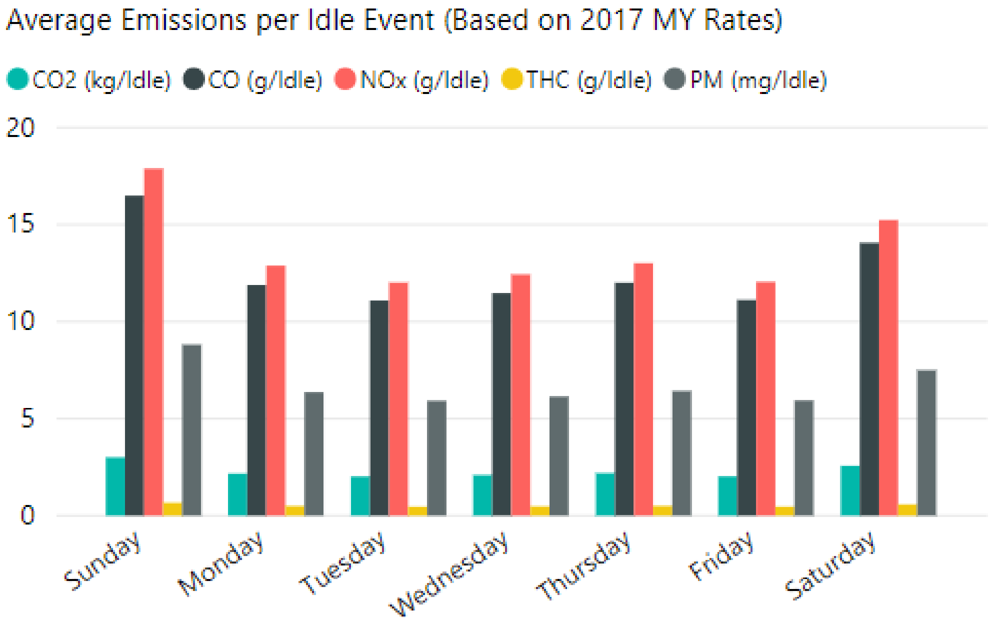
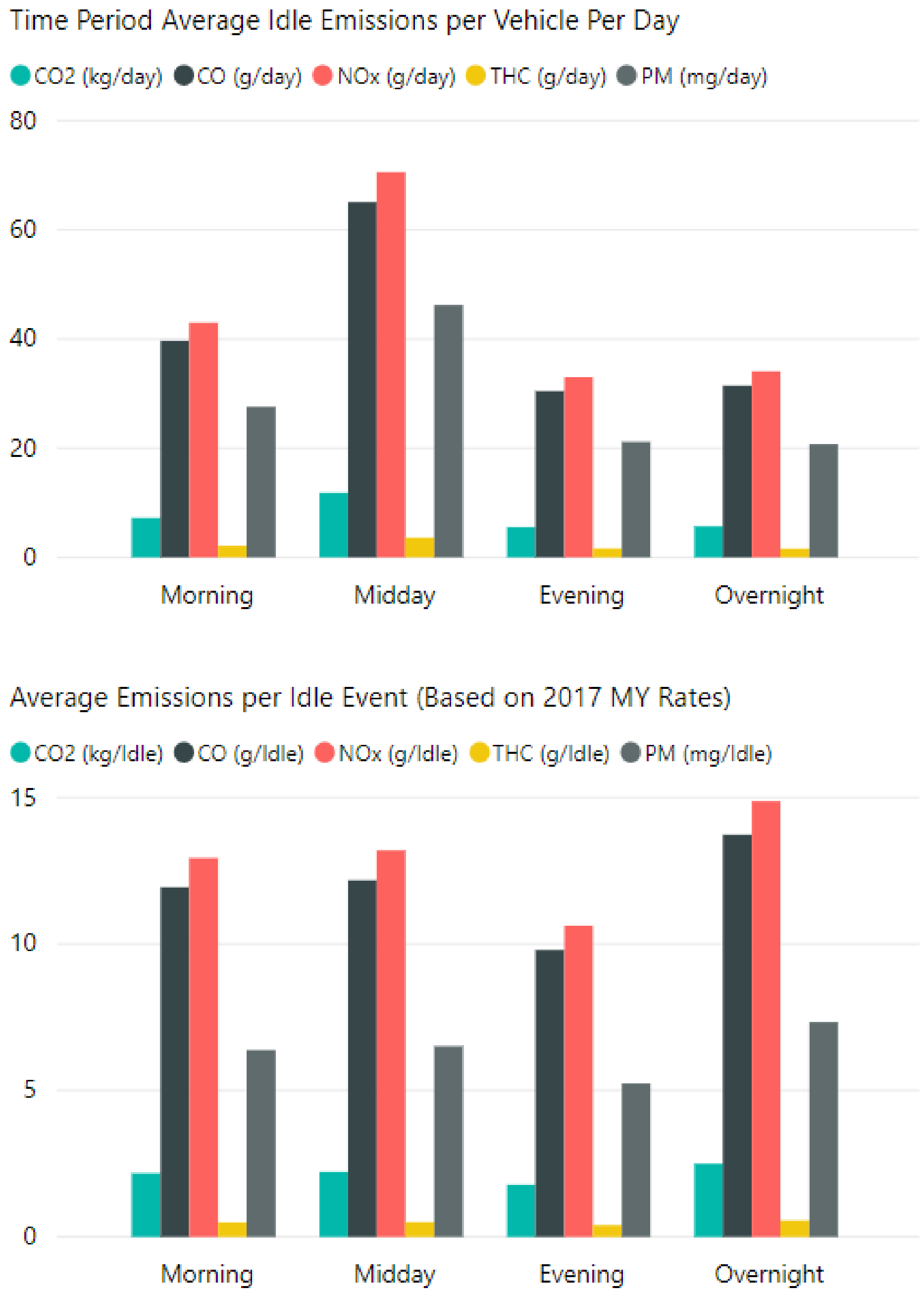


Figure 13. Idling Emissions by Week-of-Day per Vehicle (Top); Average Emissions per Idle Event (Bottom)

Emissions from idling were also analyzed by time-of-day. Figure 14 shows the average daily emissions per vehicle (top) and average emissions per idle event (bottom) by time-of-day. Average idle emissions per vehicle during the midday time period was found to be twice as high than the evening and overnight periods. The morning period was approximately 30% higher than the overnight and evening periods. The average emissions per idle event was found to be the highest for the overnight period compared to other periods due to the longer duration of idle events in the overnight period.


Time Period Average Idle Emissions per Vehicle Per Day

Average Emissions per Idle Event (Based on 2017 MY Rates)

Figure 14. Idling Emissions by Time-of-Day per Vehicle (Top); Average Emissions per Idle Event by Time Period (Bottom)

TRIP ANALYSIS

The first step in analyzing the trips from the recorded data was to define a trip. For this analysis, a trip is defined as a vehicle activity event that is separated by either a key on/off event, or an idle event that is greater than 15 minutes in duration. An additional requirement for a trip is that the minimum geographical distance between the origin and destination of a trip is 1 mile. A trip, which has the destination within a mile of the trip origin, is not considered a valid trip and is therefore excluded from the trip analysis.

A total of 6,849 trips were identified from the PAMS data collected by the research team, with an average duration of 104.43 minutes and an average geographical distance of 19.98 miles. Figure 15 shows the ODs for all valid trips that either began or ended in the H-GAC area. The longest trip that was recorded (far left point in Figure 15), either starting or ending in an H-GAC county, was just over 450 miles, and ended in Pecos County, Texas. Of the 6,849 trips, only 280 (4%) were longer than 100 miles. The trips are found to be concentrated around the urban core and port terminals in the southeast side of town and decrease with distance from the urban core. An overview of the trip OD density within the H-GAC area is shown in form of a heat map in Figure 16. The ODs within 2 miles of the vehicle’s base of operations are not shown on the map but were included in the analysis. The majority of the trips (95.05%) occurred during the week, as seen in

Table 6.

Figure 15. Trips Origin-Destination Locations for All H-GAC Trips.

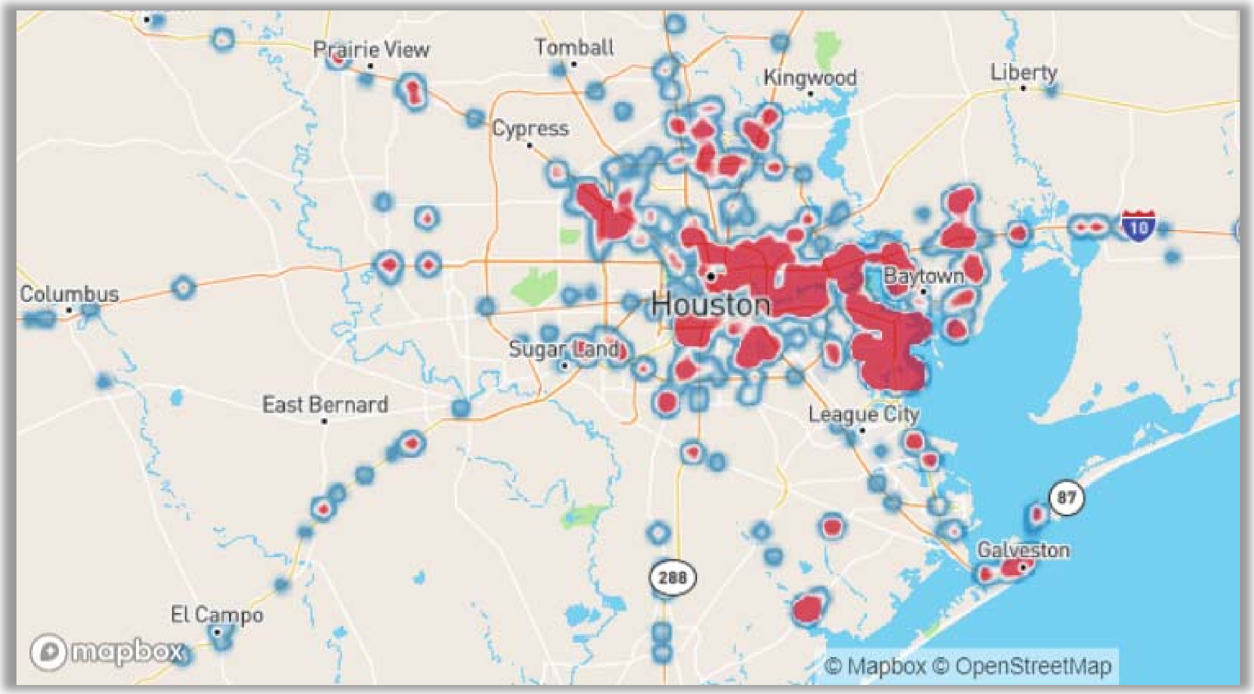


Figure 16. Heat Map of Trips Origin-Destination Locations in H-GAC Area.

Table 6. Trip Summary - Day of Week.

Day of Week	Percentage of Total Trips	Average Duration (Minutes)	Average Geographical Distance (Surface Miles)
Sunday	2.28 %	96.5	18.13
Monday	17.34 %	103.3	18.97
Tuesday	19.38 %	105.4	18.24
Wednesday	19.98 %	102.1	17.79
Thursday	19.42 %	104.5	19.10
Friday	18.92 %	104.5	18.29
Saturday	2.67 %	102.1	15.53

The trips were then further broken down by the start and end times, for both hourly comparisons and time periods over an average day. Figure 17 shows the distribution of trips by hour-of-day classified by trip start and trip end hour. The trips are found to peak from 6 AM to 6 PM with more trips starting in the morning hours and ending in the afternoon hours. Figure 18 shows the distribution of trips by time periods classified by trip start and trip end hour.

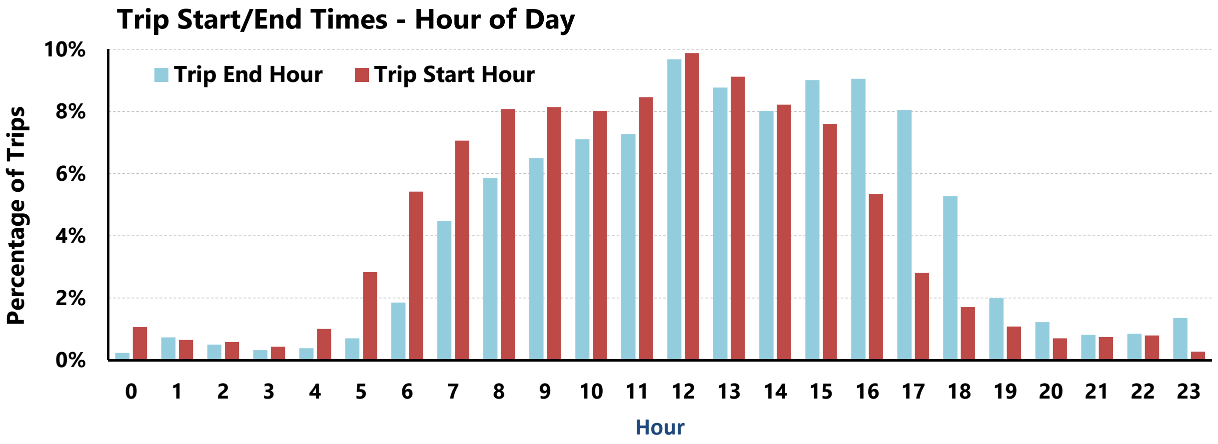


Figure 17. Distribution of Trip Start and End Times by Hour-of-Day.

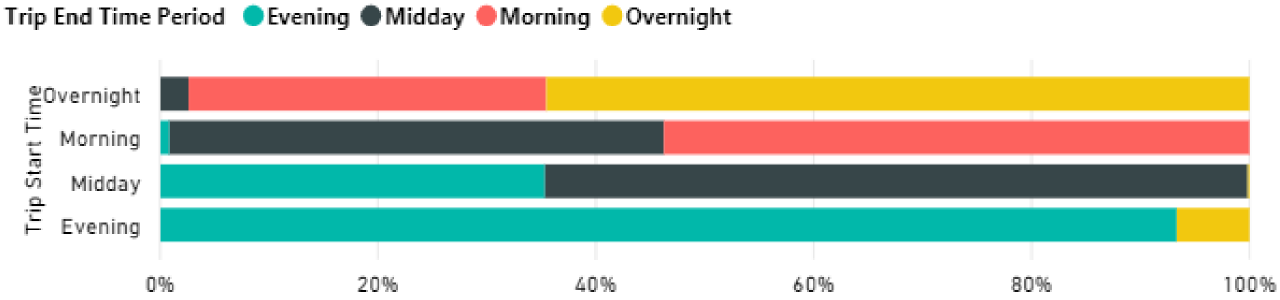


Figure 18. Trip Start and End Times - Time Period.

GEOSPATIAL ANALYSIS

The trips, and associated OD locations, were further analyzed by several geospatial categories, including the terminals that are part of PH and the 8 counties that make up the H-GAC area.

PORT TRIP ANALYSIS

A total of 8 terminals operated by the PH that were analyzed in this study. Those terminals included:

- Barbours Cut,
- Bayport,
- Industrial Park East,
- Jacintoport,
- Manchester,
- Manchester Wharves
- Southside Wharves, and
- Turning Basin.

Figure 19 shows the OD locations for the trips that started or ended at the port terminal. The concentration of these trips are found to be concentrated near the urban core and the trips decrease with distance from the core. Very few of the trips left the H-GAC area, with a few occurring outside of the area, including one that went to the north side of Dallas. Two of these terminals, Barbours Cut and Bayport, are container terminals, while the others are classified as general cargo terminals. A total of 1,117 trips either originated or ended at a port terminal for the duration of the PAMS data collection.

Table 7 shows the trip detail by port terminal and day of the week and includes any trips that started or ended in the terminal. As seen in Table 7, most of the trips from the drayage vehicles that involved a port terminal occurred in either Bayport (56.6%) or Barbours Cut (38.2%).

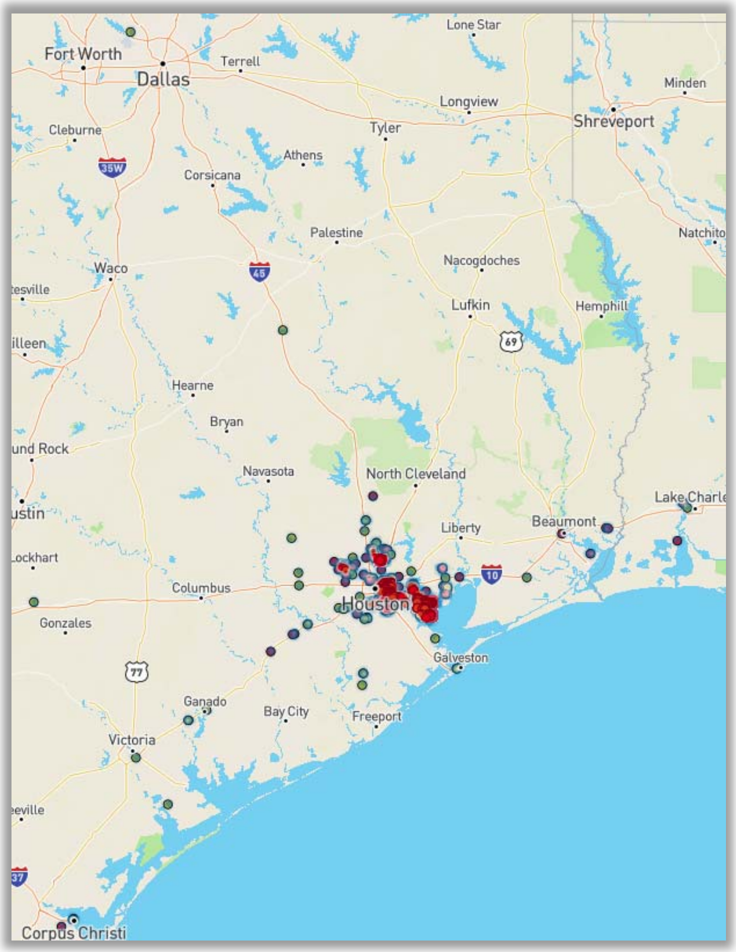


Figure 19. Origin-Destination Locations for Trips Starting or Ending at a Port Terminal.

Table 7. Trips by Port Terminal.

Day of Week	Barbours Cut	Bayport	Industrial Park East	Jacintoport	Manchester	Manchester Wharves	Southside Wharves	Turning Basin
Sunday					1	2		
Monday	94	109	1	6	2			5
Tuesday	74	148	1	7	13	1		
Wednesday	74	141	2	3	8	1		3
Thursday	80	1131	3	2	11	1	1	
Friday	103	103	3	5	4		2	5
Saturday	2				1			
Total	427	632	10	23	40	5	3	13

Figure 20 shows the distribution of the trip origins, at the different terminals, classified by time periods. It was seen that most trips began during the morning and midday periods. This graph shows the time a trip started, not when the vehicle entered the terminal.

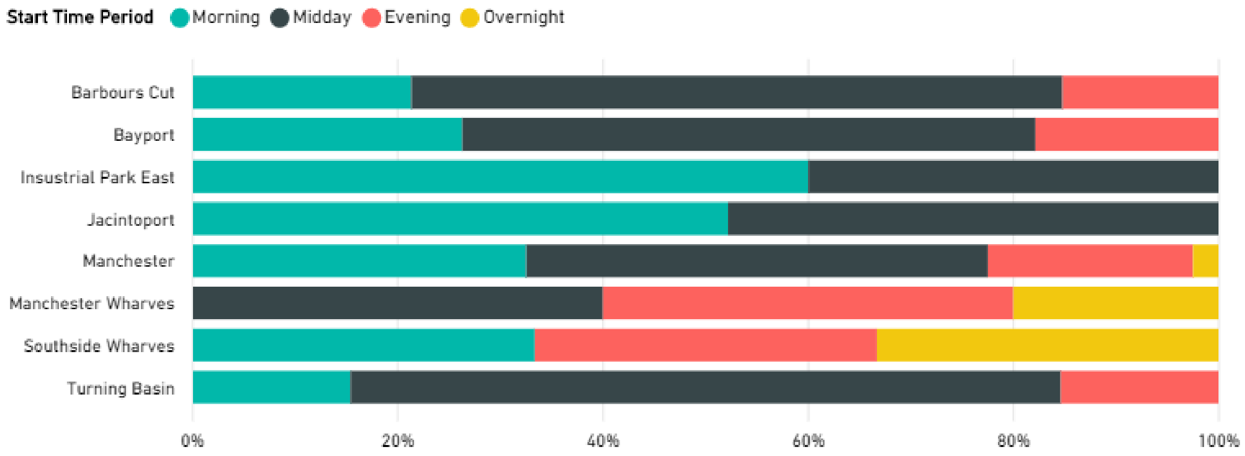


Figure 20. Port Terminal Trip Origins by Time Period.

Port Idling Activities

A total of 2,841 idling events occurred at PH terminals. The average duration was 14 minutes, and there was an average of 0.93 idle events per vehicle per day that occurred during the data collection. Table 8 shows the average duration of idle events and the total number of idle events that were measured at each terminal. A map of the idling events is shown in Figure 21.

Table 8. Idle Events by Port Terminal.

Port Terminal	Average Duration of Idle Events (minutes)	Total Number of Idle Events
Bayport	12.25	1,069
Barbours Cut	12.69	1,564
Industrial Park East	30.82	30
Jacintoport	11.93	59
Manchester	30.77	74
Manchester Wharves	70.65	7
Southside Wharves	158.91	6
Turning Basin	58.33	32

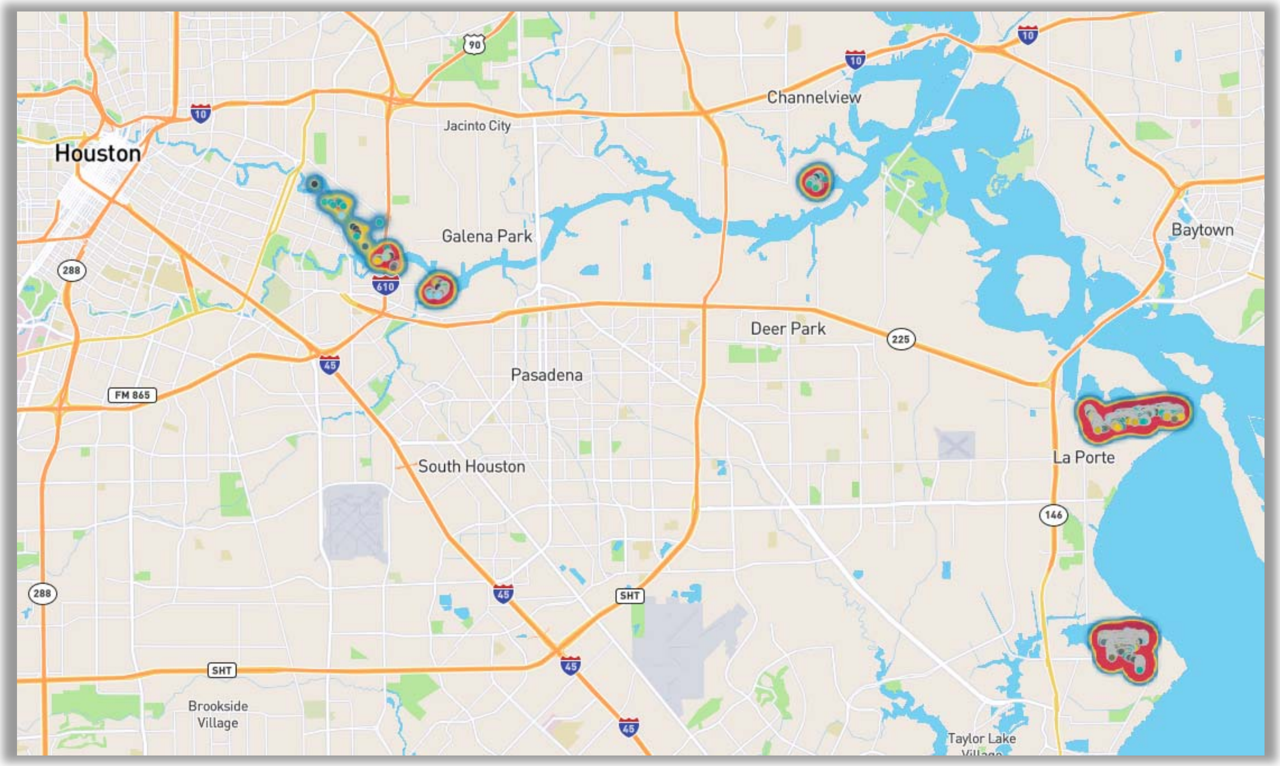


Figure 21. Map of PH Terminal Idle Events.

COUNTY TRIP ANALYSIS

Table 9 shows the trips that began or ended, by day of the week, in each of the 8 counties. Nearly 98% of all trips that occurred in the HGB area either began or ended in Harris County. Most of the trips (96.2%) both started and ended in one of the HGB counties. Figure 22 shows the density of the trip origins by county. Higher density of trip origins was seen in the H-GAC counties, those along major roads such as I-45 and I-35, and those along the coastal areas between Houston and Corpus Christi.

Table 9: Trips by HGB County.

Day of Week	Brazoria	Chambers	Fort Bend	Galveston	Harris	Liberty	Montgomery	Waller
Sunday			1	23	146			
Monday	31	30	11	30	1,118		13	2
Tuesday	47	42	25	4	1,248	3	9	8
Wednesday	34	63	15	13	1,284	4	3	14
Thursday	58	33	10	37	1,255		23	10
Friday	32	41	16	13	1,219	10	8	10
Saturday	5	4	2	19	169	2	3	
Total	207	213	80	139	6,439	19	59	44

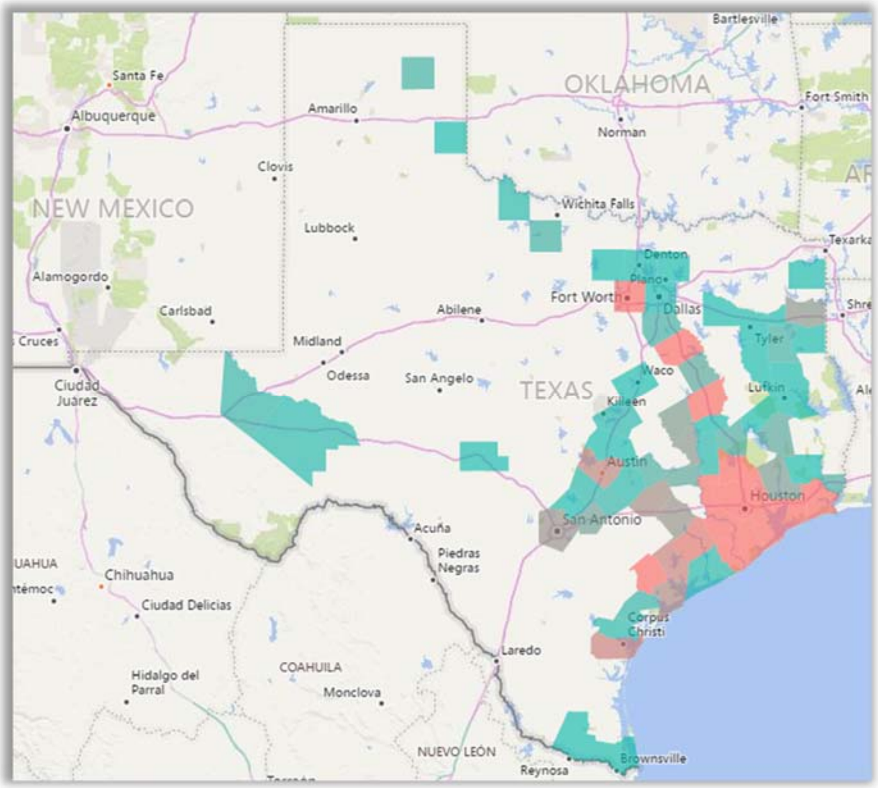


Figure 22. Texas Counties with a Minimum of 2 Trips Origins (Red indicated a minimum of 20 Trips)

COUNTY IDLING ACTIVITIES

The idling activities were also analyzed on a county-level basis, shown in Figure 23 and summarized in Table 10. As with the trip analysis, most of the events occurred in Harris County, followed by Galveston. However, the idle events that occurred in Galveston were generally much longer than those in Harris County, at 47 minutes versus 17 minutes. Higher idle duration combined with a lower number of idle events in Galveston County resulted in emissions comparable with Harris County. Figure 24 shows the total daily emission due to idling very similar between the two Counties.

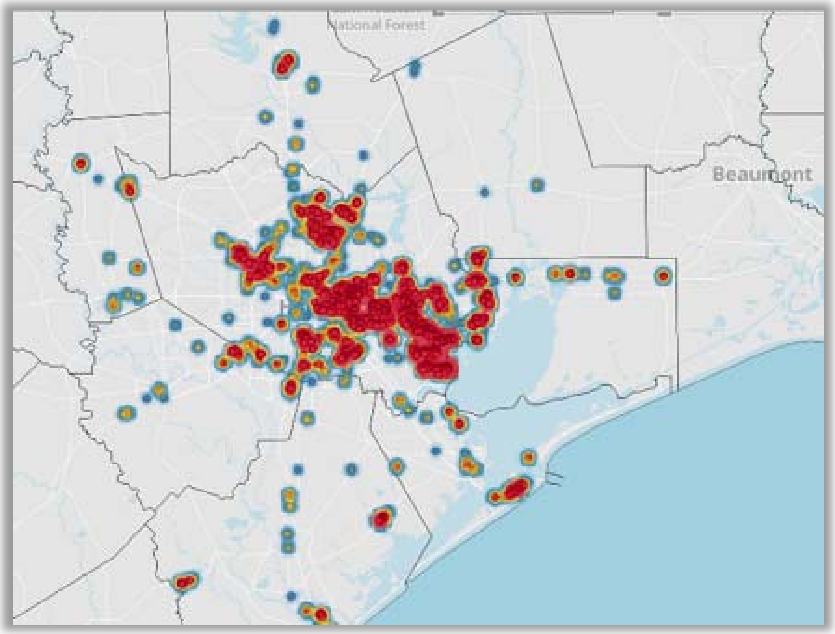


Figure 23. Map of Idling Events by HGB County.

Table 10. Summary of Idle Events by H-GAC County.

County	Average Duration of Idle Events (minutes)	Daily Events per Vehicle
Brazoria	20.78	2.8
Chambers	19.24	2.04
Fort Bend	24.73	2.46
Galveston	47.06	3.01
Harris	17.33	9.77
Liberty	18.52	1.56
Montgomery	24.71	2.39
Waller	22.64	2.16

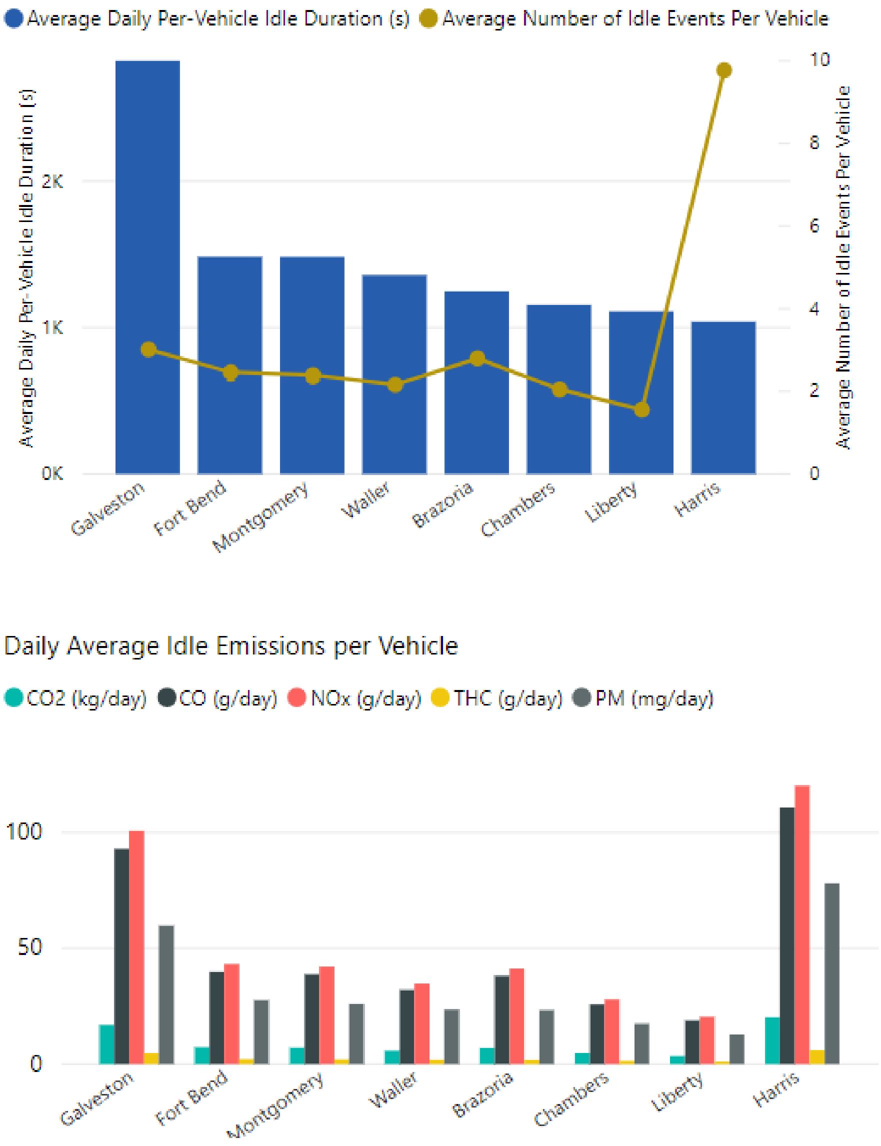
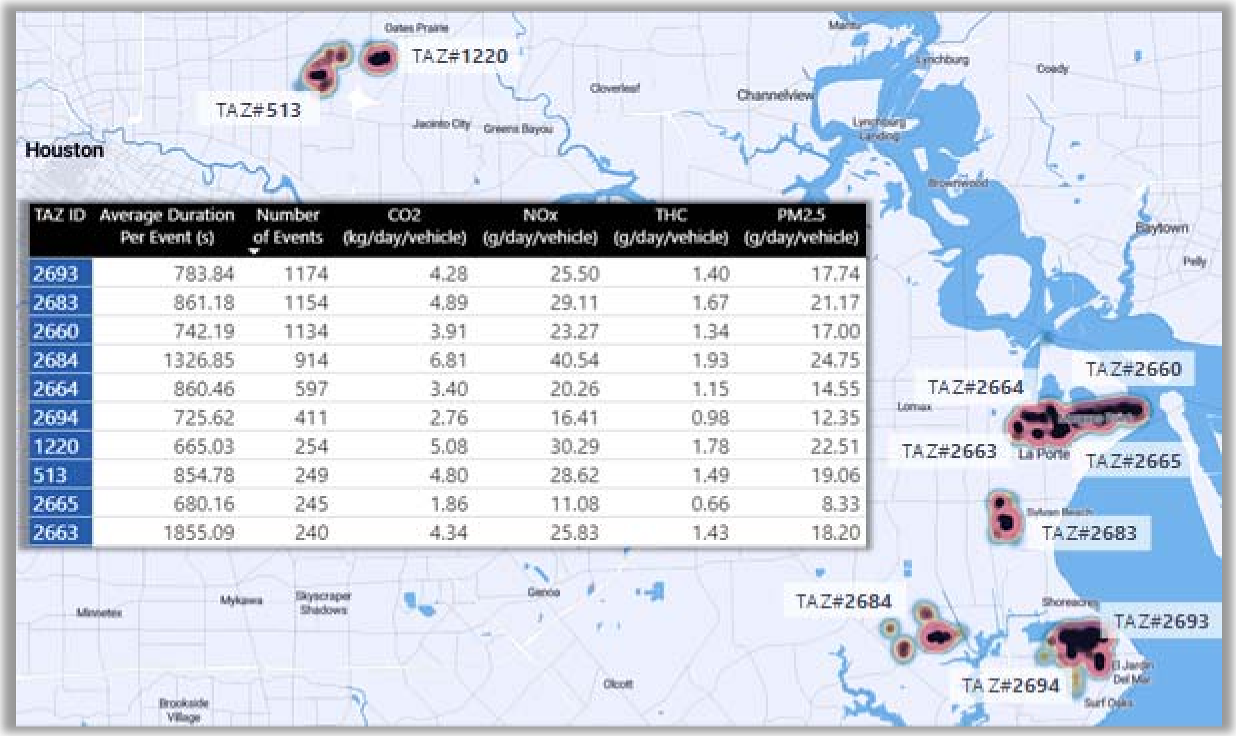


Figure 24. Average Daily Idling and Idling Emissions per Vehicle by County.

TAZ IDLING ANALYSIS

Details of the idle events were also broken down by the TAZ's defined in the Houston area network. Due to the high number of TAZs that had idle events occur during the data collection, the entire data set is not being presented here. There were 11 TAZs that had at least 200 idle events, as shown in Figure 25. The idle events included in the TAZ analysis do not include any idle events that occurred within 1.5 miles of the trucks base of operations. This was done in order to make sure that the analysis was not biased towards the TAZs that included the base of operations for the fleets that took part in the data analysis. As seen in Figure 25 some of the TAZs with the most idle events were those that include PH terminals Barbours Cut and Bayport. Some additional TAZ also had at least 200 idle events, both near the terminals but also two that are located NW of the terminals near the IH-10 and IH-610 interchange (TAZ 513 and 1220).



TAZ ID	Average Duration Per Event (s)	Number of Events	CO2 (kg/day/vehicle)	NOx (g/day/vehicle)	THC (g/day/vehicle)	PM2.5 (g/day/vehicle)
2693	783.84	1174	4.28	25.50	1.40	17.74
2683	861.18	1154	4.89	29.11	1.67	21.17
2660	742.19	1134	3.91	23.27	1.34	17.00
2684	1326.85	914	6.81	40.54	1.93	24.75
2664	860.46	597	3.40	20.26	1.15	14.55
2694	725.62	411	2.76	16.41	0.98	12.35
1220	665.03	254	5.08	30.29	1.78	22.51
513	854.78	249	4.80	28.62	1.49	19.06
2665	680.16	245	1.86	11.08	0.66	8.33
2663	1855.09	240	4.34	25.83	1.43	18.20

Figure 25. Map of TAZ Idle Events.

BASE OF OPERATIONS

The idle events were also analyzed by events that occurred at, or near (within 1.5 miles) the base where the vehicle is located. As seen in Table 11 just under 30% of all idle events occurred at the vehicle's base of operation while overall the vehicles spent a total of 16.5% of their operational time at their base.

Table 11: Idle Events: Base of Operation

	Average Duration of Idle Events (minutes)	Idle Events per Day
Base	16.04	3.2
Non-Base	18.67	8.19

IMPACT OF SCR TECHNOLOGY

The SCR system, an emissions control device used to reduce the emissions of NOx from diesel vehicles, is only effective when the exhaust temperature is within a specified temperature range. A typical SCR is capable of reducing the NOx emissions by 70-90% (*27*) when operating in the optimal temperature range. The performance of the SCR is best when the exhaust temperature is over 250°C, and at lower temperatures, the percentage of NOx reduction can be as low as 0%. Figure 26 shows the effectiveness of a typical SCR application based on the exhaust temperature of the operating vehicle.

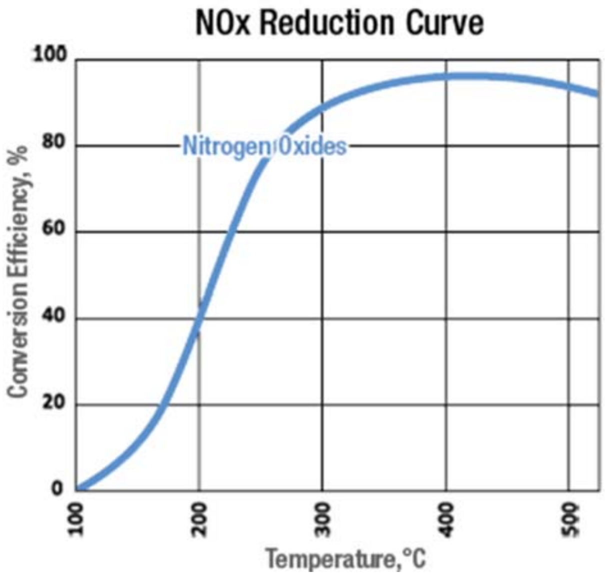


Figure 26. NOx Percentage Reduction Curve[2].

In order to determine at the effectiveness of the SCR for the data collected during this project, the research team looked at data from vehicles which reported the inlet exhaust temperature to the SCR, which was 4 of the 39 total vehicles in the project. The

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[2] Image from Nett Technologies Inc. BLUEMAX Selective Catalytic Reduction (SCR) System. https://www.nettinc.com/products/selective-catalytic-reduction-scr/bluemax, Accessed July 2018.

remaining vehicles did not report this data, and were therefore excluded from this analysis. From this data set, a total of just under 9 million records of data were collected. Figure 27 shows the distribution of the exhaust temperatures that were recorded during the data logging. It was found that 96.1% of the recorded temperatures were between 100 and 375°C; however, only 41.3% were higher than the minimum exhaust temperature for the SCR to be effective.

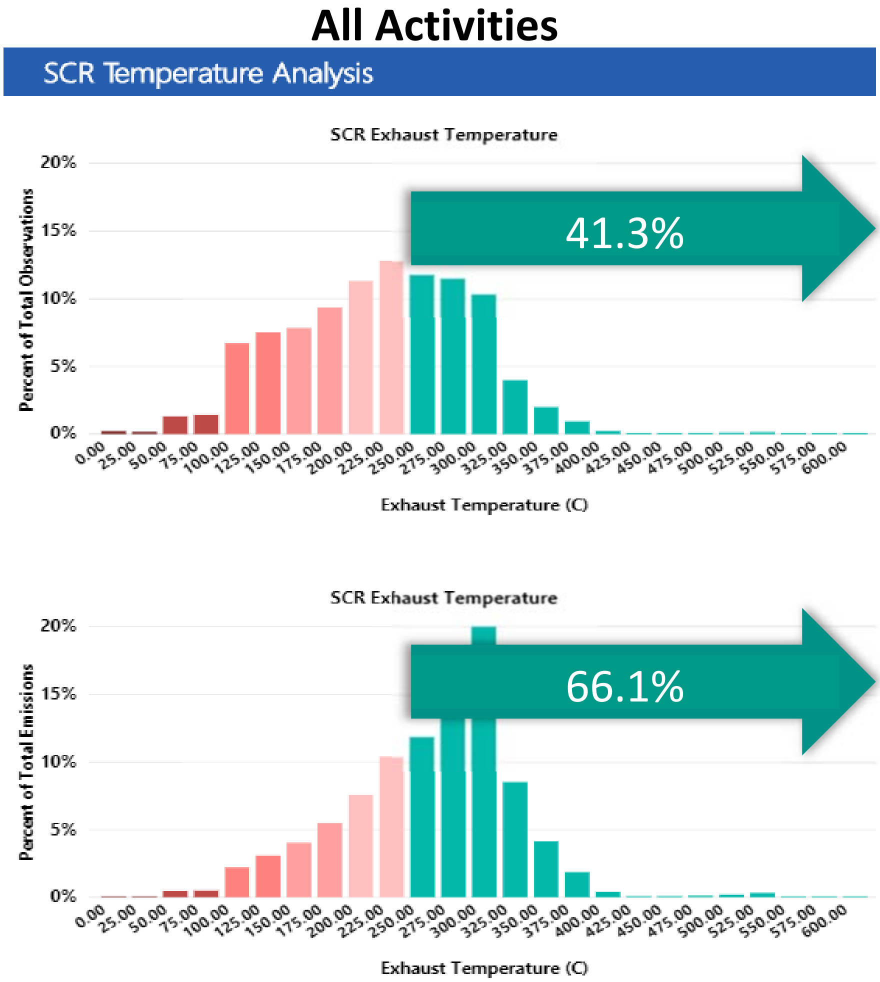

Figure 27. Distribution of Exhaust Temperatures.

Figure 28 shows the distribution of exhaust temperature under 5mph average speed. It was found that the majority of the low-speed observations had an exhaust temperature between 125 to 275° C. Approximately 17% of the observations had an exhaust temperature higher than 275° C.

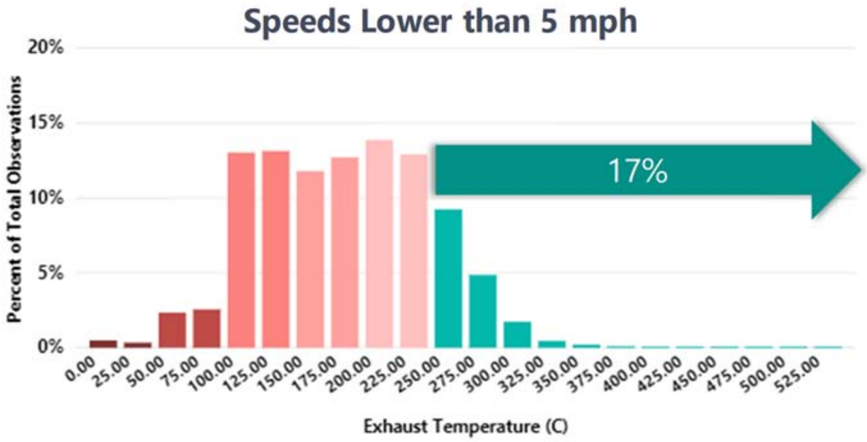

Figure 28. Distribution of Exhaust Temperatures when Speed is Lower than 5 mph.

CNG VS DIESEL COMPARISON

Another question the researchers looked at was the difference between CNG and diesel operations. The EPA MOVES model does not currently include any CNG emissions rates for heavy-duty vehicle types; therefore an emissions comparison between the two fuel types could not be conducted. A future version of MOVES is proposed to have CNG rates[3], but for this study instead of looking at the emissions impact, the research team looked at the operational impact of the two different fueling types. While MOVES does not currently have the rates for CNG, the proposed rates do give a general idea of the potential benefits of CNG versus diesel for NOx reductions. Figure 29 shows the proposed CNG rates along with the current diesel-based rates, and rates from a single in-use test. The Figure 29 shows the CNG proposed rates and the in-use testing rates are much lower than the diesel rates. The error bars for some of the in-use testing were above the diesel rates; therefore more testing data is needed to determine the actual NOx savings from the use of CNG vehicles.

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[3] Heavy-Duty CNG Vehicles in MOVES, https://www.epa.gov/sites/production/files/2017-08/documents/04-heavy-duty-cng-vehicles-in-moves-2017-06-07.pdf. Accessed July 2018

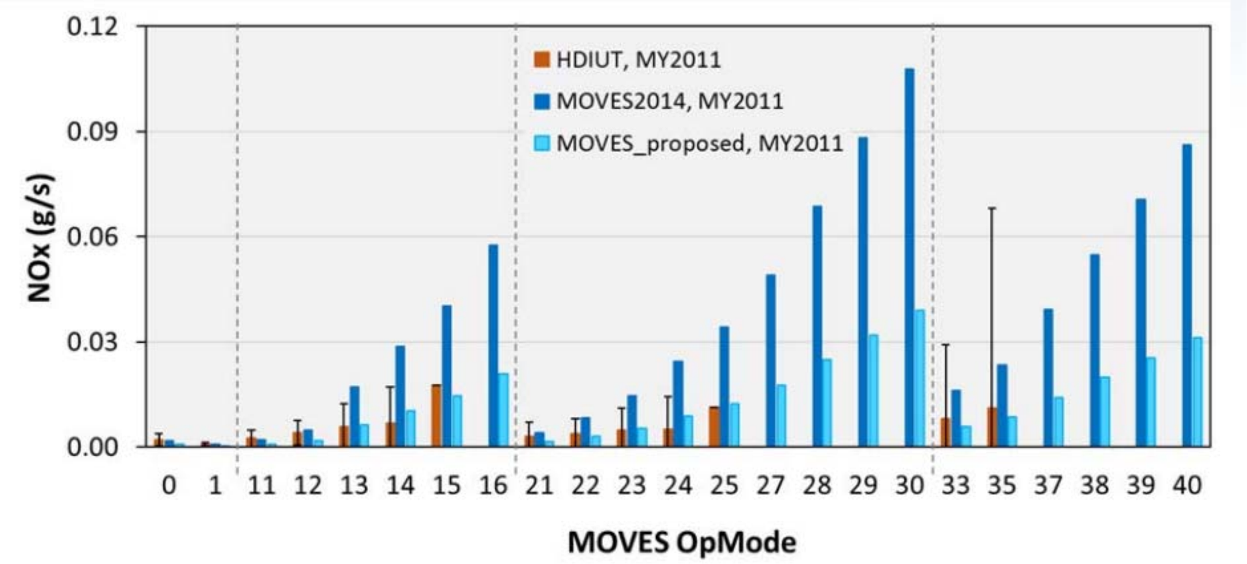

Figure 29. Proposed CNG MOVES Rates (Image courtesy U.S. EPA *(3)*).

Since there are no CNG rates for this vehicle type, the researchers instead compared the activity of the two types, to see if they are utilized differently within the same fleet. To compare the difference 8 vehicles from a fleet that operated both diesel and CNG vehicles were part of the data collection process. Of these 8 vehicles, half were diesel and half were CNG.

Table 12 shows the daily comparison between the CNG and diesel vehicles as part of the study. The table shows the CNG vehicles have a lower average speed and average daily distance, on a daily basis than the diesel counterparts. Figure 30 shows the speed range breakdown between the CNG and the diesel vehicles.

Table 12. CNG Versus Diesel Operation Comparison.

Day of Week	Average Speed (Diesel)	Average Speed (CNG)	Average Distance (Diesel)	Average Distance (CNG)
Monday	19.02	18.79	117.98	124.02
Tuesday	19.94	19.16	120.73	114.98
Wednesday	19.14	18.25	122.95	116.35
Thursday	19.77	17.78	121.21	120.71
Friday	20.46	17.82	127.34	118.54
Saturday	28.67		79.5	
Average	19.69	18.33	121.73	117.93

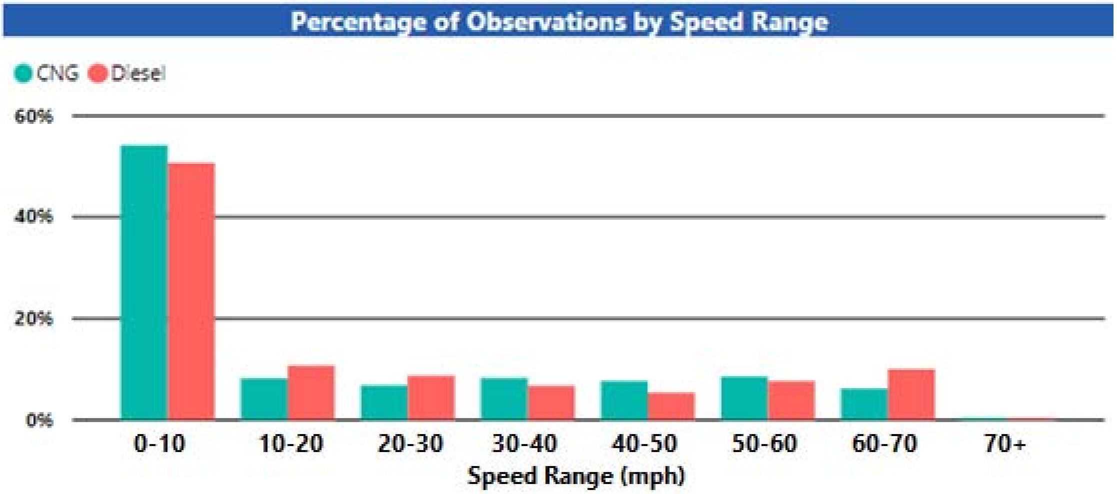

Figure 30. Speed Range CNG and Diesel Comparison.

COMPARISON OF GPS AND PAMS DATA

The HGAC staff routinely use idling duration and distance summaries provided by the GPS data provider to track compliance with the loan program requirements and study idling activity trends. The study team performed a comparative analysis between a small sample of vehicles that had both GPS and PAMS data at the same time to investigate the level of accuracy of the GPS activity summary information.

Since the data is not reported at the same sampling rate (each second for PAMS, each minute for GPS), there is no direct comparison between the data sets. Instead, the PAMS data and GPS data were aggregated on a daily basis and were then compared to each other. In a few instances, the PAMS data logger would lose data during a trip, either due to a hardware reset or some other event which caused the PAMS logger to lose power. These instances were identified in the PAMS data summaries and any day where the PAMS lost data due to any reason was excluded from the comparison analysis. The idling and distance information from GPS and PAMS systems were compared in 2 ways: daily and monthly aggregates. In order to compare the results a paired t test was conducted on the daily and monthly aggregates.

IDLING COMPARISON

The first comparison between the GPS and PAMS data sets was to compare the total idle time, by day and month, for each of the vehicles. Each of the GPS data providers provides a summary of the idle events for the fleet vehicles, and this was the basis for the comparison between the PAMS and GPS data sets. For both sets of data only idle events that were at least 5 minutes in duration were used. It should be noted that none of the GPS data providers reveal how they define an idle event. In the case of the PAMS data collected by the research team, an idle event was defined as a continuous time where the vehicle was not moving (i.e., speed of 0 mph).

Figure 31 shows the overall patterns of GPS-based idle durations. It must be noted that the y axis is an indication of the error of the GPS-based idle durations; i.e. the percentage difference of GPS-based idle durations from actual durations from PAMS data. As seen in this figure, the range of the errors for daily aggregates can be in excess of 200 percent which indicates a large random error. When the GPS-based idle durations are aggregated to monthly level, the aggregation significantly reduces the random error and the range of the error. While some individual vehicles have a relatively large average error (close to 50%), when the data from all the vehicles are combined (i.e. charts on the right-hand side) the average error for the monthly data is approximately -6 percent (i.e. underestimation).

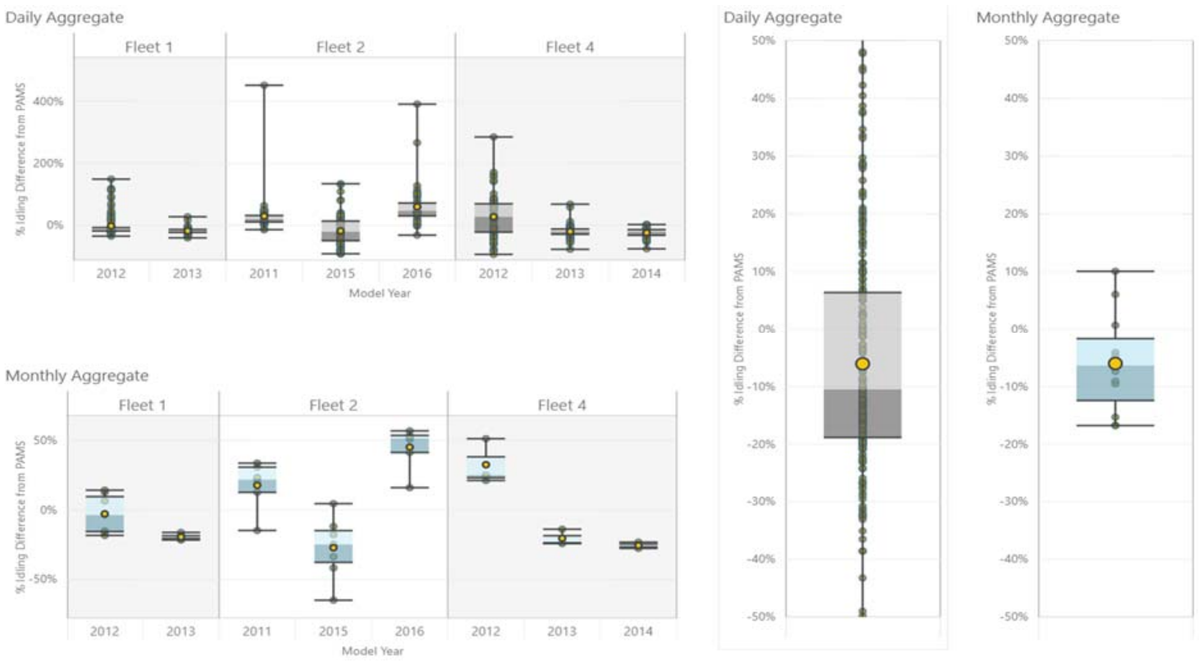

Figure 31. Box Plot of Daily and Monthly Idling from GPS and PAMS; Y Axis is the Percentage Difference of GPS Data from PAMS.

Figure 32 further shows the reduction of random error as a result of the aggregation to monthly levels. The daily scatter plot shows a large error variability in the idle duration information from the GPS data. The level of variability is significantly reduced in the monthly plot. The results of the paired t-test indicted that at a 95 percent confidence level, the differences between PAMS and GPS were not significant for the monthly aggregates. The examination of the data shown above indicates that the error in the GPS data appears to be mostly of random nature (i.e., random error which has no pattern and is unpredictable). The aggregation to monthly level is therefore very effective in reducing the large percentage errors present in the daily data. The t-test for daily data showed that for some vehicles the differences between PAMS and GPS were statistically significant at a 95% confidence level. Based on the result of the analysis, the research team recommends using the GPS-based idle duration information at a monthly aggregated level for applications such temporal and spatial analyses of the idling activities.

Figure 32. Scatter Plots of Daily and Monthly Idle Durations.

DISTANCE COMPARISON

As was done with the idle data comparison, the distance from the GPS and PAMS data sets were compared on a daily and monthly basis. Figure 33 shows the scatter plots for the distance comparison, just as Figure 31 shows the idle comparisons. As was seen in the idle comparison the difference between the GPS and PAMS data can be over 200% on the daily aggregate comparison. The monthly aggregate data is much better, with the largest error just over 20%, and the average difference only 3.29%. However, the test data showed that these differences were not significant on the monthly aggregate data.

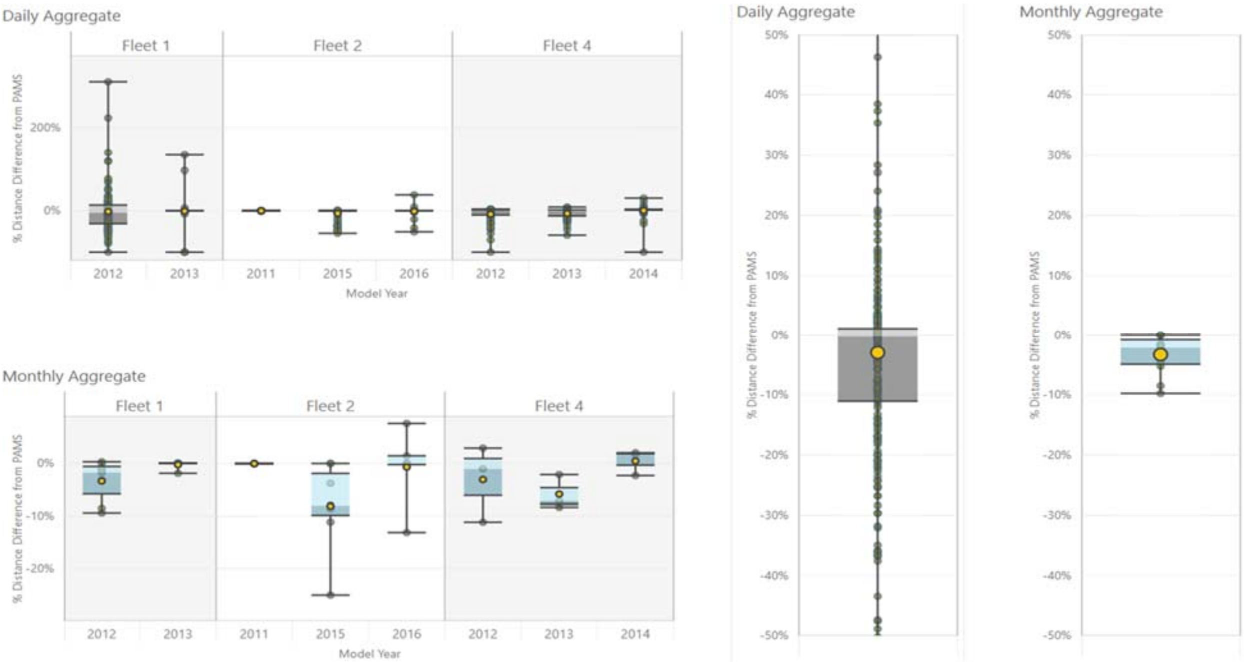

Figure 33. Box Plot of Daily and Monthly Distance Data from GPS and PAMS; Y Axis is the Percentage Difference of GPS Data from PAMS.

Figure 34 shows the scatter plot with the monthly GPS and PAMS data comparison. As the plot shows most of the monthly aggregates match each other very closely, with a few months where the GPS slightly underreports the distance when compared to the PAMS data. In addition, the bar chart in Figure 34 shows that the GPS data tends to have more days reported in the lower mileage ranges, and fewer days in the higher distance ranges. When all is averaged together, the GPS data tends to be approximately 3% lower than the PAMS data on the total mileage reported. Similar to the recommendation for the GPS-based idle information, the research team recommends using GPS-based distance information at a monthly aggregate level.

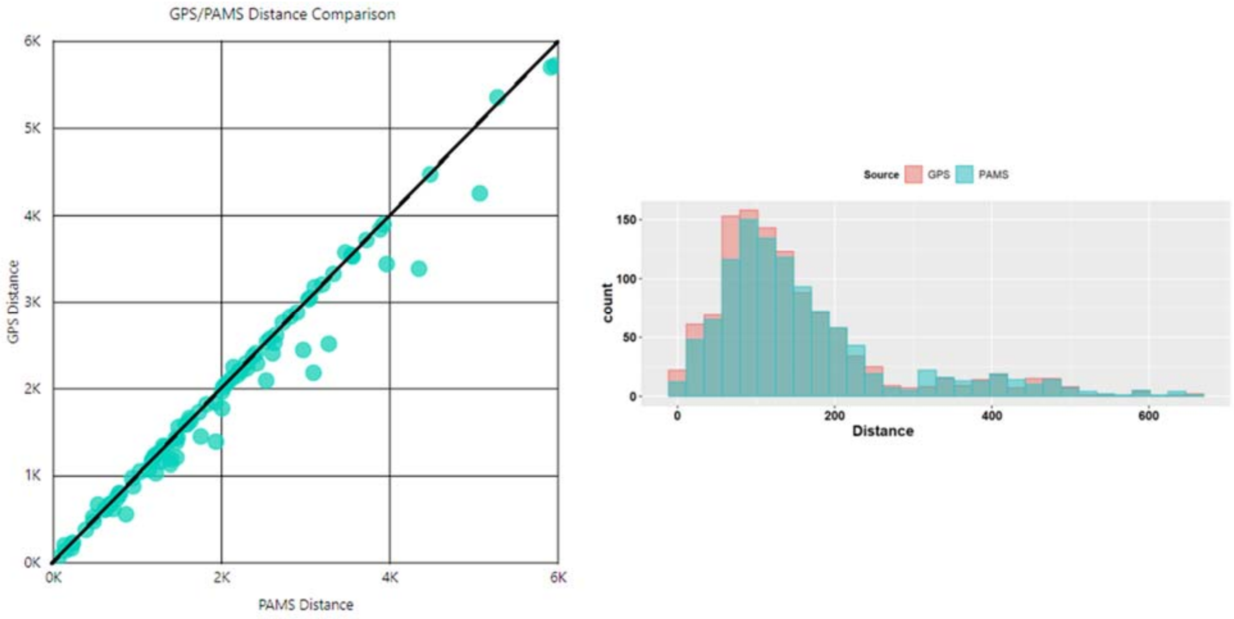

Figure 34. Scatter Plot of GPS/PAMS Monthly Distance Comparison (Left); Bar Chart with Daily Total Distances for GPS and PAMS Data (Right).

SUMMARY

This chapter presented the results of the data analysis, which included an analysis of idling, vehicle activity, trip analysis including assessment of trip ODs and further geospatial analysis of the trips. The PAMS data were used to assess SCR functionality based on exhaust temperatures. Data collected from a set of CNG trucks were also used to compare CNG and diesel truck activity and operations. Finally, the aggregate GPS data collected on DLP participants was compared against the higher-resolution PAMS data to assess consistency between the two datasets.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The overall goal of this project was to apply drayage vehicle activity data for transportation and air quality planning purposes. PAMS data (on a second-by-second basis) were collected from a set of 39 vehicles over a year, representing over 316,000 miles of operations. These trucks were mostly DLP participants operating in the HGB area, though an additional set of CNG trucks also participated in the data collection. The DLP participants in the study were also being tracked by H-GAC via GPS, through third-party data providers, who reported aggregated vehicle activity data to H-GAC over an extended period of time. The data collected and assembled as part of this study allowed for the analysis of drayage vehicle operations and emissions, as well as ancillary topics such as comparison of CNG and diesel truck operations, investigation of SCR functionality, and comparison of PAMS and GPS data.

Some of the key study findings and observations are discussed below:

- Most of the DLP activities (approx. 91%) occur between 6 AM and 7 PM, with over 95% of operations occurring on weekdays. For trips involving port terminals, a majority were either to the Barbour's Cut or Bayport terminals.
- The trucks are seen to move at low speeds overall, with significant amount of idling activities. Overall speeds for the sample DLP program trucks are low (average 18.05 mph), largely due to the vehicles idling for around 54% of the time, and being under 10 mph for 63% of the time. The vehicles averaged 185 idling minutes per day.
- Around a third (31%) of the idling events longer than 5 minutes occurred at the vehicles' base of operations. An additional 15% of the idle events occurred inside port terminals.
- When using the GPS data reported for the DLP participants, it is seen that aggregated data on distance traveled over a period of time tends to be accurate (i.e. corresponds well to PAMS data), though data assessed on a daily basis shows differences between GPS and PAMS. Similarly, GPS data does not seem to accurately report the idling time, generally underrepresenting the amount of time that a vehicle is idling during the day.
- For the trucks that reported SCR exhaust temperature, the data showed that the trucks operate approximately 58% of their time at temperatures below the

optimal temperature range for SCR technologies. This means that a large percentage of operations are occurring with the SCR not reducing the NOx emissions at the highest possible percentage.

- When looking at a fleet of vehicles that operate both CNG and diesel vehicles, the data shows that the CNG vehicles operate at lower speeds on average (18.3 mph) than the diesel counterparts (19.7 mph). The CNG vehicles also have slightly lower daily average distances (117.9) than the diesel vehicles (121.7).

The findings from this study provide insight into the activities and operations of drayage trucks in the HGB region and also present an application of PAMS data for enhanced characterization of vehicle activity and emissions. Some limitations of the study and areas to be addressed in future research include the following:

- PAMS data were only collected from a small set of fleets, so the analysis was limited to these trucks and may not be broadly generalizable.
- SCR temperature data was only reported from 8 vehicles, all part of the same fleet; therefore the SCR temperature analysis is based on one type of vehicle operation. Further data is needed on other drayage vehicles in the fleet to determine the overall impact that lower exhaust temperatures have on the SCR efficiency.
- Most of the vehicles in the study were not conducting port-related activities daily. More information is needed on vehicles that specifically operate at the port to get a better understanding of their day-to-day activities specific to the port areas.

APPENDIX A – MOVES RATES CREATION

EMISSION FACTORS ESTIMATION

Steps identified below provides information on the development of appropriate composite emission factors based on speed and roadway type.

1) Development of MOVES County Database (CDB)
2) Creating MOVES RunSpecs and Emission Rates Modeling
3) Development of VMT Mix
4) Estimate of Composite Emission Factors

STEP 1- DEVELOPMENT OF MOVES COUNTY DATABASE

MOVES is designed such that it requires information for vehicle types, ages, fuel types, and the emissions parameters to estimate emission rates. TTI research staff used latest MOVES2014a inputs in combination with TTI's State Implementation Plan (SIP)-quality inventory development methodology, designed for use with MOVES. Table A provides a brief description of the CDB input tables used for this analysis.

Table A. MOVES County Database Input Tables

MOVES Input Table	Data Category	Notes
year	Time	Designates analysis year as a base year (base year means that local activity inputs are supplied rather than forecast by the model).
state	Geography	Identifies the state (Texas) for the analysis.
county	Geography/ Meteorology	Specifies the county, local altitude, and barometric pressure (base year 2014 summer period data were provided by TCEQ).
zonemonthhour	Meteorology	Local, hourly temperature and relative humidity for the county (2014 summer period data were provided by TCEQ).
roadtype[1]	Activity	Lists the MOVES road types and associated ramp activity fractions. Road type ramp fractions were set to 0.
hpmsvtypeyear[2]	Activity	Used MOVES default national annual VMT by HPMS vehicle type.
roadtypedistribution[2]		Used MOVES default road type VMT fractions.
monthvmtfraction[2]		Used MOVES default month VMT fractions.
dayvmtfraction[2]		Used MOVES default day VMT fractions.
hourvmtfraction[2]		Used MOVES default hour VMT fractions.
avgspeeddistribution[2]		Used MOVES default average speed distributions.
sourcetypeyear[2]	Fleet	Used MOVES default national SUT populations.

MOVES Input Table	Data Category	Notes
sourcetypeage-distribution	Fleet	Local SUT age fractions estimated using TxDMV mid-year vehicle registrations and MOVES defaults, as needed. Used TxDMV latest available (2014) vehicle registrations for all years.
avft	Fleet	Local SUT fuel fractions estimated using TxDMV vehicle registration data, consistent with the data used in the sourcetypeagedistributions, and defaults where needed. Only gasoline and diesel were included, consistent with local VMT mix.
zone	Activity	Start, idle, and SHP zone allocation factors. County = zone, and all factors were set to 1.0 (required for county scale analyses).
zoneroadtype	Activity	SHO zone/roadtype allocation factors. County = zone, and all factors were set to 1.0 (required for county scale analyses).
fuelsupply	Fuel	Fuel supply, market shares were set to specify one RFG and one diesel fuel formulation.
fuelformulation	Fuel	Local gasoline and diesel formulations prepared by TTI. Used EPA RFG compliance survey sample data and TCEQ diesel survey data. The 2014 formulations were actual estimates and 2020 and later formulations were based on latest available summer (2017) actual estimates, with expected sulfur level values consistent with pertinent regulations. TTI set gasoline sulfur content to Tier 3 average annual standard and diesel sulfur consistent with federal ultra low sulfur diesel standard and recent local (TCEQ) diesel survey sample data.
imcoverage	I/M	Locality-specific I/M set-ups developed by TTI were used to represent the I/M program for each I/M county based on current I/M rules, latest modeling protocols, and the available MOVES I/M parameters (in terms of MOVES I/M “teststandards” and associated “imfactors”) for the I/M vehicles.
countyyear	Stage II	Not applicable in analysis (affects refueling emissions), but included with control program adjustments set zero.

[1] In MOVES rates mode, “ramp road type” rates are not available.

[2] Use of a default set of activity and population inputs for all MOVES runs is basic to the inventory method, e.g., MOVES default activity is normalized in the calculated rates for applicable processes, and actual local activity estimates are used in the external inventory calculations.

STEP 2- CREATING MOVES RUNSPECS AND EMISSION RATES MODELING

MOVES RunSpecs or MRS provides the instruction of how and what data to be used for estimating emission rates. Table B provides the RunSpecs information used for estimating emission rates. There will be one RunSpec and one CDB required per area per MOVES run. Each RunSpec is designed to produce a separate, corresponding MOVES output database (i.e., one output database per run). There were 4 MRS input files and 4 CDBs, and correspondingly 4 MOVES input and output databases produced under this task.

After creating RunSpecs and utilizing MOVES inputs identified in the previous step, MOVES runs were conducted for estimating emission rates. Emission rates in the MOVES output tables are provided by vehicletype, roadwaytype, pollutant, emission processes combination, which requires post-processing for application in this project.

Table B. Input Parameters for MOVES2014a Runs.

Input Item	Description
Run Specification	
Scale	Project Scale
Calculation Type	Emission Rate
Geographic Bounds	Harris County, TX
Time Period	Analysis Years: 2015 Seasons: Summer (July) Time-of-day: AM Peak (6-9 am), PM Peak (4 to 7 pm), Midday (9 am to 4 pm) and Overnight (8 pm to 6 am)
Road Type	Rural and Urban Restricted and Unrestricted Access
Vehicle Type	All
Pollutant Type	CO, NOx, VOC, CO2, PM10, PM2.5
Emission Process	Running Exhaust, Crankcase Running Exhaust, (Brake and Tire Wear &Running loses where applicable)
Project Data Manager (Project Specific Input Data)	
Link Length	One mile
Average Speed	Ranging from 2.5mph to 75mph at 1mph increment

STEP 3- DEVELOPING OF VMT MIX

The VMT mix designates the vehicle types included in the analysis and specifies the fraction of on-road fleet VMT attributable to each vehicle type by day type (i.e., average weekday) and by MOVES road type. The VMT mixes were estimated based on TTI's 24-hour average VMT mix method, expanded to produce the four-period, time-of-day estimates.[4] The procedure sets Texas vehicle registration category aggregations for MOVES SUT categories to be used in the VMT mix estimates, as well as for developing other fleet parameter inputs needed in the process (e.g., vehicle age distributions). The

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[4] Methodologies for Conversion of Data Sets for MOVES Model Compatibility, TTI, August 2009, and Update of On-Road Inventory Development Methodologies for MOVES2010b, TTI, August 2013.

VMT mix procedure produced a set of four-period, time-of-day average vehicle type VMT allocations by MOVES road type and by day type, estimated for each TxDOT district for use with the counties associated with each district. The data sources used were recent, multi-year TxDOT vehicle classification counts, year-end TxDOT/Texas Department of Motor Vehicles (TxDMV) registration data, and MOVES default data. For this analysis, 2015 VMT-Mix for TxDOT Dallas district was used.

STEP 4- ESTIMATE OF COMPOSITE EMISSION FACTORS

Emission rates and VMTmix from previous steps are used to estimate composite emission factors by single unit short-haul truck (SUSHT) and combination long-haul truck (CLHT) category by roadwaytype and speed. SUSHT and CLHT corresponding VMT mix and emission rates are multiplied to estimate composite emission factor by roadwaytype, speed and vehicle type as shown in Table C.

$$\sum_{i} \boldsymbol{Composite\ EF}\ (\boldsymbol{vehicle\ type}, \boldsymbol{Speed}, \boldsymbol{Roadwaytpe}) = \boldsymbol{Emission\ Factors}(\boldsymbol{vehicle\ type}, \boldsymbol{Speed}, \boldsymbol{Roadwaytpe}) \times \boldsymbol{VMTMix}\ (\boldsymbol{vehicle\ type}, \boldsymbol{Speed}, \boldsymbol{Roadwaytpe})$$

i = Emission Processes

Table C. Sample of Emission Rates.

Year	Roadway Type	Average Speed	SUSHT_NOX_ER	CSHT_NOX_ER
2015	Rural-Arterial	2.5	25.84117889	49.00380325
2015	Rural-Arterial	3	21.1411953	41.21664047
2015	Rural-Arterial	4	15.26610279	31.48253632
2015	Rural-Arterial	5	12.09150887	25.6421833
2015	Rural-Arterial	6	10.41320705	21.86668968
2015	Rural-Arterial	7	9.214411736	19.57469177
2015	Rural-Arterial	8	8.315330505	17.85570717
2015	Rural-Arterial	9	7.616043568	16.51872444
2015	Rural-Arterial	10	7.05659008	15.44911575
2015	Rural-Arterial	11	6.605045319	14.57401085
2015	Rural-Arterial	12	6.241930008	14.09696865
2015	Rural-Arterial	13	5.934678555	13.75154305
2015	Rural-Arterial	14	5.671319485	13.45542145
2015	Rural-Arterial	15	5.443076134	13.19882107
2015	Rural-Arterial	16	5.226311684	12.88965416
2015	Rural-Arterial	17	5.010969639	12.49742508
2015	Rural-Arterial	18	4.819551468	12.14876461

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