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MOVES2010a Regional Level Sensitivity Analysis

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This document discusses the sensitivity of various input parameter effects on emission rates using the US Environmental Protection Agency’s (EPA’s) MOVES2010a model at the regional level. Pollutants included in the study are carbon monoxide (CO), Oxides of Nitrogen (NO_X), Particulate Matter of less than 2.5 micrometers ($PM_{2.5}$), and Volatile Organic Compounds (VOCs). Similar trends for PM_{10} as reported for $PM_{2.5}$ and Nitrogen Dioxide (NO_2) as NO_X exist and inferences to these pollutants may also be made. Results are presented using the predicted emission rates (grams/mile) for running exhaust and starts across multiple MOVES source types.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS – WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS – WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

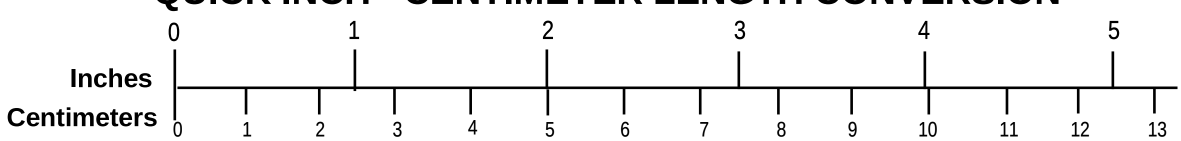
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

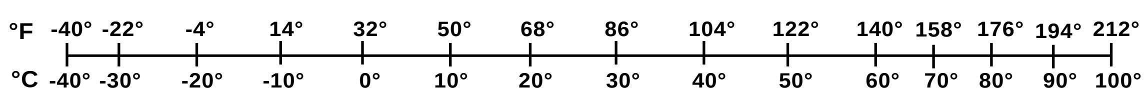
TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. SD Catalog No. C13 10286

Executive Summary

This document discusses the sensitivity of various input parameter effects on emission rates using the US Environmental Protection Agency's (EPA's) MOVES2010a[1] model (20100830 database) at the regional level. Pollutants included in the study are carbon monoxide (CO), Oxides of Nitrogen (NO_X), Particulate Matter of less than 2.5 micrometers ($PM_{2.5}$), and Volatile Organic Compounds (VOCs). Similar trends for PM_{10} as reported for $PM_{2.5}$ and Nitrogen Dioxide (NO_2) as NO_X exist and inferences to these pollutants may also be made. Results are presented using the predicted emission rates (grams/mile) for running exhaust and starts across multiple MOVES source types.

The input parameters varied in this analysis are: Temperature, Humidity, Ramp Fraction, Age Distribution, Analysis Year, and Average Speed Distribution. The input parameters of Road Type Distribution, Source Type Population, Age Distribution, Fuel, and I/M Programs were held constant utilizing the national default values from the MOVES 20100830 default database for the 2010 Analysis Year. MOVES is a complex model with many input parameters that can influence the emission rates across multiple vehicle types. The overall modeling process may include many variations and is not covered by this report. A separate project level analysis will delve more into the overall modeling process.

The results of the model sensitivity are presented for various vehicle types utilizing particular fuel types to provide an understanding of the input sensitivity independent of fleet mixture. The emission rate values are included in the results tables located in Appendices allowing the user to review the magnitude of the emissions rates across vehicle types. These data are specific for this sensitivity analysis and are not meant as absolute values for use in regional emissions analyses.

The methodology of the analysis used a local sensitivity analysis approach where a single input parameter was varied while all the other input parameters were held constant. The output emissions rates were analyzed across all MOVES vehicle types. To allow a comparison of these emission rates, a 'Baseline Case' was established. The Baseline Case used the default data from a National Scale MOVES run allowing national defaults for road type distribution, age distribution, average speed distribution, fuel, ramp fraction, and Inspection and Maintenance (I/M) programs. In order to run MOVES in a time efficient manner, a surrogate model approach was utilized to represent a county level analysis while executing MOVES for a single hour of the day. The surrogate approach utilizes a less computationally expensive method of running MOVES to obtain the overall sensitivities. A single hour was sufficient to establish the trends associated with the various model sensitivities as input parameters were varied.

While described in detail within the report, the basic findings for each evaluated parameter are presented.

- Temperature is a very sensitive parameter across all pollutants and vehicle types. The results from this analysis showed similar trends to the temperature and humidity sensitivity analysis conducted by EPA.
- Analysis Year is a very sensitive parameter especially between the years 2010 and 2020 where emission rates are seen to decrease most significantly. Emission rates further decline until the year 2040 and remain relatively unchanged thereafter. Given the analysis year requirements, prescribed for regional conformity determinations, users may not have a lot of flexibility in varying this input parameter.
- Age Distribution of the vehicle fleet is important. A proportional increase of 10 percent in the distribution of vehicles less than 10 years old caused a reduction in vehicle emission rates by approximately 16% for CO, 12% for NO_X, and 11% for $PM_{2.5}$. As expected, an older fleet with a

10% greater distribution of vehicles between 11 and 20 years old resulted in an increase in emission rates across all pollutants. This trend continued when increasing the proportion of the oldest set of vehicles between 21 and 30 years old as well. It is desirable for the users to obtain local vehicle age distribution data instead of relying on default information. This is especially true if the area's fleet consists of newer vehicles or if vehicle replacement programs are in effect.

- Ramp Fraction can be a sensitive input parameter dependent on vehicle and fuel type. A common observation for almost all vehicle types across all pollutants was that emission rates and Ramp Fraction change in a linear manner. As the Ramp Fraction increases, so do emissions rates. Diesel emissions of CO remained relatively flat showing a dependence on fuel type within the model. Alternatively, the emissions rate for $PM_{2.5}$ showed an increase for diesel fueled vehicle with increased ramp fraction while gasoline emissions remaining somewhat constant. This parameter will be greatly controlled by the highway geometric design.
- Emission rates for NO_X and CO were the most sensitive pollutants due to changes in humidity. In the case of CO, gasoline fueled vehicles showed increased emissions as humidity increased, while for NO_X, diesel fueled vehicles were most affected. All other vehicle types remained relatively insensitive to changes in humidity.
- The emission rates associated with Average Speed Distributions representing Level-of-Service (LOS) B, C, and D generally varied by only a few percentage points across all pollutants and vehicle types. Results for CO varied for all vehicle types and should be examined individually by the reader in the full report. The emissions rates associated with LOS E showed a larger variation than LOS B, C or D, while emission rates associated with LOS F were significantly higher. It was also observed that the 'Baseline case' exhibited an emission rate between LOS E and F, indicating use of default values results in a LOS E+ speed to volume relationship, indicating a conservative bias for the in model default. This is an indication that local data should be obtained and used when possible. The functional classification for arterials show a much greater change in emission rates for varying LOS than all other facility types.

It is important for the analyst to be aware of how all of these variables affect a regional analysis and the information of this report should inform in that regard. This provides an awareness of the importance of inputs during the design phase of the projects and could result in a better analytical design in regards to air quality. Default data or assumptions should not be used if it is possible to obtain local data. This is especially true for vehicle age distribution and average speed distribution with related drive schedules. For example, defaulting to the MOVES average speed distribution would result in a LOS E+ being used during analysis. This heavy congestion may not exist or may not be the outcome of a final design and if used could result in higher emission rates than would occur if the actual speed distribution were used. Temperature and humidity are location specific. The analysis year will be defined by conformity guidelines. Omitting these two input parameters, the order of impact for including actual data would be:

- Average speed distribution for arterials
- Vehicle age distribution
- Ramp fraction
- Average speed distribution for interstates
- Average speed distribution for freeways

It is always more accurate to include local data and this listing is only to be utilized as a general guide.

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1 Introduction

This document discusses the sensitivity of various input parameter effects on emission rates using the US Environmental Protection Agency's (EPA's) MOVES2010a[1] model (20100830 database) at the regional level. This sensitivity analysis includes the effects on Carbon Monoxide (CO), Oxides of Nitrogen (NO_X), Particulate Matter of less than 2.5 micrometers ($PM_{2.5}$), and Volatile Organic Compounds (VOCs) emission rates (grams/mile) for running exhaust and starts across multiple MOVES source types (e.g., passenger car, transit Bus, long-haul combination truck, etc). The temperature sensitivity associated with the evaporative emission process is also included in this analysis. The results presented in this document for $PM_{2.5}$ can also represent the sensitivity of PM_{10} and the results for NO_X may represent the sensitivity of Nitrogen Dioxide (NO_2). The following input parameters were varied in the analysis: Temperature, Humidity, Ramp Fraction, Age Distribution, Analysis Year, and Average Speed Distribution. The input parameters of Road Type Distribution, Source Type Population, Age Distribution, Fuel, and Inspection and Maintenance (I/M) Programs were held constant utilizing the national default values from the MOVES 20100830 default database for the 2010 Analysis Year. The results of the analysis show how running exhaust, start, and evaporative emissions rates are affected by the variation of analyzed input parameters and the magnitude of the changes.

2 Purpose and Scope

The purpose of this analysis is to help inform the user about the sensitivity of selected MOVES input parameters associated with a regional level analysis. As such, it is a review of the model sensitivity only, and not the overall modeling process. The EPA conducted a sensitivity analysis on the national scale in 2010 which focused on the effects of temperature and humidity across various emissions processes for all vehicles separated by fuel types (e.g., gasoline and diesel) [2]. This analysis complements the EPA temperature/humidity analysis, but also investigates a wider range of input parameters in a more comprehensive manner.

MOVES is a complex model with many input parameters that can influence the emission rates across multiple vehicle types. This sensitivity analysis focuses on user supplied input parameters when conducting regional level analyses, such as those to support State Implementation Plans (SIP) or regional emissions analyses. The results of the model sensitivity are presented for the analyzed input parameters' effect on emission rates for various vehicle types with a particular fuel type. For example, passenger cars, passenger trucks, and light commercial trucks utilize gasoline, while combination trucks, single unit trucks, buses, motor homes, and refuse trucks primarily utilize diesel fuel. The results are presented in this manner so the user can have an understanding of the sensitivity of input parameters independent of fleet mixture. The emission rate values are included in the results tables located in Appendices A through F so the user can have an understanding of the magnitude of the emissions rates across vehicle types. However, these data are not meant as absolute values for use in regional emissions analyses.

3 Methodology

A local sensitivity analysis approach was utilized where a single input parameter was varied while all other input parameters were held constant. For this analysis the sensitivities of six input parameters were analyzed; these included average speed distribution, temperature, humidity, ramp fraction, age distribution and analysis year. The output emissions rates were analyzed across all MOVES vehicle types. Table 3-1 summarizes the ranges of input parameters used in the sensitivity analysis.

Table 3-1. Summary of Input Parameter Sensitivity Values

Input Parameter	Parameter Values/Description
Temperature (Fahrenheit) includes starts and evaporative	-40º, -20º, 0º, 20º, 40º, 60º, 80º, 100º, 120º F
Humidity	0%, 20%, 40%, 50%, 60%, 80%, 100% (60º F and 80º F)
Ramp Fraction	0, 0.02, 0.04, 0.06, 0.10, 0.12 0.16, 0.20
Analysis Year	2010, 2020, 2030, 2040, 2050
Age Distribution	Group 1: +10%, Group 2: +10%, Group 3: +5%
Average Speed Distribution - Urban Restricted Access - FC 11 Urban Interstate	LOS B,C,D,E,F
Average Speed Distribution - Urban Unrestricted Access - FC 12 Urban Principal Arterial Freeway	LOS C,D,E
Average Speed Distribution - Urban Unrestricted Access - FC 14 Urban Principal Arterial Other	LOS B,C,F

The first step in conducting the sensitivity analysis was to establish a ‘Baseline Case’. Rather than create a representative county using the county information contained within the MOVES default database, the default data from a National Scale MOVES run was utilized to establish the ‘Baseline Case’. National defaults for road type distribution, age distribution, average speed distribution, fuel, ramp fraction, and I/M programs were used for the ‘Baseline Case’. Table 3-2 lists the MOVES run specification information and input data used for the ‘Baseline Case’.

In order to run MOVES in a time efficient manner for the sensitivity analysis, a surrogate model approach was utilized to represent a county level analysis while executing MOVES for a single hour of the day. A surrogate model is a computationally inexpensive method of running a computer model that represents the response of the larger, more computationally expensive model. In this case, instead of running MOVES for all hours and months typical for a regional analysis, only a single hour was run. A single hour is sufficient to establish the trends associated with the various model sensitivities of the input parameters analyzed.

Table 3-2. Baseline Case Parameter Description

Parameter	Description
Year	2010
Month	July
Day	Weekday
Hour	8:00 AM
Geographic Bounds	Nation
Road Type(s)	All
Vehicles/Fuel Type	Diesel Fuel - Combination Long-haul Truck
	Diesel Fuel - Combination Short-haul Truck
	Diesel Fuel - Intercity Bus
	Diesel Fuel - Light Commercial Truck
	Diesel Fuel - School Bus
	Diesel Fuel - Single Unit Long-haul Truck
	Diesel Fuel - Single Unit Short-haul Truck
	Diesel Fuel - Transit Bus
	Gasoline - Light Commercial Truck
	Gasoline - Passenger Car
	Gasoline - Passenger Truck
Age Distribution	2010 National default
Average Speed Distribution	National Default (8AM Weekday)
Fuel	National Default
Road Type Distribution	National Default
Ramp Fraction	National Default (0.08)
I/M Program	National Default
Vehicle Type VMT	Normalized - 1000 VMT per HPMS Vehicle Type
Source Type Population	Normalized - 1000 VMT per HPMS Vehicle Type
Temperature	60 degrees Fahrenheit (80 degrees Fahrenheit used for Humidity only)
Humidity	50%

The strategy utilized for analyzing the sensitivity for each input parameter is described below.

Temperature and Humidity

Prior to conducting this sensitivity analysis, the EPA report "*MOVES Sensitivity Analysis: The Impacts of Temperature and Humidity of Emissions*"[2] was reviewed to gain an understanding of temperature and humidity sensitivities, the method of calculation for the analysis used by EPA, and for comparison to this analysis. The analysis for this reporting differs from the ranges used in the EPA analysis in two ways. First, the EPA analyzed temperature in 10° increments, while this analysis utilized 20° increments. Second, this analysis only analyzed humidity at 60° and 80° Fahrenheit, while the EPA sensitivity analysis analyzed humidity over a wider range of temperatures based on pollutant characteristics. A summary of the EPA temperature and humidity sensitivity findings are discussed in Section 4.1 and 4.2 of this document along with the findings of this analysis. The temperature and humidity used for the 'Baseline Case' are 60° Fahrenheit and 50%, respectively.

Ramp Fraction

Ramp Fraction represents the length of time vehicles spend on ramps associated with urban and rural restricted access roadways in MOVES. The 'Baseline Case' utilized an 8% ramp fraction and the sensitivity analysis varied the ramp fraction by 2% or 4% increments from 0 to 20%, accounting for the allowable range of values within MOVES.

Analysis Year

Analysis Year sensitivity was evaluated in 10 year increments, with the 'Baseline Case' analysis year being 2010. The following years were analyzed: 2020, 2030, 2040 and 2050. The goal of analyzing this input parameter was to determine how emission rates might vary in future analysis years. The national default age distribution for 2010 was used for all analysis years.

Age Distribution

Vehicle age distribution consists of a distribution of vehicle ages from 0 to 30 years old. The 'Baseline Case' utilizes the national default age distribution for 2010. In conducting the sensitivity analysis, the 31 vehicle age ranges were divided into three groupings. Group 1 is 0-10 years old, Group 2 is 11-20 years old, and Group 3 is 21-30 years old. The vehicle age distributions were redistributed proportionally based upon the default age distributions for each of the three groups. Three sensitivity runs were conducted. The first run consisted of redistributing Group 1 by increasing the total distribution of those vehicles in that age group by 10% and proportionally decreasing the distributions in Group 2 and 3. The second run consisted of redistributing Group 2 by increasing the total distribution of those vehicles by 10% and proportionally decreasing the distributions of Groups 1 and 3. The third run consisted of redistributing Group 3 distribution by increasing the total distribution of those vehicles by 5% and proportionally decreasing the distributions in Groups 1 and 2. Group 3 was only increased by 5% because typically vehicles that are between 21-30 years old only make up approximately 3% of the total vehicle population. Therefore, a 5% redistribution accounts for over a 100% increase in vehicles 21-31 years old.

Average Speed Distribution

Average speed distribution was analyzed by comparing emission rates associated with different Levels of Service (LOS). LOS is a qualitative measure of traffic flow on a roadway and is described in the "*Highway Capacity Manual 2010*"[3]. LOS B represents speeds at or near free-flow conditions and freedom to select desired speeds are unaffected. LOS C represents speeds at or near free-flow conditions and the freedom to select desired speeds can be restricted. LOS D represents conditions of decreased speed at volume increases and limited ability to maneuver across lanes. LOS E represents conditions at or near roadway capacity and maneuverability is extremely limited. LOS F represents a breakdown in vehicle flow where volume can temporarily exceed the roadway capacity which causes the formation of queues and low travel speeds. The 'Baseline Case' utilizes the national default average speed distribution for the 8AM-9AM hour. Drive schedule data associated with various LOS contained in the MOVES default database driveschedule and driveschedulesecond tables for Urban Interstate, Urban Principal Arterial Freeway, and Urban Principal Arterial other were analyzed. The second by second data from the available LOS drive schedules were converted into average speed distributions based upon the criteria set forth in the avgspeedbin table in the MOVES default database. Table 3-3 lists speed ranges associated with each average speed distribution bin.

Table 3-3. Average Speed Distribution Bins

Bin ID	Average Bin Speed	Average Speed Bin Range
1	2.5	speed < 2.5mph
2	5	2.5mph <= speed < 7.5mph
3	10	7.5mph <= speed < 12.5mph
4	15	12.5mph <= speed < 17.5mph
5	20	17.5mph <= speed <22.5mph
6	25	22.5mph <= speed < 27.5mph
7	30	27.5mph <= speed < 32.5mph
8	35	32.5mph <= speed < 37.5mph
9	40	37.5mph <= speed < 42.5mph
10	45	42.5mph <= speed < 47.5mph
11	50	47.5mph <= speed < 52.5mph
12	55	52.5mph <= speed < 57.5mph
13	60	57.5mph <= speed < 62.5mph
14	65	62.5mph <= speed < 67.5mph
15	70	67.5mph <= speed < 72.5mph
16	75	72.5mph <= speed

4 Results

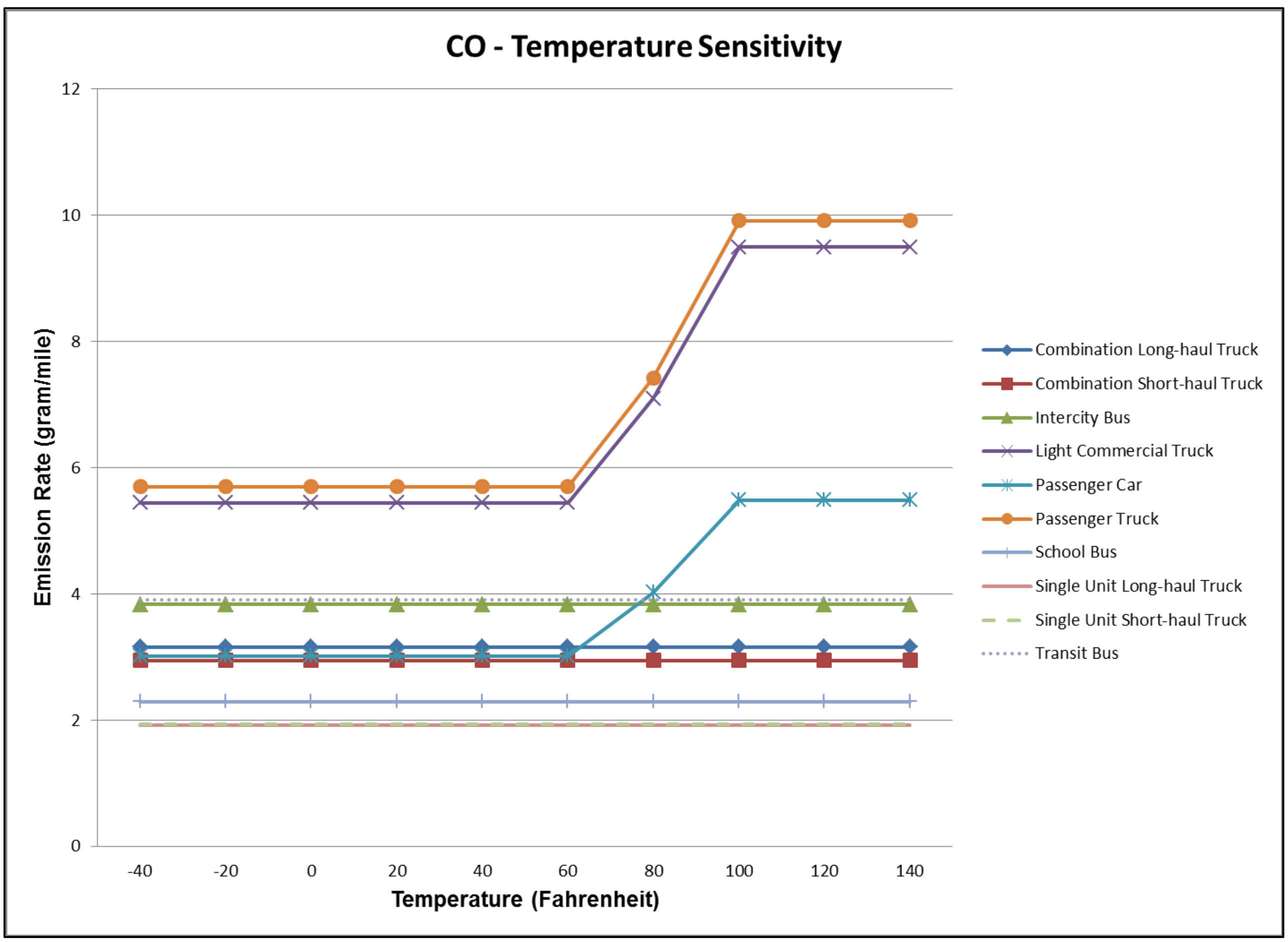
Results associated with each MOVES input parameter evaluated in the analysis are discussed in Sections 4.1 through 4.8. Each section displays a figure of one or more pollutants and discusses the trends as well as the magnitude of change associated with the input parameter. A complete set of figures and detailed tables for CO, NO_X, $PM_{2.5}$, and VOCs results for all input parameters analyzed are found in Appendices A through F.

4.1 Temperature – Running Exhaust

Temperature results from this analysis were compared with the results of the EPA temperature sensitivity analysis. In most cases the results from both analyses show similar trends across all pollutants and sensitivity ranges for gasoline fueled vehicles. However, there are cases where the results from the two analyses differ, specifically for CO and VOC emissions associated with diesel vehicles. The results from this analysis indicate no sensitivity associated with diesel vehicles for CO and VOC to temperature, while the EPA analysis indicates sensitivities between 60° and 100° Fahrenheit for diesel vehicles. This difference was raised with EPA and is being investigated.

CO and VOC experience similar trends with an increase in emission rates as temperature increases between 60° and 100° Fahrenheit for passenger cars, passenger trucks, and light commercial trucks which are mainly gasoline fueled vehicles. Vehicles which are mainly diesel fueled (Buses, Single-Unit, and Combination Trucks) do not show any change in emission rates as temperature is varied. Figure 4-1 displays the change in CO emission rates associated with the changing temperature input values.

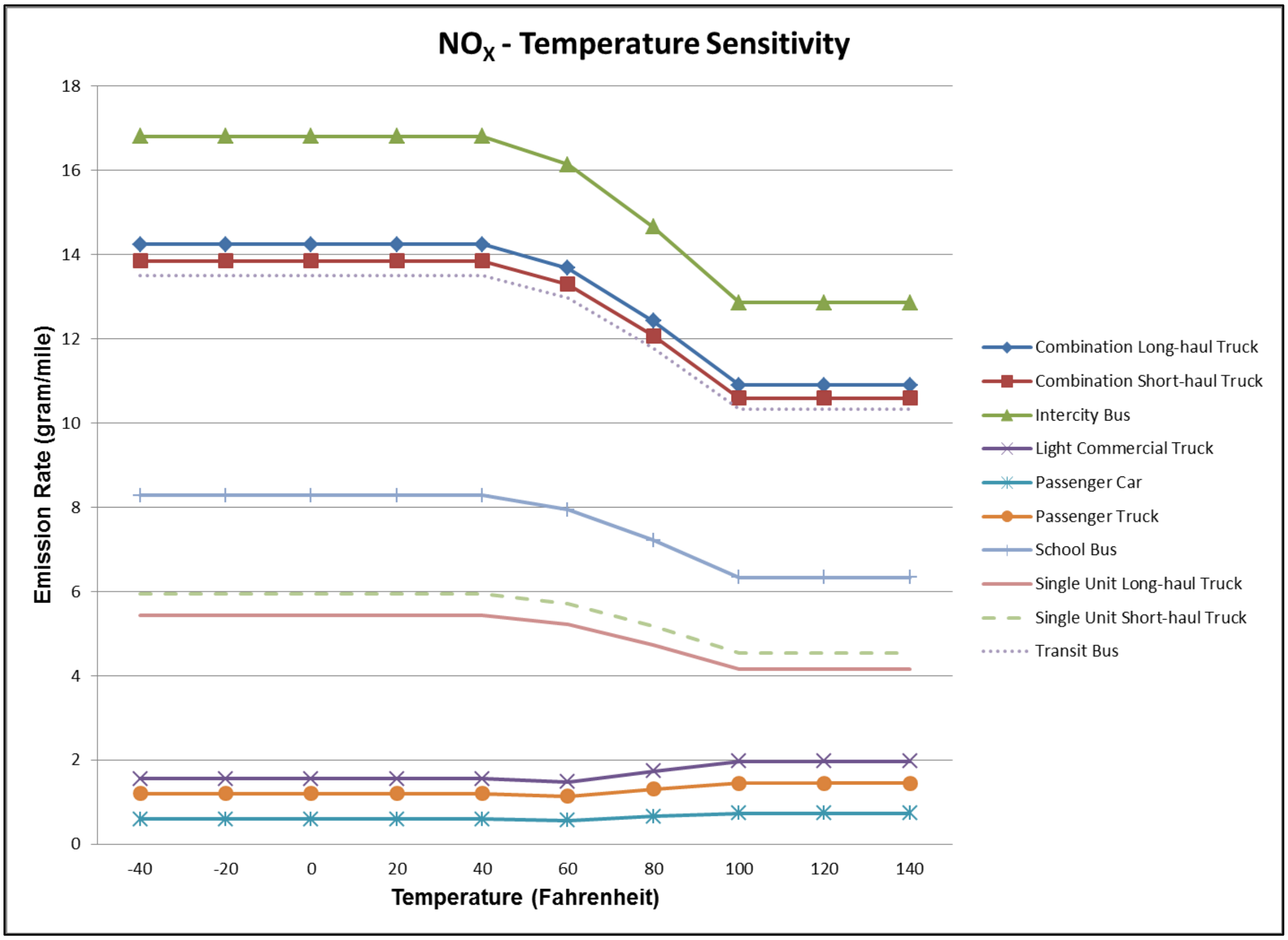
Figure 4-1. CO Temperature Sensitivity



Passenger car emissions rates increased between temperatures of 60° and 100° Fahrenheit by 82% for CO and 17% for VOC. For the same temperature range, passenger truck CO and VOC emission rates increased by 74% and 15%, respectively. Light commercial truck CO and VOC emission rates increased by 75% and 16%, respectively. The full set of temperature sensitivity result tables for CO and VOC are found in Appendix A.

NO_X emission rates are not sensitive for temperatures below 40° Fahrenheit, but are sensitive between the temperature ranges of 40° and 100° Fahrenheit for all vehicles. Figure 4-2 displays the change in NO_X emission rates associated with varying temperature model input. For temperature values above 100° Fahrenheit, NO_X emission rates show no sensitivity across all vehicle types evaluated. For passenger cars, passenger trucks, and light commercial trucks, NO_X emission rates decrease for temperatures between 40° and 60° Fahrenheit, and increase for temperatures between 60° and 100° Fahrenheit. For buses and trucks, NO_X emission rates decrease as temperature increases between 40° and 100° Fahrenheit.

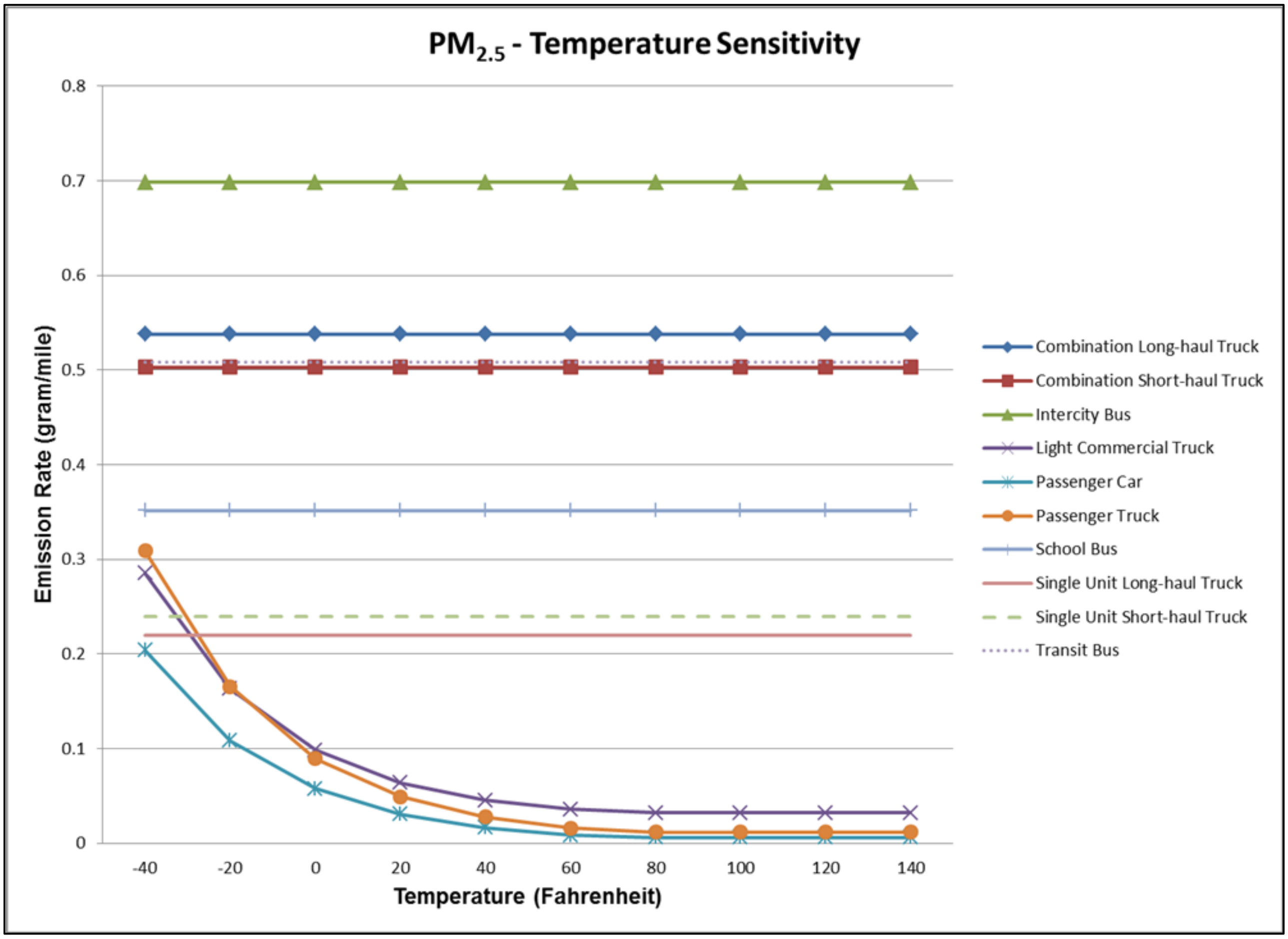
Figure 4-2. NO_X Temperature Sensitivity



Passenger car NO_X emission rates increased by 32% between 60° and 100° Fahrenheit, with passenger and light commercial trucks experiencing a similar increase in NO_X emission rates in that temperature range. NO_X emission rates for single-unit trucks, combination trucks, and buses, decreased by 20% between 60° and 100° Fahrenheit. The full set of temperature sensitivity result tables for NO_X is found in Appendix A.

Figure 4-3 displays the change in $PM_{2.5}$ emission rates associated with the changing temperature model input. $PM_{2.5}$ emission rates for passenger cars, passenger trucks, and light commercial trucks experience no sensitivity for temperatures above 80° Fahrenheit. However, the $PM_{2.5}$ emissions rates show considerable change for these same vehicle types at temperatures below 60° Fahrenheit. The $PM_{2.5}$ emission rates for passenger cars, passenger trucks, and light commercial trucks significantly increase as temperature drops below 60° Fahrenheit. For example, $PM_{2.5}$ emission rates for passenger cars are 558% higher at 0° Fahrenheit than at 60° Fahrenheit for the 'Baseline Case'. For buses and trucks, $PM_{2.5}$ emission rates are not sensitive for temperatures below 60° Fahrenheit. $PM_{2.5}$ emissions rates for these vehicles slightly increase (below 0.05%) as temperature is increased above 60° Fahrenheit. The full set of temperature sensitivity result tables for $PM_{2.5}$ is found in Appendix A.

Figure 4-3. $PM_{2.5}$ Temperature Sensitivity

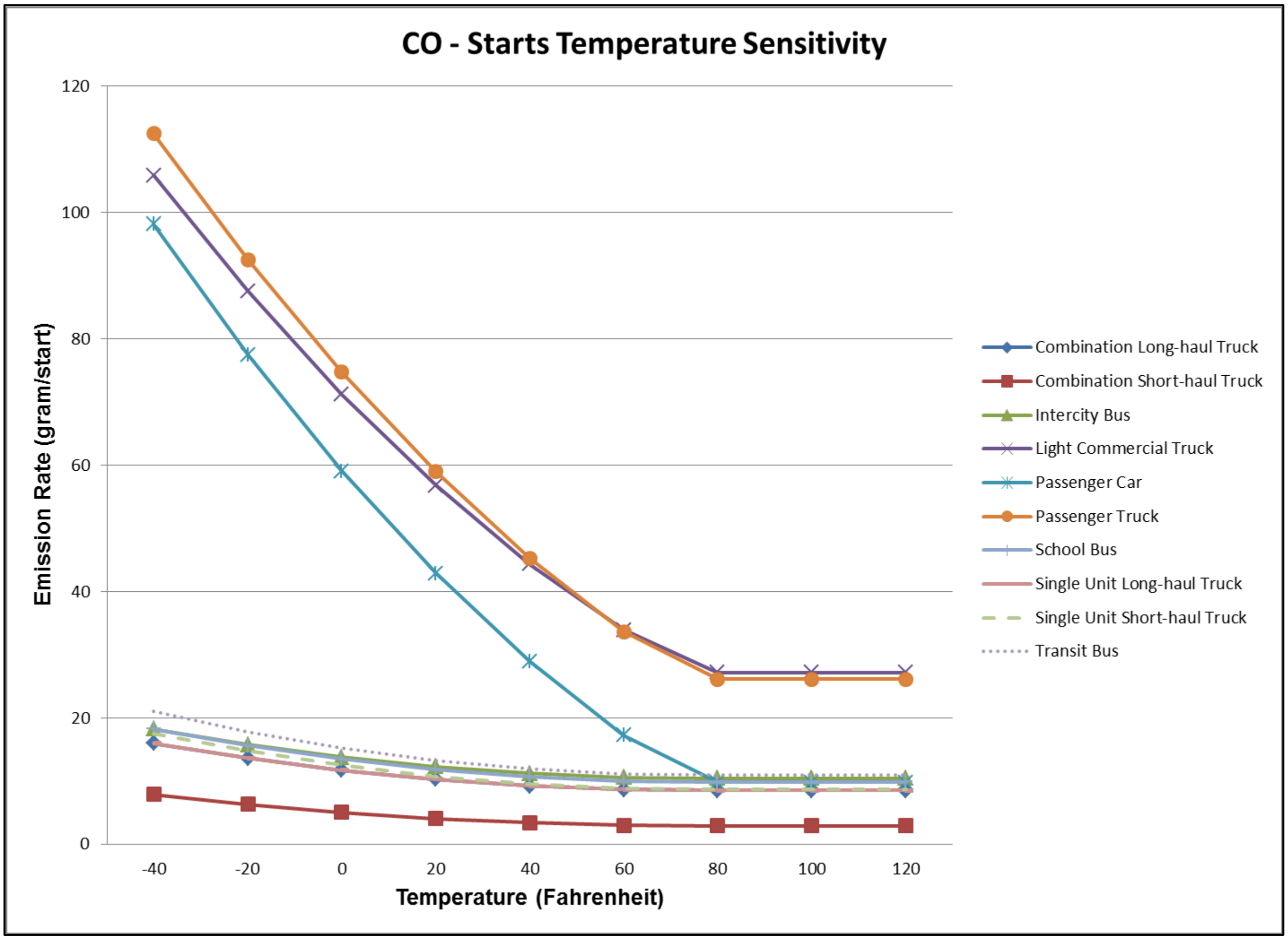


4.2 Temperature – Starts

Vehicle start emissions generated during the first few minutes of driving generate emissions which are higher than normal running emissions. This is due to emission-control equipment not being at its optimal operating temperature. There are two components of vehicle starts that contribute to this affect: vehicle soak time and ambient temperature. This analysis only focused on the sensitivity of the ambient temperature component.

CO and VOC emission rates for starts experience similar trends as ambient temperature is varied. Figure 4-4 displays the change in CO emission rates for starts associated with varying temperature inputs.

Figure 4-4. Starts CO Temperature Sensitivity

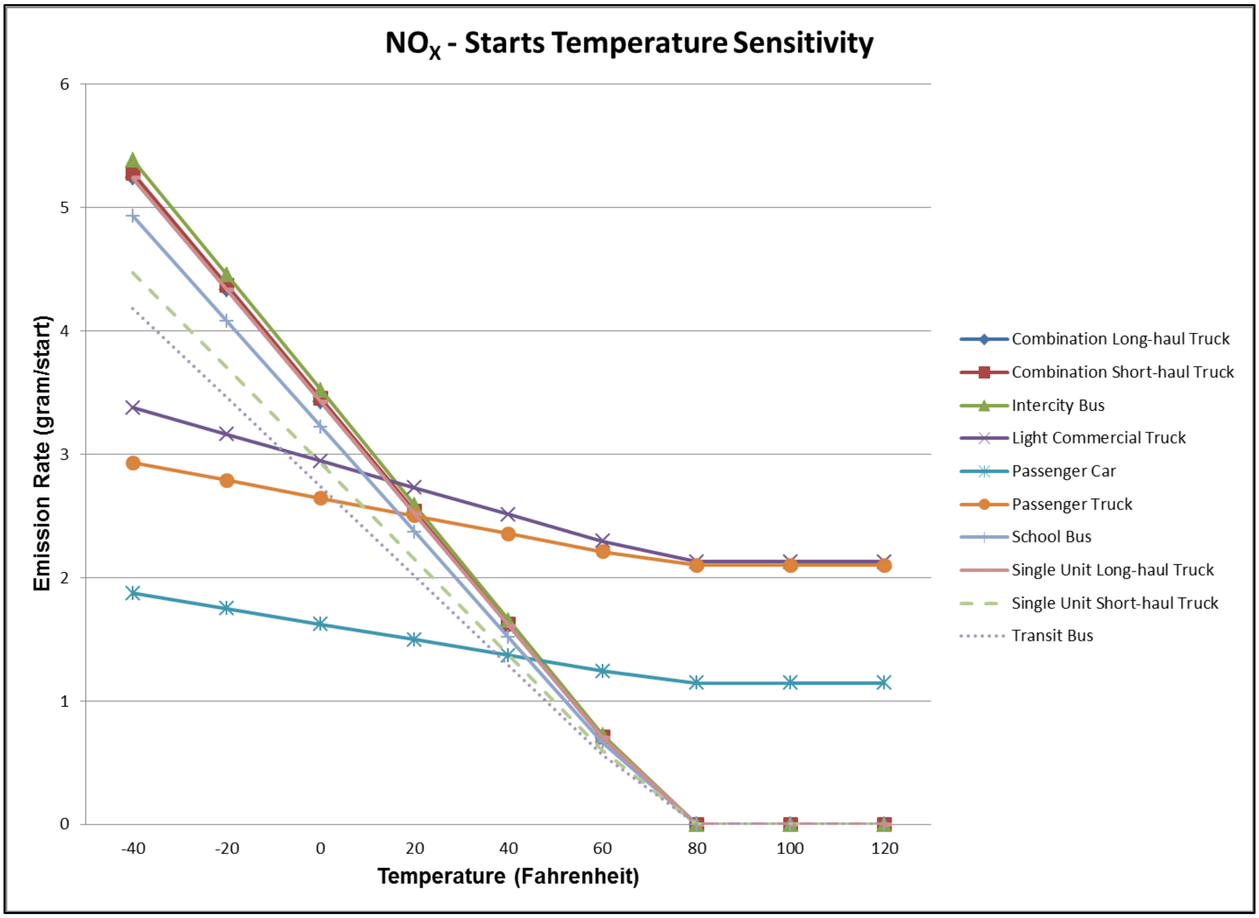


CO and VOC emission rates for starts are not sensitive for ambient temperatures above 80° Fahrenheit across all vehicle types. Passenger car, passenger truck, and light commercial truck CO emission rates for starts are 242%, 122%, and 110% higher, respectively, at 0° Fahrenheit compared to the 'Baseline' case at 60° Fahrenheit. CO emission rates for starts of buses, single-unit, and combination trucks ranged between 30%-68% higher at 0° Fahrenheit compared to the 'Baseline' case at 60° Fahrenheit.

The VOC emission rates for starts of passenger cars, passenger trucks, and light commercial trucks are 426%, 215%, and 213% higher, respectively, at 0° Fahrenheit compared to emission rates at 60° Fahrenheit. VOC emission rates for starts of buses, single-unit, and combination trucks are all 387% higher at 0° Fahrenheit compared to the 'Baseline' case at 60° Fahrenheit. It is noted that the VOC emission rates for starts of buses, single-unit, and combination trucks experience the same trend in that the percentage change associated with the temperature variation does not differ across these vehicle types. The full set of temperature sensitivity result tables for CO and VOC associated with starts is found in Appendix A.

Figure 4-5 displays the change in NO_X emission rates for starts associated with changing temperature model inputs.

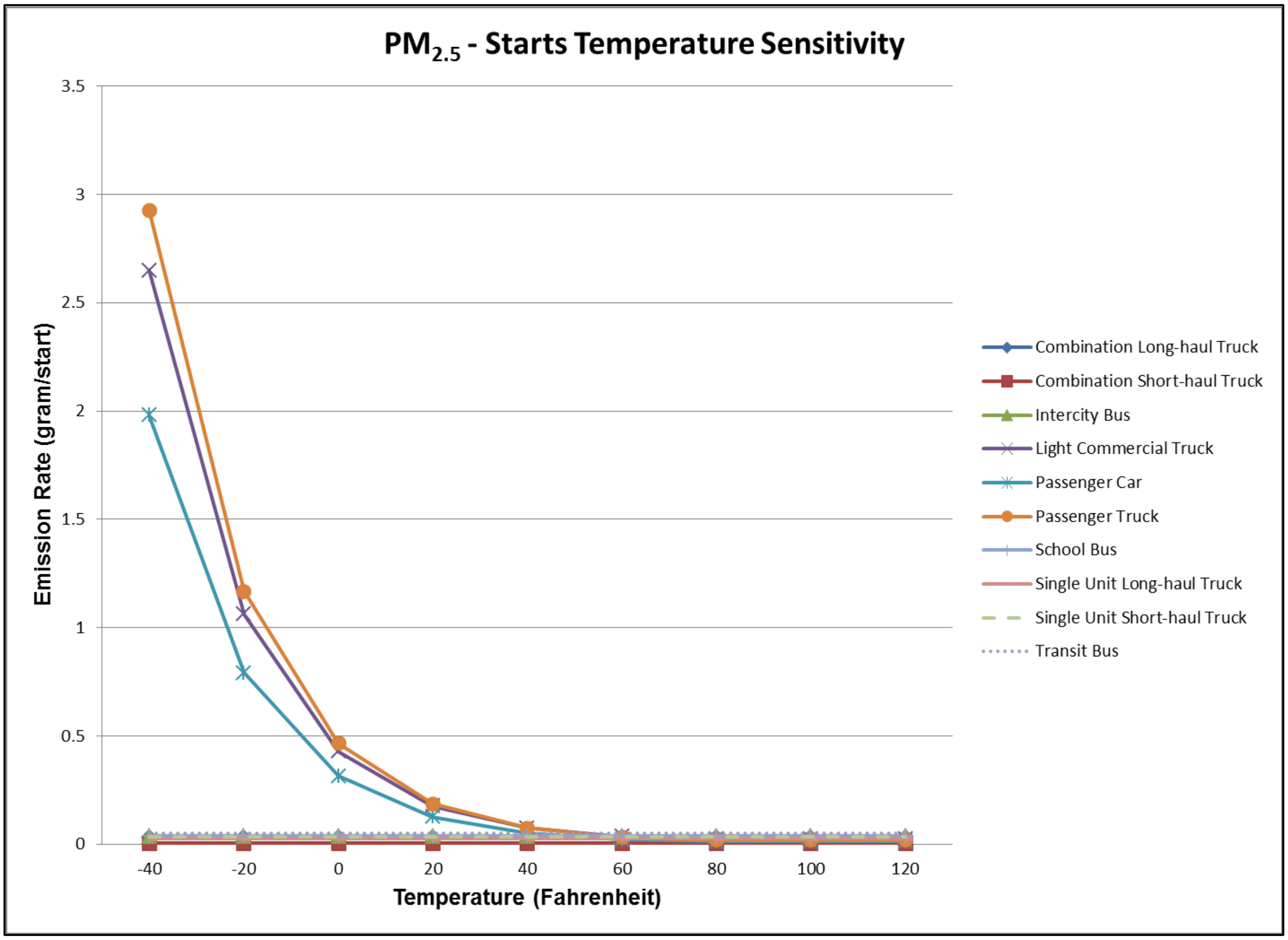
Figure 4-5. Starts NO_X Temperature Sensitivity



NO_X emission rates for starts are not sensitive for ambient temperatures above 80° Fahrenheit across all vehicle types. The NO_X emission rates for starts of passenger cars, passenger trucks, and light commercial trucks range from 20% to 30% higher at 0° Fahrenheit, compared to emission rates at 60° Fahrenheit for these vehicle types. NO_X emission rates for starts of school buses, single-unit, and combination trucks are all 387% higher at 0° Fahrenheit, compared to the 'Baseline' case at 60° Fahrenheit. It is noted that NO_X emission rates for starts of buses, single-unit, and combination trucks experience the same trend in the percentage change associated with the temperature variation across these vehicle types. The full set of temperature sensitivity result tables for NO_X associated with starts is found in Appendix A.

Figure 4-6 displays the change in $PM_{2.5}$ emission rates for starts associated with different temperature model inputs. The $PM_{2.5}$ emission rates for starts of buses, single-unit trucks, and combination trucks illustrate very little sensitivity to temperature changes. The overall percent change in emission rates for starts across temperatures is less than 1%. $PM_{2.5}$ emission rates for starts of passenger cars, passenger trucks, and light commercial trucks experience significant sensitivity at lower temperatures. The percent change in $PM_{2.5}$ emission rates for starts of these vehicle types ranges from 1,108% to 1,444% higher at 0° Fahrenheit, compared to the 'Baseline' case at 60° Fahrenheit. The full set of temperature sensitivity result tables for $PM_{2.5}$ associated with starts is found in Appendix A.

Figure 4-6. Starts $PM_{2.5}$ Temperature Sensitivity



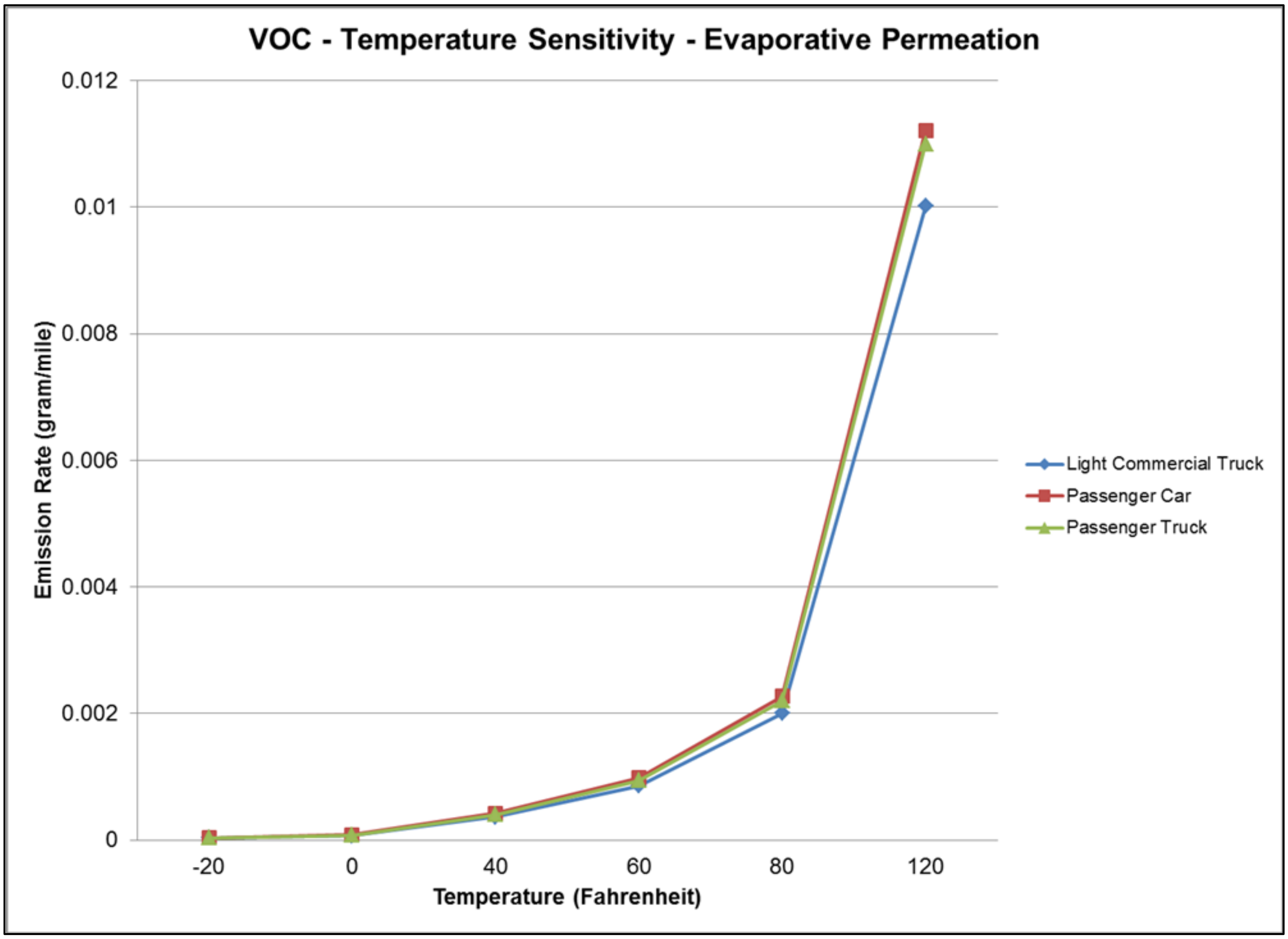
Overall, the temperature results for starts from this analysis experience similar trends to those observed in the EPA Sensitivity Analysis for all pollutants and vehicle types.

4.3 Temperature – Evaporative Emissions

Three emissions processes were analyzed associated with evaporative emissions. They include evaporative fuel leaks, evaporative fuel vapor venting, and evaporative permeation. The VOC emission rates (grams/hour) were analyzed to determine sensitivity to temperature. VOCs are the only pollutant within the scope of the analysis that can be modeled with the Evaporative pollutant processes within MOVES. Only passenger car, passenger truck, and light commercial truck vehicle types were available for inclusion in the sensitivity analysis of evaporative emission rates.

VOC emission rates for passenger cars, passenger trucks, and light commercial trucks did not experience any sensitivity associated with temperature for the evaporative fuel leaks and evaporative fuel vapor venting emission processes. However, VOC emission rates for the evaporative permeation emission process are sensitive to temperature. Figure 4-7 displays the change in VOC emission rates for evaporative permeation associated with varying temperature. VOC emission rates for evaporative permeation increase with higher temperatures across all vehicle types analyzed. The VOC emission rates for these vehicle types vary by between -96% at -20° Fahrenheit and approximately 1,000% at 120° Fahrenheit, relative to the baseline case. A detailed table of results of temperature sensitivity for evaporative permeation is found in Appendix A.

Figure 4-7. Evaporative Permeation - VOC Temperature Sensitivity

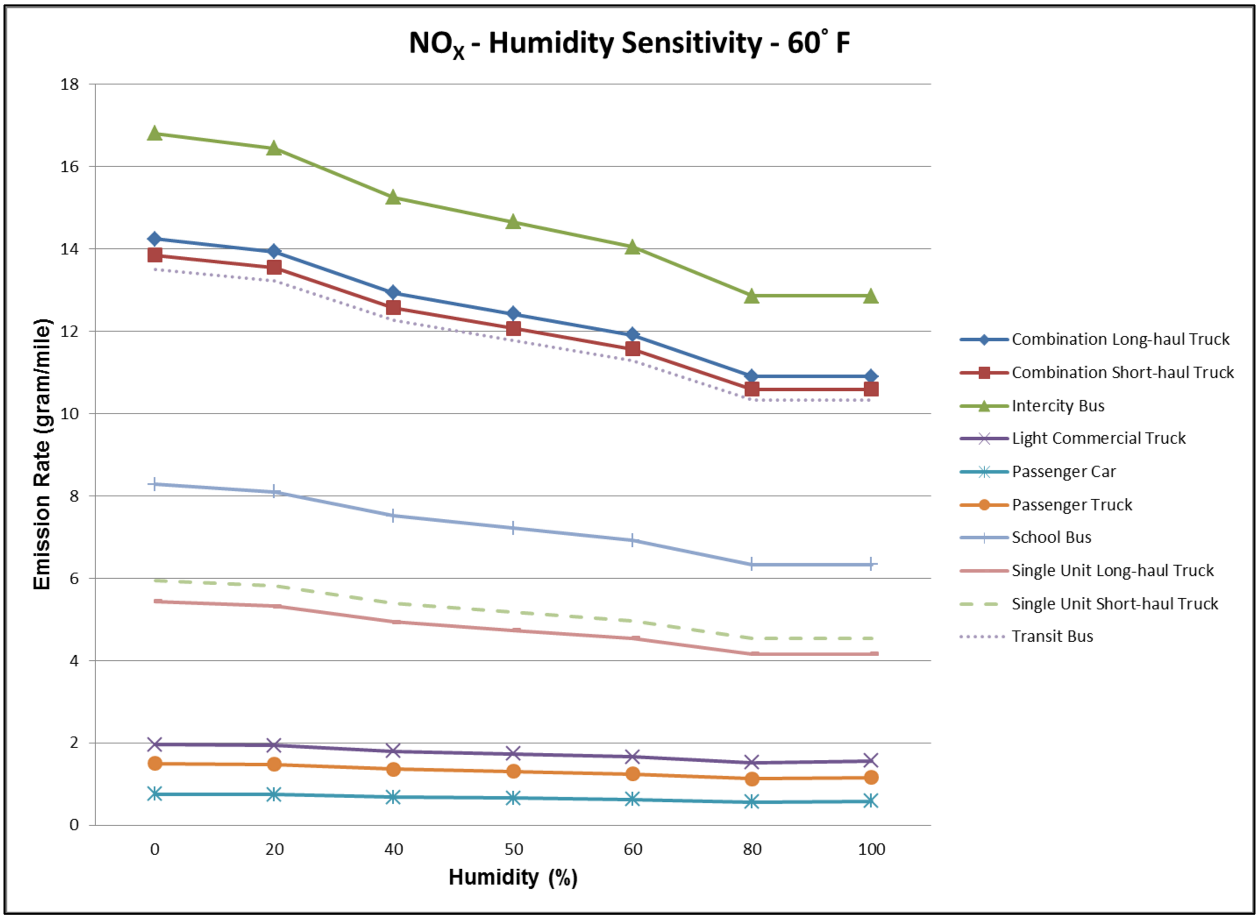


4.4 Humidity – Running Exhaust

Humidity was analyzed at temperatures of 60° (the temperature of the 'Baseline Case') and 80° Fahrenheit. Two temperature values were utilized because CO, $PM_{2.5}$, and VOC emission rates were not found to be sensitive to changes in humidity at 60° Fahrenheit. Only NO_X emission rates are sensitive to humidity for both temperature values analyzed. However, at 80° Fahrenheit there are sensitivities for the emission rates of CO, $PM_{2.5}$, and VOC for passenger car, passenger truck, and light commercial truck vehicle types. Neither buses, single-unit, nor combination trucks indicated sensitivities for these pollutants. The percent change in CO emission rates for these vehicle types ranged from an approximate 5% decrease at 0% humidity, to an increase of approximately 8% at 100% humidity, when compared to the 'Baseline Case'. The percent change in VOC emission rates due to the variation of humidity values shows a similar trend as CO emissions rates. The percent change in VOC emission rates for these vehicle types ranged from an approximate 1.5% decrease at 0% humidity to an increase of approximately 2% at 100% humidity when compared to the 'Baseline Case' humidity. The sensitivity associated with $PM_{2.5}$ for these vehicle types is negligible at 80° Fahrenheit, and varied only 0.01% across the entire humidity range. The full set of humidity sensitivity result figures and tables for CO, $PM_{2.5}$, and VOC is found in Appendix B.

Figure 4-8 and Figure 4-9 display the change in NO_X emission rates with varying humidity inputs at temperatures of 60° and 80° Fahrenheit, respectively.

Figure 4-8. NO_X Humidity Sensitivity - 60° Fahrenheit

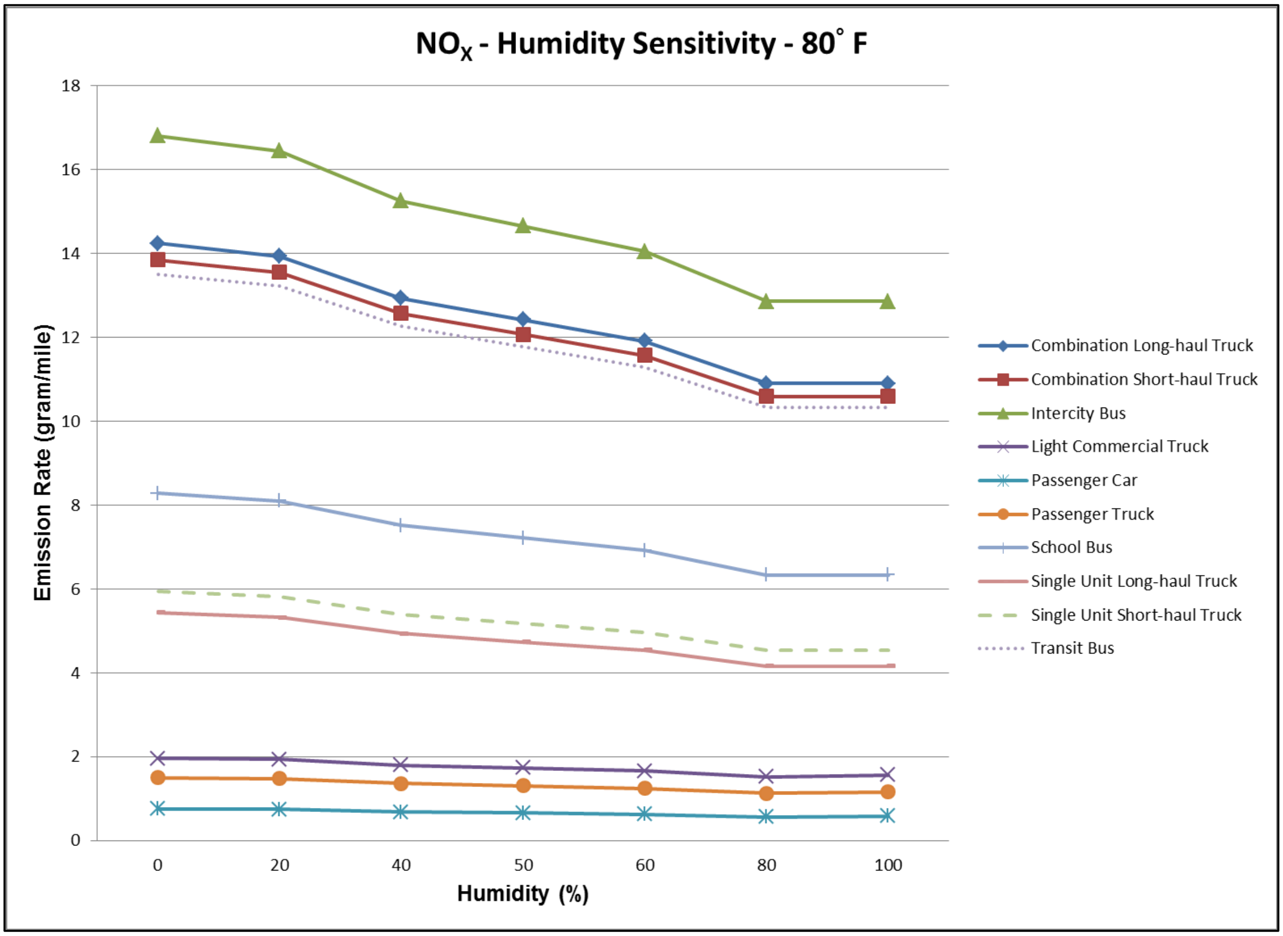


NO_X emission rates decrease as humidity values increase across all vehicle types for both 60° and 80° Fahrenheit. At 60° Fahrenheit, passenger cars, passenger trucks, and light commercial trucks NO_X emission rates experience an approximately 6% increase (at 0% humidity) to a decrease of approximately 12% (at 100% humidity), when compared to the 'Baseline Case'. At a temperature of 80° Fahrenheit, NO_X emission rates for these vehicle types experience an approximately 13% increase (at 0% humidity) to a decrease of approximately 11% (at 100% humidity), when compared to the 'Baseline Case'.

For buses, single-unit trucks, and combination trucks the NO_X emission rates illustrate the same trends. However, the trends for these vehicle types do vary slightly when comparing the two temperatures analyzed. At 60° Fahrenheit, the emission rates increase by 4% (at 0% humidity) and decrease by 9% (at 100%) for these vehicle types. At 80° Fahrenheit, the emission rates increase by 15% (at 0% humidity) to a decrease of 12% (at 100% humidity), when compared to the 'Baseline Case'. The full set of humidity sensitivity result figures and tables for NO_X is found in Appendix B.

The humidity results illustrate the same trends observed in the EPA sensitivity analysis for humidity at temperatures of 60° and 80° Fahrenheit. EPA has conducted a more rigorous analysis of humidity and analyzed more temperature profiles than contained in this analysis.

Figure 4-9. NO_X Humidity Sensitivity - 80° Fahrenheit

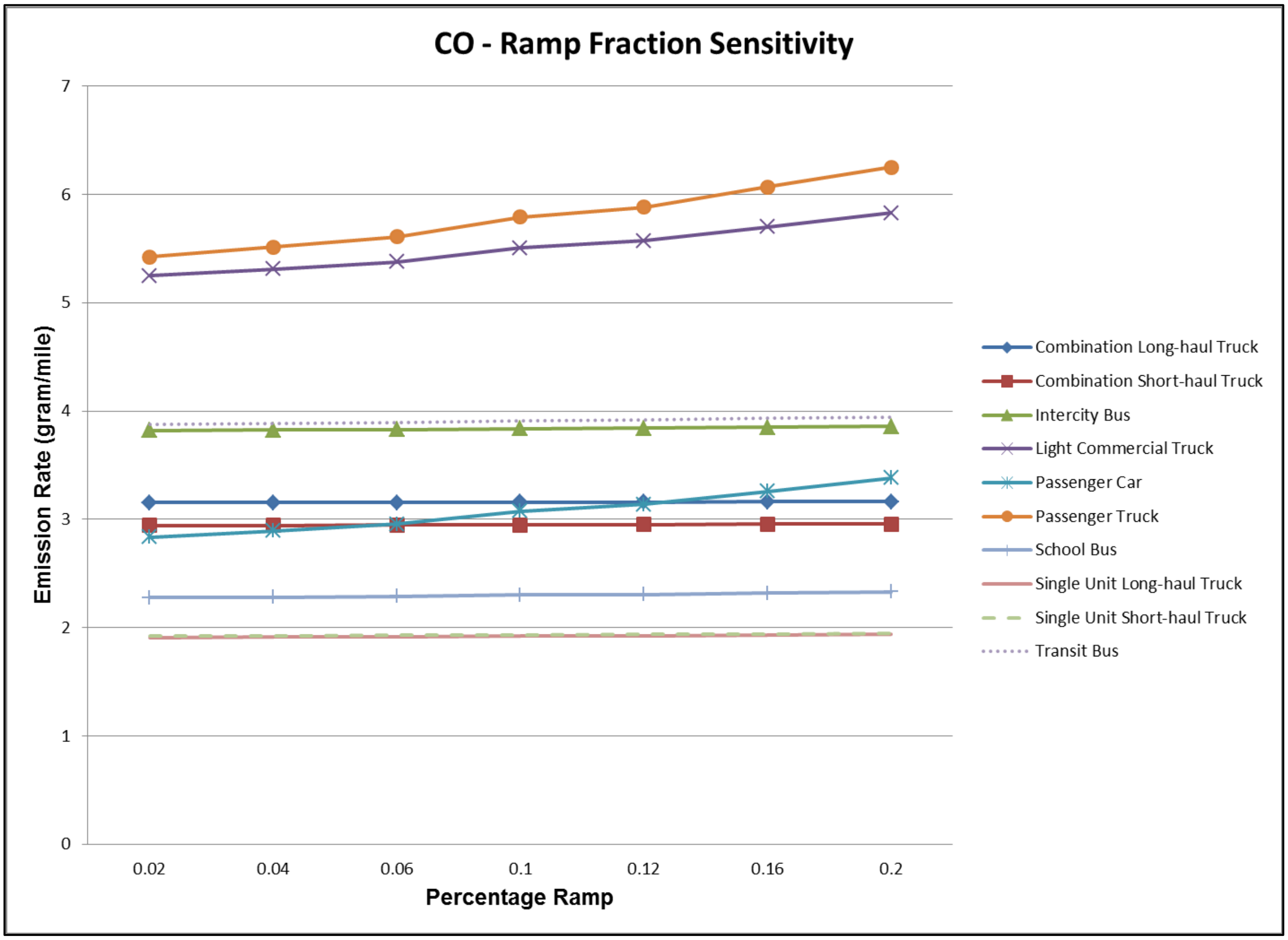


4.5 Ramp Fraction – Running Exhaust

The emission rate results for varying ramp fraction experience a linear response for all vehicle types across all pollutants. In general, the emission rate increases as ramp fraction increases. Exceptions occur for VOC emission rates associated with intercity, transit buses, short and long-haul combination trucks, where the emission rates slightly decrease as ramp fraction increases.

Figure 4-10 displays the change in CO emission rates associated with varying the ramp fraction input in MOVES. The CO emission rates for passenger cars and trucks change by approximately 1% (and 0.5% for light commercial trucks) for every 0.01 change in ramp fraction value. There is very little sensitivity associated with ramp fraction for CO emission rates of buses, single-unit, and combination trucks. For those vehicle types CO emission rates typically vary by less than 1% through the entire range of ramp fraction values (Ramp fraction of 0.0 to 0.20).

Figure 4-10. CO Ramp Fraction Sensitivity



VOC emission rates for buses, single-unit, and combination trucks experience the same trend as CO for ramp fraction in that there is very little sensitivity to the input parameter over the entire range of ramp fraction values. VOC emission rates for passenger cars, passenger trucks, and light commercial trucks are more sensitive to ramp fraction and vary by ± 2.9%, ±2%, and ± 1.2%, respectively, relative to the 'Baseline Case' (National Default of 0.08 ramp fraction value) between the range of ramp fraction values of 0 and 0.16.

NO_X emission rates for passenger cars varied by ± 2%, and by ±1% for passenger trucks over the range of 0 and 0.16. The emission rates for intercity buses, transit buses, and school buses vary by ± 0.5%, ±1.2%, and ±2.9%, respectively. Combination long-haul trucks experience no sensitivity due to ramp fraction while combination short-haul trucks vary by less than ± 0.05%. NO_X emission rates for single-unit short haul and single-unit long-haul trucks are more sensitive to ramp fraction, varying by ±3.8% and ±4.2% respectively, when compared to the other vehicle types for the range of ramp fraction values of 0 to 0.16.

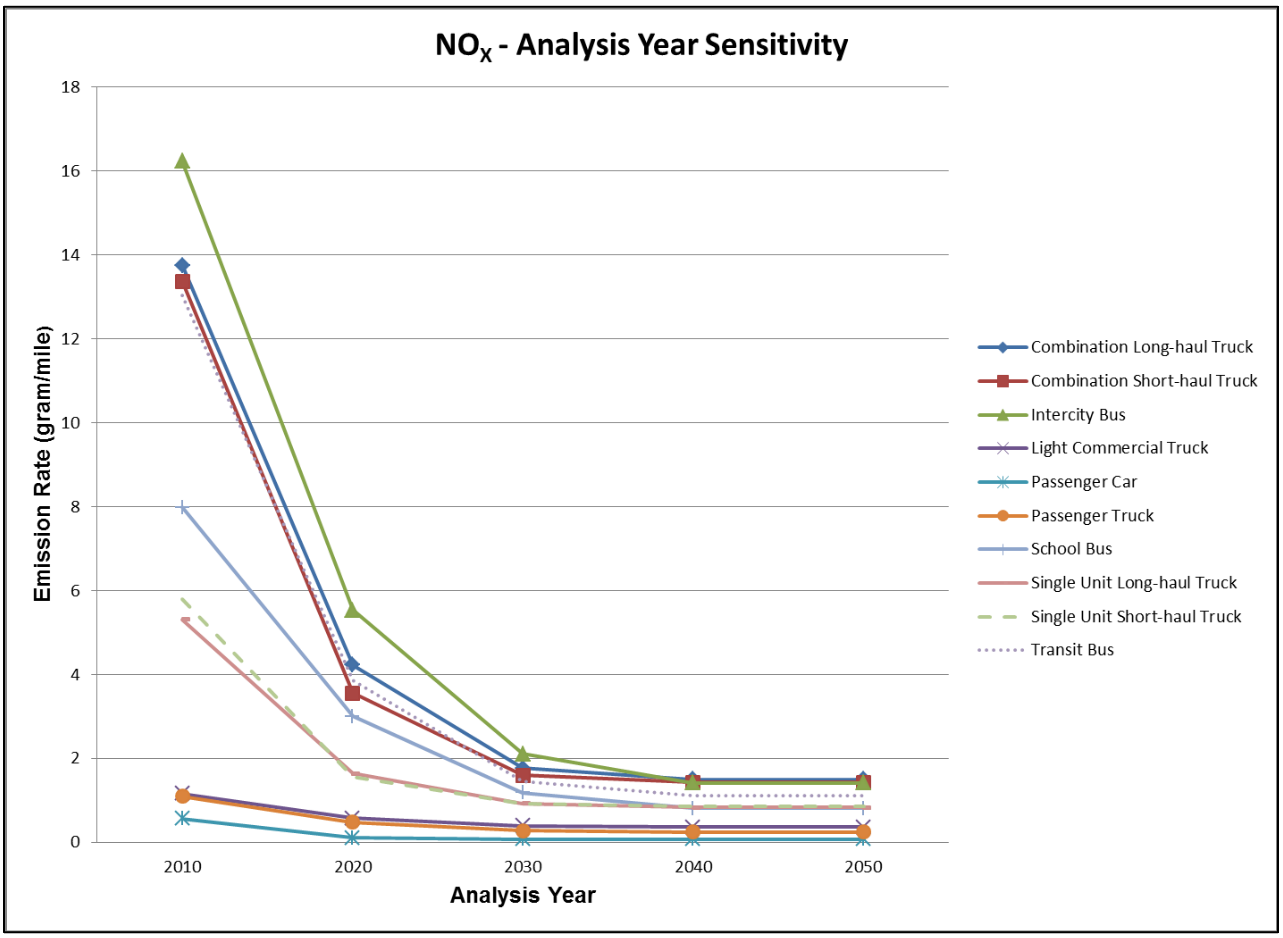
$PM_{2.5}$ emission rates are more sensitive to ramp fraction compared to the other pollutants, especially for passenger cars and trucks. $PM_{2.5}$ emission rates for passenger cars and passenger trucks change ±2% and ±1.5%, respectively, for every 0.01 change in ramp fraction value. Light commercial trucks experience an approximate ± 1% change for every 0.01 change in ramp fraction value. $PM_{2.5}$ emission rates for intercity buses, transit buses, and school buses vary by ± 2.1%, ± 3.3%, and ±4.1% respectively, for the range of ramp fraction values of 0 and 0.16. Single-unit and combination trucks $PM_{2.5}$ emission rates vary within ± 3.1% for the range of ramp fraction values of 0 and 0.16. The full set of ramp fraction sensitivity result figures and tables for CO, NO_X, $PM_{2.5}$, and VOC is found in Appendix C.

4.6 Analysis Year – Running Exhaust

The emissions rates by analysis year significantly decrease between the years 2010 and 2020 for all pollutants across all vehicle types. In general, there is a significant decrease in emissions rates between the 2020 and 2030 modeling years, although not as dramatic compared to the emission rates decrease between 2010 and 2020. Between 2030 and 2050, emissions rates decrease in a more gradual manner or level off. These trends are typical across all pollutants and vehicles types.

Figure 4-11 displays the change in NO_X emission rates associated with analysis year. The NO_X emission rates for passenger cars decreased by approximately 80% between the 2010 and 2020 modeling years. The passenger truck NO_X emission rate decreases by approximately 56% and for light commercial trucks emission rate decreases by 50.5% for the same time period. The NO_X emission rates for buses are between 66% and 70% lower in 2020, as compared to 2010. In 2030, the NO_X emission rates for buses are between 85% and 90% lower, as compared to 2010. For single-unit and combination trucks, NO_X emission rates are 64% to 74% lower in 2020, compared to 2010. In 2030, the NO_X emission rates are 82% to 89% lower than the 2010 NO_X emission rates for these vehicle types.

Figure 4-11. NO_X Analysis Year Sensitivity



The CO emissions rates for passenger cars, passenger trucks, and light commercial trucks decrease from 42% to 49% between the 2010 and 2020 modeling years. For buses, the CO emission rates decrease by 58% to 62% in 2020, compared to 2010. Single-unit and combination truck CO emission rates are 66% to 72% lower in 2020, compared to 2010.

Between 2010 and 2020 the $PM_{2.5}$ emissions rates for passenger cars, passenger trucks, and light commercial trucks decrease between 22% and 37%. $PM_{2.5}$ emissions rates for buses experience a 67% to 72% decrease in that same time period. $PM_{2.5}$ emissions rates for single-unit and combination trucks are between 70% and 81% lower in 2020, compared to 2010.

VOC emissions rates are between 58% and 81% lower for passenger cars, passenger trucks, and light commercial trucks in 2020 compared to 2010. VOC emissions rates for buses are between 62% and 67% lower for that same time period. Single-unit and combination truck VOC emission rates are 65% and 79% lower in 2020, compared to 2010.

Appendix D contains all tables and figures that summarize the sensitivity results for all pollutants and vehicles types associated with analysis year.

4.7 Age Distribution – Running Exhaust

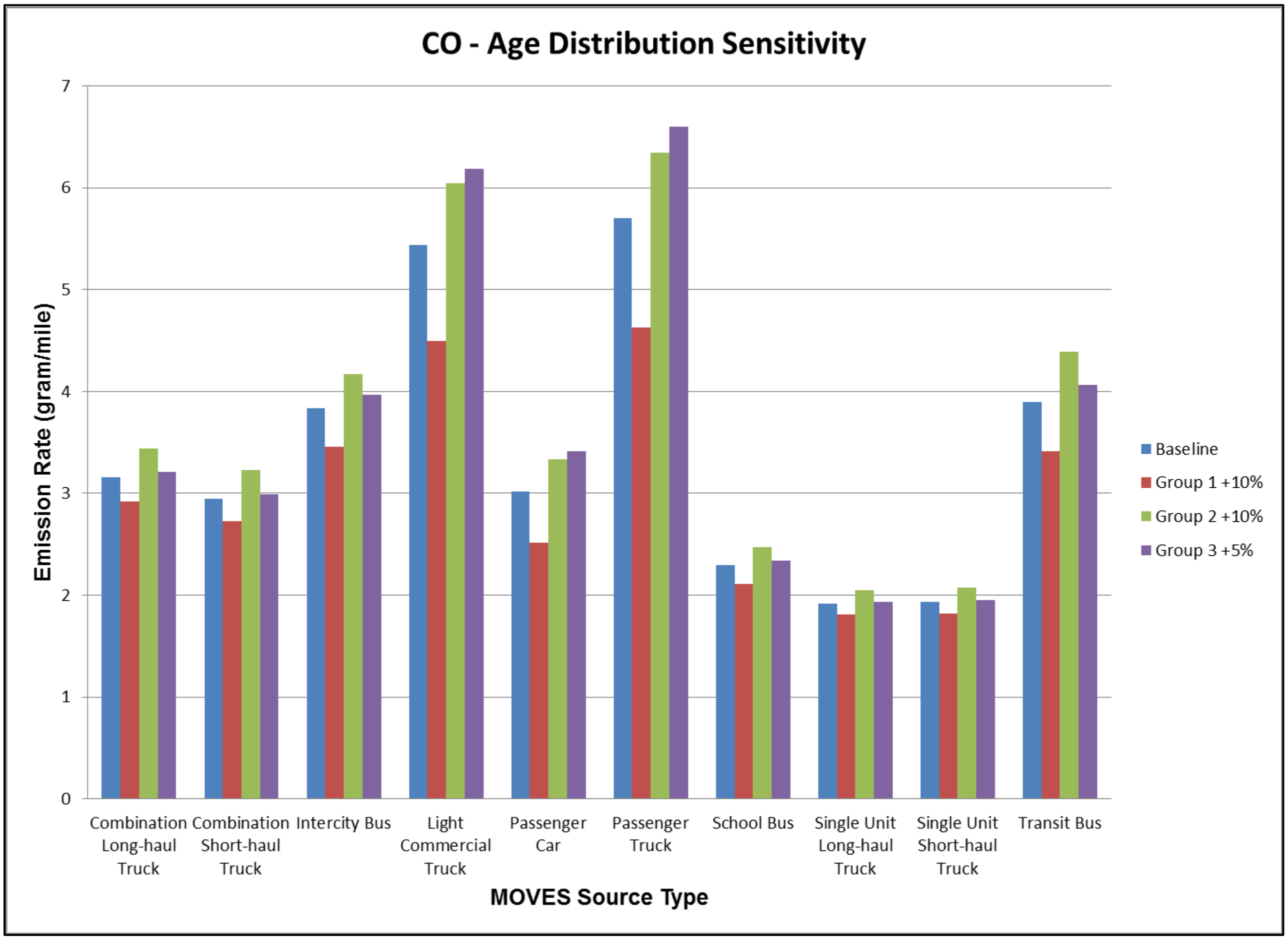
As mentioned in Section 3, for conducting the sensitivity analysis the 31 vehicle age ranges were divided into three groupings. Group 1 represents vehicles 0-10 years old, Group 2 represents vehicles 11-20 years old, and Group 3 represents vehicles 21-30 years old. The vehicle age distributions were redistributed proportionally based upon the default age distributions for each of the three groups. Three sensitivity runs were conducted. The first run consisted of redistributing Group 1 by increasing the total distribution of those vehicles in that age group by 10% and proportionally decreasing the distributions in Group 2 and 3. The second run consisted of redistributing Group 2 by increasing the total distribution of those vehicles by 10% and proportionally decreasing the distributions of Groups 1 and 3. The third run consisted of redistributing Group 3 distribution by increasing the total distribution of those vehicles by 5% and proportionally decreasing the distributions in Groups 1 and 2. Group 3 was only increased by 5% because typically vehicles that are between 21-30 years old make up only ±3% of the total vehicle population. Therefore, a 5% redistribution accounts for over a 100% increase in vehicles 21-31 years old. Figure 4-12 displays the change in CO emission rates associated with varying age distribution within MOVES.

The CO emission rates decrease within the range of 17% to 19% when the distribution of newer vehicles in Group 1 is increased for passenger cars, passenger trucks, and light commercial trucks. For these vehicle types the CO emission rates increases within the range of 11% to 16% as the distribution of older vehicles are increased in Group 2 and Group 3.

The CO emission rates for buses, single unit and combination trucks all have the same trend as age distribution is varied. The CO emission rates decrease within a range of 6% to 13% when the distribution of newer vehicles in Group 1 is increased and increase as the distribution of older vehicles increases within a range of 1% to 13% in Group 2 and Group 3 when compared to the ‘Baseline Case’.

The NO_X emission rates decrease within a range of 8% to 20% when the distribution of newer vehicles in Group 1 is increased for passenger cars, passenger trucks, light commercial trucks, buses, single unit and combination trucks. For these vehicle types the NO_X emission rates increases within a range of 2% to 16% as the distribution of older vehicles are increased in Group 2 and Group 3 when compared to the ‘Baseline Case’.

Figure 4-12. CO Age Distribution Sensitivity



The $PM_{2.5}$ emission rates decrease within a range of 7% to 20% when the distribution of newer vehicles in Group 1 is increased for passenger cars, passenger trucks, light commercial trucks, buses, single unit and combination trucks. For all vehicle types the $PM_{2.5}$ emission rates increase within a range of 3% to 20% as the distribution of older vehicles are increased in Group 2 and Group 3 compared to the 'Baseline Case'.

The VOC emission rates decrease within a range of 20% to 29% when the distribution of newer vehicles in Group 1 is increased for passenger cars, passenger trucks, and light commercial trucks. For these vehicle types the VOC emission rates increase within a range of 14% to 24% as the distribution of older vehicles are increased in Group 2 and Group 3. The VOC emission rates for buses, single-unit, and combination trucks all have the same trend as age distribution is varied. The VOC emission rates decrease within a range of 5% to 11% when the distribution of newer vehicles in Group 1 is increased for these vehicle types. The VOC emission rates increase within a range of 1% to 11% as the distribution of older vehicles are increased in Group 2 and Group 3 when compared to the 'Baseline Case'.

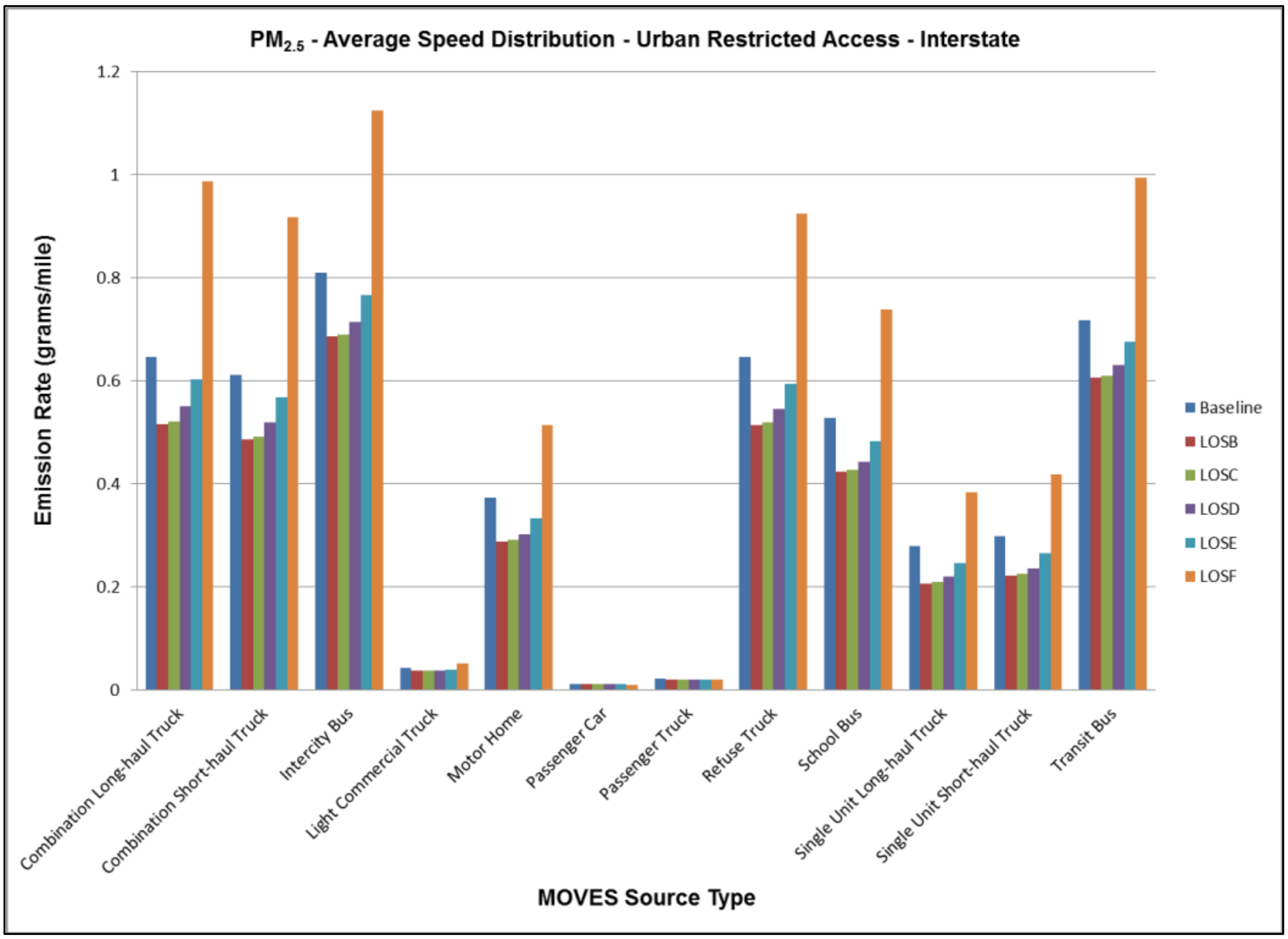
Appendix E contains all tables and figures which includes the sensitivity results for all pollutants and vehicle types that are associated with age distribution.

4.8 Average Speed Distribution – Running Exhaust

Figure 4-13 through Figure 4-15 displays the change in $PM_{2.5}$ emission rates associated with changing average speed distributions within MOVES representing various LOS for different functional classes. Only results for $PM_{2.5}$ emission rates are discussed in this section and figures and detailed result tables for all pollutants are located in Appendix F.

In general, Urban Interstate and Principal Arterial Freeways experience similar trends across most vehicle types for $PM_{2.5}$ in that emission rates increase as the LOS deteriorates with the exception of LOS F where $PM_{2.5}$ emission rates are dramatically higher compared to the 'Baseline Case'. However, an opposite trend is observed for passenger cars and passenger trucks where the emission rates decrease as LOS deteriorates. For these vehicles, LOS F $PM_{2.5}$ emission rates are lower than LOS B, C, D, and E.

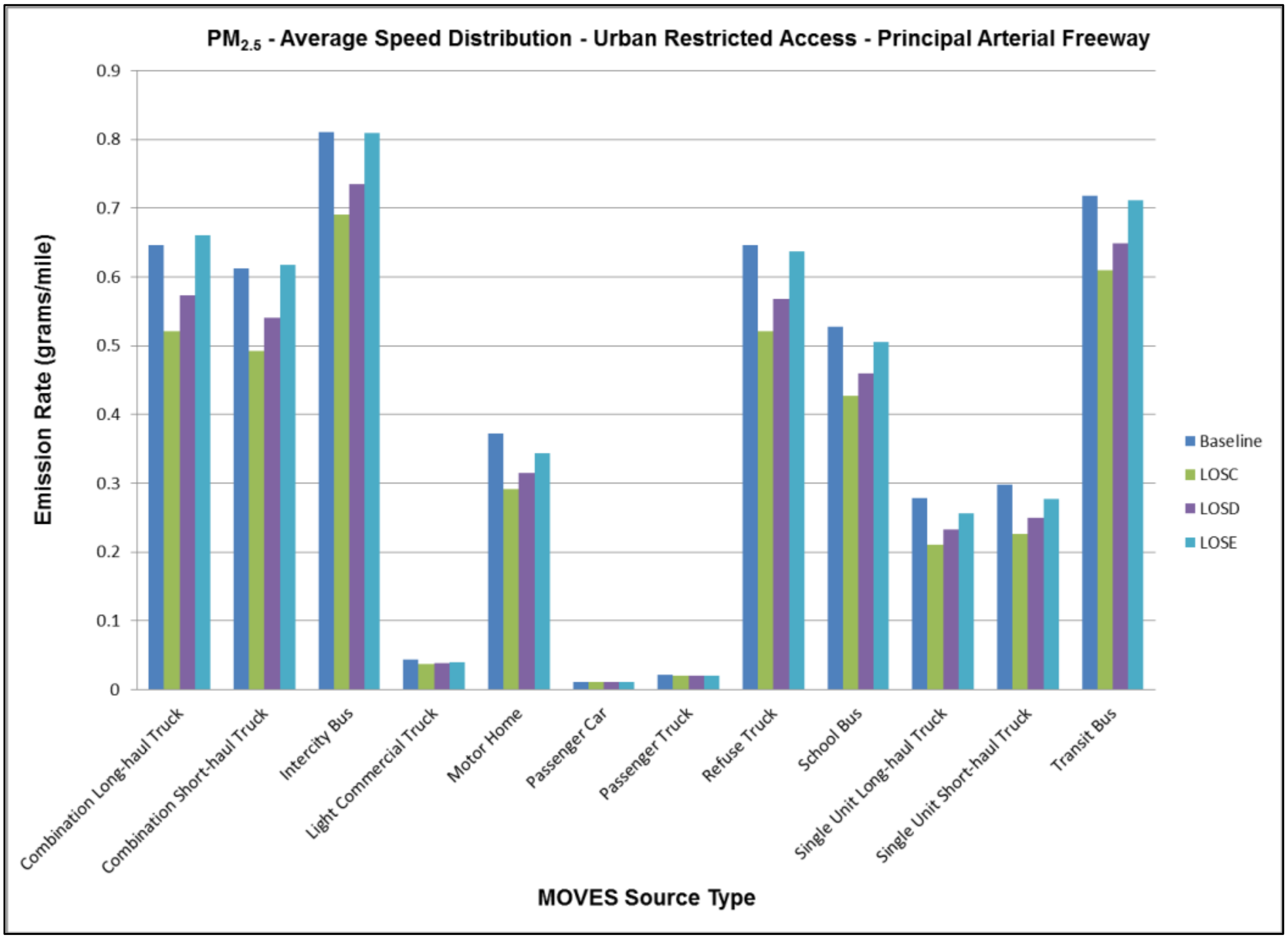
Figure 4-13. $PM_{2.5}$ Average Speed Distribution Sensitivity Urban Restricted Access – Interstate



The $PM_{2.5}$ emission rates for passenger cars and passenger trucks vary between -6% and -16% on Urban Interstates and Principal Urban Arterial Freeways across the various LOS when compared to the 'Baseline Case'. $PM_{2.5}$ emission rates for light commercial trucks vary between -13% and 20% on these functional classes for the various LOS.

The $PM_{2.5}$ emission rates for buses vary between -20% and 40% on Urban Interstates and Principal Urban Arterial Freeways across the various LOS when compared to the 'Baseline Case'. While refuse trucks and motor homes vary between -23% and 43%. The $PM_{2.5}$ emission rates for single-unit and combination trucks vary between -26% and 53%.

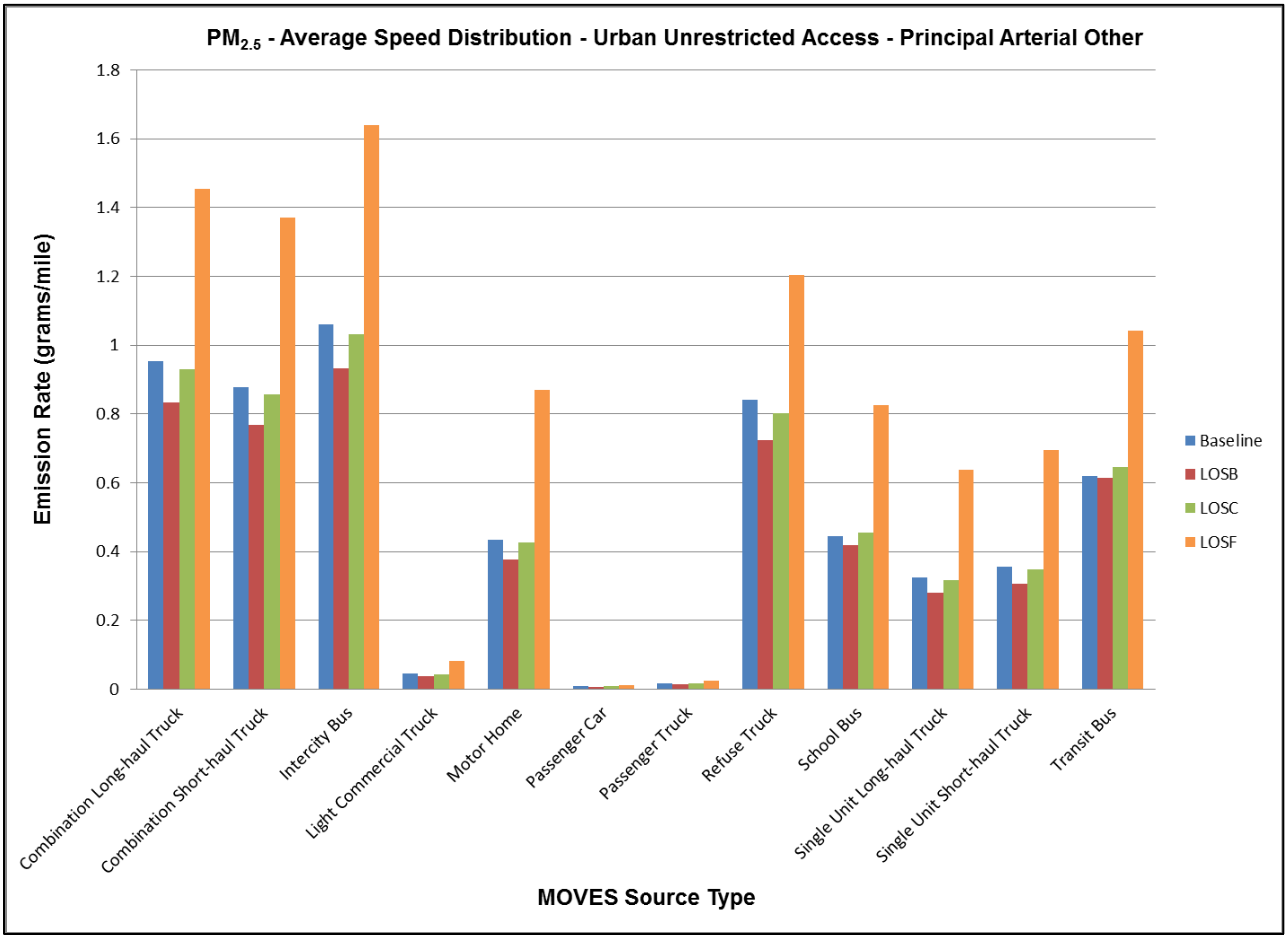
Figure 4-14. $PM_{2.5}$ Average Speed Distribution Sensitivity Urban Restricted Access – Principal Arterial Freeway



$PM_{2.5}$ emission rates for passenger cars and passenger trucks on the principal Urban Arterial Other functional class varies between -12% and 49% across the various LOS when compared to the 'Baseline Case' while light commercial trucks vary between -14% and 84%.

On the Principal Urban Arterial Other, $PM_{2.5}$ emission rates for buses vary between -12% and 85% when comparing the various LOS to the 'Baseline Case'. $PM_{2.5}$ emission rates for refuse trucks and motor homes vary between -14% and 100%. Single-unit and combination truck $PM_{2.5}$ emission rates vary between -14% and 97% across the various LOS for this functional class.

Figure 4-15. $PM_{2.5}$ Average Speed Distribution Sensitivity Urban Unrestricted Access – Principal Arterial Other



5 Summary

The results of the analysis highlight the sensitivity of selected parameters within MOVES2010a. The input parameters analyzed have been ranked based upon their respective effect on vehicle emission rates. This ranking, along with the ability of the air quality practitioner to manipulate these parameters within the model are important considerations.

Table 5-1 lists the various input parameters by the maximum change in emission rates for passenger cars for the Criteria Pollutants selected for analysis. When the percent change in emission rates for other vehicle types is greater than passenger cars, notation has been included in the Comment column. The total range of emission rate change is listed for both running emissions and starts for the Temperature input parameter. It should be noted that pollutant emissions change at different rates, and in some cases passenger cars change to a lesser degree than other vehicle types, and above all, comparisons are always made to the 'Baseline Case' emission rate. Each input variable is discussed below.

Temperature

Temperature is a very sensitive parameter across all pollutants and vehicle types. The results from this analysis showed similar trends to the temperature and humidity sensitivity analysis conducted by EPA. Although this variable has a large effect, the degree to which it may be varied is highly dependent on the location of the analysis and regional conformity rules or SIP guidance.

Analysis Year

Analysis Year is a very sensitive parameter especially between the years 2010 and 2020 where emission rates are seen to decrease significantly as shown in Table 5-1. There is also a significant decrease in emission rates between the years 2020 and 2030 for most vehicle types. Emission rates decrease at a noticeably reduced rate between the years 2030 and 2040 and remain relatively unchanged for the period 2040 to 2050 due to MOVES model assumptions of vehicle fleet turnover and emission controls in place. Given the analysis year requirements for conformity and SIP purposes, users may not have a lot of flexibility in varying analysis years. It is still important to understand the impact of different analysis years on emissions rates especially in the context of prioritizing regionally significant projects inTransportation Improvement Programs and Long Range Plans. There is clearly a project timing element of benefit to the air quality practitioner.

Vehicle Age Distribution

Age Distribution of the vehicle fleet is a parameter often analyzed by air quality practitioners prior to implementing an associated emission reduction strategy. A proportional increase of 10 percent in the distribution of vehicles less than 10 years old in the fleet caused a reduction in vehicle emission rates by approximately 16 percent for CO, 12 percent for NO_X, 11 percent for $PM_{2.5}$. Gasoline powered vehicles showed a decrease of 28 percent. As expected, an older fleet with a 10% greater distribution of vehicles between 11 and 20 years old resulted in an increase in emission rates across all pollutants. This trend continued when increasing the proportion of the oldest set of vehicles between 21 and 30 years old.

Table 5-1. Maximum Range of Change for Criteria Pollutants

Input Parameter	Range of Input Values	Pollutant Evaluated	Emission Rate % Change	Comment
Temperature	-40 – 120° F	CO, running	0 – 82	
		NOX, running	0 – 32	Light Commercial Trucks
		$PM_{2.5}$ running	-22 – 2225	
		CO start	-43 – 468	
		NOX start	-8 – 51	Buses, Light Duty and Combination Trucks
		$PM_{2.5}$ start	-43 – 9600	
Analysis Year	2010 – 2050	CO	0 – -49.3	All other vehicle types
		NOX	0 – -86	Buses, Single Unit Short-Haul and Combination Long-Haul Trucks
		$PM_{2.5}$	0 – -36	Buses and all Trucks
Age Dist.	Group 1 – 3	CO	-16.7 – 13.3	Passenger Trucks and Light Commercial Trucks
		NOX	-19.6 – 10.4	-
		$PM_{2.5}$	-19.2 – 20.5	-
Ramp Fraction	0 – 0.2	CO	-8 – 12	-
		NOX	-2 – 3	Single Unit and Combination Trucks
		$PM_{2.5}$	-15 – 22	-
Humidity	0 – 100 %	CO@80°F	-5.42 – 8.21	-
		NOX@60°F	-13.09 – 5.86	-
		NOX@80°F	-11.03 – 14.76	Buses, Pass. Trucks, Single Unit and Combination Trucks
		$PM_{2.5}$@80°F	-0.01 – 0.01	-
Speed Dist. Interstate	LOS B – F	CO	-5.34 – 4.55	Buses and all Trucks
		NOX	-1.25 - 6.01	All other vehicle types
		$PM_{2.5}$	-16.48 – -5.85	All other vehicle types
Speed Dist. Freeways	LOS C, D, E	CO	-5.23 – -1.33	All other vehicles with the exception of Passenger Trucks and Refuse
		NOX	-2.05 – 3.9	All other vehicle types
		$PM_{2.5}$	-8.43 – -4.51	All other vehicle types
Speed Dist. Arterials*	LOS B,C,F	CO	-11.92 – 53.23	Buses, Light Commercial Trucks, Single-Unit and Combination Trucks
		NOX	-4.96 – 20.03	All other vehicle types
		$PM_{2.5}$	-11.57 – 43.38	All other vehicle types

*See text on this variable

Ramp Fraction

Ramp Fraction can be a sensitive input parameter dependent on vehicle and fuel type. A common observation for almost all vehicle types across all pollutants was that emission rates and Ramp Fraction change in a similar manner. That is, as the Ramp Fraction increases, so do emissions rates. For example, the emissions for CO increased markedly for gasoline fueled vehicles as ramp fraction increased. Diesel emissions of CO remained relatively flat showing a dependence on fuel type within the model. Alternatively, the emissions rate for $PM_{2.5}$ showed an increase for diesel fueled vehicle with increased ramp fraction while gasoline emissions remained relatively constant. This parameter will be greatly controlled by the highway geometric design and often related to the amount of activity along a freeway or interstate. Near the urban core, ramps will likely occur more often than in more rural settings.

Humidity

Emission rates for NOx and CO were the most sensitive pollutants to changes in humidity. The results from this analysis showed similar trends to the temperature and humidity analysis conducted by EPA. In the case of CO, gasoline fueled vehicles showed increased emissions as humidity increased, while for NOx, the diesel fueled vehicles were most affected. All other vehicle types remained relatively insensitive to changes in humidity. As with temperature, the values used for humidity are defined by the season and location. The degree to which these can be changed will be limited.

Average Speed Distribution

This MOVES Sensitivity Analysis examined only three functional classes; interstates, freeways, and arterials. The results varied significantly for the functional class being analyzed. The average speed for each functional class was associated with different groupings of Level of Service (LOS) by functional class. Not all LOS data contained within the MOVES model were available for analysis for each functional class. Interstates included LOS B through F, freeways were limited to LOS C through E, and arterials only included LOS B, C and F. The different LOS as well as facility types resulted in different speed distributions for each functional class category.

The emission rates associated with Average Speed Distributions representing LOS B, C, and D generally varied by only a few percentage points across all pollutants and vehicle types. Results for CO were varied for all vehicle types and should be examined individually by the reader in the table and figures located in Appendix F. The emissions rates associated with LOS E showed a larger variation than LOS B, C or D, while emission rates associated with LOS F were significantly higher. It was also observed that the ‘Baseline case’ exhibited an emission rate between LOS E and F, indicating use of default values causes the analysis to be evaluated on the basis of an E+ LOS. This would imply a congested condition if the default values in the MOVES Model are used. This is an indication that local data should be obtained and used whenever possible. Of particular significance is the average speed distribution for arterials. This functional classification shows a much greater change in emission rates when varying LOS than the other facility types.

Although identifying and changing the average speed distribution parameter is one of the more complex substitutions associated with MOVES due to the multiple drive schedules applied, the increased accuracy of the analysis that results will be noticeably improved. Vehicle activity information will generally be derived from either a Traffic Demand Model or the Highway Performance Monitoring System (HPMS) and in cases of design or existing traffic where expected congestion is better than LOS E, this is particularly important and would result in lower analyzed emission rates.

Summary

In general, the input variables described in this study cannot be readily changed. Temperature and humidity depend on the season and location and must be selected using either conformity or SIP guidelines. The analysis year is a function of the type of regional analysis being conducted and is primarily dictated by guidelines for these analyses (e.g., conformity determination or SIP analysis). Vehicle age distribution is directly related to the region analyzed although programs such as vehicle replacement could have a significant effect. Ramp fraction is a function of geometric design and is generally greater in more urbanized areas. Average speed distribution is a function of traffic volume, vehicle mix, and geometric design. Even so, it is important for the analyst to be aware of how these variables affect a regional analysis and the information contained in this report should inform in that regard. This allows input during the design phase of the projects and could result in a better analytical design in regards to air quality.

Even more important is not to rely on default data or assumptions if it is possible to obtain local data. This is especially true for vehicle age distribution and average speed distribution with related drive schedules. For example, defaulting to the MOVES average speed distribution would result in a LOS E+ being incorporated in the analysis. This heavy congestion may not exist or may not be the outcome of a final design and if used could result in higher emission rates than would occur if the actual speed distribution were used. Local data should be used in place of defaults where possible. Temperature and humidity are location specific and the user will most likely not have any flexibility in altering these values due to requirements of SIPs and conformity guidance requirements. The analysis year will also be defined by conformity guidelines. Omitting the temperature and humidity parameters due to these reasons, the order of impact for including local data would be as follows:

- Average speed distribution for arterials
- Vehicle age distribution
- Ramp fraction
- Average speed distribution for interstates
- Average speed distribution for freeways

A general guide for increased accuracy when calculating on-road mobile source emissions is to use as much locally generated data as possible.

6 References

1 Environmental Protection Agency (EPA), *Motor Vehicle Emission Simulator (MOVES) 2010 User Guide*. EPA-420-B-09-041. December 2009.

2 Choi, D., Beardsley, M., Brzezinski, D., Koupal, J., Warila, J., *MOVES Sensitivity Analysis: The Impacts of Temperature and Humidity on Emissions*., EPA Office of Transportation Air Quality.

3 Transportation Research Board, *Highway Capacity Manual (HCM) 2010*. 2010

Appendix A. Temperature Sensitivity Results

Carbon Monoxide (CO) – Running Exhaust

Figure A-1. CO Temperature Sensitivity

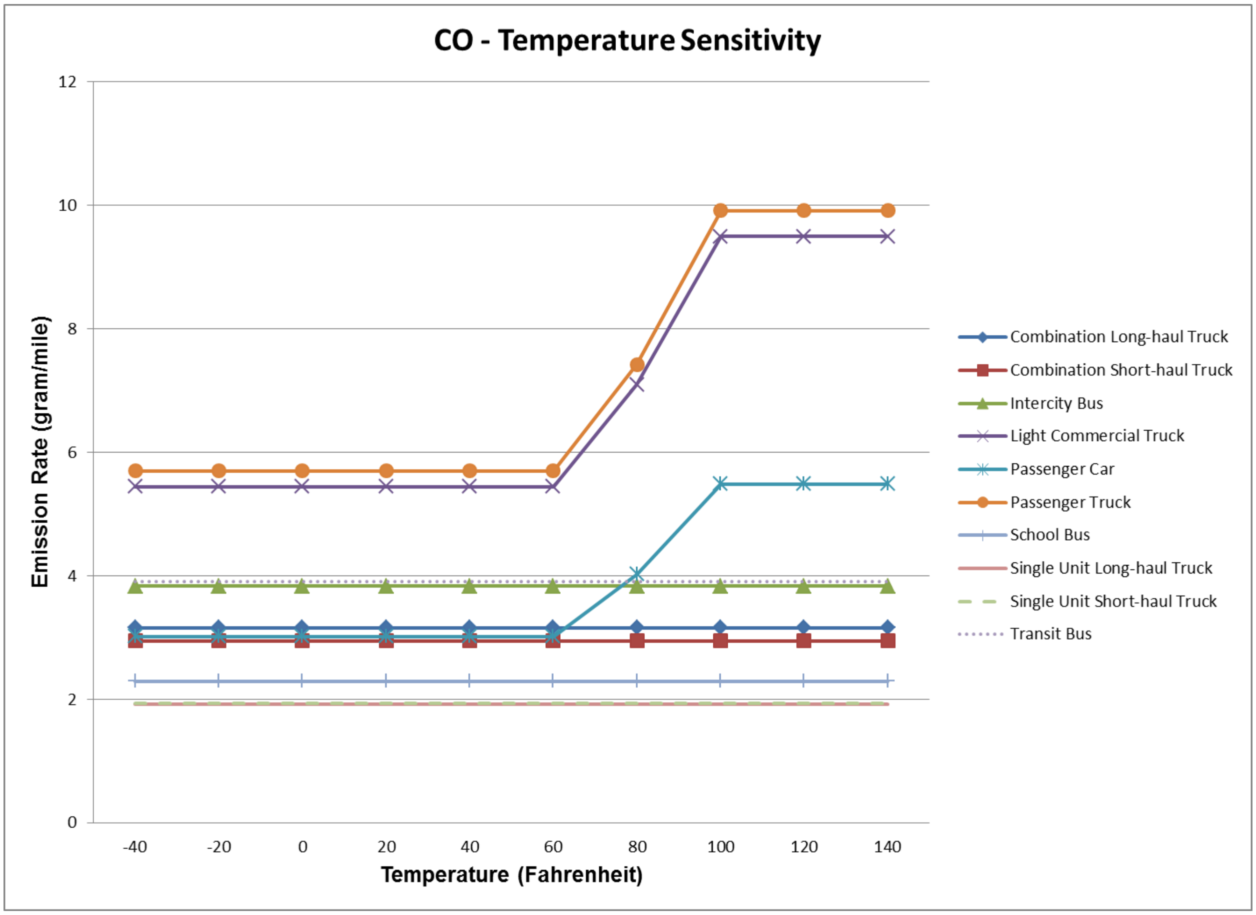


Table A-1. Passenger Car, Passenger Truck, and Light Commercial Truck CO Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	3.016	0%	5.699	0%	5.441	0%
-20	3.016	0%	5.699	0%	5.441	0%
0	3.016	0%	5.699	0%	5.441	0%
20	3.016	0%	5.699	0%	5.441	0%
40	3.016	0%	5.699	0%	5.441	0%
60	3.016	0%	5.699	0%	5.441	0%
80	4.026	33%	7.420	30%	7.099	30%
100	5.488	82%	9.910	74%	9.497	75%
120	5.488	82%	9.910	74%	9.497	75%

Oxides of Nitrogen (NOX) – Running Exhaust

Figure A-2. NO_X Temperature Sensitivity

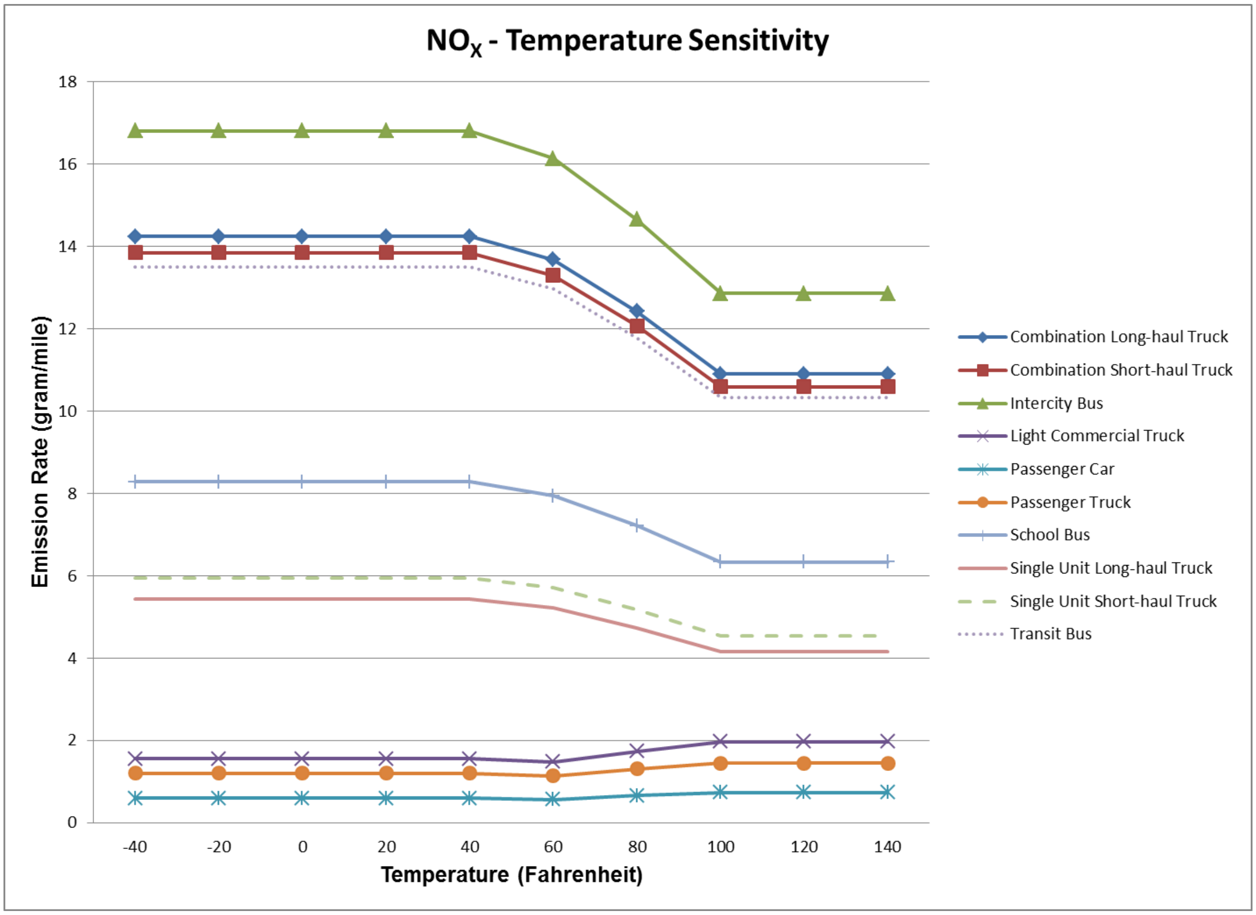


Table A-2. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	0.593	6%	1.203	6%	1.556	5%
-20	0.593	6%	1.203	6%	1.556	5%
0	0.593	6%	1.203	6%	1.556	5%
20	0.593	6%	1.203	6%	1.556	5%
40	0.593	6%	1.203	6%	1.556	5%
60	0.561	0%	1.137	0%	1.477	0%
80	0.657	17%	1.306	15%	1.731	17%
100	0.739	32%	1.449	27%	1.971	33%
120	0.739	32%	1.449	27%	1.971	33%

Table A-3. Bus NO_X Temperature Sensitivity

Temperature (Fahrenheit)	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	16.805	4%	13.510	4%	8.276	4%
-20	16.805	4%	13.510	4%	8.276	4%
0	16.805	4%	13.510	4%	8.276	4%
20	16.805	4%	13.510	4%	8.276	4%
40	16.805	4%	13.510	4%	8.276	4%
60	16.131	0%	12.968	0%	7.945	0%
80	14.653	-9%	11.779	-9%	7.216	-9%
100	12.859	-20%	10.337	-20%	6.333	-20%
120	12.859	-20%	10.337	-20%	6.333	-20%

Table A-4. Single Unit and Combination Truck NO_X Temperature Sensitivity

Temperature (Fahrenheit)	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	5.947	4%	5.438	4%	13.846	4%	14.244	4%
-20	5.947	4%	5.438	4%	13.846	4%	14.244	4%
0	5.947	4%	5.438	4%	13.846	4%	14.244	4%
20	5.947	4%	5.438	4%	13.846	4%	14.244	4%
40	5.947	4%	5.438	4%	13.846	4%	14.244	4%
60	5.708	0%	5.220	0%	13.291	0%	13.673	0%
80	5.185	-9%	4.742	-9%	12.072	-9%	12.420	-9%
100	4.550	-20%	4.161	-20%	10.594	-20%	10.899	-20%
120	4.550	-20%	4.161	-20%	10.594	-20%	10.899	-20%

Particulate Matter (PM2.5) – Running Exhaust

Figure A-3. $PM_{2.5}$ Temperature Sensitivity

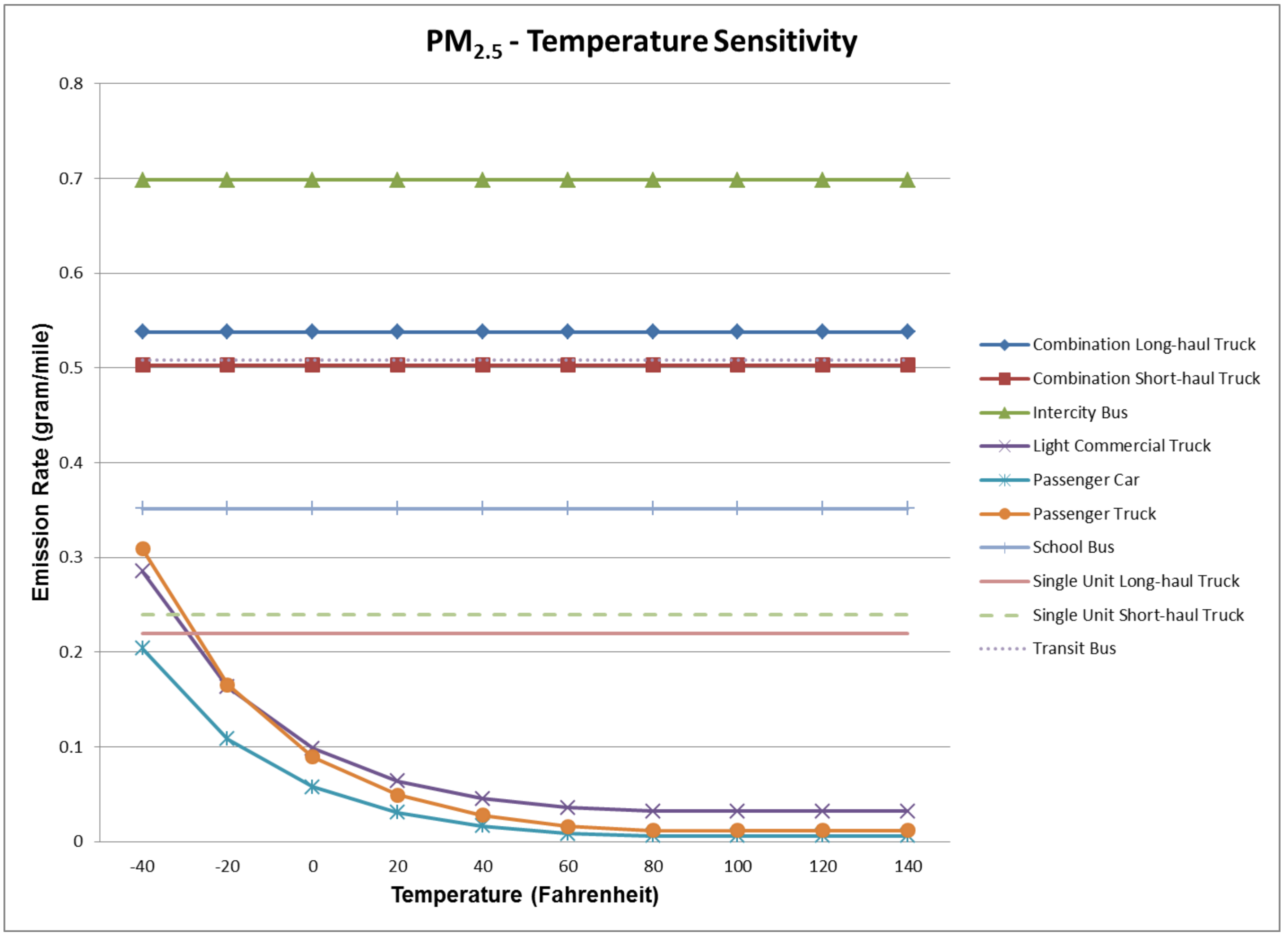


Table A-5. Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	0.2039	2225%	0.3087	1794%	0.2854	694%
-20	0.1085	1137%	0.1657	916%	0.1634	355%
0	0.0577	558%	0.0896	450%	0.0985	174%
20	0.0307	250%	0.0492	202%	0.0640	78%
40	0.0164	87%	0.0277	70%	0.0457	27%
60	0.0088	0%	0.0163	0%	0.0359	0%
80	0.0060	-32%	0.0121	-26%	0.0323	-10%
100	0.0060	-32%	0.0121	-26%	0.0323	-10%
120	0.0060	-32%	0.0121	-26%	0.0323	-10%

Table A-6. Bus $PM_{2.5}$ Temperature Sensitivity

Temperature (Fahrenheit)	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	0.6983	0.00%	0.5085	0.00%	0.3515	0.00%
-20	0.6983	0.00%	0.5085	0.00%	0.3515	0.00%
0	0.6983	0.00%	0.5085	0.00%	0.3515	0.00%
20	0.6983	0.00%	0.5085	0.00%	0.3515	0.00%
40	0.6983	0.00%	0.5085	0.00%	0.3515	0.00%
60	0.6983	0.00%	0.5085	0.00%	0.3515	0.00%
80	0.6984	0.01%	0.5086	0.01%	0.3516	0.01%
100	0.6984	0.02%	0.5086	0.02%	0.3516	0.02%
120	0.6984	0.02%	0.5086	0.02%	0.3516	0.02%

Table A-7. Single Unit and Combination Truck $PM_{2.5}$ Temperature Sensitivity

Temperature (Fahrenheit)	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	0.2397	0.00%	0.2200	0.00%	0.5027	0.00%	0.5378	0.00%
-20	0.2397	0.00%	0.2200	0.00%	0.5027	0.00%	0.5378	0.00%
0	0.2397	0.00%	0.2200	0.00%	0.5027	0.00%	0.5378	0.00%
20	0.2397	0.00%	0.2200	0.00%	0.5027	0.00%	0.5378	0.00%
40	0.2397	0.00%	0.2200	0.00%	0.5027	0.00%	0.5378	0.00%
60	0.2397	0.00%	0.2200	0.00%	0.5027	0.00%	0.5378	0.00%
80	0.2397	0.02%	0.2201	0.02%	0.5027	0.01%	0.5379	0.01%
100	0.2398	0.04%	0.2201	0.04%	0.5028	0.03%	0.5379	0.03%
120	0.2398	0.04%	0.2201	0.04%	0.5028	0.03%	0.5379	0.03%

Volatile Organic Compounds (VOC) – Running Exhaust

Figure A-4. VOC Temperature Sensitivity

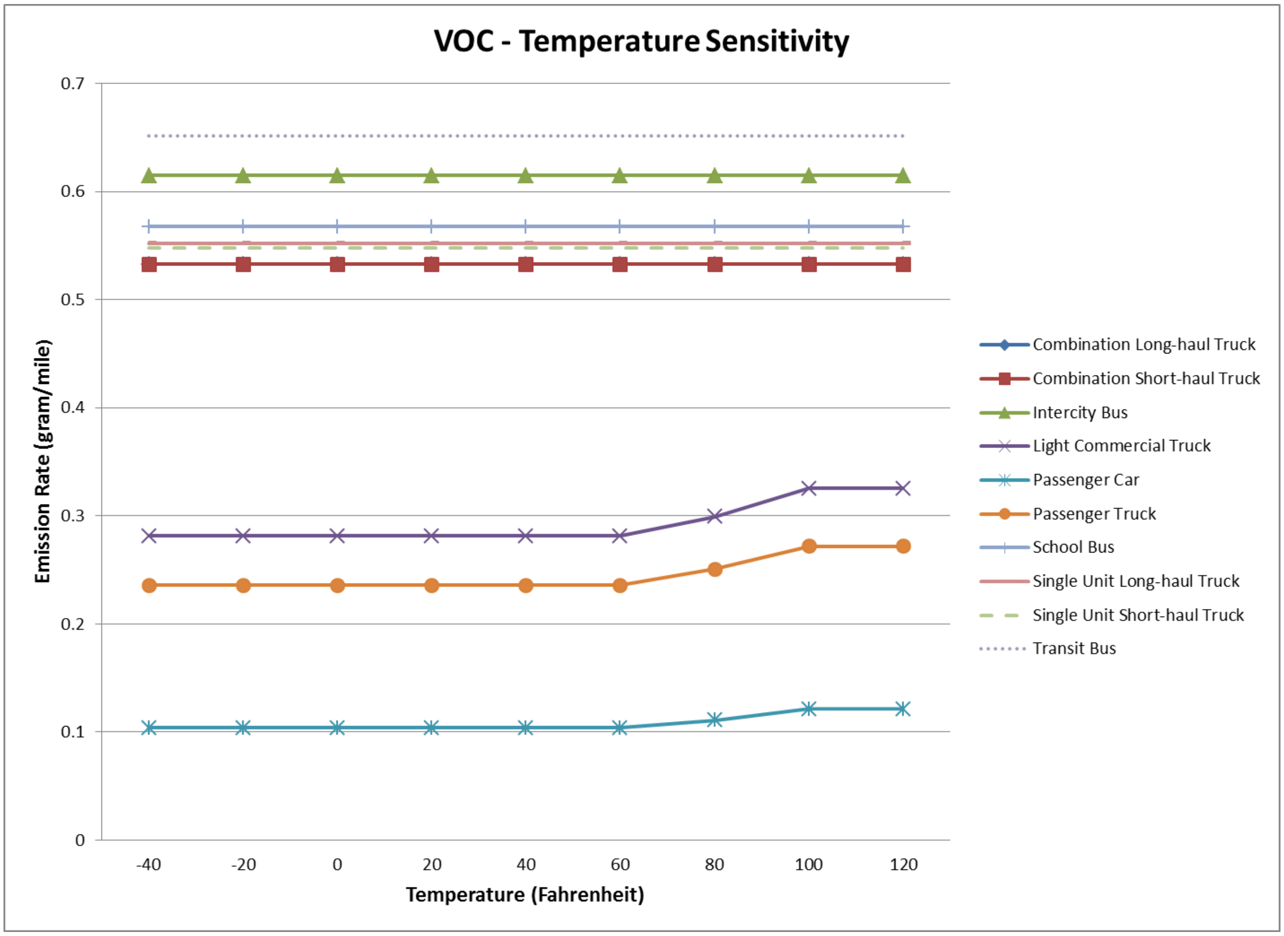


Table A-8. Passenger Car, Passenger Truck, and Light Commercial Truck VOC Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
-40	0.104	0%	0.236	0%	0.281	0%
-20	0.104	0%	0.236	0%	0.281	0%
0	0.104	0%	0.236	0%	0.281	0%
20	0.104	0%	0.236	0%	0.281	0%
40	0.104	0%	0.236	0%	0.281	0%
60	0.104	0%	0.236	0%	0.281	0%
80	0.111	7%	0.251	6%	0.299	6%
100	0.121	17%	0.272	15%	0.326	16%
120	0.121	17%	0.272	15%	0.326	16%

Carbon Monoxide (CO) – Starts

Figure A-5. Starts CO Temperature Sensitivity

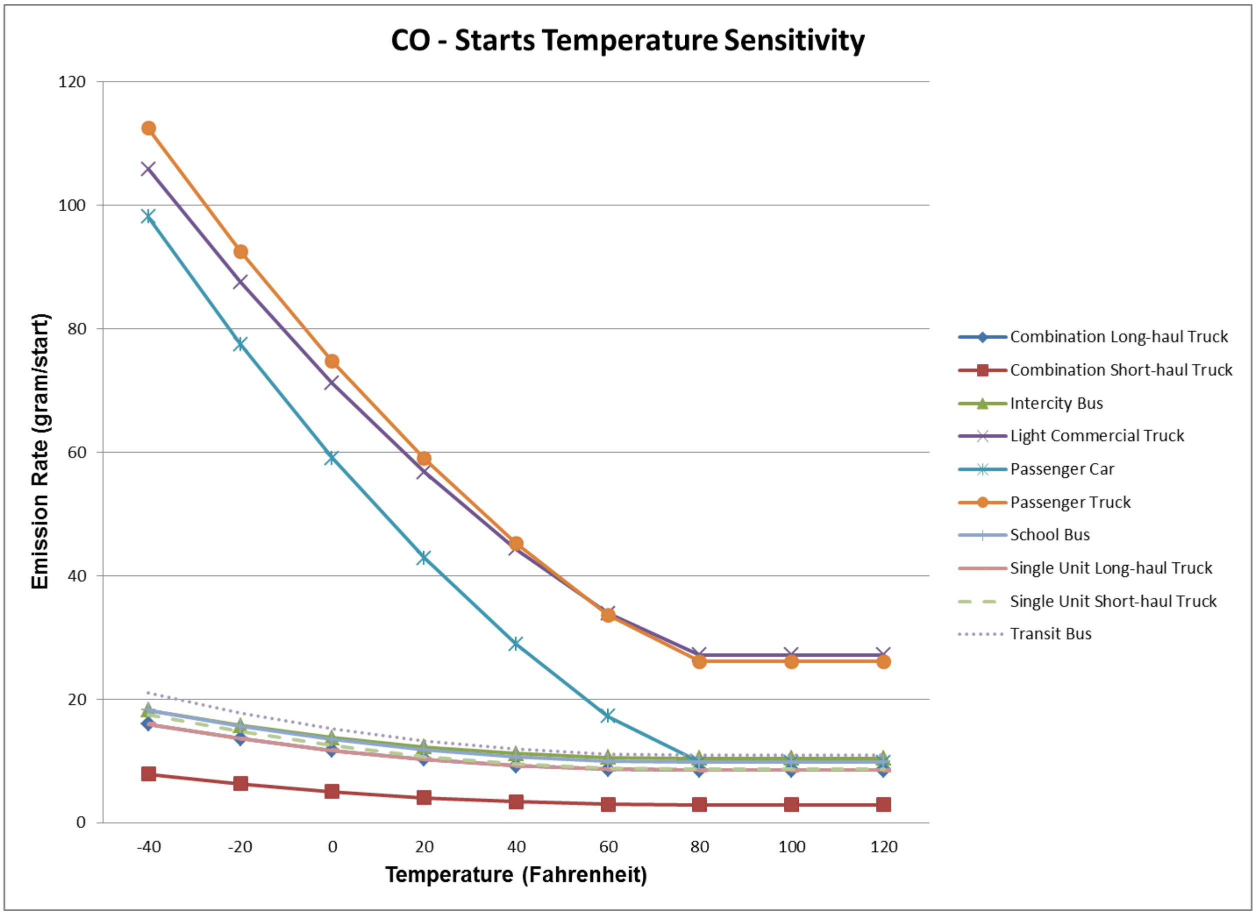


Table A-9. Starts - Passenger Car, Passenger Truck, and Light Commercial Truck CO Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	98.154	468%	112.450	234%	105.893	212%
-20	77.460	348%	92.530	175%	87.538	158%
0	59.026	242%	74.692	122%	71.162	110%
20	42.851	148%	58.933	75%	56.763	67%
40	28.936	67%	45.255	34%	44.343	31%
60	17.280	0%	33.657	0%	33.901	0%
80	9.805	-43%	26.105	-22%	27.173	-20%
100	9.805	-43%	26.105	-22%	27.173	-20%
120	9.805	-43%	26.105	-22%	27.173	-20%

Table A-10. Starts - Bus CO Temperature Sensitivity

Temperature (Fahrenheit)	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	18.254	72%	20.982	88%	18.255	82%
-20	15.789	49%	17.815	60%	15.606	56%
0	13.791	30%	15.249	37%	13.460	34%
20	12.261	16%	13.283	19%	11.816	18%
40	11.198	6%	11.918	7%	10.674	6%
60	10.602	0%	11.152	0%	10.034	0%
80	10.462	-1%	10.972	-2%	9.883	-2%
100	10.462	-1%	10.972	-2%	9.883	-2%
120	10.462	-1%	10.972	-2%	9.883	-2%

Table A-11. Starts - Single Unit and Combination Truck CO Temperature Sensitivity

Temperature (Fahrenheit)	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	17.545	99%	15.984	84%	7.916	163%	15.984	84%
-20	14.737	67%	13.630	57%	6.335	111%	13.630	57%
0	12.461	41%	11.722	35%	5.053	68%	11.722	35%
20	10.718	21%	10.261	18%	4.071	35%	10.261	18%
40	9.507	8%	9.245	7%	3.389	13%	9.246	7%
60	8.828	0%	8.677	0%	3.007	0%	8.677	0%
80	8.669	-2%	8.543	-2%	2.917	-3%	8.543	-2%
100	8.669	-2%	8.543	-2%	2.917	-3%	8.543	-2%
120	8.669	-2%	8.543	-2%	2.917	-3%	8.543	-2%

Oxides of Nitrogen (NOX) – Starts

Figure A-6. Starts NO_X Temperature Sensitivity

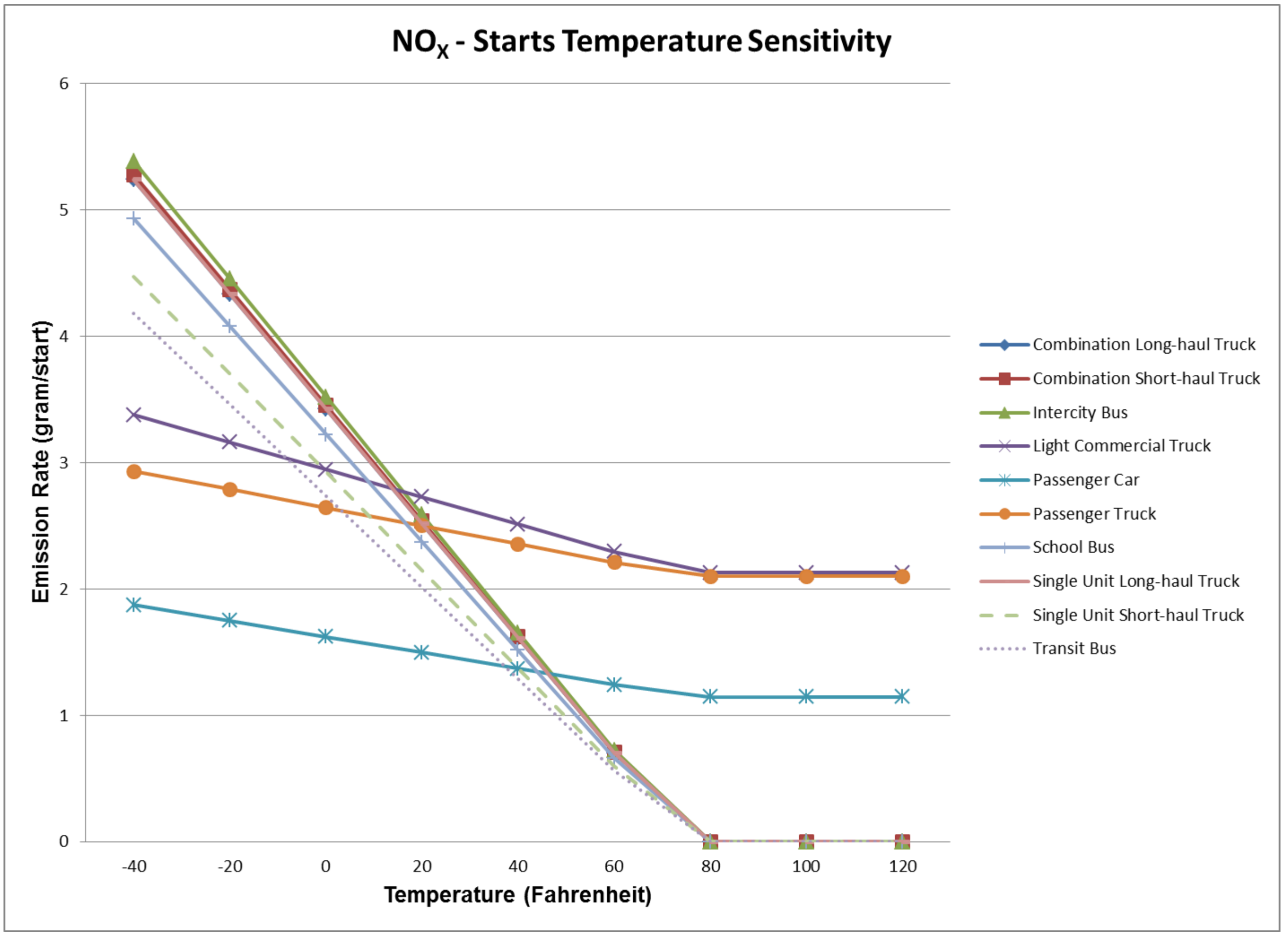


Table A-12. Starts - Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Temperature Sensitivity

	Passenger Car		Passenger Truck		Light Commercial Truck	
Temperature (Fahrenheit)	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	1.874	51%	2.932	33%	3.377	47%
-20	1.748	41%	2.788	26%	3.161	38%
0	1.622	30%	2.644	20%	2.945	28%
20	1.496	20%	2.500	13%	2.728	19%
40	1.369	10%	2.356	7%	2.512	9%
60	1.243	0%	2.212	0%	2.296	0%
80	1.145	-8%	2.101	-5%	2.128	-7%
100	1.145	-8%	2.101	-5%	2.128	-7%
120	1.145	-8%	2.101	-5%	2.128	-7%

Table A-13. Starts - Bus NO_X Temperature Sensitivity

	Intercity Bus		Transit Bus		School Bus	
Temperature (Fahrenheit)	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	5.386	646%	4.179	646%	4.931	646%
-20	4.453	517%	3.455	517%	4.077	517%
0	3.520	387%	2.731	387%	3.223	387%
20	2.588	258%	2.008	258%	2.369	258%
40	1.655	129%	1.284	129%	1.515	129%
60	0.722	0%	0.560	0%	0.661	0%
80	0.000	-100%	0.000	-100%	0.000	-100%
100	0.000	-100%	0.000	-100%	0.000	-100%
120	0.000	-100%	0.000	-100%	0.000	-100%

Table A-14. Starts - Single Unit and Combination Truck NO_X Temperature Sensitivity

	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
Temperature (Fahrenheit)	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	4.471	646%	5.239	646%	5.280	646%	5.239	646%
-20	3.696	517%	4.331	517%	4.366	517%	4.331	517%
0	2.922	387%	3.424	387%	3.451	387%	3.424	387%
20	2.148	258%	2.517	258%	2.537	258%	2.517	258%
40	1.374	129%	1.610	129%	1.623	129%	1.610	129%
60	0.600	0%	0.703	0%	0.708	0%	0.703	0%
80	0.00000	-100%	0.000	-100%	0.000	-100%	0.000	-100%
100	0.00000	-100%	0.000	-100%	0.000	-100%	0.000	-100%
120	0.00000	-100%	0.000	-100%	0.000	-100%	0.000	-100%

Particulate Matter (PM2.5) – Starts

Figure A-7. Starts $PM_{2.5}$ Temperature Sensitivity

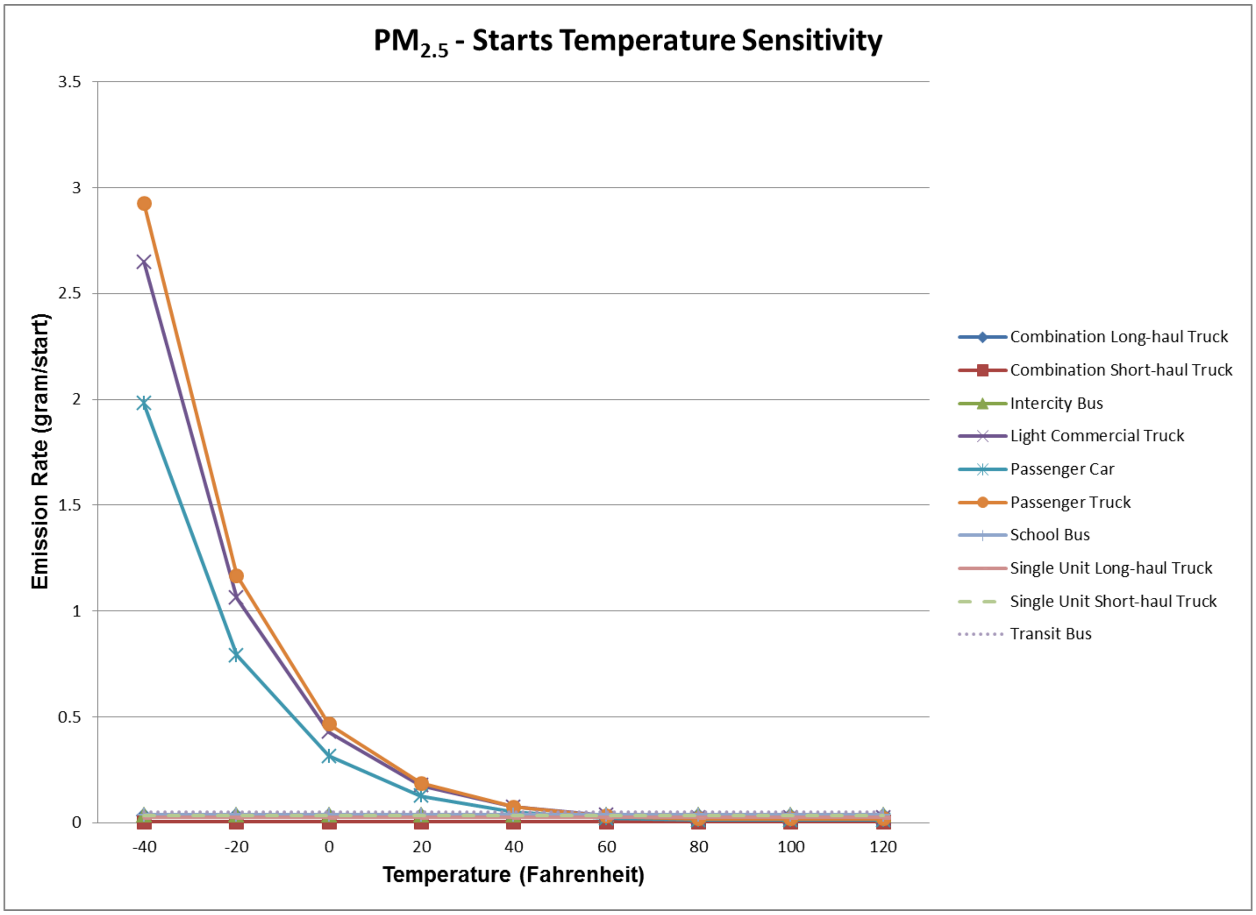


Table A-15. Starts - Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	1.980	9600%	2.926	9382%	2.650	7367%
-20	0.790	3769%	1.167	3683%	1.062	2892%
0	0.315	1444%	0.466	1411%	0.429	1108%
20	0.126	517%	0.187	505%	0.176	397%
40	0.051	147%	0.075	144%	0.076	113%
60	0.020	0%	0.031	0%	0.035	0%
80	0.012	-43%	0.018	-42%	0.024	-33%
100	0.012	-43%	0.018	-42%	0.024	-33%
120	0.012	-43%	0.018	-42%	0.024	-33%

Table A-16. Starts - Bus $PM_{2.5}$ Temperature Sensitivity

Temperature (Fahrenheit)	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	0.03513	0.49%	0.05257	0.39%	0.03702	0.46%
-20	0.03509	0.36%	0.05251	0.29%	0.03698	0.33%
0	0.03505	0.24%	0.05247	0.19%	0.03694	0.22%
20	0.03501	0.14%	0.05242	0.11%	0.03690	0.13%
40	0.03499	0.06%	0.05239	0.05%	0.03688	0.06%
60	0.03496	0.00%	0.05236	0.00%	0.03685	0.00%
80	0.03495	-0.04%	0.05235	-0.04%	0.03684	-0.04%
100	0.03494	-0.07%	0.05233	-0.06%	0.03683	-0.07%
120	0.03494	-0.08%	0.05233	-0.07%	0.03683	-0.08%

Table A-17. Starts - Single Unit and Combination Truck $PM_{2.5}$ Temperature Sensitivity

Temperature (Fahrenheit)	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	0.03608	0.43%	0.02572	0.53%	0.00420	0.59%	0.03079	0.45%
-20	0.03604	0.32%	0.02568	0.39%	0.00419	0.43%	0.03076	0.32%
0	0.03600	0.21%	0.02565	0.26%	0.00419	0.29%	0.03073	0.22%
20	0.03597	0.13%	0.02562	0.16%	0.00418	0.17%	0.03070	0.13%
40	0.03595	0.06%	0.02560	0.07%	0.00418	0.08%	0.03068	0.06%
60	0.03593	0.00%	0.02558	0.00%	0.00418	0.00%	0.03066	0.00%
80	0.03591	-0.04%	0.02557	-0.05%	0.00417	-0.05%	0.03065	-0.04%
100	0.03591	-0.06%	0.02556	-0.08%	0.00417	-0.09%	0.03064	-0.07%
120	0.03590	-0.07%	0.02556	-0.09%	0.00417	-0.10%	0.03064	-0.07%

Volatile Organic Compounds (VOC) – Starts

Figure A-8. Starts VOC Temperature Sensitivity

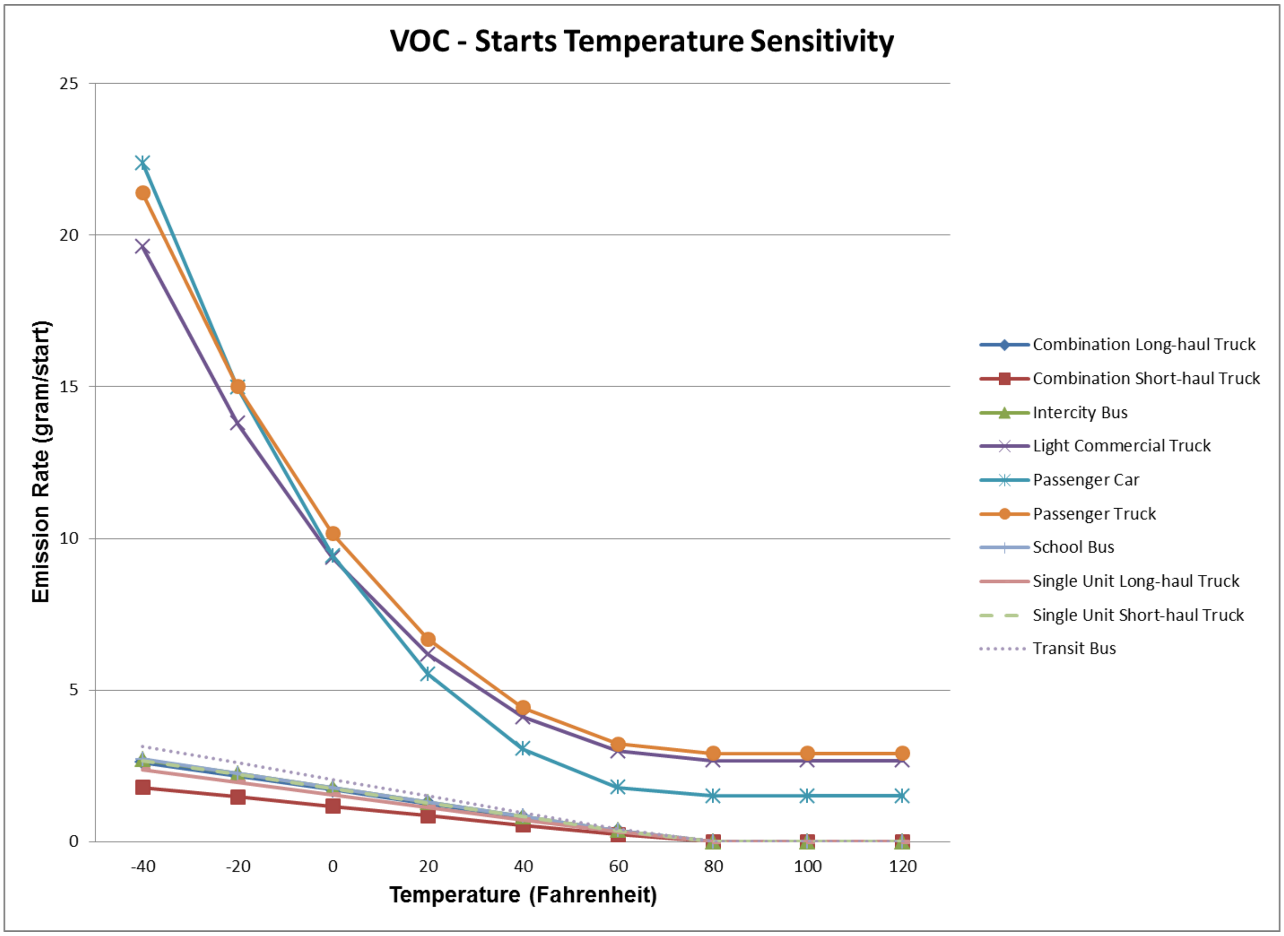


Table A-18. Starts - Passenger Car, Passenger Truck, and Light Commercial Truck VOC Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car Emission Rate (gram/start)	Passenger Car % difference	Passenger Truck Emission Rate (gram/start)	Passenger Truck % difference	Light Commercial Truck Emission Rate (gram/start)	Light Commercial Truck % difference
-40	22.380	1148%	21.391	564%	19.612	555%
-20	14.973	735%	15.005	366%	13.786	361%
0	9.430	426%	10.155	215%	9.361	213%
20	5.532	208%	6.681	107%	6.186	107%
40	3.059	71%	4.424	37%	4.113	37%
60	1.793	0%	3.223	0%	2.992	0%
80	1.504	-16%	2.918	-9%	2.683	-10%
100	1.504	-16%	2.918	-9%	2.683	-10%
120	1.504	-16%	2.918	-9%	2.683	-10%

Table A-19. Starts - Bus VOC Temperature Sensitivity

Temperature (Fahrenheit)	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	2.71044	646%	3.146	646%	2.724	646%
-20	2.24105	517%	2.601	517%	2.252	517%
0	1.77166	387%	2.056	387%	1.780	387%
20	1.30227	258%	1.512	258%	1.309	258%
40	0.83289	129%	0.967	129%	0.837	129%
60	0.36350	0%	0.422	0%	0.365	0%
80	0.00000	-100%	0.000	-100%	0.000	-100%
100	0.00000	-100%	0.000	-100%	0.000	-100%
120	0.00000	-100%	0.000	-100%	0.000	-100%

Table A-20. Starts - Single Unit and Combination Truck VOC Temperature Sensitivity

Temperature (Fahrenheit)	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-40	2.676	646%	2.385	646%	1.783	646%	2.615	646%
-20	2.213	517%	1.972	517%	1.474	517%	2.162	517%
0	1.749	387%	1.559	387%	1.165	387%	1.709	387%
20	1.286	258%	1.146	258%	0.857	258%	1.256	258%
40	0.822	129%	0.733	129%	0.548	129%	0.803	129%
60	0.359	0%	0.320	0%	0.239	0%	0.351	0%
80	0.00000	-100%	0.000	-100%	0.000	-100%	0.000	-100%
100	0.00000	-100%	0.000	-100%	0.000	-100%	0.000	-100%
120	0.00000	-100%	0.000	-100%	0.000	-100%	0.000	-100%

Volatile Organic Compounds (VOC) – Evaporative Permeation

Figure A-9. Evaporative Permeation - VOC Temperature Sensitivity

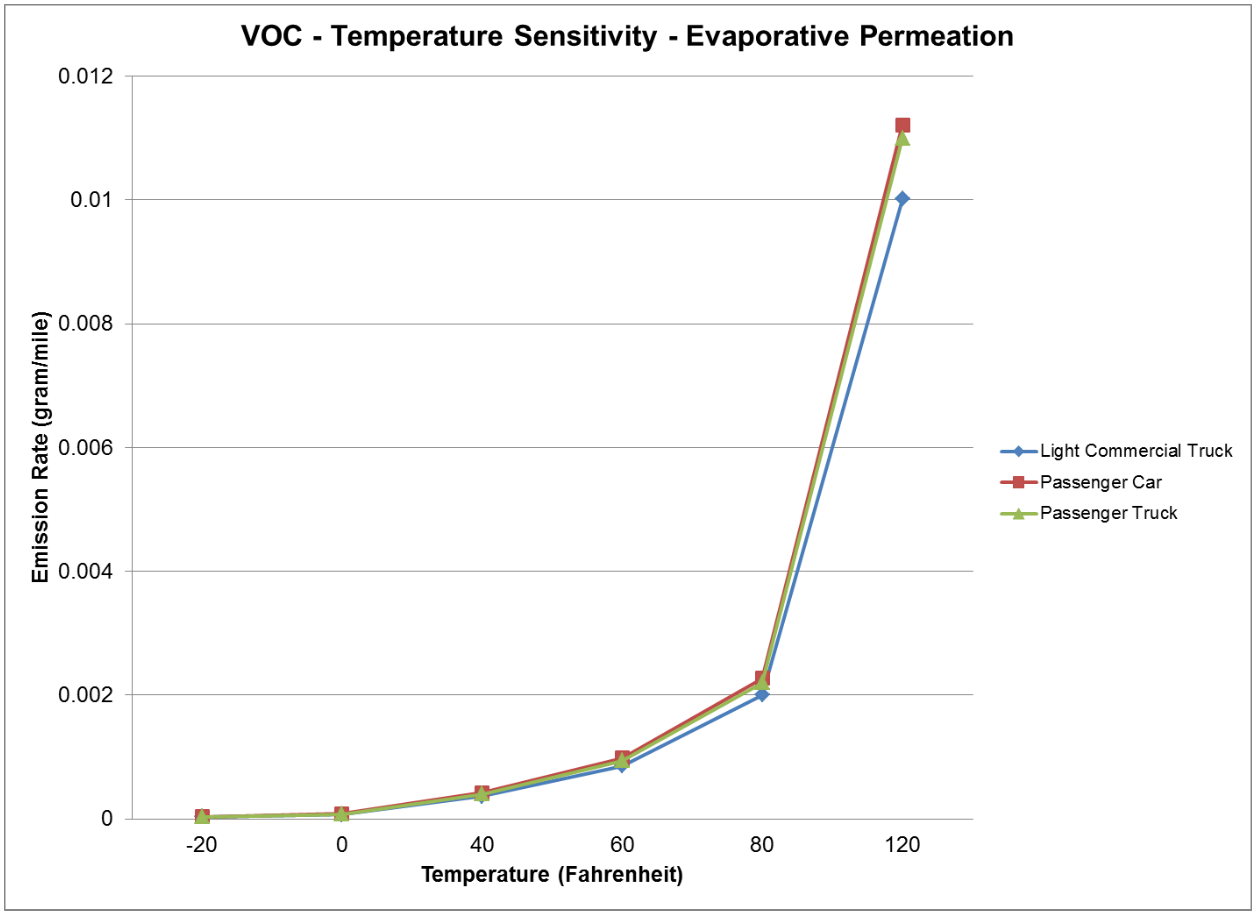


Table A-21. Evaporative Permeation - Passenger Car, Passenger Truck, and Light Commercial Truck VOC Temperature Sensitivity

Temperature (Fahrenheit)	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference	Emission Rate (gram/start)	% difference
-20	0.0000355	-96%	0.0000339	-96%	0.0000308	-96%
0	0.0000801	-92%	0.0000765	-92%	0.0000696	-92%
40	0.00042063	-57%	0.000400351	-57%	0.000364387	-57%
60	0.000978759	0%	0.000940833	0%	0.000856394	0%
80	0.002271759	132%	0.002197808	134%	0.002000858	134%
120	0.011211069	1045%	0.010999203	1069%	0.010011955	1069%

Appendix B. Humidity Sensitivity Results

Carbon Monoxide (CO) – Running Exhaust

Figure B-10. CO Humidity Sensitivity - 80° Fahrenheit

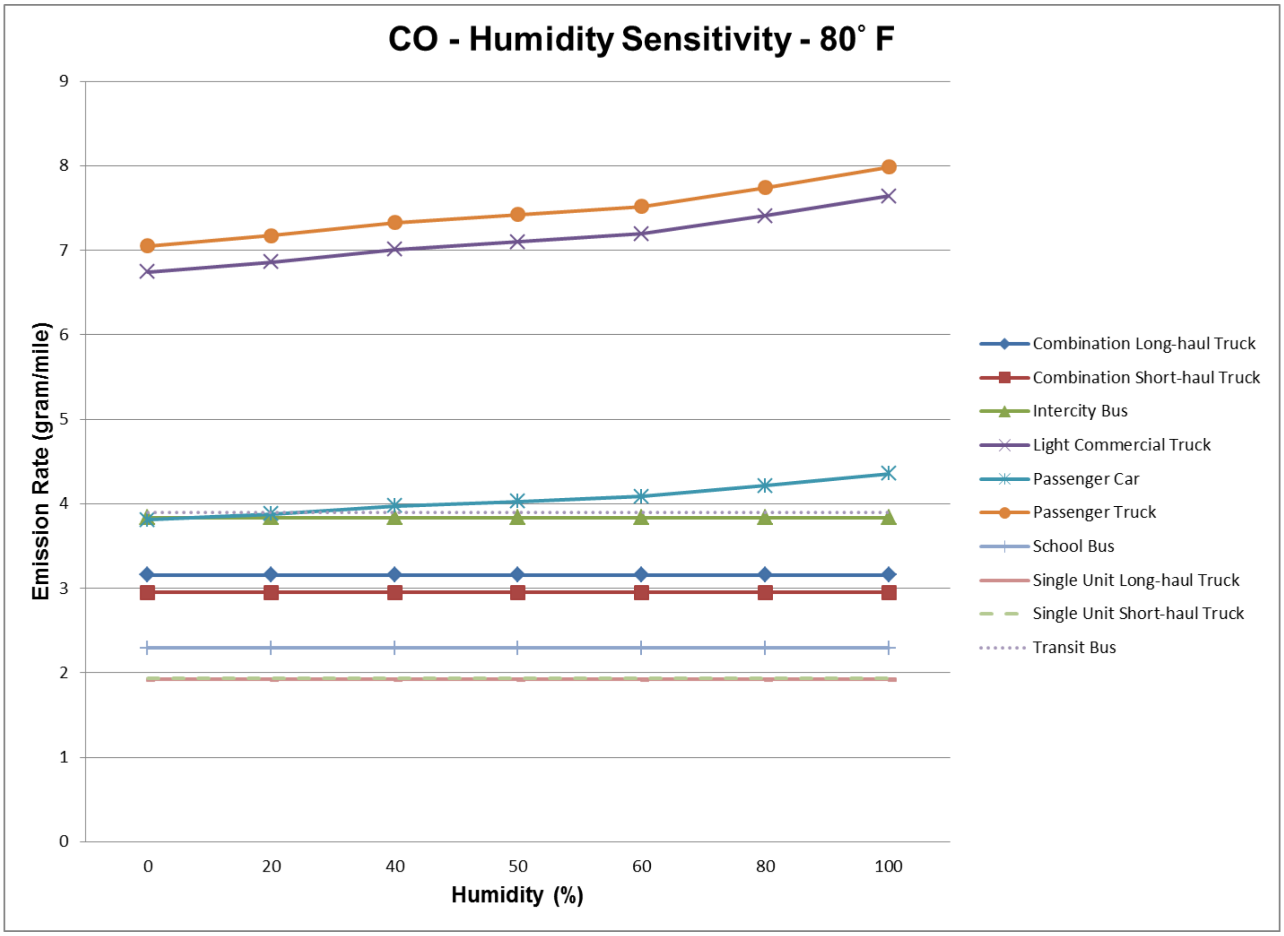


Table B-22. Passenger Car, Passenger Truck, and Light Commercial Truck CO Humidity Sensitivity - 80° Fahrenheit

Humidity	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	3.8081	-5.42%	7.0479	-5.01%	6.7405	-5.05%
20	3.8800	-3.63%	7.1704	-3.36%	6.8585	-3.38%
40	3.9728	-1.33%	7.3283	-1.23%	7.0106	-1.24%
50	4.0264	0.00%	7.4197	0.00%	7.0987	0.00%
60	4.0846	1.44%	7.5188	1.34%	7.1942	1.35%
80	4.2134	4.64%	7.7383	4.29%	7.4056	4.32%
100	4.3569	8.21%	7.9827	7.59%	7.6410	7.64%

Oxides of Nitrogen (NOX) – Running Exhaust

Figure B-11. NO_X Humidity Sensitivity - 60° Fahrenheit

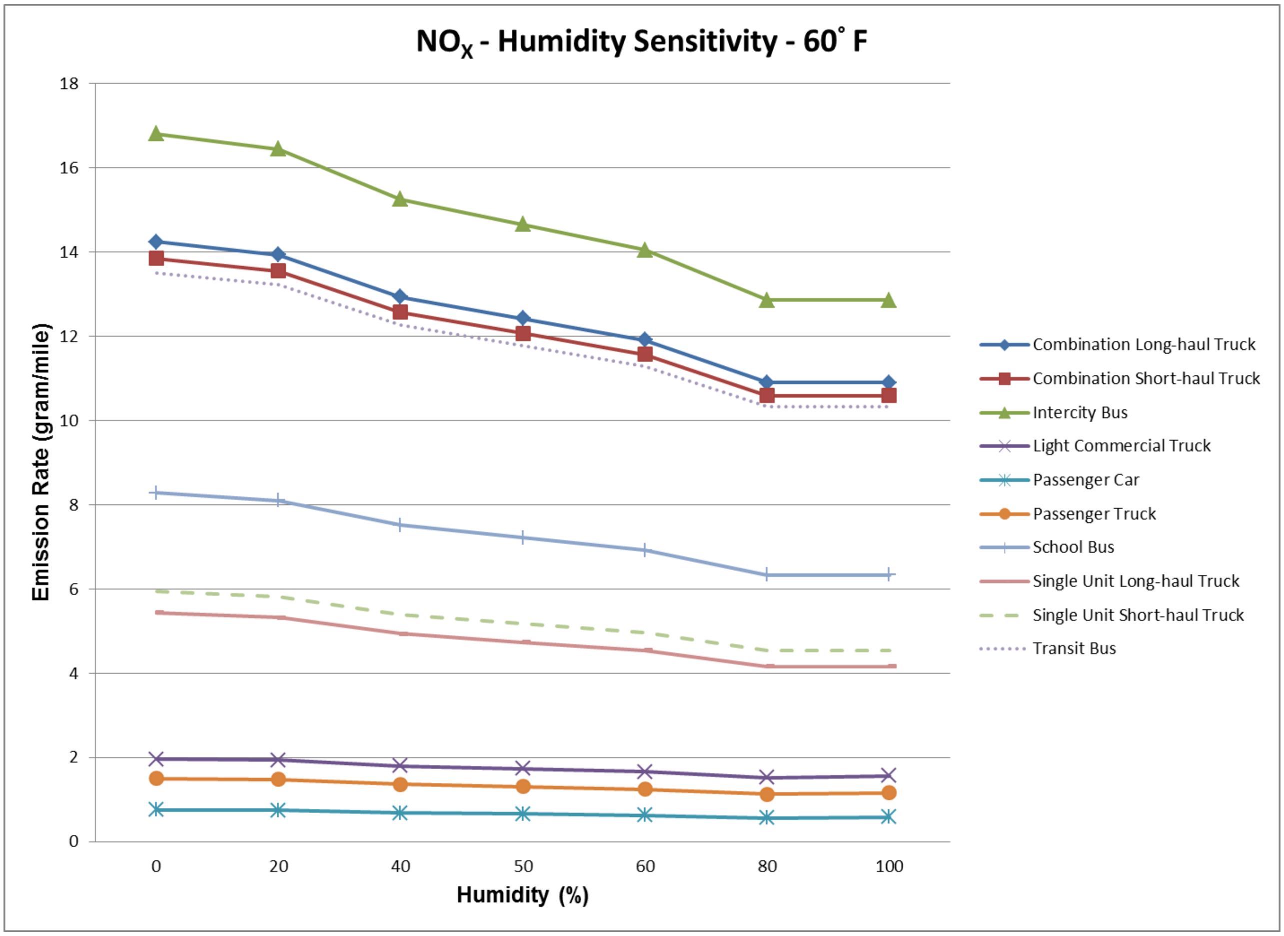


Table B-23. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Humidity Sensitivity - 60° Fahrenheit

Humidity	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.5935	5.86%	1.2028	5.78%	1.5564	5.35%
20	0.5935	5.86%	1.2028	5.78%	1.5564	5.35%
40	0.5751	2.59%	1.1661	2.55%	1.5123	2.37%
50	0.5606	0.00%	1.1371	0.00%	1.4773	0.00%
60	0.5460	-2.60%	1.1080	-2.56%	1.4422	-2.37%
80	0.5167	-7.83%	1.0494	-7.72%	1.3717	-7.15%
100	0.4872	-13.09%	0.9903	-12.91%	1.3007	-11.96%

Table B-24. Bus NO_X Humidity Sensitivity - 60° Fahrenheit

Humidity	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	16.8050	4%	13.5096	4%	8.2764	4%
20	16.8050	4%	13.5096	4%	8.2764	4%
40	16.4291	2%	13.2074	2%	8.0913	2%
50	16.1314	0%	12.9680	0%	7.9446	0%
60	15.8326	-2%	12.7279	-2%	7.7975	-2%
80	15.2318	-6%	12.2449	-6%	7.5016	-6%
100	14.6267	-9%	11.7584	-9%	7.2036	-9%

Table B-25. Single Unit and Combination Truck NO_X Humidity Sensitivity - 60° Fahrenheit

Humidity	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	5.9465	4%	5.4383	4.18%	13.8456	4%	13.8456	4%
20	5.9465	4%	5.4383	4.18%	13.8456	4%	13.8456	4%
40	5.8135	2%	5.3167	1.85%	13.5358	2%	13.5358	2%
50	5.7081	0%	5.2203	0.00%	13.2905	0%	13.2905	0%
60	5.6024	-2%	5.1236	-1.85%	13.0443	-2%	13.0443	-2%
80	5.3898	-6%	4.9292	-5.58%	12.5494	-6%	12.5494	-6%
100	5.1757	-9%	4.7334	-9.33%	12.0508	-9%	12.0508	-9%

Figure B-12. NO_X Humidity Sensitivity - 80° Fahrenheit

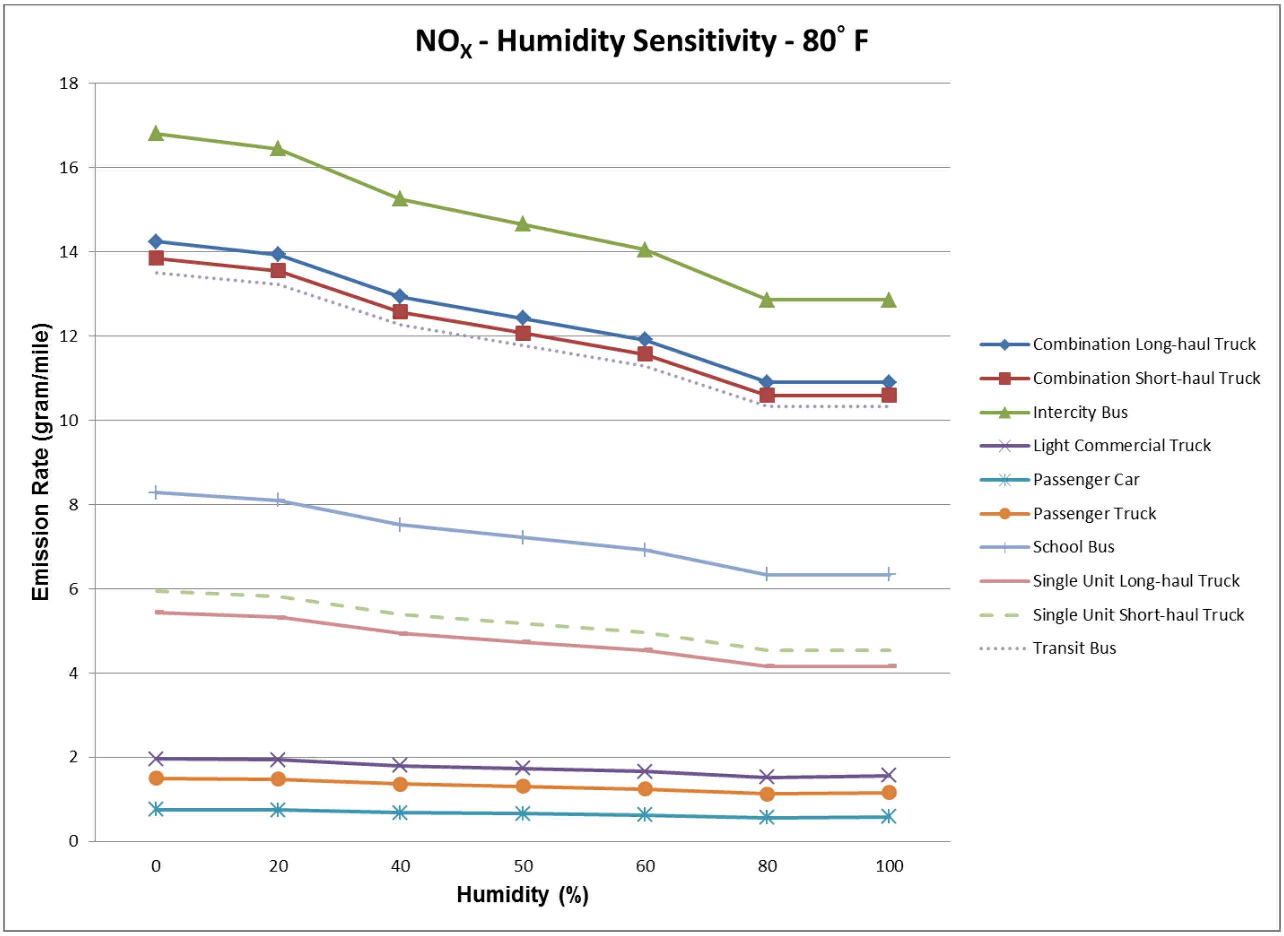


Table B-26. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Humidity Sensitivity - 80° Fahrenheit

Humidity	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.7538	14.76%	1.5000	14.86%	1.9553	12.99%
20	0.7453	13.46%	1.4817	13.46%	1.9367	11.91%
40	0.6867	4.55%	1.3652	4.54%	1.8000	4.01%
50	0.6569	0.00%	1.3059	0.00%	1.7306	0.00%
60	0.6264	-4.64%	1.2454	-4.63%	1.6600	-4.08%
80	0.5648	-14.02%	1.1237	-13.96%	1.5181	-12.28%
100	0.5844	-11.03%	1.1603	-11.15%	1.5690	-9.34%

Table B-27. Bus NO_X Humidity Sensitivity - 80° Fahrenheit

Humidity	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	16.8050	15%	13.5096	15%	8.2764	15%
20	16.4392	12%	13.2155	12%	8.0963	12%
40	15.2523	4%	12.2614	4%	7.5117	4%
50	14.6525	0%	11.7792	0%	7.2163	0%
60	14.0485	-4%	11.2935	-4%	6.9188	-4%
80	12.8587	-12%	10.3371	-12%	6.3328	-12%
100	12.8587	-12%	10.3371	-12%	6.3328	-12%

Table B-28. Single Unit and Combination Truck NO_X Humidity Sensitivity - 80° Fahrenheit

Humidity	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	5.9465	15%	5.4383	14.69%	13.8455	15%	13.8455	15%
20	5.8171	12%	5.3200	12.19%	13.5442	12%	13.5442	12%
40	5.3971	4%	4.9359	4.09%	12.5663	4%	12.5663	4%
50	5.1848	0%	4.7417	0.00%	12.0721	0%	12.0721	0%
60	4.9711	-4%	4.5463	-4.12%	11.5744	-4%	11.5744	-4%
80	4.5501	-12%	4.1612	-12.24%	10.5942	-12%	10.5942	-12%
100	4.5501	-12%	4.1612	-12.24%	10.5942	-12%	10.5942	-12%

Particulate Matter (PM2.5) – Running Exhaust

Figure B-13. $PM_{2.5}$ Humidity Sensitivity - 80˚ Fahrenheit

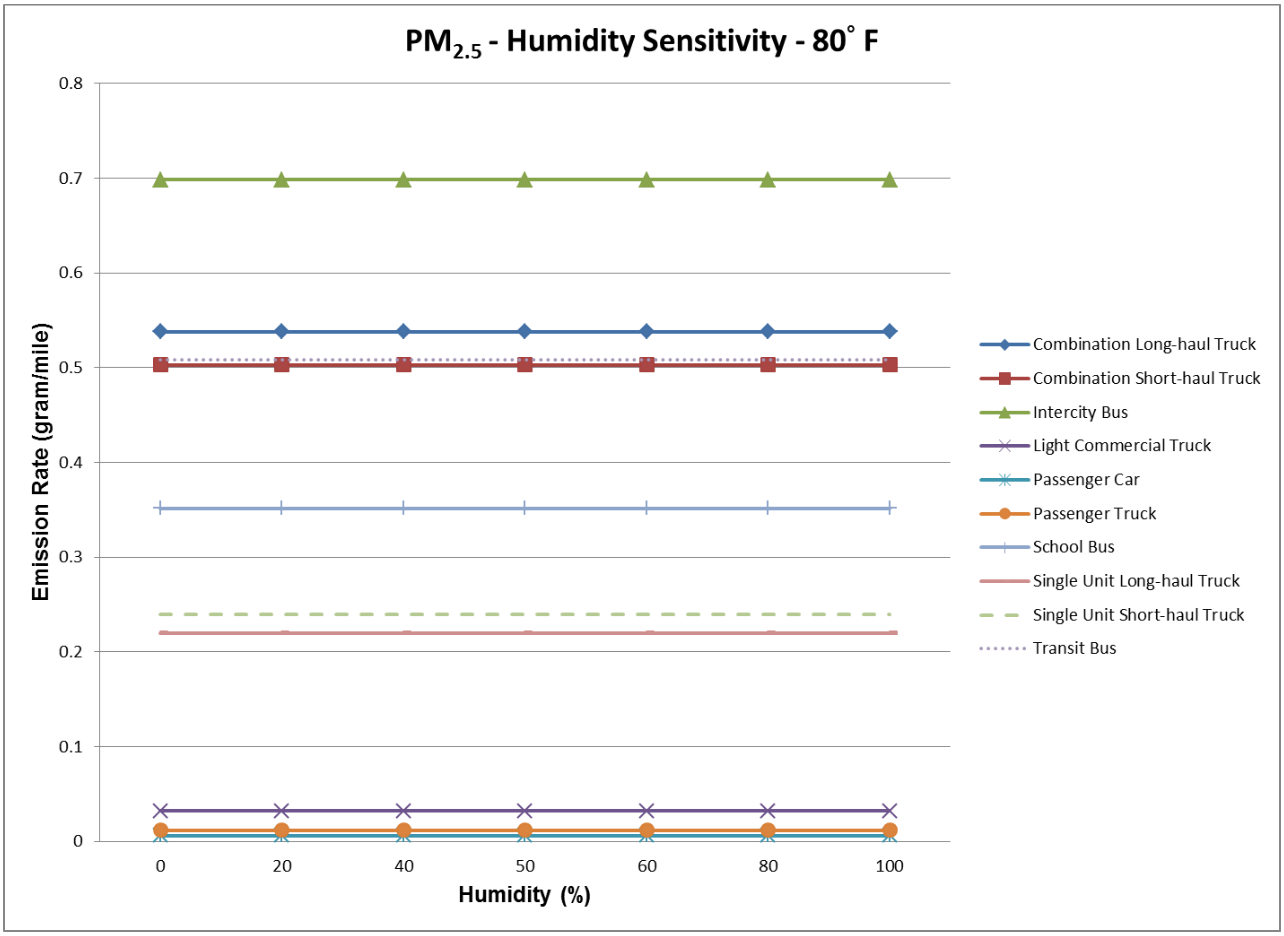


Table B-29. Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Humidity Sensitivity - 80˚ Fahrenheit

Humidity	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.005955	-0.01%	0.012083	-0.01%	0.032327	0.00%
20	0.005956	-0.01%	0.012083	0.00%	0.032327	0.00%
40	0.005956	0.00%	0.012083	0.00%	0.032328	0.00%
50	0.005956	0.00%	0.012083	0.00%	0.032328	0.00%
60	0.005956	0.00%	0.012084	0.00%	0.032328	0.00%
80	0.005956	0.01%	0.012084	0.01%	0.032329	0.00%
100	0.005957	0.01%	0.012085	0.01%	0.032330	0.01%

Volatile Organic Compounds (VOC) – Running Exhaust

Figure B-14. VOC Humidity Sensitivity - 80° Fahrenheit

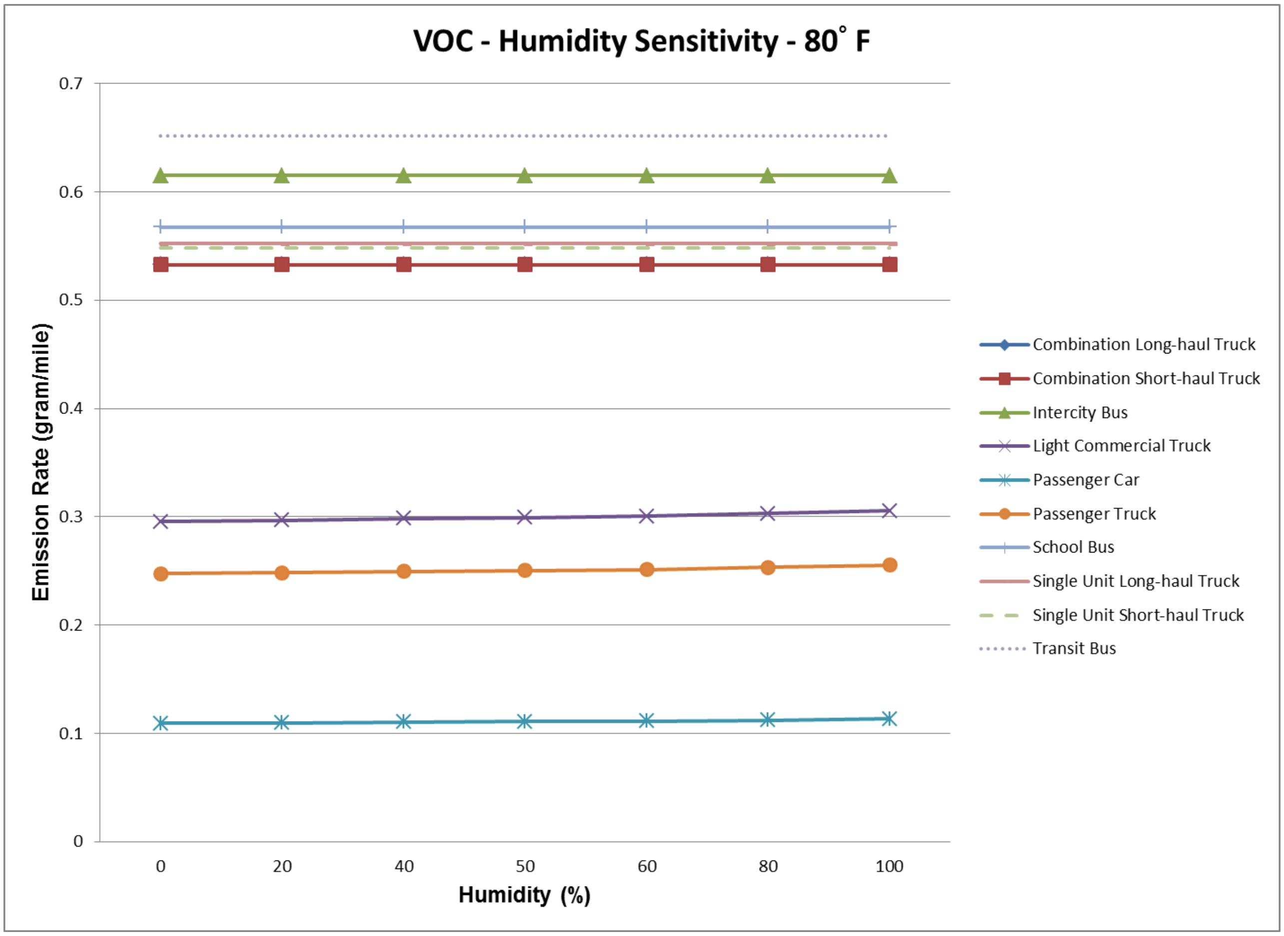


Table B-30. Passenger Car, Passenger Truck, and Light Commercial Truck VOC Humidity Sensitivity - 80° Fahrenheit

Humidity	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.1093	-1.40%	0.2474	-1.26%	0.2956	-1.30%
20	0.1099	-0.94%	0.2484	-0.85%	0.2969	-0.87%
40	0.1105	-0.34%	0.2498	-0.31%	0.2985	-0.32%
50	0.1109	0.00%	0.2506	0.00%	0.2995	0.00%
60	0.1113	0.37%	0.2514	0.34%	0.3005	0.35%
80	0.1122	1.20%	0.2533	1.08%	0.3028	1.12%
100	0.1132	2.12%	0.2553	1.91%	0.3054	1.97%

Appendix C. Ramp Fraction Sensitivity Results

Carbon Monoxide (CO) – Running Exhaust

Figure C-15. CO Ramp Fraction Sensitivity

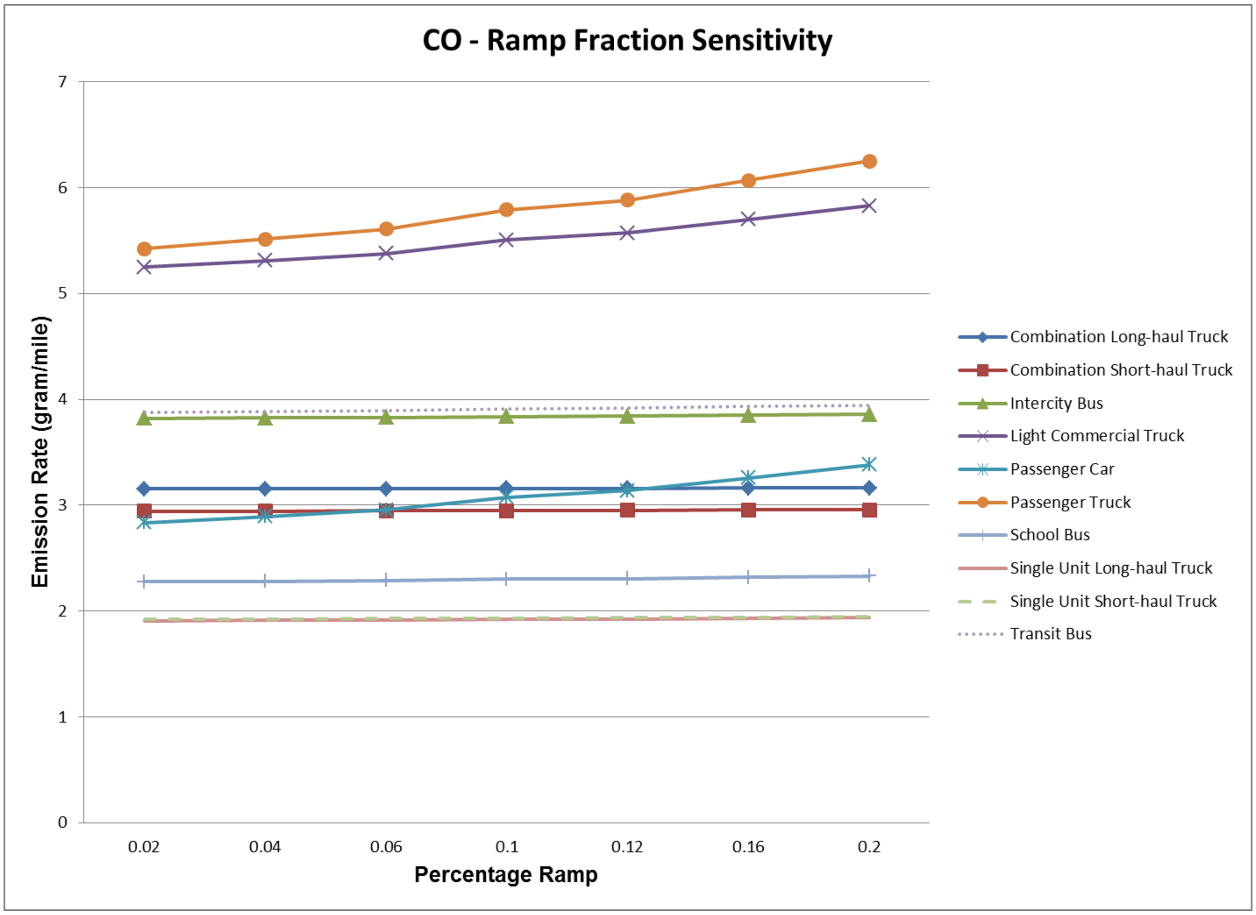


Table C-31. Passenger Car, Passenger Truck, and Light Commercial Truck CO Ramp Fraction Sensitivity

Ramp Fraction	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	2.774	-8%	5.331	-6%	5.182	-5%
0.02	2.834	-6%	5.423	-5%	5.247	-4%
0.04	2.895	-4%	5.515	-3%	5.312	-2%
0.06	2.956	-2%	5.607	-2%	5.376	-1%
0.08	3.016	0%	5.699	0%	5.441	0%
0.1	3.077	2%	5.791	2%	5.506	1%
0.12	3.138	4%	5.883	3%	5.570	2%
0.16	3.259	8%	6.067	6%	5.700	5%
0.2	3.381	12%	6.251	10%	5.829	7%

Table C-32. Bus CO Ramp Fraction Sensitivity

Ramp Fraction	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	3.818	-0.4%	3.872	-0.7%	2.270	-1.0%
0.02	3.822	-0.3%	3.880	-0.6%	2.276	-0.8%
0.04	3.826	-0.2%	3.887	-0.4%	2.282	-0.5%
0.06	3.830	-0.1%	3.894	-0.2%	2.288	-0.3%
0.08	3.834	0.0%	3.901	0.0%	2.294	0.0%
0.1	3.837	0.1%	3.909	0.2%	2.300	0.3%
0.12	3.841	0.2%	3.916	0.4%	2.305	0.5%
0.16	3.849	0.4%	3.931	0.7%	2.317	1.0%
0.2	3.857	0.6%	3.945	1.1%	2.329	1.5%

Table C-33. Single Unit and Combination Truck CO Ramp Fraction Sensitivity

Ramp Fraction	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	1.920	-0.6%	1.907	-0.6%	2.942	-0.2%	3.152	-0.1%
0.02	1.922	-0.4%	1.910	-0.4%	2.943	-0.2%	3.153	-0.1%
0.04	1.925	-0.3%	1.913	-0.3%	2.945	-0.1%	3.154	-0.1%
0.06	1.928	-0.1%	1.916	-0.1%	2.946	-0.1%	3.155	0.0%
0.08	1.931	0.0%	1.919	0.0%	2.948	0.0%	3.156	0.0%
0.1	1.933	0.1%	1.921	0.1%	2.949	0.1%	3.157	0.0%
0.12	1.936	0.3%	1.924	0.3%	2.951	0.1%	3.159	0.1%
0.16	1.941	0.6%	1.930	0.6%	2.954	0.2%	3.161	0.1%
0.2	1.947	0.8%	1.936	0.9%	2.957	0.3%	3.163	0.2%

Oxides of Nitrogen (NOX) – Running Exhaust

Figure C-16. NO_X Ramp Fraction Sensitivity

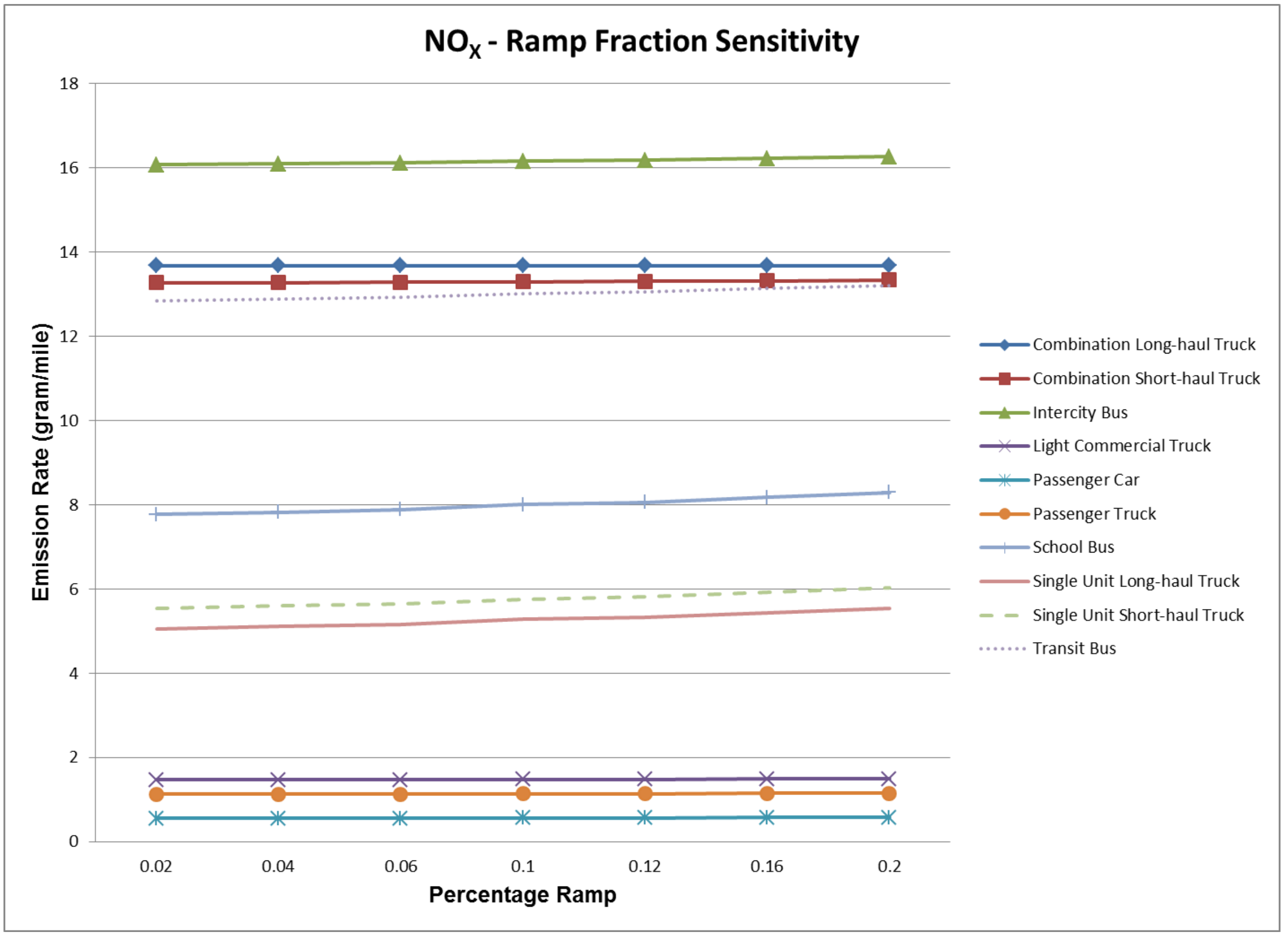


Table C-34. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Ramp Fraction Sensitivity

Ramp Fraction	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.549	-2%	1.125	-1%	1.467	-1%
0.02	0.552	-2%	1.128	-1%	1.469	-1%
0.04	0.555	-1%	1.131	-1%	1.472	0%
0.06	0.558	-1%	1.134	0%	1.475	0%
0.08	0.561	0%	1.137	0%	1.477	0%
0.1	0.564	1%	1.140	0%	1.480	0%
0.12	0.566	1%	1.143	1%	1.483	0%
0.16	0.572	2%	1.149	1%	1.488	1%
0.2	0.578	3%	1.155	2%	1.493	1%

Table C-35. Bus NO_X Ramp Fraction Sensitivity

Ramp Fraction	Intercity Bus Emission Rate (gram/mile)	Intercity Bus % difference	Transit Bus Emission Rate (gram/mile)	Transit Bus % difference	School Bus Emission Rate (gram/mile)	School Bus % difference
0	16.046	-0.5%	12.806	-1.2%	7.712	-2.9%
0.02	16.067	-0.4%	12.847	-0.9%	7.770	-2.2%
0.04	16.089	-0.3%	12.887	-0.6%	7.828	-1.5%
0.06	16.110	-0.1%	12.928	-0.3%	7.886	-0.7%
0.08	16.131	0.0%	12.968	0.0%	7.945	0.0%
0.1	16.153	0.1%	13.008	0.3%	8.003	0.7%
0.12	16.174	0.3%	13.049	0.6%	8.061	1.5%
0.16	16.217	0.5%	13.130	1.2%	8.177	2.9%
0.2	16.259	0.8%	13.211	1.9%	8.293	4.4%

Table C-36. Single Unit and Combination Truck NO_X Ramp Fraction Sensitivity

Ramp Fraction	Single Unit Short-haul Truck Emission Rate (gram/mile)	Single Unit Short-haul Truck % difference	Single Unit Long-haul Truck Emission Rate (gram/mile)	Single Unit Long-haul Truck % difference	Combination Short-haul Truck Emission Rate (gram/mile)	Combination Short-haul Truck % difference	Combination Long-haul Truck Emission Rate (gram/mile)	Combination Long-haul Truck % difference
0	5.492	-3.8%	5.003	-4.2%	13.261	-0.2%	13.674	0.0%
0.02	5.546	-2.8%	5.057	-3.1%	13.269	-0.2%	13.673	0.0%
0.04	5.600	-1.9%	5.112	-2.1%	13.276	-0.1%	13.673	0.0%
0.06	5.654	-0.9%	5.166	-1.0%	13.283	-0.1%	13.673	0.0%
0.08	5.708	0.0%	5.220	0.0%	13.291	0.0%	13.673	0.0%
0.1	5.762	0.9%	5.275	1.0%	13.298	0.1%	13.673	0.0%
0.12	5.816	1.9%	5.329	2.1%	13.305	0.1%	13.673	0.0%
0.16	5.924	3.8%	5.438	4.2%	13.320	0.2%	13.673	0.0%
0.2	6.032	5.7%	5.546	6.2%	13.334	0.3%	13.673	0.0%

Particulate Matter (PM2.5) – Running Exhaust

Figure C-17. $PM_{2.5}$ Ramp Fraction Sensitivity

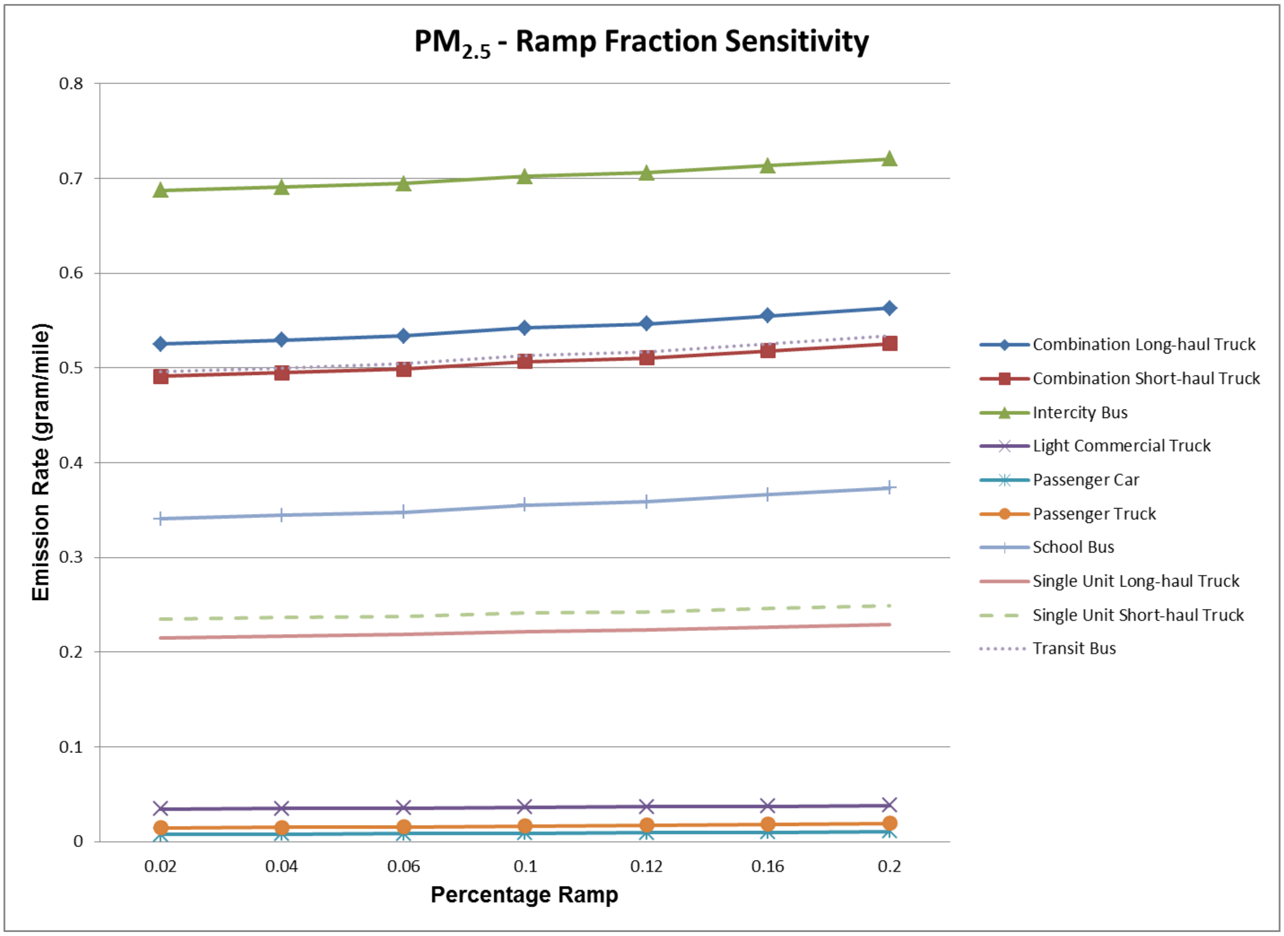


Table C-37. Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Ramp Fraction Sensitivity

	Passenger Car		Passenger Truck		Light Commercial Truck	
Ramp Fraction	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.00749	-15%	0.01426	-12%	0.03426	-5%
0.02	0.00781	-11%	0.01477	-9%	0.03468	-3%
0.04	0.00813	-7%	0.01528	-6%	0.03509	-2%
0.06	0.00845	-4%	0.01579	-3%	0.03551	-1%
0.08	0.00877	0%	0.01630	0%	0.03592	0%
0.1	0.00909	4%	0.01681	3%	0.03634	1%
0.12	0.00941	7%	0.01732	6%	0.03676	2%
0.16	0.01005	15%	0.01834	12%	0.03759	5%
0.2	0.01069	22%	0.01936	19%	0.03842	7%

Table C-38. Bus $PM_{2.5}$ Ramp Fraction Sensitivity

	Intercity Bus		Transit Bus		School Bus	
Ramp Fraction	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.683	-2.1%	0.492	-3.3%	0.337	-4.1%
0.02	0.687	-1.6%	0.496	-2.5%	0.341	-3.1%
0.04	0.691	-1.1%	0.500	-1.7%	0.344	-2.1%
0.06	0.695	-0.5%	0.504	-0.8%	0.348	-1.0%
0.08	0.698	0.0%	0.509	0.0%	0.352	0.0%
0.1	0.702	0.5%	0.513	0.8%	0.355	1.0%
0.12	0.706	1.1%	0.517	1.7%	0.359	2.1%
0.16	0.713	2.1%	0.525	3.3%	0.366	4.1%
0.2	0.721	3.2%	0.534	5.0%	0.373	6.2%

Table C-39. Single Unit and Combination Truck $PM_{2.5}$ Ramp Fraction

	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
Ramp Fraction	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.233	-2.7%	0.214	-2.8%	0.487	-3.0%	0.521	-3.1%
0.02	0.235	-2.0%	0.215	-2.1%	0.491	-2.3%	0.525	-2.4%
0.04	0.236	-1.4%	0.217	-1.4%	0.495	-1.5%	0.529	-1.6%
0.06	0.238	-0.7%	0.218	-0.7%	0.499	-0.8%	0.534	-0.8%
0.08	0.240	0.0%	0.220	0.0%	0.503	0.0%	0.538	0.0%
0.1	0.241	0.7%	0.222	0.7%	0.506	0.8%	0.542	0.8%
0.12	0.243	1.4%	0.223	1.4%	0.510	1.5%	0.546	1.6%
0.16	0.246	2.7%	0.226	2.8%	0.518	3.0%	0.555	3.1%
0.2	0.249	4.1%	0.229	4.2%	0.526	4.6%	0.563	4.7%

Volatile Organic Compounds (VOC) – Running Exhaust

Figure C-18. VOC Ramp Fraction Sensitivity

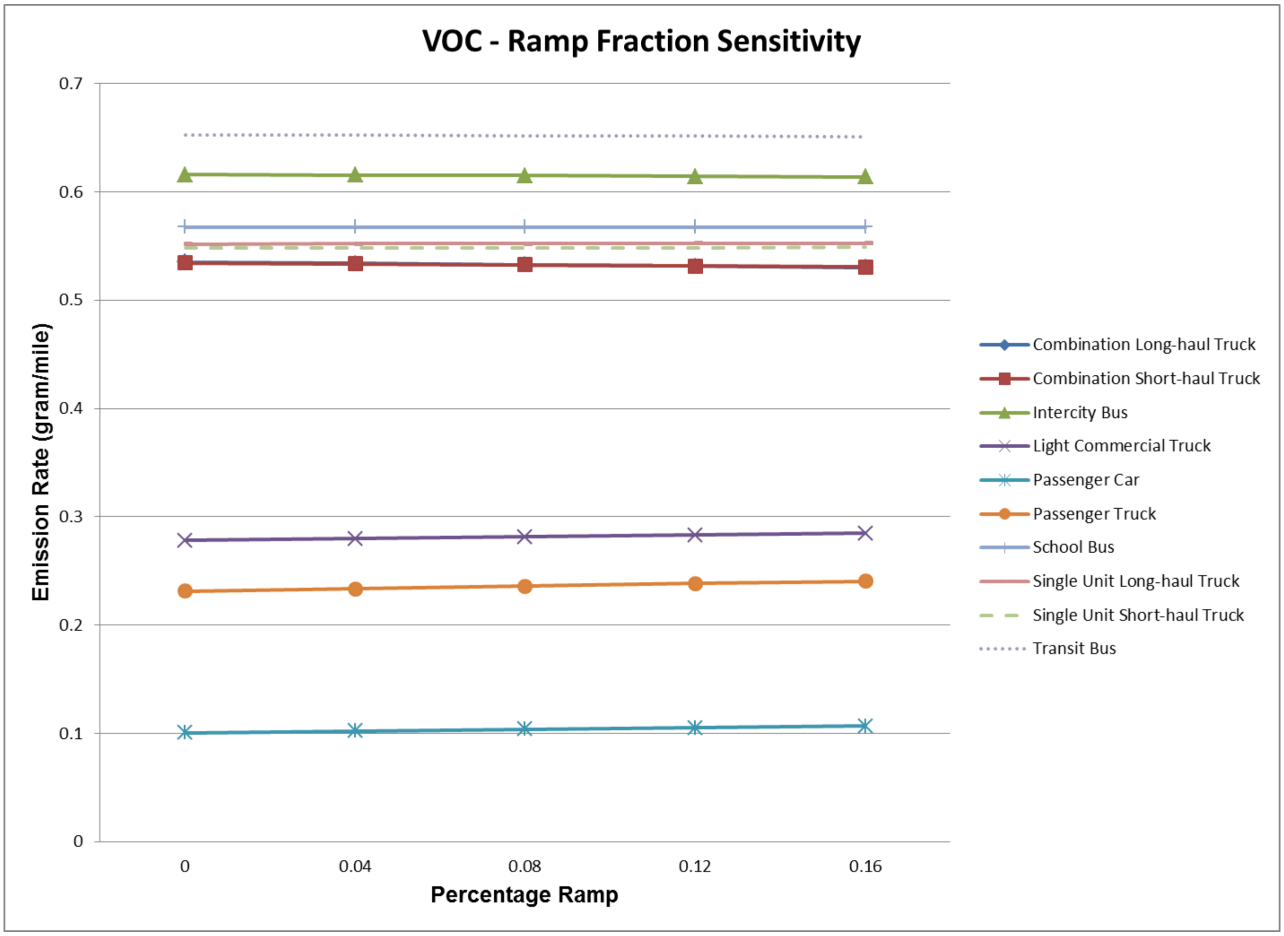


Table C-40. Passenger Car, Passenger Truck, and Light Commercial Truck VOC Ramp Fraction Sensitivity

Ramp Fraction	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.1007	-2.9%	0.2313	-2.0%	0.2780	-1.2%
0.02	0.1015	-2.2%	0.2324	-1.5%	0.2789	-0.9%
0.04	0.1022	-1.4%	0.2336	-1.0%	0.2797	-0.6%
0.06	0.1030	-0.7%	0.2347	-0.5%	0.2806	-0.3%
0.08	0.1037	0.0%	0.2359	0.0%	0.2814	0.0%
0.1	0.1045	0.7%	0.2371	0.5%	0.2823	0.3%
0.12	0.1052	1.4%	0.2382	1.0%	0.2832	0.6%
0.16	0.1067	2.9%	0.2406	2.0%	0.2849	1.2%
0.2	0.1082	4.3%	0.2429	3.0%	0.2866	1.8%

Table C-41. Bus VOC Ramp Fraction Sensitivity

Ramp Fraction	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.6158	0.15%	0.6528	0.14%	0.56735	-0.02%
0.02	0.6156	0.11%	0.6526	0.11%	0.56737	-0.01%
0.04	0.6153	0.07%	0.6523	0.07%	0.56739	-0.01%
0.06	0.6151	0.04%	0.6521	0.04%	0.56741	0.00%
0.08	0.6149	0.00%	0.6519	0.00%	0.56743	0.00%
0.1	0.6147	-0.04%	0.6516	-0.04%	0.56745	0.00%
0.12	0.6144	-0.07%	0.6514	-0.07%	0.56748	0.01%
0.16	0.6140	-0.15%	0.6509	-0.14%	0.56752	0.02%
0.2	0.6135	-0.22%	0.6505	-0.21%	0.56756	0.02%

Table C-42. Single Unit and Combination Truck VOC Ramp Fraction Sensitivity

Ramp Fraction	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
0	0.5479	-0.07%	0.5518	-0.08%	0.5345	0.4%	0.5354	0.5%
0.02	0.5480	-0.05%	0.5520	-0.06%	0.5340	0.3%	0.5347	0.4%
0.04	0.5481	-0.04%	0.5521	-0.04%	0.5336	0.2%	0.5341	0.2%
0.06	0.5482	-0.02%	0.5522	-0.02%	0.5331	0.1%	0.5334	0.1%
0.08	0.5483	0.00%	0.5523	0.00%	0.5326	0.0%	0.5328	0.0%
0.1	0.5484	0.02%	0.5524	0.02%	0.5321	-0.1%	0.5321	-0.1%
0.12	0.5485	0.04%	0.5525	0.04%	0.5317	-0.2%	0.5315	-0.2%
0.16	0.5486	0.07%	0.5527	0.08%	0.5307	-0.4%	0.5302	-0.5%
0.2	0.5488	0.11%	0.5530	0.12%	0.5297	-0.5%	0.5289	-0.7%

Appendix D. Analysis Year Sensitivity Results

Carbon Monoxide (CO) – Running Exhaust

Figure D-19. CO Analysis Year Sensitivity

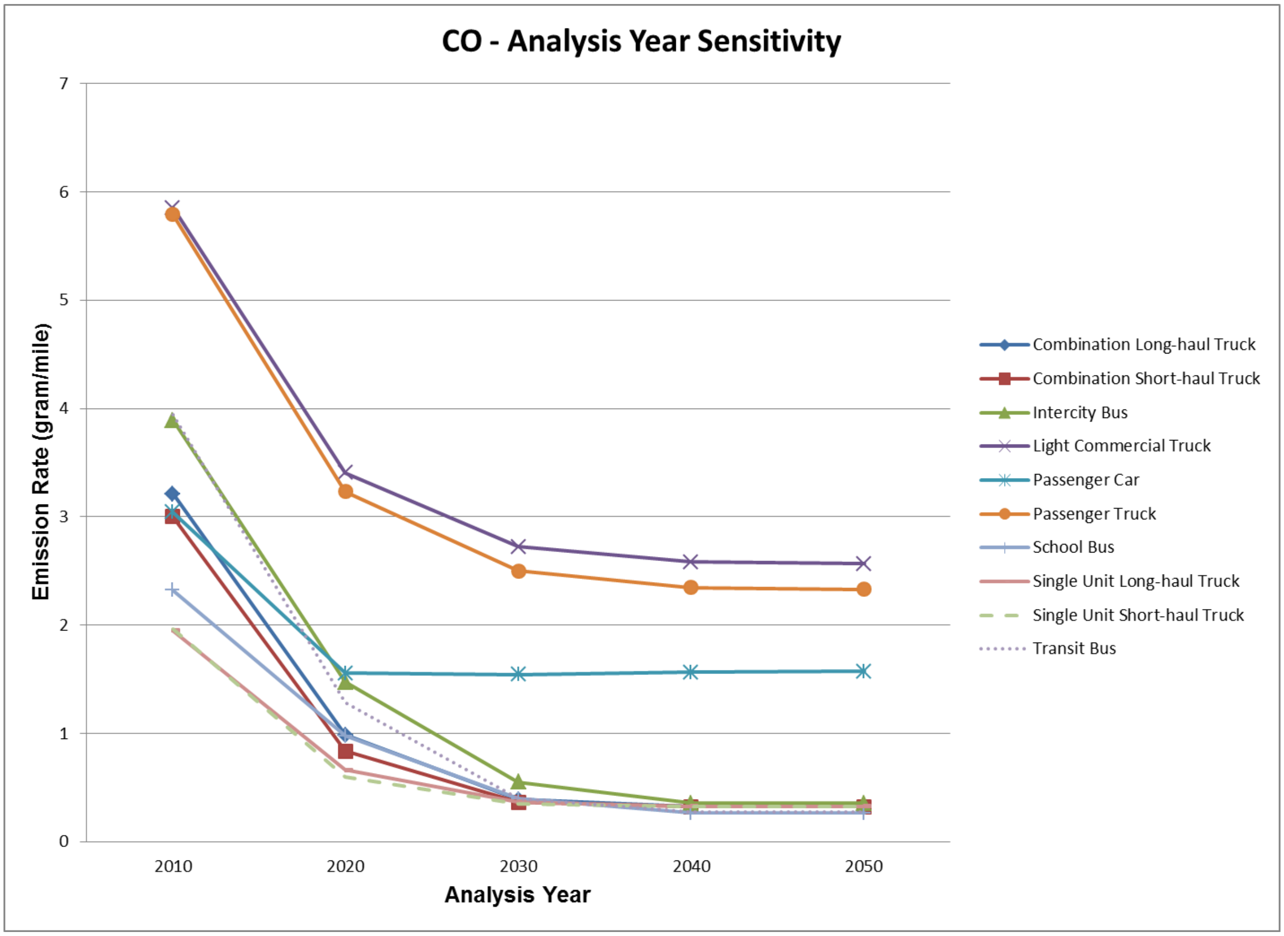


Table D-43. Passenger Car, Passenger Truck, and Light Commercial Truck CO Analysis Year Sensitivity

Analysis Year	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	3.0420	0.0%	5.7886	0.0%	5.8541	0.0%
2020	1.5569	-48.8%	3.2329	-44.2%	3.4060	-41.8%
2030	1.5427	-49.3%	2.4998	-56.8%	2.7231	-53.5%
2040	1.5665	-48.5%	2.3487	-59.4%	2.5837	-55.9%
2050	1.5710	-48.4%	2.3309	-59.7%	2.5661	-56.2%

Table D-44. Bus CO Analysis Year Sensitivity

Analysis Year	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	3.8782	0%	3.9297	0%	2.3145	0%
2020	1.4687	-62.1%	1.2835	-67.3%	0.9735	-57.9%
2030	0.5488	-85.8%	0.3969	-89.9%	0.3956	-82.9%
2040	0.3550	-90.8%	0.2739	-93.0%	0.2643	-88.6%
2050	0.3546	-90.9%	0.2737	-93.0%	0.2640	-88.6%

Table D-45. Single Unit and Combination Truck CO Analysis Year Sensitivity

Analysis Year	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	1.9581	0%	1.9457	0%	2.9938	0%	3.2042	0%
2020	0.5999	-69.4%	0.6609	-66.0%	0.8362	-72.1%	0.9814	-69.4%
2030	0.3536	-81.9%	0.3667	-81.2%	0.3651	-87.8%	0.3883	-87.9%
2040	0.3282	-83.2%	0.3272	-83.2%	0.3229	-89.2%	0.3240	-89.9%
2050	0.3281	-83.2%	0.3271	-83.2%	0.3228	-89.2%	0.3239	-89.9%

Oxides of Nitrogen (NOX) – Running Exhaust

Figure D-20. NO_X Analysis Year Sensitivity

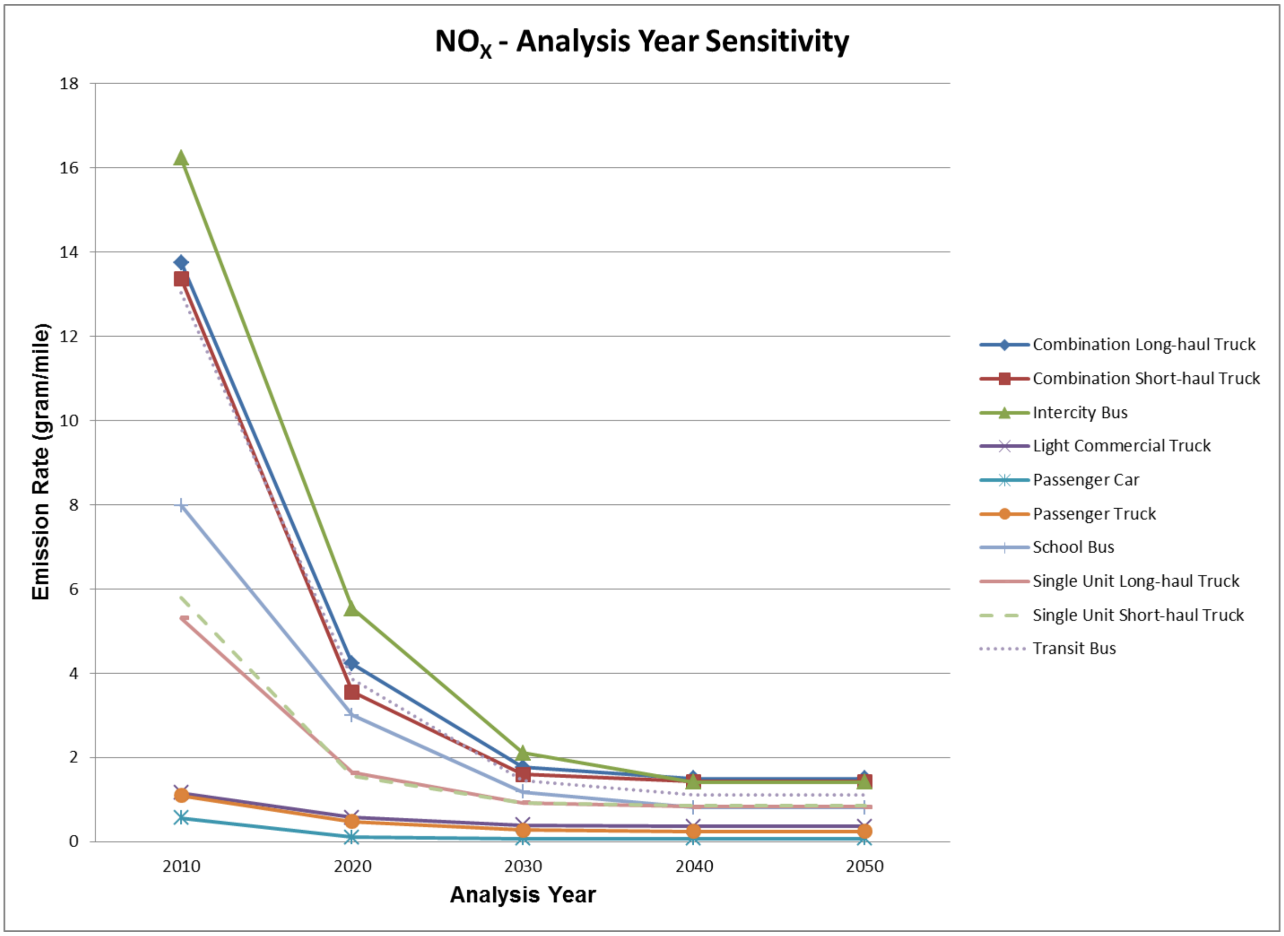


Table D-46. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Analysis Year Sensitivity

Analysis Year	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	0.5598	0.0%	1.0943	0.0%	1.1630	0.0%
2020	0.1117	-80.1%	0.4786	-56.3%	0.5754	-50.5%
2030	0.0786	-86.0%	0.2794	-74.5%	0.3919	-66.3%
2040	0.0789	-85.9%	0.2479	-77.3%	0.3630	-68.8%
2050	0.0791	-85.9%	0.2469	-77.4%	0.3619	-68.9%

Table D-47. Bus NO_X Analysis Year Sensitivity

Analysis Year	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	16.2205	0%	13.0218	0%	7.9839	0%
2020	5.5322	-65.9%	3.8647	-70.3%	2.9956	-62.5%
2030	2.1091	-87.0%	1.4611	-88.8%	1.1784	-85.2%
2040	1.4181	-91.3%	1.1212	-91.4%	0.8081	-89.9%
2050	1.4150	-91.3%	1.1197	-91.4%	0.8063	-89.9%

Table D-48. Single Unit and Combination Truck NO_X Analysis Year Sensitivity

Analysis Year	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	13.2825	0%	5.7961	0%	5.3052	0%	7.2077	0%
2020	3.4577	-74.0%	1.5592	-73.1%	1.6381	-69.1%	2.6163	-63.7%
2030	1.4534	-89.1%	0.9200	-84.1%	0.9292	-82.5%	1.3025	-81.9%
2040	1.3010	-90.2%	0.8544	-85.3%	0.8329	-84.3%	0.9583	-86.7%
2050	1.3003	-90.2%	0.8541	-85.3%	0.8324	-84.3%	0.9562	-86.7%

Particulate Matter (PM2.5) – Running Exhaust

Figure D-21. $PM_{2.5}$ Analysis Year Sensitivity

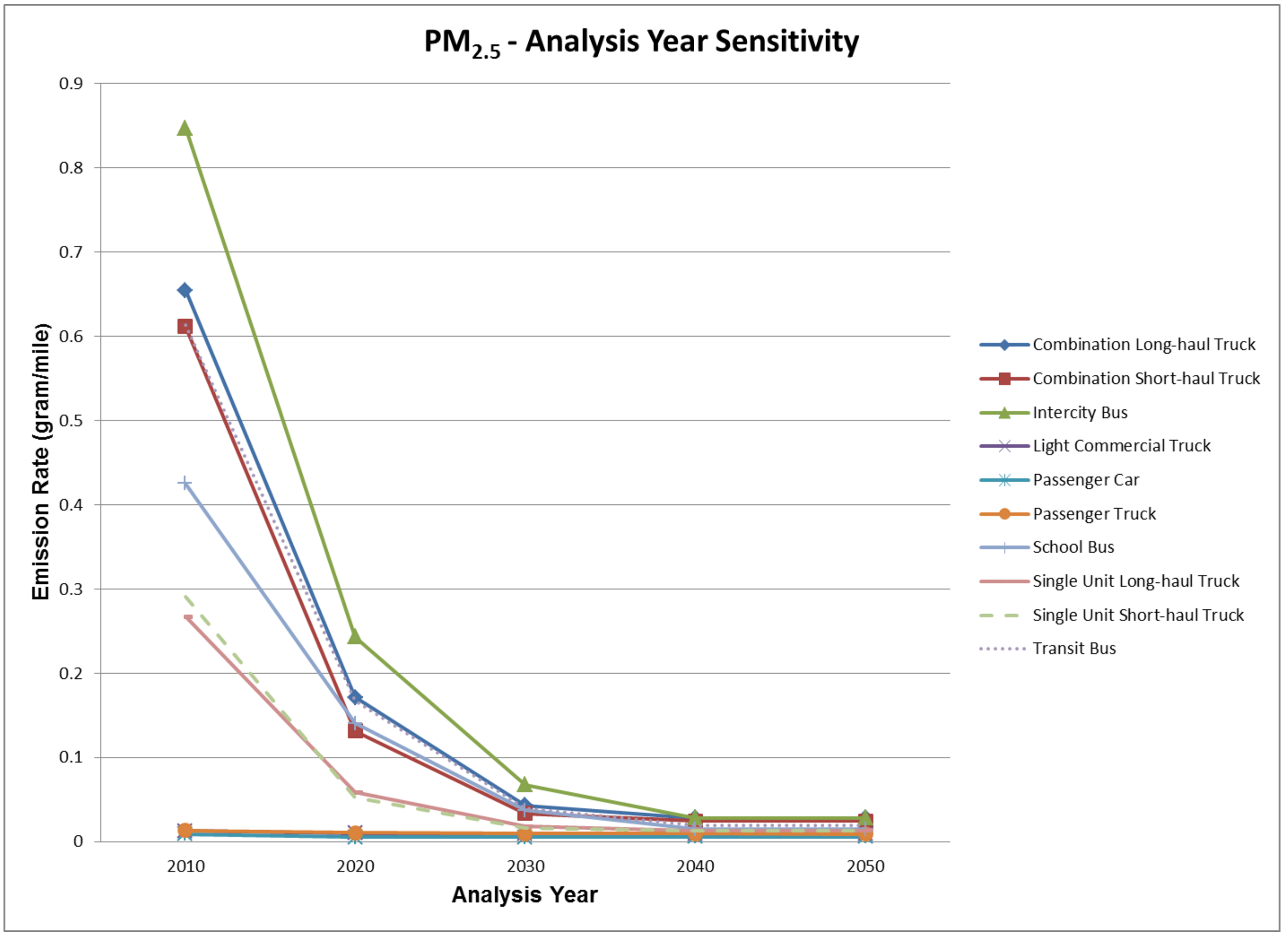


Table D-49. Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Analysis Year Sensitivity

Analysis Year	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	0.0088	0.0%	0.0133	0.0%	0.0126	0.0%
2020	0.0055	-37.4%	0.0104	-21.7%	0.0099	-21.8%
2030	0.0055	-37.6%	0.0096	-28.0%	0.0092	-27.5%
2040	0.0056	-36.3%	0.0093	-30.2%	0.0089	-29.5%
2050	0.0056	-36.0%	0.0092	-30.9%	0.0088	-30.1%

Table D-50. Bus $PM_{2.5}$ Analysis Year Sensitivity

Analysis Year	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	0.7066	0%	0.5113	0%	0.3548	0%
2020	0.2057	-70.9%	0.1419	-72.2%	0.1186	-66.6%
2030	0.0607	-91.4%	0.0359	-93.0%	0.0333	-90.6%
2040	0.0279	-96.0%	0.0193	-96.2%	0.0149	-95.8%
2050	0.0279	-96.1%	0.0193	-96.2%	0.0149	-95.8%

Table D-51. Single Unit and Combination Truck $PM_{2.5}$ Analysis Year Sensitivity

Analysis Year	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	0.5607	0%	0.2434	0%	0.2234	0%	0.3035	0%
2020	0.1234	-78.0%	0.0455	-81.3%	0.0508	-77.2%	0.0897	-70.4%
2030	0.0330	-94.1%	0.0161	-93.4%	0.0172	-92.3%	0.0275	-90.9%
2040	0.0254	-95.5%	0.0133	-94.5%	0.0130	-94.2%	0.0130	-95.7%
2050	0.0254	-95.5%	0.0133	-94.5%	0.0130	-94.2%	0.0129	-95.7%

Volatile Organic Compounds (VOC) – Running Exhaust

Figure D-22. VOC Analysis Year Sensitivity

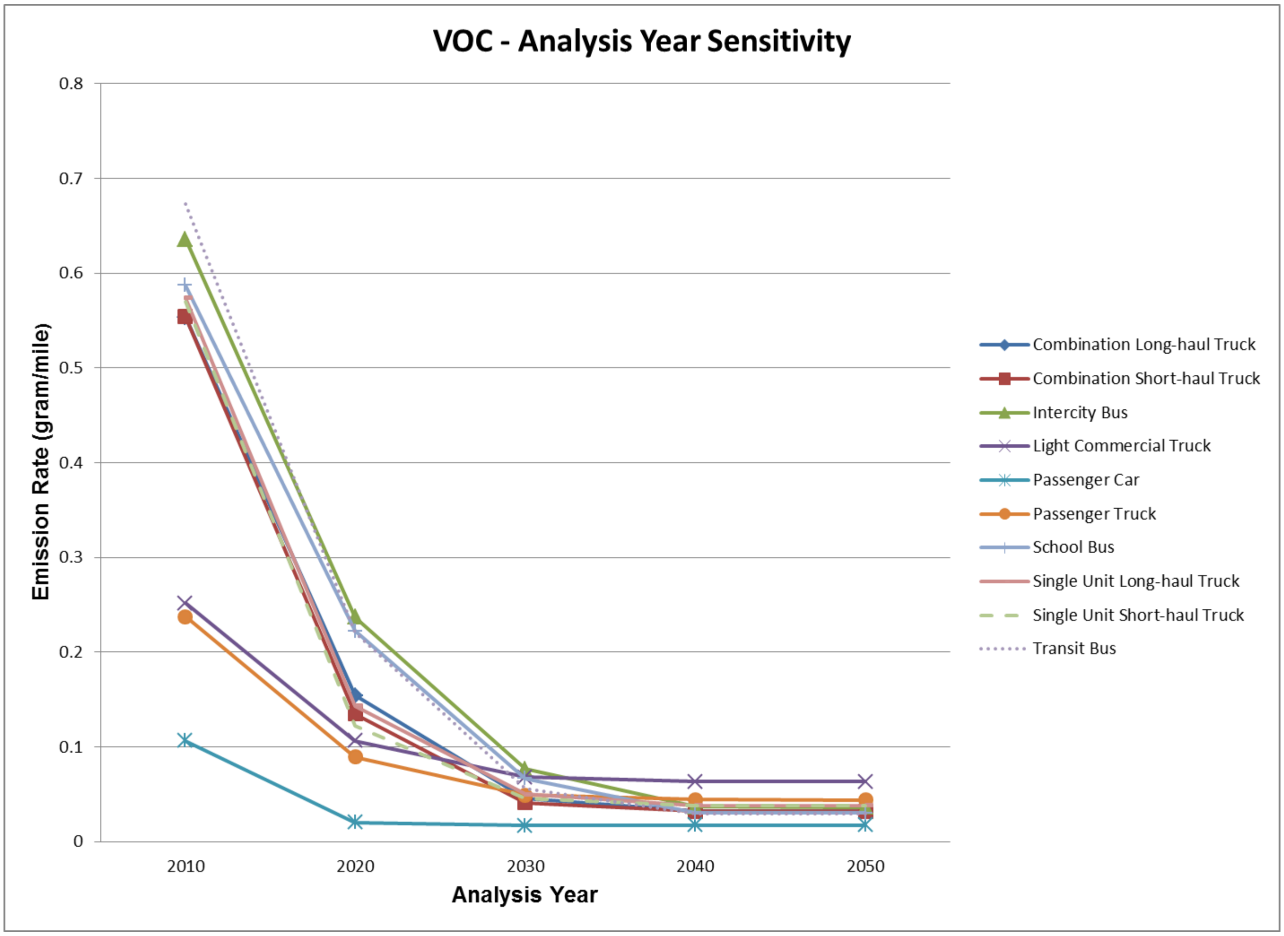


Table D-52. Passenger Car, Passenger Truck, and Light Commercial Truck VOC Analysis Year Sensitivity

	Passenger Car		Passenger Truck		Light Commercial Truck	
Analysis Year	**Emission Rate (gram/mile)**	**% difference**	**Emission Rate (gram/mile)**	**% difference**	**Emission Rate (gram/mile)**	**% difference**
2010	0.1050	0.0%	0.2344	0.0%	0.2484	0.0%
2020	0.0202	-80.8%	0.0884	-62.3%	0.1051	-57.7%
2030	0.0167	-84.1%	0.0486	-79.3%	0.0673	-72.9%
2040	0.0172	-83.6%	0.0439	-81.3%	0.0628	-74.7%
2050	0.0173	-83.5%	0.0436	-81.4%	0.0624	-74.9%

Table D-53. Bus VOC Analysis Year Sensitivity

Analysis Year	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	0.6233	0%	0.6602	0%	0.5756	0%
2020	0.2331	-62.6%	0.2170	-67.1%	0.2184	-62.0%
2030	0.0757	-87.9%	0.0555	-91.6%	0.0658	-88.6%
2040	0.0367	-94.1%	0.0297	-95.5%	0.0305	-94.7%
2050	0.0366	-94.1%	0.0297	-95.5%	0.0304	-94.7%

Table D-54. Single Unit and Combination Truck VOC Analysis Year Sensitivity

Analysis Year	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
2010	0.6378	0%	0.5585	0%	0.5626	0%	0.7245	0%
2020	0.1558	-75.6%	0.1201	-78.5%	0.1410	-74.9%	0.2530	-65.1%
2030	0.0470	-92.6%	0.0453	-91.9%	0.0500	-91.1%	0.0831	-88.5%
2040	0.0373	-94.2%	0.0380	-93.2%	0.0384	-93.2%	0.0397	-94.5%
2050	0.0373	-94.2%	0.0380	-93.2%	0.0383	-93.2%	0.0396	-94.5%

Appendix E. Age Distribution Sensitivity Results

Carbon Monoxide (CO) – Running Exhaust

Figure E-23. CO Age Distribution Sensitivity

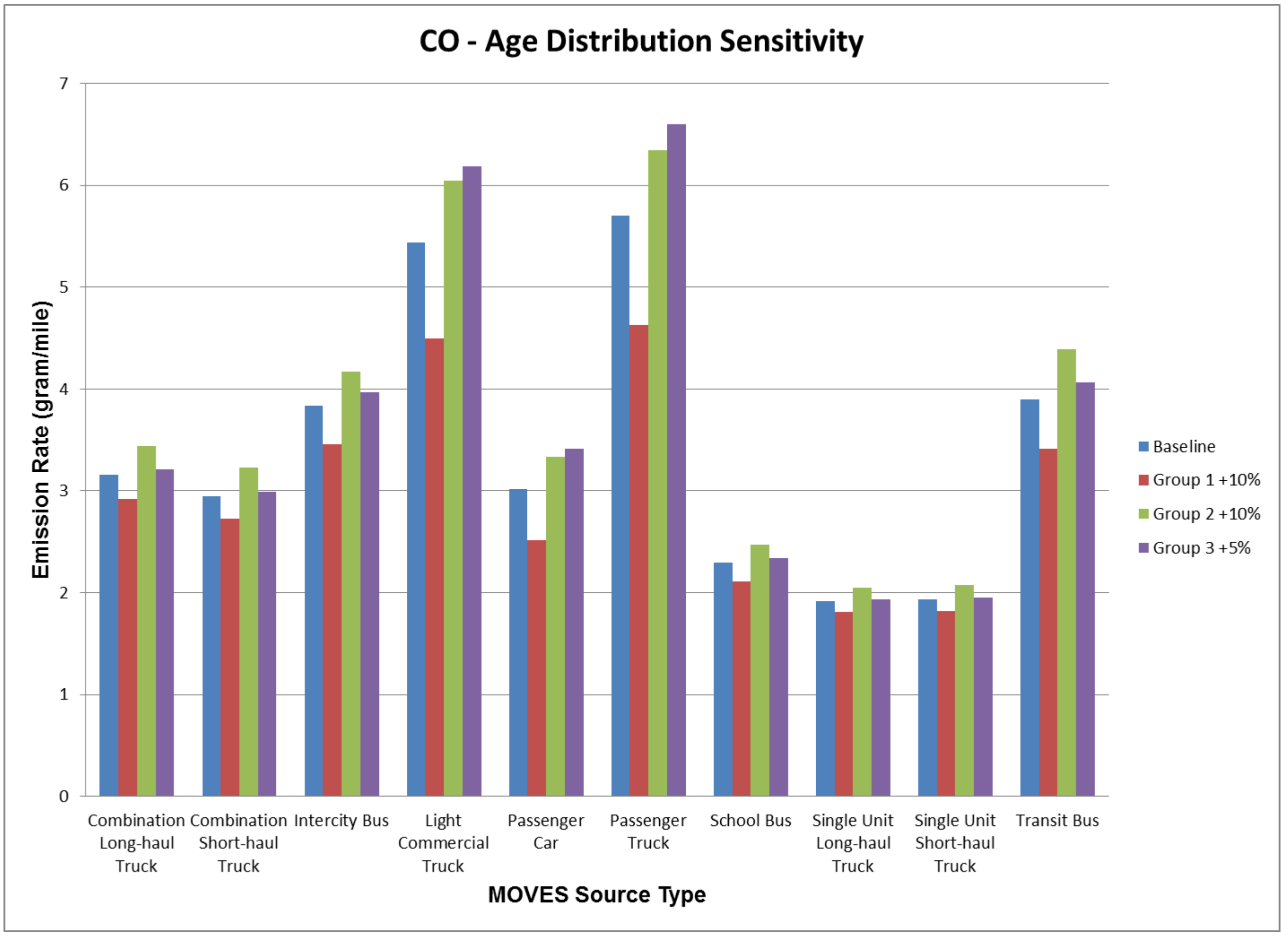


Table E-55. Passenger Car, Passenger Truck, and Light Commercial Truck CO Age Distribution Sensitivity

Age Distribution	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	3.016	0%	5.699	0%	5.441	0%
Group 1 +10% (0-10 years)	2.513	-16.7%	4.624	-18.9%	4.496	-17.4%
Group 2 +10% (11-20 years)	3.332	10.5%	6.342	11.3%	6.045	11.1%
Group 3 +5% (21-30 years)	3.416	13.3%	6.602	15.8%	6.186	13.7%

Table E-56. Bus CO Age Distribution Sensitivity

Age Distribution	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	3.834	0%	3.901	0%	2.294	0%
Group 1 +10% (0-10 years)	3.458	-9.8%	3.413	-12.5%	2.113	-7.9%
Group 2 +10% (11-20 years)	4.171	8.8%	4.391	12.6%	2.475	7.9%
Group 3 +5% (21-30 years)	3.969	3.5%	4.069	4.3%	2.339	2.0%

Table E-57. Single Unit and Combination Truck CO Age Distribution Sensitivity

Age Distribution	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	1.931	0%	1.919	0%	2.948	0%	3.156	0%
Group 1 +10% (0-10 years)	1.818	-5.8%	1.814	-5.5%	2.725	-7.6%	2.920	-7.5%
Group 2 +10% (11-20 years)	2.076	7.5%	2.044	6.5%	3.232	9.7%	3.438	8.9%
Group 3 +5% (21-30 years)	1.948	0.9%	1.937	1.0%	2.994	1.6%	3.207	1.6%

Oxides of Nitrogen (NOX) – Running Exhaust

Figure E-24. NO_X Age Distribution Sensitivity

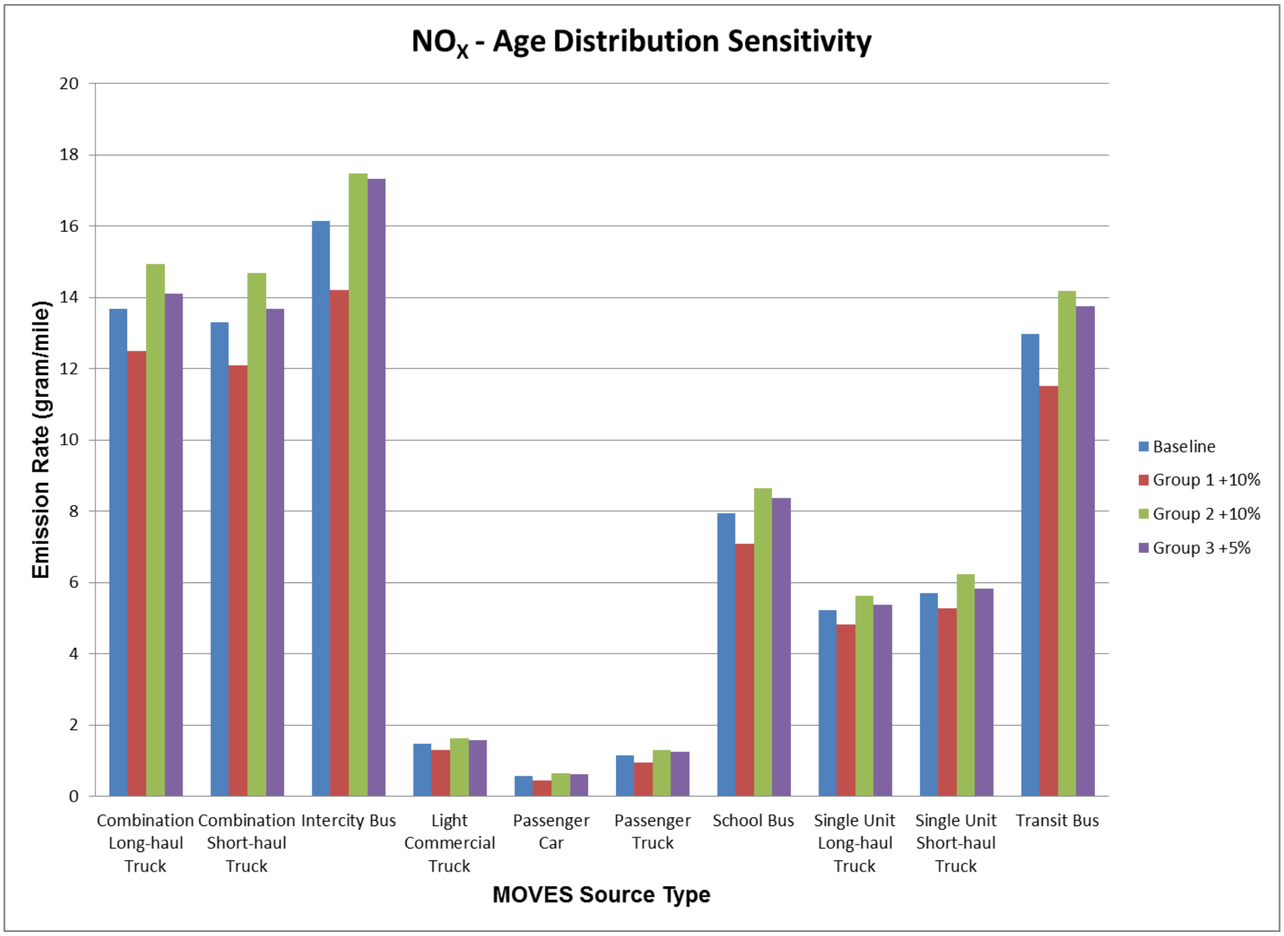


Table E-58. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Age Distribution Sensitivity

Age Distribution	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.561	0%	1.137	0%	1.477	0%
Group 1 +10% (0-10 years)	0.451	-19.6%	0.942	-17.2%	1.301	-12.0%
Group 2 +10% (11-20 years)	0.653	16.4%	1.295	13.9%	1.621	9.7%
Group 3 +5% (21-30 years)	0.619	10.4%	1.249	9.8%	1.578	6.8%

Table E-59. Bus NO_X Age Distribution Sensitivity

Age Distribution	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	16.131	0%	12.968	0%	7.945	0%
Group 1 +10% (0-10 years)	14.198	-12.0%	11.522	-11.1%	7.085	-10.8%
Group 2 +10% (11-20 years)	17.475	8.3%	14.176	9.3%	8.653	8.9%
Group 3 +5% (21-30 years)	17.327	7.4%	13.761	6.1%	8.360	5.2%

Table E-60. Single Unit and Combination Truck NO_X Age Distribution Sensitivity

Age Distribution	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	5.708	0%	5.220	0%	13.291	0%	13.673	0%
Group 1 +10% (0-10 years)	5.274	-7.6%	4.830	-7.5%	12.098	-9.0%	12.490	-8.7%
Group 2 +10% (11-20 years)	6.226	9.1%	5.624	7.7%	14.691	10.5%	14.936	9.2%
Group 3 +5% (21-30 years)	5.832	2.2%	5.369	2.9%	13.688	3.0%	14.111	3.2%

Particulate Matter (PM2.5) – Running Exhaust

Figure E-25. $PM_{2.5}$ Age Distribution Sensitivity

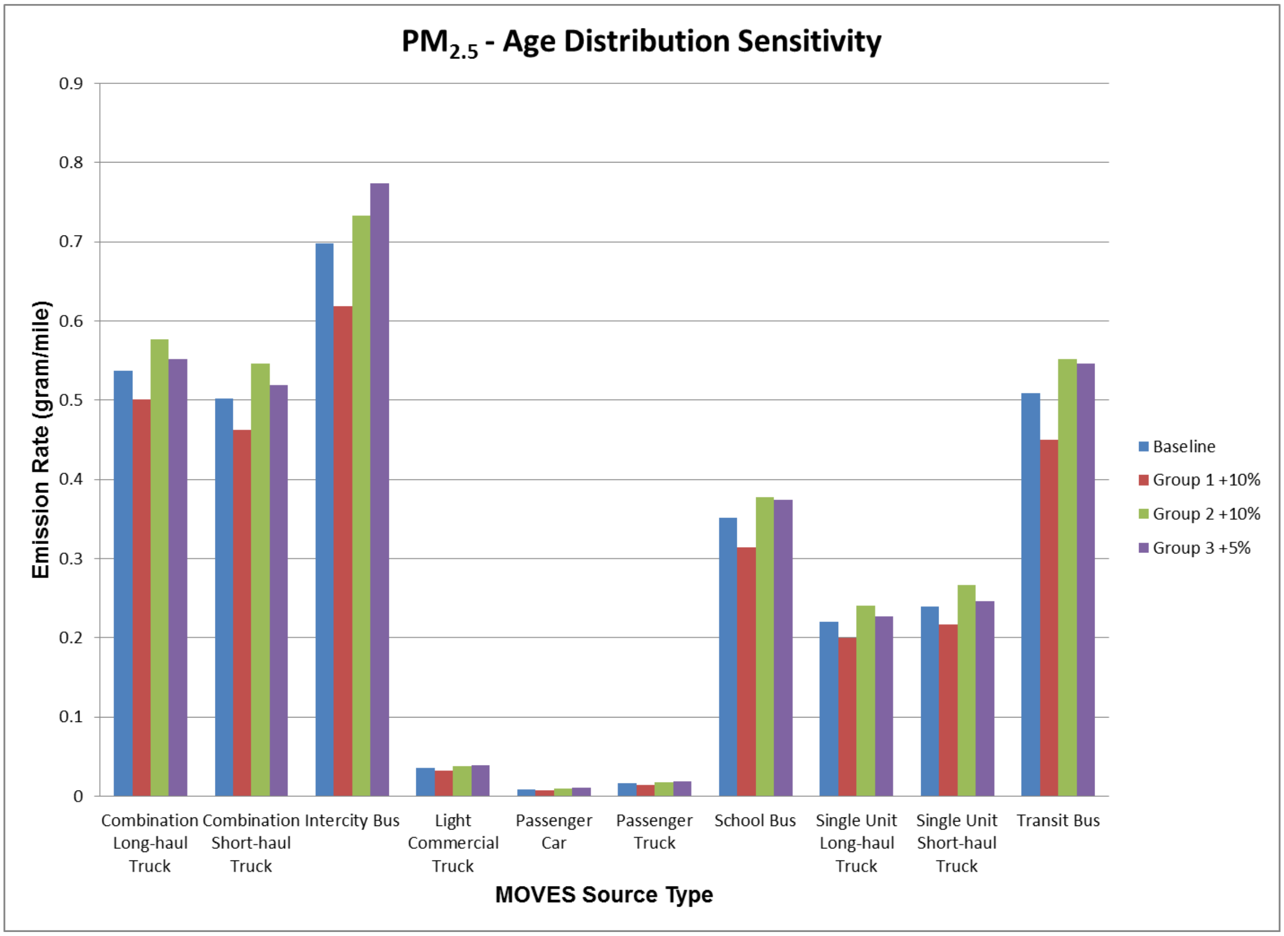


Table E-61. Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Age Distribution Sensitivity

Age Distribution	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.009	0%	0.016	0%	0.036	0%
Group 1 +10% (0-10 years)	0.007	-19.2%	0.014	-14.7%	0.032	-11.1%
Group 2 +10% (11-20 years)	0.009	7.8%	0.018	8.5%	0.039	7.5%
Group 3 +5% (21-30 years)	0.011	20.5%	0.018	12.7%	0.039	8.3%

Table E-62. Bus $PM_{2.5}$ Age Distribution Sensitivity

Age Distribution	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.698	0%	0.509	0%	0.352	0%
Group 1 +10% (0-10 years)	0.618	-11.5%	0.450	-11.4%	0.315	-10.4%
Group 2 +10% (11-20 years)	0.733	5.0%	0.552	8.6%	0.378	7.5%
Group 3 +5% (21-30 years)	0.774	10.9%	0.546	7.5%	0.374	6.4%

Table E-63. Single Unit and Combination Truck $PM_{2.5}$ Age Distribution Sensitivity

Age Distribution	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.240	0%	0.220	0%	0.503	0%	0.538	0%
Group 1 +10% (0-10 years)	0.217	-9.5%	0.200	-9.1%	0.463	-7.9%	0.501	-6.9%
Group 2 +10% (11-20 years)	0.266	11.1%	0.241	9.6%	0.547	8.8%	0.577	7.2%
Group 3 +5% (21-30 years)	0.247	3.0%	0.227	3.2%	0.519	3.3%	0.552	2.7%

Volatile Organic Compounds (VOC) – Running Exhaust

Figure E-26. VOC Age Distribution Sensitivity

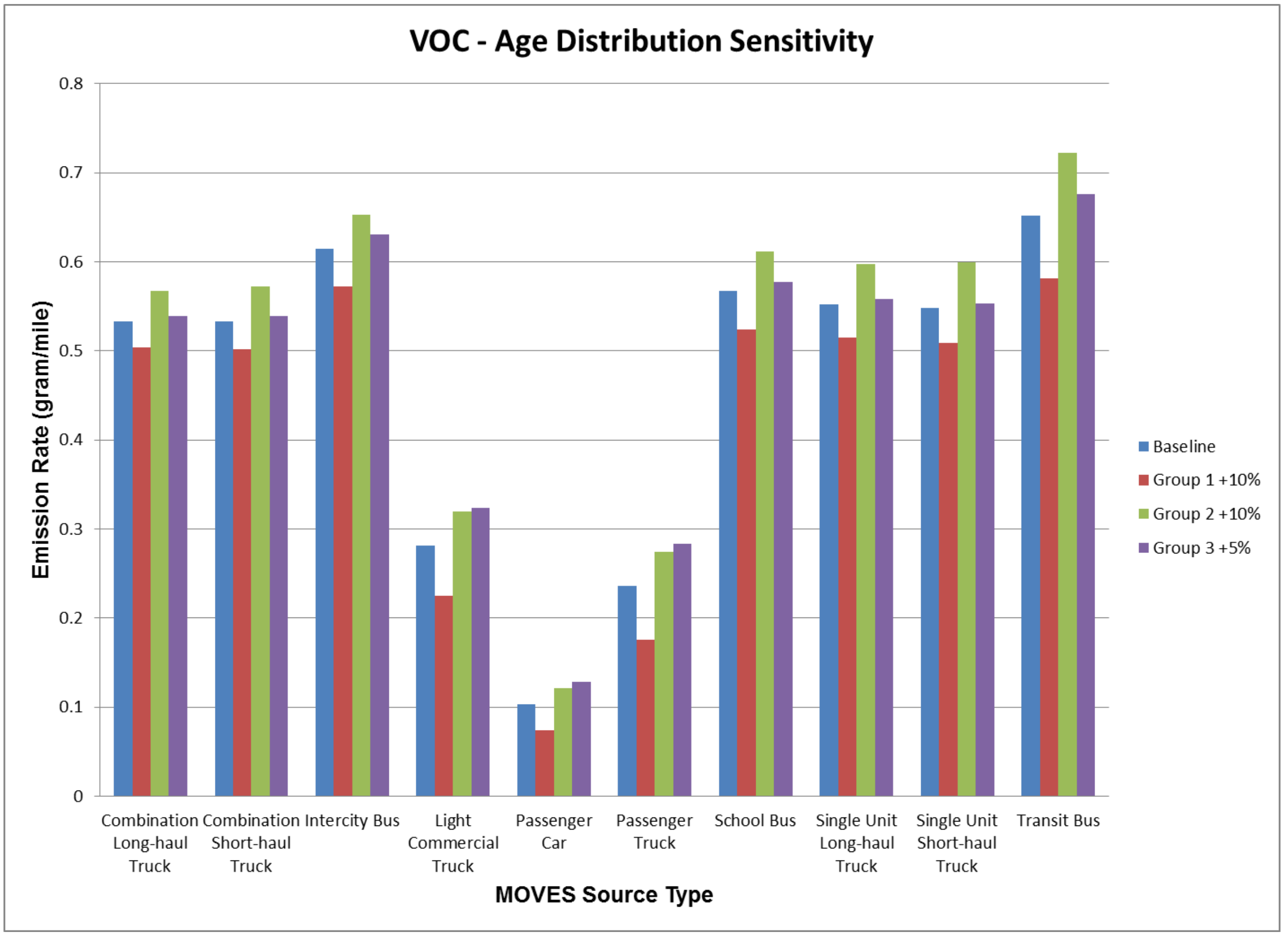


Table E-64. Passenger Car, Passenger Truck, and Light Commercial Truck VOC Age Distribution Sensitivity

Age Distribution	Passenger Car		Passenger Truck		Light Commercial Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.104	0%	0.236	0%	0.281	0%
Group 1 +10% (0-10 years)	0.074	-28.6%	0.176	-25.4%	0.225	-20.0%
Group 2 +10% (11-20 years)	0.121	17.1%	0.274	16.2%	0.319	13.5%
Group 3 +5% (21-30 years)	0.128	23.7%	0.283	20.1%	0.323	14.9%

Table E-65. Bus VOC Age Distribution Sensitivity

Age Distribution	Intercity Bus		Transit Bus		School Bus	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.615	0%	0.652	0%	0.567	0%
Group 1 +10% (0-10 years)	0.573	-6.9%	0.582	-10.8%	0.524	-7.6%
Group 2 +10% (11-20 years)	0.653	6.2%	0.722	10.8%	0.611	7.7%
Group 3 +5% (21-30 years)	0.630	2.5%	0.676	3.7%	0.578	1.8%

Table E-66. Single Unit and Combination Truck VOC Age Distribution Sensitivity

Age Distribution	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	0.548	0%	0.552	0%	0.533	0%	0.533	0%
Group 1 +10% (0-10 years)	0.509	-7.1%	0.515	-6.7%	0.502	-5.8%	0.504	-5.4%
Group 2 +10% (11-20 years)	0.600	9.4%	0.598	8.2%	0.572	7.4%	0.567	6.4%
Group 3 +5% (21-30 years)	0.554	1.0%	0.558	1.0%	0.539	1.3%	0.539	1.2%

Appendix F. Average Speed Distribution Sensitivity Results

Carbon Monoxide (CO) – Running Exhaust

Figure F-27. CO Average Speed Distribution Sensitivity Urban Restricted Access - Interstate

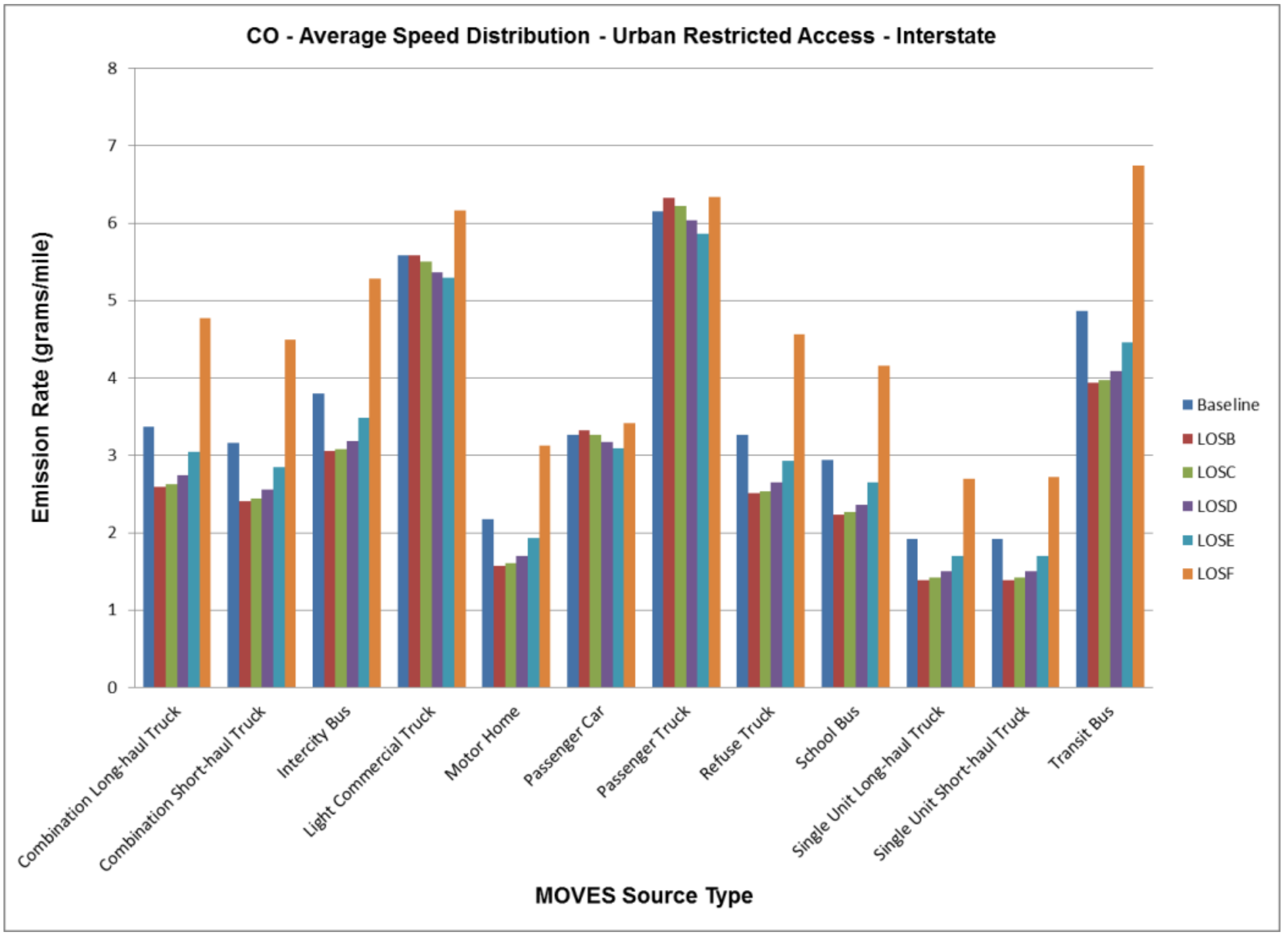


Figure F-28. CO Average Speed Distribution Sensitivity Urban Restricted Access – Principal Arterial Freeway

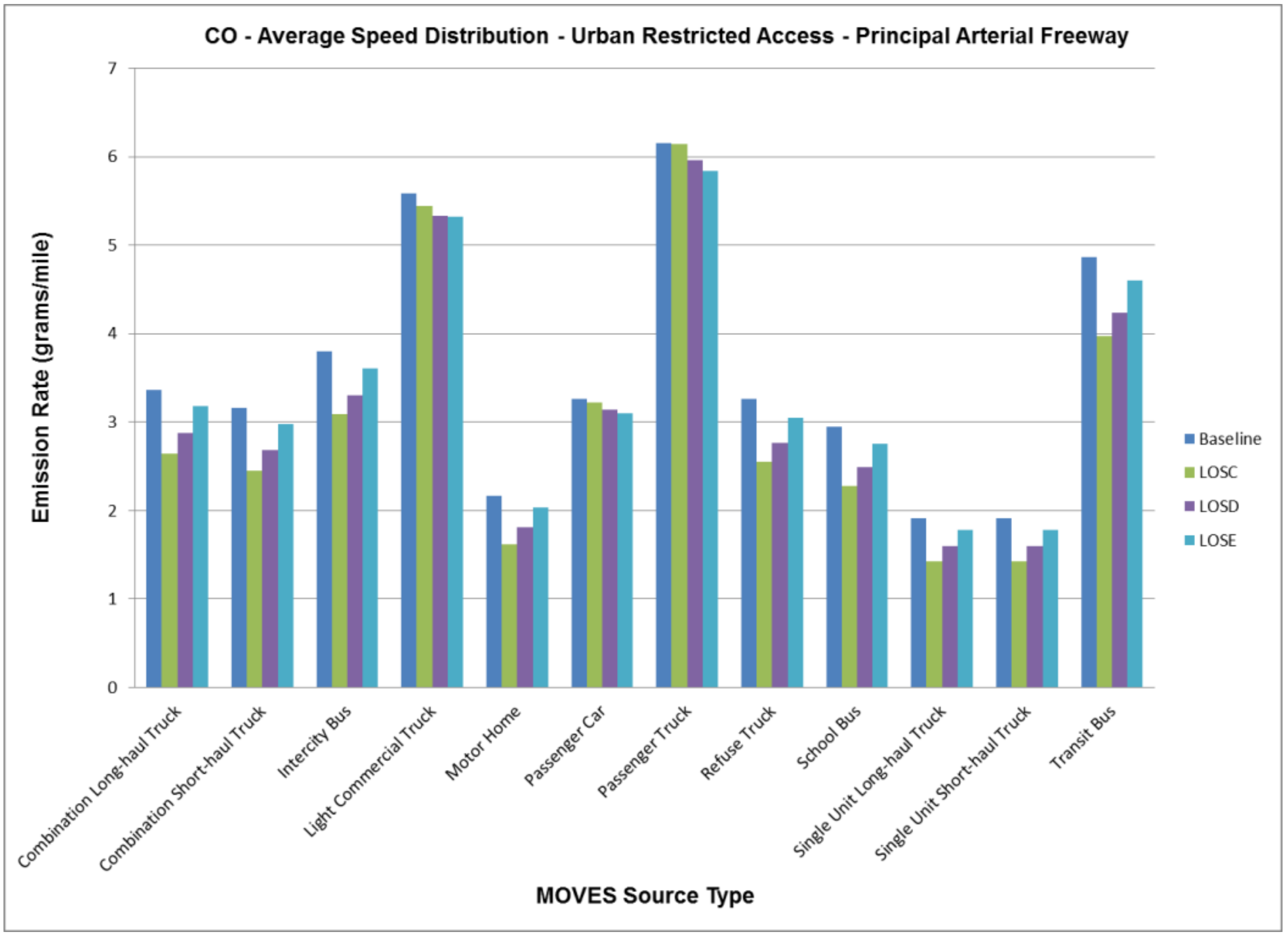


Figure F-29. CO Average Speed Distribution Sensitivity Urban Unrestricted Access – Principal Arterial Other

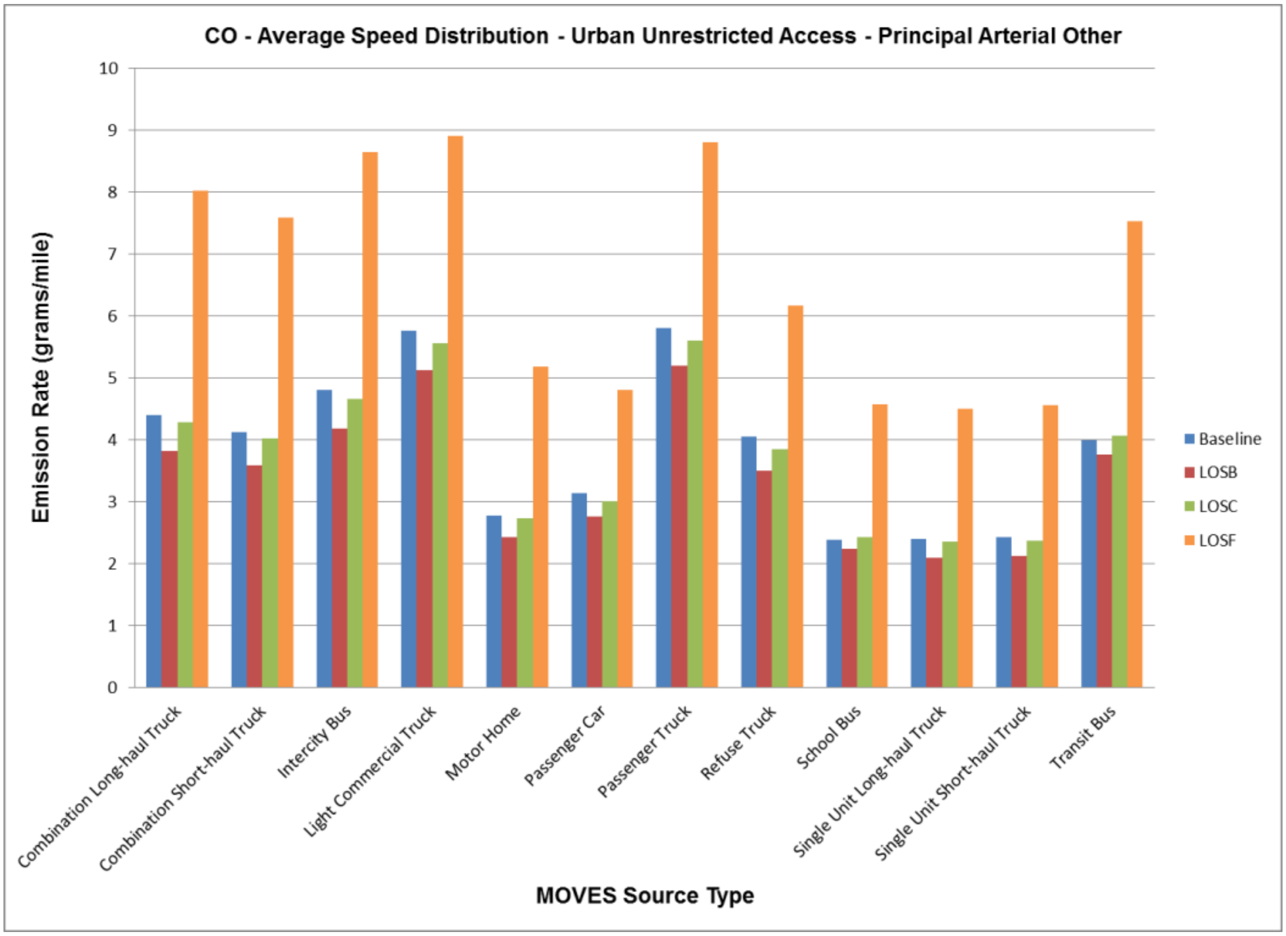


Table F-67. Passenger Car, Passenger Truck, and Light Commercial Truck CO Average Speed Distribution Sensitivity

LOS	Functional Classification	Passenger Car		Passenger Truck		Light Commercial Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	3.2666	-	6.1569	-	5.5812	-
B	Urban Interstate	3.3190	1.60%	6.3256	2.74%	5.5891	0.14%
C	Urban Interstate	3.2677	0.03%	6.2257	1.12%	5.5079	-1.31%
D	Urban Interstate	3.1697	-2.97%	6.0303	-2.06%	5.3676	-3.83%
E	Urban Interstate	3.0922	-5.34%	5.8578	-4.86%	5.2963	-5.10%
F	Urban Interstate	3.4154	4.55%	6.3389	2.96%	6.1593	10.36%
C	Principal Urban Arterial -Freeway	3.2233	-1.33%	6.1422	-0.24%	5.4391	-2.54%
D	Principal Urban Arterial -Freeway	3.1408	-3.85%	5.9602	-3.19%	5.3295	-4.51%
E	Principal Urban Arterial -Freeway	3.0957	-5.23%	5.8383	-5.17%	5.3171	-4.73%
Baseline	Principal Urban Arterial - Other	3.1326	-	5.8018	-	5.7634	-
B	Principal Urban Arterial - Other	2.7593	-11.92%	5.1945	-10.47%	5.1241	-11.09%
C	Principal Urban Arterial - Other	3.0027	-4.15%	5.5966	-3.54%	5.5535	-3.64%
F	Principal Urban Arterial - Other	4.8000	53.23%	8.8009	51.69%	8.9038	54.49%

Table F-68. Bus CO Average Speed Distribution Sensitivity

LOS	Functional Classification	Intercity Bus		Transit Bus		School Bus	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	3.803	-	4.865	-	2.945	-
B	Urban Interstate	3.052	-19.74%	3.937	-19.07%	2.228	-24.34%
C	Urban Interstate	3.082	-18.97%	3.970	-18.40%	2.262	-23.17%
D	Urban Interstate	3.182	-16.32%	4.087	-16.00%	2.363	-19.76%
E	Urban Interstate	3.486	-8.34%	4.454	-8.46%	2.645	-10.18%
F	Urban Interstate	5.276	38.74%	6.747	38.67%	4.161	41.32%
C	Principal Urban Arterial -Freeway	3.089	-18.79%	3.974	-18.31%	2.273	-22.81%
D	Principal Urban Arterial -Freeway	3.305	-13.09%	4.235	-12.97%	2.489	-15.47%
E	Principal Urban Arterial -Freeway	3.608	-5.13%	4.605	-5.36%	2.753	-6.50%
Baseline	Principal Urban Arterial - Other	4.812	-	3.988	-	2.386	-
B	Principal Urban Arterial - Other	4.176	-13.22%	3.767	-5.53%	2.233	-6.42%
C	Principal Urban Arterial - Other	4.661	-3.13%	4.063	1.88%	2.424	1.56%
F	Principal Urban Arterial - Other	8.648	79.73%	7.526	88.73%	4.575	91.71%

Table F-69. Refuse Truck and Motor Home CO Average Speed Distribution Sensitivity

LOS	Functional Classification	Refuse Truck		Motor Home	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	3.260	-	2.169	-
B	Urban Interstate	2.507	-23.09%	1.575	-27.40%
C	Urban Interstate	2.539	-22.11%	1.607	-25.92%
D	Urban Interstate	2.644	-18.89%	1.698	-21.73%
E	Urban Interstate	2.930	-10.11%	1.932	-10.92%
F	Urban Interstate	4.557	39.80%	3.120	43.86%
C	Principal Urban Arterial -Freeway	2.551	-21.74%	1.617	-25.45%
D	Principal Urban Arterial -Freeway	2.767	-15.13%	1.808	-16.66%
E	Principal Urban Arterial -Freeway	3.044	-6.61%	2.035	-6.17%
Baseline	Principal Urban Arterial - Other	4.056	-	2.778	-
B	Principal Urban Arterial - Other	3.502	-13.67%	2.433	-12.43%
C	Principal Urban Arterial - Other	3.847	-5.15%	2.732	-1.66%
F	Principal Urban Arterial - Other	6.167	52.04%	5.187	86.70%

Table F-70. Single Unit and Combination Truck CO Average Speed Distribution Sensitivity

LOS	Functional Classification	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	1.917	-	1.915	-	3.159	-	3.366	-
B	Urban Interstate	1.388	-27.57%	1.387	-27.56%	2.408	-23.79%	2.597	-22.83%
C	Urban Interstate	1.418	-26.03%	1.417	-25.99%	2.442	-22.70%	2.631	-21.83%
D	Urban Interstate	1.497	-21.91%	1.496	-21.88%	2.553	-19.19%	2.743	-18.49%
E	Urban Interstate	1.704	-11.09%	1.702	-11.11%	2.851	-9.76%	3.048	-9.43%
F	Urban Interstate	2.717	41.77%	2.692	40.55%	4.491	42.15%	4.767	41.63%
C	Principal Urban Arterial -Freeway	1.428	-25.49%	1.428	-25.43%	2.454	-22.31%	2.642	-21.48%
D	Principal Urban Arterial -Freeway	1.595	-16.79%	1.595	-16.74%	2.681	-15.14%	2.872	-14.67%
E	Principal Urban Arterial -Freeway	1.785	-6.89%	1.780	-7.05%	2.977	-5.78%	3.179	-5.55%
Baseline	Principal Urban Arterial - Other	2.420	-	2.393	-	4.129	-	4.396	-
B	Principal Urban Arterial - Other	2.117	-12.53%	2.101	-12.22%	3.587	-13.13%	3.819	-13.13%
C	Principal Urban Arterial - Other	2.376	-1.85%	2.353	-1.67%	4.024	-2.53%	4.281	-2.62%
F	Principal Urban Arterial - Other	4.552	88.05%	4.495	87.83%	7.585	83.72%	8.026	82.56%

Oxides of Nitrogen (NOX) – Running Exhaust

Figure F-30. NO_X Average Speed Distribution Sensitivity Urban Restricted Access - Interstate

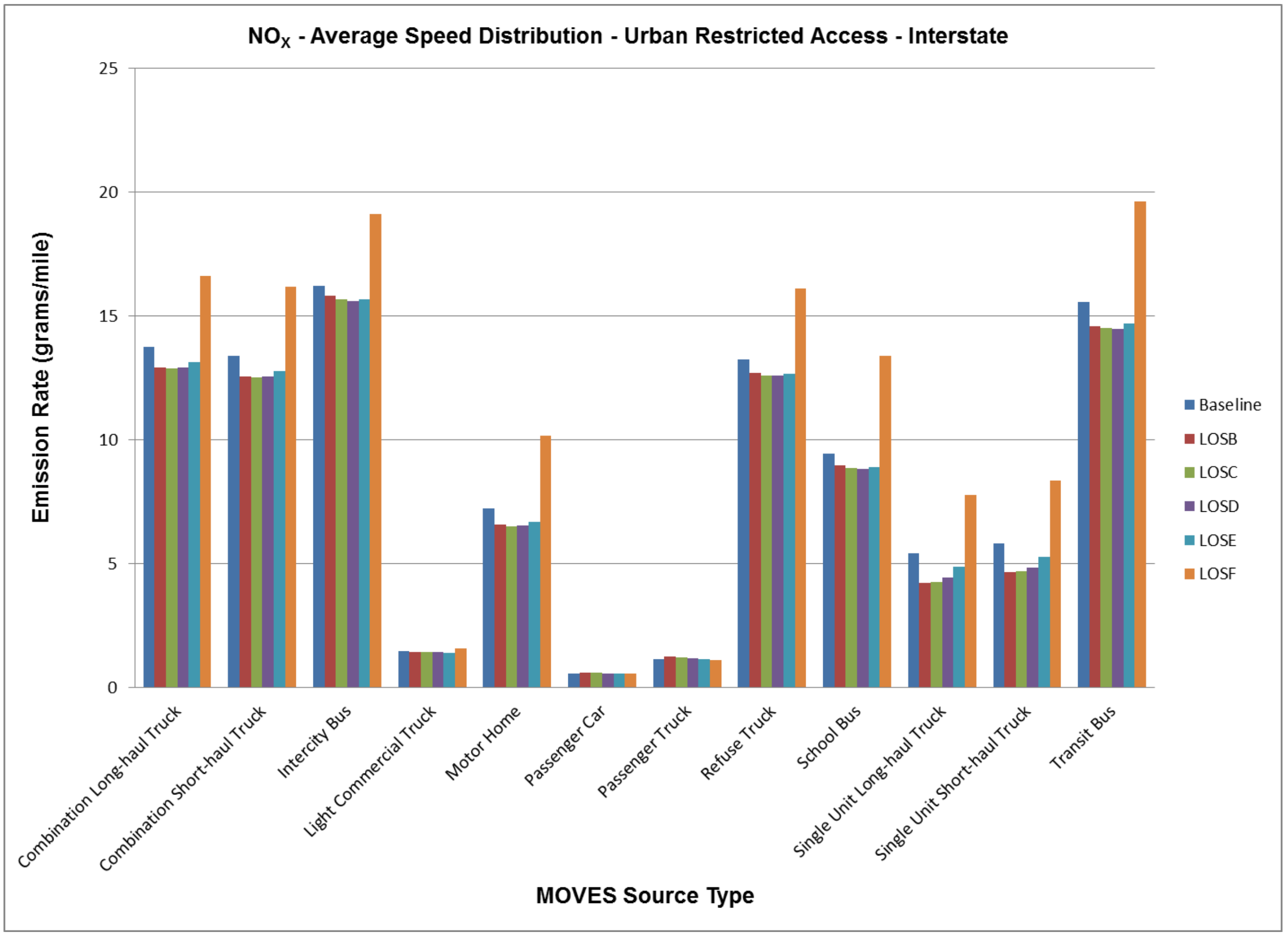


Figure F-31. NO_X Average Speed Distribution Sensitivity Urban Restricted Access – Principal Arterial Freeway

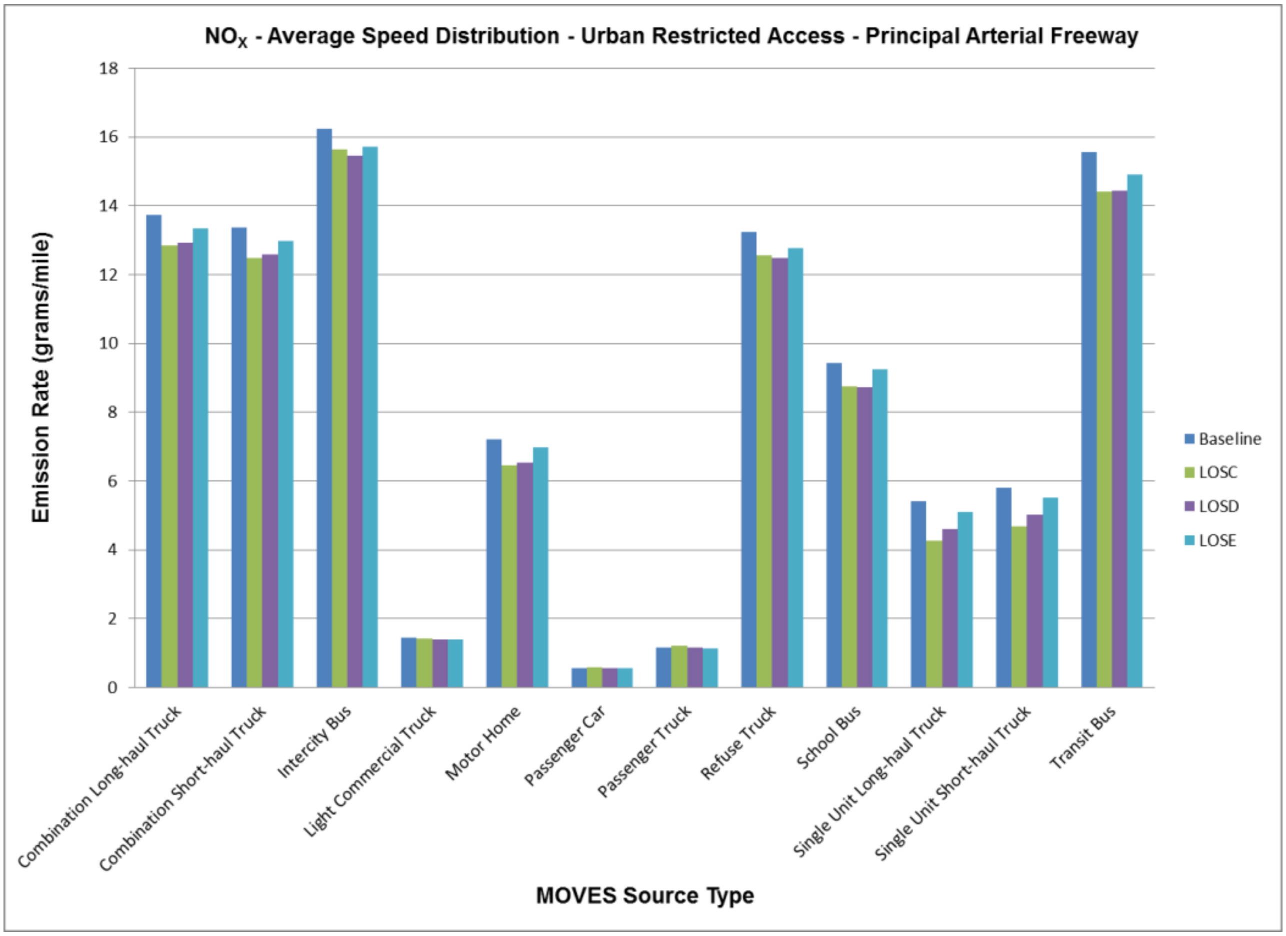


Figure F-32. NO_X Average Speed Distribution Sensitivity Urban Unrestricted Access – Principal Arterial Other

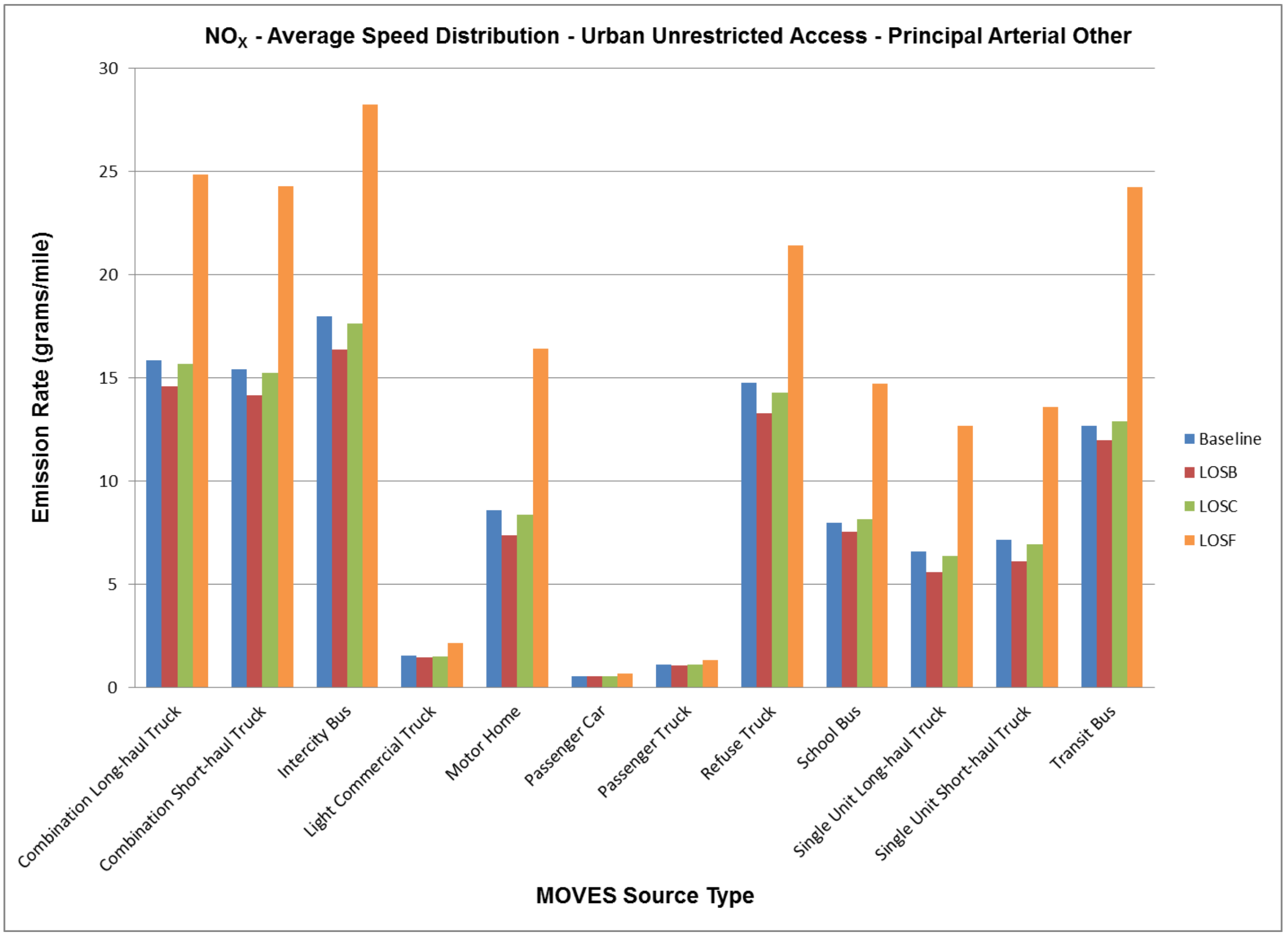


Table F-71. Passenger Car, Passenger Truck, and Light Commercial Truck NO_X Average Speed Distribution Sensitivity

LOS	Functional Classification	Passenger Car		Passenger Truck		Light Commercial Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.5632	-	1.1536	-	1.4484	-
B	Urban Interstate	0.5970	6.01%	1.2348	7.04%	1.4458	-0.18%
C	Urban Interstate	0.5902	4.80%	1.2205	5.80%	1.4340	-0.99%
D	Urban Interstate	0.5761	2.30%	1.1908	3.23%	1.4155	-2.27%
E	Urban Interstate	0.5562	-1.25%	1.1431	-0.91%	1.4043	-3.04%
F	Urban Interstate	0.5578	-0.96%	1.1145	-3.39%	1.5897	9.76%
C	Principal Urban Arterial -Freeway	0.5851	3.90%	1.2112	4.99%	1.4253	-1.59%
D	Principal Urban Arterial -Freeway	0.5661	0.52%	1.1658	1.06%	1.4049	-3.00%
E	Principal Urban Arterial -Freeway	0.5517	-2.05%	1.1274	-2.27%	1.4027	-3.15%
Baseline	Principal Urban Arterial - Other	0.5626	-	1.1124	-	1.5456	-
B	Principal Urban Arterial - Other	0.5347	-4.96%	1.0783	-3.07%	1.4370	-7.03%
C	Principal Urban Arterial - Other	0.5534	-1.65%	1.1020	-0.94%	1.5157	-1.94%
F	Principal Urban Arterial - Other	0.6753	20.03%	1.3298	19.54%	2.1688	40.32%

Table F-72. Bus NO_X Average Speed Distribution Sensitivity

		Intercity Bus		Transit Bus		School Bus	
LOS	**Functional Classification**	**Emission Rate (gram/mile)**	**% difference**	**Emission Rate (gram/mile)**	**% difference**	**Emission Rate (gram/mile)**	**% difference**
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	16.233	-	15.563	-	9.430	-
B	Urban Interstate	15.805	-2.64%	14.597	-6.20%	8.981	-4.77%
C	Urban Interstate	15.691	-3.34%	14.504	-6.80%	8.864	-6.01%
D	Urban Interstate	15.608	-3.85%	14.476	-6.98%	8.817	-6.50%
E	Urban Interstate	15.673	-3.45%	14.693	-5.59%	8.889	-5.74%
F	Urban Interstate	19.125	17.82%	19.620	26.07%	13.396	42.05%
C	Principal Urban Arterial -Freeway	15.639	-3.66%	14.424	-7.32%	8.753	-7.18%
D	Principal Urban Arterial -Freeway	15.459	-4.77%	14.435	-7.25%	8.725	-7.48%
E	Principal Urban Arterial -Freeway	15.725	-3.13%	14.921	-4.13%	9.252	-1.89%
Baseline	Principal Urban Arterial - Other	17.970	-	12.689	-	7.965	-
B	Principal Urban Arterial - Other	16.391	-8.78%	11.998	-5.45%	7.552	-5.18%
C	Principal Urban Arterial - Other	17.637	-1.85%	12.891	1.59%	8.154	2.38%
F	Principal Urban Arterial - Other	28.254	57.23%	24.241	91.04%	14.714	84.73%

Table F-73. Refuse Truck and Motor Home NO_X Average Speed Distribution Sensitivity

LOS	Functional Classification	Refuse Truck Emission Rate (gram/mile)	Refuse Truck % difference	Motor Home Emission Rate (gram/mile)	Motor Home % difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	13.248	-	7.224	-
B	Urban Interstate	12.699	-4.14%	6.566	-9.11%
C	Urban Interstate	12.606	-4.84%	6.512	-9.87%
D	Urban Interstate	12.589	-4.97%	6.531	-9.59%
E	Urban Interstate	12.664	-4.41%	6.689	-7.41%
F	Urban Interstate	16.122	21.69%	10.151	40.51%
C	Principal Urban Arterial -Freeway	12.569	-5.12%	6.446	-10.77%
D	Principal Urban Arterial -Freeway	12.472	-5.86%	6.540	-9.47%
E	Principal Urban Arterial -Freeway	12.780	-3.53%	6.971	-3.50%
Baseline	Principal Urban Arterial - Other	14.749	-	8.596	-
B	Principal Urban Arterial - Other	13.301	-9.81%	7.383	-14.11%
C	Principal Urban Arterial - Other	14.270	-3.24%	8.379	-2.52%
F	Principal Urban Arterial - Other	21.412	45.18%	16.406	90.86%

Table F-74. Single Unit and Combination Truck NO_X Average Speed Distribution Sensitivity

LOS	Functional Classification	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	5.810	-	5.408	-	13.378	-	13.743	-
B	Urban Interstate	4.671	-19.59%	4.225	-21.88%	12.546	-6.21%	12.905	-6.09%
C	Urban Interstate	4.699	-19.11%	4.264	-21.16%	12.517	-6.43%	12.874	-6.32%
D	Urban Interstate	4.845	-16.61%	4.422	-18.23%	12.571	-6.03%	12.928	-5.93%
E	Urban Interstate	5.265	-9.38%	4.868	-9.98%	12.764	-4.59%	13.135	-4.43%
F	Urban Interstate	8.350	43.72%	7.758	43.45%	16.196	21.07%	16.614	20.89%
C	Principal Urban Arterial -Freeway	4.691	-19.25%	4.268	-21.08%	12.483	-6.69%	12.842	-6.56%
D	Principal Urban Arterial -Freeway	5.017	-13.65%	4.611	-14.74%	12.577	-5.98%	12.932	-5.90%
E	Principal Urban Arterial -Freeway	5.521	-4.97%	5.094	-5.80%	12.985	-2.94%	13.351	-2.85%
Baseline	Principal Urban Arterial - Other	7.165	-	6.578	-	15.411	-	15.866	-
B	Principal Urban Arterial - Other	6.105	-14.79%	5.580	-15.17%	14.163	-8.10%	14.589	-8.05%
C	Principal Urban Arterial - Other	6.946	-3.05%	6.369	-3.18%	15.233	-1.15%	15.682	-1.16%
F	Principal Urban Arterial - Other	13.593	89.72%	12.679	92.77%	24.274	57.52%	24.861	56.69%

Particulate Matter (PM2.5) – Running Exhaust

Figure F-33. $PM_{2.5}$ Average Speed Distribution Sensitivity Urban Restricted Access - Interstate

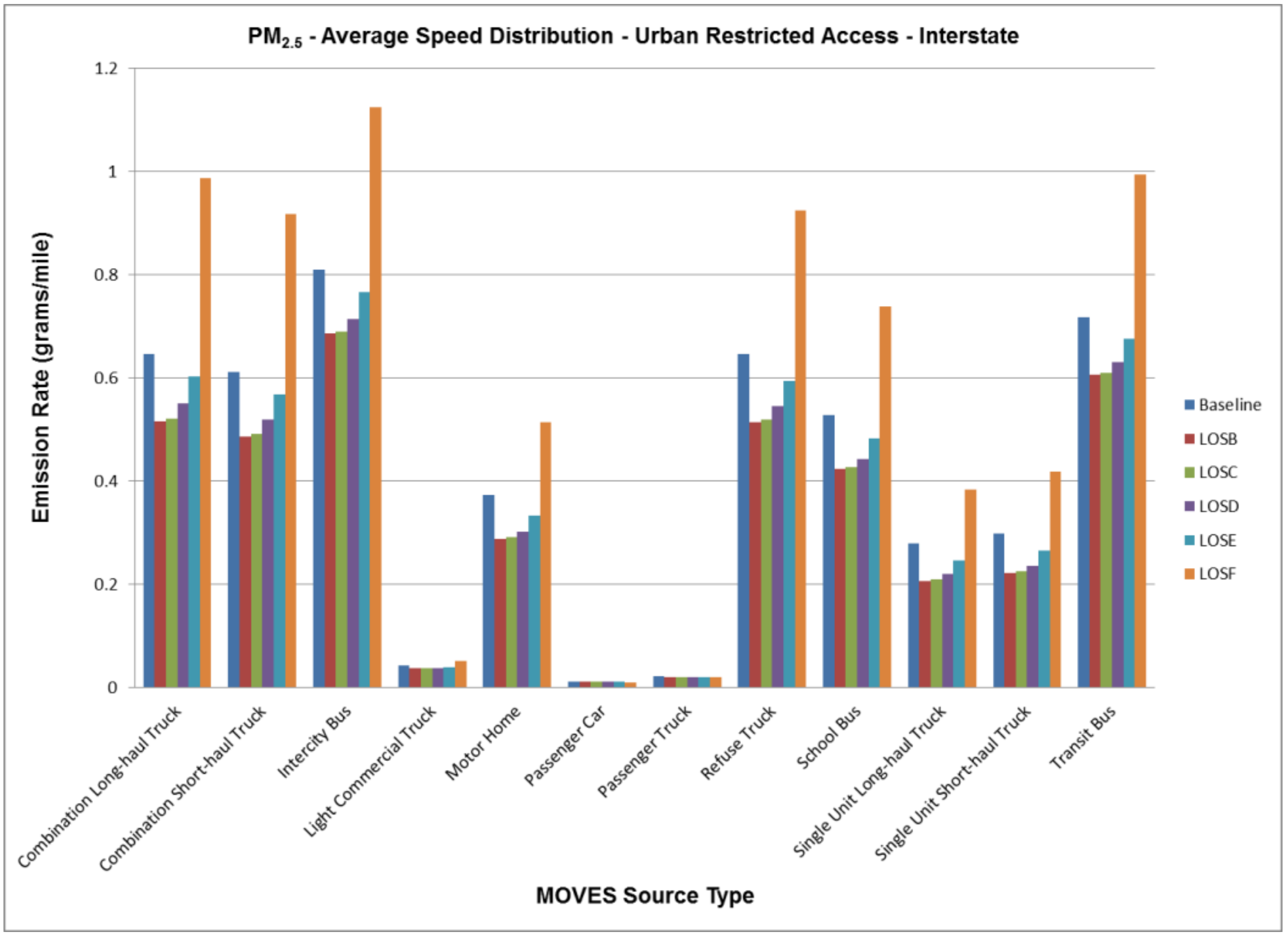


Figure F-34. $PM_{2.5}$ Average Speed Distribution Sensitivity Urban Restricted Access – Principal Arterial Freeway

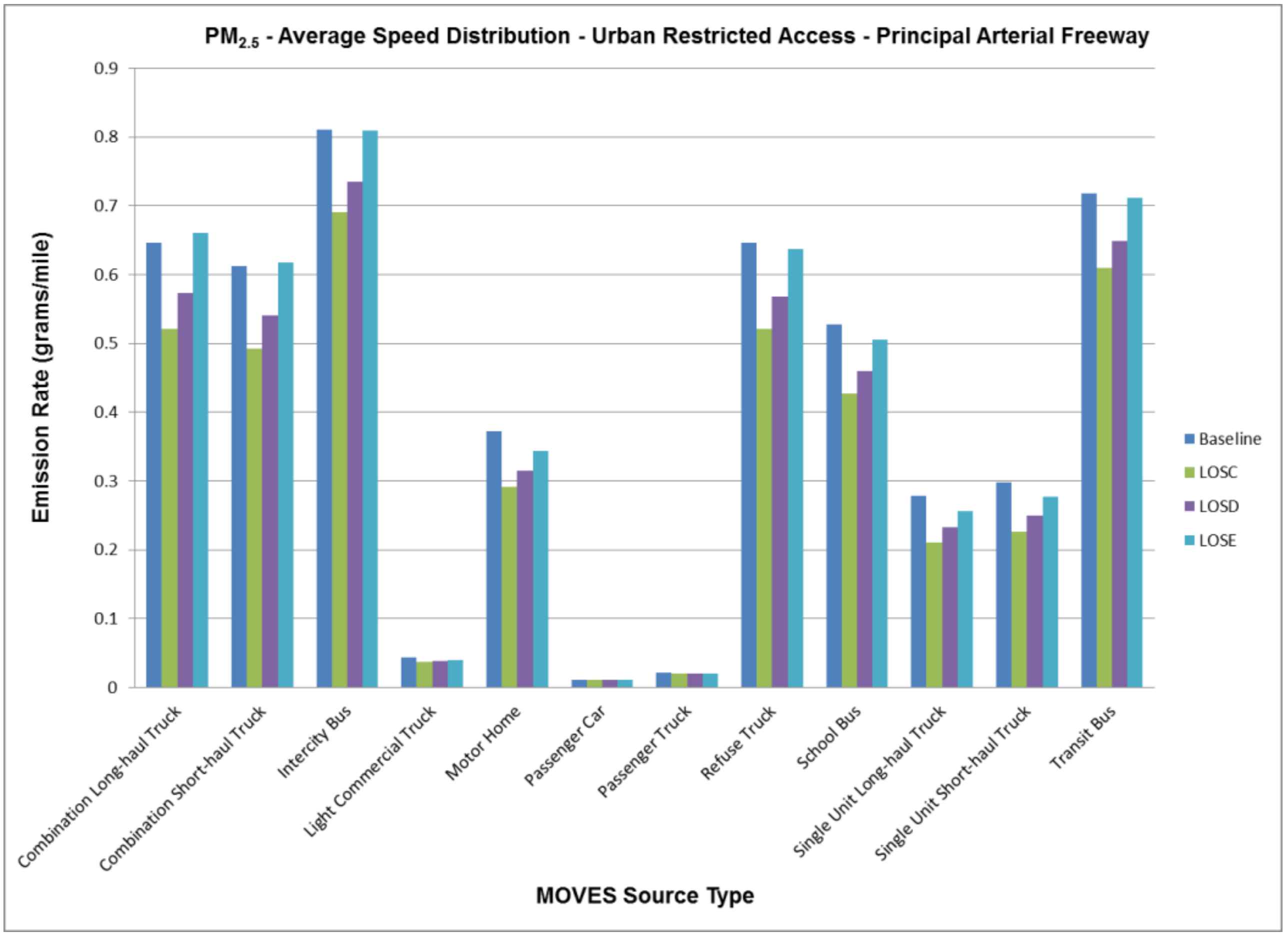


Figure F-35. $PM_{2.5}$ Average Speed Distribution Sensitivity Urban Unrestricted Access – Principal Arterial Other

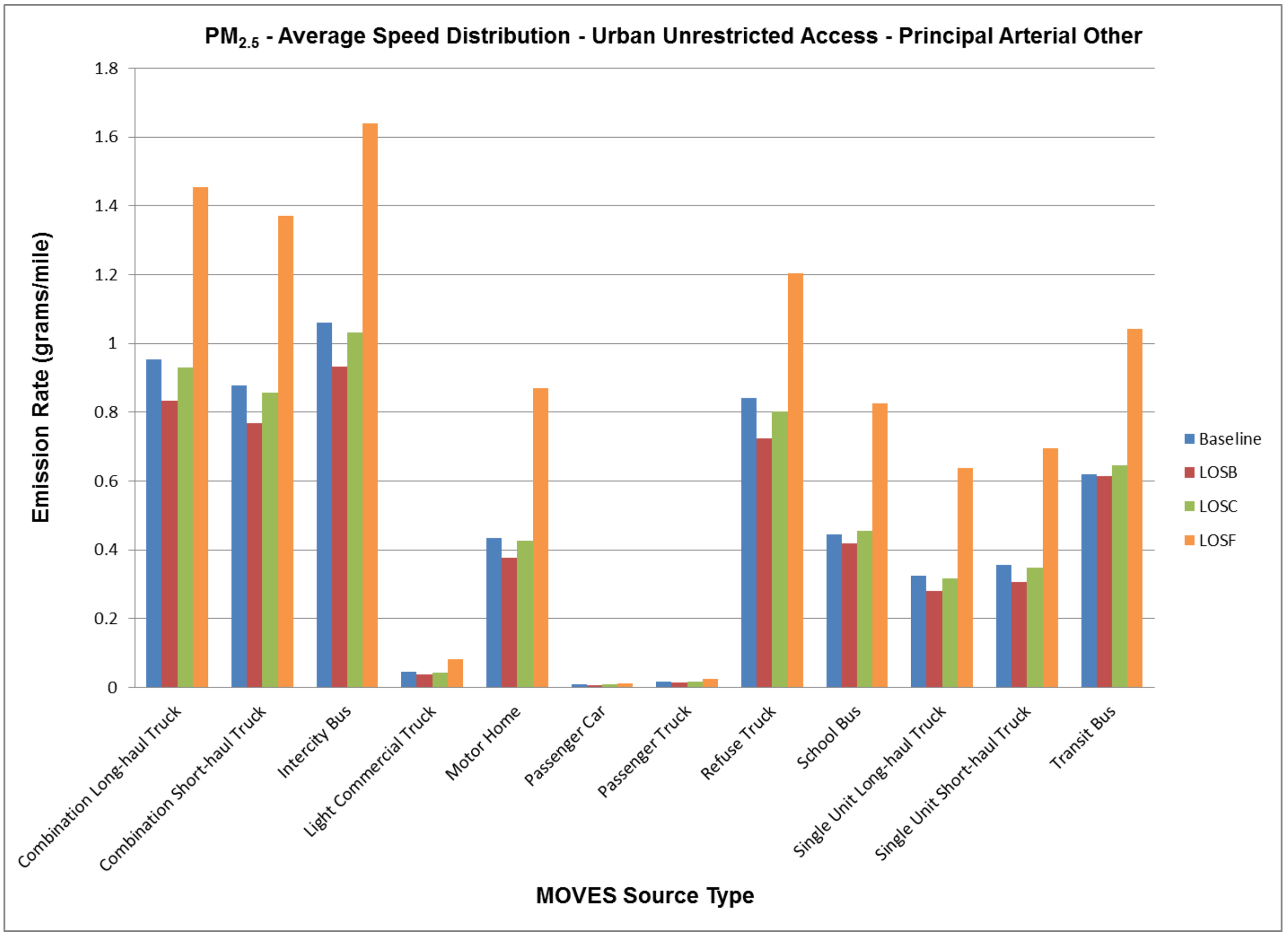


Table F-75. Passenger Car, Passenger Truck, and Light Commercial Truck $PM_{2.5}$ Average Speed Distribution Sensitivity

LOS	Functional Classification	Passenger Car		Passenger Truck		Light Commercial Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.0115	-	0.0217	-	0.0431	-
B	Urban Interstate	0.0108	-6.46%	0.0203	-6.21%	0.0374	-13.14%
C	Urban Interstate	0.0109	-5.85%	0.0204	-5.68%	0.0375	-12.91%
D	Urban Interstate	0.0108	-6.09%	0.0204	-6.05%	0.0378	-12.22%
E	Urban Interstate	0.0106	-7.80%	0.0201	-7.39%	0.0393	-8.71%
F	Urban Interstate	0.0096	-16.48%	0.0191	-11.76%	0.0517	20.12%
C	Principal Urban Arterial -Freeway	0.0109	-5.94%	0.0204	-5.87%	0.0374	-13.07%
D	Principal Urban Arterial -Freeway	0.0110	-4.51%	0.0207	-4.68%	0.0386	-10.31%
E	Principal Urban Arterial -Freeway	0.0106	-8.43%	0.0200	-7.93%	0.0398	-7.72%
Baseline	Principal Urban Arterial - Other	0.0083	-	0.0163	-	0.0451	-
B	Principal Urban Arterial - Other	0.0073	-11.57%	0.0144	-11.43%	0.0387	-14.19%
C	Principal Urban Arterial - Other	0.0078	-5.16%	0.0156	-4.54%	0.0433	-4.05%
F	Principal Urban Arterial - Other	0.0118	43.38%	0.0244	49.35%	0.0830	84.13%

Table F-76. Bus $PM_{2.5}$ Average Speed Distribution Sensitivity

LOS	Functional Classification	Intercity Bus		Transit Bus		School Bus	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.811	-	0.718	-	0.527	-
B	Urban Interstate	0.686	-15.37%	0.607	-15.49%	0.423	-19.76%
C	Urban Interstate	0.690	-14.84%	0.610	-14.97%	0.427	-18.99%
D	Urban Interstate	0.713	-11.99%	0.630	-12.27%	0.443	-16.08%
E	Urban Interstate	0.767	-5.40%	0.676	-5.83%	0.483	-8.42%
F	Urban Interstate	1.124	38.73%	0.994	38.44%	0.739	40.12%
C	Principal Urban Arterial -Freeway	0.690	-14.84%	0.610	-15.01%	0.428	-18.90%
D	Principal Urban Arterial -Freeway	0.735	-9.38%	0.649	-9.67%	0.460	-12.78%
E	Principal Urban Arterial -Freeway	0.810	-0.12%	0.712	-0.81%	0.506	-4.11%
Baseline	Principal Urban Arterial - Other	1.061	-	0.620	-	0.445	-
B	Principal Urban Arterial - Other	0.933	-12.12%	0.614	-1.06%	0.420	-5.76%
C	Principal Urban Arterial - Other	1.031	-2.84%	0.647	4.27%	0.455	2.32%
F	Principal Urban Arterial - Other	1.639	54.41%	1.043	68.14%	0.825	85.36%

Table F-77. Refuse Truck and Motor Home $PM_{2.5}$ Average Speed Distribution Sensitivity

LOS	Functional Classification	Refuse Truck Emission Rate (gram/mile)	Refuse Truck % difference	Motor Home Emission Rate (gram/mile)	Motor Home % difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.646	-	0.373	-
B	Urban Interstate	0.514	-20.53%	0.288	-22.84%
C	Urban Interstate	0.520	-19.59%	0.291	-21.89%
D	Urban Interstate	0.545	-15.73%	0.301	-19.12%
E	Urban Interstate	0.595	-8.00%	0.332	-10.87%
F	Urban Interstate	0.925	43.15%	0.514	37.92%
C	Principal Urban Arterial -Freeway	0.521	-19.43%	0.292	-21.71%
D	Principal Urban Arterial -Freeway	0.568	-12.19%	0.315	-15.38%
E	Principal Urban Arterial -Freeway	0.637	-1.43%	0.344	-7.69%
Baseline	Principal Urban Arterial - Other	0.840	-	0.435	-
B	Principal Urban Arterial - Other	0.725	-13.73%	0.378	-13.25%
C	Principal Urban Arterial - Other	0.803	-4.41%	0.427	-2.02%
F	Principal Urban Arterial - Other	1.204	43.28%	0.870	99.77%

Table F-78. Single Unit and Combination Truck $PM_{2.5}$ Average Speed Distribution Sensitivity

LOS	Functional Classification	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.298	-	0.278	-	0.612	-	0.647	-
B	Urban Interstate	0.221	-25.80%	0.206	-26.00%	0.487	-20.50%	0.516	-20.23%
C	Urban Interstate	0.225	-24.46%	0.210	-24.61%	0.492	-19.60%	0.521	-19.40%
D	Urban Interstate	0.236	-20.86%	0.220	-21.06%	0.518	-15.30%	0.550	-14.90%
E	Urban Interstate	0.265	-11.08%	0.247	-11.35%	0.568	-7.16%	0.603	-6.77%
F	Urban Interstate	0.418	40.10%	0.383	37.59%	0.917	49.85%	0.987	52.68%
C	Principal Urban Arterial -Freeway	0.227	-24.08%	0.211	-24.15%	0.492	-19.56%	0.521	-19.41%
D	Principal Urban Arterial -Freeway	0.250	-16.21%	0.233	-16.38%	0.540	-11.73%	0.573	-11.39%
E	Principal Urban Arterial -Freeway	0.277	-7.19%	0.256	-7.92%	0.618	1.00%	0.661	2.24%
Baseline	Principal Urban Arterial - Other	0.357	-	0.324	-	0.878	-	0.954	-
B	Principal Urban Arterial - Other	0.307	-14.17%	0.279	-13.89%	0.768	-12.53%	0.833	-12.72%
C	Principal Urban Arterial - Other	0.348	-2.64%	0.316	-2.44%	0.856	-2.41%	0.930	-2.54%
F	Principal Urban Arterial - Other	0.695	94.57%	0.638	96.73%	1.370	56.09%	1.456	52.60%

Volatile Organic Compounds (VOC) – Running Exhaust

Figure F-36. VOC Average Speed Distribution Sensitivity Urban Restricted Access - Interstate

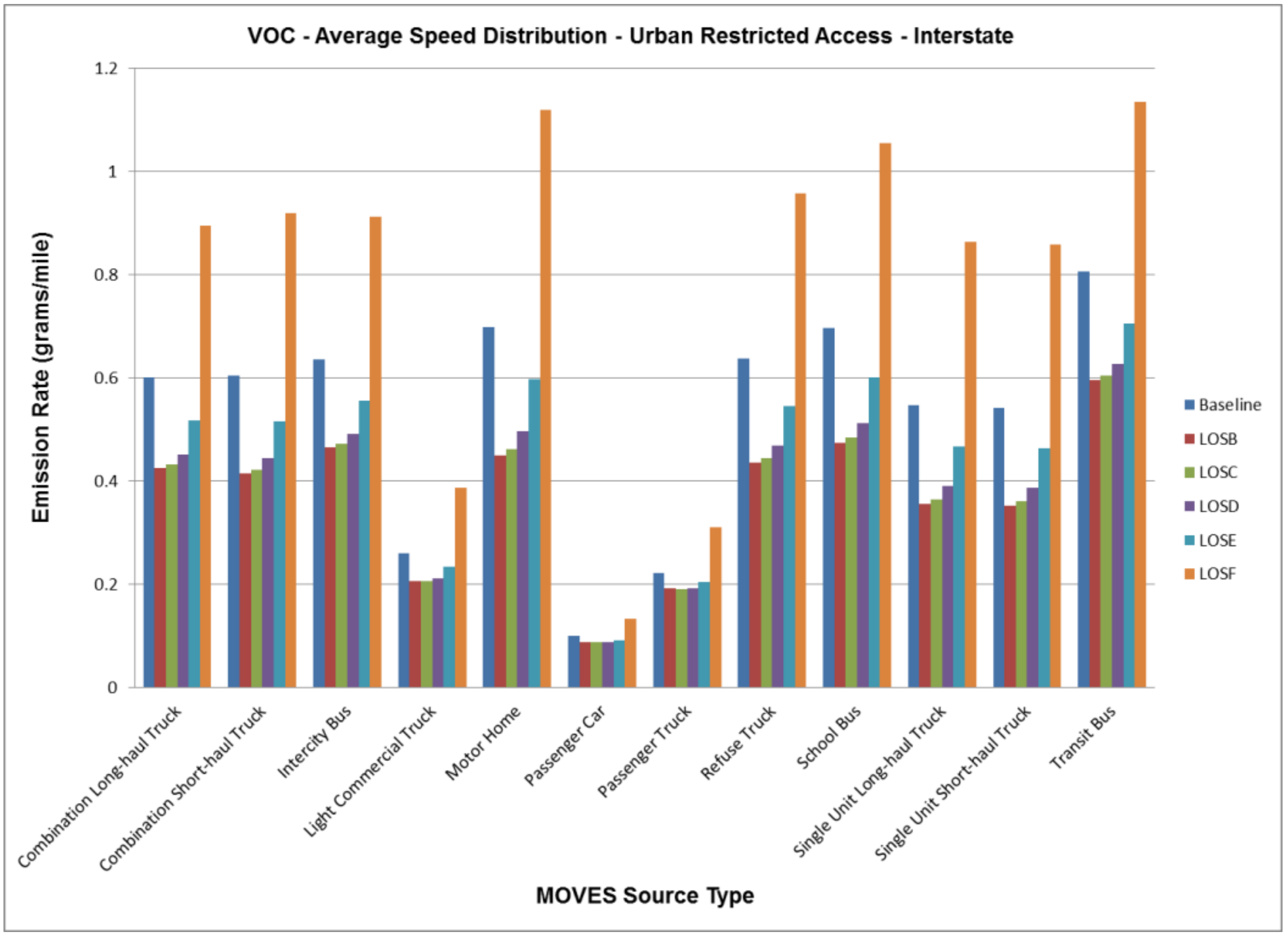


Figure F-37. VOC Average Speed Distribution Sensitivity Urban Restricted Access – Principal Arterial Freeway

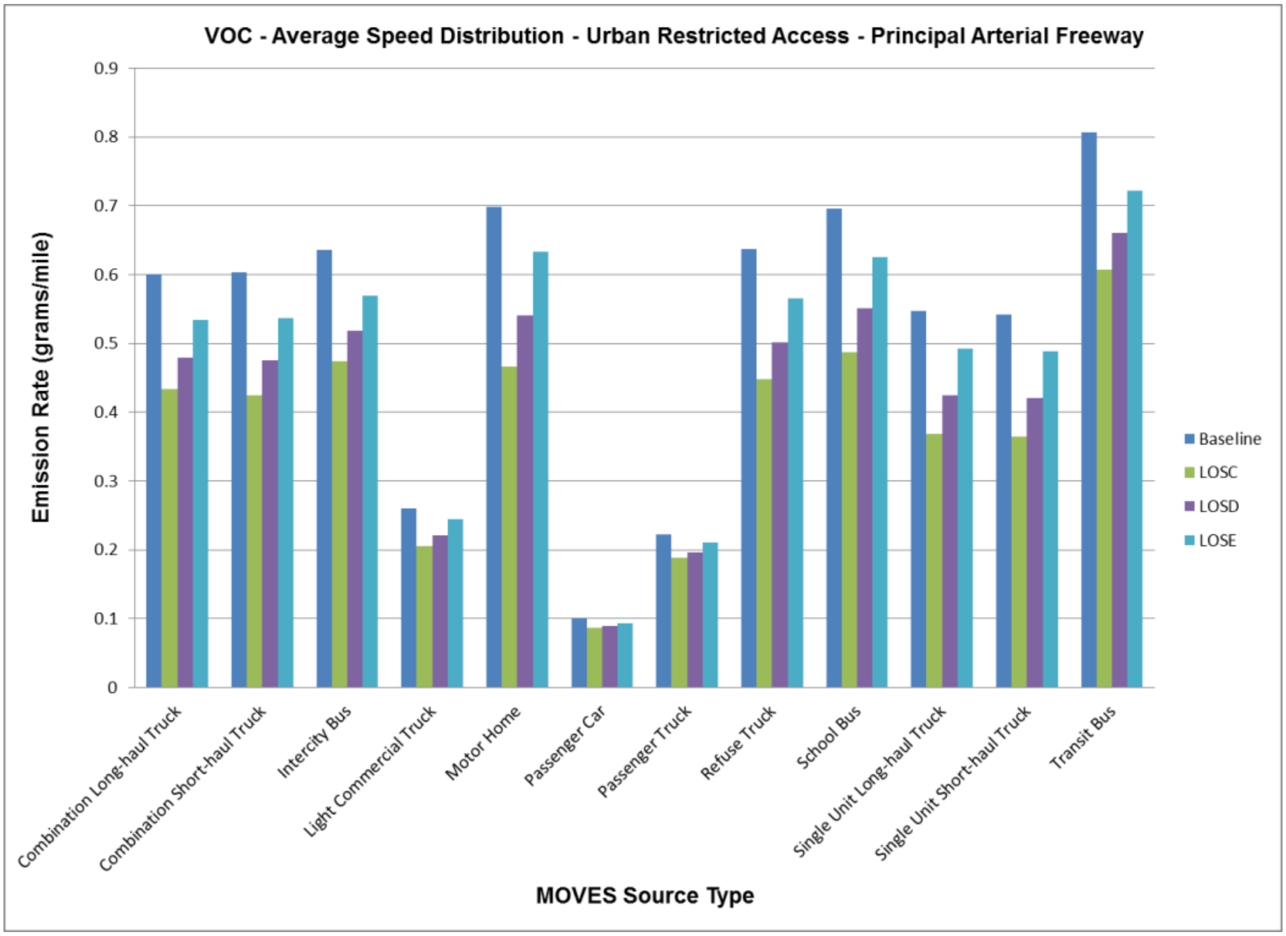


Figure F-38. VOC Average Speed Distribution Sensitivity Urban Unrestricted Access – Principal Arterial Other

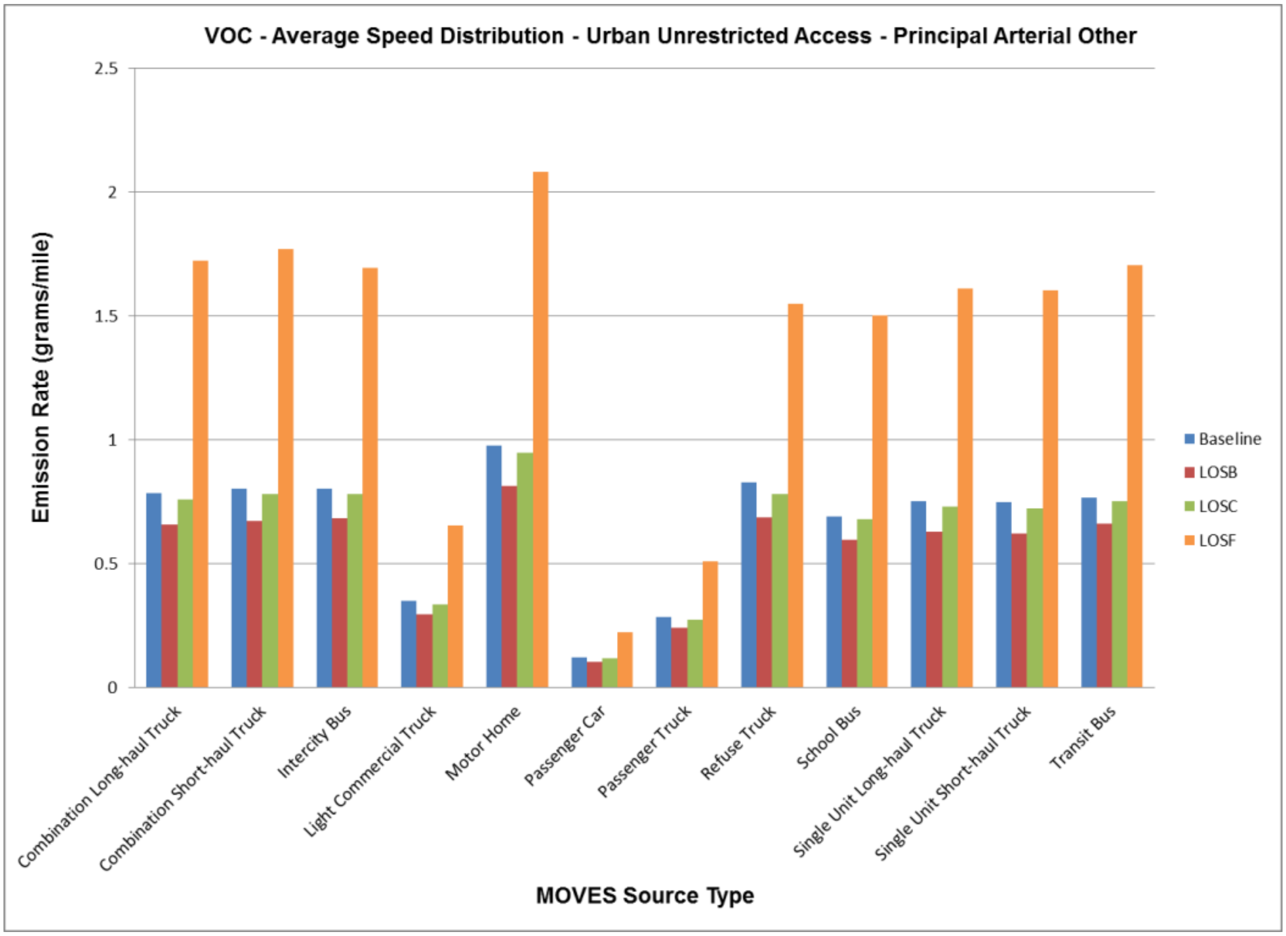


Table F-79. Passenger Car, Passenger Truck, and Light Commercial Truck VOC Average Speed Distribution Sensitivity

LOS	Functional Classification	Passenger Car		Passenger Truck		Light Commercial Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.1006	-	0.2226	-	0.2598	-
B	Urban Interstate	0.0873	-13.19%	0.1914	-14.02%	0.2055	-20.90%
C	Urban Interstate	0.0869	-13.56%	0.1905	-14.41%	0.2061	-20.66%
D	Urban Interstate	0.0871	-13.36%	0.1917	-13.90%	0.2115	-18.58%
E	Urban Interstate	0.0917	-8.84%	0.2043	-8.22%	0.2346	-9.71%
F	Urban Interstate	0.1335	32.73%	0.3102	39.37%	0.3871	49.01%
C	Principal Urban Arterial -Freeway	0.0863	-14.18%	0.1891	-15.07%	0.2054	-20.93%
D	Principal Urban Arterial -Freeway	0.0889	-11.63%	0.1961	-11.90%	0.2204	-15.14%
E	Principal Urban Arterial -Freeway	0.0939	-6.67%	0.2109	-5.25%	0.2449	-5.72%
Baseline	Principal Urban Arterial - Other	0.1223	-	0.2841	-	0.3508	-
B	Principal Urban Arterial - Other	0.1041	-14.88%	0.2423	-14.71%	0.2956	-15.72%
C	Principal Urban Arterial - Other	0.1177	-3.77%	0.2734	-3.78%	0.3369	-3.96%
F	Principal Urban Arterial - Other	0.2244	83.48%	0.5087	79.04%	0.6537	86.37%

Table F-80. Bus VOC Average Speed Distribution Sensitivity

LOS	Functional Classification	Intercity Bus Emission Rate (gram/mile)	Intercity Bus % difference	Transit Bus Emission Rate (gram/mile)	Transit Bus % difference	School Bus Emission Rate (gram/mile)	School Bus % difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.636	-	0.807	-	0.697	-
B	Urban Interstate	0.466	-26.79%	0.596	-26.16%	0.474	-32.02%
C	Urban Interstate	0.472	-25.74%	0.604	-25.10%	0.484	-30.54%
D	Urban Interstate	0.491	-22.74%	0.627	-22.24%	0.513	-26.36%
E	Urban Interstate	0.555	-12.68%	0.706	-12.51%	0.601	-13.75%
F	Urban Interstate	0.913	43.54%	1.136	40.76%	1.056	51.54%
C	Principal Urban Arterial -Freeway	0.475	-25.36%	0.608	-24.69%	0.488	-29.97%
D	Principal Urban Arterial -Freeway	0.518	-18.49%	0.661	-18.08%	0.551	-20.85%
E	Principal Urban Arterial -Freeway	0.570	-10.41%	0.721	-10.58%	0.626	-10.15%
Baseline	Principal Urban Arterial - Other	0.802	-	0.766	-	0.689	-
B	Principal Urban Arterial - Other	0.683	-14.88%	0.660	-13.90%	0.597	-13.40%
C	Principal Urban Arterial - Other	0.780	-2.82%	0.752	-1.81%	0.680	-1.31%
F	Principal Urban Arterial - Other	1.696	111.37%	1.704	122.38%	1.504	118.29%

Table F-81. Refuse Truck and Motor Home VOC Average Speed Distribution Sensitivity

LOS	Functional Classification	Refuse Truck		Motor Home	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.637	-	0.699	-
B	Urban Interstate	0.436	-31.60%	0.450	-35.67%
C	Urban Interstate	0.444	-30.28%	0.461	-34.00%
D	Urban Interstate	0.469	-26.47%	0.497	-28.94%
E	Urban Interstate	0.545	-14.46%	0.597	-14.58%
F	Urban Interstate	0.958	50.38%	1.119	60.13%
C	Principal Urban Arterial -Freeway	0.448	-29.76%	0.466	-33.38%
D	Principal Urban Arterial -Freeway	0.502	-21.28%	0.541	-22.65%
E	Principal Urban Arterial -Freeway	0.565	-11.35%	0.633	-9.48%
Baseline	Principal Urban Arterial - Other	0.826	-	0.977	-
B	Principal Urban Arterial - Other	0.688	-16.78%	0.813	-16.78%
C	Principal Urban Arterial - Other	0.782	-5.37%	0.946	-3.17%
F	Principal Urban Arterial - Other	1.550	87.60%	2.080	112.86%

Table F-82. Single Unit and Combination Truck VOC Average Speed Distribution Sensitivity

LOS	Functional Classification	Single Unit Short-haul Truck		Single Unit Long-haul Truck		Combination Short-haul Truck		Combination Long-haul Truck	
		Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference	Emission Rate (gram/mile)	% difference
Baseline	Urban Interstate/Principal Urban Arterial - Freeway	0.542	-	0.547	-	0.604	-	0.601	-
B	Urban Interstate	0.353	-34.93%	0.356	-34.85%	0.415	-31.25%	0.425	-29.22%
C	Urban Interstate	0.361	-33.32%	0.365	-33.24%	0.422	-30.03%	0.432	-28.15%
D	Urban Interstate	0.387	-28.52%	0.391	-28.45%	0.445	-26.29%	0.452	-24.84%
E	Urban Interstate	0.463	-14.57%	0.467	-14.55%	0.516	-14.43%	0.517	-13.96%
F	Urban Interstate	0.858	58.19%	0.863	57.86%	0.919	52.34%	0.896	49.04%
C	Principal Urban Arterial -Freeway	0.365	-32.71%	0.368	-32.64%	0.425	-29.58%	0.434	-27.75%
D	Principal Urban Arterial -Freeway	0.421	-22.43%	0.424	-22.37%	0.475	-21.26%	0.479	-20.29%
E	Principal Urban Arterial -Freeway	0.488	-9.96%	0.492	-9.94%	0.536	-11.13%	0.534	-11.19%
Baseline	Principal Urban Arterial - Other	0.748	-	0.752	-	0.804	-	0.784	-
B	Principal Urban Arterial - Other	0.623	-16.73%	0.627	-16.59%	0.671	-16.52%	0.658	-16.11%
C	Principal Urban Arterial - Other	0.724	-3.19%	0.729	-3.10%	0.779	-3.07%	0.761	-2.99%
F	Principal Urban Arterial - Other	1.603	114.38%	1.611	114.13%	1.771	120.21%	1.722	119.66%