Texas A&M Transportation Institute

Oversize/Overweight Heavy-Duty Vehicle Emissions Impacts Study for the Dallas-Fort Worth Non-attainment Area

FINAL REPORT

Prepared for the

North Central Texas Council of Governments (NCTCOG)

March 2020

Environment and Air Quality Division

Oversize/Overweight Heavy-Duty Vehicle Emissions Impacts Study for the Dallas-Fort Worth Non-attainment Area: Final Report

DATE: May 18, 2020

TO: Jason Brown
North Central Texas Council of Governments (NCTCOG)

COPY TO: Chris Klaus, NCTCOG
Huong Duong, NCTCOG
Jenny Narvaez, NCTCOG
Vivek Thimmavajjhala, NCTCOG

FROM: Reza Farzaneh, PhD, P.E.
Jeremy Johnson
Madhu Venogupal
Adam Mayer
Rohit Jaikumar
Dan Seedah, PhD, P.E.
Jolanda Prozzi
Environment and Air Quality Division, Texas A&M Transportation Institute

FOR MORE INFORMATION:

Jolanda Prozzi
(512) 407-1104
j-prozzi@tti.tamu.edu

ACKNOWLEDGMENTS

This study was conducted by the Texas A&M Transportation Institute (TTI) from funding provided by the North Central Texas Council of Governments (NCTCOG). The authors of this report would like to thank Chris Klaus, Jason Brown, Huong Duong, Vivek Thimmavajjhala, Jenny Navarez, and the entire NCTCOG team for their input and contributions to this project.

Additionally, TTI would like to thank the following for their assistance and participation in the project:

- Bill Knowles from the Texas Department of Transportation and Jimmy Archer from the Texas Department of Motor Vehicles for facilitating access to weigh-in-motion and permit data, respectively.
- A1 Towing, Barry's Heavy Haul, and Lone Star Transportation for their participation in the data collection efforts using portable emissions measurement systems and portable activity measurement systems.
- Major Chris Nordloh from the Texas Highway Patrol; Lieutenant Monty Kea, Alexis Crockett, and Sergeant Matt Kasenic from Garland Commercial Vehicle Enforcement; Lieutenant Daniel Plumer from the Dallas Sheriff's Office; Officer Scott Hayney from the Lewisville Police Department; and Staff Sargent John Hurt and Officer Larry Tapp from the Dallas County Sheriff's Department Commercial Vehicle Enforcement Division for allowing the research team to observe the overweight vehicle enforcement efforts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Currently, the Dallas-Fort Worth (DFW) region is in violation of federal ambient air quality standards for ozone. The reduction of oxides of nitrogen (NO_x) emissions, an ozone precursor, is an important part of achieving regional air quality goals. Heavy-duty vehicles (HDVs) are a major contributor of NO_x emissions, contributing a significant proportion of total on-road emissions. Within the HDV population, it is believed that oversize (OS)/overweight (OW) vehicles generate higher levels of emissions than an average HDV due to excessive load on the engine during OS/OW operations. However, there is limited existing information/knowledge on this subject. Therefore, it is important to develop a systematic approach to understanding the contribution of these vehicles to regional emissions and to develop appropriate policies to reduce OS/OW NO_x emissions.

The overall goal of the project was to estimate the emissions impacts of OS/OW vehicles operating in the DFW non-attainment (NA) area. The project objective was accomplished through the completion of three main activities:

- Characterization of OS/OW operations in the DFW region—To determine the impact of OS/OW operations, the research team first looked at the status of OS/OW operations in the area. This task included analyzing currently available data on OS/OW activities in the area, including weigh-in-motion (WIM) data from the Texas Department of Transportation (TxDOT), OS/OW permit data from the Texas Department of Motor Vehicles (TxDMV), and data on commercial vehicle weight-related violations from the Texas Department of Public Safety (TxDPS).
- OS/OW activity and emissions data collection—To determine the impact of OS/OW activities, the research team collected and analyzed vehicle activity and emissions data from a sample of OS/OW vehicles. The data collection effort included real-world activity data collection and emissions testing using portable emissions measurement systems (PEMS).
- Analysis and estimation of OS/OW vehicle operations and emission rates—The collected field data were used to develop emission rates for different OS/OW scenarios used in the analysis to quantify the emissions impacts of OS/OW operations in the DFW area. The analyses were based on methods used in the U.S. Environmental Protection Agency's (EPA's) MOtor Vehicle Emissions Simulator (MOVES) model.

This report provides a summary of the work conducted and the results obtained from the data analysis. The first section, OS/OW Vehicle Operations in NCTCOG Region,

summarizes OS/OW vehicle operations in the NCTCOG region, the OS/OW Activity and Emissions Data Collection section summarizes the OS/OW vehicle activity and emissions data that were collected for the project, the OS/OW Emissions Data Analysis section summarizes the analysis of the OS/OW emissions data, and finally the Regional Emissions Impact of OS/OW Operations section summarizes the estimation of the regional impacts of OS/OW operations. Additional information and analyses conducted are included as appendices to this report:

A. Appendix A includes a brief history of OS/OW regulations, the current limits set for permitted and non-permitted loads, the type of permits issued in Texas, and the movement restrictions for operating permitted loads.
B. Appendix B includes information on OS/OW vehicle operations from sources identified during the literature review, including recent studies on OS/OW vehicle operations in Texas.
C. Appendix C provides the WIM data from the WIM stations in the NCTCOG area by vehicle classification.
D. Appendix D provides a summary of other studies that evaluated the emissions impacts of OW vehicles.
E. Appendix E describes the study design plan that guided the data collection efforts that were conducted for the study.
F. Appendix F describes the data-processing steps used to obtain the emission rate information from the raw emissions data collected during the testing task.
G. Appendix G covers the unauthorized OS/OW field campaign and results from the data collection.
H. Appendix H provides all the emission rates calculated from the data collected during the testing of a sample of OS/OW vehicles.

OS/OW VEHICLE OPERATIONS IN NCTCOG REGION

This section outlines OS/OW vehicle operations in the NCTCOG region. The findings in this section are based on the analysis of three main sources of OS/OW operations data in the area:

- WIM data from TxDOT.
- Texas Permitting and Routing Optimization System (TxPROS) permit data from TxDMV.
- Commercial vehicle violations data from the TxDPS Commercial Vehicle Enforcement Service.[a]

Figure 1 summarizes the information included in each data source.

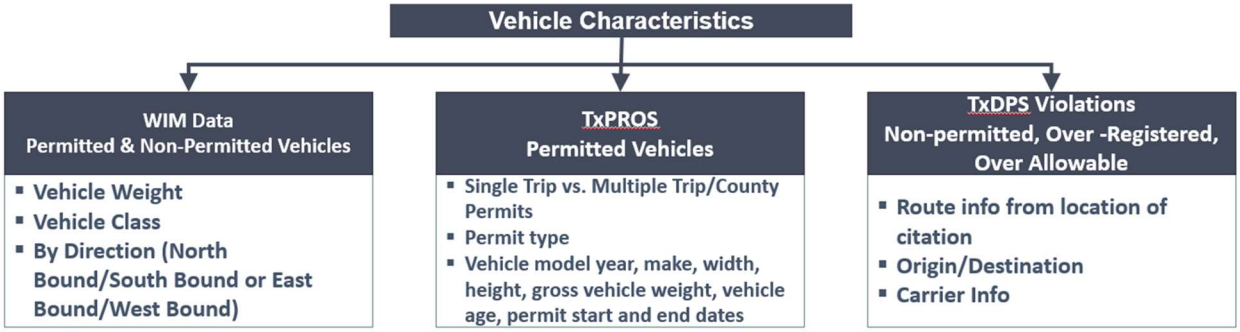

Figure 1. OS/OW Data Sources and Permit Types

The NCTCOG area covers 16 counties in the DFW area. Figure 2 outlines the counties in the NCTCOG region.

a. TxDPS commercial vehicle enforcement officers use portable static or WIM scales to check the axle weights of commercial vehicles. Officers direct a vehicle suspected of being overweight to a flat, leveled area to measure and verify the weights. Scales are positioned in front of the axles. The truck driver carefully moves the vehicle forward until the axles are directly over the scales (portable scales) or slowly moves the vehicle over the scales (WIM).

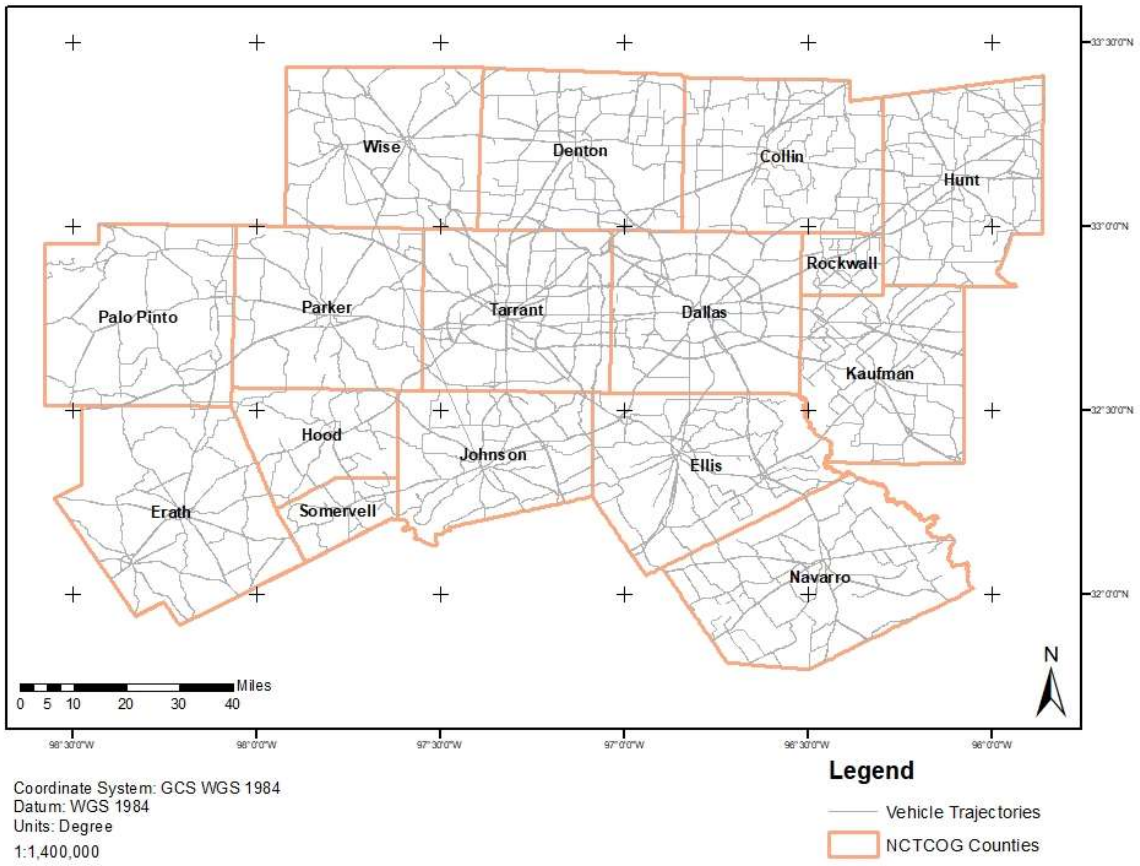

Figure 2. NCTCOG Counties

WEIGH-IN-MOTION DATA

TxDOT operates 39 WIM sites in Texas, including four sites in the geographical boundaries of NCTCOG. Two additional sites are located on major interstate corridors just outside the boundaries of the NCTCOG counties. Figure 3 shows the WIM sites in Texas and within the NCTCOG boundaries.

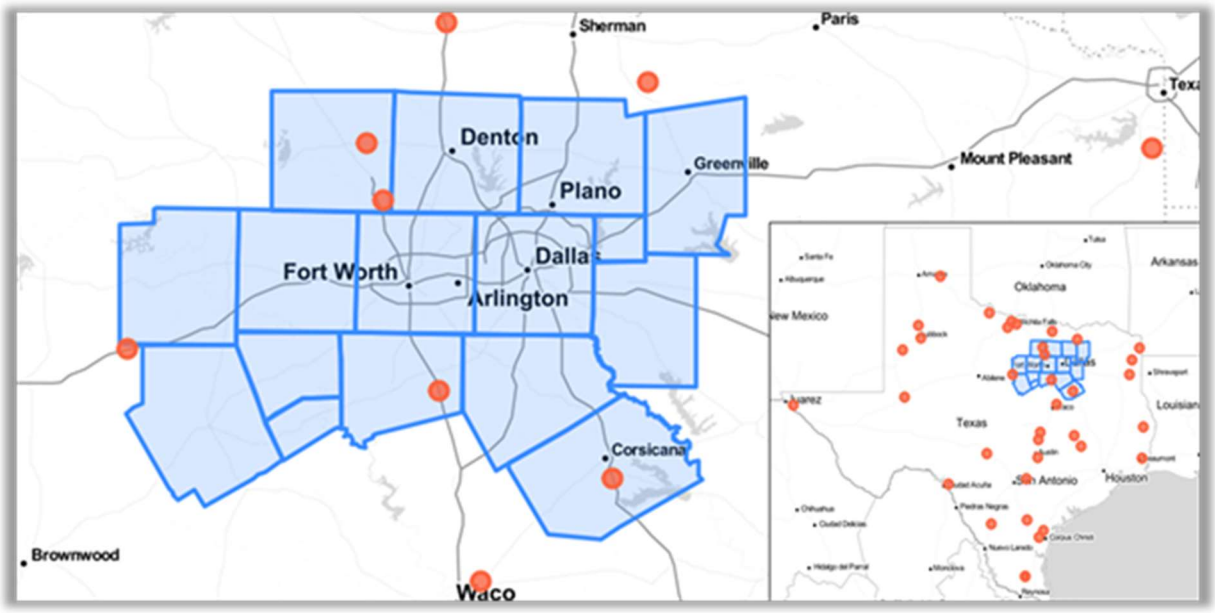

Figure 3. TxDOT WIM Sites within NCTCOG Boundaries and Texas

The WIM sites record data using the Vehicle Tracking Recording Information System (VTRIS) developed by the Federal Highway Administration. The sites record the following per-vehicle data:

- Time and date.
- Lane number.
- Speed.
- Vehicle classification.
- Wheel load.
- Axle load.
- Axle group load.
- Gross vehicle weight (GVW).
- Individual axle spacing.
- Overall vehicle length.
- Violation code.

Three years of data for each of the four WIM sites within the NCTCOG boundaries were analyzed for this study. The exception was for the site near Corsicana, which was missing data from February 2016 to December 2017. Figure 4 shows the vehicle count

distribution for each of the sites by year. Approximately 10.5 million vehicles were recorded in the three years included in the WIM data analysis.

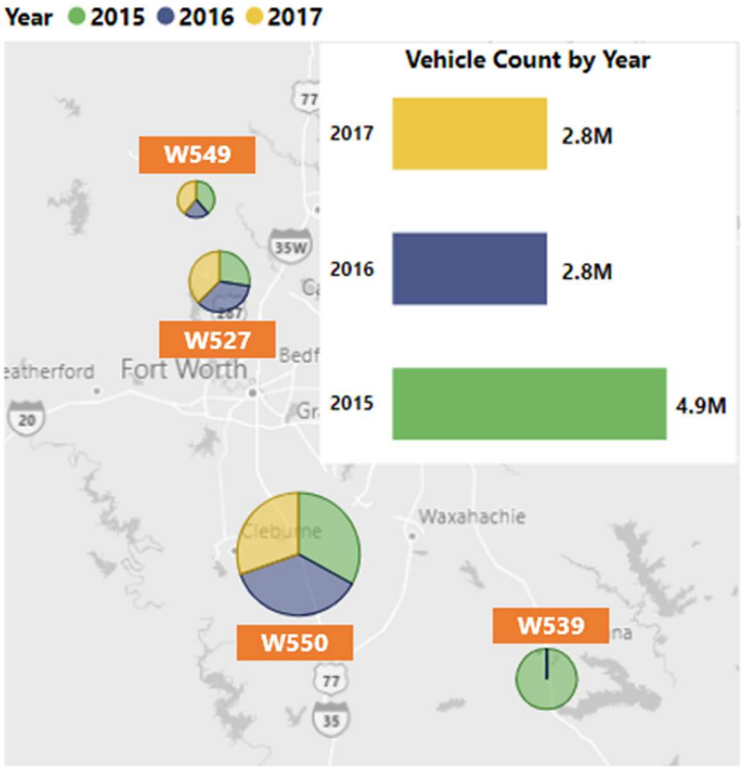

Figure 4. WIM Vehicle Count Distribution by Year

Figure 5 shows the percentage of all heavy-duty trucks by weight that were included in the WIM data. The average weight of all trucks was 55,930 pounds, with just over 13 percent of the trucks being over the 80,000-pound limit. Of the vehicles that exceeded the 80,000-pound limit, 90.6 percent were classified as Class 9 trucks (shown in Figure 6), which are single-trailer five-axle configurations. The average truck weight for Class 13 trucks (multi-trailer configurations with seven or more axles) was much higher, at 112,300 pounds, than the average weight of 83,700 pounds for Class 9. Class 10 trucks also recorded a higher average weight (92,300 pounds) than Class 11 and 12 trucks (approximately 60,000 pounds). Class 8 trucks recorded the third highest average vehicle weights at 90,500 pounds. Appendix C includes a more detailed discussion of the WIM data by truck classification.

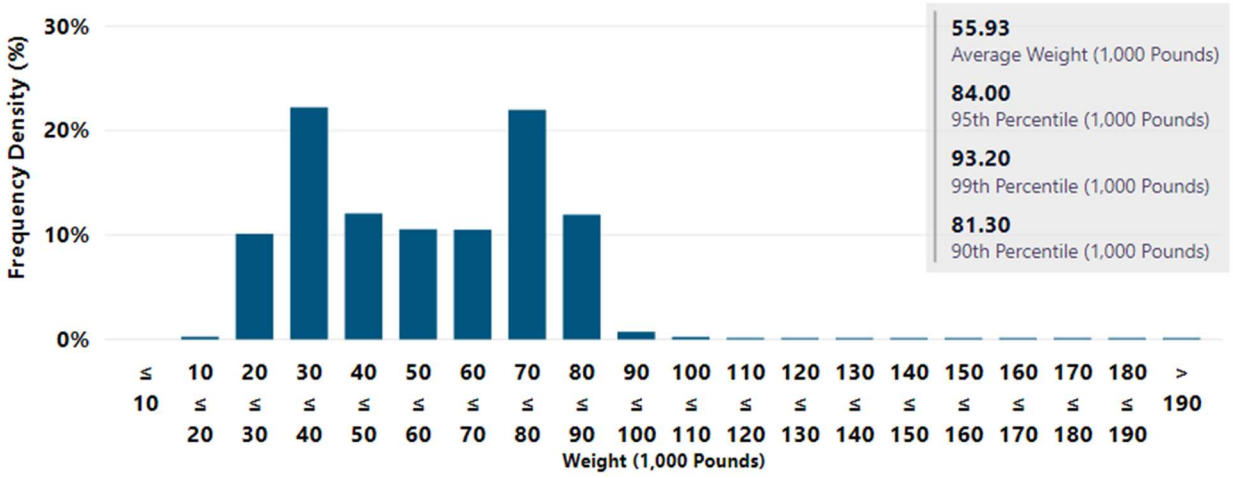

Figure 5. Percentage of Heavy-Duty Trucks by Weight Recorded at WIM Stations

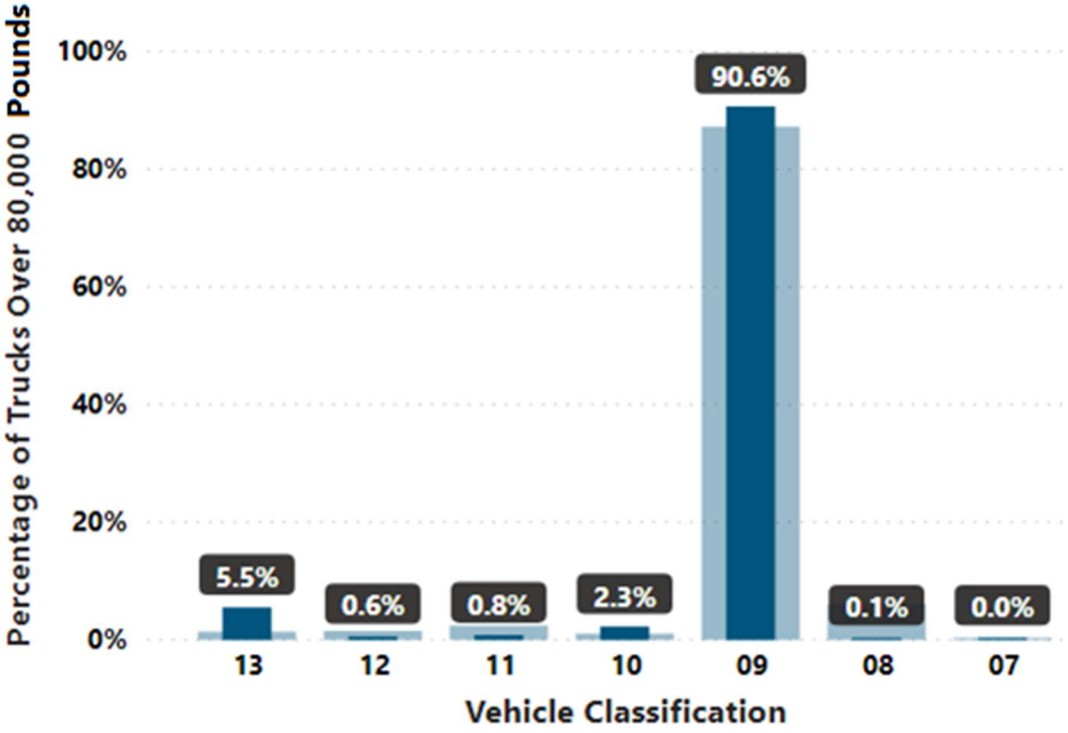

Figure 6. Vehicle Class Distribution of Trucks Exceeding 80,000 Pounds (in Comparison to Percentage of All Trucks Regardless of Weight in Lighter Shade)

PERMIT DATA

The second data set analyzed for understanding OS/OW operations in the NCTCOG region was the TxPROS permit data. Two main groups of permit data are available from TxPROS:

- Single-trip routed permits.
- Multi-trip, non-routed county permits.

Previous studies have demonstrated that single-trip routed permits account for more than 80 percent of the total vehicle permits issued by TxDMV (1, 2, 3). However, multi-trip, non-routed county permits account for more trips because these permits can be used multiple times in a given time period and sometimes for multiple vehicle types. The vehicle miles traveled (VMT) may, therefore, be much higher than for the single-trip routed permits. Table 1 outlines the permit types from TxPROS that are applicable to the NCTCOG region.

Table 1: Applicable OS/OW TxPROS Permit Types in NCTCOG Area

Permit Group	Permit Type
Single Trip Permits (Origin to Destination)	• General Non-Divisible Permit • Manufactured Housing Permit • Super Heavy Permit • House Move Permit • Cranes and Well-Servicing Units

Multiple County Trip Permits (Permitted Counties)	• Temporary Registration Permit
	• Divisible Loads Annual Permit
	  ○ Over Axle/Over Gross Weight Tolerance Permit
	  ○ Utility Pole Permit
	  ○ Timber Permit
	• Non-Divisible Loads
	  ○ 30/60/90-Day Permits
	  ▪ Limited Width or Length
	  ▪ Quarterly Hubometer
	  ○ Annual Permits
	  ▪ Vehicle-Specific Envelope
	  ▪ Hay
	  ▪ Manufactured Housing Annual (20-Mile Radius)
	  ▪ Mobile Crane
	  ▪ Well-Servicing Unit
	  ▪ Rig-Up Truck
	  ▪ Water Well Drilling Machinery and Equipment
	  ▪ Ready-Mixed Concrete Trucks
	  ▪ Annual Length Permit
	  ▪ Fluid Milk Transport Permit
	  ▪ Company-Specific Envelope

Non-Applicable Permits (Permits not applicable in NCTCOG Region)	• Intermodal Shipping Container Pert Permit • Self-Propelled Off-Road Equipment • Federal Disaster Relief Permit • North Texas Intermodal Permits

The study team analyzed TxPROS data from September 2015 to August 2018. Table 2 shows that the total number of route and county permits pertaining to the NCTCOG geographical boundary was between 22 and 25 percent of the annual statewide total. As in previous studies, the study team found that single-trip routed permits accounted for more than 80 percent of the total vehicle permits issued. Table 3 shows an increasing number of both multi-trip non-routed county permits and single-trip routed permits in the NCTCOG region between fiscal year (FY) 2016 and FY2018.

Table 2. Number/Percentage of NCTCOG Permits by Fiscal Year (September to August)

Period	Statewide Total	NCTCOG	Percent of Statewide Total (Percent)
FY 2016	665,700	146,456	22.0
FY 2017	701,826	173,136	24.7
FY 2018	810,310	179,374	22.1

Table 3. Distribution of NCTCOG Single-Trip and Multi-Trip Permits by Fiscal Year

Period	Single-Trip Routed Permits	Percent Total (Percent)	Multi-Trip Non-Routed County Permits	Percent Total (Percent)
FY 2016	125,917	86	20,539	14
FY 2017	142,213	82	30,923	18
FY 2018	145,546	81	33,828	19

Figure 7 shows the truck age distribution for all permit types. It was found that 39.3 percent of the permitted vehicles were five years old or less, 33.8 percent were between five and 15 years old, and 26.8 percent were older than 15 years. Vehicles 30 years old or more accounted for 0.47 percent of vehicle permits issued.

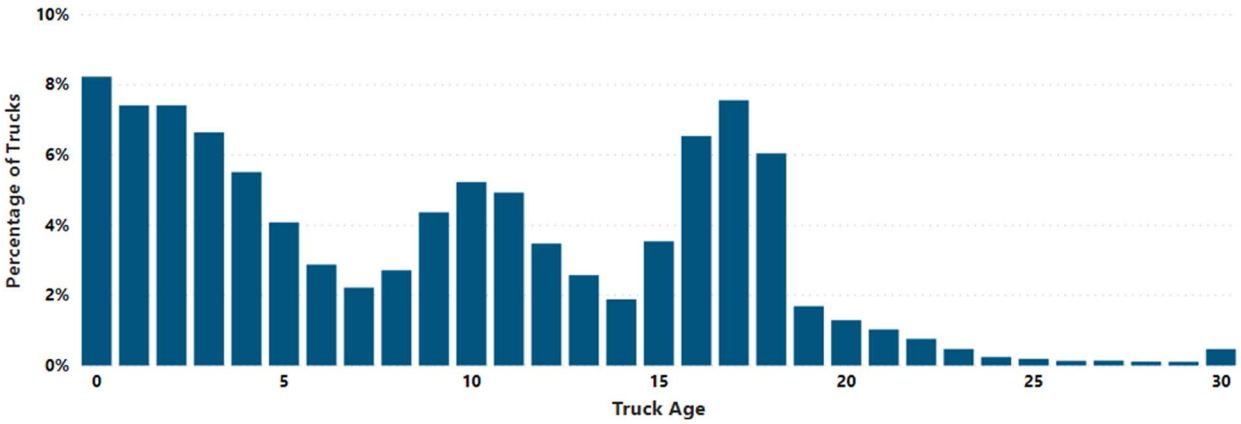

Figure 7. Truck Age Distribution (Permit Data)

Single-Trip Routed Permit Data

TxPROS single-trip routed permit data use an automated routing algorithm that considers factors such as (1):

- *Geometric restrictions* (e.g., vertical clearance, structure height, lane width, load ratings, and at-grade railroad crossings).
- *Temporal restrictions* (e.g., roadway maintenance activities, construction activities, special events, and curfews).
- *Maneuvering restrictions (*e.g., one-way attributes, access roads, and turn restrictions).
- *Special instructions* for certain roadway segments (e.g., flagmen needed to traverse a certain bridge).

At any point in time, the Texas roadway network has an estimated 1,500 restrictions. In addition to these restrictions, TxPROS uses impedances such as length, volume, and speed to identify the optimum route when multiple options are available (1).

Routed VMT within the NCTCOG boundaries ranged between 10 and 150 miles, accounting for 68.1 percent of all trips (Figure 8). However, a significant number (17.4 percent) of trips were longer than 250 miles. In comparison, the distance between the farthest county boundaries on Interstate 20 (i.e., Thurber [Erath County] to Interstate 30 near Campbell [Hunt County]) is approximately 160 miles.

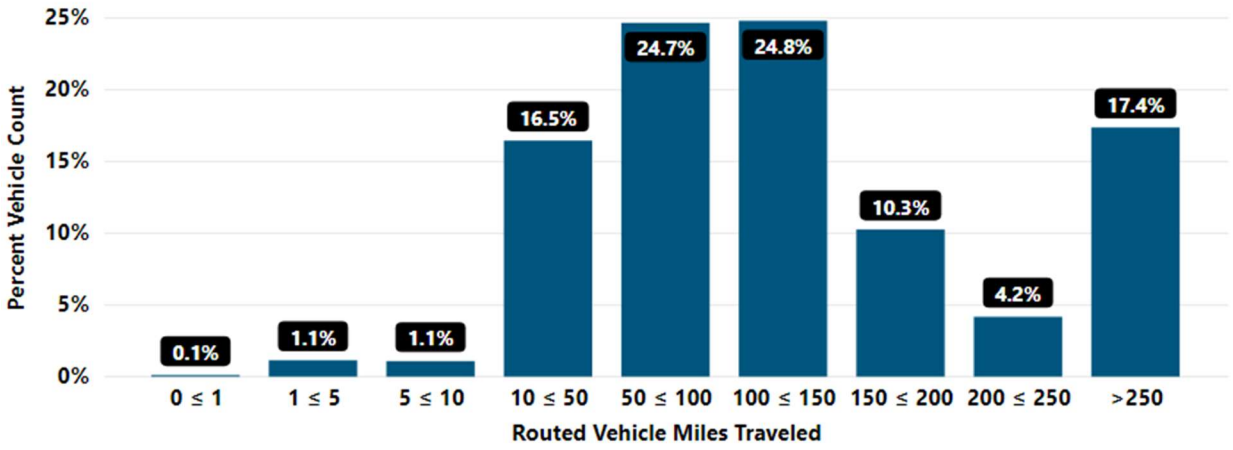

Figure 8. Truck Miles Traveled by Routed Vehicles in NCTCOG Boundaries

Figure 9 shows that 96.5 percent of routed vehicles weighed more than 80,000 pounds, and 15 percent weighed between 110,000 and 120,000 pounds. Of the routed vehicles, 11.4 percent weighed more than 190,000 pounds.

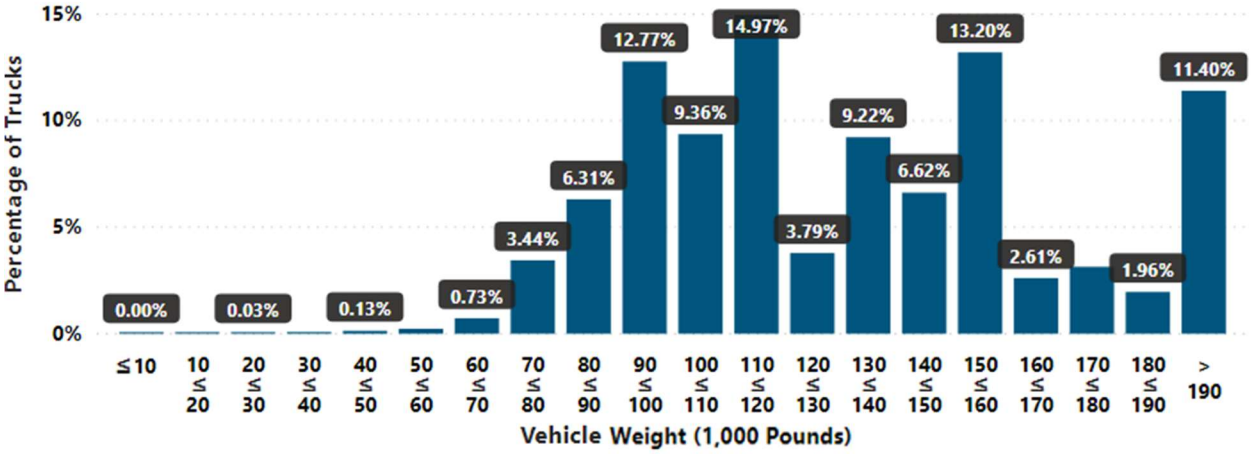

Figure 9. Truck Weight Distribution of Routed Vehicles

Figure 10 shows that the majority of the routed vehicle permits (78.1 percent) are general permits[b] followed by manufactured housing (16.5 percent) and portable building (3.7 percent) permits.

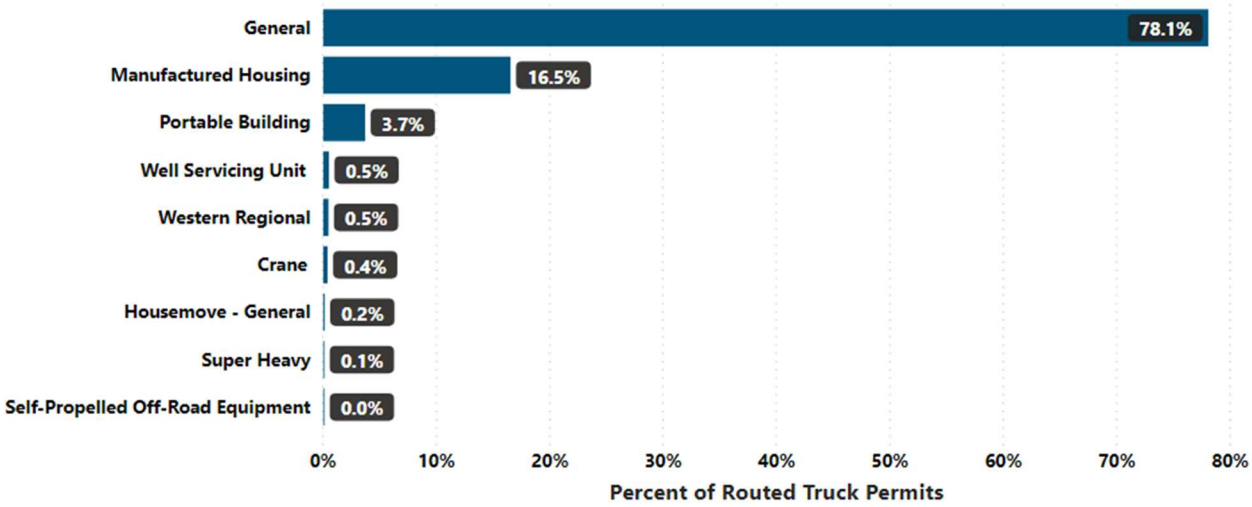

Figure 10. Percentage of Routed Truck Permit Types

Figure 11 shows that the general permit covers a variety of commodities, with the majority being general construction equipment (44.7 percent), oil and gas industry

b. Appendix A provides information for each of the 29 permit types that are issued in Texas. A general OS/OW permit authorizes the movement of a non-divisible load in a single, continuous movement from point A to point B. A single-trip manufactured housing permit authorizes the movement of manufactured housing and industrialized buildings and housing in a single, continuous movement from point A to point B. The permit is valid for five days, and the housing units can be transported on any returnable undercarriage or temporary chassis system. A general single-trip OS/OW permit is required when a stack of manufactured housing frames is hauled.

equipment (15.4 percent), manufacturing equipment (7.5 percent), road construction equipment (5.8 percent), and wind energy industry equipment (4.6 percent).

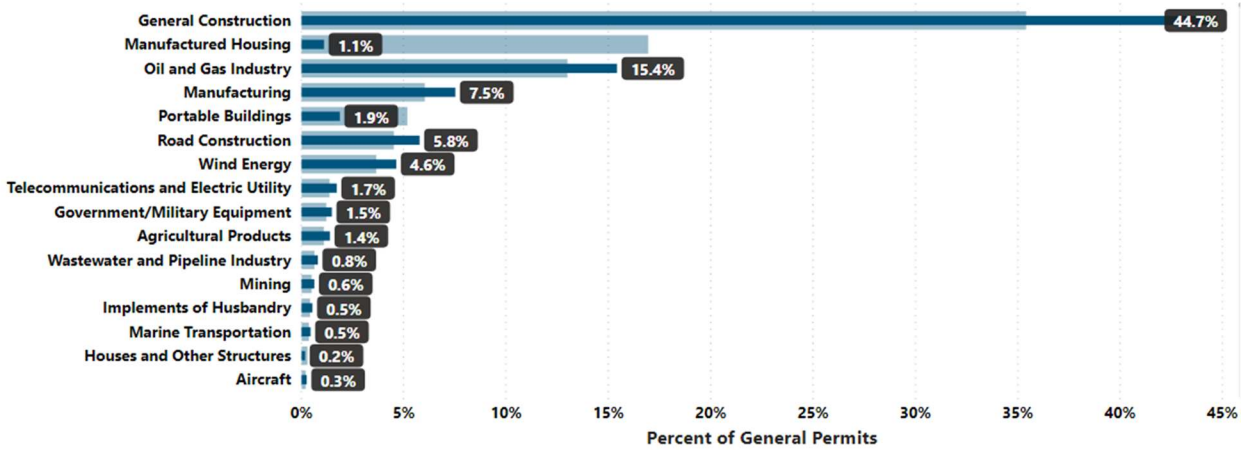

Figure 11. Percentage of General Permit Commodities Moved (in Comparison to Percentage of All Routed Permit Commodities Shown in Lighter Shade)

Multi-trip, Non-routed County Permits

The following permit types are categorized as multi-trip, non-routed county permits:

- Temporary registration permit.
- Over axle/over gross weight tolerance permit.
- Utility pole permit.
- Timber permit.
- Limited width or length.
- Quarterly hubometer.
- Vehicle specific envelope.
- Fracking trailer.
- Hay.
- Implements of husbandry.
- Manufactured housing annual (20-mile radius).
- Mobile crane.
- Well-servicing unit.
- Rig-up truck.
- Water well-drilling machinery and equipment.
- Ready-mixed concrete trucks.
- Annual length permit.
- Fluid milk transport permit.
- Company-specific envelope.

Some of these permit types cover multiple days (30, 60, or 90) or even a whole year (Appendix A includes a detailed description of the permit types). Furthermore, the company-specific annual envelope permit is issued to a specific company (not a specific vehicle) and may be used to operate any registered truck owned or leased to that company. Each company-specific permit only allows one vehicle to be operated at a given time with a specific permit, but a company may purchase more than one permit

(4). Due to these rules for the company-specific permits, the actual miles driven (as well as the vehicle model, year, and gross weight) by each vehicle within the allowable time period is unknown.

Figure 12 shows that in the NCTCOG region, most (89.6 percent) of the multi-trip county permits are over axle/over gross weight tolerance permits, with ready-mixed concrete permits accounting for the remaining 10.4 percent of the multi-trip county permits issued between September 2015 and August 2018.

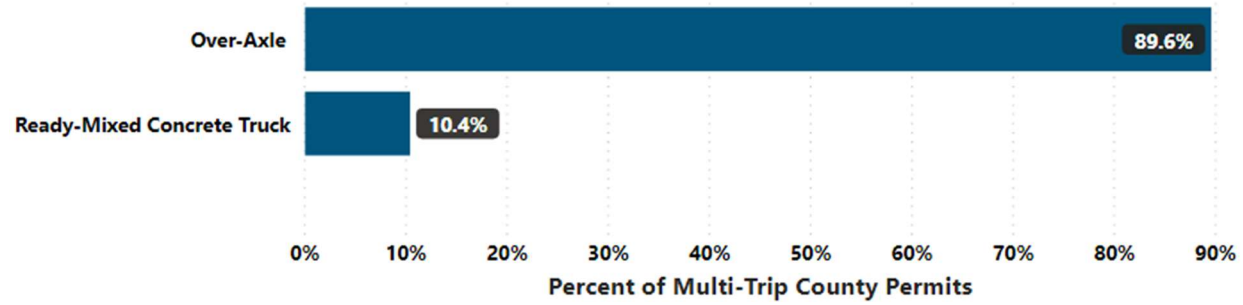

Figure 12. Percentage of Multi-Trip County Permit Types

Figure 13 shows that the majority (45.6 percent) of the multi-trip county permits are used for moving general construction materials, followed by oil and gas industry equipment (25.8 percent), agricultural products (7.7 percent), manufacturing equipment (6.5 percent), and road construction equipment (3.9 percent).

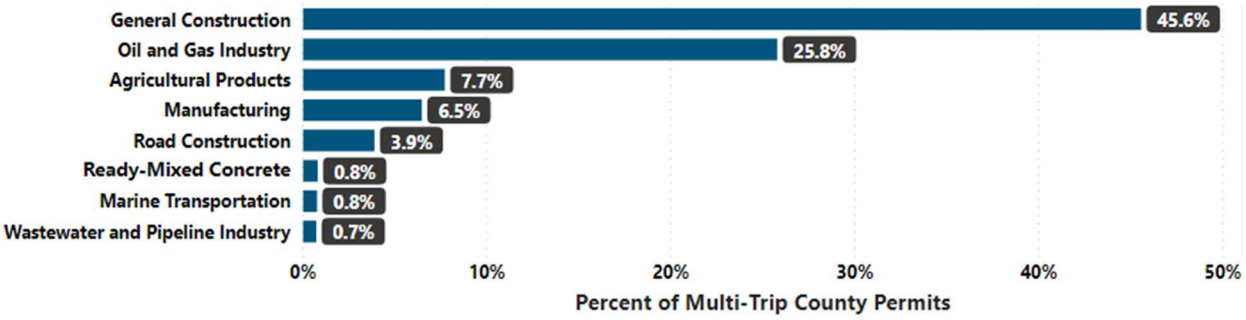

Figure 13. Commodities Moved by Multi-Trip County Permits

TxDPS Violations Data

The third data set analyzed on OS/OW operations in the NCTCOG region was the violation data provided by TxDPS. TxDPS performed 166,860 inspections in the NCTCOG region between January 2015 and September 2018. These inspections resulted in

459,139 violations,[c] of which 11,925 (2.6 percent) were related to weight. Figure 14 shows the weight-related violations. Most of the weight-related violations (4,740) were trucks over the allowable GVW.

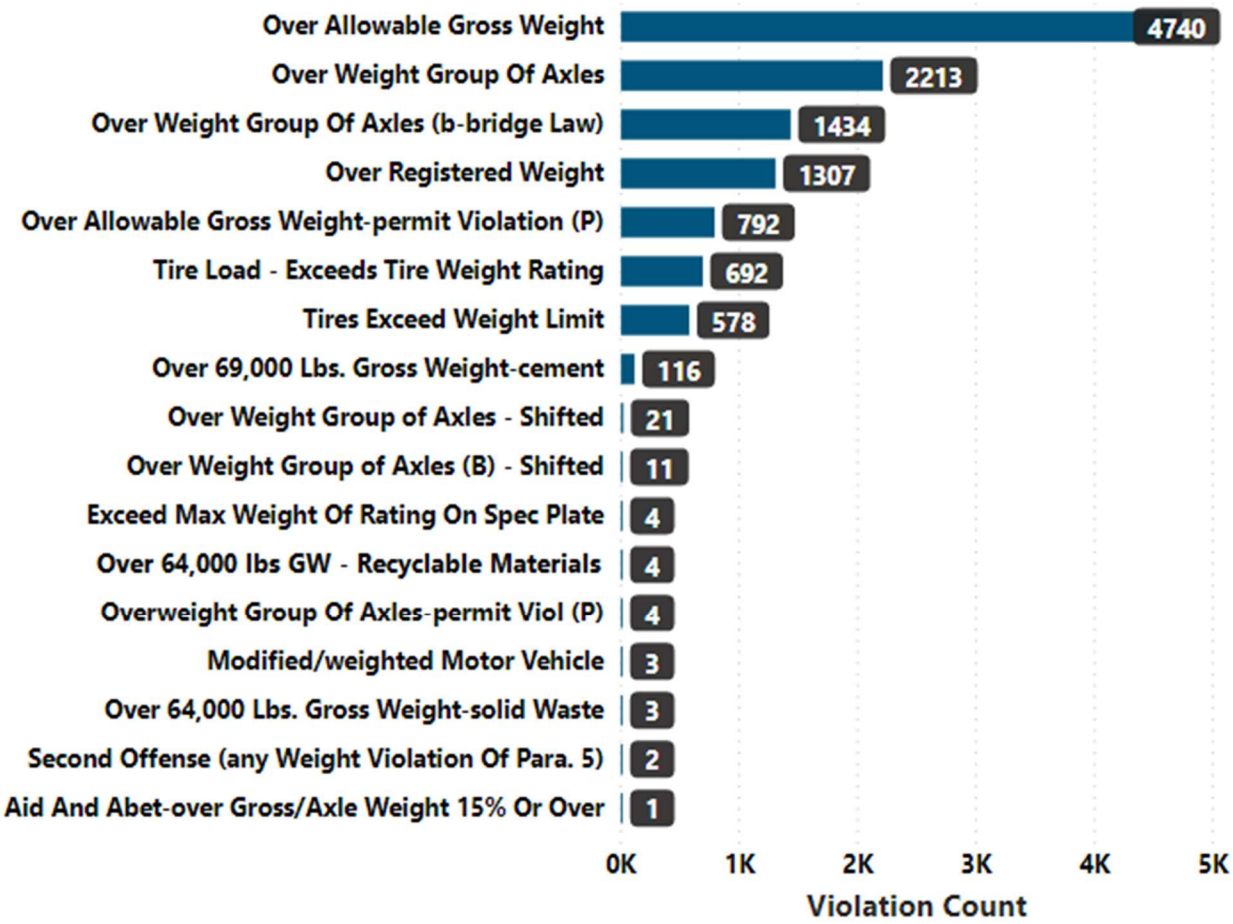

Figure 14. Weight-Related Violations

The study team identified 7,984 unique vehicles with one or more violations. Figure 15 provides the breakdown of violating vehicles by NCTCOG county. Tarrant, Dallas, Johnson, Wise, and Denton Counties—through which the north-south Interstate 35/45 corridors and Interstate 20/30 traverse—recorded the highest number of vehicles with one or more violations.

c. More than one violation is often recorded per vehicle.

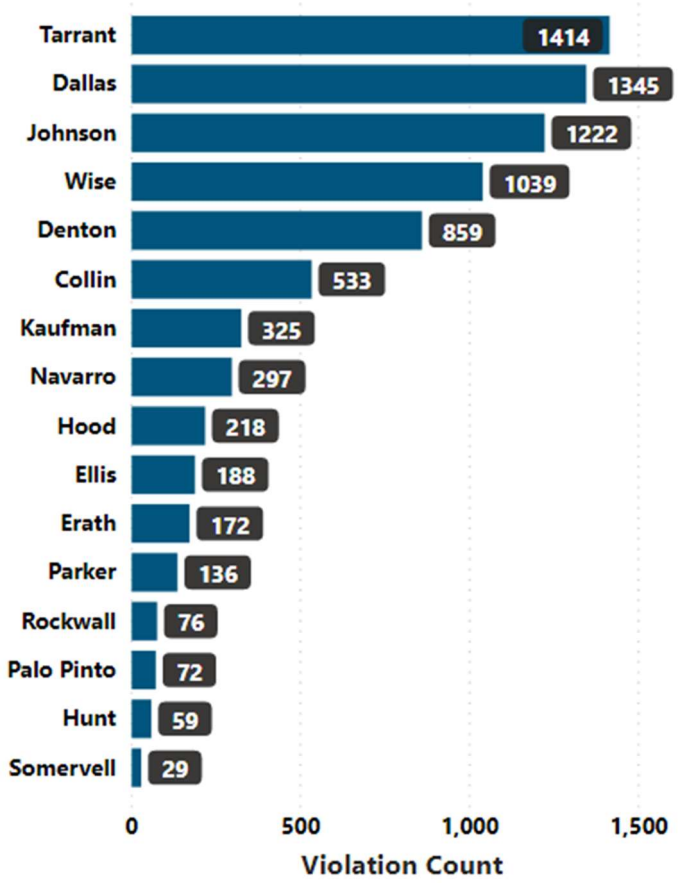

Figure 15. Number of Violating Vehicles by County

Figure 16 shows that almost all (99.4 percent) of the violating vehicles have a GVW of less than 80,000 pounds. In other words, these vehicles exceeded the federal maximum weight limits for their respective vehicle classes (Appendix A provides more details on maximum weight limits).

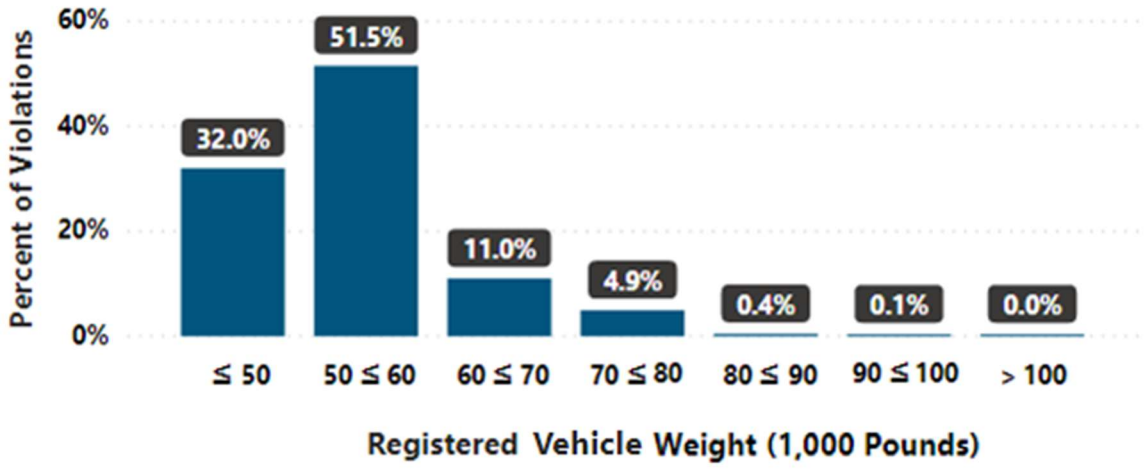

Figure 16. Registered Gross Vehicle Weights of Violating Vehicles

OS/OW ACTIVITY AND EMISSIONS DATA COLLECTION

The main objective of this study was to characterize and estimate the regional emissions impacts of OS/OW operations in the NCTCOG NA area. The emission estimation methodology used is based on the EPA MOVES model. Upon the review of the TxDOT WIM data, the TxPROS permit data, and the TxDPS violation data, the research team identified four major data categories needed to estimate the overall emissions impact of OS/OW operations in the NCTCOG region. The four areas identified were:

- OS/OW vehicle characteristics (outlined in the previous section).
- OS/OW vehicle activity.
- OS/OW vehicle emission rates.
- Unauthorized OS/OW vehicle operations.

The first three bulleted items are needed for estimating emissions from any OS/OW truck operations, that is, both those that have obtained a permit and those that operate illegally. Figure 17 illustrates the data needs and potential data sources identified by the study team for estimating OS/OW emissions. Appendix E provides a detailed overview of the workplan that was developed to guide the study.

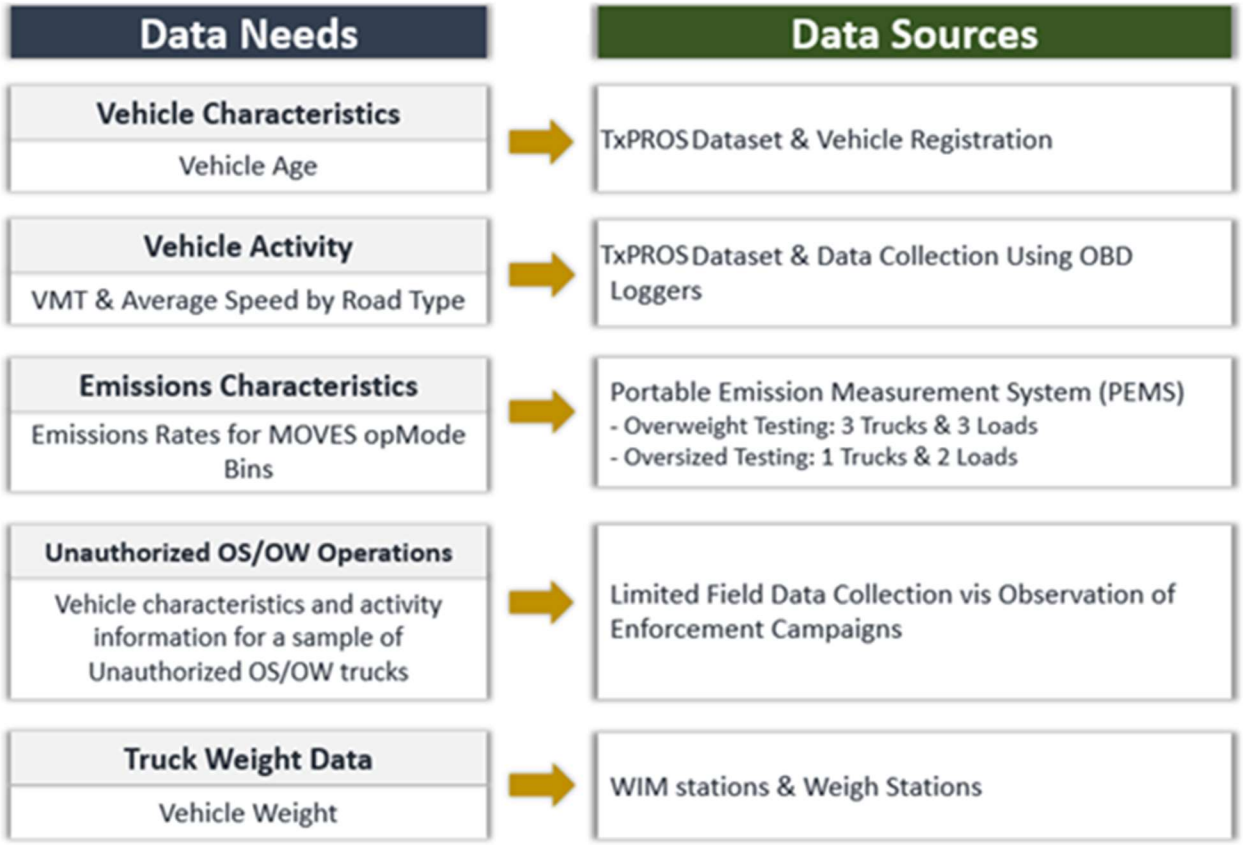

Figure 17. Study Design Data Needs and Sources

OS/OW Vehicle Activity Data Collection

As described in Appendix E, the vehicle activity data collection involved installing portable activity measurement systems (PAMS) devices on vehicles moving OS/OW loads to collect data on how they operate. The PAMS logger used in this study (shown in Figure 18) connects to the vehicle's J1939 data port and logs data at a 1-Hz frequency (i.e., second-by-second data). The logger collects both vehicle data (e.g., vehicle speed, engine speed, engine load, and many other parameters) and global positioning system (GPS) data (i.e., location and speed).

Figure 18. HEMData PAMS Data Logger

Four vehicles participated in the vehicle activity data collection. Three of them operated in the NCTCOG region, while the fourth truck was headquartered in the Bryan-College Station area. Table 4 shows the information collected on the four trucks. The PAMS data collection resulted in approximately 457 hours of vehicle operations information for the four test vehicles, covering approximately 17,500 miles of travel.

Table 4. PAMS Test Vehicles Information

Year/Make/Model	Engine Make/Model	Beginning Miles	Data Collection Start Date	Data Collection End Date
2009 Kenworth T8	Cummins ISX 485	429,937	4/2/19	4/18/19
2009 Kenworth T8	Cummins ISX 485	431,784	4/1/19	6/17/19
2007 Peterbilt 378	CAT C15	635,789	4/1/19	6/20/19
2014 Peterbilt 367	ISX15 500	236,541	7/15/19	8/14/19

Activity Data Processing

The collected PAMS data were imported into Microsoft® Power BI,[d] and a data model was established. The Power BI files used for the data processing and analysis contained all the data—that is, PAMS and PEMS data—collected for this task. The PAMS data table contained the vehicle interface (VI) and GPS data combined into a single table. Table 5 shows a list of the parameters from the PAMS table that were used in this study.

d. Microsoft Power BI is described at https://powerbi.microsoft.com/en-us/.

Table 5. Summary of VI Parameters Used in the PAMS Data Table

PAMS All Data	
Vehicle ID	SCR Intermediate NH3 (ppm)
Daily Data Count	SCR Intermediate Temperature (°C)
VI Date	SCR Outlet NO_x (ppm)
Time	SCR Outlet Temperature (°C)
Actual Engine—Percent Torque (%)	Speed (km/h)
Engine Percent Load at Current Speed (%)	Latitude
Engine Speed (rpm)	Longitude
Wheel-Based Speed (km/h)	GPS Ground Speed (mph)
Combined Wheel Speed (Km/h)	Altitude (m)
SCR Intake NO_x (ppm)	Number of Satellites
SCR Intake Temperature (°C)	Fix Type
Trip ID	Link ID

SCR = selective catalyst reduction

The combined wheel speed (see Table 5) was obtained by merging the speed data from VI and the GPS data sets. If the VI data were present for the same timestamp without any error flag, then VI speed was used. Otherwise, GPS speed was used, as long as the fix type was greater than three, which indicates a good GPS speed measurement. If both the VI speed and GPS speeds were invalid, the data point was not included in the analysis.

Figure 19 shows the spatial movement of the trucks that were monitored. The second-by-second PAMS data set was conflated with the road network information. The link ID was obtained by processing the data in ArcGIS Pro software. The processing involved map-matching the second-by-second positions of the trucks to the TxDOT functional class shape file using the spatial join tool in ArcGIS. ArcGIS matches each point to the nearest road link. In addition, researchers obtained the loading status (loaded or not loaded) for the trips from the companies.

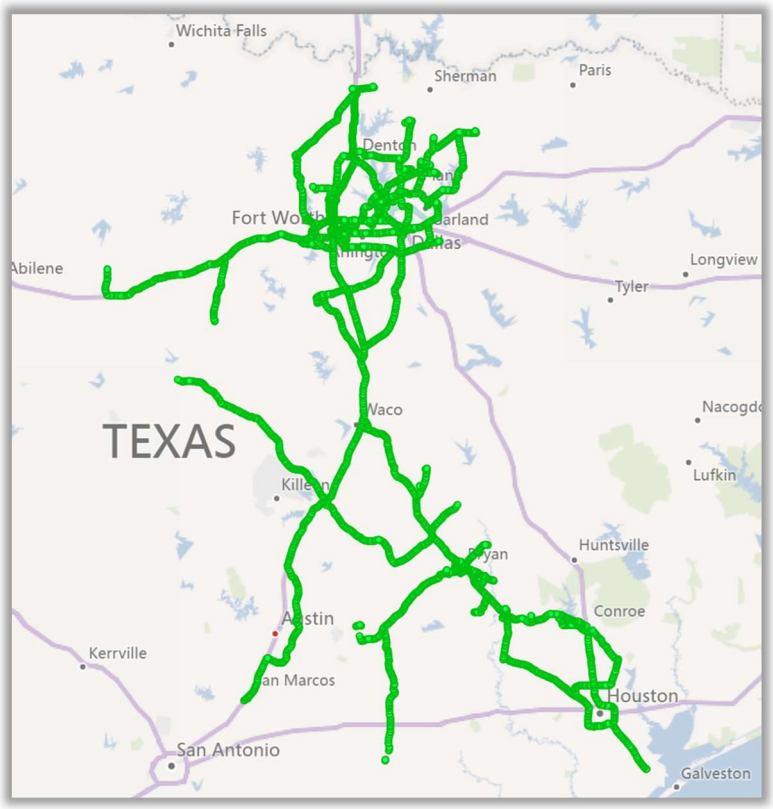

Figure 19. Truck Movement from PAMS Data

In addition to the VI data stored in the PAMS table, the research team added additional reference tables to the Power BI file, which allowed the PAMS data to be linked to other information, such as the vehicle information. Table 6 shows a summary of the different tables and parameters included in each table.

Table 6. Summary of Reference Tables in Power BI File

Trip Table	Time Sequence	Vehicle Information	MOVES Bins	TxDOT Functional Classification
Trip ID Origin Latitude Origin Longitude Destination Latitude Destination Longitude Total Trip Distance (miles) Total Trip Duration (s) Date Vehicle ID Loaded/Unloaded	Time Sequence (s)	Company ID Vehicle ID Combination Weight (pounds) Date of Manufacture VIN Engine Make Engine Model Engine Family Engine Model Year Rolling Resistance A Rotating Resistance B Drag Coefficient C	OpMode Bin Order Lower Speed (mph) Upper Speed (mph) Speed Class	Link ID Functional Class MOVES Functional Class Road Name Road Type

After establishing the data model, the second-by-second PAMS data were used to calculate the vehicle specific power (VSP) and scaled tractive power (STP) values from the EPA MOVES model. MOVES uses VSP to link emissions to power demand on a vehicle's engine. VSP is a combined measure of instantaneous speed, acceleration, road grade, and road load for a vehicle.

STP is calculated on a second-by-second basis for a medium- or heavy-duty vehicle operating over a specific speed trajectory (i.e., a drive cycle or drive schedule). Operating mode bins (opMode bins) are then defined according to the corresponding instantaneous speed and STP values. MOVES uses a database of emission rates for each opMode bin and vehicle type combination to calculate the emissions associated with any given combination of drive cycle and vehicle type based on the distribution of time spent in opMode bins. Figure 20 shows the operating mode bins using the STP MOVES calculation, and Figure 21 graphically demonstrates the process. Appendix D provides additional details on the MOVES model and calculating the VSP and STP values.

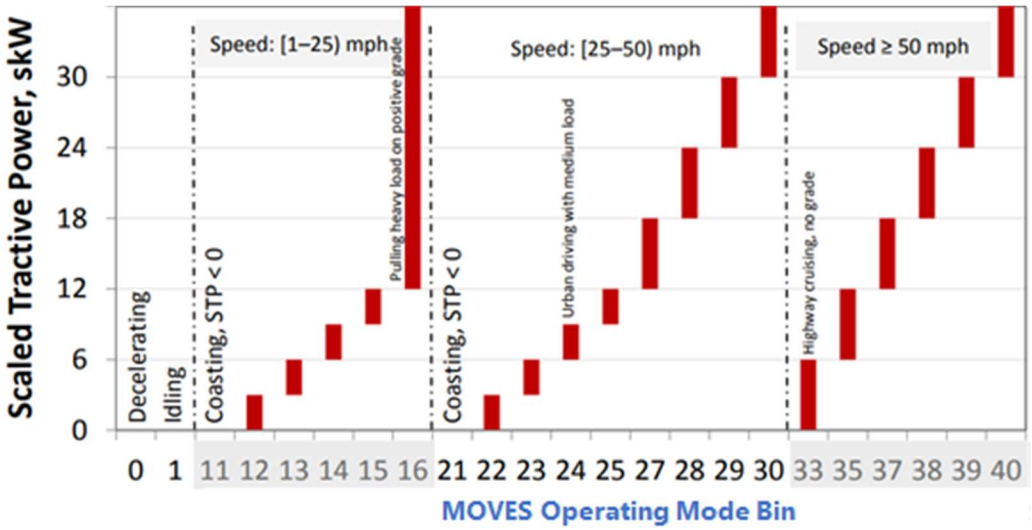

Figure 20. MOVES OpMode Definitions[e]

e. More information about running exhaust criteria pollutant emission rates is at https://www.epa.gov/sites/production/files/2017-01/documents/running-exhaust-cri-pollutant-emission-rates-my-2010-hd-vehicles.pdf.

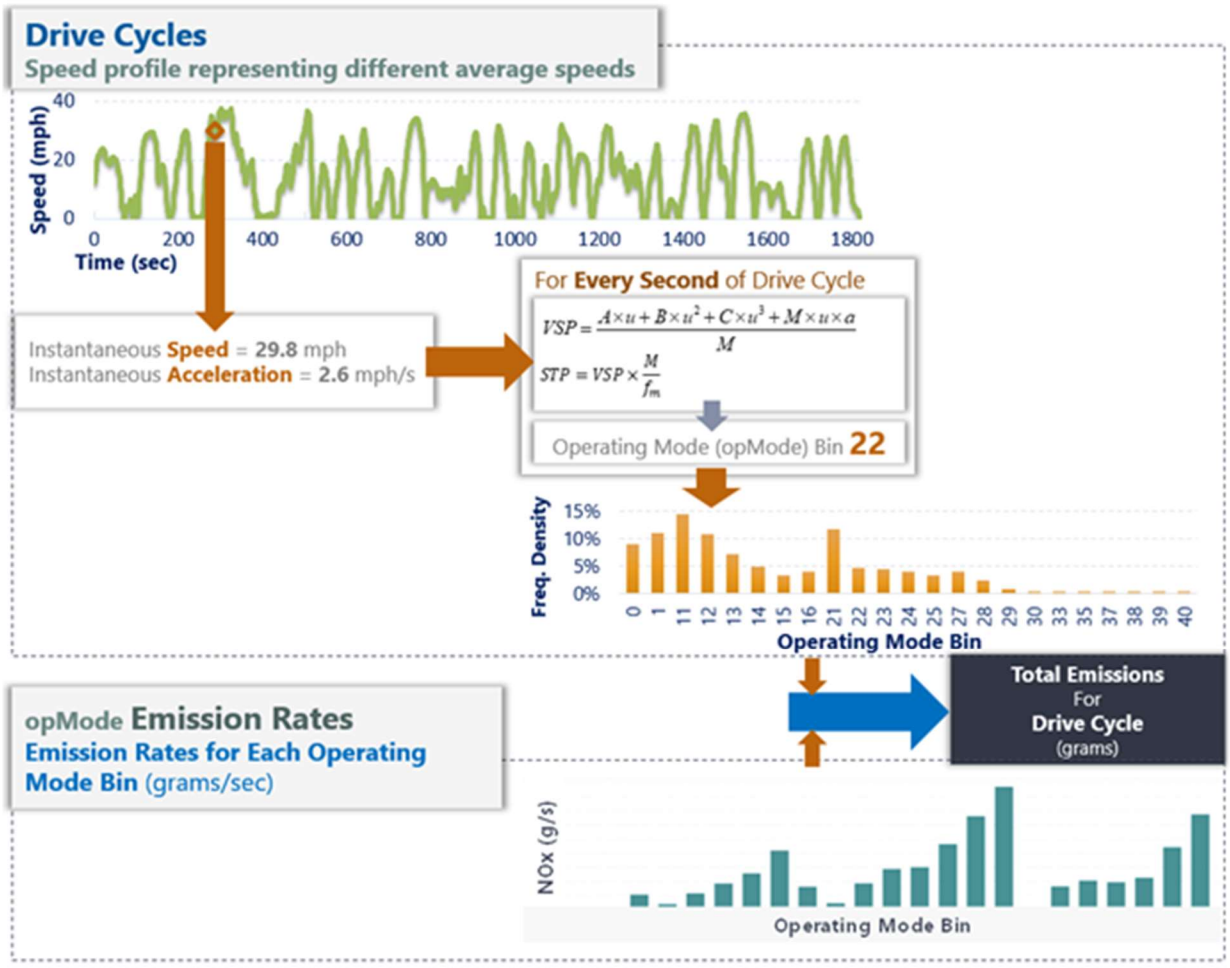

Figure 21. Emissions Estimation Process in MOVES

Activity Data Analysis Findings

Using the data visualization and analytics capabilities of Power BI, the research team extracted the aggregated trucks' activity parameters from the second-by-second data. Each data point was then associated with a road type using map matching and the TxDOT functional classification table. Figure 22 shows the VMT and the average driving speed of the trucks operating in the NCTCOG area by type of day (weekday or weekend day) and road type (restricted or unrestricted access). Most of the truck VMTs (x percent) occurred on restricted-access roads, which include freeways and highways.

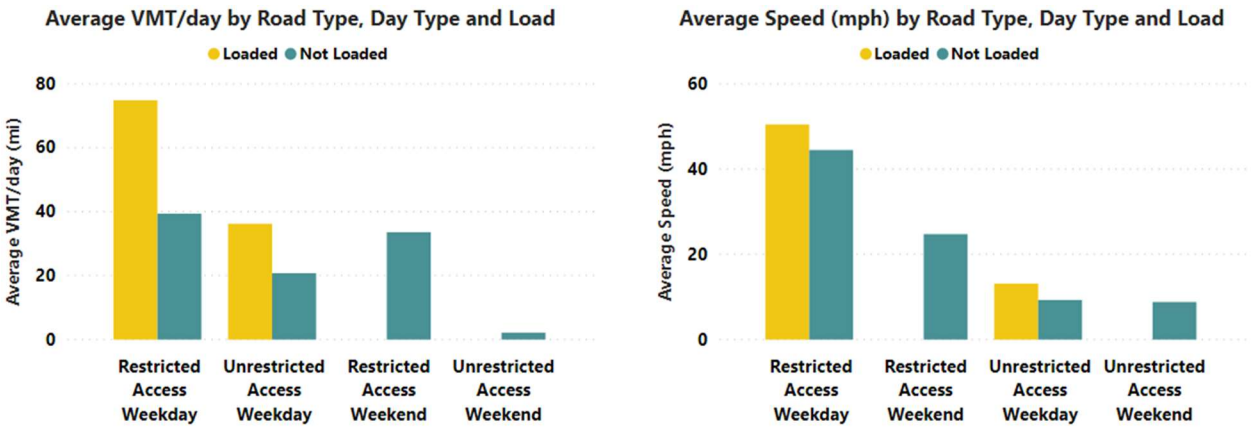

Figure 22. VMT and Speed by Road Type, Day Type, and Load for NCTCOG Region

The activity data were also used to summarize the opMode bin distributions by road type and loading state, which are shown in Figure 23 and Figure 24. These distributions indicate that the loaded trips have a higher number of high-engine-load opMode bins for speeds higher than 50 mph on restricted-access roads and 25 mph on unrestricted-access roads. There is a high amount of idling (opMode bin 1) while driving on unrestricted roadways (arterials and local roads), which may be a result of loading/unloading and signalized/unsignalized intersections.

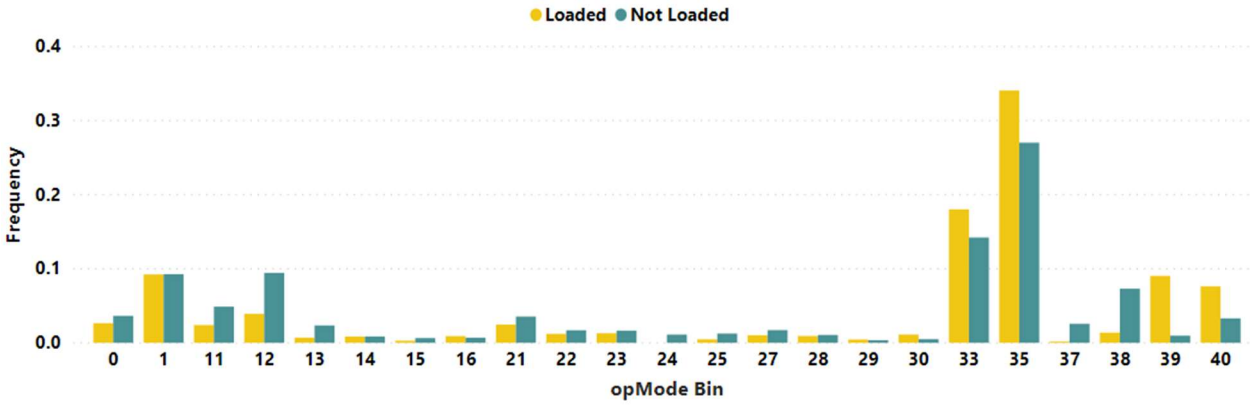

Figure 23. Restricted-Access OpMode Bin Distribution for NCTCOG Region

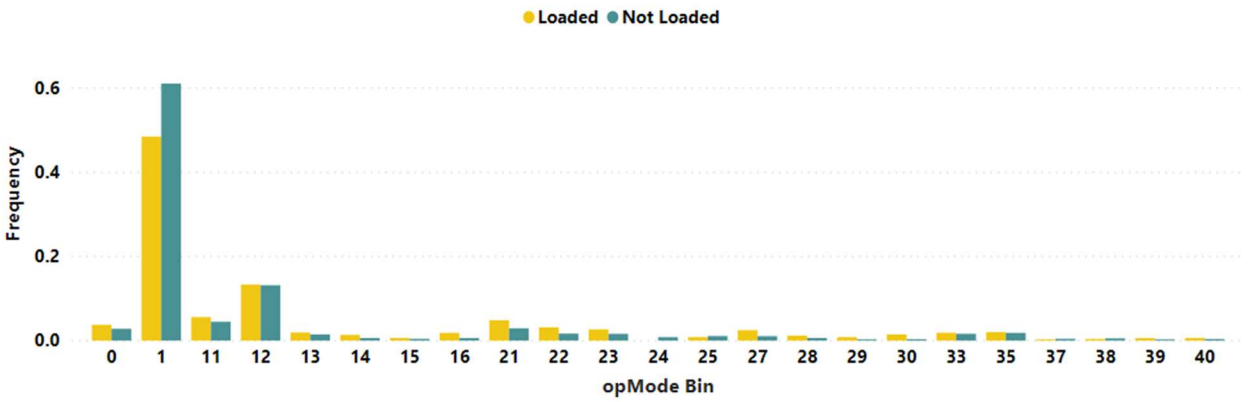

Figure 24. Unrestricted-Access opMode Bin Distribution for NCTCOG Region

OS/OW Vehicle Emissions Data Collection

To characterize the impact of load on a truck's emissions, the research team collected tailpipe emissions measurements from a sample of OS/OW trucks. The emissions testing was conducted with two PEMS units: one for measuring gaseous pollutants and one for particulate matter (PM). Appendix E provides details on the PEMS equipment used in the study.

Test Vehicles

Three vehicles were used for the emissions testing. The vehicles were chosen to cover a range of model years and NO_x emission control technologies. The selected vehicles also ensured that the sample of vehicles would be representative of the OS/OW fleet distribution (see TxPROS data in Figure 7). Table 7 shows the information for the vehicles that participated in the emissions testing.

Table 7. Emissions Testing Vehicles

Model Year	Make/Model	Engine Make/Model	Engine Family	Emissions Control System	Weight (Truck and Trailer)
2014	Peterbilt 367	Cummins ISX15 500	DCEXH0912XAU	EGR, PTOX, SCR	42,100
2009	International LF627	Cummins ISX 435ST	8CEXH0912XAK	PCM, EGR, PTOX	43,800
2005	Peterbilt 379	CAT C15	Not applicable*	Not applicable*	42,240

* The engine sticker on the 2005 Peterbilt was missing, and the engine family and emission control system could not be determined.

Test Routes

All emissions testing for this study was conducted on or around the Texas A&M University RELLIS Campus. The Texas A&M Transportation Institute's Environmental and Emissions Research Facility (EERF), which is located on the RELLIS Campus, served as the base and a central testing location for all PEMS testing conducted for this study. The emissions testing was conducted in two phases: a low-speed phase followed by a high-speed phase.

All low-speed tests were conducted on the RELLIS Campus. The RELLIS Campus is located on what was previously Bryan Air Field,[f] which includes a set of runways. These runways were used for the low-speed testing. The trucks were driven from the EERF to one of the runways on the RELLIS Campus. Once on the runway, the trucks were driven back and forth at speeds from 0 to 45 mph, including different acceleration rates. The length of the runway that was used is approximately 1.25 miles. Figure 25 shows a map depicting the GPS traces of one of the low-speed tests at the RELLIS Campus.

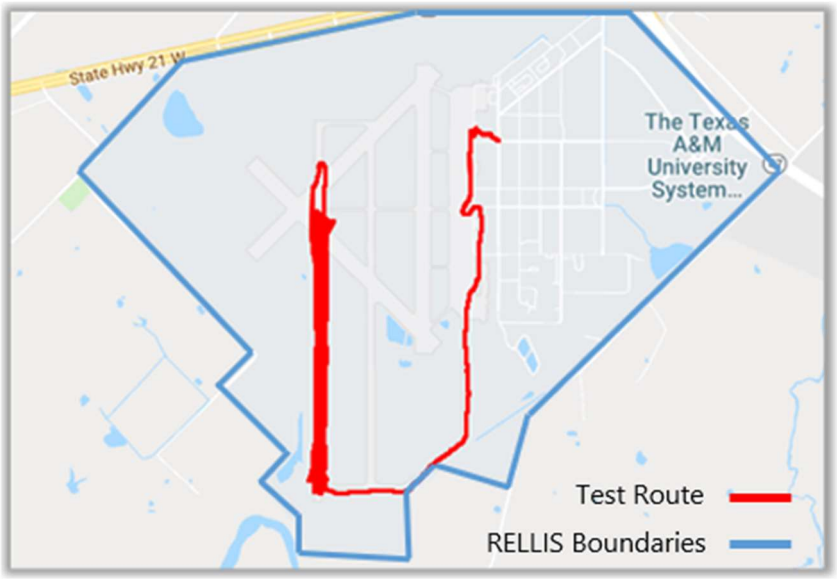

Figure 25. Map of Low-Speed Testing on RELLIS Campus

Due to the limited length of the runways, the high-speed testing could not be conducted on the RELLIS Campus. Instead, all high-speed testing was conducted on State Highway 21 (shown in Figure 26), which is just north of the RELLIS Campus. The high-speed testing was conducted using a route from the RELLIS Campus southwest toward Caldwell, Texas. During this trip, the vehicles were driven at high speeds (up to

f. Information about the history of the RELLIS Campus is at https://rellis.tamus.edu/history/.

70 mph, depending on the capability of the truck), while also going through different acceleration patterns. Figure 26 shows a map of the high-speed test route.

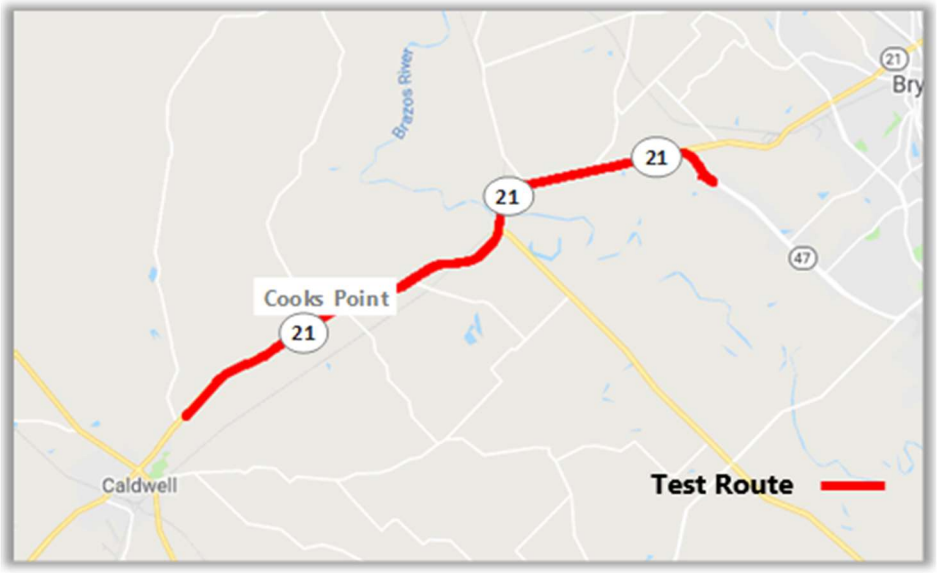

Figure 26. Map of High-Speed Test Route on State Highway 21

Emission Measurement Tests

Two separate test scenarios were developed to determine the emission impacts of OW and OS loads.

Overweight Tests

The OW tests included three different test weight groups: light/normal weight, medium/legal limit, and heavy/overweight for each of the three test vehicles. Each test weight load was the same for each of the vehicles. The load consisted of concrete blocks that were loaded on the trailer as follows:

- *Light/normal weight* (Figure 27)—The light load consisted of 9,640 pounds of concrete, resulting in a total weight of approximately 55,000 pounds.
- *Medium/legal limit* (Figure 28)—The medium load consisted of 41,560 pounds of concrete, resulting in a total weight of approximately 80,000 pounds.
- *Heavy/overweight* (Figure 29)—The heavy load consisted of 62,300 pounds of concrete, resulting in a total weight of approximately 105,000 pounds.

Each of the weight tests were conducted for each of the trucks for both the low-speed and high-speed test phases.

Figure 27. Light Load (9,640 Pounds)

Figure 28. Medium Load (41,560 Pounds)

Figure 29. Heavy Load (62,300 Pounds)

Oversized Test

Two of the three trucks, model year (MY) 2014 and 2005, were also tested with an OS load. The OS load comprised bales of hay that were stacked on the trailer to be OS yet have a weight similar to that of the normal test load. The total weight of the load used for the OS testing was 13,200 pounds, with the total approximate weight of 55,000 pounds. The OS load was just over 12 feet high at its highest point and approximately 12.5 feet wide, which is approximately 4 feet wider than allowed for a non-permitted load. Figure 30 shows the OS load used in this study.

Figure 30. OS Load (12 Feet High by 12.5 Feet Wide)

OS/OW EMISSIONS DATA ANALYSIS

Appendix F describes the steps used to process the raw data captured by the PEMS equipment. After completing the data processing, the research team developed multiple visual dashboards in Power BI to extract various combinations of parameters at different aggregation levels. The data analysis focused on the emissions of participating trucks under different loading scenarios. Because NO_x emissions are the focus of this study, the research team performed a detailed analysis of NO_x data to understand changes in NO_x as a result of changes in key parameters such as weight and operational conditions. Researchers also developed summary statistics for the other pollutants. Appendix H includes summaries of all the rates calculated for all pollutants, MYs, and scenario combinations.

Calculation of Emission Rates

The analysis of the emissions data collected from the testing of the sample OS/OW vehicles produced an emission value, in grams per second (g/sec), for every data point (Appendix D provides a description). In addition to the emission rate, each second of data was also assigned to a MOVES opMode bin. The average of all the instantaneous emission rate observations assigned to a certain opMode bin represents the average emission rate for that opMode bin. Figure 31 shows an example of average carbon dioxide (CO_2) emission rates by opMode bin.

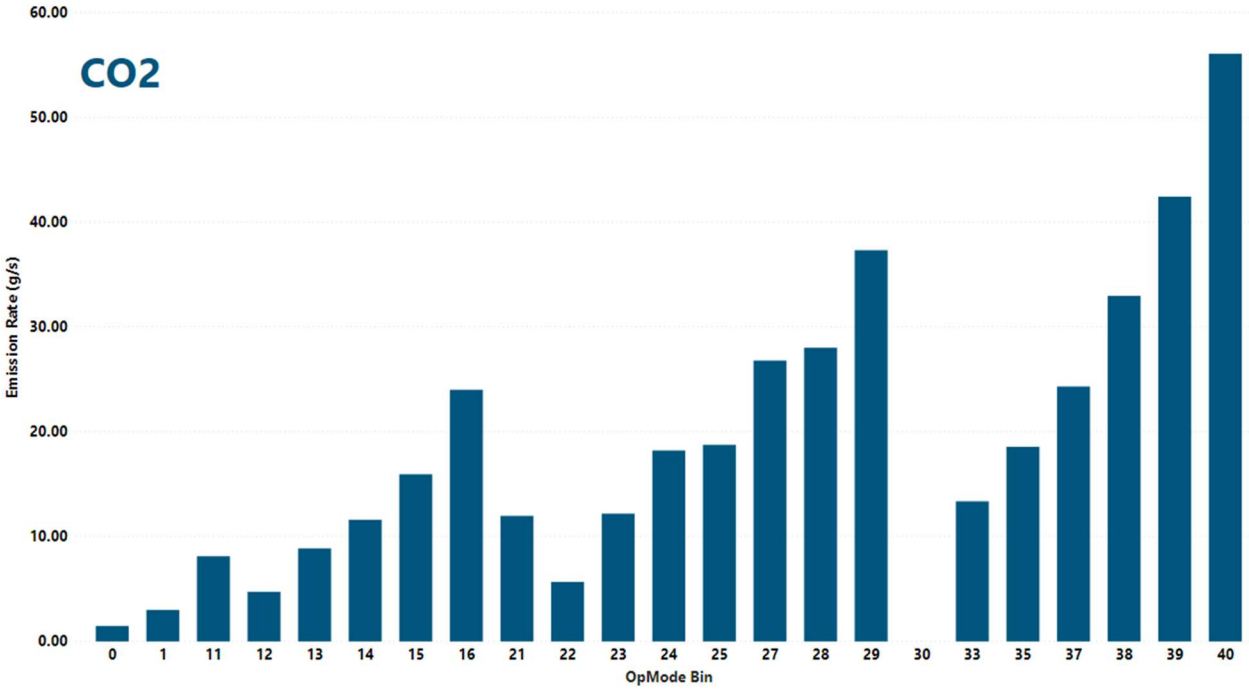

Figure 31. Example of opMode Emission Rates for CO_2

The concept of opMode bin as implemented in MOVES normalizes the instantaneous operational condition and engine load of a vehicle. The current implementation of opMode bins in MOVES results in the underlying assumption that regardless of the weight of the vehicle, emission rates for a specific opMode bin would not change. The research team used the emissions data collected in this study to examine this assumption by developing opMode emission rates for each loading scenario and truck.

The formula used to calculate the opMode bin for every data point—which was used to calculate the opMode distribution for the activity data analysis—uses instantaneous speed and acceleration to calculate the VSP and STP values. These equations are shown in Equation 1 and Equation 2.

Equation 1. VSP Speed-Based Equation

$$VSP = \frac{A \times u + B \times u^2 + C \times u^3 + M \times u \times a}{M}$$

Equation 2. STP Speed-Based Equation

$$\mathrm{STP} = \mathrm{VSP} \times \frac{\mathrm{M}}{\mathrm{f_m}}$$

EPA found that using speed and acceleration for on-road testing was inaccurate due to the impact of other variables, such as the wind speed and road grade (5). Therefore, an

alternative approach was developed to calculate the STP values using instantaneous power and torque instead of speed and acceleration. The new formula for calculating STP is shown in Equation 3.

Equation 3: STP Power Equation

$$STP = \frac{\eta_{driveline}(\omega_{eng}\tau_{eng} - P_{loss,acc})}{f_{scale}}$$

In the equation, $\eta_{driveline}$ is the driveline efficiency, ω_{eng} is the engine speed, τ_{eng} is the engine torque, $P_{loss,acc}$ is the accessory load, and f_{scale} is an STP scaling factor. HDVs of MY2010 or newer use a scaling factor of 10, compared to 17.1 for MYs prior to 2010 (6).

Two of the vehicles tested in this study were pre-2010 MYs (f_{scale} of 17), and one was MY2014 (f_{scale} of 10*).* Additionally, the 2005 vehicle tested during the study did not have a working onboard diagnostics data port, and therefore the engine information required calculating the STP based on power and torque. Therefore, the emission rates for each vehicle were calculated using separate equations:

- *MY2005*—calculated the STP using the speed/acceleration formula and f_{scale} of 17.1.
- *MY2009*—calculated the STP using the power/torque formula and f_{scale} of 17.1.
- *MY2014*—calculated the STP using the power/torque formula and f_{scale} of 10.

Adjusted NO_x Emission Rates

Since NO_x is the focus of this study, the research team focused on parameters that can have an impact on NO_x emission rates. One of the factors that were identified was the exhaust temperature for the MY2014 truck, which is equipped with an SCR system.

The 2004 NO_x standard for on-road diesel engines was the first step by EPA and the California Air Resources Board to substantially lower the NO_x levels from heavy-duty diesel vehicles (HDDVs). The 2004 standard was set to bring down the NO_x emissions from any new 2004 or newer year heavy-duty diesel engine to approximately 2.0 grams per brake-horsepower-hour (g/bhp-hr). Under this standard, the discharge of crankcase emissions into the atmosphere was not allowed.

The 2007 standards are the most stringent diesel emissions standards to date. The 2007 standards include very stringent limits for NO_x (0.20 g/bhp-hr) and PM (0.01 g/bhp-hr). All the 2007 and newer heavy-duty diesel engines must comply with the PM emission limits. However, the NO_x standard was implemented in phases between 2007 and 2010. As a result, very few diesel engines had NO_x emissions levels lower than 0.20 g/bhp-hr

before 2010. Instead, most diesel engine manufacturers certified their 2007–2009 engines to a fleet average NO_x limit of 1.2 g/bhp-hr. Most diesel engine manufacturers used exhaust gas recirculation (EGR) to reach this fleet average level. All the new on-road heavy-duty diesel engines manufactured since 2010 must be certified to a NO_x emission level of 0.20 g/bhp-hr. This is commonly referred to as the 2010 NO_x standard for heavy-duty diesel engines, which is actually the full implementation of the 2007 standard.

SCR is the key emission reduction technology that is used to comply with the 2010 NO_x standard. Most SCR systems used in on-road applications inject urea into the exhaust stream, which reacts with NO_x in the presence of a catalyst. The reaction results in diatomic nitrogen, water, and CO_2. Currently, SCR systems need the vehicle's exhaust to be at least 200°C to achieve a significant NO_x reduction (7).

The research team examined the impact of exhaust temperature by extracting SCR temperature data corresponding to the PAMS data collected during the emissions test from the MY2014 test vehicle. Figure 32 shows the profile for exhaust temperature and the recorded instantaneous NO_x emission mass (milligrams per second) for the OW scenario. As the figure shows, once the exhaust temperature is over 200°C (the middle section of the graph), the NO_x readings are substantially lower than when the temperature is below 200°C (the beginning and end of the time sequence).

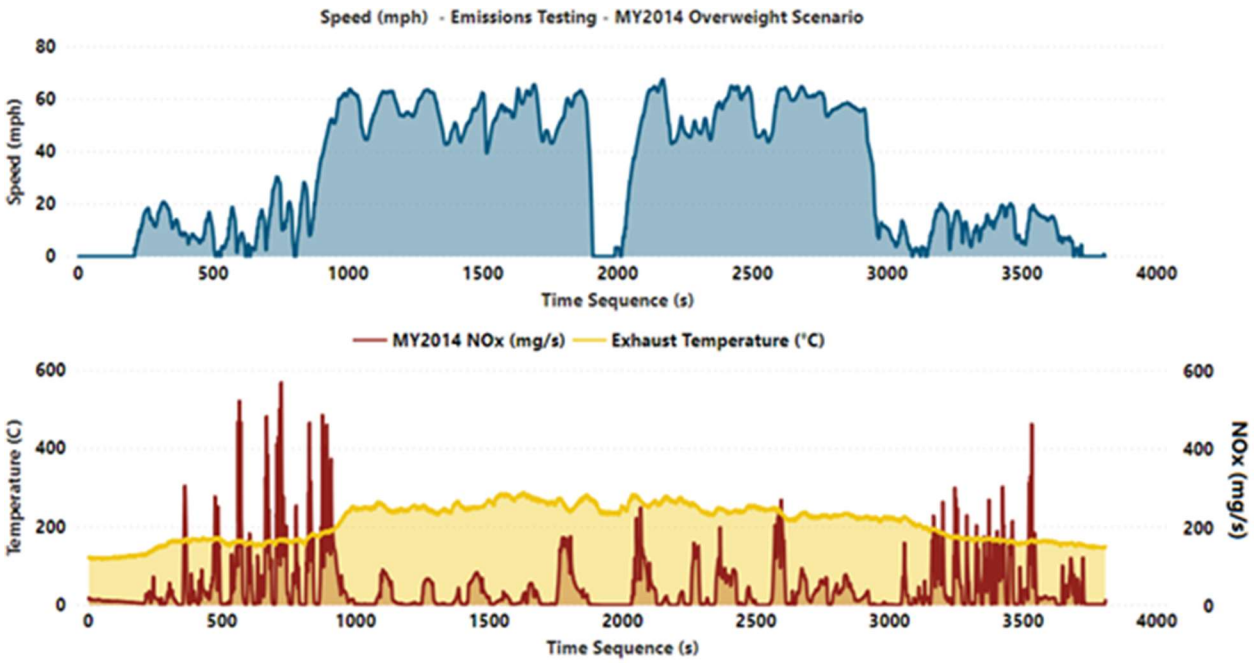

Figure 32. Exhaust Temperature, NO_x, and Speed from OW Scenario

Further examination of the speed profile of the vehicle reveals two trends:

- First, the exhaust temperatures are higher than 200°C when the vehicle is traveling at highway speeds.
- Second, changes of exhaust temperatures are gradual. As a result, a low-speed or idling event occurring immediately after a high-speed event may still have an exhaust temperature higher than 200°C for a period of time.

These two trends suggest that the exhaust temperature profile of a test may not be representative of the real-world driving condition for some of the opMode bins. Since the exhaust temperature profile has a substantial impact on the NO_x levels, a simple aggregation of NO_x observations from an emission test may result in emission rates that are different from the ones that occur under real-world driving conditions.

For the MY2014 truck, the research team collected real-world activity data in addition to the emissions and activity during the PEMS testing. The research team used the PAMS-recorded SCR intake temperatures from these two data sets to study the differences between the two driving conditions. Researchers divided the SCR intake temperatures into three groups: lower than 200°C, 200°C to 300°C, and higher than 300°C. Using these temperature groups, temperature distribution profiles were calculated for all combinations of load scenarios and opMode bins. Figure 33 and Figure 34 shows a sample of these profiles.

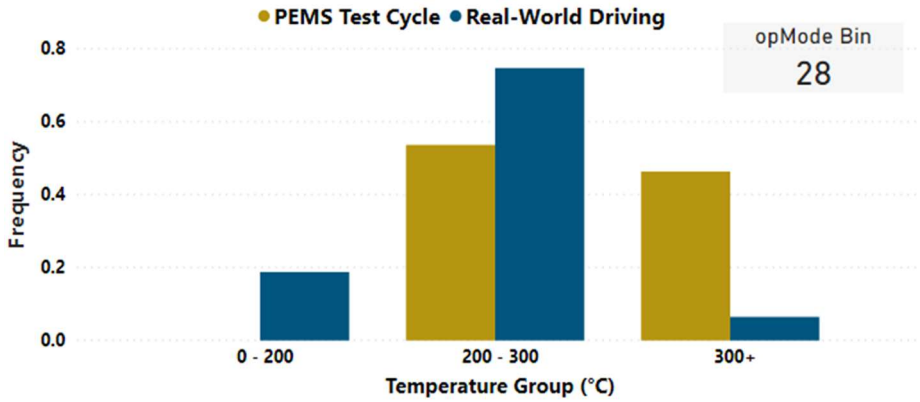

Figure 33: Real World and PEMS Testing opMode Bin 28 SCR Temperature Profiles

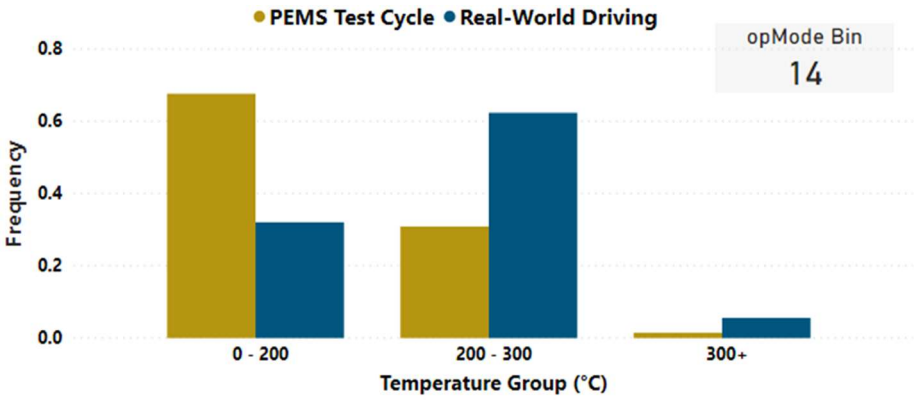

Figure 34. Real World and PEMS Testing opMode Bin 28 SCR Temperature Profiles

Figure 33 and Figure 34 shows that the SCR inlet temperature profiles for testing conditions are substantially different from those from the real-world driving conditions. The research team used a Kolmogorov-Simonov Goodness-of-Fit test (KS test) to determine whether the differences between the two temperature profiles are statistically significant. The KS test results confirmed that for the majority of the opMode and load scenarios, the differences are statistically significant at a 5 percent significance level.

To correct for the differences in the temperatures between the real-world and PEMS testing, the research team implemented the following steps to adjust the opMode emission rates based on the real-world SCR inlet temperature profiles:

1. Using PAMS data from real-world activity data collection, develop SCR inlet temperature profiles for each opMode bin.
2. Calculate the percentage of time spent at each SCR inlet temperature group for each opMode bin.
3. Using PAMS data from emissions testing, develop SCR inlet temperature profiles for each opMode bin and scenario (OW, OS, legal limit, and normal).
4. Calculate the average emission rate for the opMode bin's SCR inlet temperature group for each scenario.
5. Estimate the temperature-adjusted emission rate for each opMode by calculating the weighted average of the temperature groups' emission rates weighted by the percentage of observations in that group from the real-world PAMS data.

Figure 35 through Figure 38 show the original and adjusted emission rates that were estimated using this methodology. The differences between the original and adjusted emission rates are minimal for most opMode and scenario combinations, averaging a difference of approximately 0.1 g/sec. However, some of the bins, especially the higher

acceleration rate opModes for the OS and OW tests, showed a difference of up to 0.5 g/sec. The temperature adjustment generally reduced the average NO_x emission rates for the higher engine load bins (opMode bins 33–40). This reduction highlights the fact that under real-world conditions, the SCR temperatures are most of the time higher than 200°C for those opMode bins.

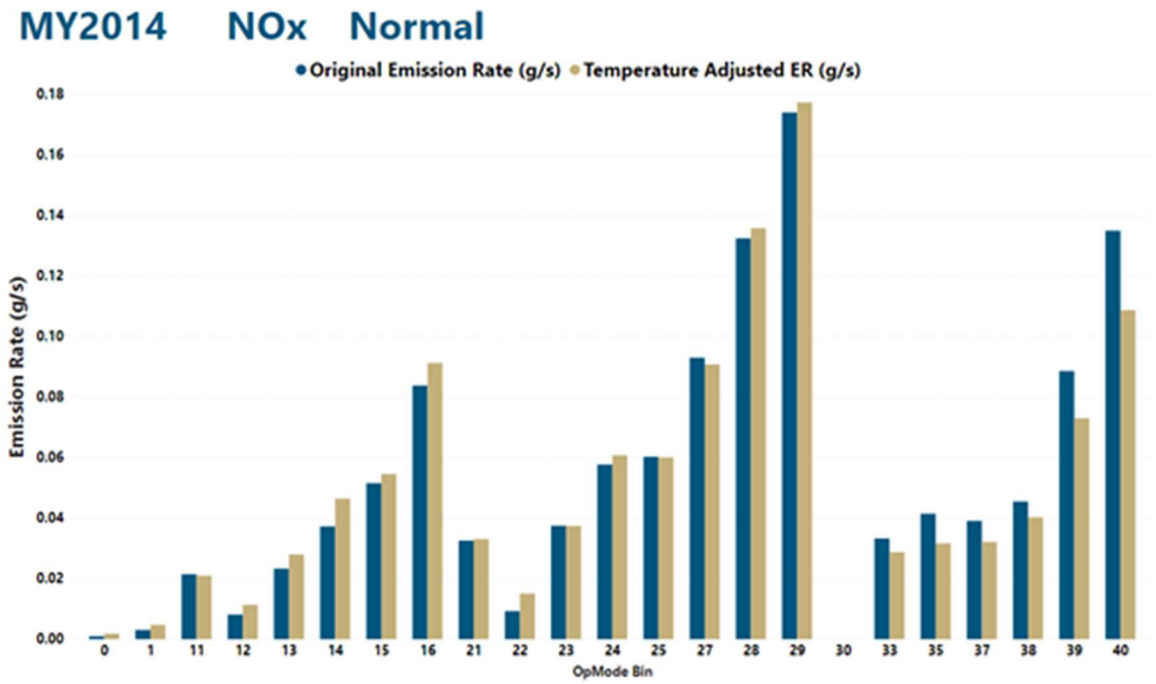

Figure 35. MY2014 Normal Weights Original and Adjusted Emission Rates

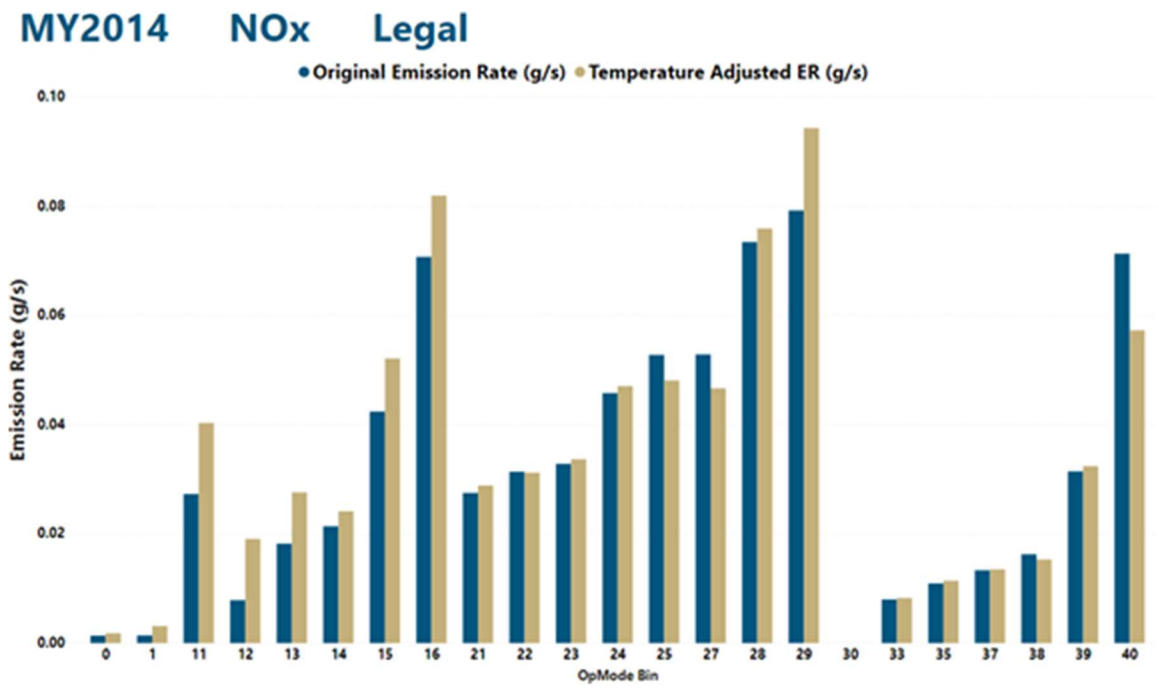

Figure 36. MY2014 Legal Limit Weights Original and Adjusted Emission Rates

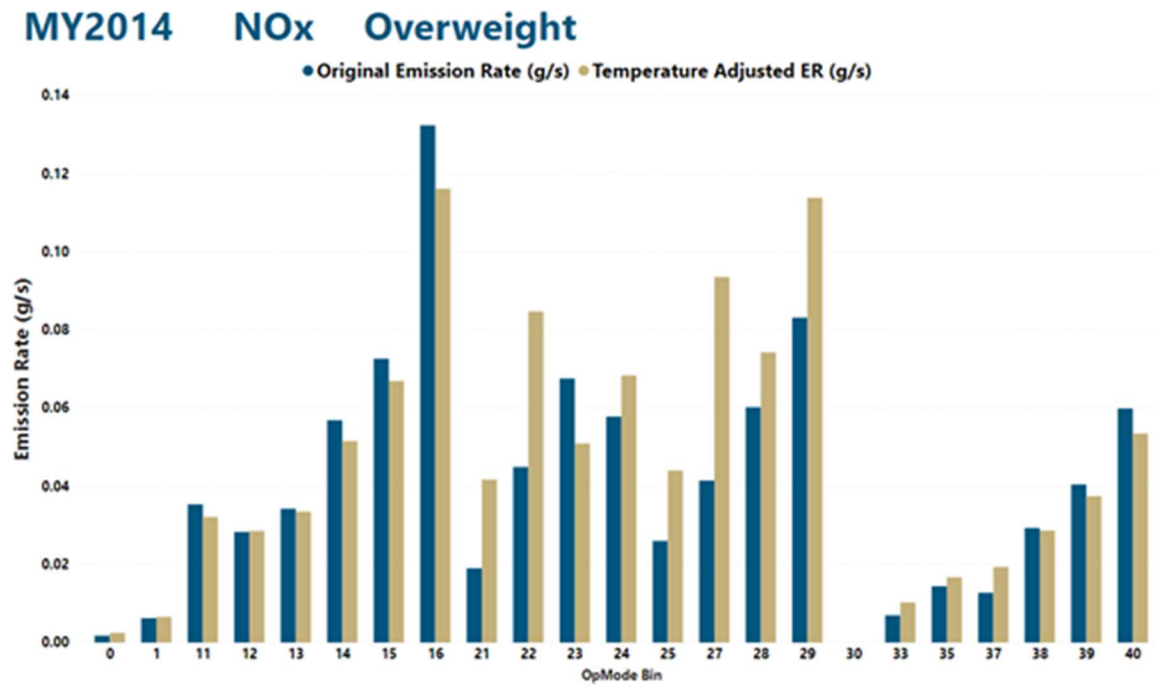

Figure 37. MY2014 Overweight Original and Adjusted Emission Rates

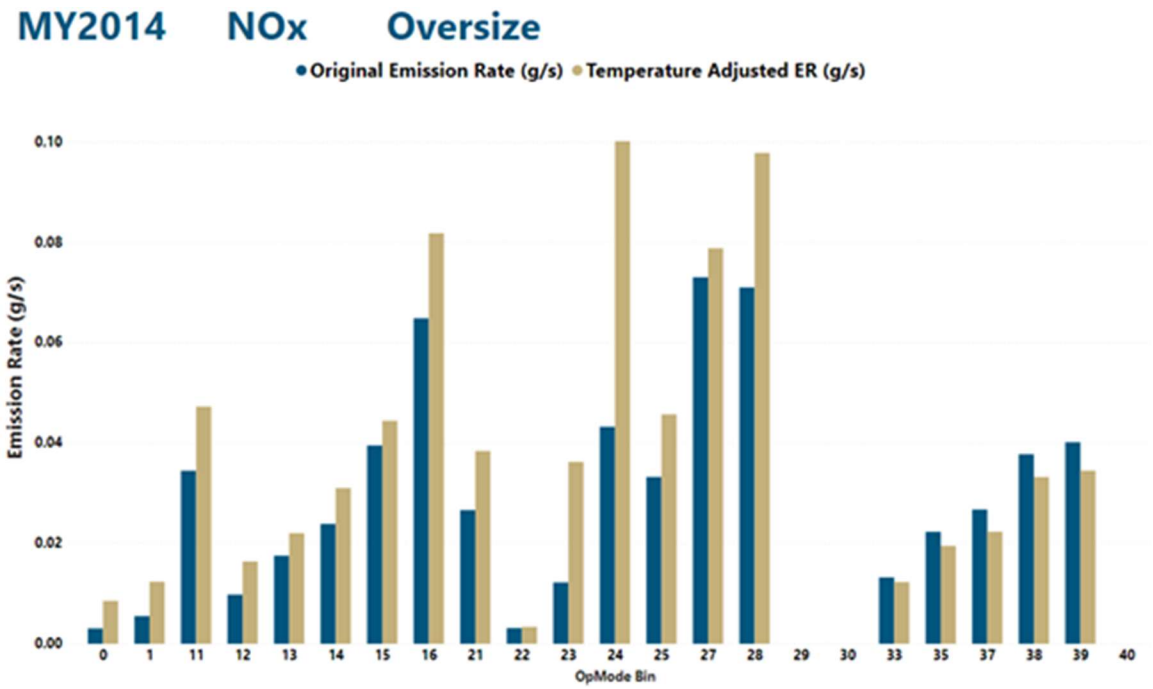

Figure 38. MY2014 Oversize Original and Adjusted Emission Rates

Effect of Vehicle Weight on Emissions

As previously described, each of the vehicles that took part in the PEMS testing were tested under three different load weights. Using the PEMS data from the different weights allowed the research team to analyze the potential effect that the load weight has on a truck's emissions. The focus of this section is on the NO_x emissions of the vehicles. However, Appendix H provides graphs of the other pollutants.

Figure 39 through Figure 41 show the NO_x emission rates estimated for each of the vehicles under all three loads. As the graphs show, both the MY2005 and MY2009 vehicles show a similar trend. For almost all opMode bins where the vehicle is accelerating (opMode bins higher than 1), the normal weight has the lowest NO_x emission rates, followed by the legal limit, and the OW test has the highest NO_x emission rates. In a few instances, the NO_x emission rates for the normal weight are slightly higher than the legal limit, or the NO_x emission rates for the legal limit are slightly higher than the OW. These are generally bins with low acceleration rates (i.e., bin 30) or that have a low number of data points (which could impact the calculation of the average).

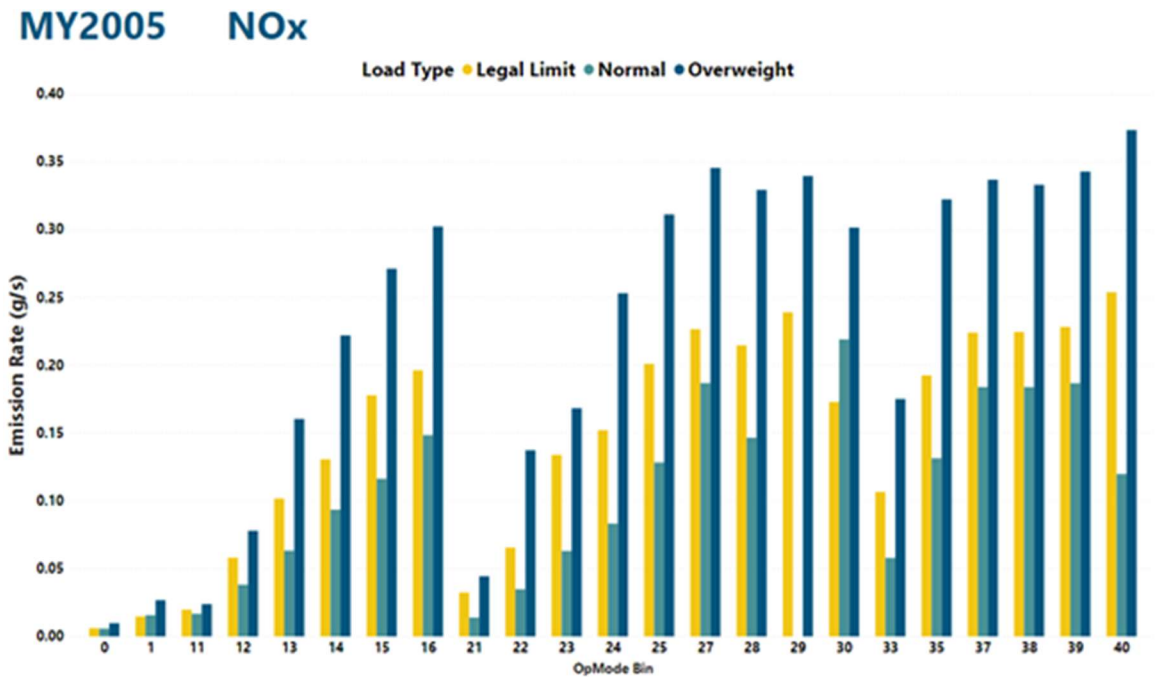

Figure 39. MY2005 NO_x Emission Rates (g/sec) by Load Type

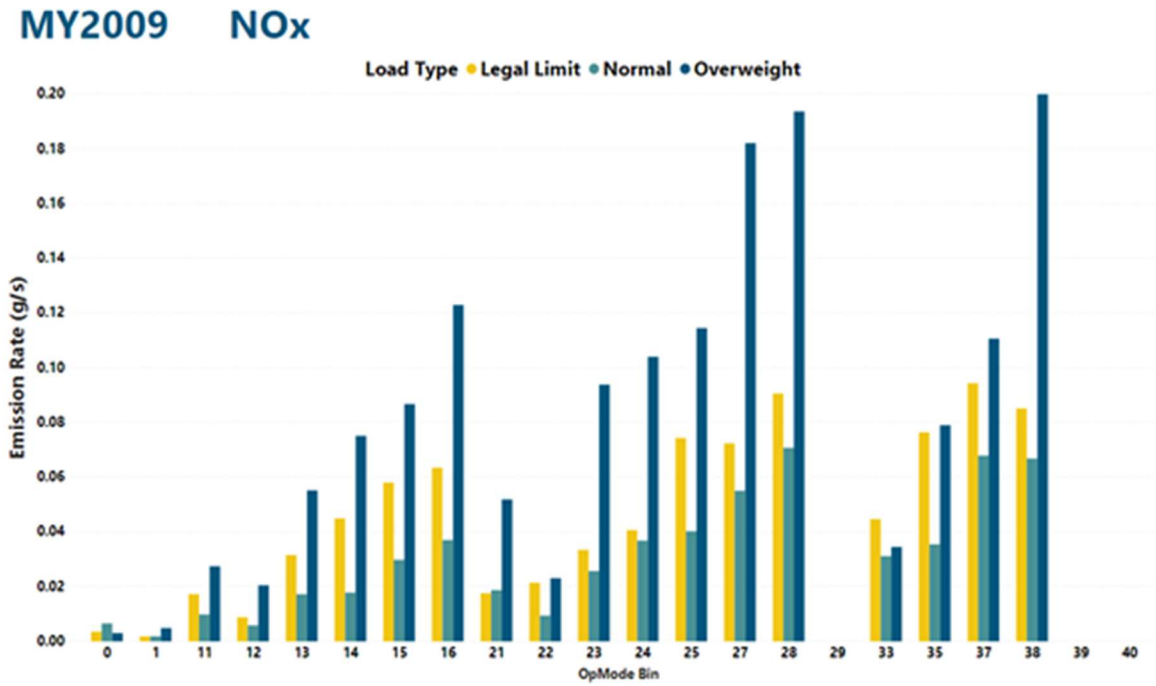

Figure 40. MY2009 NO_x Emission Rates (g/sec) by Load Type

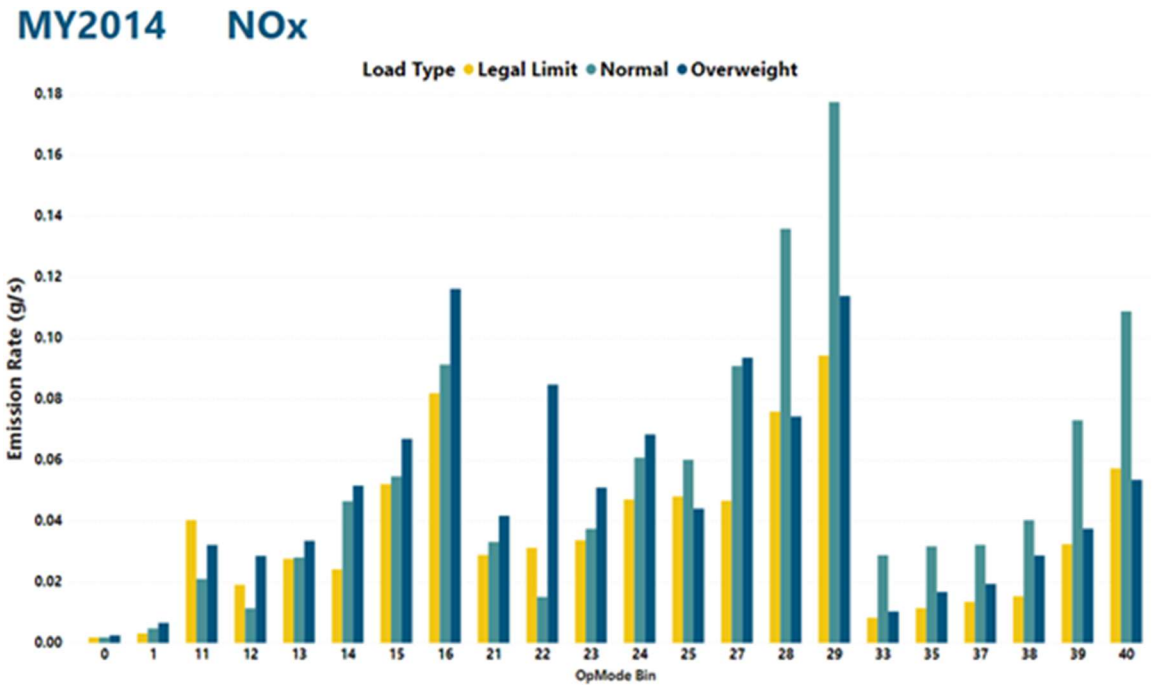

Figure 41. MY2014 NO_x Emission Rates (g/sec) by Load Type

As the figures show, the emission rates for an opMode can be different as a result of total vehicle weight. This observation points to the possibility that the current implementation of opMode bins in MOVES may not accurately capture the impact of weight. The research team originally planned to compare the emission rate results obtained in this study to the opMode emission rates from MOVES 2014. However, during the testing, the research team learned of substantial changes to the HDDV NO_x emission rates in the next version of MOVES (MOVES 201x). The research team did not have access to the MOVES 201x HDDV NO_x emission rates and so extracted sample MOVES 201x rates from EPA documents to compare to the emission rate results obtained in this study. Figure 42 through Figure 44 show those comparisons.

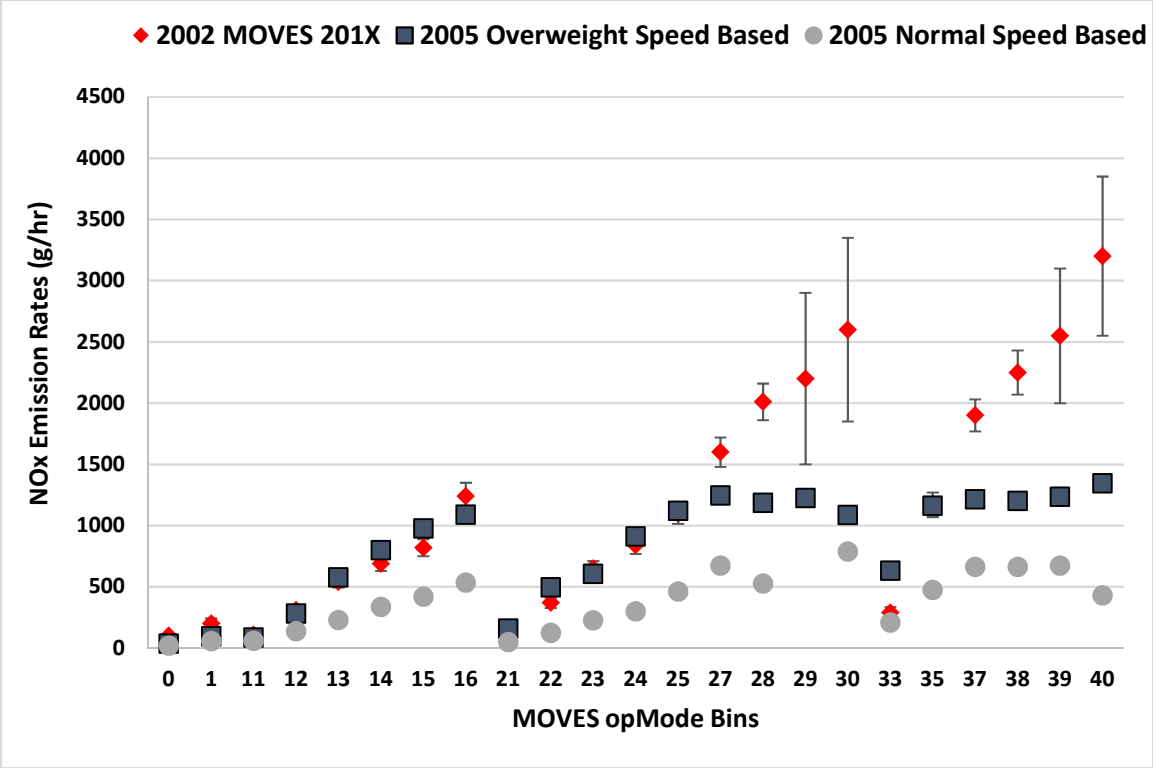

Figure 42. MY2005 Emission Rates Compared to MOVES 201x MY2002 Emission Rates

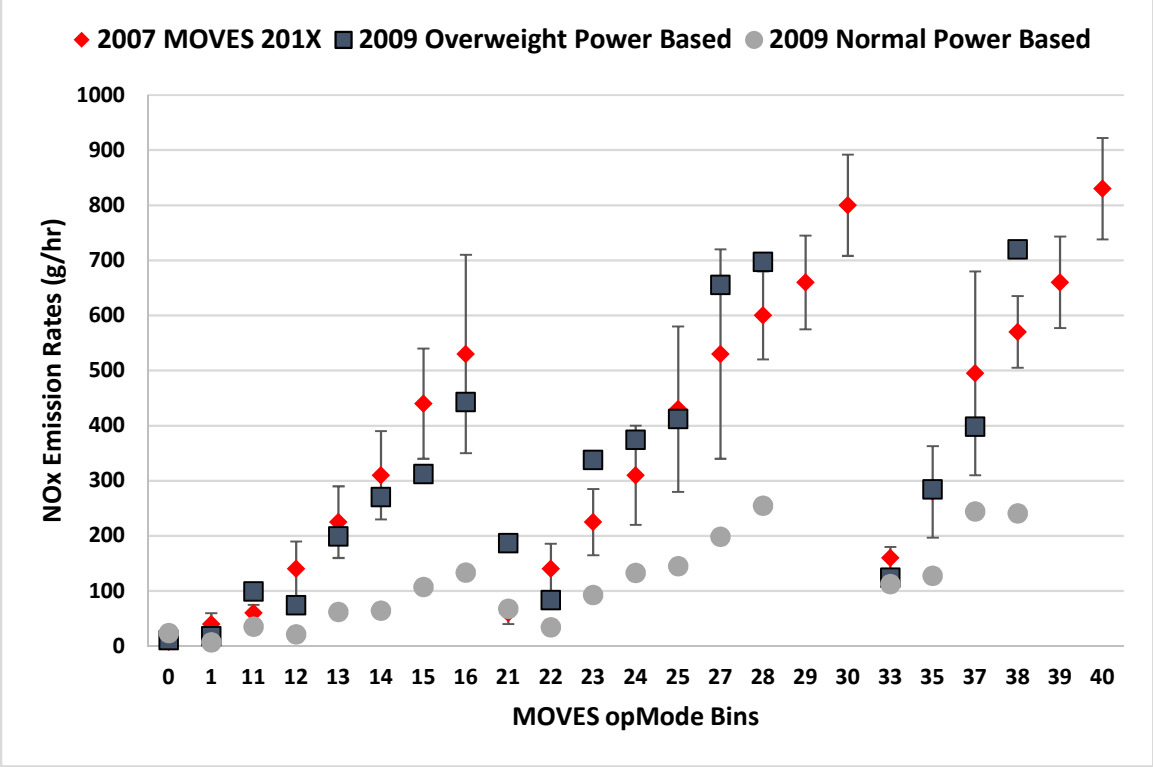

Figure 43. MY2009 Emission Rates Compared to MOVES 201x MY2007 Emission Rates

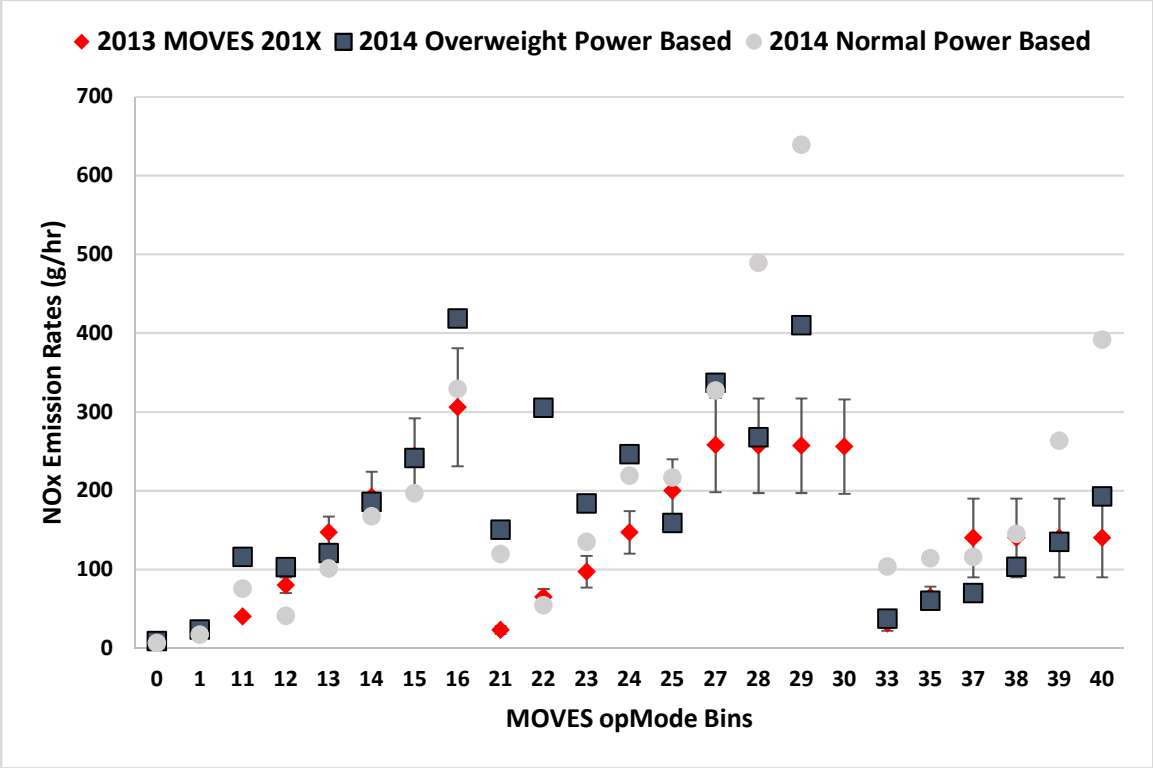

Figure 44. MY2014 Emission Rates Compared to MOVES 201x MY2013 Emission Rates

The pattern in the emission rates for the MY2014 vehicle, shown in Figure 44, is not the same as for the other MY rates. The data from the MY2014 vehicle show similar emission rates in the low-speed bins (11–16) to the 2005 and 2009 rates in that the OW rates are higher. However, moving to the higher-speed bins (33–40) and the bins with higher acceleration rates (28–29), the normal load rates are higher than both the legal limit and OW NOx emission rates.

This is likely due to the impact of the exhaust temperatures on SCR-equipped vehicles. As discussed in the previous section, the exhaust temperature has a substantial impact on the NO_x emission rates of the MY2014 vehicle due to the SCR technology. As Figure 45 shows, the average temperatures for these opMode bins are near, or below, the 200°C threshold where the SCR is most effective. For these bins, the NO_x emission rates for different load types are similar to those for the MY2005 and MY2009 vehicles. However, in opMode bins 21 and above, the average exhaust temperatures are generally above 200°C, especially for the legal limit and OW load types. When the exhaust gas temperature is higher than this limit, the SCR is more efficient in reducing NO_x and the NO_x rates are lower than the normal load.

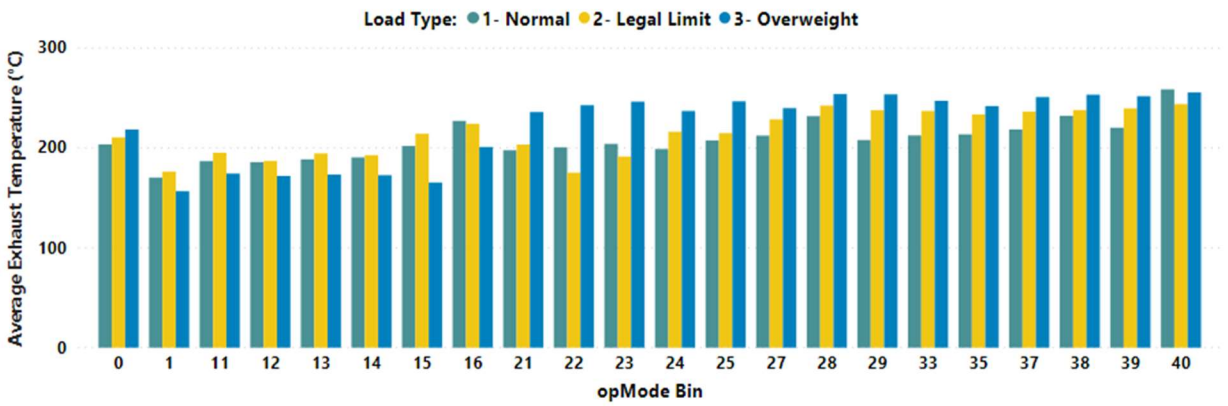

Figure 45. Average Exhaust Temperature

Figure 46 shows the NO_x emission rates for each MY with a normal load weight. Under the normal load weight, the SCR-equipped MY2014 vehicle has higher, or the same, NO_x emission rates than the MY2009 truck under every low- or medium-speed opMode. The MY2005 truck has higher rates than the MY2014 truck in all opModes, but the differences are smaller in the lower- and medium-speed bins. The EGR-equipped MY2009 truck has the lowest NOx rates among the three vehicles for the normal load scenario. Figure 47 shows that the MY2014 vehicle has lower emission rates than the MY2005 and MY2009 trucks under the OW load at speeds higher than 25 mph and high-load opMode bins.

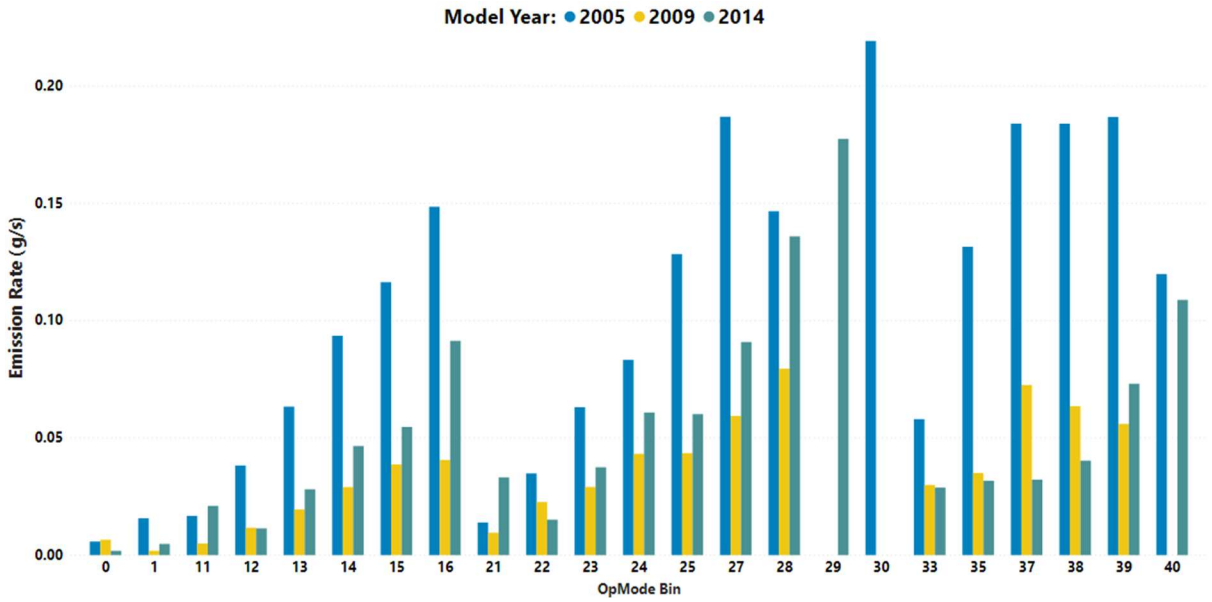

Figure 46. Normal-Load NO_x Emission Rates by Model Year

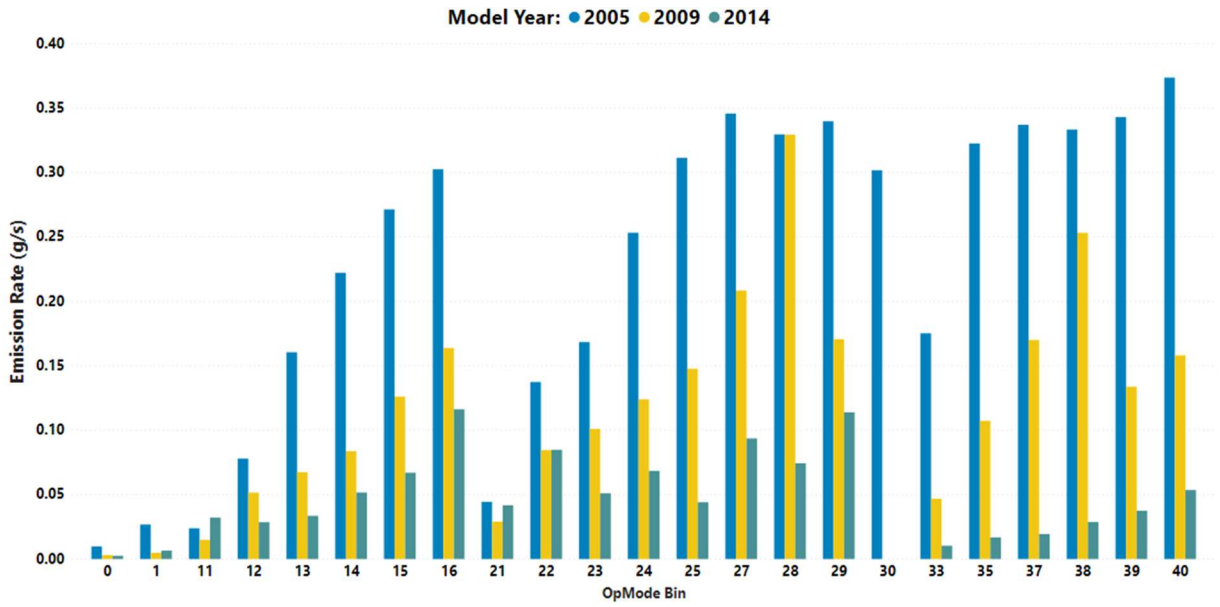

Figure 47. Overweight NO_x Emission Rates by Model Year

The results in Figure 46 and Figure 47 suggest that there may be instances where newer trucks equipped with an SCR have increased NO_x emissions with lighter loads compared to carrying OW loads due to the temperature of the exhaust. The research team acknowledges the limited number of trucks that were tested in this study. The emissions data that were collected are only for a single SCR-equipped vehicle, and overall the number of observations for each opMode bin is low. However, the results point to a potentially substantial overall NO_x impact from SCR-equipped heavy-duty diesel trucks, especially from those operating in low-speed urban conditions.

Effect of Load Size on Emissions

Two of the vehicles (MY2005 and MY2014) were tested with an OS load (with a total weight approximately similar to the normal load). Figure 48 and Figure 49 show the NO_x emission rates for the normal and OS loads for MY2005 and MY2014, respectively.

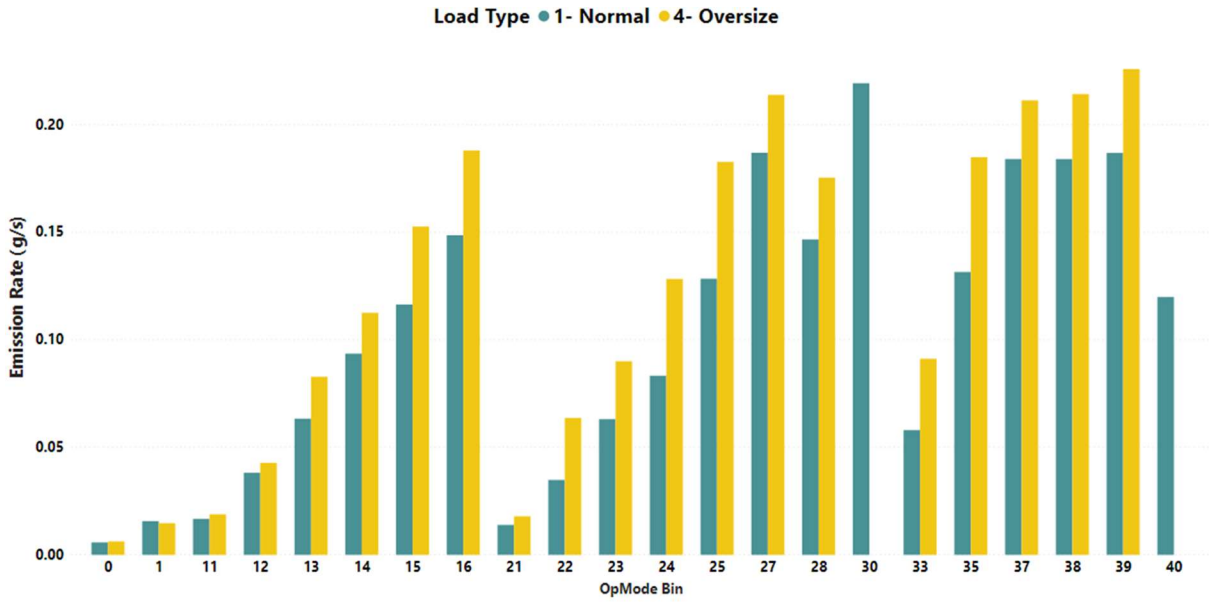

Figure 48. MY2005 NO_x Emission Rates by Load Size

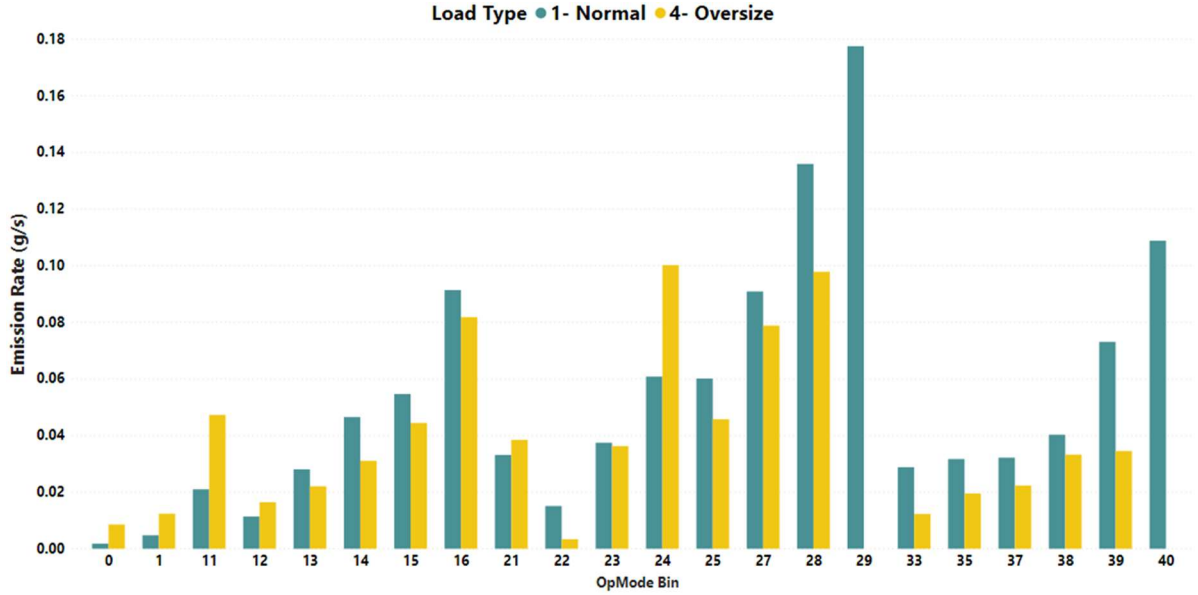

Figure 49. MY2014 NO_x Emission Rates by Load Size

The effect of load size on the NO_x emission rates is generally similar to what is seen for the load weight. On the MY2005 vehicle, the OS load's NO_x emission rates are higher than the normal load in the case of almost every opMode bin where the vehicle is accelerating. The MY2014 emission rates show that for low-acceleration bins at speeds below 50 mph (bins 11–12 and 21–24), the rates are similar or the OS load is slightly higher. In the bins with speeds over 50 mph (33–40) and lower-speed bins with higher acceleration rates (14–16 and 25–29), the normal load's NO_x emission rate is always higher than the OS load. Similar to the discussion in the impact of weight section

previously, the vehicle is working harder at the higher speeds, which leads to increased exhaust/SCR temperatures, and therefore the SCR is working more efficiently and lowering the NO_x emissions in these bins.

REGIONAL EMISSIONS IMPACTS OF OS/OW OPERATIONS

The goal of this study is to develop an understanding of the emission impacts of OS/OW operations in the NCTCOG region. The results from the previous sections were combined to develop an inventory of OS/OW vehicle operations in the NCTCOG region. The activity characteristics obtained from the PAMS data were used in the context of the overall emission inventory of the region. Also, the emission rates from the PEMS testing were used to estimate the total emissions from regional OS/OW operations. Different scenarios were developed by using the percentage of trucks exceeding the legal limits obtained from the WIM data. Scenarios were used to understand the potential emission impacts of changes in OS/OW operations. The results presented in this section are for truck weights of 110,000 pounds, which can be considered an upper boundary for the truck weight distribution in the NCTCOG region.

METHODOLOGY

The activity data and emission rates discussed in previous sections were used to estimate the regional emission impacts of OS/OW operations in the NCTCOG region. Figure 50 shows the steps used to conduct the regional estimations for multiple scenarios representing different percentages of OS/OW VMT (5, 10, 15, and 20 percent), as well as an alternative truck age distribution (assuming all trucks are MY2010 or newer). The scenarios considered the prevailing percentage of trucks exceeding the legal limits according to the WIM data, which ranges from 6.9 percent to 13 percent of the trucks being over the 80,000-pound limit.

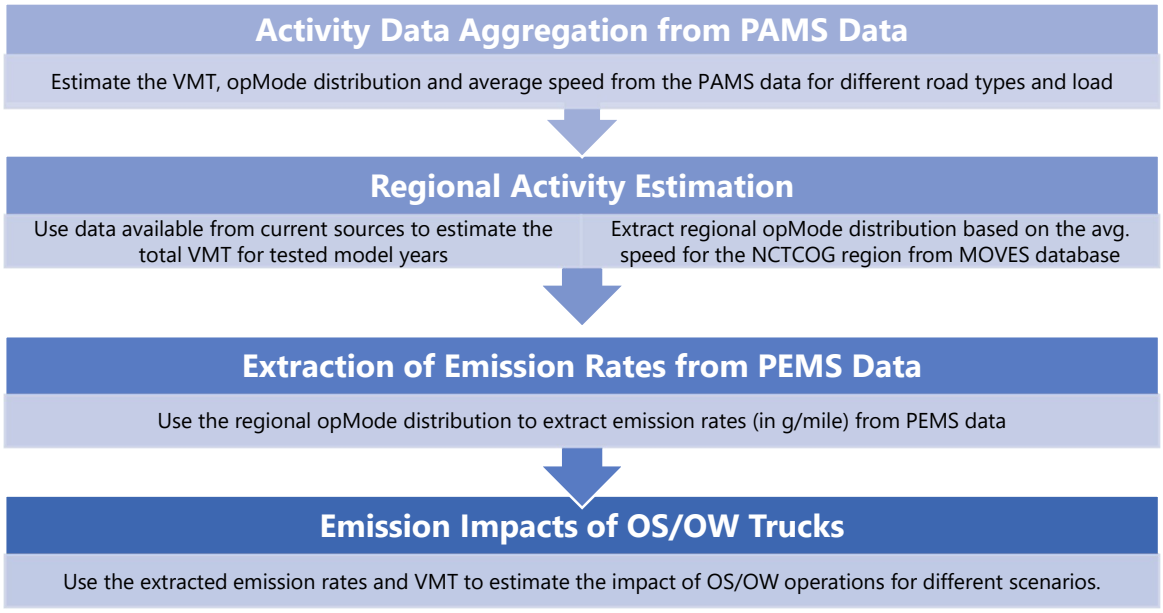

Figure 50. Emissions Estimation Process—OS/OW Operations in the NCTCOG Region

Activity Data Aggregation from PAMS Data

The main objective of this step was to identify the VMT and average speed of OS/OW trucks by different types of roads (e.g., freeways and arterials) in the NCTCOG region using the real-world PAMS data collected as part of this study. Figure 22 shows the regional VMT and speed of OS/OW trucks by road type. Figure 23 and Figure 24 show the opMode distribution by road type and load type.

Regional Activity Estimation

The regional activity estimation consisted of two sub-steps: the VMT estimation and the opMode distribution estimation.

Regional VMT Estimation

In this step, the research team estimated the total baseline VMT of all the trucks and the different MYs using various publicly available databases. The Air Emissions Reporting Rule (AERR) requires state air agencies prepare and submit a comprehensive statewide Periodic Emissions Inventory (PEI) and any applicable modeling inputs to EPA every three years. The latest available AERR data were for 2017. The research team used the 2017 AERR VMT estimates for the DFW 12-county area as the starting point to assess the impact of the OW (loaded) versus normal weight from MOVES sourcetype vehicle

category 61 (diesel only).[g] The research team disaggregated the AERR 61 sourcetype VMT using the following:

- The Texas specific age distribution.
- The alternative vehicle and fuels technology (AVFT) MOVES inputs used in the AERR for the DFW 12-county area emissions estimation.
- The mileage accumulation rate (MAR) by MY available in the MOVES default database.

The following steps describe the methodology used to extract the VMT specific to the three MYs:

1. The 2017 AERR county VMT summary files for the 12-county DFW NA area were acquired. The VMT attributed to diesel sourcetype 61 for each county was extracted and summed to estimate the totals by different road types (see Figure 51). The data show that most of the travel by these vehicles occurred on freeways.

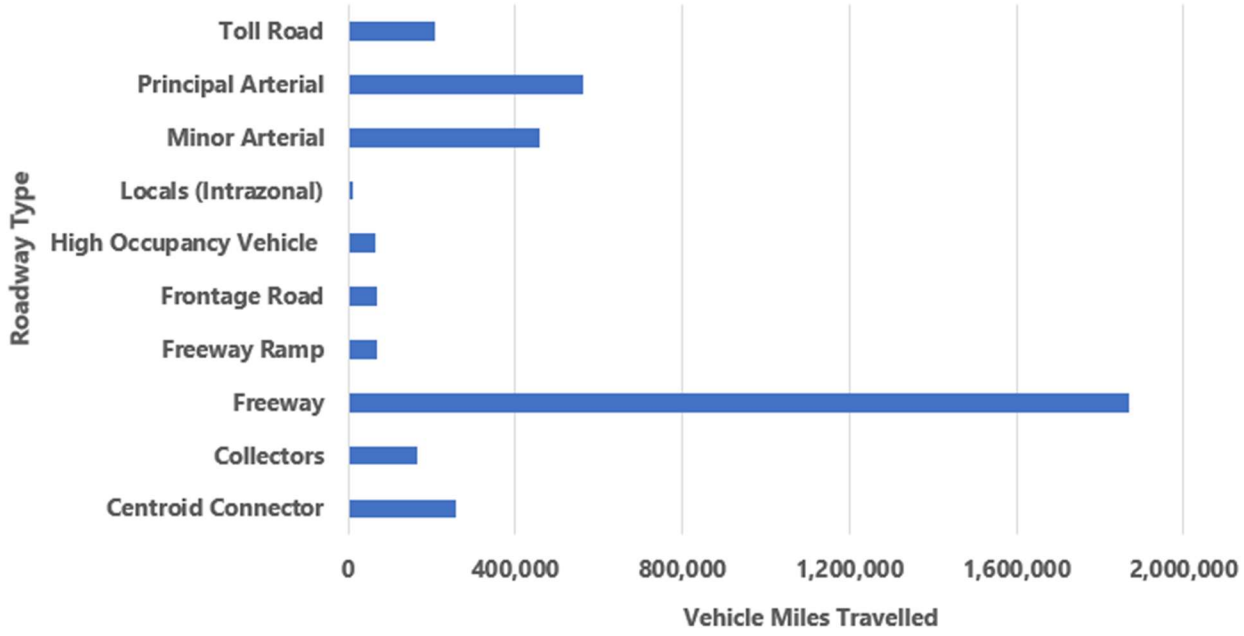

Figure 51. VMT by Different Roadway Types in the DFW Area

2. The age and AVFT distribution (percentage of vehicles that are diesel) by vehicle age for sourcetype 61 were extracted from the MOVES county databases used in the development of the 2017 AERR emission rates. Figure 52 and Figure 53 show

g. The MOVES default average weight for sourcetype 61 is approximately 55,000 pounds.

the sourcetype 61 age distribution and associated diesel fraction, respectively, for each MY. The distributions show that most trucks (approximately 57 percent) are less than 10 years old, and just under 90 percent of the trucks are diesel, regardless of age.

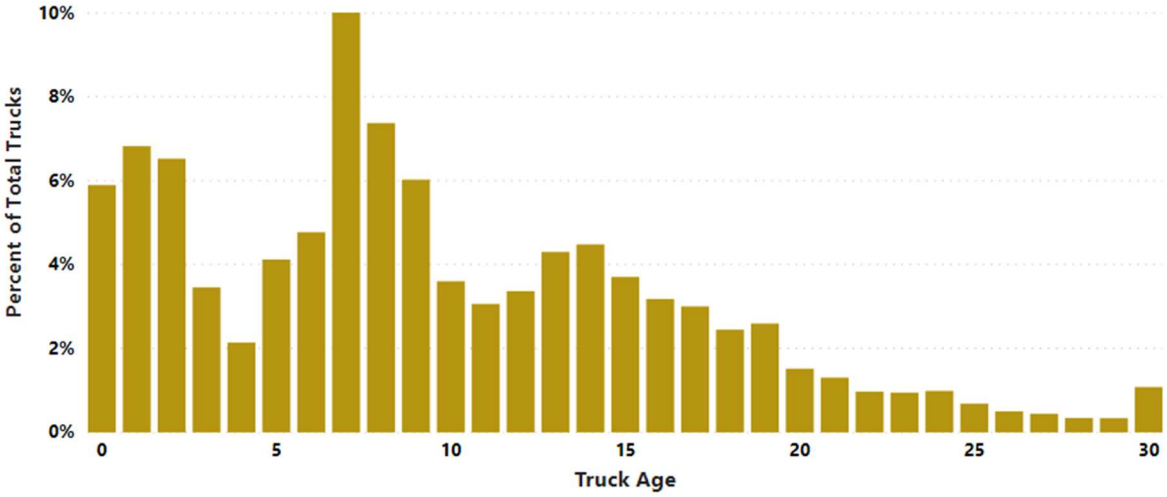

Figure 52. Age Distribution by Model Year

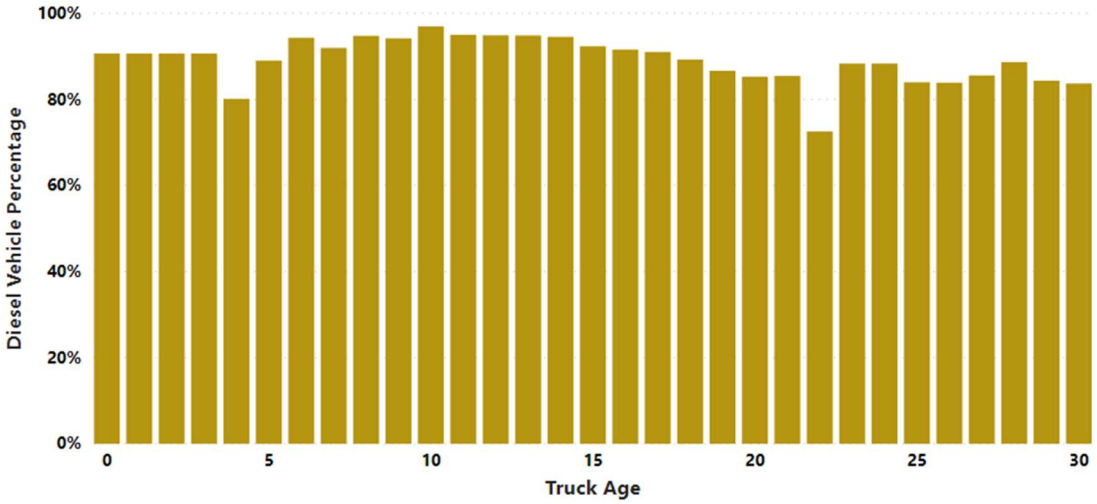

Figure 53. Diesel Fraction by Model Year

3. The two data sets shown in Figure 52 and Figure 53 were used to estimate the age distribution of diesel vehicles. The normalized age distribution, shown in Figure 54, provides the diesel percentage for sourcetype 61 in each MY.

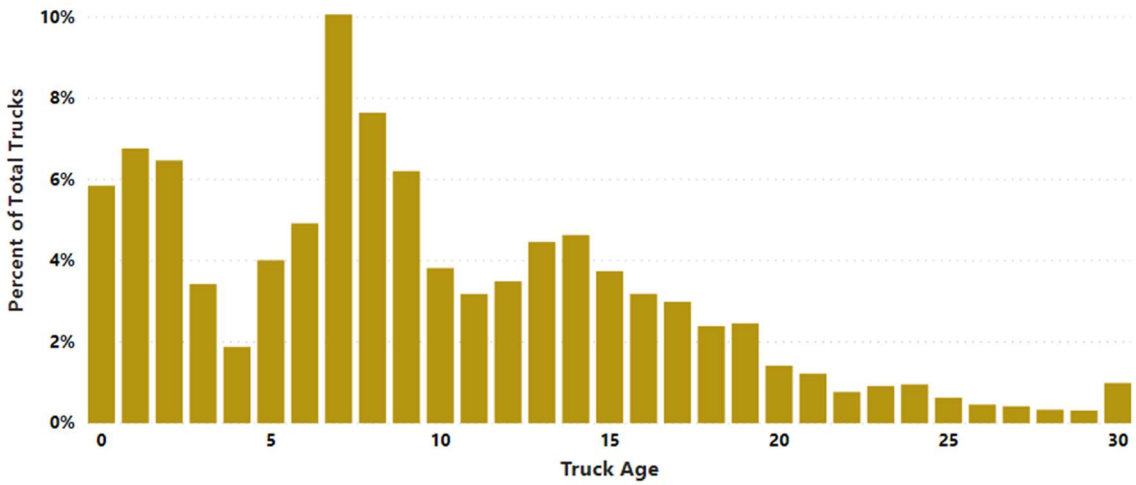

Figure 54. Normalized Diesel Age Distribution

4. Once the percentage of diesel trucks was calculated for each MY, the research team determined the travel associated with each MY. MOVES assumes that older vehicles travel less than newer vehicles. The default MOVES database has MAR values for 31 MYs (for all vehicles types). This database was used to determine the average annual travel fractions by MY. The MARs were extracted from the default database and normalized (shown in Figure 55).

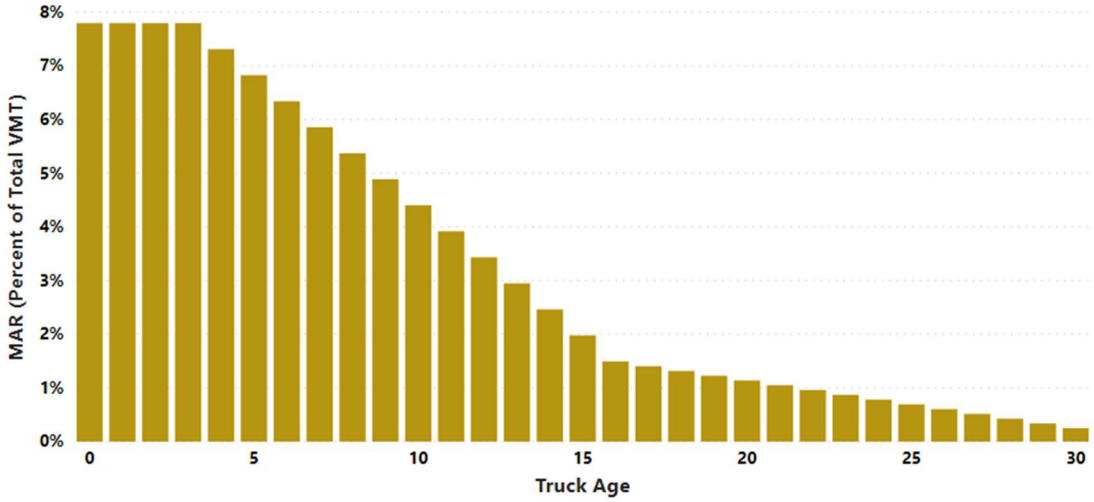

Figure 55. Mileage Accumulation Rate by Vehicle Age

5. The normalized MARs (Figure 55) were multiplied by the normalized diesel age distribution (Figure 54) to estimate the VMT fractions (shown in Figure 56). The VMT fractions were used in disaggregating sourcetype 61 VMT for the three MYs included in the final analysis.

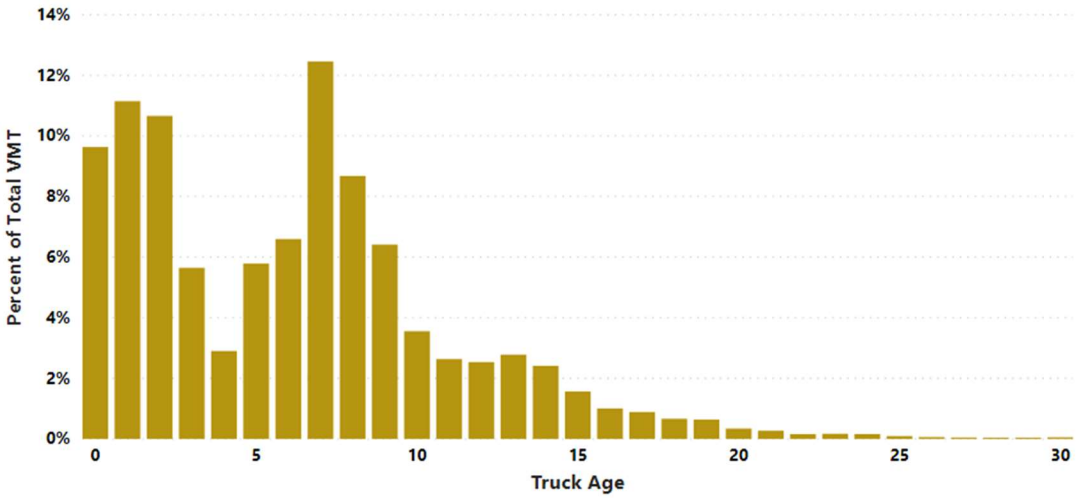

Figure 56. VMT Fraction by Model Year

6. The disaggregated VMT were then grouped into three bins based on the MY of the vehicle. The MY groups were selected to align with the vehicles that were used in the PEMS testing. The MY groups were:
    - 1987–2006.
    - 2007–2009.
    - 2010–2017.
7. The AERR VMT is grouped by the DFW regional travel model roadway types. It was, however, necessary to group the VMT into the MOVES roadway types—restricted access (all freeways) and unrestricted access (all arterials)—to estimate the emissions impact (see Table 8). Table 8 shows that most of the truck VMT are from vehicles that are MY2010 or newer. These VMT values were used as the baseline value for the different emissions scenarios that were tested.

Table 8. VMT by Road Type and Model Year Group

Model Year Group	Unrestricted Access	Restricted Access
1987–2006	251,203	365,385
2007–2009	283,477	412,330
2010–2017	985,656	1,433,680

Regional opMode Distribution Estimation

The next step was to estimate the opMode distributions for the NCTCOG region. The research team used the opMode distributions for the sourcetype 61 from MOVES to estimate the emission rates for different speeds. The average speeds shown in Table 9 were estimated from the PAMS data collected for this project (see Figure 22). Four

different combinations of load and road type were used in the analysis. The opMode distributions for these four combinations were developed using MOVES project scale runs with AERR inputs as applicable.

Table 9. Summary of Average Speed by Road Type and Loads for opMode Distribution Estimation

Scenario ID	Road Type	Average Speed (mph)	Load
RA-OW	Restricted Access (Freeway/Highway)	51	Overweight
RA-N	Restricted Access (Freeway/Highway)	48	Normal
UA-OW	Unrestricted Access (Arterial)	17	Overweight
UA-N	Unrestricted Access (Arterial)	13	Normal

Figure 57 shows the opMode distributions for the different speeds. The data show that the vehicles operate more in the higher opModes on the restricted-access roads (freeways) and more in the lower opModes on unrestricted-access roadways (arterials). This is due to the higher average speeds on the freeways and lower speeds on the arterials.

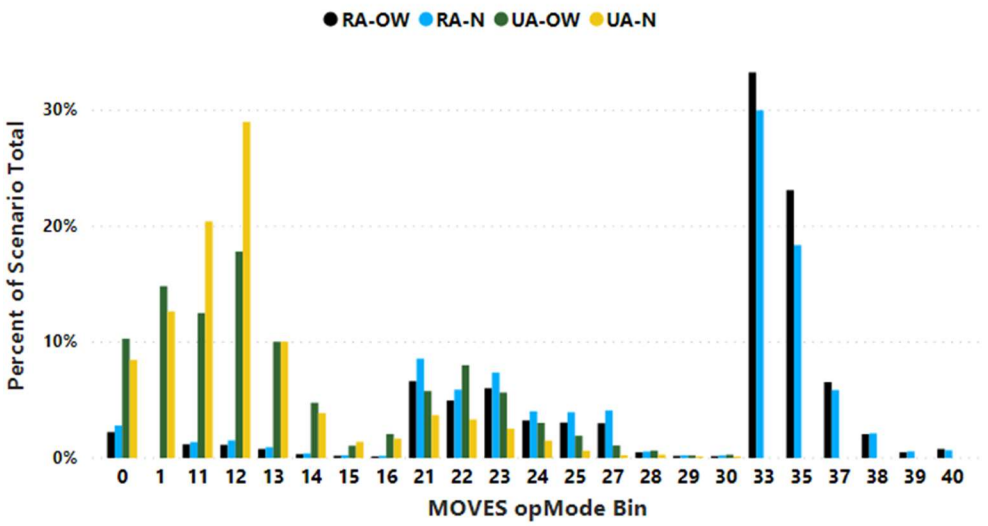

Figure 57. opMode Distribution by Road Type and Load for DFW Region

Extraction of Emission Rates from PEMS Data

Given the VMT and opMode distributions for the region, the next step in determining the overall emissions impact of OS/OW operations required emission rates. Figure 39 through Figure 41 show the emission rates for the different loads. As previously described, the emission rates used were adjusted based on both the PEMS and PAMS data collected as part of this project. The rates shown in Figure 39 through Figure 41 are

in grams per second. For this analysis the rates were adjusted to grams per mile for each scenario.

The average speeds and opMode distributions for the DFW NA region were used to calculate the emission rates for the different road types and loads shown in Table 10.

Table 10. NO_x Emission Rates (in Grams per Mile)

Model Year	Restricted Access (Freeways)		Unrestricted Access (Arterials)	
	OW	Normal	OW	Normal
2005	15.63	6.44	21.58	10.40
2009	4.67	2.39	8.35	2.97
2014	1.50	2.93	6.79	4.90

Emission Impacts of OS/OW Trucks

Based on an analysis of the PAMS data collected in this study, it was estimated that 67.4 percent of travel occurs on freeways and 32.6 percent on arterials. Furthermore, the WIM data collected from three DFW stations (see Figure 5) showed that the percentage of vehicles over 80,000 pounds ranged from 6.9 to 12 percent. Based on this information, the research team assumed four different scenarios of OW truck VMT (i.e., 5, 10, 15, and 20 percent of total VMT was assigned to OW trucks). The DFW NA-area VMT by the three MY groups was then used to estimate the VMT associated with each MY group as shown in Table 8. Each scenario was run twice: once using the mixture of MY vehicles for the OW operations and a second time where all the OW operations were conducted by MY2010 or newer trucks. Table 11 shows the eight different scenarios evaluated.

Table 11. Scenarios to Evaluate the Emission Impacts of Overweight Operations

Scenarios	Proportion of OS/OW VMT	Model Year
A	5%	Mixture of 3 MY groups consistent with 2017 AERR
B	10%	
C	15%	
D	20%	
E	5%	All OW operations are MY2010 or newer
F	10%	
G	15%	
H	20%	

Table 8 and Table 10 were combined by multiplying the corresponding VMT and the emission rates for OW and normal trucks to estimate the overall emission impacts for each of the eight scenarios. Figure 58 shows the NO_x emission impact (tons per day) for

each of the eight scenarios. The results show that accounting for OS/OW trucks in the total regional VMT results in an increase in NO_x emissions. The scenarios that assume all the trucks are MY2010 or newer (scenarios E through H) resulted in lower NO_x emission impacts than the current MY assumptions (scenarios A through D).

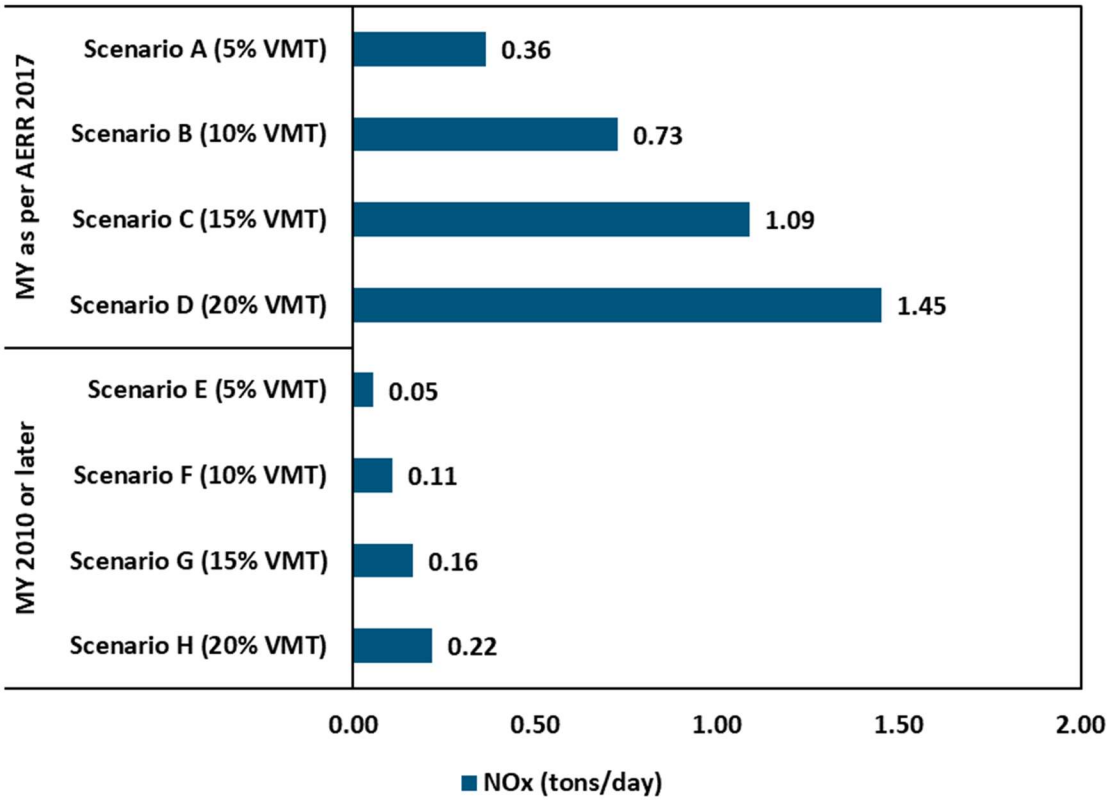

Figure 58. NO_x Emission Impacts (Tons per Day) of Different Scenarios with Different Percentages of OS/OW Trucks in the Fleet Mix and Model Year Assumptions

SUMMARY AND CONCLUSIONS

The overall goal of the project was to estimate the emissions impacts of OS/OW vehicles operating in the DFW NA area. The project objective was accomplished through the completion of three main activities that were documented in this report:

- Characterization of OS/OW operations in the DFW region.
- OS/OW activity and emissions data collection.
- Analysis and estimation of OS/OW vehicle operations and emission rates.

The main findings of the emissions analysis that were conducted as part of this study are as follows:

- The current MOVES opMode equations do not appear to capture the impact of weight on the emission rates of HDDVs.
- Given how the SCR technology performs, specifically its reduced efficiency in lower-exhaust-temperature situations, users must be cautious when using PEMS testing and data from a controlled setting to capture NO_x emission rates. An exhaust temperature adjustment methodology may be needed to ensure that the opMode emission rates are representative of real-world truck emissions based on the exhaust temperatures.
- Unlike vehicles prior to MY2010, which had no SCR, newer SCR-equipped trucks can have lower emission rates under heavier loads, especially in higher-speed and -power opMode bins, which typically have higher exhaust temperatures. In SCR-equipped trucks, heavier loads may actually reduce NO_x emissions under certain driving conditions.
- Under normal loads (MOVES default weight), the SCR did not seem to provide any emissions benefit at speeds under 50 mph.
- The benefits of the SCR are much greater when carrying heavier loads due to the increased exhaust temperatures. In some of the higher-speed and -power opMode bins (e.g., opMode bin 40), the OW NO_x rate can be as much as 50 percent lower than the normal load rate.

Regarding the potential emission impacts of OS/OW operations in the NCTCOG region, the key findings from the analysis are as follows:

- The collected PAMS data show that the majority of the OS/OW VMT (67.4 percent) occurred on freeways at a higher average speed (51 mph) than on arterials (17 mph).

- Since VMT is a major factor in the emissions analysis, there is a linear increase in NO_x emissions given an increase in the percentage of OS/OW VMT.
- The NO_x emissions impact can range from 0.36 tons/day to 1.45 tons/day based on different assumptions about the percentage of OS/OW VMT and MY distributions.
- In scenarios where all OS/OW activity was attributed to MY2010 or newer trucks, the emission analysis showed a reduction in emission impacts (85 percent) compared to scenarios where the MY distribution of the fleet was based on AERR 2017.

The study provides increased insight into the emission impacts of a potential increase in the number of OS/OW vehicles in the fleet mix. Although there is some uncertainty about the current composition of OS/OW trucks in the overall fleet mix, the scenarios considered in this study were based on the best available data sources to date. The results can be improved as follows:

- The number of trucks (i.e., three trucks for corresponding MYs) used for PEMS testing provides a limited sample. The results can be improved with more vehicles and emission testing during real-world use (rather than the controlled test routes used in the study). Further measurement of truck activity and emissions for entire fleets will provide a deeper understanding of the emission impacts of the OS/OW operations.
- The results from this analysis can be expanded to include other potential vehicle types, such as single-unit and other combination trucks.

Finally, the results from this study (e.g., the temperature-dependent performance of SCR in the newer trucks and its impact on emissions at higher load) can be used to consider the NO_x impacts of expanding SCR to other fleet types, such as garbage collection vehicles, local delivery trucks, and buses. However, due to the reduced effectiveness of existing SCR technologies at lower exhaust temperatures more data is required related to the activity, especially the exhaust temperatures during average operating weights (approximately 55,000 pounds), to ensure that the exhaust temperatures are in the optimal range for SCR effectiveness.

Additionally, there may be some opportunities to reduce the overall impact of OS/OW operations by incentivizing the use of HD diesel trucks newer than 2010 (with SCR technologies) for heavier loads, especially when the route(s) involves large portions of highway driving.

REFERENCES

1. Middleton, D., Y. Li, J. Le, and N. Koncz. *Accommodating Oversize and Overweight Loads: Technical Report.* Report 0-6404-1. Texas A&M Transportation Institute, 2012.

2. Prozzi, J. A., P. Buddhavarapu, S. Kouchaki, J. Weissmann, A. Weissmann, N. Jiang, K. Savage, and C. M. Walton. *Infrastructure-Friendly Vehicles to Support Texas Economic Competitiveness.* Report 0-6817-1, University of Texas at Austin, 2016.

3. Quiroga, C., E. Kraus, and I. Tsapakis. *Truck Traffic and Truck Loads Associated with Unconventional Oil and Gas Developments in Texas*. Prepared for the Texas Department of Transportation Maintenance Division. Texas A&M Transportation Institute, 2015.

4. TxDMV. *Company Specific Envelope*. https://www.txdmv.gov/oversize-weight-permits/company-specific-envelope. Accessed Oct. 31, 2018.

5. U.S. EPA. *Exhaust Emissions Rates for Heavy-Duty On-Road Vehicles in MOVES2014.* EPA-420-R-15-105a, November 2015.

6. U.S. EPA. *Updates to MOVES Heavy Duty Running Exhaust Rates: Diesel, Gasoline, and Natural Gas.* Presented April 2010. https://www.epa.gov/sites/production/files/2019-06/documents/04-updates-hd-running-exhaust-rates-2019-04-10.pdf. Accessed Oct. 31, 2018.

7. K. Boriboonsomsin, T. Durbin, G. Scora, K. Johnson, D. Sandez, A. Vu, Y. Jiang, A. Burnette, S. Yoon, J. Collins, Z. Dai, C. Fulper, S. Kishan, M. Sabisch, and D. Jackson. Real-World Exhaust Temperature Profiles of On-Road Heavy-Duty Diesel Vehicles Equipped with Selective Catalytic Reduction. *Science of the Total Environment*, Vol. 634, pp. 909–921, 2018.