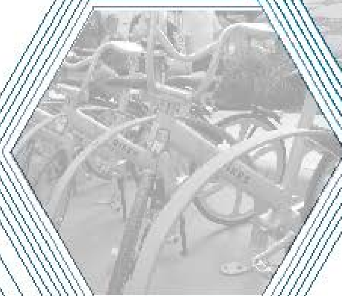

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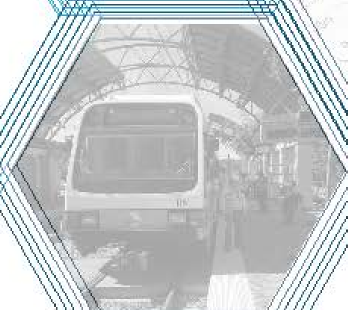

FINAL REPORT

CENTER FOR TRANSPORTATION EQUITY, DECISIONS & DOLLARS

ENVIRONMENTAL JUSTICE IMPLICATIONS OF ROADWAY TOPOGRAPY

FINAL PROJECT REPORT

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Center for Transportation, Equity, Decisions and Dollars **(CTEDD)**

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16. Abstract

This study evaluates environmental justice implications of roadway topography. Most MPOs and transportation agencies use a fixed buffer of 200 meters to identify the population that is at-risk of unsafe exposure to mobile emissions near roadways. Current analysis methodologies are unable to account for the impact that road grade has on emission quantities and therefore, pollutant concentrations in air.

This study used Vissim® - an advance traffic simulation tool to generate both grade-sensitive and grade-insensitive vehicle speed and acceleration data from a 9-mile high traffic corridor of Atlanta's Interstate 75. The vehicle activity data was subsequently analyzed with MOVES-Matrix to generate CO and $PM_{2.5}$ emission rates for about 310 segments that make up the project corridor. The USEPA air dispersion modeling tool – AERMOD was then used to estimate the distribution of pollutant concentrations at receptors distributed throughout the areas adjacent to the corridor. This concentration data was subsequently used to generate heat maps that facilitated the comparison of the extents of the 200-meter buffer and the extents of a single contour of value equal to the NAAQS limit for the relevant pollutant. For any given scenario, the buffer is deemed adequate if it is able to completely contain contour.

The study finds that under free flow traffic conditions, the buffer is adequate for all the scenarios examined. However, for congested traffic conditions the study finds the buffer inadequate for CO dispersion. For $PM_{2.5}$ dispersion under congested traffic, the findings show that the buffer is adequate. However, it is noted that this study uses only about 50 percent of the Heavy-Duty truck composition in the corridor fleet. HDVs are major contributors to onroad mobile $PM_{2.5}$ pollution. Furthermore, the findings do not account for background $PM_{2.5}$ concentrations in the project corridor.

These findings are relevant because they indicate that a universal fixed buffer may not be the best way to identify vulnerable populations to near-road emission exposure. Buffer distances should be decided with consideration to the type of pollutant, fleet composition, average speeds, road grade, and local weather.

17. Key Words
Emissions, Near-road, Hotspot, MOVES, AERMOD, Vissim, PM2.5

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Abstract

Mobile emissions from highways and roads have been shown to have detrimental impacts on public health. These harmful health effects further raise concerns about environmental justice because most users of the highways and roads do not reside in the adjacent areas where the most unsafe concentration levels of pollutants are usually found. In an effort to make better planning and policy decisions, Metropolitan Planning Organizations (MPOs) and other transportation agencies use a fixed buffer distance of 200 meters from the road to identify the population that is likely to be exposed to unsafe levels of emitted pollutants. By implication they have set the boundaries of potentially unsafe exposure at 200 meters. However, such planning activities do not consider the potential impact of road grade on the quantity of emissions, which can also have a direct influence on the spatial variability of the pollutant concentrations. The higher the quantity of pollutant emitted the wider the lateral extent from the road over which a certain threshold concentration can be found. Furthermore, it has been shown that omission of road grade can result in about 30 percent underestimation or overestimation of emission quantity. Thus, it is possible that the current fixed buffer distance of 200 meters may or may not be adequate in identifying all the population that may be at risk of unsafe exposure.

This study evaluated the adequacy or inadequacy of the fixed buffer of 200 meters. The study area spans about 9.2 miles of a high traffic portion of Atlanta's Interstate 75. It used Vissim®, an advanced traffic microsimulation tool to generate both grade-sensitive and grade-insensitive vehicle speed and acceleration data that were subsequently analyzed with MOVES-Matrix to determine emission rates for the project corridor. Road grade information for the project area was extracted from the United States Digital Elevation Model. The estimated emission rates for the corridor were input into AERMOD to estimate the spatial variability of pollutant concentration levels in the areas adjacent to the study area. A heat map diagram of the spatial variability data was superimposed with buffer lines representing 200-, 400-, and 1,000-meter offsets off the road edge. Additionally, a contour representing the National Ambient Air Quality Standard (NAAQS) threshold concentration for the relevant pollutant was also superimposed on the heat map and a visual evaluation was made to determine how well the buffer lines are able to contain the NAAQS contour. The study evaluated many scenarios made up of different combinations of pollutants (CO and $PM_{2.5}$), AERMOD analysis options (Flat and Screen), seasonal periods (summer and winter), daily traffic periods (morning and evening), and network options (with and without grade). Evaluation of the buffer's adequacy was determined for both free flow and congested traffic conditions.

For the free flow conditions, the study finds the 200-meter buffer to be adequate for all the scenarios evaluated. It was able to completely contain the NAAQS limit for the relevant pollutant. However, under congested traffic conditions the findings showed that the buffer is inadequate for CO dispersion. At least, three receptors that were located on the buffer had concentrations that were higher than the NAAQS limit. Also, for $PM_{2.5}$ dispersion under congested traffic conditions, the study finds the buffer to be adequate. But it should be noted that this study uses only about half of the likely HDV composition in the corridor fleet and HDVs are major contributors to onroad mobile $PM_{2.5}$ pollution. In addition, this study does not consider background $PM_{2.5}$ concentrations in the corridor.

The study's findings are relevant because overall they show that a fixed buffer might not work in all circumstances. The buffer should be set with consideration given to pollutant type, corridor speeds, fleet composition, road grade profile, and local weather.

Chapter I: Introduction

Mobile emissions from highways are known to have harmful effects on public health. Through air dispersion, the public becomes exposed to the emitted pollutants leading to various detrimental impacts including asthma, reduced lung function in children, cardiovascular morbidity, adverse birth outcomes, cognitive decline, lung cancer, and increased risk of autism in children. Please see the literature review section of this report for more information on various studies that identified these health impacts.

These harmful effects also raise concerns of environmental justice because their severity is highest near transportation networks but most of the users of the network may not reside in the areas near the network. Environmental justice analysis methodologies attempt to identify the vulnerable (unsafely exposed) populations near highways. These methodologies, which are often used in regional transportation planning, use a fixed distance buffer analysis to demarcate the critical extent of emission dispersion from the highway and thus, the boundary of vulnerable population.

The spatial variability of emitted pollutant concentrations away from the highway depends to a large extent on the quantity emitted. One important factor that influences the quantity of emitted pollutants from vehicles is road grade because it directly impacts the engine load. The greater the engine load the more the quantity of emissions and vice-versa. However, the established analysis methodologies do not account for the effect of roadway topography. To a large extent these methodologies rely on vehicle activity data from travel demand models and the current generation of travel demand models have been unable to capture the effect of roadway topography on vehicle activity. It has been shown that roadway topography could result in overestimation or underestimation of the quantity of emissions (Liu et al. 2019). Therefore, it is possible, depending on local conditions, that a fixed distance buffer analysis could overestimate or underestimate the boundaries of the affected population.

This research investigated the implications of roadway topography on the adequacy of this fixed distance buffer that has a ubiquitous value of 200 meters. Using vehicle activity data sourced from a Vissim® simulation of a high traffic highway corridor, the researchers used the MOVES-Matrix (Guensler et al. 2018) to estimate emission inventories from the corridor. The near-road dispersion analysis for the estimated pollutant quantities was performed using the United States Environmental Protection Agency (USEPA) air dispersion model, AERMOD (United States Environmental Protection Agency 2019).The output from AERMOD was used to investigate the spatial variability of emitted pollutant concentration levels from the highway in order to verify the adequacy or inadequacy of the 200-meter buffer.

A 2002 study (USDOT et al. 2002) on *Transportation Benefits and Burdens in the Atlanta Region* (a precursor to environmental justice analysis) identified the importance of topography to transportation air quality issues in Atlanta. Furthermore, the study noted the need to consider topography and local weather patterns in attempts to characterize populations that are proximate to vehicle emissions. However, there has been no subsequent study to develop an analysis methodology to implement this recommendation. This current study offers a timely and instrumental contribution to bridge the gap between emission analysis, environmental justice, and topography.

The main goal of this current research is to generate awareness and constructive discussions among practitioners and stakeholders on whether our existing methodologies are doing enough to help us identify the real size of the population that is vulnerable to unsafe exposure of pollutants from the transportation network.

Chapter II: Literature Review

Mobile Emissions and Effect of Road Grade

Many urban areas are grappling with the consequences of harmful air emissions. These emissions are contributed by local stationary sources (e.g. factory plants), mobile sources (e.g. transportation vehicle related activities), and regional background sources (pollutants transported by wind from one part of a region to another). Pollutant air emissions from mobile sources include carbon monoxide (CO) and particulate matter ($PM_{2.5}$ and PM_{10}) from vehicle exhaust, the wear and tear of tires due to friction from the pavement surface as the tires roll, and from the wear and tear of brake pads due to frication as the brakes operate. $PM_{2.5}$ includes fine inhalable particles and liquid droplets that are at most 2.5 micrometers in diameter while PM_{10} includes all fine inhalable particles that are at most 10 micrometers in diameter. The quantity of vehicle-related emissions can vary due to factors such as vehicle size, age, speed, traffic, and road grade.

The United States Environmental Protection Agency (USEPA) requires metropolitan planning organizations (MPOs) to use the MOtor Vehicle Emissions Simulator (MOVES) to inventory vehicle emissions. Additionally, to determine the size of the population that could be exposed to unsafe levels of vehicle emissions and air dispersion, MPOs are required to utilize a type of buffer analysis (Tayarani et al. 2016). This buffer analysis requires defining a certain critical distance around high-volume roads where vehicular emission concentrations can be expected to be high. A distance of 200 meters is often used as default, because it has been reported that the highest concentrations of pollutant emissions from the transportation network are generally found within a 200-meter range (Brugge et al. 2007).

Road grade data has traditionally been left out of transportation planning models. However, road grade is critical for accurate modeling of vehicle emissions due to its effect on engine load. Specifically, in MOVES, regional emission inventory analysis ignores the effect of road grade (Liu et al. 2019). Furthermore, planning models used by MPOs and other transportation agencies often utilize vehicle speed and acceleration data sourced from travel demand models that are unable to incorporate road grade into their networks. This limited attention paid to the impact of real-world road grade on speed-acceleration and emissions is mainly due to the lack of high-resolution road grade data or unawareness of grade impact (Sentoff et al. 2015; Wood et al. 2016; Yazdani Boroujeni and Frey 2014).

A recent study (Liu et al. 2019) found that ignoring a grade level of about +/- 2% can result in $PM_{2.5}$ emission estimates that are at least +/- 30% off. It should be noted that their analysis did not include heavy-duty vehicles, which are a primary source of vehicle exhaust PM emissions. Zhang et al. (2015) found that a 4% road grade could increase near roadway emissions of CO and NO_X from 39% to 61%, factoring in heavy-duty vehicles. However, their research did not look to understand the effects of road grade on emissions of $PM_{2.5}$, nor how these emissions disperse within areas adjacent to the roadway. Through our analysis we hope to get a better understanding of how all of these factors; road grade, heavy-duty vehicles, and distance from roadway, collectively can affect the concentration of $PM_{2.5}$ and CO.

The extent of mobile emission dispersion in air depends on the quantity of the emissions, and the quantity of emissions also depends on engine load. Since engine load is affected by road grade, then including road grade in analysis could affect extent of emission dispersion and this could have implications on the use of a fixed buffer distance of 200 meters to identify the size of the population that is vulnerable to unsafe auto emission exposure. Therefore, it would be beneficial to the on-going discussion on near-road health impacts to investigate the adequacy or inadequacy of the widely accepted buffer distance of 200 meters when grade is accounted for in the analysis.

Mobile Emissions and Consequences to Public Health

Particulate matter ($PM_{2.5}$) can be harmful to humans and it has been shown to have various detrimental impacts on health (Cesaroni et al. 2008; Crouse et al. 2009) including asthma and reduced lung function in children (Brunekreef et al. 1997; Clark et al. 2010; Gauderman et al. 2007; Jerrett et al. 2008; Kim Janice et al. 2008), cardiovascular morbidity, mortality, adverse birth outcomes, and cognitive decline (Batterman et al. 2014). Raz et al. (2015) have also indicated that the risk of autism doubles when pregnant women in the third trimester are exposed to $PM_{2.5}$ by reason of proximity to high traffic. Furthermore, Brugge et al. (2007), found a significant relationship between $PM_{2.5}$ and instances of lung cancer in two separate studies when controlling for smoking and other risk behaviors. Peters et al. (2004), found that exposure to traffic was associated with the onset of myocardial infarctions and heart attacks, in the hour following. In addition, the time spent exposed to traffic was positively associated with the chance of myocardial infarction. These harmful effects of auto emissions pose significant health challenges on the public. Also, they impose a high cost on the national economy, as there are about 30 million people living within 100 meters of a major highway facility (Brugge et al. 2007).

Additionally, Chang et al. (2017) found that of $PM_{2.5}$ related premature deaths, 72% occur within 1,000 meters of the roadway. Understanding that $PM_{2.5}$ has been shown to be fatal to humans as far as 1,000 meters away from the roadway is an indication that the fixed 200-meter buffer may not fully envelop all those affected by $PM_{2.5}$. In 2010, the Health Effects Institute (HEI) recommended extending the buffer to 300-500 meters to account for changes in vehicle count, size, age and changes in meteorological conditions (Health Effects Institute 2010).
This further highlights the importance of understanding how road grade could affect the dispersion of $PM_{2.5}$ near roadways, to fully understand who is at risk of negative health outcomes due to onroad mobile emissions.

Overall, literature has documented that the exposure to roadway $PM_{2.5}$, is associated with decreased health and the potential for death, especially for those that spend long periods of their days on or near roadways. What is not well understood, is if our current methodologies are accurately determining the lateral extent of potentially unsafe exposure so that the public could be well informed.

Environmental Justice and Air Quality

The detrimental effects of exposure to onroad mobile emissions have been found to be disproportionally concentrated in low-income and minority communities. A review of literature by Carrier et al. (2014) shows that previous studies in different nations (Canada, United States, United Kingdom, and New Zealand) all found that low-income households are the main population sub-group susceptible to vehicle emission exposure because of their proximity to highways. Their proximity maximizes their exposure to $PM_{2.5}$ and the magnitude of the negative health outcomes increases with length of exposure (O'Neill et al. 2003). Therefore, low-income communities and communities of color have been the most at risk for experiencing the negative health outcomes caused by vehicle emissions.

A study of the entire United States also found that while 19% of the U.S. population lives near high-volume roadways, higher rates of traffic measured by volume and density are correlated with the location of lower-income homes of color (Rowangould 2013). Likewise, Tian et al. (2013) found that the most vulnerable population specifically to $PM_{2.5}$ is usually non-white. Morello-Frosch and Jesdale (2006), concurrently found that cancer risk due to air pollution were highest in census tracts of extremely segregated metropolitan areas. Concentrating specifically on $PM_{2.5}$ and ozone, with $PM_{2.5}$ being a major vehicle emission, Miranda et al. (2011), found that within areas with consistent air quality monitoring, non-Hispanic blacks largely make-up the communities with the poorest air quality. Therefore, low-income communities of color seem to disproportionately bear negative health costs of roadway transportation systems. It has also been shown that a majority of U.S. counties with residents living near high-volume roadways do not have air quality monitoring systems (Rowangould 2013). This makes it all the more important that the environmental justice buffer analysis is as accurate as possible to proactively protect these communities. Knowing how to spatially identify all affected persons accurately will help to improve policymaking around transportation pollution and equity.

Dynamics of Near-Roadway Particulate Matter

To accurately estimate the concentration of $PM_{2.5}$ along roadways, the model must factor in each element that affects particle dispersion. As stated, the spread of pollutant concentration level from the road depends on several factors including quantity of pollutant emitted, ambient conditions, such as wind and temperature, and road topography. The quantity of pollutant emitted in mobile exhaust is a function of engine load. Ideally this estimation procedure would require real-world driving cycles or speed-acceleration joint distributions (SAJDs) as input data (Liu et al. 2019).

Also, the concentration gradient of $PM_{2.5}$ can vary significantly depending on weather patterns and seasonal changes in meteorological trends can greatly affect what type of weather will be positively associated with $PM_{2.5}$ concentrations. A study of temperature, relative humidity, and wind speed on the dispersion of $PM_{2.5}$, by Olvera et al. (2018) found that low-wind and temperature in winter was correlated with high $PM_{2.5}$ concentrations, while high-wind and low-humidity in spring were also associated with high $PM_{2.5}$ concentrations.

Knowing that emissions can vary based on a variety of conditions, it is important to utilize the most accurate particle dispersion models. The US EPA recommends the steady-state plume modeling software AERMOD for regulatory modeling of air quality. Additionally, a study of five emission dispersion models found that AERMOD was one of the most effective for replicating real-world pollutant concentrations (Heist et al. 2013). The authors also found that AERMOD performed reliably over a variety of wind speeds. As this research is looking to better understand the regulatory buffers used to determine those at greatest risk for negative health outcomes due to air quality, AERMOD will be the model used in this study.

Chapter III: Methodology

Data

The study area for this research is the high traffic Interstate 75 (I-75) corridor bounded by the Interstate 285 (I-285) interchange to the south and the Interstate 575 (I-575) interchange to the north. This corridor covers about 9.2 miles of interstate traffic.

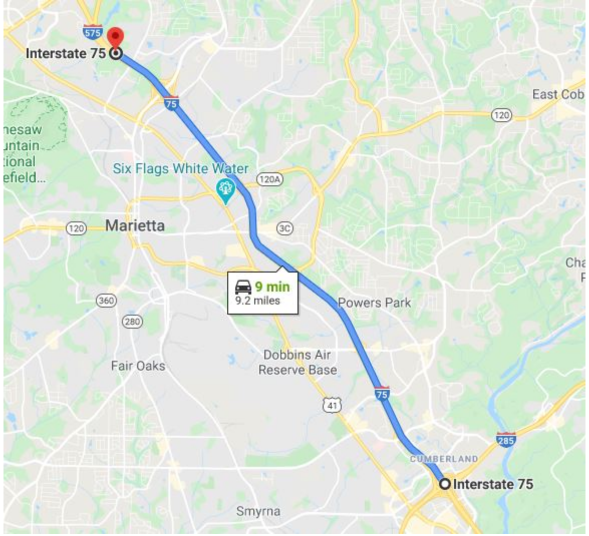

Figure 1. Map of Project Corridor

To accurately model and assess the pollutant concentration and dispersion in areas adjacent to the study corridor, the geographical information system (GIS) network of the corridor was extracted from the larger Atlanta Regional Commission (ARC) GIS network of Atlanta's highway system. The boundaries of the extracted GIS network (i.e. interstate ramps and start and end points on the main trunk line) of the corridor provided a framework to create a subnet of Atlanta's Activity Based Travel Demand Model (ABM) for year 2020. The subnet was used to extract information on all vehicle trips entering or exiting the corridor. A custom script was developed to analyze the vehicle trips data and produce origin – destination (O-D) matrices of the study corridor for every 30 minutes within a day. The script checked the vehicle trips data for trip chaining where vehicles reenter the analysis area and counted every entry as a separate trip. The ABM data that was available did not include heavy-duty truck traffic. Heavy-duty truck composition for the O-D matrices was obtained by analyzing Georgia Department of Transportation (GDOT) Traffic Analysis and Data Application (TADA) information. The TADA data showed three continuous count stations (CSS); one near the beginning of the project corridor and south of the I-285 interchange, and the other two within the project corridor. The two within the project corridor have both been inactive since 2016 but their last recorded truck percentage was 11%. However, the one at the beginning of the project corridor is still active and the recorded truck percentages on it were 4% from 2016-2018 and 3% for 2019. Therefore, the study assumed a conservative estimate of 4% truck composition for the O-D matrices. Figure 2 shows the flowchart of the project methodology.

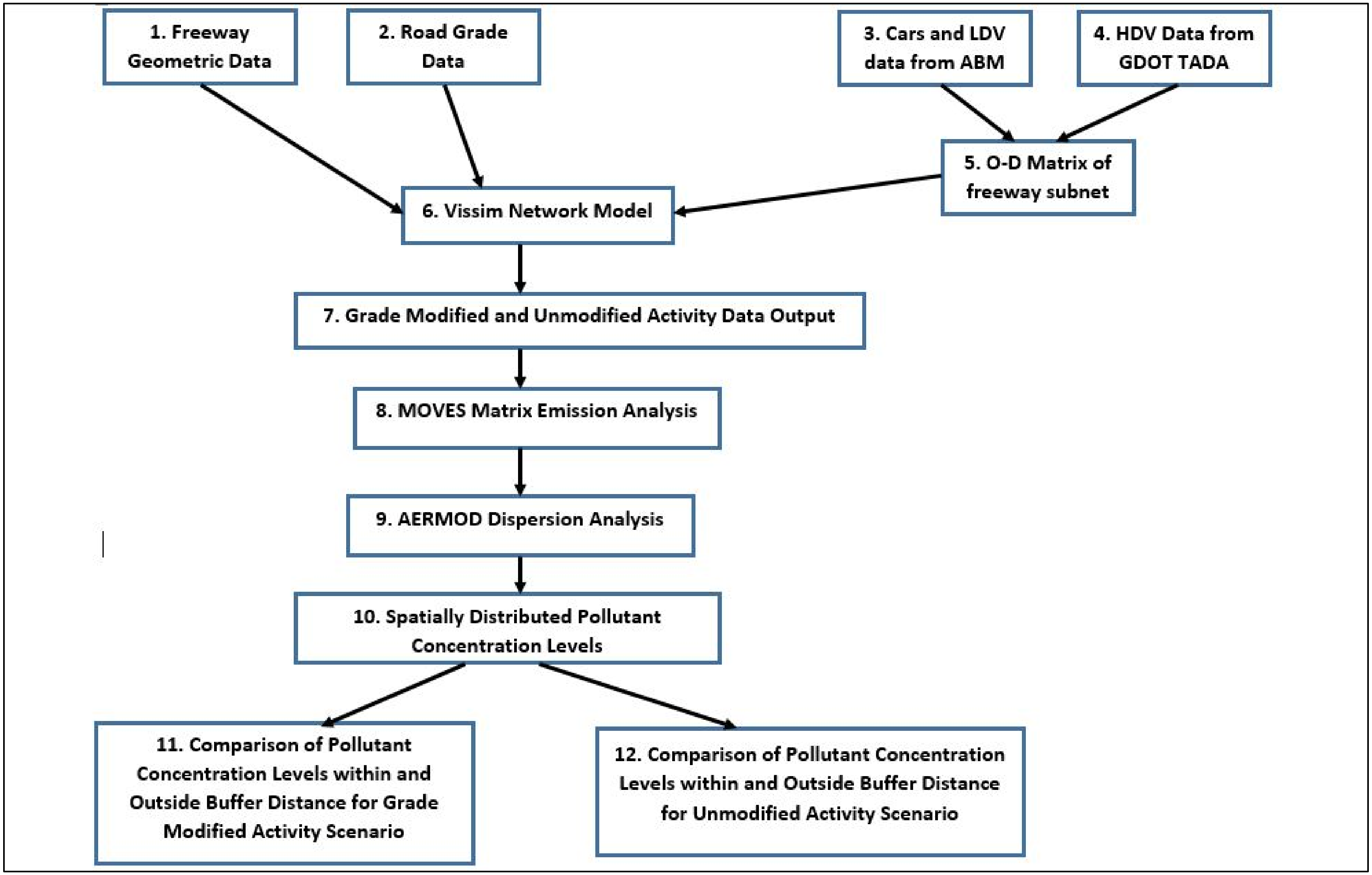

Figure 2. Flowchart of Methodology

In order to access the impact of roadway topography on emissions within the project corridor, the analysis must have access to detailed roadway topographical data. The roadway topography data for the project corridor was extracted from the United States Digital Elevation Model (US DEM) database using a streamlined method developed by Georgia Tech researchers (Liu, et al., 2018). This streamlined method has been verified to generate accurate road grade information with a root mean-square error (RSME) of 0.20-0.23% for highways and 0.50-0.60% for local roads. This streamlined method was used to generate centerline road grade at 10 meter intervals for the project corridor. Figure 3 shows the longitudinal grade profile of the project corridor starting from the south end to the north end.

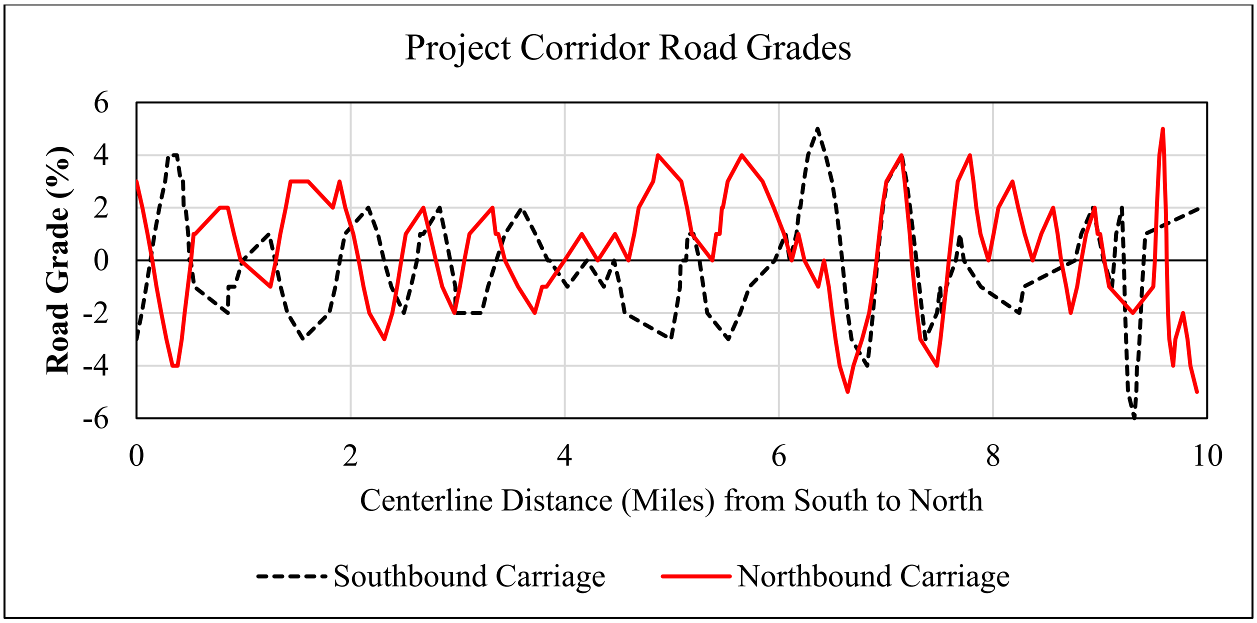

Figure 3. Longitudinal Grade Profile of Project Corridor

To attain reasonable accuracy in modeling of vehicle emissions requires real-world vehicle activity data in the form of driving cycles. These vehicle activity data were obtained by simulating traffic in the project corridor using the prior mentioned O-D matrix and Vissim® microscopic traffic simulation software. Also, successful modeling of emission air dispersion over an area with AERMOD requires meteorological data. For this study, this data was obtained from the Georgia Environmental Protection Division (Georgia EPD 2018) as AERMET hourly data for 2017.

Simulation of Project Corridor Traffic Using Vissim®

Vissim® was used to develop a microscopic traffic simulation of traffic in the project corridor. The coded Vissim® network included the northbound and southbound carriages and connecting ramps of Atlanta's Interstate 75 within the project corridor. Road geometry including number of lanes and horizontal curvature data were obtained from Bing® Maps, an interactive satellite imagery developed by Microsoft®. Vissim® allows the use of this interactive satellite imagery as a background map so that road network can be directly drawn to scale over the map without the need for field measurements. Centerline road grade data at 10-meter intervals obtained from the US DEM was coded into the network links. The grade data did not include the connecting ramps because the emission inventory analysis was limited to the mainline of the interstate. The developed Vissim® network of the project corridor was made up of 310 links. The links were chosen to reflect homogenous segments of the highway, i.e. segments with the same number of lanes and road grade. The length of a link was chosen with careful consideration to its curvature such that the polygon describing the link can be defined by 10 or less vertices. This ensured that all the links were in conformity with the input requirements of AERMOD, which was used in subsequent air dispersion analysis for emissions. The prior mentioned O-D matrices were also entered into the Vissim® model at 30 minute intervals for 24 hours.

The study developed another copy of the model that had no grade information. This second model is essentially the same as the travel demand models used by MPOs and other transportation agencies to generate vehicle speed and acceleration information. Thus, there were two Vissim® models of the project corridor; one with appended grade information (hereafter called grade-sensitive model) and the other without grade information (hereafter called grade-insensitive model).

Vehicle speed and acceleration output from the model with appended grade information reflects the impact of grade on vehicle activity. Therefore, by analyzing the output of the two models separately in the subsequent emission inventory and air dispersion analysis and then comparing the results, the impact of grade can be determined.

Both models were verified by conducting a conservation of mass analysis to ensure that all traffic entering the network exits the network.

Emission Modeling with MOVES-Matrix

As stated earlier, the USEPA recommended tool for vehicle emissions modeling is MOVES. Researchers from Georgia Tech have developed the MOVES-Matrix (Guensler et al. 2018) to facilitate efficient modeling using MOVES. The MOVES-Matrix is a database containing MOVES runs that have been iterated across all factors that influence emission rates for specific source type, model year, fuel type, speed and acceleration, road grade, calendar year, applicable regional regulatory parameters, and specific ambient conditions of temperature and humidity. Therefore, a user is able to look-up emission rates from the database without running MOVES.

The output from the Vissim® models (speed, acceleration, road grade, and vehicle characteristics info) and meteorological data for Atlanta were used to estimate emission rates from the MOVES-Matrix for each network link in Vissim®. Georgia Tech researchers have also developed a script to facilitate emissions inventory with MOVES-Matrix. The script requires the following as input in Microsoft Excel csv files:

- **Link Information File**

For this study, the file contained input information for each of the 310 links. There must be a link file for every scenario and hour combination for which emission inventory will be estimated. The input information provided for each link were:

- Link ID
- County ID
- Zone ID
- Road Type ID (for this project the road type id is 4 which indicates controlled access)
- Length (in miles)
- Volume

- Average Speed (mph)
- Description (for this project all links were described as urban restricted)
- Average Grade (%)

- **Source Age Distribution File**

This input file contains the age distribution within each source (vehicle type) across a 30 year horizon starting backwards from the project analysis year. The distribution for a particular source across the 30 year horizon must sum to one. For this study, the researchers used the projected source age distribution for the Atlanta area. The input information included in the file includes:

- Age ID (vehicle age, ranges from 0 to 30 for each source)
- Source Type (IDs for the various vehicle types)
- Age Fraction (the fraction of vehicles with a particular age within a particular vehicle fleet)
- Year ID (projected analysis year)

- **Source Type Distribution File**

This input file contains the fraction of operating time for each source per link modeled. There must be a source type distribution input file for each hour and simulation scenario that emission inventory will be estimated. The sum of the operating time fractions for all sources on a link should sum to one. The input data fields contained in the file include:

- Link ID
- Source Type ID
- Source Type Hourly Fraction

- **Meteorological Information File**

This input file contains temperature and humidity information for each analysis hour for which emission inventory will be estimated. Where hourly data is limited or unavailable then the average daily temperature and humidity can also be used. This study uses the average daily temperature and humidity for the Atlanta region. Also, the study required two meteorological files representing winter and summer periods. Daily average temperature values of 45ºF and 80ºF was used for winter and summer periods respectively. Similarly daily average humidity values of 70% and 75% were used for winter and summer periods respectively. The data fields contained in the file include:

- Month ID
- Zone ID
- Hour ID (a number between 1 and 24)
- Temperature (between 0 – 110ºF in bins of 5ºF)
- Humidity (between 0 – 100% in bins of 5%)

- **Operating Information File**

This input file contains information that tells MOVES-Matrix the format of the provided operating information. The input file is not needed when the operating information is based on the default MOVES driving cycle. This study uses custom operating schedules in the form of vehicle operating modes. The file contains information on operating mode fractions for each link per source type. The operating mode fractions for a link and source combination must sum to one. The main data fields contained in the file include:

- Source Type ID

- Link ID
- Operating Mode ID
- Operating Mode Fraction

The operating modes were determined by first calculating the Vehicle-Specific Power (VSP) for the light-duty vehicles and Scaled-Tractive Power (STP) for the heavy-duty vehicles according to Equation 1. As can be inferred from Equation 1, the VSP/STP analysis can either include grade or omit grade. For this study the scenarios that utilize grade-sensitive speed and acceleration output from Vissim®, included the road grade in VSP/STP calculations. Therefore, the eventual emissions estimated for those scenarios reflect the impact of grade.

$$VSP(STP)_t = \left(\frac{A}{M}\right)V_t + \left(\frac{B}{M}\right)V_t^2 + \left(\frac{C}{M}\right)V_t^3 + \left(\frac{m}{M}\right)(a_t + g * \sin\theta_t)V_t \qquad (1)$$

Where:

V_t = velocity at time t (m/sec)
a_t = acceleration at time t (m/sec^2)
θ_t = road grade (radians or degrees, as needed in sine calculation algorithms)
g = gravitational acceleration (9.81 m/sec^2)
m = vehicle mass (tonnes)
M = fixed mass factor for the source type (tonnes)
A = rolling resistance (kW-sec/m)
B = rotating resistance (kW-sec^2/m^2)
C = aerodynamic drag (kW-sec^3/m^3)
M in VSP = fixed mass factor for source type (tonnes), m=M for VSP calculations
M in STP = scaling factor to scale STP ranges to within the same range as VSP (tonnes)

This study simulated interstate traffic with passenger cars and heavy-duty trucks (single unit long-haul trucks, and combination long-haul trucks). The VSP/STP parameters adopted for these vehicle types in the analysis are shown below in Table 1 and Table 2 shows the VSP and speed values that define different operating mode IDs.

Table 1. VSP/STP Parameters for Simulated Vehicles in Project Corridor

Parameter	Passenger Vehicle	Single Unit Long-Haul Truck	Combination Long-Haul Truck
Vehicle mass (m)	1.4788	Randomly selected in range 4.5 - 40	
Fixed mass factor (M)	1.4788	17.1	17.1
Rolling resistance (A)	0.156461	0.498699	2.08126
Rotating resistance (B)	0.002002	0.0	0.0
Aerodynamic drag (C)	0.000493	0.001474	0.004188

Table 2. Speed and VSP Characteristics of Different Operating Modes

Speed Range	VSP Category	Operating Mode ID

Speed 0-25 mph	Braking	0
	Idle	1
	VSP < 0	11
	VSP 0-3	12
	VSP 3-6	13
	VSP 6-9	14
	VSP 9-12	15
	VSP >= 12	16
Speed 25-50 mph	VSP < 0	21
	VSP 0-3	22
	VSP 3-6	23
	VSP 6-9	24
	VSP 9-12	25
	VSP 12-18	27
	VSP 18-24	28
	VSP 24-30	29
	VSP >= 30	30
Speed > 50 mph	VSP < 6	33
	VSP 6-12	35
	VSP 12-18	37
	VSP 18-24	38
	VSP 24-30	39
	VSP >= 30	40

Dispersion Analysis of Emitted Pollutants

Pollutant air dispersion analysis with AERMOD in this study required emission rates for each of the 310 road links defining the project corridor. In addition, the area of each link, AERMET meteorological data, and a list of predefined receptor coordinates were required as input for AERMOD.

The emission rates for each link must be in grams per second per squared-meter ($g/s/m^2$). Therefore, emission inventory output of MOVES-Matrix (in grams) for each link was divided by the inventory duration (i.e. 3,600 seconds) and the area of the polygon (in m^2) delineating the link. The emission rates used in AERMOD were held constant for the duration of each model run.

Also, the study uses different receptor groups for calculating the spatial variability of pollutant concentration levels in areas adjacent to the project corridor. The receptor groupings are based on distance from the road edge. Also, spacing of receptors within the receptor groups increases with distance from the road edge. The various groups are described below.

- R1_receptors: This is a line of receptors located at 5 meters from the road edge and spaced at 100 meters from each other along the length of the road.
- R2_receptors: This is a line of receptors located at 50 meters from the road edge and spaced 100 meters from each other along the length of the road.
- R3_receptors: This is a line of receptors located at 100 meters from the road edge and spaced at 200 meters from each other along the length of the road.
- R4_receptors: This is a line of receptors located at 200 meters from the road edge and spaced at 200 meters from each other along the length of the road.
- R5_receptors: This is a line of receptors located at 400 meters from the road edge and spaced at 400 meters from each other along the length of the road.
- R6_receptors: This is a line of receptors located at 800 meters from the road edge and spaced at 500 meters from each other along the length of the road.
- R7_receptors: These receptors cover the rest of the area and they are spaced at 500 meters

Figure 4 shows the setup of the line source and receptors. The air dispersion analysis performed in this study uses the "AREA" method in AERMOD (Wu et al. 2016). This method was chosen because of the ease of application and interpretation of results. Other AERMOD methods like "VOLUME" may provide more accurate modeling of physical phenomena but the overall statistics is not expected to be much different.

Also, both Screen and Flat analysis options in AERMOD were used in this study. AERMOD Screen option was used to filter out scenarios that don't pose air quality concerns. The Screen model option estimates the worst possible one hour receptor concentrations. It does this by forcing model calculations to represent values for plum centerline, regardless of source-receptor-wind direction orientation (United States Environmental Protection Agency 2018). The Flat option tells AERMOD to use the non-regulatory analysis option that assumes a flat terrain of the areas surrounding the project corridor. Therefore, it is assumed that there are no elevated locations like hills, high-rise buildings, etc. that can influence dispersion. The EPA states that Flat model option is assumed for most highways and transit projects (United States Environmental Protection Agency 2013).

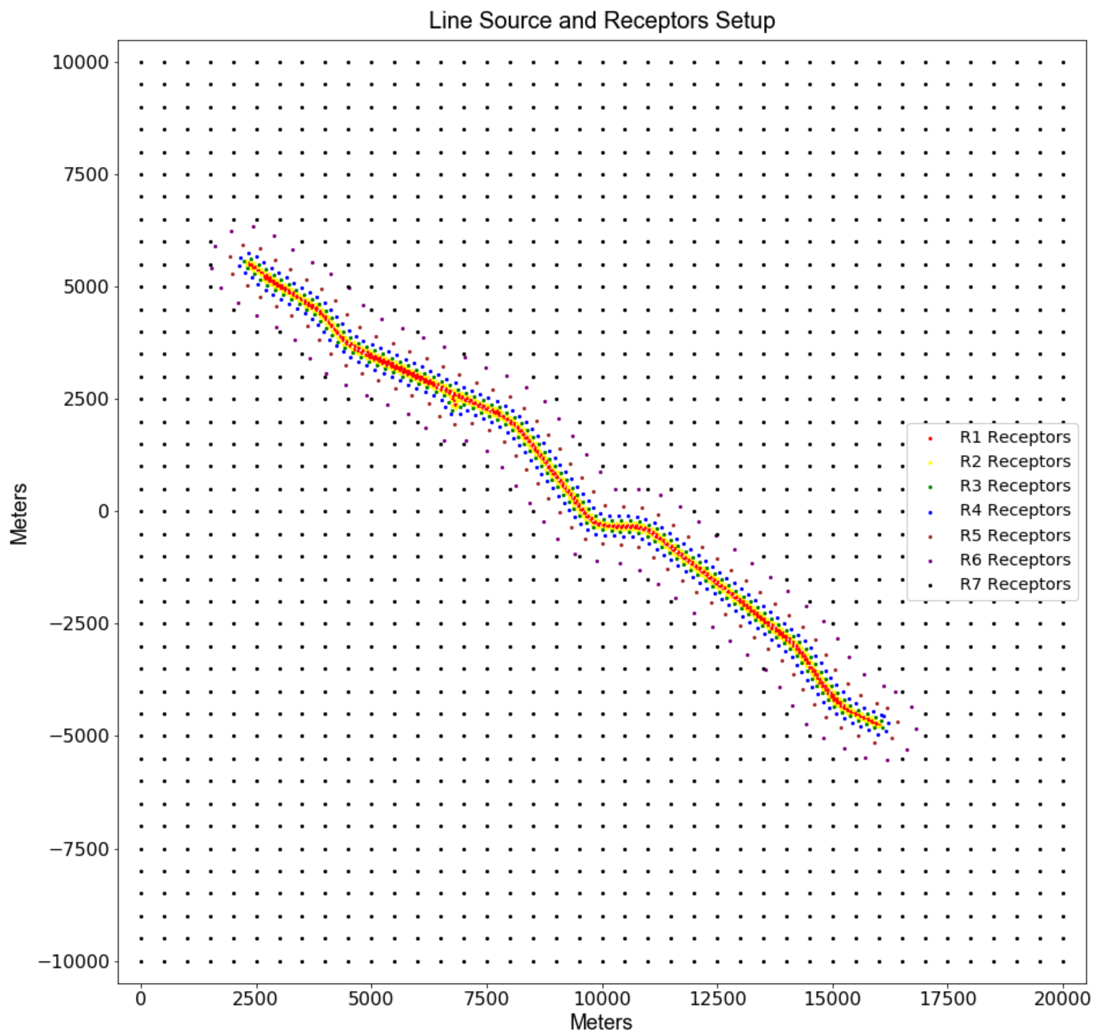

Figure 4 Line Source and Receptors Setup

For the model runs that used the Flat model option, the US EPA recommends averaging times in the National Ambient Air Quality Standards (NAAQS) to be used; annual for $PM_{2.5}$ and 8 hours for CO. Therefore, AERMOD simulated all hours in a year to determine the annual average $PM_{2.5}$ concentration and maximum 8-hour CO concentration at each receptor. These averaging times meet NAAQS Primary Standard which provides public health protection that includes protection for sensitive populations such as asthmatics, children, and the elderly. Table 3 presents the adopted NAAQS table for CO and $PM_{2.5}$ that was used in this study.

Table 3. Adopted National Ambient Air Quality Standard for CO and $PM_{2.5}$

Pollutant	Standard	Averaging Time	Level	Form
Carbon Monoxide (CO)	Primary	8-hours	9 ppm	Not to be exceeded more than once per year
Particle Pollution ($PM_{2.5}$)	Primary	1 year	12 $\mu g/m^3$	Annual mean, averaged over 3 years

Adopted from: https://www.epa.gov/criteria-air-pollutants

Spatial Analysis of Dispersed Concentrations

A spatial analysis of the receptor concentrations from each model run (scenario) was performed to assess if the current ubiquitous fixed buffer of 200 meters used to demarcate the potential extent of unsafe population exposure is able to contain all estimated concentrations that are greater than the NAAQS threshold value. In addition, the spatial analysis helped to determine if the effect of road grade can be visually detected by comparing spatial maps of pollutant concentration levels for corresponding grade-sensitive and grade-insensitive scenarios.

In order to successfully perform this spatial analysis, receptor concentrations from each model run were used to generate a heat-map of concentrations in the areas adjacent to the project corridor. Next, the road edge line was offset by distances of 200 meters, 400 meters, and 1,000 meters on either side. Finally, a single contour plot representing the NAAQS threshold value was superimposed and compared with the road edge offsets. The study hypothesizes that if the fixed buffer of 200 meters is adequate to capture the potential extent of unsafe population exposure, then the NAAQS threshold contour should be completely contained within the 200-meter road edge offsets. This also implies that none of the receptors located on the buffer line should have a concentration value that is higher than the NAAQS threshold value.

Chapter IV: Results

The results discussed in this chapter relate to air dispersion analysis for $PM_{2.5}$ and CO performed in this study.

Convergence of Vissim® Traffic Simulation Models

As discussed prior, this study developed two main Vissim® simulation models. One model was coded with road centerline grade information (grade-sensitive model) while the other model contained no grade information (grade-insensitive model). The grade-sensitive models were run to convergence with 4 hours of morning and evening vehicle trips respectively. Convergence was defined by two conditions that must all be met. The first condition requires that the percentage change in travel time on all paths within any 10 minute evaluation interval, compared to the same interval in previous iteration should be less than 15 percent. The second condition offers a little relaxation to the first condition by requiring that the actual share of paths which have converged in the model must be at least 90 percent. The model is assumed to be converged upon the first instance of 90 percent path convergence. The evening period model took a total of 29 iterations to converge (see Figure 4). The morning period model was started with the converged path and cost files from the evening period model. This enabled it to converge with smaller number of iterations (see Figure 5).

Next, the grade-insensitive models were developed from their corresponding copies of the grade-sensitive models. The converged morning and evening period path (routing) and link costs files were used to setup the models for all evaluated scenarios.

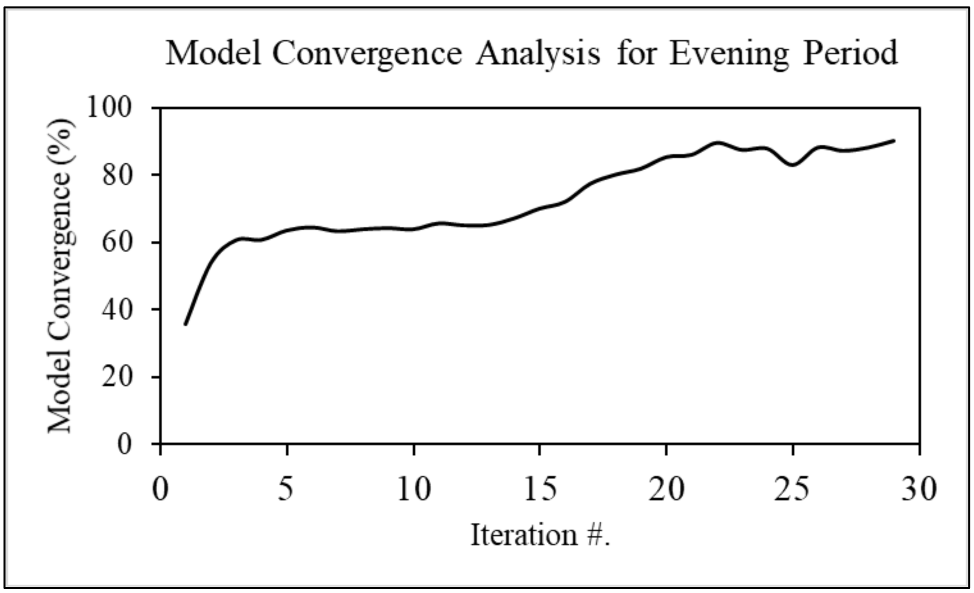

Figure 5. Model Convergence Analysis for Evening Period

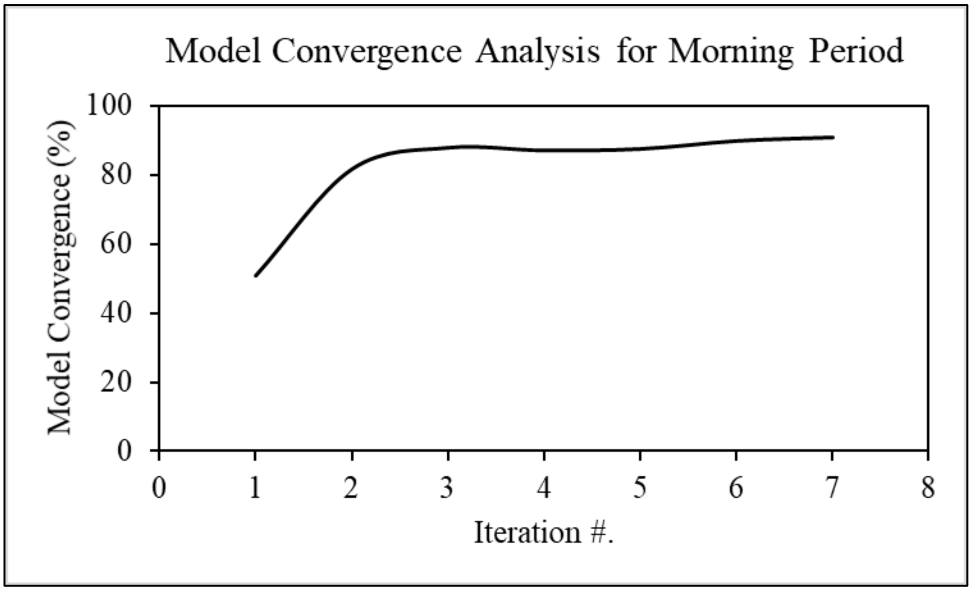

Figure 6. Model Convergence Analysis for Morning Period

Vehicle Speed Distribution in Project Corridor

The vehicle speed and acceleration outputs from both the grade-sensitive and grade-insensitive models were analyzed to see how vehicle speeds were affected by incorporating road grade in the project simulation models. The models were run with the developed O-D matrix resulting in about 20,000 vehicle trips through the project's subnet for an hour in both morning and evening periods. Also, the model setup, especially unrestrained boundary conditions resulted in a free flow average corridor speed of about 60 mph. Further analysis of the speed outputs by source showed that passenger car speeds varied little, with speeds being closer to the corridor average, and there wasn't much difference between the grade-sensitive and grade-insensitive models. However, HDV average speeds showed notable difference in some cases between grade-sensitive and grade-insensitive scenarios (varying between 30 mph to 57 mph). This can be inferred from the passenger car and HDV speed plots displayed in Figure 6 through Figure 13.

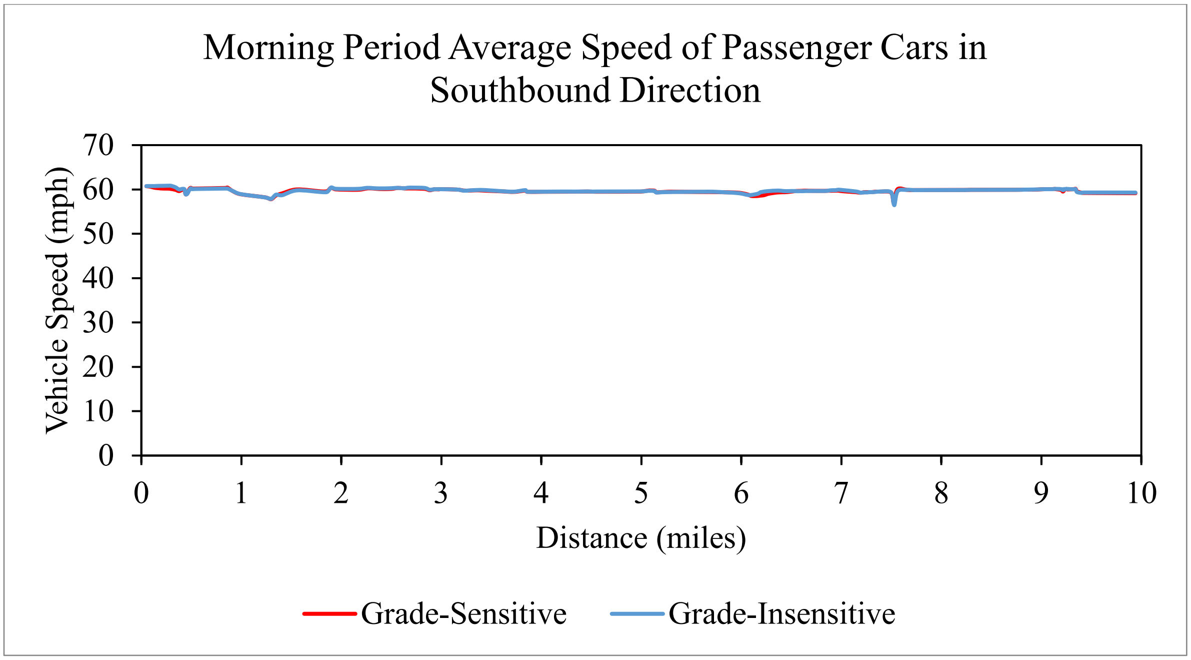

Figure 7. Average Speed of Passenger Cars in Southbound Direction during Morning Period

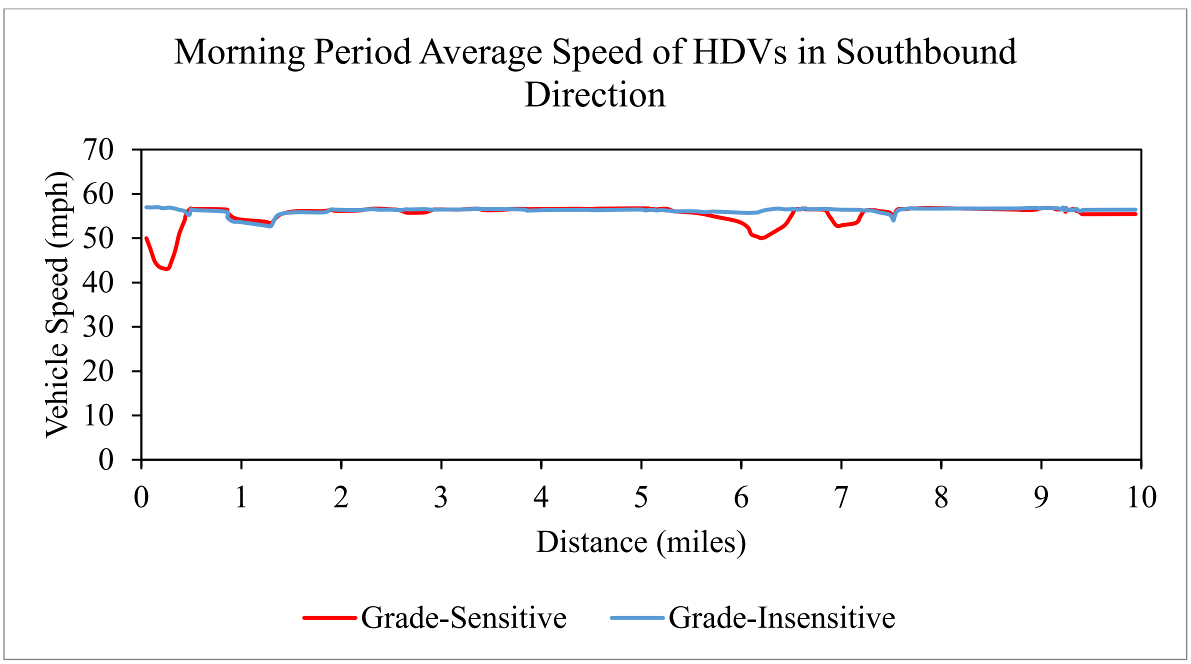

Figure 8. Average Speed of HDVs in Southbound Direction during Morning Period

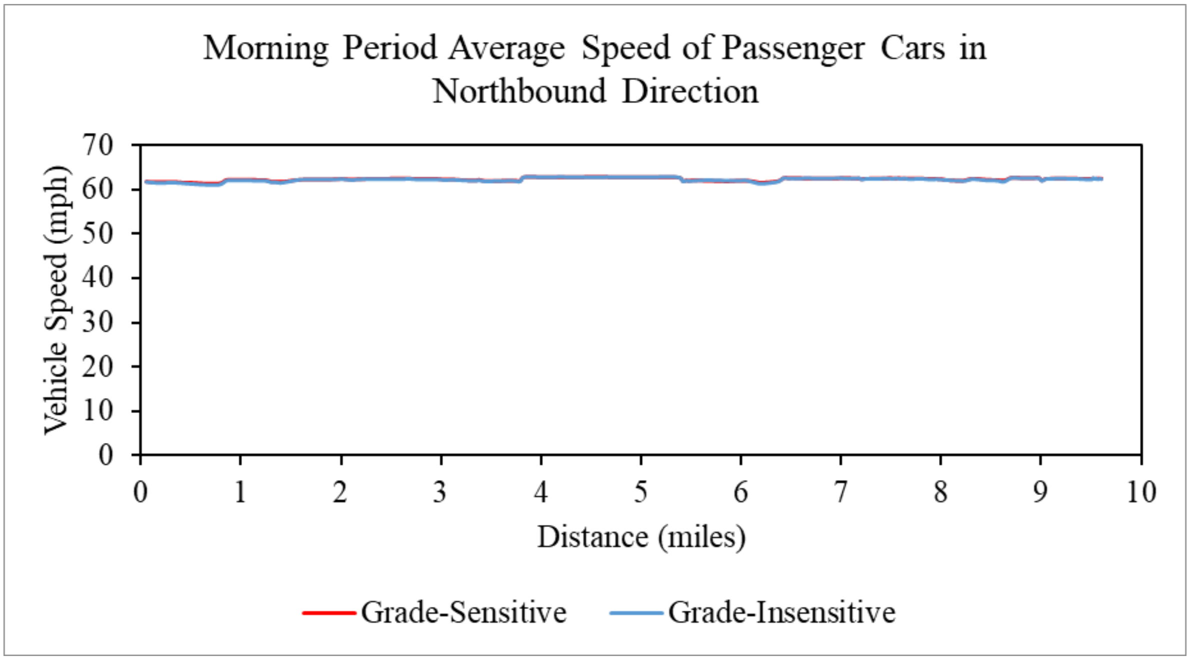

Figure 9. Average Speed of Passenger Cars in Northbound Direction during Morning Period

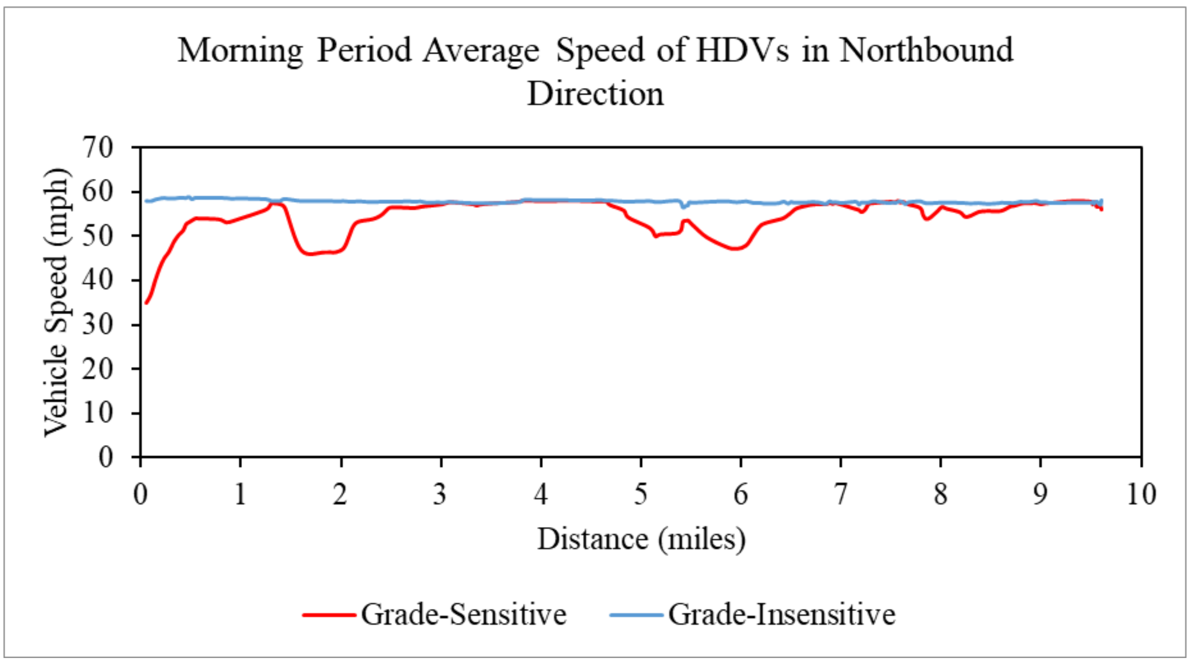

Figure 10. Average Speed of HDVs in Northbound Direction during Morning Period

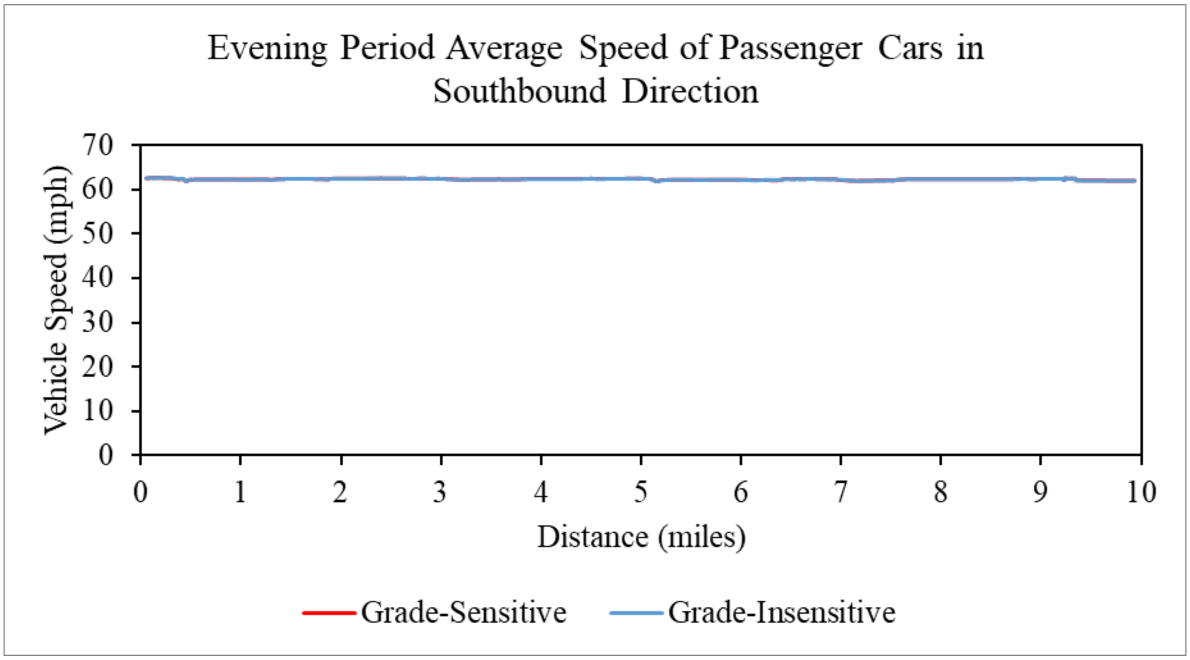

Figure 11. Average Speed of Passenger Cars in Southbound Direction during Evening Period

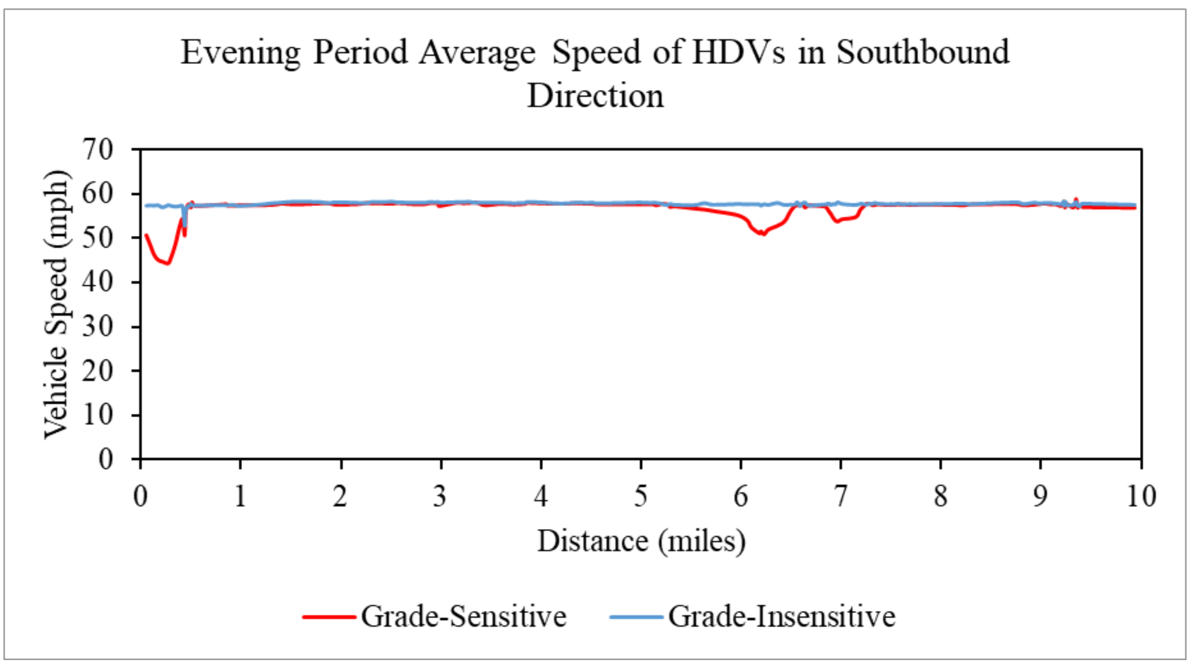

Figure 12. Average Speed of HDVs in Southbound Direction during Evening Period

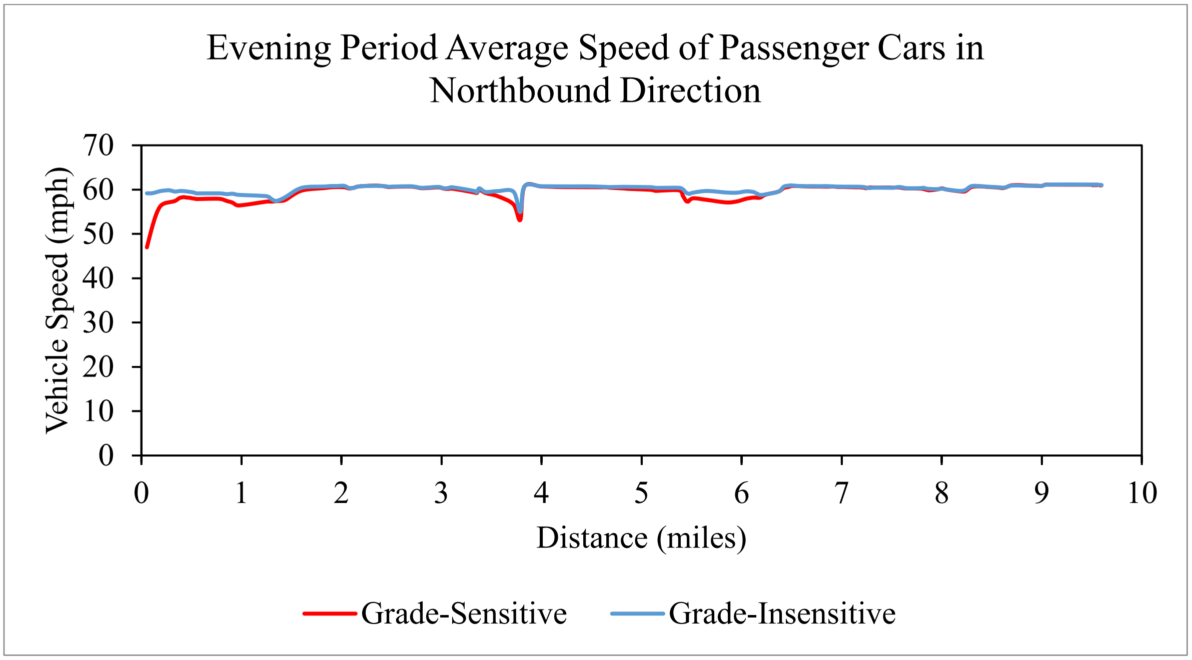

Figure 13. Average Speed of Passenger Cars in Northbound Direction during Evening Period

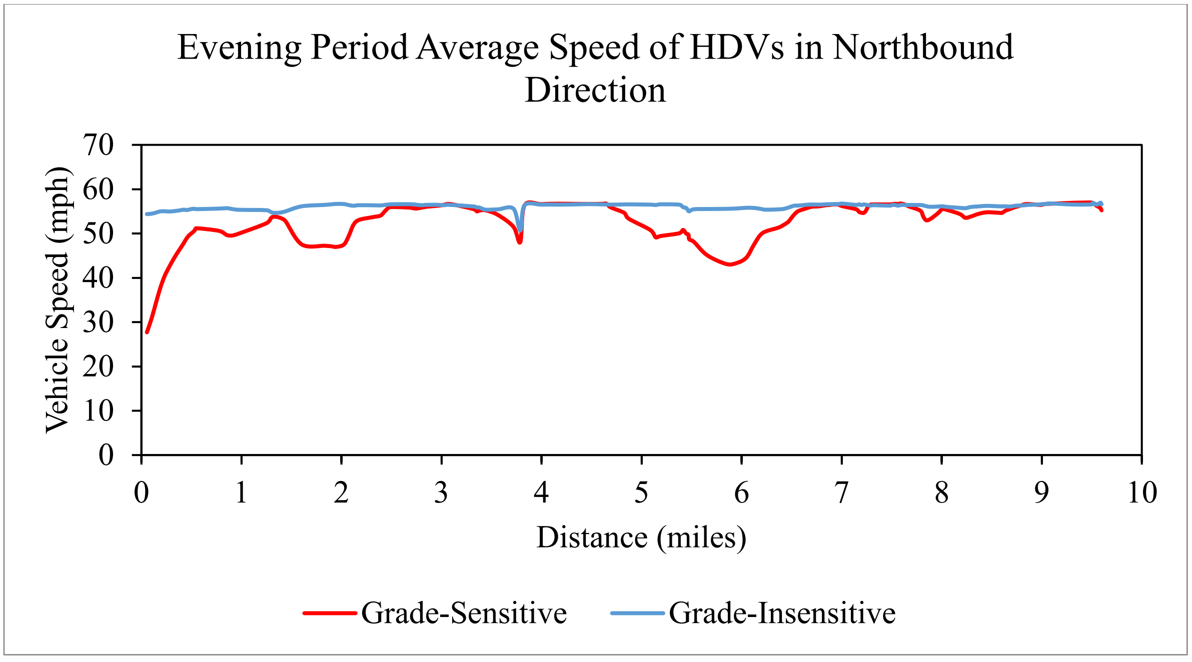

Figure 14. Average Speed of HDVs in Northbound Direction during Evening Period

Vehicle Operating Mode Distribution in Project Corridor

Next, the study also analyzed the distribution of vehicle-specific-power (VSP) / scaled-tractive-power (STP) in MOVES operating mode bins for passenger cars and HDVs respectively. The analyses showed that passenger car operating mode bin distribution between the grade-sensitive and grade-insensitive scenarios are more closely matched than HDV operating mode distribution for the same scenarios. HDV operating mode bins in the grade-sensitive scenarios were seen to spread out more into lower operating mode bins than in grade-insensitive scenarios. This observation supports the earlier inference drawn by analyzing speed profiles. Figure 14 through Figure 21 presents the vehicle operating mode distribution plots for passenger cars and HDVs.

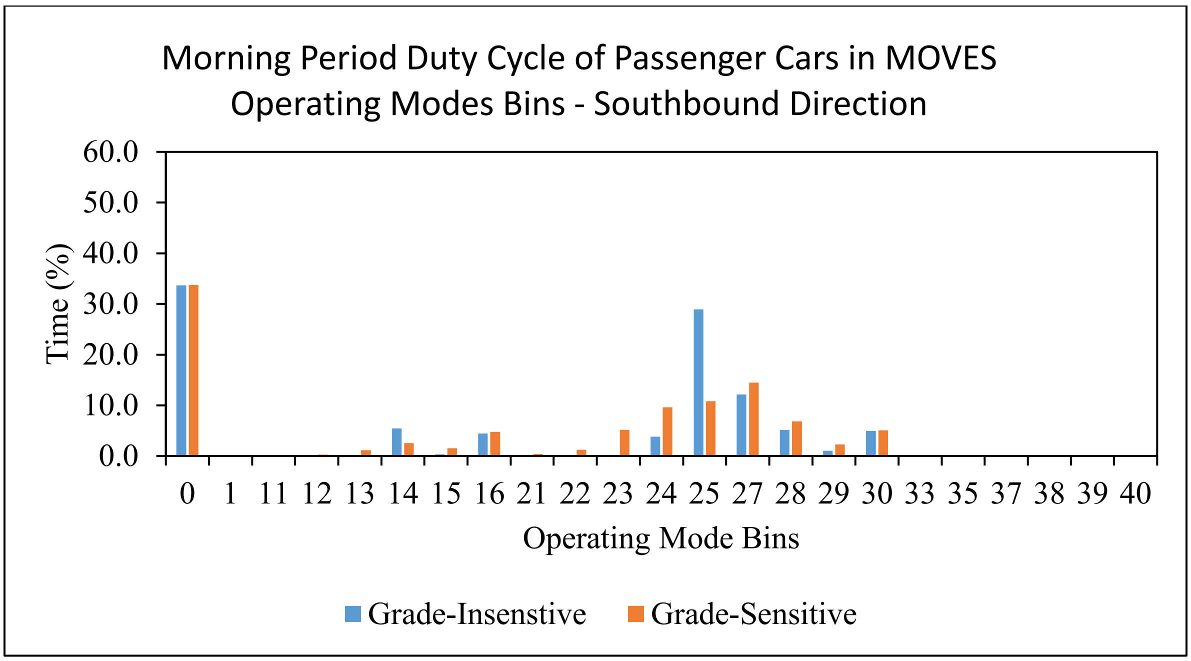

Figure 15. Operating Mode Distribution of Passenger Cars in Southbound Direction during Morning Period

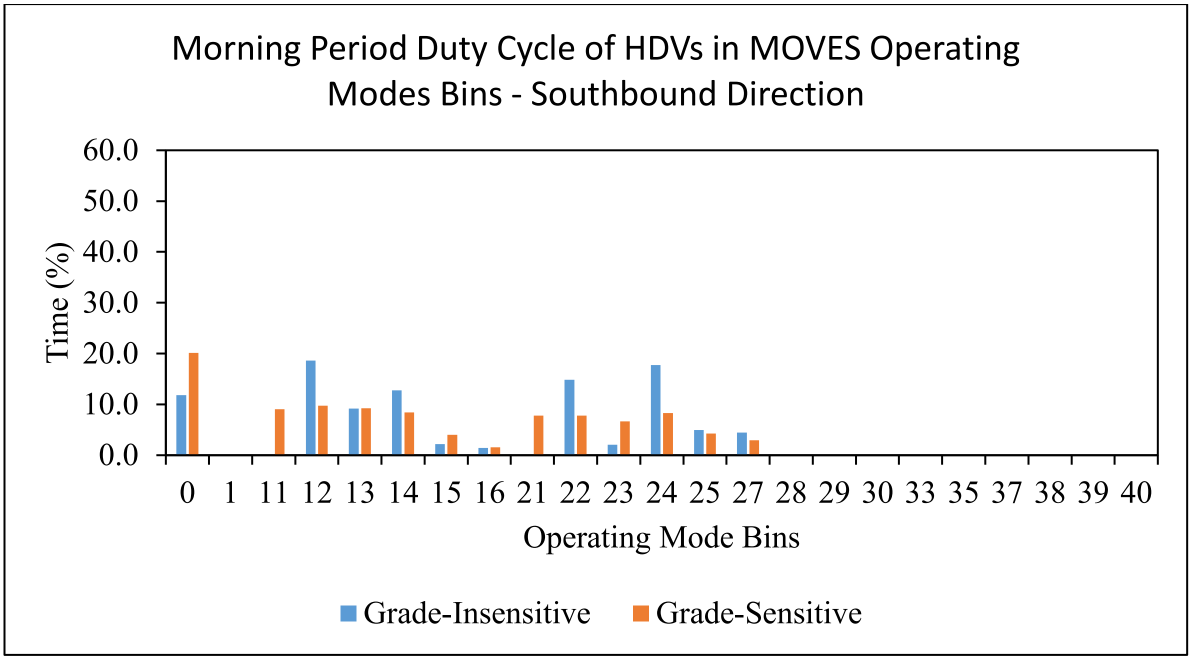

Figure 16. Operating Mode Distribution of HDVs in Southbound Direction during Morning Period

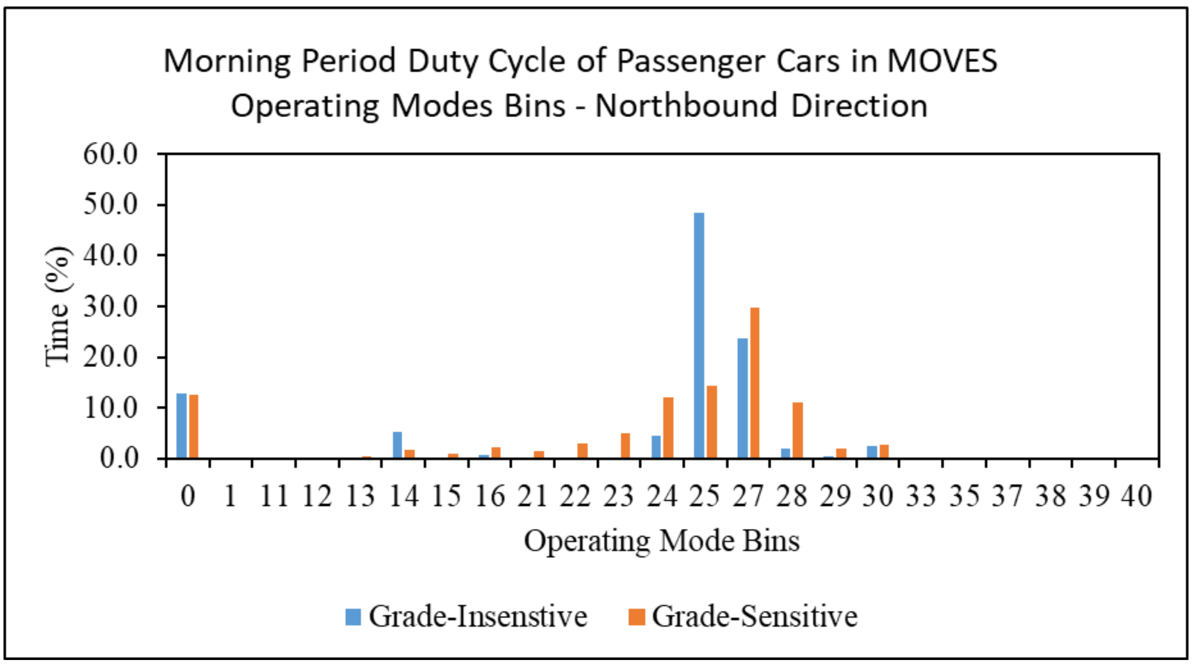

Figure 17 Operating Mode Distribution of Passenger Cars in Northbound Direction during Morning Period

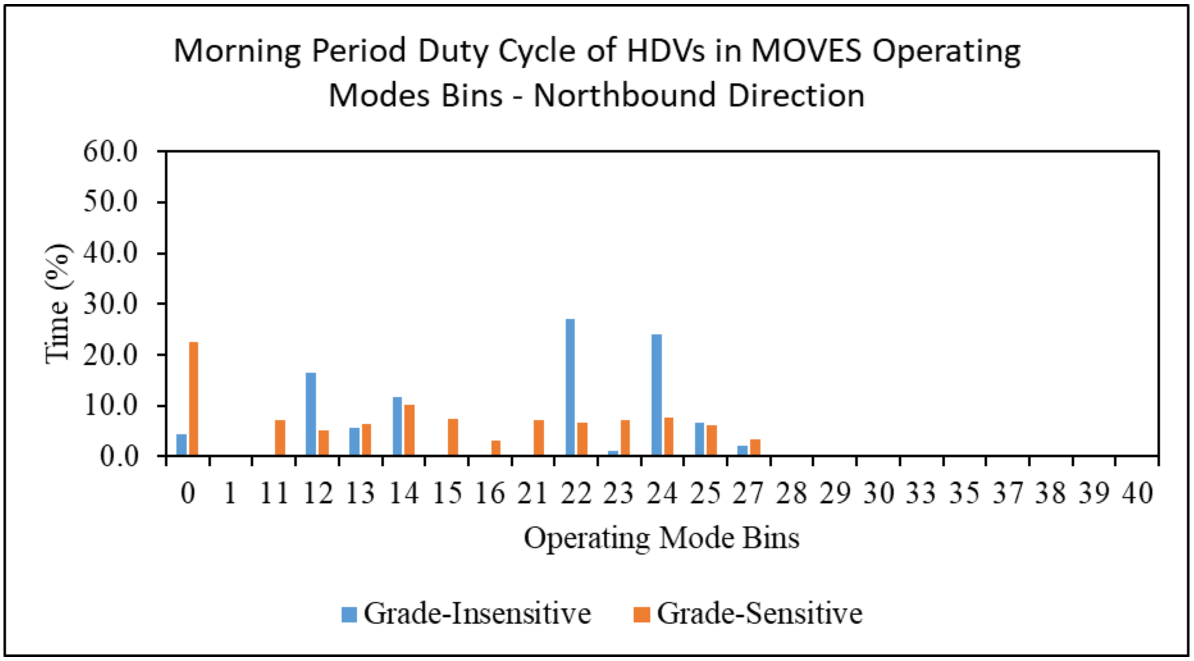

Figure 18. Operating Mode Distribution of HDVs in Northbound Direction during Morning Period

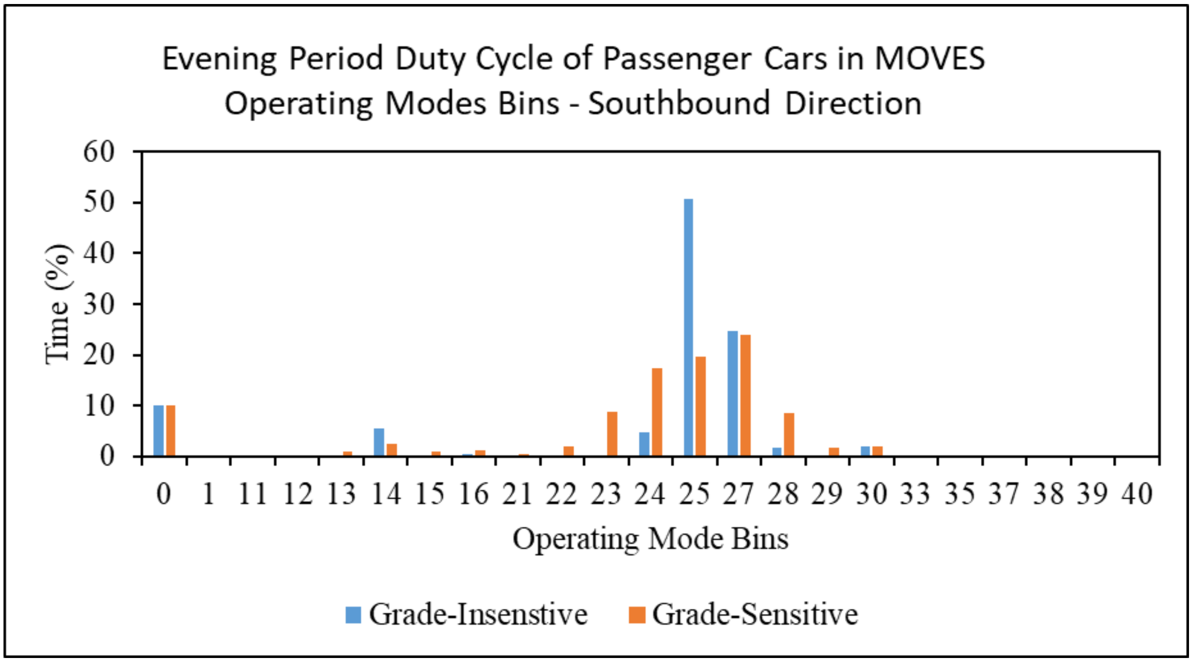

Figure 19. Operating Mode Distribution of Passenger Cars in Southbound Direction during Evening Period

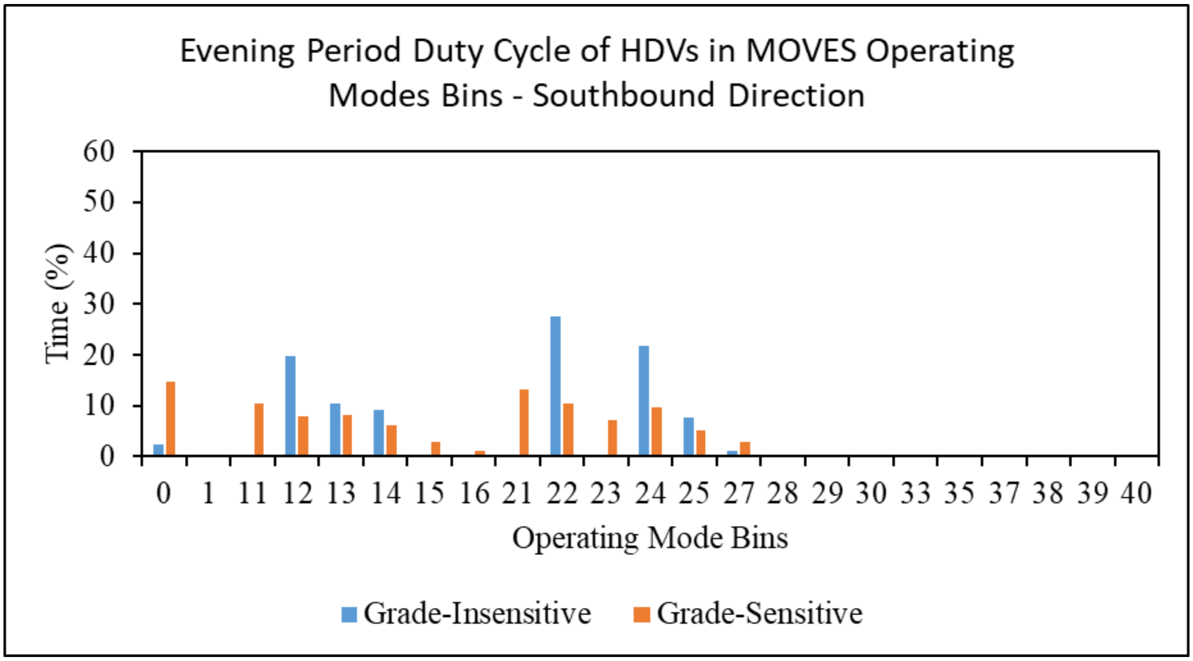

Figure 20. Operating Mode Distribution of HDVs in Northbound Direction during Evening Period

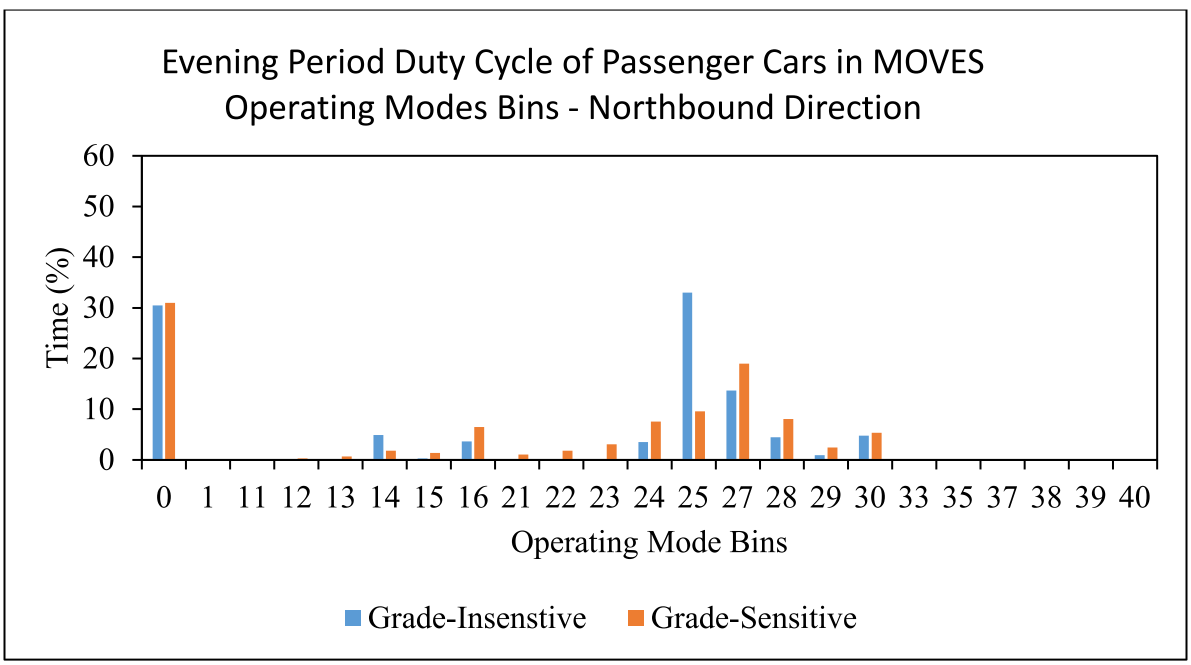

Figure 21. Operating Mode Distribution of Passenger Cars in Northbound Direction during Evening Period

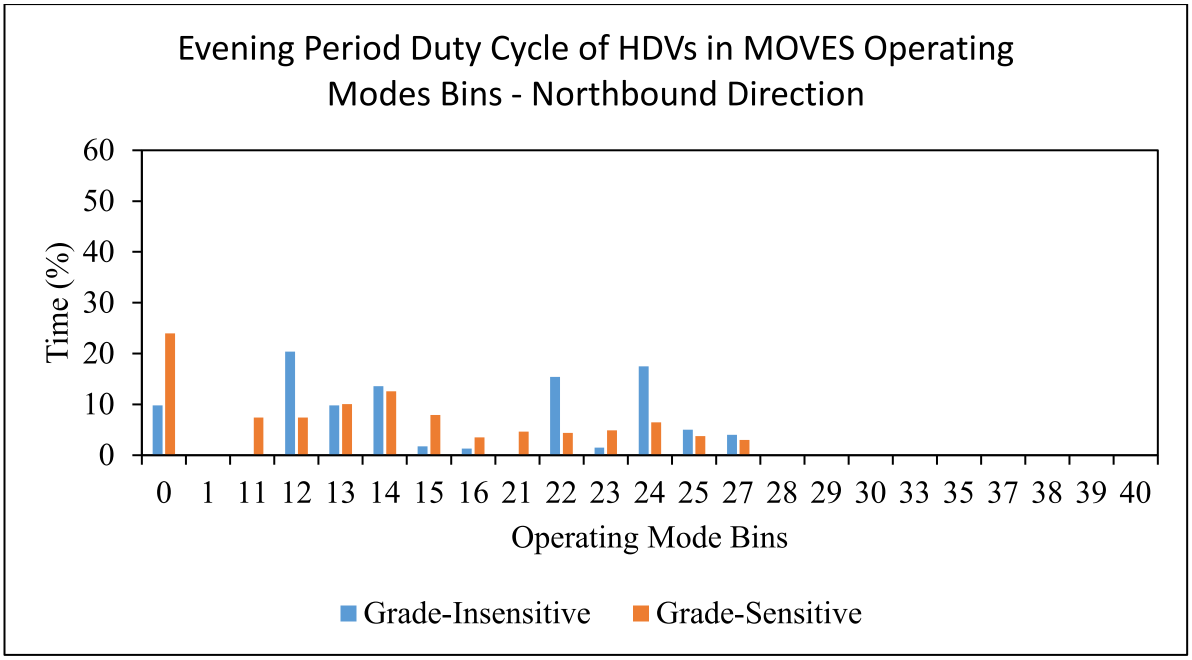

Figure 22. Operating Mode Distribution for HDVs in Northbound Direction during Evening Period

Spatial Analysis of Carbon Monoxide Air Dispersion

AERMOD Screen analysis was performed first for CO dispersion. In all there were 8 scenarios; 4 runs each for winter and summer periods, and within each of these seasonal periods there were two runs for morning and evening periods. Finally, for each set of morning or evening period there were two model runs. One run uses MOVES emission inventory data that is based on grade-sensitive vehicle speed and accelerations as well as MOVES VSP calculations that account for grade effects. The other run does not capture the effect of grade at all.

AERMOD outputs CO receptor concentrations in micrograms per cubic meter ($\mu g/m^3$). However, the USEPA NAAQS threshold value for CO is defined in parts per million (ppm). Therefore, the study converted the AERMOD outputs before developing heat maps for spatial analysis. The conversion formula (Boguski 2006) is given below in Equation 2.

$$Concentration\ (ppm) = \frac{24.45 * Concentration\ (\mu g/m^3)}{Molecular\ Weight * 1{,}000} \quad (2)$$

The results of the AERMOD Screen analysis shows that there is no notable visual difference in spatial variability of CO dispersion between corresponding grade-sensitive and grade-insensitive scenarios. There were about 20,000 vehicles in each scenario and almost all the vehicles are passenger cars whose speed and operating modes were found to be quite unresponsive to road grade in this study. Therefore, it is understandable that no notable visual difference in CO dispersion was seen between the grade-sensitive and grade-insensitive scenarios because passenger car engines contribute more CO emissions than HDV engines. Next, it was observed that the summer scenarios (see Figure 22 through Figure 25) show higher concentrations and spread of CO compared to the corresponding winter scenarios (see Figure 26 through Figure 29). The highest CO concentrations and spread can be seen in the grade-sensitive summer evening scenario.

When a contour of value 9 ppm (NAAQS threshold) was superimposed on the heat maps, the contour was well contained within the 200-meter buffer in all the winter scenarios. For the summer scenarios the buffer was just able to contain the contour in some places and the contour actually crossed the buffer in the grade-sensitive summer evening scenario (see Figure 25) Since AERMOD Screen analysis is expected to yield the worst-possible one hour receptor concentrations, this observation indicates that only the grade-sensitive summer evening scenario needs further detailed analysis with AERMOD Flat analysis option.

The results of the detailed analysis with AERMOD Flat analysis option indicated that the 200-meter buffer will be adequate to contain the NAAQS contour. Therefore, the overall results for CO dispersion is that the existing 200-meter buffer will be adequate for the road grade profile and average corridor speed (free flow) evaluated in this study.

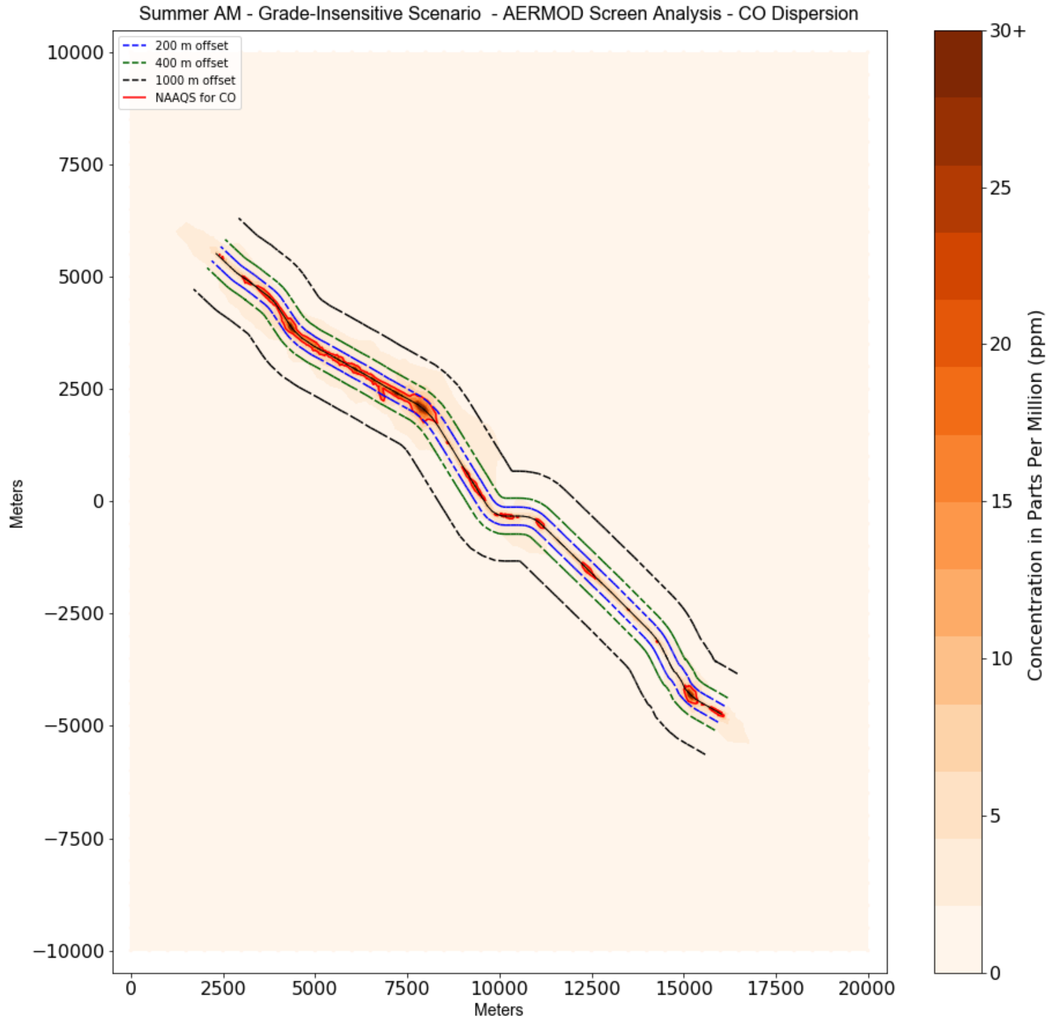

Figure 23. Spatial Analysis of Dispersed CO Concentration for Summer Morning Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

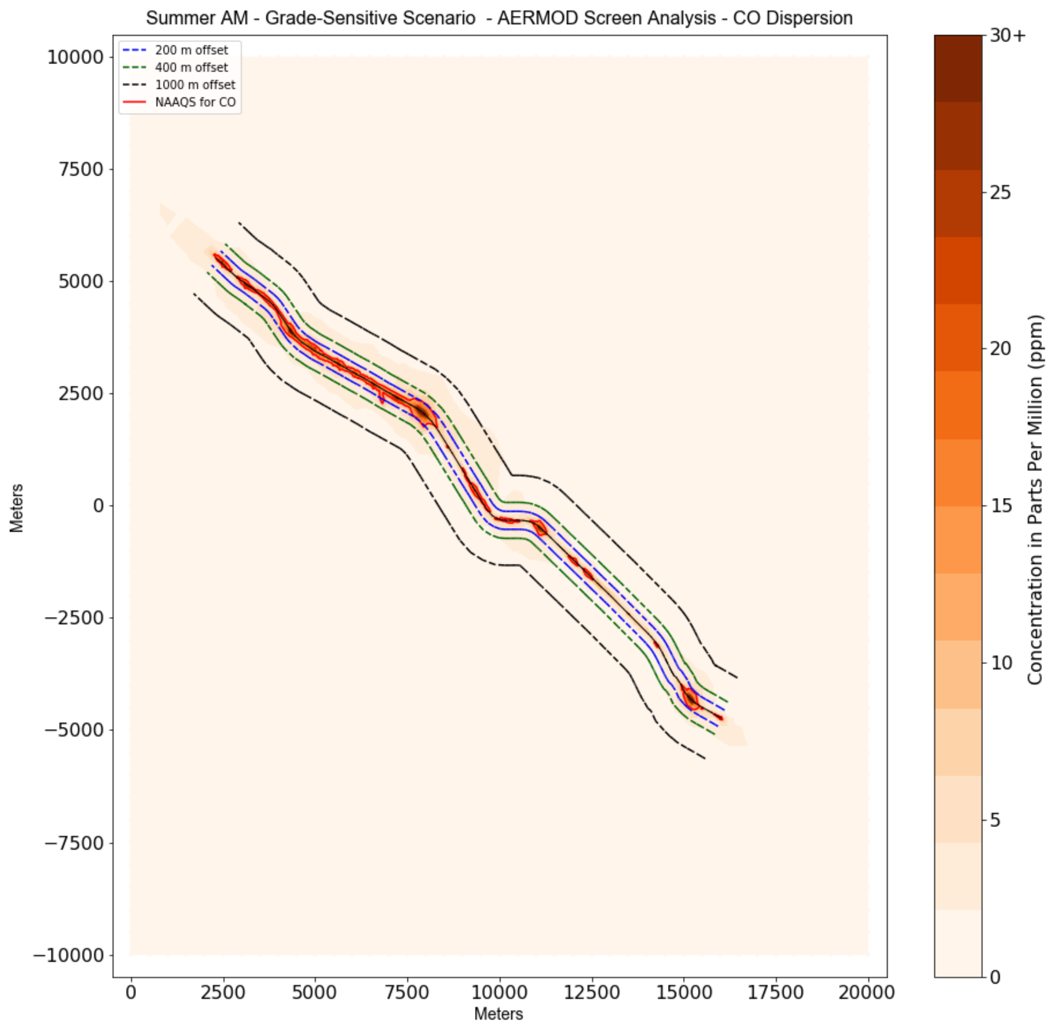

Figure 24. Spatial Analysis of Dispersed CO Concentration for Summer Morning Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

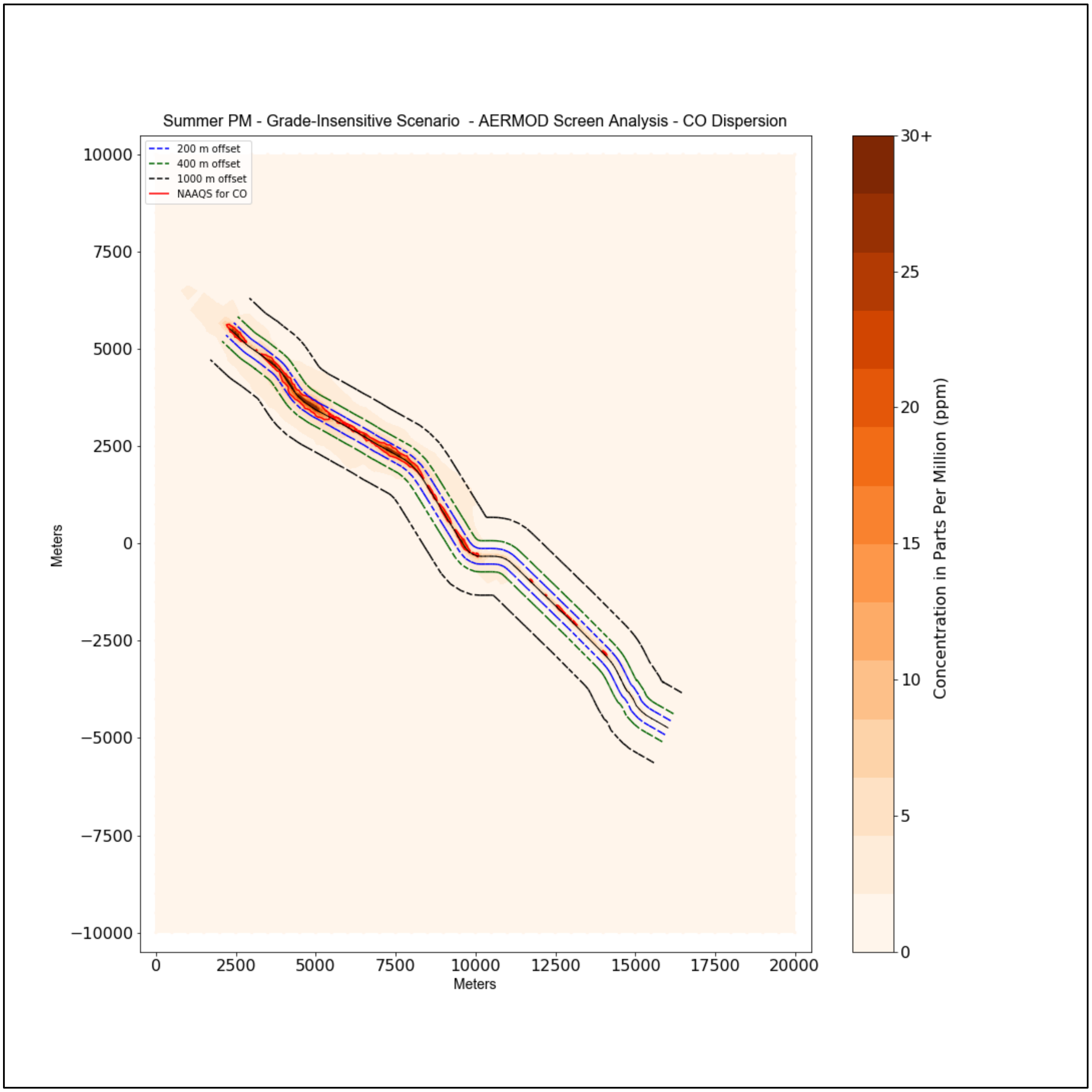

Figure 25. Spatial Analysis of Dispersed CO Concentration for Summer Evening Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

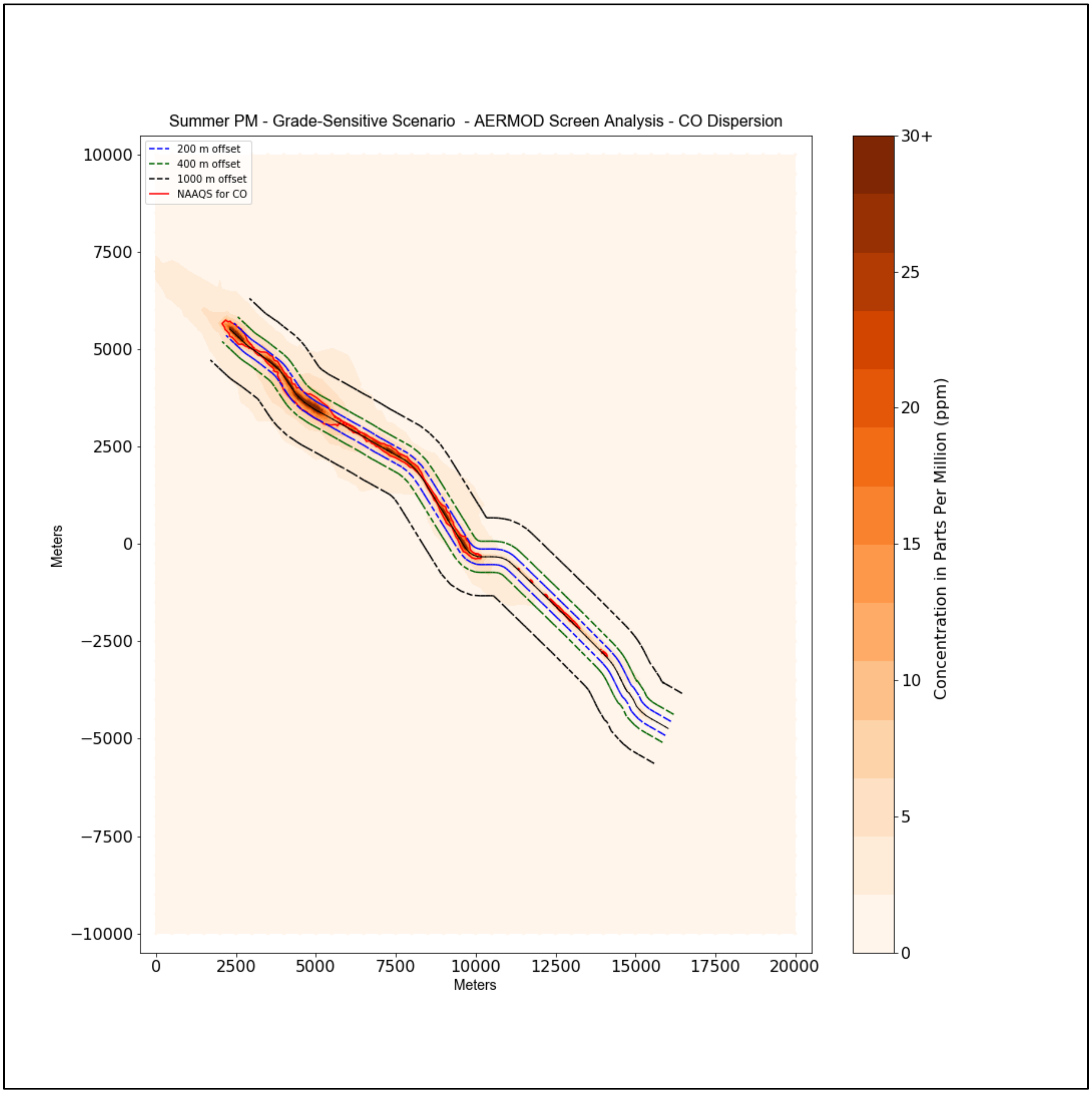

Figure 26. Spatial Analysis of Dispersed CO Concentration for Summer Evening Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

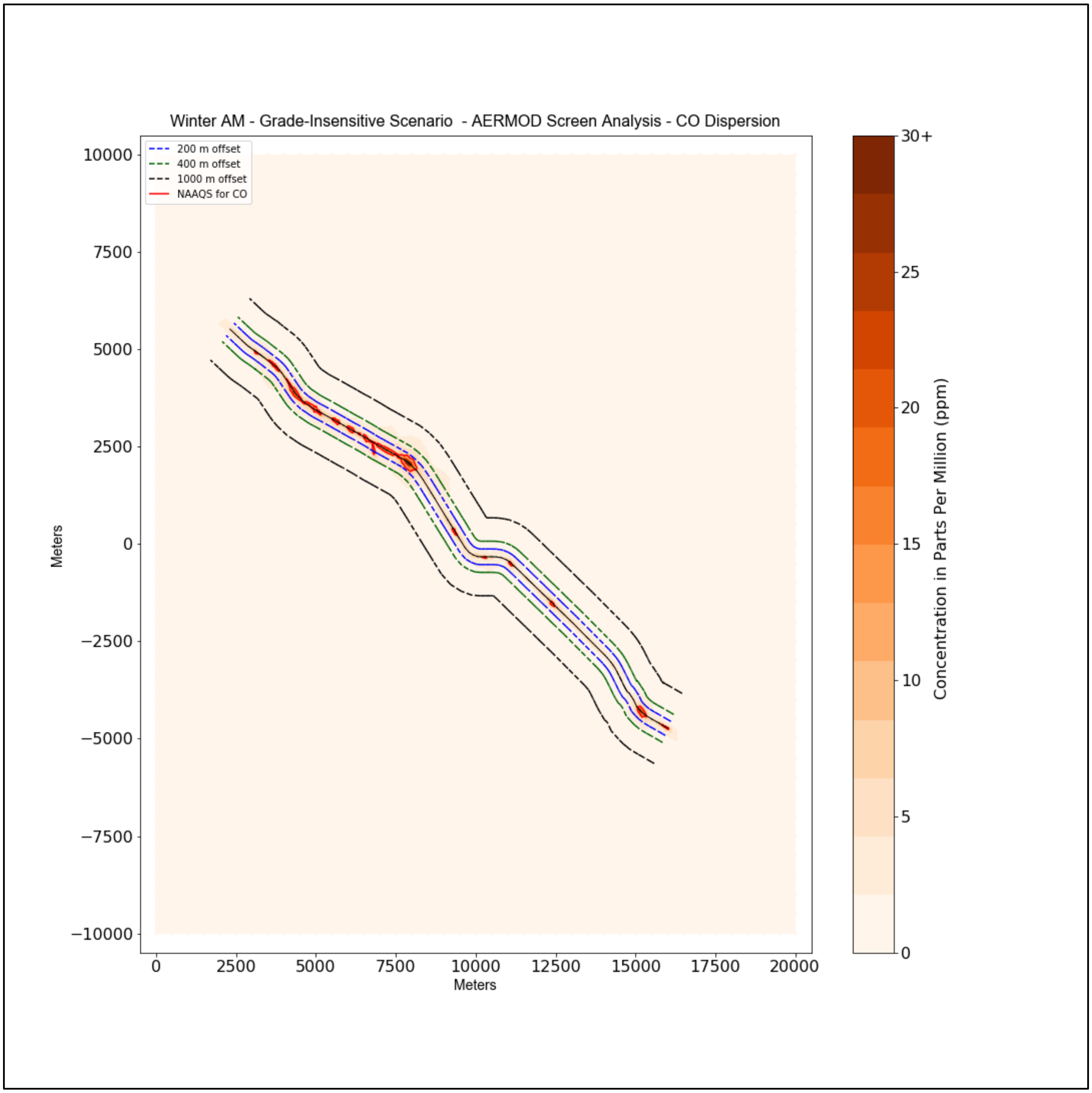

Figure 27. Spatial Analysis of Dispersed CO Concentration for Winter Morning Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

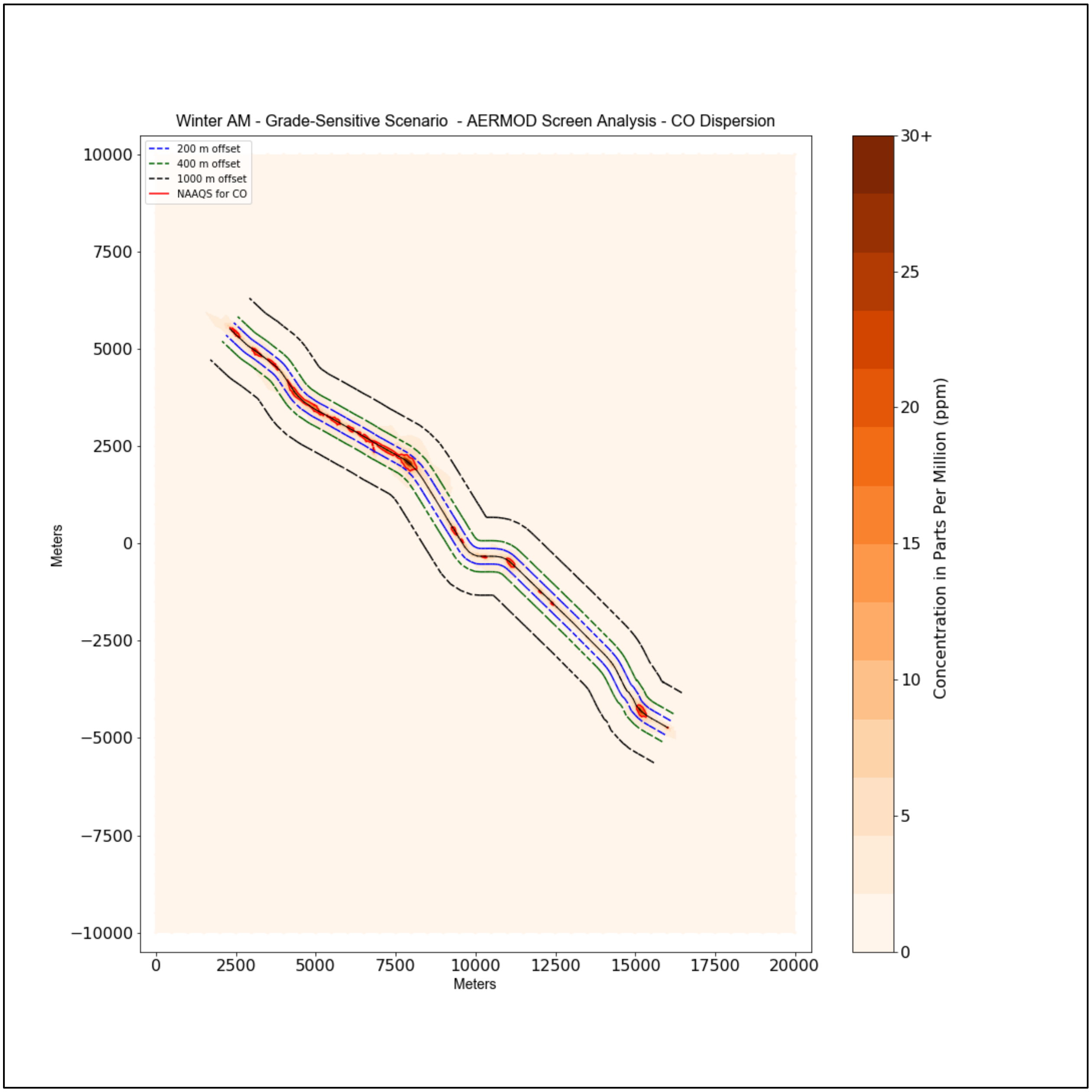

Figure 28. Spatial Analysis of Dispersed CO Concentration for Winter Morning Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

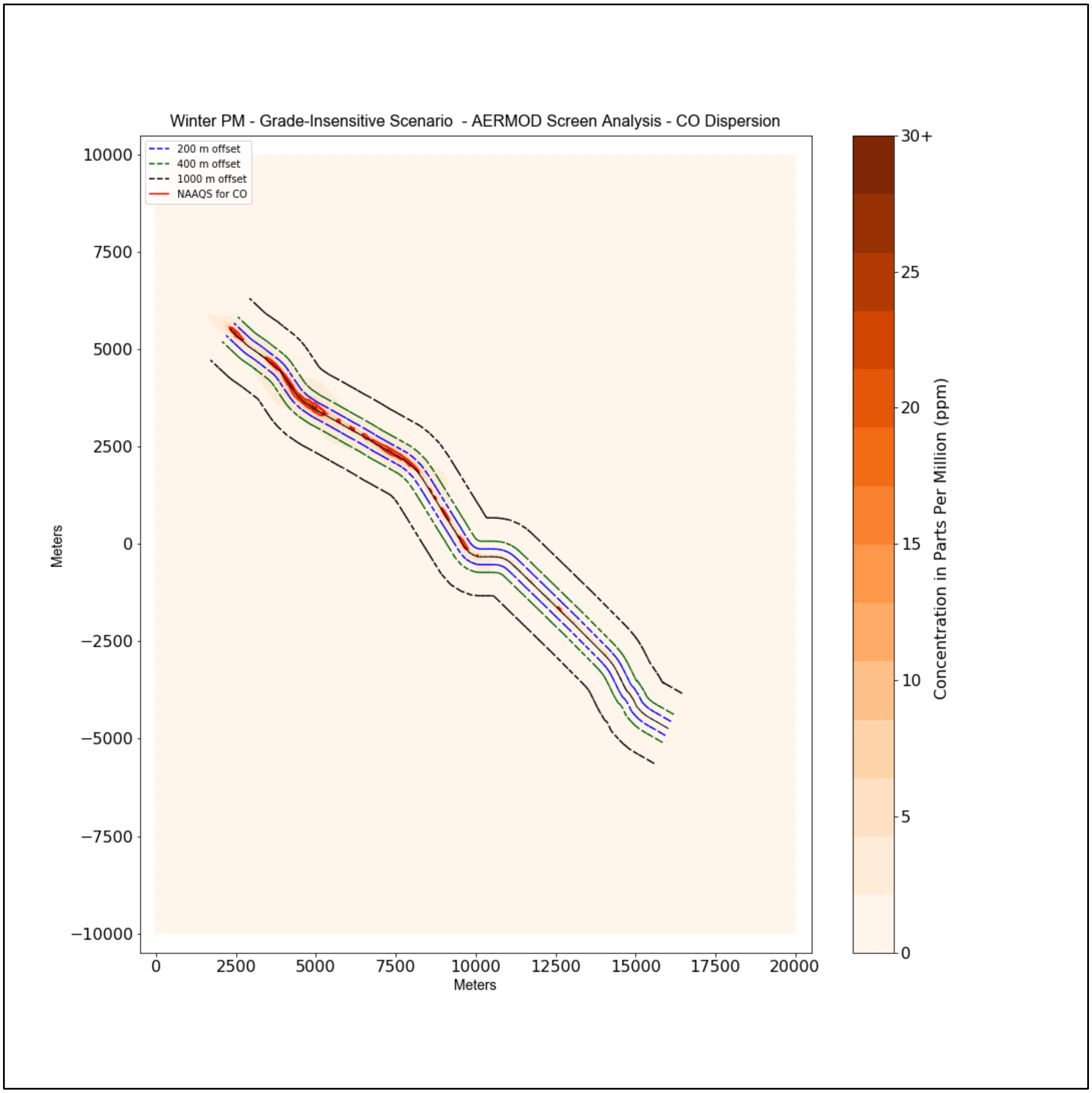

Figure 29. Spatial Analysis of Dispersed CO Concentration for Winter Evening Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

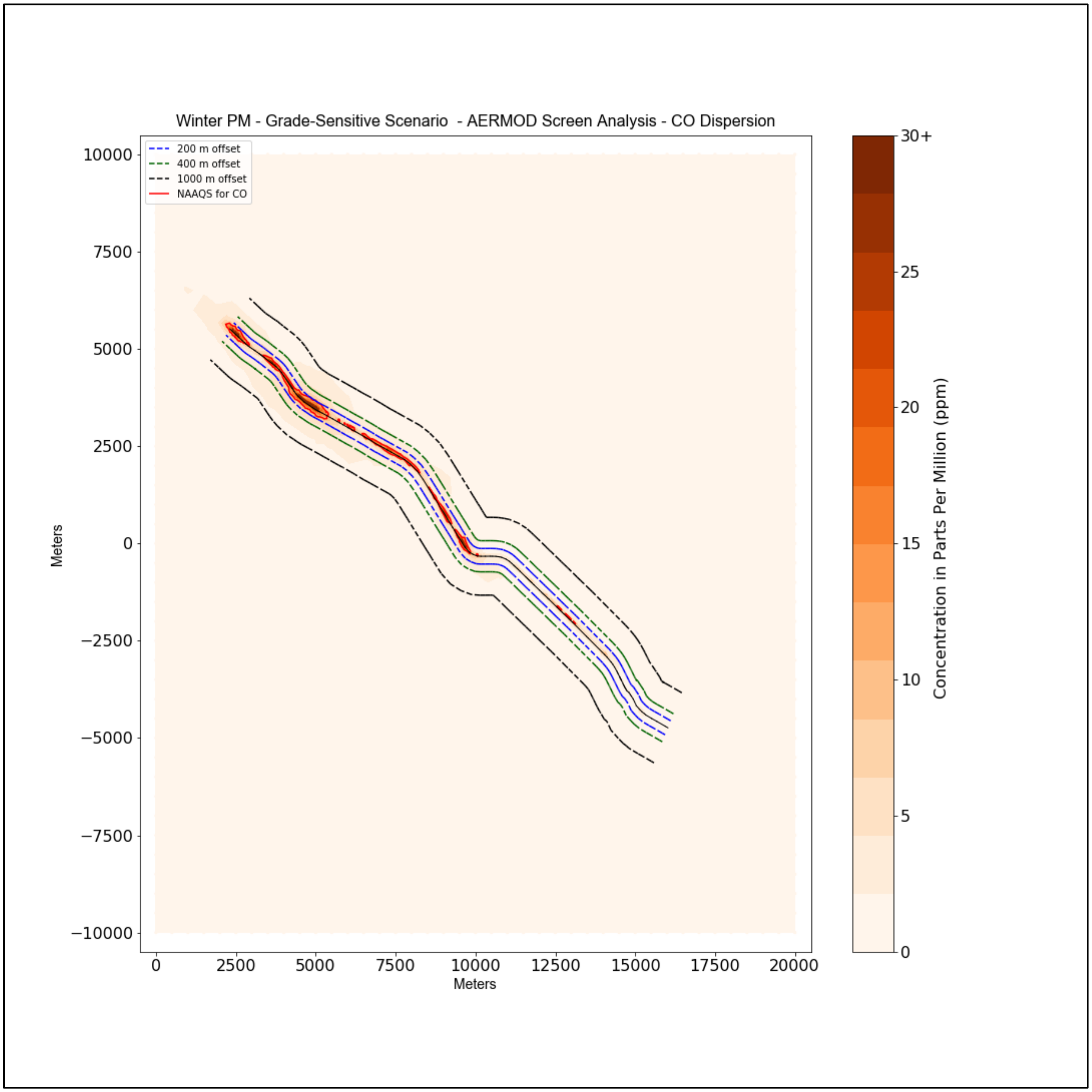

Figure 30. Spatial Analysis of Dispersed CO Concentration for Winter Evening Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

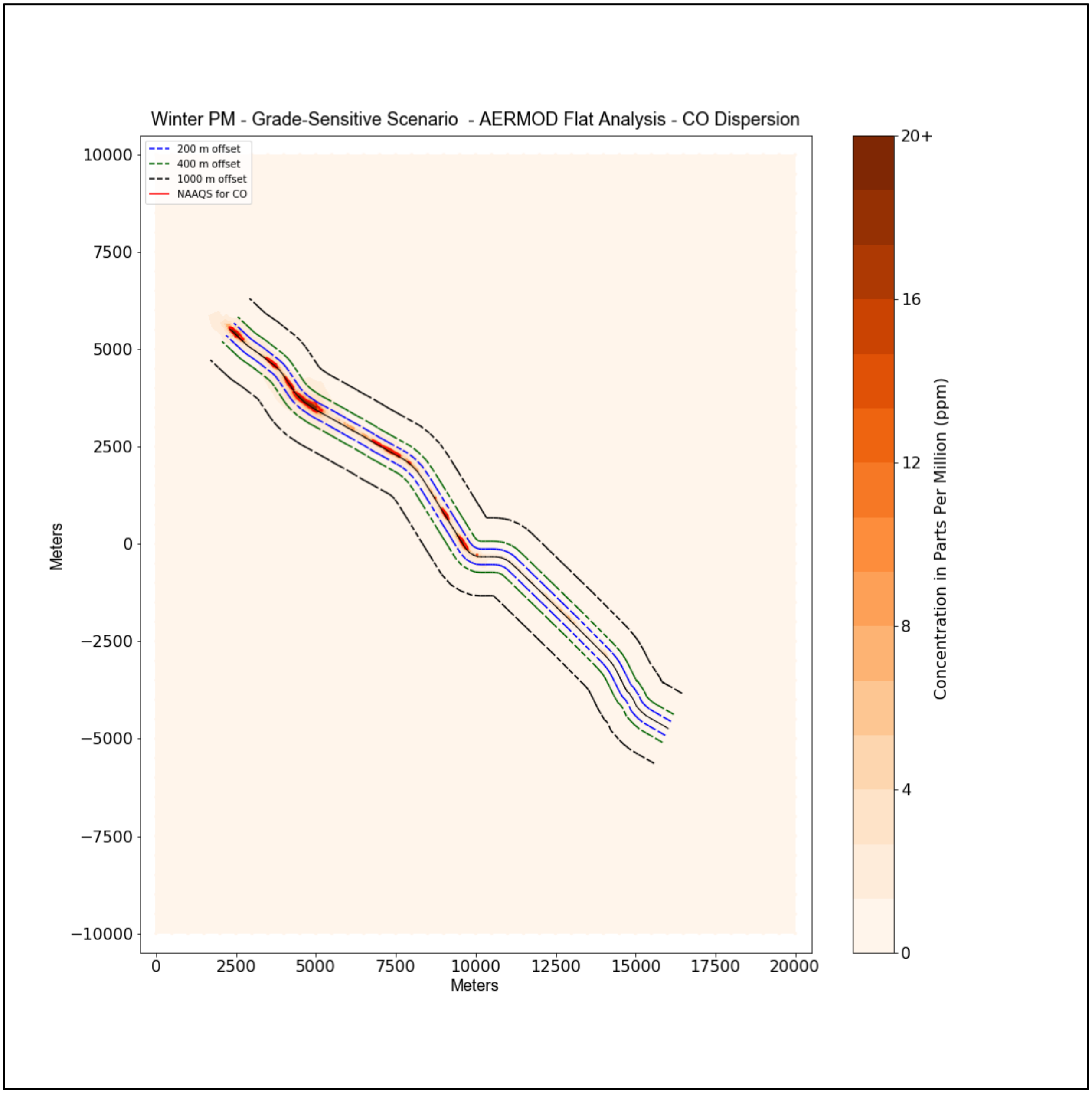

Figure 31. Spatial Analysis of Dispersed CO Concentration for Summer Evening Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Flat Analysis Option

Spatial Analysis of Particulate Matter ($PM_{2.5}$) Air Dispersion

As in the case of CO dispersion analysis, an initial AERMOD Screen analysis was performed for $PM_{2.5}$ dispersion. In all there were 8 scenarios; 4 runs each for winter and summer periods, and within each of these seasonal periods there were two runs for morning and evening periods. For each set of morning or evening period there were two model runs. One run uses MOVES emission inventory data that is based on grade-sensitive vehicle speed and accelerations as well as MOVES VSP calculations that account for grade effects. The other run does not capture the effect of grade at all.

The results of the screen analysis show notable visual difference between grade-sensitive scenarios and their corresponding grade-insensitive scenarios. Also, the difference is more notable in the winter (see Figure 36 through Figure 39) than in the summer (see Figure 31 through Figure 34). The highest concentrations and spread of $PM_{2.5}$ was found in the grade-sensitive winter evening scenario (see Figure 38).

Next, in all the scenarios the study finds that the 200-meter buffer is inadequate and it fails to contain the NAAQS threshold contour of 12 $\mu g/m^3$ at several places in the corridor. In fact, in all cases it was found that a buffer of 400 meters would still be inadequate in several places. The most notable case of inadequacy was found in the grade-sensitive winter evening scenario which showed that even a buffer of 1-kilometer on either side of the road would be barely adequate.

Since AERMOD Screen analysis is expected to yield the worst-possible one hour receptor concentrations, this observation indicates that all the scenarios need further detailed analysis with AERMOD Flat analysis option. However, detailed analysis with AERMOD Flat analysis option on the grade-sensitive winter evening scenario (the worst of the scenarios) showed that the existing 200-meter buffer would be adequate to contain the NAAQS contour of 12 $\mu g/m^3$ (see Figure 40). Therefore, it can be deduced that for the road grade profile and average corridor speed (free flow) evaluated in this study, the existing 200-meter buffer will be adequate for all the $PM_{2.5}$ dispersion scenarios.

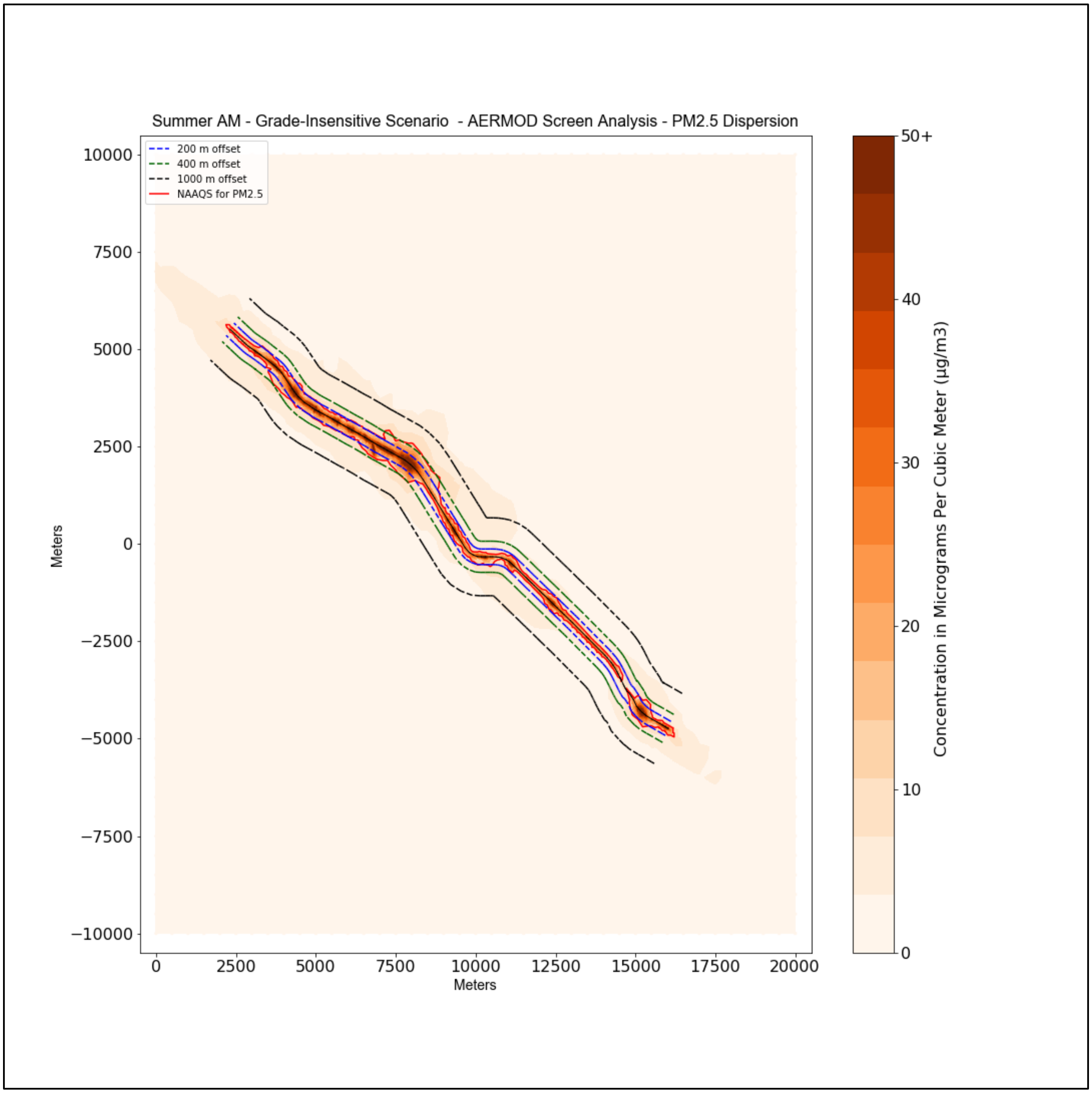

Figure 32. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Summer Morning Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

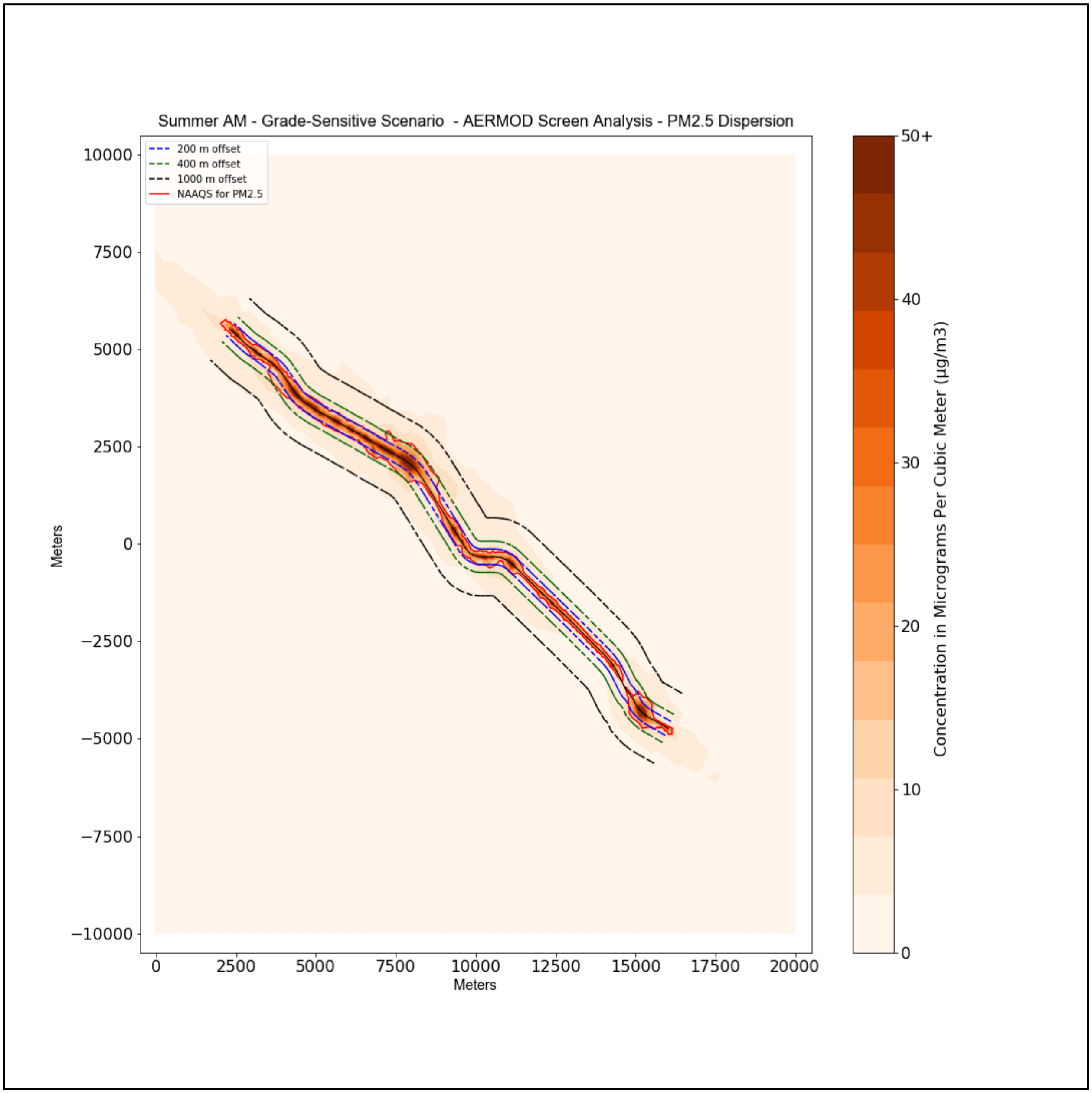

Figure 33. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Summer Morning Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

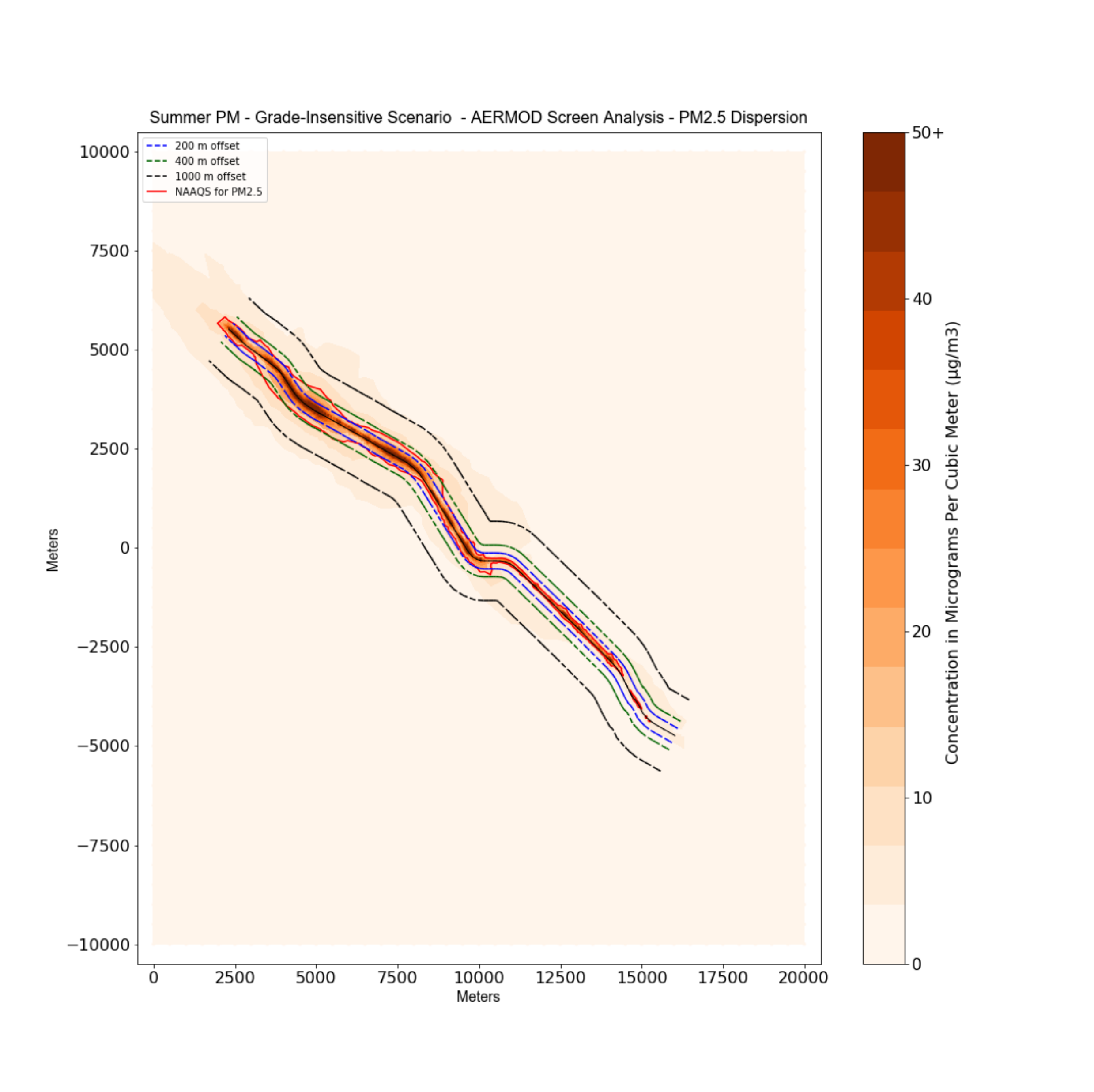

Figure 34. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Summer Evening Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

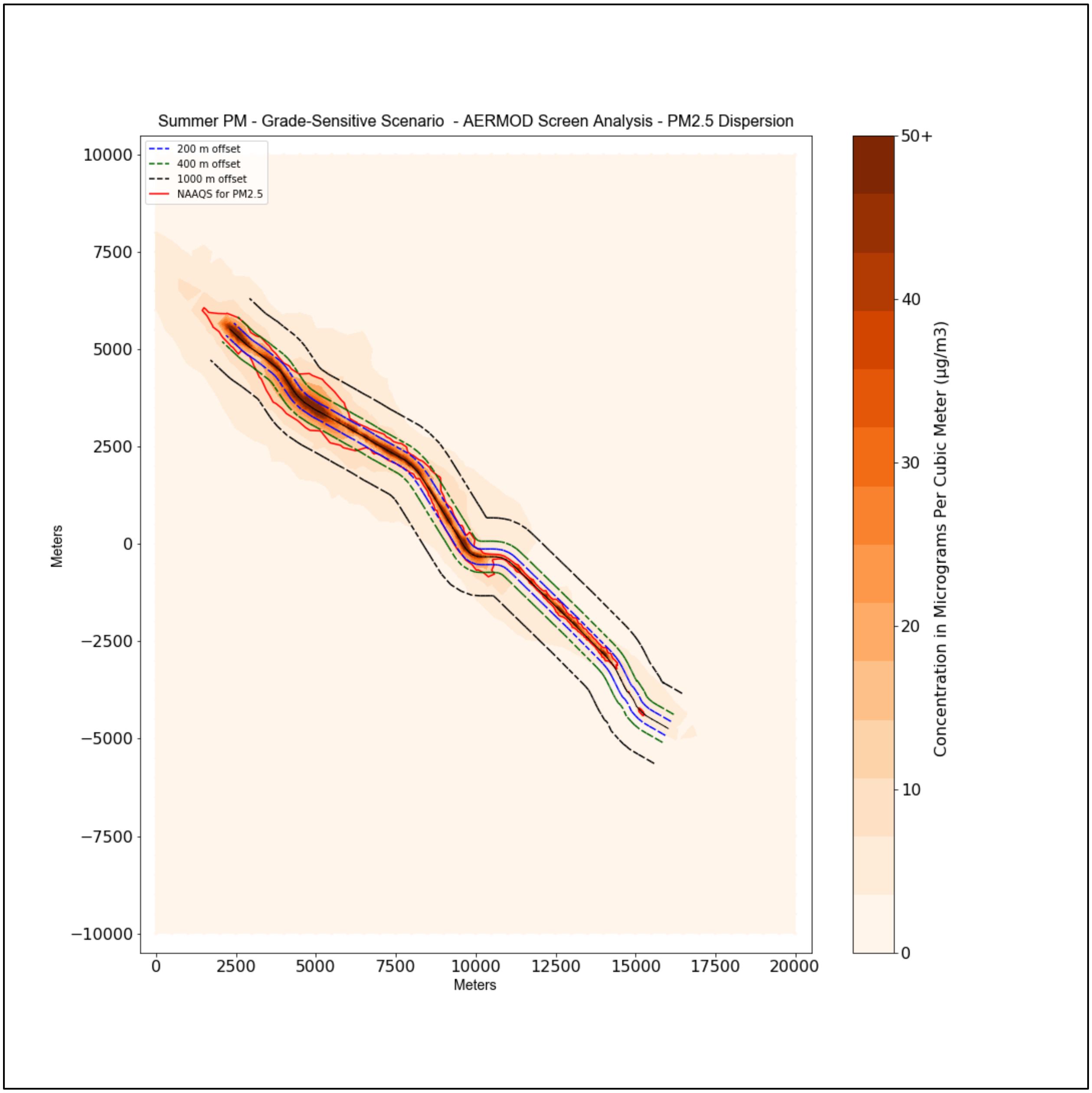

Figure 35. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Summer Evening Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

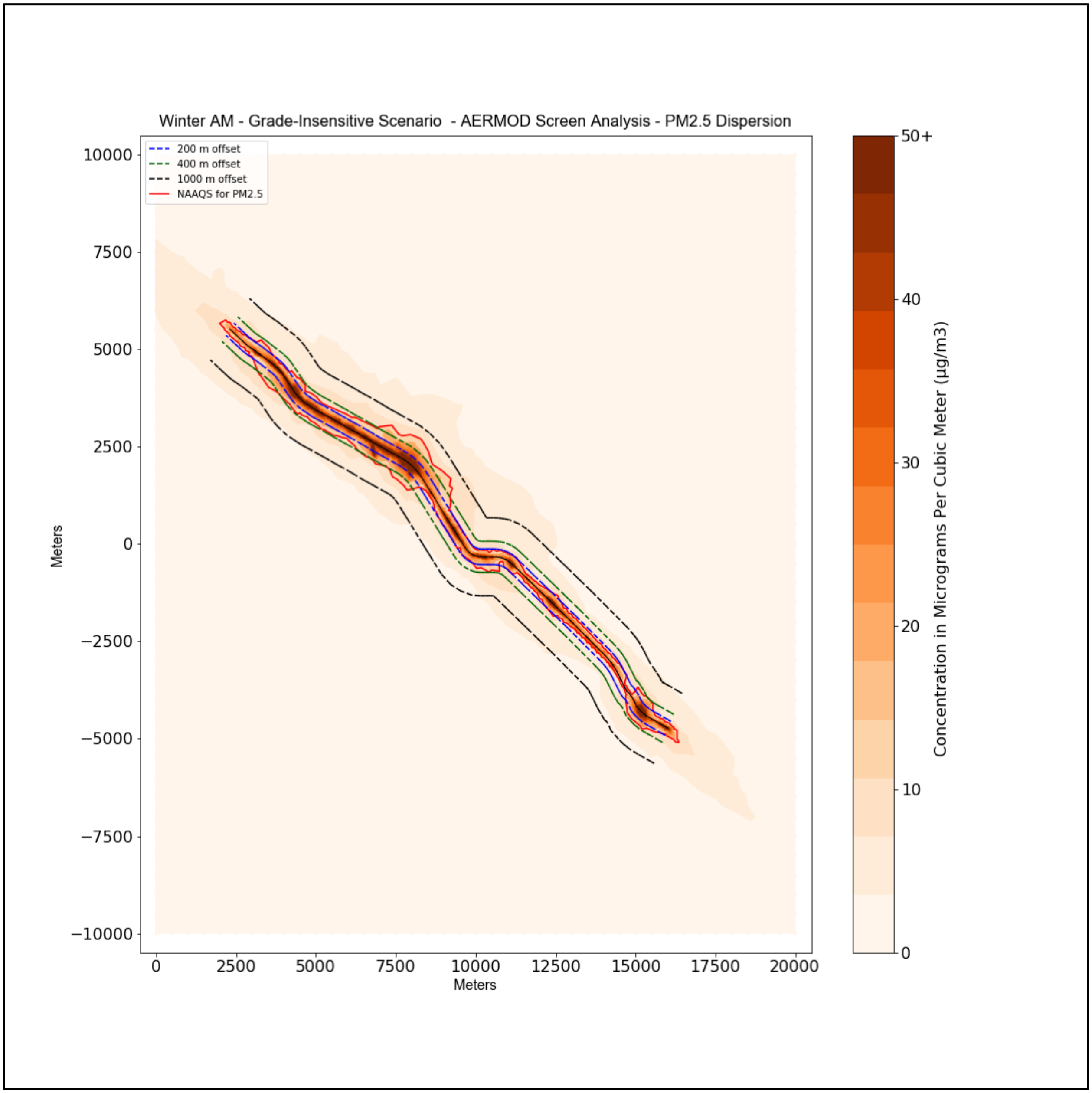

Figure 36. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Winter Morning Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

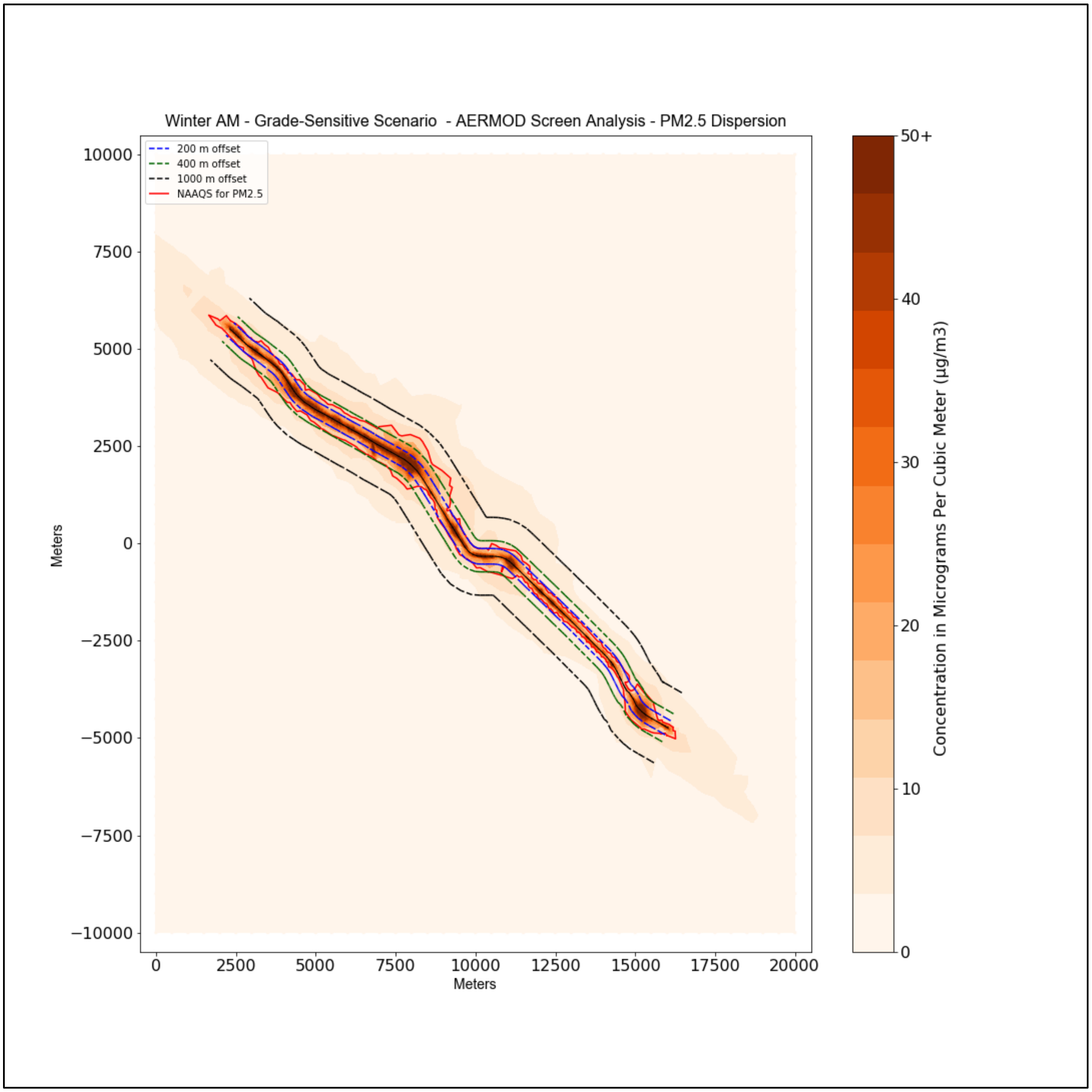

Figure 37. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Winter Morning Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

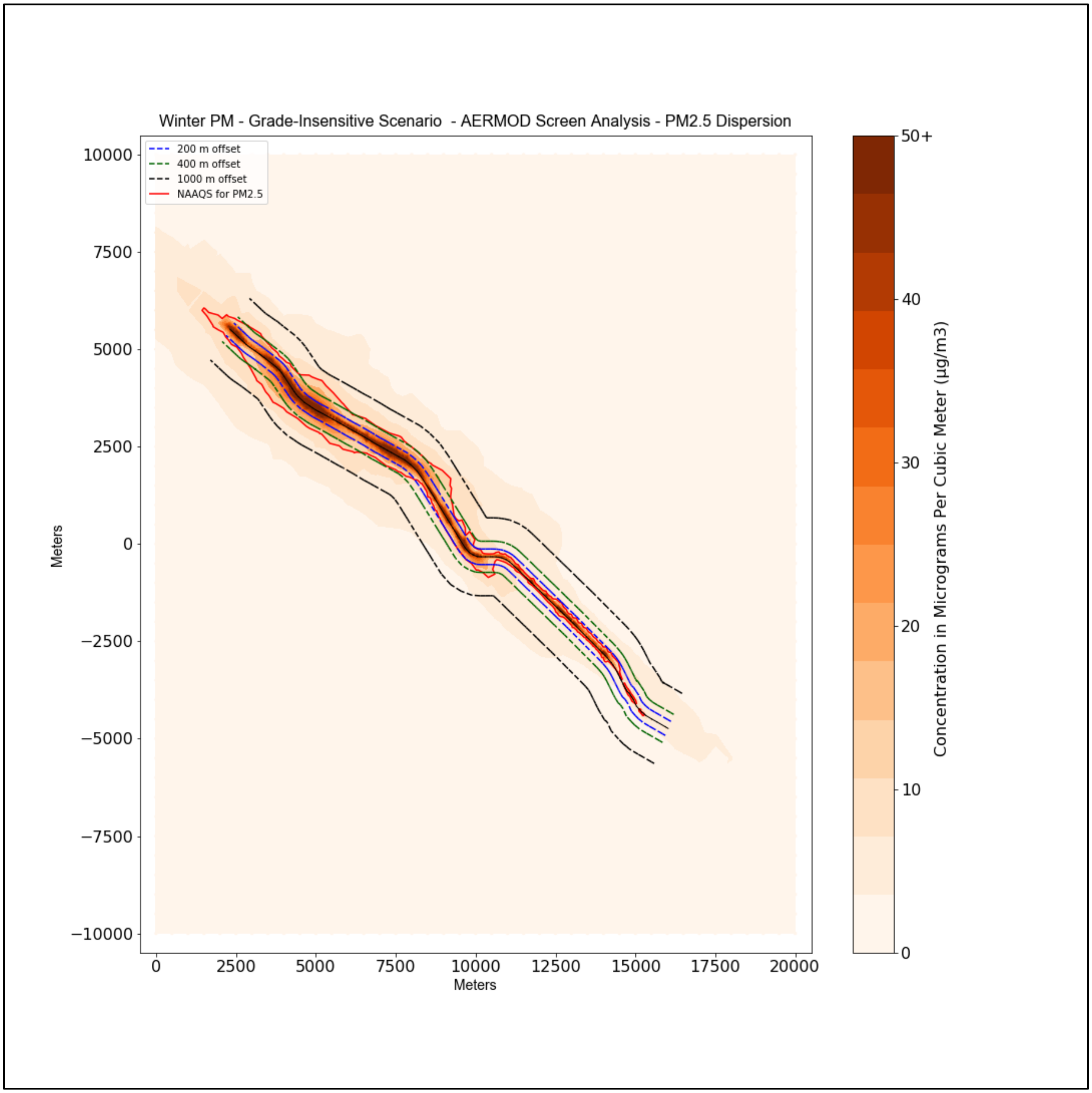

Figure 38. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Winter Evening Period Based on Grade-Insensitive Traffic Simulation Model and AERMOD Screen Analysis Option

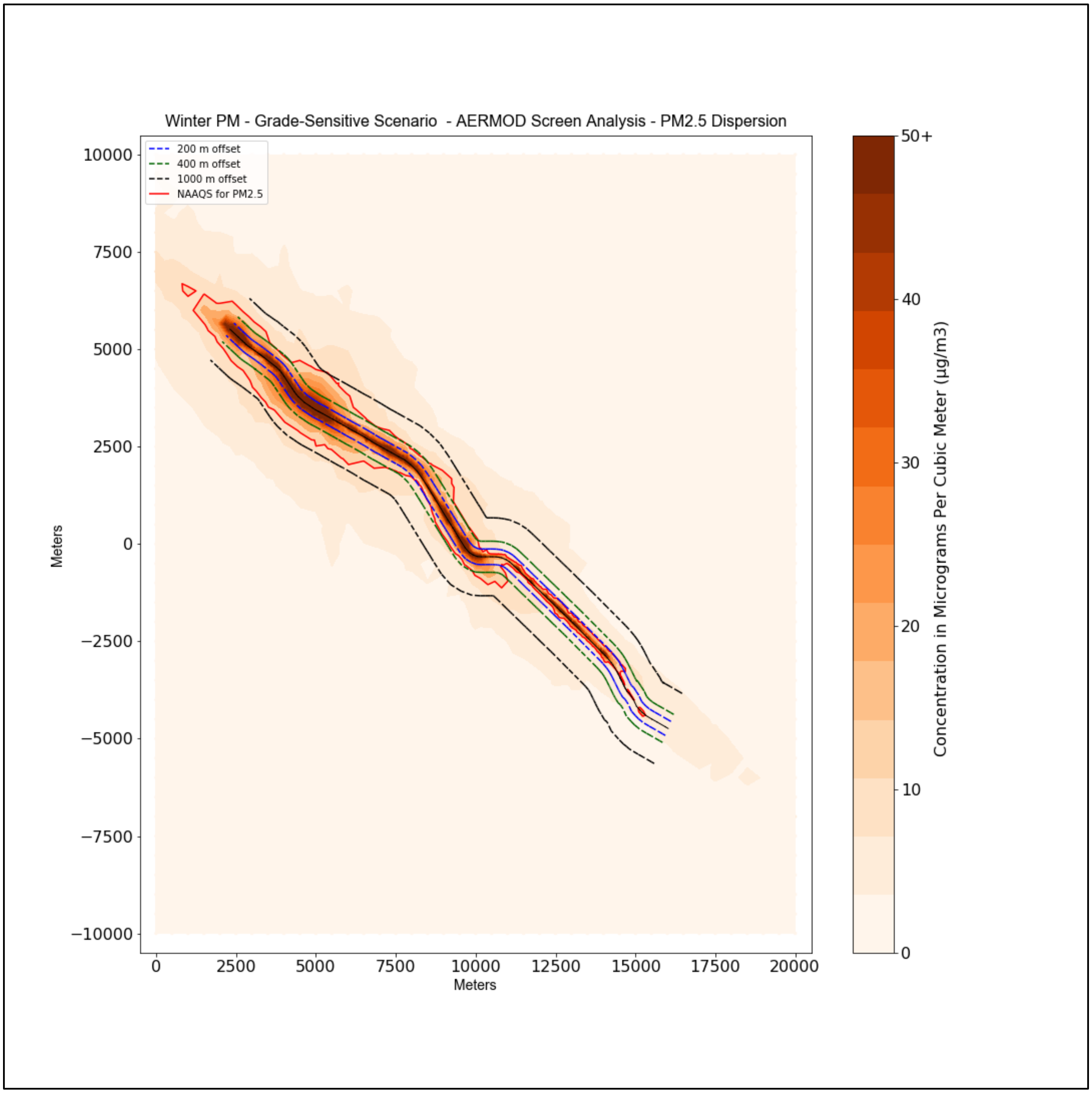

Figure 39. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Winter Evening Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Screen Analysis Option

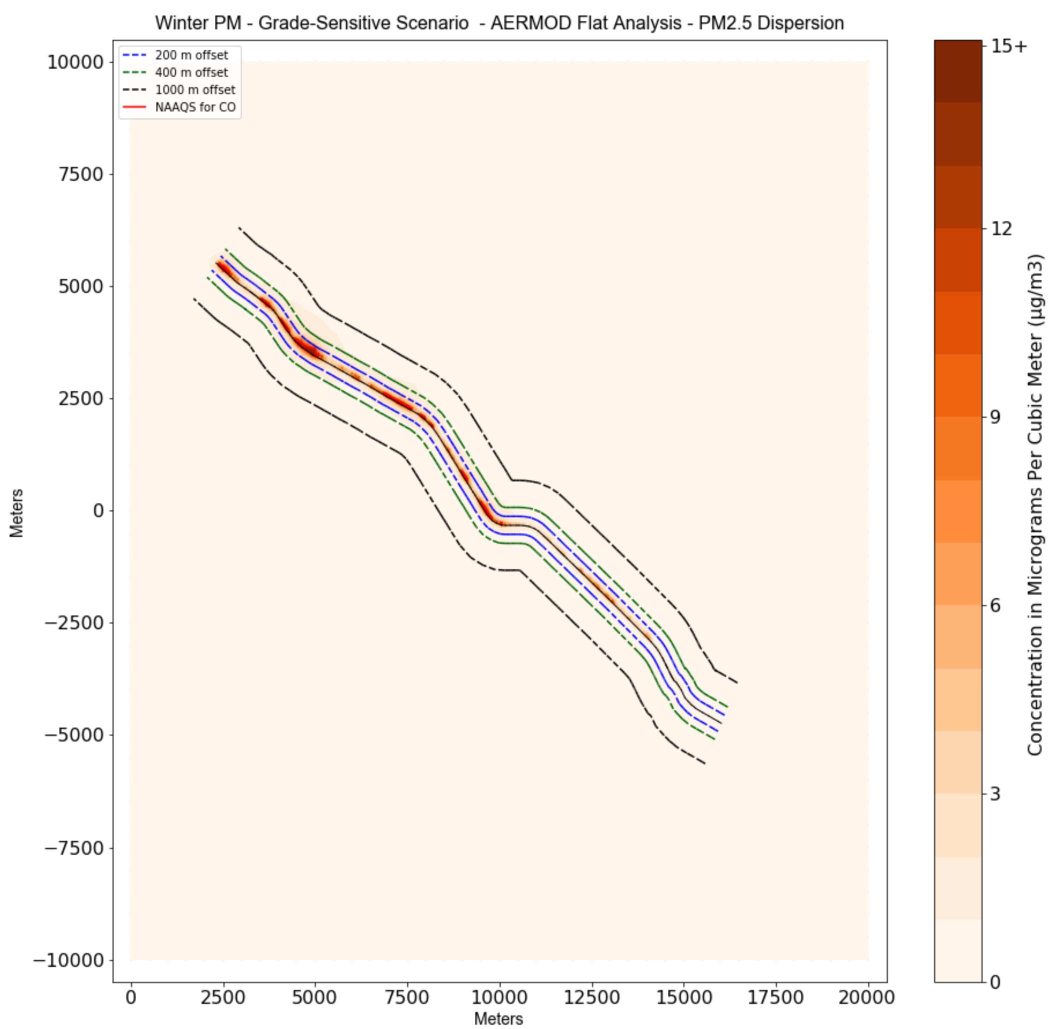

Figure 40. Spatial Analysis of Dispersed $PM_{2.5}$ Concentration for Winter Evening Period Based on Grade-Sensitive Traffic Simulation Model and AERMOD Flat Analysis Option

Chapter V: Assessing the Potential Impact of Congested Conditions in Study Corridor on Adequacy of 200-Meter Buffer

Based on local knowledge the researchers are aware that the simulated average speed of 60 mph used in this study is characteristic of free flow conditions the corridor. Therefore, the researchers also evaluated the adequacy of the 200-meter buffer during congested conditions in the study corridor. To do this, the researchers used an average speed of 30 mph to represent congested conditions in the corridor. It was not necessary to build additional models just to gain insight into the impact of congestion because the only important difference between congested conditions and the free flow conditions modeled in this study is the speed of vehicles. All other key factors such as the road network, grade profile, meteorology, and dispersion ratio at the receptors will remain unchanged.

Changing the speed of vehicles in the corridor will cause a proportional change in the length of time vehicles speed in the corridor. This will result in a proportional change in the total emissions from the corridor. The researchers made the assumption that reducing average corridor speed by 50 percent to simulate congested conditions will approximately double the total emissions from the corridor. This will also result in approximately double the pollutant concentrations at the receptors.

The study extracted and doubled the AERMOD predicted CO and $PM_{2.5}$ concentrations at all the receptors located at 200 meters from the road edge (R4 receptors). This analysis was performed for the worst scenario identified for both pollutants; grade-sensitive summer evening period for CO and grade-sensitive winter period for $PM_{2.5}$. The receptor concentrations were then compared to the relevant NAAQS value to see if the receptor concentrations on the 200-meter buffer are less than or at the most equal to the NAAQS limit. Figure 41 and Figure 42 presents the distribution of CO and PM2.5 concentrations at the receptors respectively.

For CO dispersion, it can be seen that there are three receptors that have concentrations higher than the NAAQS limit of 9 ppm. Further, analysis showed that even if the assumed proportional change in emission quantities and concentrations in air is reduced from 2.0 to 1.5, at least one receptor will still have a concentration value higher than the NAAQS limit. For PM2.5, Figure 42 shows that all the receptor concentrations are below the NAAQS limit of $12 \mu g/m^3$. The maximum observed PM receptor concentration value is $8 \mu g/m^3$. It should be noted that this study also used a low estimate of truck percentage in the corridor and the study does not also account for background concentrations.

The Georgia Environmental Protection Division has a near-road $PM_{2.5}$ monitoring station on Georgia Tech campus. This station is less than 50 feet from Interstate-75 (same Interstate modeled in this study) and has annual $PM_{2.5}$ design values of $9.7 \mu g/m^3$. This location has a nearby GDOT TADA continuous counting station that shows a truck percentage of 4 percent (similar to what is used in this study). With similar conditions, our congestion analysis estimates PM2.5 concentration values of $8 \mu g/m^3$ at 200 meters (656 feet). Therefore, we believe our congestion analysis is reasonably accurate.

Therefore, it does seem that under free flow conditions the 200-meter buffer holds as adequate but under congested conditions the buffer might be inadequate for the road and grade profile evaluated in this study. The findings also show that adequacy of a buffer may very well depend on the specific pollutant and local conditions.

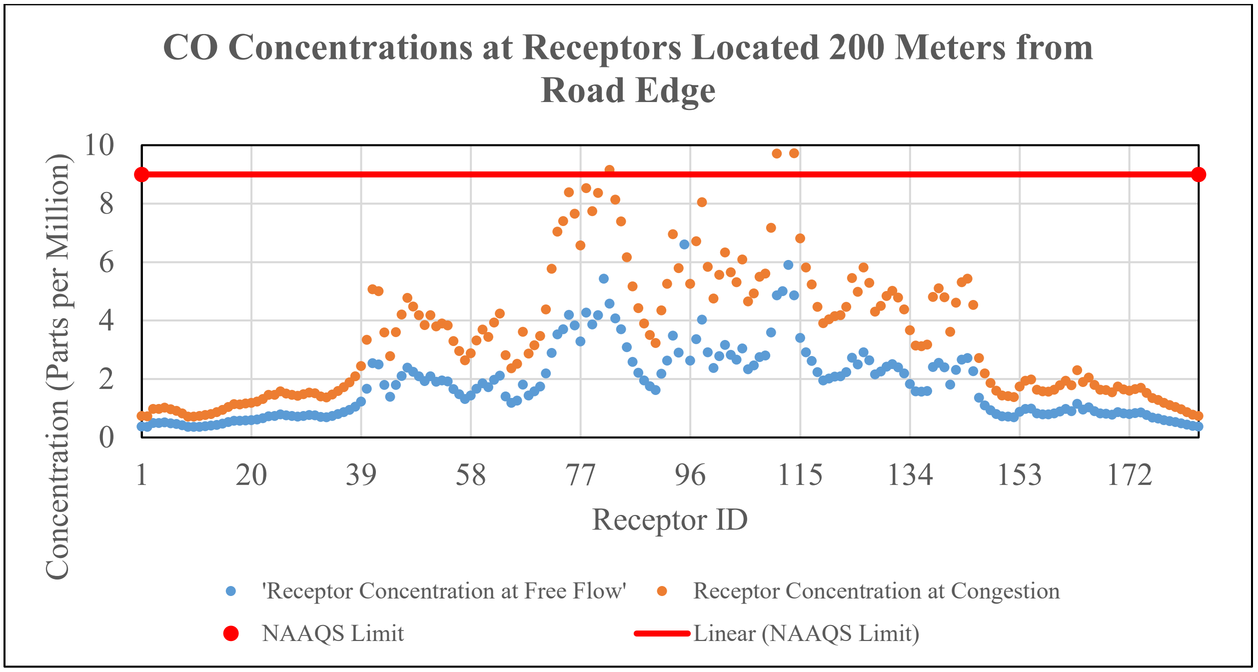

Figure 41. Receptor Concentrations for CO at 200-Meter Buffer during Free Flow and Congested Traffic Conditions

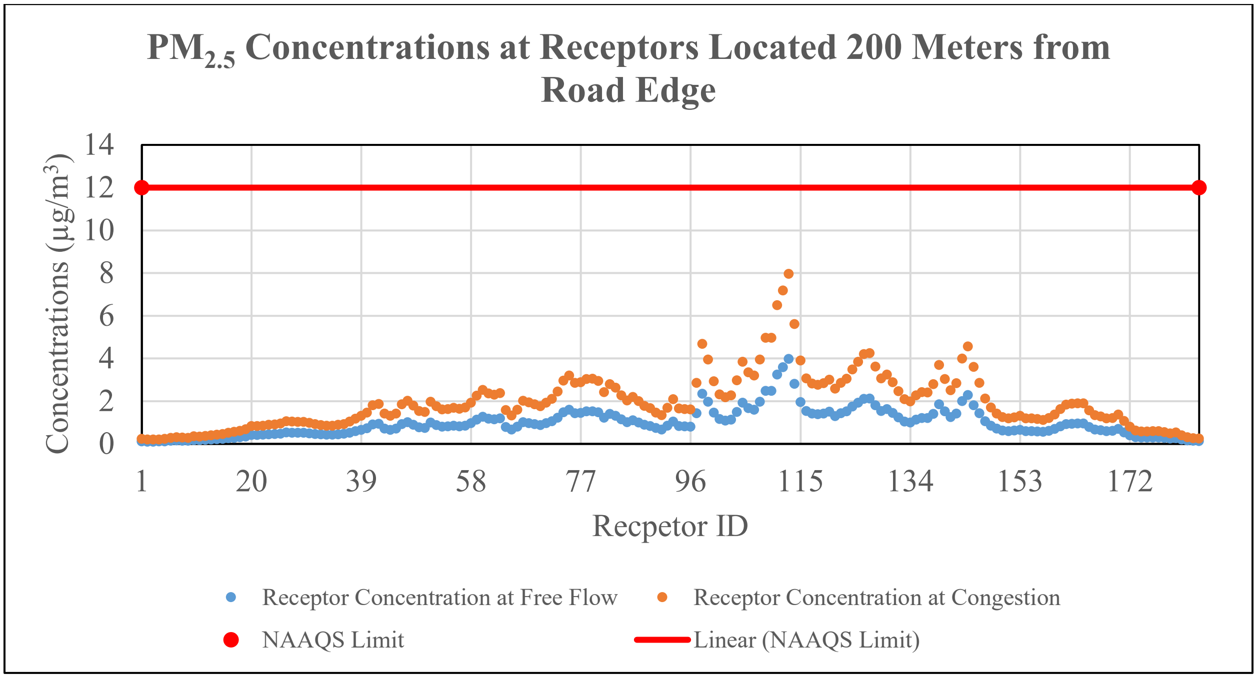

Figure 42. Receptor Concentrations for PM2.5 at 200-Meter Buffer during Free Flow and Congested Traffic Conditions

Chapter VI: Conclusions

This study evaluates the environmental justice implications of roadway topography. Two sets of vehicle activity data were used to successfully complete this study. One set reflected the impact of road grade on vehicle speed and acceleration while the other set was free of road grade influence. The latter is representative of the data that is currently used by MPOs and other transportation agencies in their planning because existing travel demand models are unable to capture road grade in their network. The study used Vissim® – an advanced traffic microsimulation model to generate both grade-sensitive and grade-insensitive vehicle activity data. The roadway topography data for the project corridor was extracted from the United States Digital Elevation Model (US DEM) database using a streamlined method developed by Georgia Tech researchers.

The project corridor, covers about 9 miles of Atlanta's Interstate 75 and is located immediately north of the interchange with Interstate 285. The vehicle fleet within this corridor is very diverse but for the sake of this study only passenger cars and heavy-duty vehicles (HDV) were simulated. Truck composition in this corridor can be as high as 9 – 11 percent but this study used a very conservative estimate of 4 percent. Vehicle speed and acceleration data from the Vissim® simulation were analyzed with MOVES-Matrix to generate CO and $PM_{2.5}$ emission rates for the corridor. The emission rates were subsequently used in AERMOD to simulate pollutant air dispersion over the adjacent areas. Pollutant concentration at modeled receptor locations throughout the adjacent areas were used to generate heat maps. The heat maps were then superimposed with a contour representing the NAAQS threshold concentration level for public safety for the relevant pollutant (9 ppm for CO and 12 $\mu g/m^3$ for $PM_{2.5}$). The heat maps were also superimposed with lines representing the centerline of the carriageway and 200-, 400-, and 1000-meter buffer lines off the road edge on either side.

Currently, most MPOs and transportation agencies use a buffer distance of 200 meters to identify the population that is likely to be unsafely exposed to onroad mobile emissions. In evaluating the adequacy of this buffer for a given scenario, the study visually examines if the buffer is able to completely contain the superimposed NAAQS contour. If the contour is completely contained in the buffer then the buffer is assumed to be adequate for the scenario. The study analyzed several scenarios reflecting different combinations of the two pollutants, two AERMOD analysis options (Flat and Screen), two seasonal periods (winter and summer), two daily periods (morning and evening), and two road networks (grade-sensitive and grade-insensitive). An initial AERMOD Screen analysis option was used to filter out scenarios that do not warrant further detailed analysis with AERMOD Flat analysis option.

First, the findings show that unlike passenger cars, HDV speeds show a notable difference between corresponding the grade-sensitive and grade-insensitive scenarios. Similarly, passenger car operating mode distributions were found to be closely matched between the grade-sensitive scenarios and grade-insensitive scenarios than for HDVs. For HDVs the operating modes become more spread out into lower bins as one moves from the grade-insensitive to the grade-sensitive scenario.

Next, evaluating the adequacy of the 200-meter buffer was done for both free flow traffic conditions and congested traffic conditions in the study corridor. Under free flow conditions, the study finds the 200-meter buffer adequate for all the scenarios examined. However, under congested traffic conditions the study finds the 200-meter buffer inadequate for CO dispersion. At least there were three receptors located at 200 meters from the road edge with CO concentrations higher than the NAAQs limit.

In the case of $PM_{2.5}$, the study finds the 200-meter buffer adequate for the network, road grade profile, and vehicle fleet used in this study. However, it should be noted that this study used a low HDV composition (about 50 percent less than the actual truck composition in the corridor). This could have impacted the results because HDVs are major contributors of onroad $PM_{2.5}$ emissions. Furthermore, the highest observed $PM_{2.5}$ concentration under congested conditions among receptors located at 200 meters from the road edge was 8 µg/m3. Also, this study does not take into consideration background $PM_{2.5}$ concentrations in the project corridor.

Finally, based on the results from this study it seems that a ubiquitous one-size-fits-all buffer distance of 200-meters may not be the best approach to demarcate the boundary of populations that are likely to be unsafely exposed to onroad mobile emissions. Buffer distances should be pollutant specific. Also, the buffer distance must reflect fleet composition, average traffic conditions, road grade profile, and local meteorology.

References

Batterman, S., Ganguly, R., Isakov, V., Burke, J., Arunachalam, S., Snyder, M., Robins, T., and Lewis, T. (2014). "Dispersion Modeling of Traffic-Related Air Pollutant Exposures and Health Effects among Children with Asthma in Detroit, Michigan." In *Transportation Research Record: Journal of the Transportation Research Board*, *No*. (2452), p.p pp 105–113.

Boguski, T. (2006). "Understanding Units of Measurements." https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.files/fileid/14285.(June 2020).

Brugge, D., Durant, J.L., and Rioux, C. (2007). "Near-Highway Pollutants in Motor Vehicle Exhaust: A Review of Epidemiologic Evidence of Cardiac and Pulmonary Health Risks." In *Environmental Health*, *No*. *6*(1), p.p 23.

Brunekreef, B., Janssen, N.A.H., De Hartog, J., Harssema, H., Knape, M., and Van Vliet, P. (1997). "Air Pollution from Truck Traffic and Lung Function in Children Living near Motorways." In *Epidemiology*, *No*. *8*(3), p.p 298-303.

Carrier, M., Apparicio, P., Séguin, A.-M., and Crouse, D. (2014). "Ambient Air Pollution Concentration in Montreal and Environmental Equity: Are Children at Risk at School?" In *Case Studies on Transport Policy*, *No*. *2*(2), p.p pp 61-69.

Cesaroni, G., Badaloni, C., Porta, D., Forastiere, F., and Perucci, C.A. (2008). "Comparison between Various Indices of Exposure to Traffic-Related Air Pollution and Their Impact on Respiratory Health in Adults." In *Occupational and environmental medicine*, *No*. *65*(10), p.p 683-690.

Chang, S.Y., Vizuete, W., Serre, M., Vennam, L.P., Omary, M., Isakov, V., Breen, M., and Arunachalam, S. (2017). "Finely Resolved on-Road Pm2.5 and Estimated Premature Mortality in Central North Carolina." In *Risk Anal*, *No*. *37*(12), p.p 2420-2434.

Clark, N.A., Demers, P.A., Karr, C.J., Koehoorn, M., Lencar, C., Tamburic, L., and Brauer, M. (2010). "Effect of Early Life Exposure to Air Pollution on Development of Childhood Asthma." In *Environmental Health Perspectives*, *No*. *118*(2), p.p 284-290.

Crouse, D.L., Goldberg, M.S., and Ross, N.A. (2009). "A Prediction-Based Approach to Modelling Temporal and Spatial Variability of Traffic-Related Air Pollution in Montreal, Canada." In *Atmospheric Environment*, *No*. *43*(32), p.p 5075-5084.

Gauderman, W.J., Vora, H., McConnell, R., Berhane, K., Gilliland, F., Thomas, D., Lurmann, F., Avol, E., Kunzli, N., Jerrett, M., and Peters, J. (2007). "Effect of Exposure to Traffic on Lung Development from 10 to 18 Years of Age: A Cohort Study." In *Lancet*, *No*. *369*(9561), p.p 571-577.

Georgia EPD (2018). "Georgia Aermet Meteorological Data." https://epd.georgia.gov/air-protection-branch-technical-guidance-0/air-quality-modeling/georgia-aermet-meteorological-data.

Guensler, R., Liu, H., Xu, X., Lu, H., Rodgers, M., National Center for Sustainable, T., Georgia Institute of Technology, A., Office of the Assistant Secretary for, R., and Technology. (2018). "Moves-Matrix for High-Performance Emission Rate Model Applications."

Health Effects Institute. (2010). "Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects." Special Report 17, Boston, MA.

Heist, D., Isakov, V., Perry, S., Snyder, M., Venkatram, A., Hood, C., Stocker, J., Carruthers, D., Arunachalam, S., and Owen, R.C. (2013). "Estimating near-Road Pollutant Dispersion: A Model Inter-Comparison." In *Transportation Research Part D: Transport and Environment*, *No. 25*, p.p 93-105.

Jerrett, M., Shankardass, K., Berhane, K., Gauderman, W.J., Künzli, N., Avol, E., Gilliland, F., Lurmann, F., Molitor Jassy, N., Molitor John, T., Thomas Duncan, C., Peters, J., and McConnell, R. (2008). "Traffic-Related Air Pollution and Asthma Onset in Children: A Prospective Cohort Study with Individual Exposure Measurement." In *Environmental Health Perspectives*, *No. 116*(10), p.p 1433-1438.

Kim Janice, J., Huen, K., Adams, S., Smorodinsky, S., Hoats, A., Malig, B., Lipsett, M., and Ostro, B. (2008). "Residential Traffic and Children's Respiratory Health." In *Environmental Health Perspectives*, *No. 116*(9), p.p 1274-1279.

Liu, H., Rodgers, M.O., and Guensler, R. (2019). "Impact of Road Grade on Vehicle Speed-Acceleration Distribution, Emissions and Dispersion Modeling on Freeways." In *Transportation Research Part D: Transport and Environment*, *No. 69*, p.p pp 107-122.

Miranda, M.L., Edwards, S.E., Keating, M.H., and Paul, C.J. (2011). "Making the Environmental Justice Grade: The Relative Burden of Air Pollution Exposure in the United States." In *International journal of environmental research and public health*, *No. 8*(6), p.p 1755-1771.

Morello-Frosch, R.Jesdale, B.M. (2006). "Separate and Unequal: Residential Segregation and Estimated Cancer Risks Associated with Ambient Air Toxics in U.S. Metropolitan Areas." In *Environmental health perspectives*, *No. 114*(3), p.p 386-393.

O'Neill, M.S., Jerrett, M., Kawachi, I., Levy, J.I., Cohen, A.J., Gouveia, N., Wilkinson, P., Fletcher, T., Cifuentes, L., and Schwartz, J. (2003). "Health, Wealth, and Air Pollution: Advancing Theory and Methods." In *Environ Health Perspect*, *No. 111*(16), p.p 1861-70.

Olvera, A., Hector, A., Myers, B., Weigel, M., and Armijos, R. (2018). "The Value of Using Seasonality and Meteorological Variables to Model Intra-Urban Pm2.5 Variation." In *Atmospheric Environment*, *No. 182*, p.p 1-8.

Peters, A., von Klot, S., Heier, M., Trentinaglia, I., Hörmann, A., Wichmann, H.E., and Löwel, H. (2004). "Exposure to Traffic and the Onset of Myocardial Infarction." In *New England Journal of Medicine*, *No. 351*(17), p.p 1721-1730.

Raz, R., Roberts, A.L., Lyall, K., Hart, J.E., Just, A.C., Laden, F., and Weisskopf, M.G. (2015). "Autism Spectrum Disorder and Particulate Matter Air Pollution before, During, and after Pregnancy: A Nested Case-Control Analysis within the Nurses' Health Study Ii Cohort." In *Environ Health Perspect*, *No. 123*(3), p.p 264-70.

Rowangould, G.M. (2013). "A Census of the Us near-Roadway Population: Public Health and Environmental Justice Considerations." In *Transportation Research Part D: Transport and Environment*, *No. 25*, p.p 59-67.

Sentoff, K.M., Aultman-Hall, L., and Holmén, B.A. (2015). "Implications of Driving Style and Road Grade for Accurate Vehicle Activity Data and Emissions Estimates." In *Transportation Research Part D: Transport and Environment*, *No. 35*, p.p 175-188.

Tayarani, M., Poorfakhraei, A., Nadafianshahamabadi, R., and Rowangould, G.M. (2016). "Evaluating Unintended Outcomes of Regional Smart-Growth Strategies: Environmental Justice and Public Health Concerns." In *Transportation Research Part D: Transport and Environment*, *No. 49*, p.p pp 280-290.

Tian, N., Xue, J., and Barzyk, T.M. (2013). "Evaluating Socioeconomic and Racial Differences in Traffic-Related Metrics in the United States Using a Gis Approach." In *J Expo Sci Environ Epidemiol*, *No*. *23*(2), p.p 215-22.

United States Environmental Protection Agency. (2013). "Module 4: Using Aermod for Pm Hot-Spot Analysis." In.

United States Environmental Protection Agency. (2018). "User's Guide for the Ams/Epa Regulatory Model (Aermod)."

United States Environmental Protection Agency. (2019). "Aermod Implementation Guide." U.S.E.P. Agency

USDOT, FHWA, and FTA. (2002). "Transportation Benefits and Burdens in the Atlanta Region."

Wood, E., Duran, A., and Kelly, K. (2016). "Epa Ghg Certification of Medium- and Heavy-Duty Vehicles: Development of Road Grade Profiles Representative of Us Controlled Access Highways." In *SAE International Journal of Commercial Vehicles*, *No*. *9*, p.p 94-104.

Wu, Y., Niemeier, D., and Transportation Research, B. (2016). "Strategy of Aermod Configuration for Transportation Conformity Hot-Spot Analyses."

Yazdani Boroujeni, B.Frey, H.C. (2014). "Road Grade Quantification Based on Global Positioning System Data Obtained from Real-World Vehicle Fuel Use and Emissions Measurements." In *Atmospheric Environment*, *No*. *85*, p.p 179-186.

Zhang, W., Lu, J., Xu, P., and Zhang, Y. (2015). "Moving Towards Sustainability: Road Grades and on-Road Emissions of Heavy-Duty Vehicles—a Case Study." In *Sustainability*, *No*. *7*(9).