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DRAFT FOR REVIEW

Connectivity Impacts:

Emissions Impacts of Connectivity

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Prepared for the Texas Department of Transportation

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Introduction

The goal of this task is to study air quality impacts of intermodal freight facilities associated with connectivity in urban areas and to identify mitigating strategies to improve air quality from these source emitters. To achieve this goal, the following tasks were performed:

- Investigate the connectivity status and air quality impact of intermodal freight facilities through a case study;
- Identify best connectivity-oriented practices and emissions reduction strategies to mitigate adverse air quality impacts of these facilities; and
- Use link-level (mezoscopoic) traffic and emissions modeling to examine the effectiveness of the selected connectivity scenarios.

Many intermodal freight facilities including truck/rail facilities and port facilities (ship/rail/truck) are located in large urban areas where air quality is a concern. Reducing emissions of truck activity at, and around, intermodal freight facilities can help reduce emissions in urban areas. The focus of this task was on emissions benefits for connectivity improvements. The following section of this report provides a brief overview of literature discussing various congestion mitigation techniques which could be applicable to intermodal freight facilities. The remainder of the report describes the development and application of a case study and the results.

Literature Review

Nonattainment areas throughout the U.S. are seeking emissions reduction measures strategies to improve air quality and retain federal funding for transportation projects. This section highlights what connectivity-related emissions reduction strategies successfully have been applied at intermodal facilities, and how connectivity and air quality might be related.

Definition of Connectivity

Connectivity in this context relates to the ease of connecting from an origin to a destination by means of available routes, travel options, and travel times. Connectivity improvement may take the form of additional choices (routes or modes) or changes that will reduce travel time. Additional lanes and/or node connectors are not the only methods to improve connectivity. Improved travel time due to less congestion or improved road conditions can improve the ease of reaching a destination and therefore increase the connectivity.

Best Practices and Emissions Reduction Strategies

Literature from research on intermodal hubs and ports throughout the U.S. revealed several connectivity-related strategies that have been employed successfully to reduce emissions.

Reduced Vehicle Miles Traveled

Literature suggests that as connectivity increases, congestion and average travel times will decrease as more routes are made available to each driver. Trip distances are decreased in many cases when connectivity is high, thus reducing VMT and vehicle emissions.[1] Some contrasting research has suggested that directly relating VMT with vehicle emissions might be erroneous. With the numerous variables that are involved in emissions production, the same trip might cause more or less emissions depending on vehicle, driver behavior, travel speeds, or engine temperature. [2] There is far more literature that suggests that fewer miles traveled will equate to fewer emissions. A 1996 study suggested that VMT reductions led to a sharp decrease in running emissions, primarily particulate matter (PM) and oxides of nitrogen (NO_x) while carbon monoxide (CO) and total organic gases (TOG) were less directly related to VMT. CO and TOG were found to be most closely related to the number of cold starts.[3]

Clean air campaigns have been implemented and are currently frequently promoted throughout the U.S. to reduce driving and thus reduce emissions. The Colorado State Department of Transportation (CDOT) reported a 13% reduction in CO emissions concurrent with a 9% reduction in VMT due to their promoted “No Drive Days.” The model which produced the estimates also concluded that the emissions from the remaining vehicles that did drive on those days included a reduction of emissions due to reduced congestion. Further investigation proved that actually only 2% of emissions reductions should be credited due to the reduced VMT, suggesting that VMT reduction did result in fewer emissions but maybe did not have as great an effect as first predicted[4].

The following sections provide general and site specific transportation control measures that can be used to reduce VMT and emissions.

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[1] Frank, L.D. and P. Engelke. *Multiple impacts of the built environment on public health: Walkable places and the exposure to air pollution.* International Regional Science Review, 2005. 28(2): p. 193-216.
[2] Frank, L.D., B. Stone, and W. Bachman. *Linking land use with household vehicle emissions in the central puget sound: methodological framework and findings.* Transportation Research Part D-Transport and Environment, 2000. 5(3): p. 173-196.
[3] Henderson, D.K., B.E. Koenig, and P.L. Mokhtarian. *Using travel diary data to estimate the emissions impacts of transportation strategies: The puget sound telecommuting demonstration project.* Journal of the Air & Waste Management Association, 1996. 46(1): p. 47-57.
[4] Stedman, D.H. *Automobile Carbon-Monoxide Emission.* Environmental Science & Technology, 1989. 23(2): p. 147-149.

Improved Connectivity

The Trans Texas Corridor Advisory Committee stated that criteria for determining the most efficient freight movement corridors were dependent on both mitigating air quality degradation and maintaining connectivity.[5] Improving connectivity provides more options and sometimes shorter travel distances for drivers and thus the roadway system can self-mitigate congestion because drivers tend to drive the shorter available distances to avoid congestion if possible.

A contrasting study of motorcycles in Taiwan showed that, per distance in urban driving (with congestion and interrupted flow), 30% more fuel is consumed than in rural areas with little to no congestion. The argument can be raised that in urban areas where more connectivity exists, more congestion also exists thus connectivity may not directly equate to fewer emissions. It was also found that the difference in vehicle produced emissions levels per VMT were not statistically significant between urban and rural areas.[6]

On-road vehicle emissions testing has shown that of the four standard driving modes – acceleration, deceleration, cruising, and idling – the acceleration/deceleration mode is more polluting than the steady-speed driving modes (cruising and idling) both in terms of grams per time and distance.[7] This knowledge urges planners and engineers to develop systems that will require fewer stops and create less congestion; a condition that is smooth and close to free-flow will require less acceleration and deceleration and thus incur fewer emissions.

Improved Facility Operations

Intermodal facilities have been identified as a source emitter of emissions from freight vehicles. These facilities bring freight from different parts of the world to one location via water, air, rail and/or roads. Trucks arriving at intermodal facilities usually must pass through entrance inspections and paperwork checking to enter an intermodal facility and those vehicles missing information or that are unscheduled, etc. must wait to be processed. These delays in retrieving cargo are usually accompanied by diesel engine trucks idling for minutes, sometimes hours at a time. Operational improvements can improve emissions as fewer trucks idle.

Increasing the efficiency of intermodal facility operations is a heavily studied and implemented transportation control measure primarily to the economic benefits for the facility. Bottleneck locations are identified to find the most appropriate location in which to focus congestion and

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[5] Harrison, R. *Design and Operation of Inland Ports as Nodes of the Trans-Texas Corridor*. 2006. Center for Transportation Research, University of Texas at Austin.
[6] Chen, K.S., et al. *Motorcycle emissions and fuel consumption in urban and rural driving conditions.* The Science of The Total Environment, 2003. 312(1-3): p. 113-122.
[7] Tong, H., W. Hung, and C. Cheung. *On-road motor vehicle emissions and fuel consumption in urban driving conditions.* Journal of the Air & Waste Management Association (1995), 2000. 50(4): p. 543.

delay mitigation efforts. Individual facility operations can be a great cause of delay. Union Pacific Railroad touts that their new intermodal facility in Dallas, Texas can reduce the average check-in process time from four minutes to a mere 30 seconds due to technological advances and operational optimization. Similar improvements can be made at other facilities to safely reduce the delay that trucks experience entering or exiting intermodal freight facilities.

A survey of over 1,000 truck operators concluded that congestion and delays could be reduced by truck-only roadways into ports and intermodal facilities, advanced vehicle clearance systems (AVCS), and longer operating hours to improve facility operations.[8]

Appointment Based Access Control System

Some specified research has been conducted in the field of appointment-based access control systems at container ports and facilities to reduce congestion, delay and emissions due to increasingly constrained capacity. These systems require that all drayage trucks (trucks that operate in the local area – basically all non-long-haul trucks) schedule appointments for drop-off or pick-up with the port authority or facility operator. The purpose of these systems is to normalize the distribution of truck traffic at any given facility throughout the day and reduce congestion peaks that have existed in the past which results in excessive idling. A Californian legislative bill passed in 2003, commonly known as the "Lowenthal Bill" (Assembly Bill 2650), imposed fines on terminal operators for trucks idling in queues in and around port terminals for longer than 30 minutes. This same bill allowed ports to avoid said fines if an approved drayage appointment system was put in place. These systems are common place in California today. Mathematical modeling has been researched to optimize scheduling and in routing trucks through the drop-off/pick-up process. Results of one study reported that port productivity of drayage trucks can be increased by 10-24% when access capacity is increased by 30% with the introduction of an appointment-based access system.[9] With increased productivity and capacity, fewer emissions will be produced as trucks are allowed more free-flow driving time and less idling and acceleration/deceleration time.

Improved Road Surface Conditions

Drayage costs can be reduced by improving roads that connect ports to the highway network. Better connectivity of ports and intermodal facilities to the highway network could reduce costs for draymen, those who are paid by the trip, rather than by the hour potentially allowing them to

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[8] Golob, T.F. and A.C. Regan. *Freight industry attitudes towards policies to reduce congestion.* Transportation Research Part E-Logistics and Transportation Review, 2000. 36(1): p. 55-77.
[9] Namboothiri, R. and A.L. Erera. *Planning local container drayage operations given a port access appointment system.* Transportation Research Part E-Logistics and Transportation Review, 2008. 44(2): p. 185-202.

make more trips in a day.[10] Higher and more consistent speeds can be maintained on a road without potholes, ruts or large cracks and thus fewer emissions will be produced by decelerating and accelerating on poor quality roadways.

Replacement of Aging Fleet Vehicles/Engines

Volunteer aging vehicle replacement (VAVR) programs have been shown to be less effective than originally thought. An older vehicle would be expected to produce more emissions and newer models with more advanced technologies would produce less. Using actual data to determine the variability of results, it was found that VAVR programs reduced only about 25% of emissions that were projected by the California Air Resources Board (CARB) method in the worst case scenario. Other scenarios were tested and proved that reductions of reactive organic gases (ROGs) could be reduced by 40% more than CARB estimated. ROGs are mostly affected by VAVR programs, while CO and NO_x are effected less by these programs. Observed data has shown that newer engines do create fewer emissions under the same operating conditions, but research has shown that the specific VAVR programs are not always efficient in replacing older engines with newer engines and truly discontinuing use of the older engines.[11]

Connectivity and Air Quality

The connection between poor connectivity in a system and truck emissions has had little direct attention. The mitigation strategies previously mentioned normally stem the debate as to whether connectivity reduces emissions, because increasing connectivity usually reduces VMT by providing a more direct route, which is specifically important for freight movements.

Ports in Texas

Although the case study conducted in this research deals with an inland intermodal freight hub, ports also act as intermodal hubs. The research team considered using a port as a case study but upon review of available ports and connectivity options, an inland intermodal hub was chosen as a more appropriate case study.

Research in the field of intermodal freight hubs is not limited to inland hubs, but ports receive attention as well. A study conducted by Harrison[18] defined drayage trucks as those which have an origin and destination within the same urban area. Since port drayage trucks operate strictly within the urban area they are targeted as having a greater impact on local congestion and ambient air quality than long-range trucks. Cargo delivered to the Barbour’s Cut and Bayport Terminals in the Houston area depend mostly on dray trucks to deliver goods to local customers,

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[10] Resor, R.R. and J.R. Blaze. *Short-haul rail intermodal - Can it compete with trucks?* Intermodal Freight Transportation, Freight Transportation Planning, 2004 (1873): p. 45-52.
[11] Dill, J. *Estimating emissions reductions from accelerated vehicle retirement programs.* Transportation Research Part D-Transport and Environment, 2004. 9(2): p. 87-106.

regional distribution centers, or rail yards. A survey of 103 port drivers revealed that the average drayage trip, excluding those who traveled over 100 miles (inter-city trucks) was 47.5 miles, with an average of 3.2 trips to the port per day. This same survey found that truck operators encountered the most congestion on Barbour's Cut Boulevard, Interstate 10, and I-610 North (access routes close to the port), suggesting that increased connectivity could reduce this congestion and benefit the industry financially and reduce emissions. Traffic delays were identified due to construction zones, inadequate number of lanes, crashes or stalled vehicles. Another air quality enhancement technique found in that study was replacing older engines with new ones that create fewer emissions.[12]

Analysis Approach

The goal of this task is to show how vehicle emissions related to intermodal freight facilities can be reduced by different transportation control measures. A before-and-after case study was conducted for one intermodal facility. Microscopic traffic simulation models were used with MOVES10a data and local historical traffic counts to quantify the trucks associated with access to the facility. Different control measures were loaded into the simulation model, and the traffic simulations were run again to estimate emissions using MOVES data.

Transportation control measures modeled include:

- Increasing connectivity by adding new road links, and
- Increasing the operating speeds of existing roads by improving surface conditions.

The Freight Analysis Framework (FAF) database created by the Federal Highway Administration (FHWA) was calibrated to ensure accurate results. A comparison of the before-and-after conditions was used to demonstrate how a specific site might benefit from the tested measures to reduce tailpipe emissions.

Case Study of Englewood Intermodal Facility in Houston

This section details the reasons behind selecting the Englewood Intermodal Facility as a case study for this connectivity and emissions research.

There are many intermodal facilities in the state of Texas, but three hubs – in the Fort Worth, Dallas, and Houston areas – see a large percentage of the volume of truck traffic and thus would benefit the most from connectivity-related measures and could provide the most information

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[12] Harrison, R., et al. *Characteristics of drayage operations at the Port of Houston, Texas.* Transportation Research Record, 2007(2033): p. 31-37.

when used for a case study. Travel time is high in both the Dallas/Fort Worth and Houston areas ranking them among the top 15 in the U.S. for congestion cost, annual delay, and annual excess fuel consumed according to the Texas Transportation Institute's (TTI) Mobility Data. The candidate facilities are described in the following.

Alliance Global Logistics Hub – 1801 Intermodal Pkwy, Haslet, TX 76052

This regional intermodal freight facility is located in a rural area with little development in the neighboring parcels of land. The Alliance Intermodal Facility lies just off I-35W within Tarrant County in and adjacent to Fort Worth. Tarrant County is currently within the Dallas-Fort Worth nonattainment area and thus is a fitting candidate to benefit from connectivity or congestion improvements. Further investigation into the site was to verify applicability of this site for a case study. This intermodal facility is owned by Hillwood Properties and is part of a master-planned community providing world-class aviation, office, industrial, retail, education, residential and recreational opportunities. According to Alliance, a population of 48 million within the U.S. can be served by a truck within one day from the Alliance Intermodal Hub and 111 million within two days.

Data from 2007 indicates that the freight volume (lifts/year) was 567,000 with an average of 884 trucks entering the facility daily.

Dallas Logistics Hub – 4425 Forney St., Mesquite, TX 75149

This facility is located in a moderately developed area in Dallas within an industrial park with some business parks and residences nearby. Dallas County, where the site is located, is also a nonattainment county and could greatly benefit from fewer emissions caused by this intermodal facility. Owned by the Allen Group, the Dallas Logistics Hub is adjacent to Union Pacific's Southern Dallas Intermodal Terminal, a potential BNSF intermodal facility, four major highway connectors (I-20, I-30, I-635, and Loop 12 [Buckner Boulevard]) and a future air cargo facility at Lancaster Airport. The facility touts 6,000 master-planned acres for 60 million square feet of distribution, manufacturing, office, and retail developments.

As of 2006 the freight volume (lifts/year) was 284,000 with an average of 778 trucks entering the facility daily.

Englewood Intermodal Facility – 5500 Wallisville Rd., Houston, TX 77020

This facility is located in a fully-developed area of Houston and is surrounded by residences. It appears that efforts have been made to provide this hub with improved connectivity, including road geometrics. The Englewood Intermodal Facility is located in Harris County and the Greater Houston area that is also in nonattainment for the eight-hour ground-level ozone standard. The Houston-Galveston region serves a major rail hub and the Englewood facility includes a major classification yard for the southern part of Texas and serves the petrochemical industry along the Texas Gulf Coast according to Union Pacific.

As of 2006, the freight volume (lifts/year) was 206,000 with an average of 564 trucks entering the facility daily.

Although the Englewood Intermodal Facility has the smallest landmass, the lowest freight volume, and fewest trucks entering per day of the three hubs, the facility is within the city limits of Houston and is surrounded by residential development. As such, it may have a greater emissions impact on its surroundings than the other two hubs. The facility rests inside the I-610 Loop and near the intersection of US 59 and I-10. Visual analysis of each of the facilities from aerial images as well as analysis of the FAF network led the research team to select Englewood as the case study for this research due to the large amount of traffic on arterial roads immediately surrounding the intermodal facility and the proximity of the facility to residential development.

Data Source

This section discusses the use of the FAF07 data which provided average annual daily traffic (AADT) as well as average annual daily truck traffic (AADTT) volumes. The volumes were available only per link, not by direction. Data for a six-month period (October 2007-March 2008) was available from Houston TranStar and was used to determine directional split. The splits on the majority of major arterials were close to 50-50; the minor arterials were also assumed to have a 50-50 split. For example, the split on I-10 was 47% - 53% eastbound and westbound, respectively. TranStar data was also used to divide the average daily direction traffic into hourly volumes. Peak hours were chosen to be used in the model, based on observation of the historic data the AM peak was determined to be from 7-9 a.m. and the PM peak was 3-5 p.m. A mid-day period was also chosen for analysis from 11 a.m.-1 p.m. The percentage of heavy vehicles on each arterial was determined using the AADT and AADTT provided within the FAF07 data for each arterial.

Since no turning volumes were available from historical data and given that origin-destination pairs were not known, the model was calibrated using the first hourly volumes from the AM peak period. All traffic volumes were balanced by this one peak hour to ensure that the number of vehicles entering and exiting the model were equivalent to those provided by the FAF07 data. The distribution of traffic was held constant in all three analysis periods which were modeled. In three of the enhanced connectivity scenarios, additional links were added to the network and traffic distribution was divided evenly from the existing links and the new links. Only freight vehicles traveling to and from the intermodal facility were permitted to use the new links since minor arterial traffic volumes and distributions were unknown.

The MOVES 2010a model was used to determine emissions rates for both passenger vehicles and heavy vehicles. For ease in simulation and data analysis, only gasoline-fueled passenger vehicles and diesel-fueled combination short-haul heavy vehicles were used in the emissions estimation. All road facilities were assumed to be restricted urban within the model and five pollutant rates based on speed were used including those for THC, CO, NOx, carbon dioxide (CO_2), and particulate matter of 2.5 microns or less ($PM_{2.5}$).

Micro-Simulation with VISSIM

VISSIM micro-simulation software was used to create and run the models. This software package allowed the research team to have flexibility in input points for traffic, differing speed limits on road classes and in different scenarios, and was initially thought to contain a robust emissions modeling feature. The emissions feature proved inapplicable to this situation and thus the MOVES emissions rates were used with the VISSIM model outputs, including vehicle volumes on each link in the network, vehicle speeds per second and vehicle type (passenger vehicle or heavy vehicle).

Construction and Calibration of Micro-Simulation Model

In the construction of the VISSIM model, assumptions were made for ease in simulation and model output. Calibration of the model was completed using the FAF data along with the Houston TranStar historical data, providing two sources of historical data to compare with the model output. In the base case of the model, traffic volumes and speeds as well as traffic distribution closely matched the historical data for the major arterials in the highway network. Some minor adjustments were needed in the simulation model to assure that highway driving behaviors were being observed by the simulated vehicles. Figure 1 shows the basic network that was modeled.

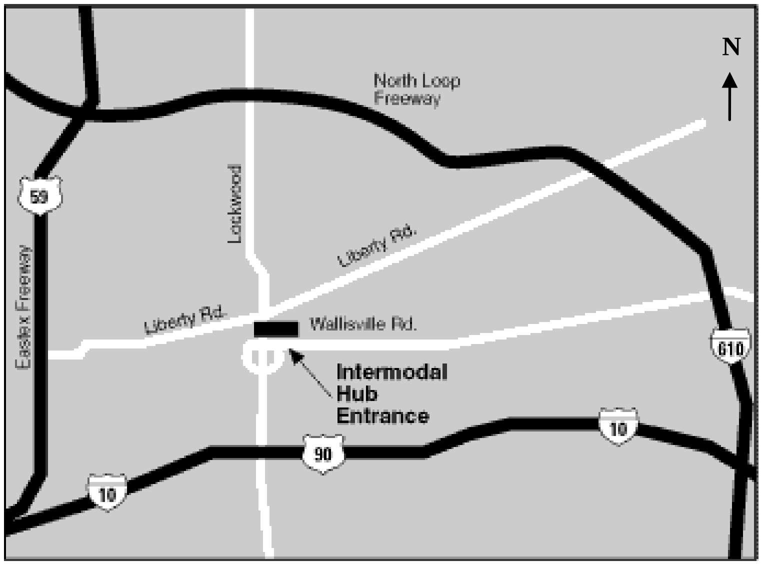

Figure 1. Location of Englewood and Surrounding Arterial Network.
(Source: www.uprr.com)

After the base model was created, the scenarios were also created in separate models. The following describes the five scenarios that were modeled.

Scenario 1: Same network, but with increased speed on Lockwood Drive (refer to Figure 1 for a graphical view of the network), which is the main entrance arterial to the Englewood Intermodal facility. The speed was raised in the model from 35 mph to 45 mph; this change could simulate improved road conditions, or simply an increase in speed limit. This change could also come from the addition of a "truck only" lane on Lockwood Drive with a 45 mph speed limit.

Scenario 2: This scenario saw the addition of new links. The FAF07 network did not include Wallisville Road as a connector to I-610 (to the east of Englewood). With this added link freight vehicles would have the ability to use Wallisville as a less congested means of arriving at or leaving from Englewood to routes either on the east or south of the intermodal facility. In this scenario, only heavy vehicles traveling to and/or from Englewood were permitted to use this facility and the speed was limited to 35 mph. Trip distribution was made by giving equal opportunity for heavy vehicles to use the existing FAF07 routes or to choose the new link to travel to/from Englewood.

Scenario 3: This scenario is similar in concept to Scenario 2, but with additional links to the west using Liberty Road. This link is not included on the FAF07 network, but was added to the model to determine emissions benefits from using a less congested roadway to travel to and/or from Englewood to US 59, which then connects to I-610 to the north and I-10 to the south.

Scenario 4: This scenario has all of the new links to the east and west. Both Liberty Road and Wallisville Road were included in the network for use by heavy vehicles traveling to and/or from the intermodal facility. Again, these facilities were both given speeds of 35 mph (which could be improved to 45 mph for more emissions benefits).

Scenario 5: Combining all the previous scenarios, this scenario includes the new Wallisville and Liberty links as well as increased speed on Lockwood. This allows connectivity to the east and west as well as improved connectivity on Lockwood for greater ease of access to the Englewood Intermodal Facility.

Model Assumptions

Assumptions used in the creation of the model are discussed in this section.

- Temporal distributions from US 90, an arterial serving the local area, were used for all of the minor arterials in the model since data for the minor arterials is not collected and thus could not be provided by TranStar.
- Truck volumes exiting the Englewood facility and their hourly distribution might have been used to more accurately model the 2007 scenario but could not be obtained for use in the model. For simplicity and consistency within the model, entering and exiting volumes were determined to be temporally equal based on the FAF07 data. As a result, this model assumes s rigorous scheduling program where truck traffic into and out of the intermodal facility is uniformly distributed throughout the operating hours of 6 a.m. to 11 p.m.
- Although some traffic control devices are present in the existing network, for simplicity in model creation and outputs, no traffic control devices were included in the model. All roadways in the model were free-flow, with no traffic signals, no school zones, and no bus stops, although these causes of delay do exist on the minor arterials within the existing system.
- When new links were added to the model for connectivity scenarios, only heavy vehicles traveling to and from the intermodal facility were permitted use of the new links.
- All passenger cars were treated equal within the model for application of the MOVES emissions rates. Emissions rates were calculated based on vehicle age distribution from Texas vehicle registration data.
- All heavy vehicles were treated equal within the model for application of the MOVES emissions rates as well.

- The model assumed a traffic distribution of simply balanced traffic volumes on each arterial. Due to the fact that the trip distributions remained the same during all scenarios the emissions changes can be seen with a simple comparison.

Results

This section describes the analysis process step-by-step with graphs, tables, and charts displaying the data used, information found, and the outputs from the models. All model outputs can be found in the Appendix, but limited results are displayed in the body of the report.

Analysis began by extracting traffic volumes from the FHWA's FAF07 database. These traffic volumes are contained within an Arc GIS file. The GIS file was clipped to contain all the surrounding arterials roadways in close proximity to the Englewood Intermodal Facility. The roadways included: US 59, US 90, I-10, the northeast quadrant of the I-610 Loop, and Lockwood Drive. The FAF07 data is per link, not directional, nor temporal in nature. Simple AADT and AADTT (trucks) were provided so historical directional data and hourly volumes were used from the Houston TranStar database. After these data were collected and assigned to peak hour volumes, the VISSIM model was created.

The model was run for each peak hour according to the varying traffic volumes and directional traffic flows. The output of the model runs revealed second-by-second link volumes and vehicle speeds for both passenger cars and heavy vehicles, which were then collected and averaged for each hour within the peak hour. Table 1 is a small portion (7 of 114 links) of the AM peak hour output from the base case model run.

Table 1. Base Case Model Output for the AM Peak Hour.

	Heavy Vehicle		Passenger Car	
Link	**Volume (veh/hr)**	**Speed (mph)**	**Volume (veh/hr)**	**Speed (mph)**
1	45	32	650	32
2	70	32	1080	31
3	29	32	408	32
4	97	32	1404	32
5	84	32	863	31
6	43	32	827	31
7	76	31	830	31

With the vehicle volumes and speeds for each link, the emissions can be found from each link using the MOVES2010a emissions rates, which are assigned by vehicle type and speed.

Table 2 shows the five emissions rates used in this research for vehicle speeds 20-25 mph in grams per mile.

Table 2. Emissions Rates (g/mi) from MOVES2010a for Travel Speeds 20-25 mph.

	Heavy Vehicles					Passenger Cars				
Speed mph	THC	CO	NOx	CO2-Atm	PM 2.5	THC	CO	NOx	CO2-Atm	PM 2.5
20	**0.8**	**2.5**	**6.0**	**1710.4**	**0.3**	**0.09**	**3.6**	**0.4**	**487.1**	**0.004**
21	0.8	2.5	5.8	1673.7	0.3	0.09	3.6	0.3	476.0	0.004
22	0.8	2.4	5.7	1637.1	0.3	0.09	3.5	0.3	464.8	0.004
23	0.7	2.4	5.6	1600.5	0.3	0.09	3.5	0.3	453.7	0.004
24	0.7	2.3	5.4	1563.8	0.3	0.08	3.4	0.3	442.6	0.004
25	**0.7**	**2.2**	**5.3**	**1527.2**	**0.3**	**0.08**	**3.3**	**0.3**	**431.4**	**0.004**

Emissions rates from the MOVES2010a model are provided at 5 mph increments and were interpolated on a linear assumption to apply to average link speeds. The speeds from the model were rounded to the nearest whole number for simplicity in interpolation and application of the emissions rates.

In determining the emissions for the entire network, the second hour of each peak period was used. This was due to the fact that the second hour of simulation began with a fully saturated network and thus the complete hour was similar to actual operating conditions in the network. The average speed was used from each link during that hour (for each peak period/analysis period) to determine which emissions rate would be assigned to each link (in the 114 link network). Then the hourly volume of traffic on each link (volume of heavy vehicles and passenger vehicles separately) was multiplied along with the link length with the emissions rates to determine the total emissions for a one hour time period throughout the network, for each of the analysis periods. Table 3 shows the results from the base case scenario in regard to the emissions for the AM peak hour.

Table 3. Total Base Case Network Emissions for the AM Peak Hour.

	Pollutant:	**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
Passenger Cars:	(grams/hour)	9,227	521,019	48,846	48,061,666	878
	(pounds/hour)	20.3	1,148.6	107.7	105,957.8	1.9
Heavy Vehicles:	(grams/hour)	4,627	17,776	43,391	12,993,698	2,228
	(pounds/hour)	10.2	39.2	95.7	28,646.2	4.9
Total Emissions:	(grams/hour)	**13,854**	**538,795**	**92,237**	**61,055,364**	**3,106**
	(pounds/hour)	**30.5**	**1,187.8**	**203.3**	**134,604.0**	**6.8**

Table 3 shows that emissions are much higher from the passenger cars, which is to be expected being that they account for more than 90% of the traffic in the network. The major concern is that about 10% of the traffic (heavy vehicles) is accounting for a large percentage of the NOx and $PM_{2.5}$ vehicle emissions, which is also evident from Table 3. A graphical demonstration makes this even more apparent; Figure 2 shows the data from Table 3 in a graphical format for a percentage comparison of passenger car and heavy vehicle emissions.

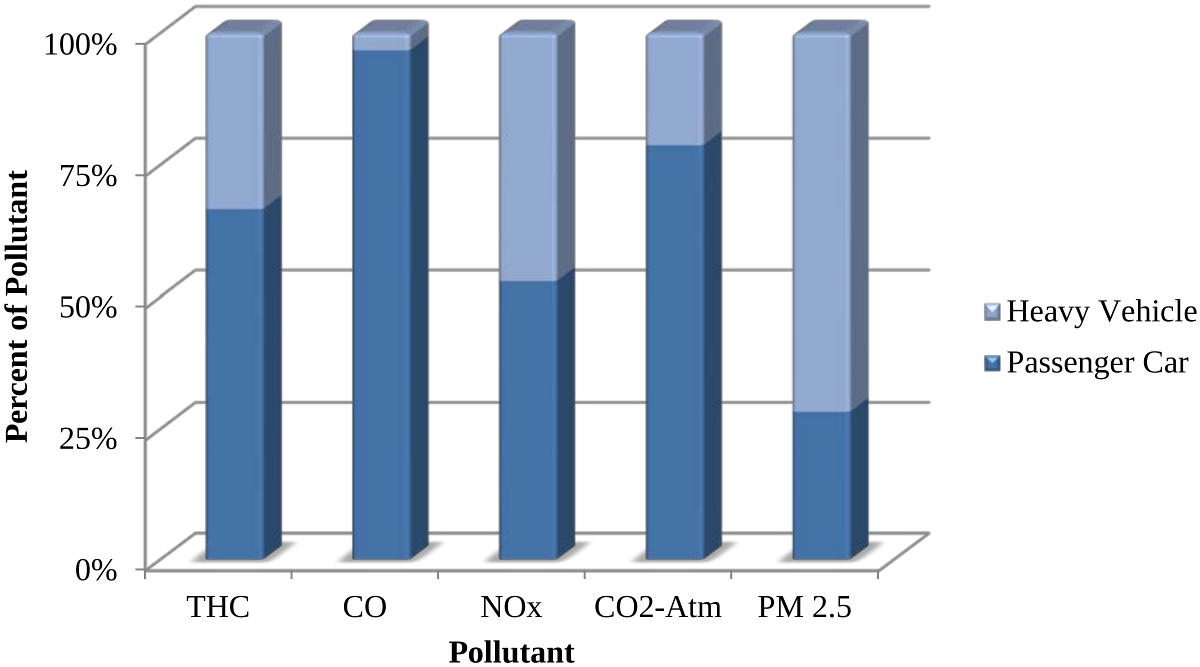

Figure 2. Base Case Heavy vs. Passenger Vehicles in Percent of Pollutant for the AM Peak Hour.

Following the completion of the base case model, five different scenarios were built and run for each of the three analysis periods. A quick review shows the five scenarios are as follows (see Figure 1 for a graphical reference):

Scenario 1: Increased speed limit on Lockwood Drive.

Scenario 2: Addition of Wallisville Road to network.

Scenario 3: Addition of Liberty Road to network (without Wallisville)

Scenario 4: Addition of Liberty and Wallisville Road to the network.

Scenario 5: Increased speed limit on Lockwood Drive and addition of both Liberty and Wallisville Road.

The emissions changes for all improvement scenarios were very minimal. This is due to the fact the heavy vehicles were the only vehicles with routes or speeds modified (except in scenario 1), and that those vehicles only account for less than 10% of all the traffic volume in the model. Most of the differences between the scenarios and the base case were within the 0-1% range, which could be within the error range of the VISSIM model as well. Overall, the results were not conclusive that adding the specific links to the network or increasing the speed of existing arterials would significantly reduce total tailpipe emissions. The following five graphs (Figures 3-7) illustrate the results of each scenario compared with the base case model.

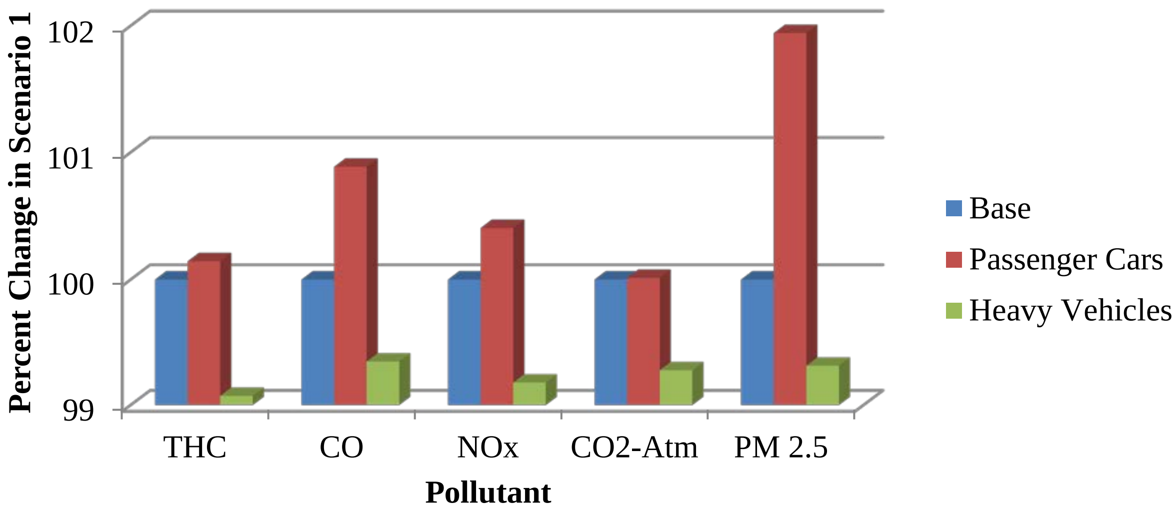

Figure 3. Scenario 1 Comparison with the Base Case.

Figure 3 shows that when taking the base case at 100%, all the pollutants, except CO_2-Atm for the passenger car category, actually produced more pollutants than in the base case, while the heavy vehicles preformed better for each pollutant. Note that even though the scale of these figures suggest dramatic differences, Scenario 1 saw the greatest improvement at 0.93% and the worst increase in emissions at 1.94% more emissions. These values represented in Figures 3-7 are averages of the AM, Mid-Day, and PM peak periods. The appendix includes all of the results.

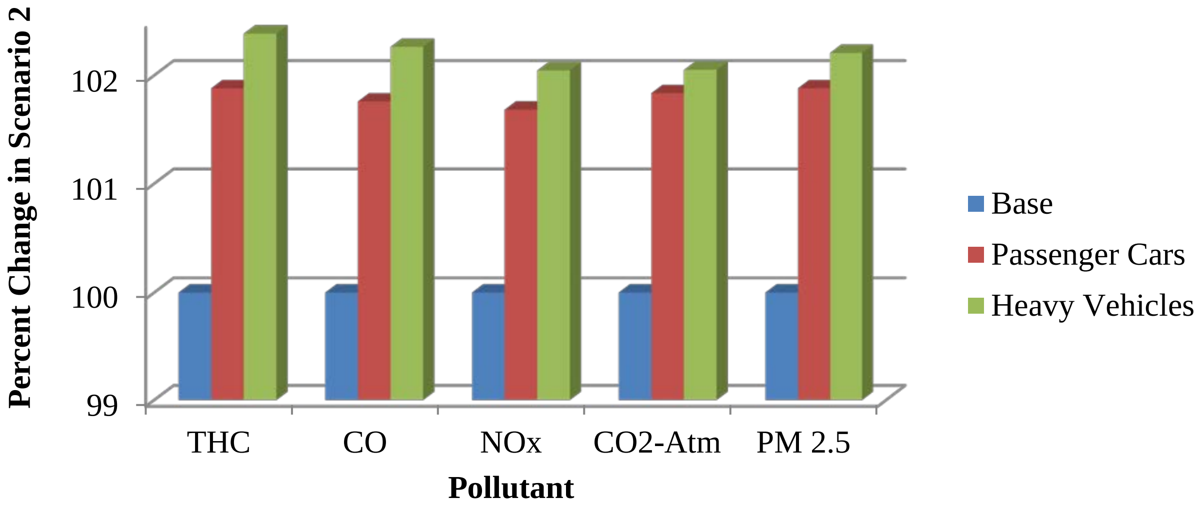

Figure 4. Scenario 2 Comparison with the Base Case.

Scenario 2 shows that adding Wallisville with a 35 mph speed limit is not particularly beneficial, but these results are showing network-wide emissions, not only those from Englewood, and there could be inherent errors in the VISSIM model at such small percentages.

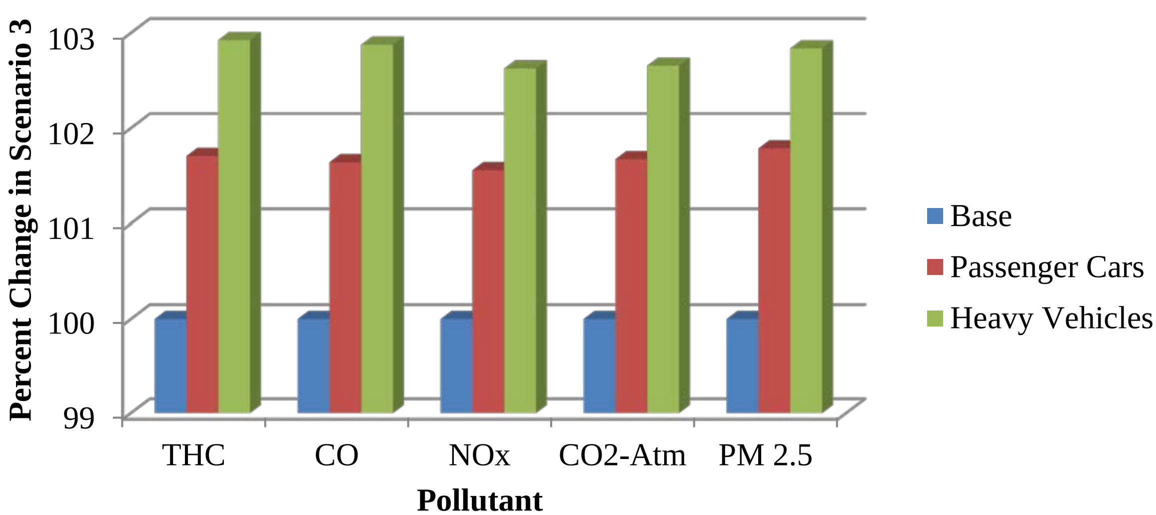

Figure 5. Scenario 3 Comparison with the Base Case.

Scenario 3 shows even greater amounts of emissions with Liberty Road being added to the network. Adding longer distances at 35 mph is causing the heavy vehicles to create more emissions. Heavy vehicles emit less of these five pollutants at 45 mph than at 35 mph according to the MOVES2010a model and increasing the speed may increase the benefits on these additional links.

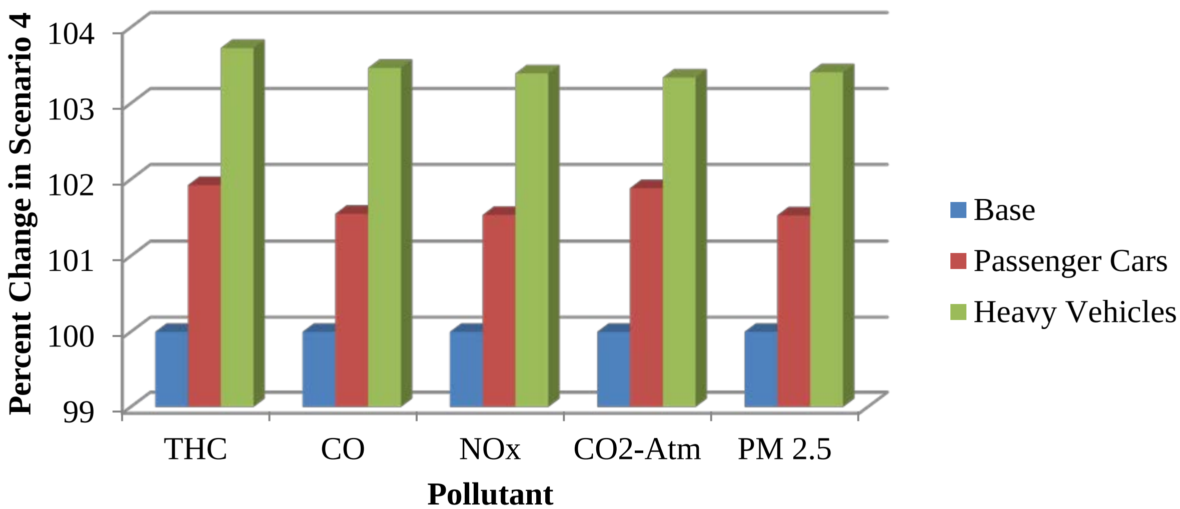

Figure 6. Scenario 4 Comparison with the Base Case.

Having both Liberty and Wallisville added to the network further increases the distance freight vehicles travel on 35 mph roads to reach or leave the Englewood Intermodal Facility and these heavy vehicle emissions are almost 3.5% higher than in the base case for each pollutant as is shown in Figure 6.

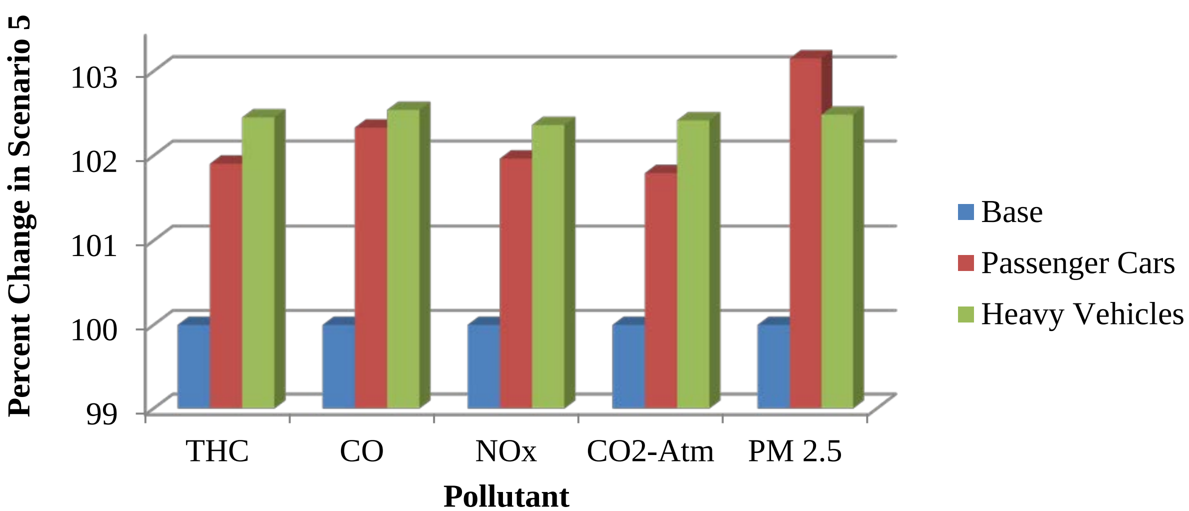

Figure 7. Scenario 5 Comparison with the Base Case.

With the increased speed on Lockwood and the decreased distance traveled on 35 mph roads, the heavy vehicle emissions are not as high as in the previous scenarios, but still all vehicles create more emissions in Scenario 5.

To compare the individual analysis periods and each pollutant, graphs were created to show the effect of each scenario on the individual pollutants. Figure 8 is an example of one of those 15 graphs. Figure 8 shows the effect each scenario had on NO_x for the AM analysis period (for the other 14 graphs, see the Appendix).

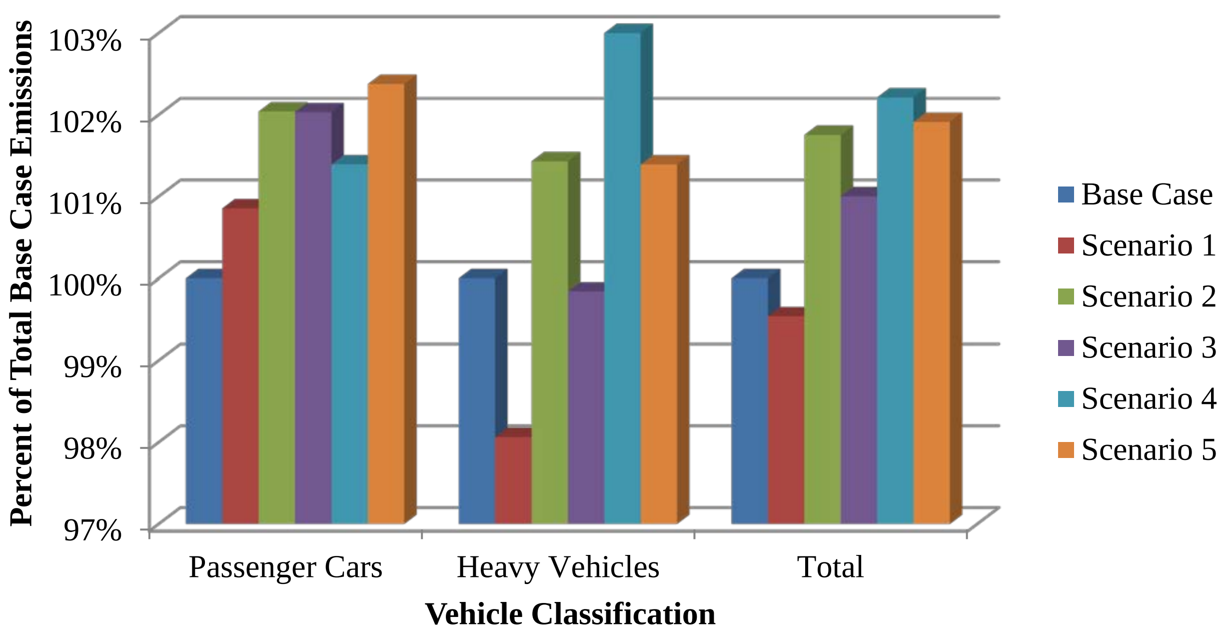

Figure 8. Scenario Comparison for NO_x during the AM Peak Period by Vehicle Class.

Figure 8 shows that the emissions from the heavy vehicles improved in Scenarios 1 and 3 but overall only Scenario 1 improved the amount of NO_x emitted during the AM peak hour. Note that the differences are small and the scale of the graph may magnify the differences; the overall improvement for Scenario 1 was 0.5% of the base case.

Examination of all 15 charts shows that only Scenario 1 appears to consistently equal or improve on the baseline scenario. This means that an increase in speed along Lockwood would accomplish more to reduce emissions in *this* case than the other options. An examination of the network reveals that the additional links add distance to trips to and from the hub, so while the routes may be less congested, the added distance adds enough emissions to offset reductions due to decreased congestion. Another case study in which increased connectivity leads to reduced travel distance in addition to reduced congestion would be much more productive in reducing emissions.

Note that inherent errors in the VISSIM model seem to exist due to the fact that the passenger cars' emissions increased in Scenarios 2, 3, and 4 although the only difference for those vehicles in those three scenarios is that there are fewer heavy vehicles on the major arterials. This does not seem to equate to more emissions, but then again the difference is at maximum of 1.9%.

Conclusions

This task developed an approach and methodology for determining the emissions impacts of connectivity-based congestion mitigation strategies. The case study for a selected intermodal freight hub showed low levels of emissions reduction - with Scenario 1 showing a slight decrease in emissions for heavy vehicles by increasing the speed of the access road to the intermodal facility from 35 to 45 mph. Connectivity improvements that shorten overall travel distance or significantly reduce congestion can also be expected to reduce emissions. In this specific analysis, a study of the emissions impacts of only freight traffic rather than all traffic using the network being examined could better reflect the relative benefits of the improved connectivity scenarios. All trips would still need to be modeled to obtain the proper trip route and speed impacts of connectivity changes.

Further studies of connectivity impacts using the methodology developed in this task could help validate this approach and estimate emissions impacts for various strategies or scenarios. Studies using trip origin-destination pairs to assure that traffic assignment is congruent with both before-and-after network characteristics is a potential area of investigation. Application of the study approach to dense urban areas for the comparison of grid-based and radial road networks is another area of investigation that could potentially help demonstrate the emissions benefits of providing greater connectivity.

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APPENDIX

MOVES2010a Emissions Rates by Speed and Vehicle Type

	Heavy Vehicles					Passenger Cars				
Speed mph	THC	CO	NOx	CO2-Atm	PM 2.5	THC	CO	NOx	CO2-Atm	PM 2.5
20	**0.81**	**2.55**	**5.98**	**1710.38**	**0.31**	**0.09**	**3.63**	**0.35**	**487.12**	**0.004**
21	0.78	2.48	5.84	1673.74	0.30	0.09	3.57	0.35	475.98	0.004
22	0.75	2.42	5.70	1637.10	0.29	0.09	3.51	0.35	464.84	0.004
23	0.72	2.36	5.56	1600.47	0.28	0.09	3.46	0.34	453.70	0.004
24	0.69	2.29	5.42	1563.83	0.28	0.08	3.40	0.34	442.56	0.004
25	**0.66**	**2.23**	**5.28**	**1527.19**	**0.27**	**0.08**	**3.34**	**0.33**	**431.42**	**0.004**
26	0.65	2.19	5.22	1512.09	0.26	0.08	3.33	0.33	424.89	0.004
27	0.63	2.15	5.16	1496.99	0.26	0.08	3.32	0.33	418.36	0.004
28	0.61	2.11	5.10	1481.88	0.26	0.08	3.31	0.33	411.83	0.004
29	0.59	2.07	5.03	1466.78	0.26	0.08	3.30	0.33	405.30	0.005
30	**0.57**	**2.03**	**4.97**	**1451.68**	**0.25**	**0.08**	**3.29**	**0.33**	**398.77**	**0.005**
31	0.56	1.99	4.85	1418.24	0.25	0.08	3.35	0.33	396.46	0.005
32	0.55	1.95	4.73	1384.79	0.24	0.08	3.42	0.33	394.15	0.005
33	0.54	1.91	4.61	1351.35	0.24	0.08	3.49	0.33	391.84	0.005
34	0.53	1.87	4.49	1317.90	0.23	0.08	3.55	0.34	389.53	0.006
35	**0.52**	**1.83**	**4.37**	**1284.46**	**0.22**	**0.08**	**3.62**	**0.34**	**387.22**	**0.006**
36	0.51	1.81	4.32	1270.34	0.22	0.08	3.67	0.34	385.46	0.006
37	0.50	1.79	4.26	1256.23	0.22	0.08	3.72	0.34	383.70	0.006
38	0.49	1.77	4.20	1242.11	0.22	0.07	3.78	0.34	381.95	0.007
39	0.48	1.74	4.15	1228.00	0.21	0.07	3.83	0.35	380.19	0.007
40	**0.47**	**1.72**	**4.09**	**1213.88**	**0.21**	**0.07**	**3.88**	**0.35**	**378.43**	**0.007**
41	0.46	1.70	4.04	1201.42	0.21	0.07	3.91	0.35	376.86	0.007
42	0.46	1.69	3.99	1188.96	0.21	0.07	3.95	0.35	375.28	0.007
43	0.45	1.67	3.94	1176.51	0.21	0.07	3.98	0.35	373.70	0.008
44	0.44	1.65	3.89	1164.05	0.20	0.07	4.02	0.35	372.12	0.008
45	**0.43**	**1.63**	**3.84**	**1151.59**	**0.20**	**0.07**	**4.05**	**0.35**	**370.55**	**0.008**
46	0.43	1.61	3.79	1137.52	0.20	0.07	4.05	0.35	368.31	0.008
47	0.42	1.59	3.74	1123.44	0.20	0.07	4.04	0.35	366.06	0.008
48	0.41	1.57	3.69	1109.37	0.20	0.07	4.04	0.35	363.82	0.008
49	0.41	1.55	3.64	1095.29	0.19	0.07	4.03	0.35	361.58	0.008
50	**0.40**	**1.54**	**3.58**	**1081.22**	**0.19**	**0.07**	**4.03**	**0.35**	**359.34**	**0.008**
51	0.39	1.52	3.54	1069.21	0.19	0.07	4.00	0.35	357.25	0.008
52	0.39	1.50	3.50	1057.20	0.19	0.07	3.97	0.35	355.17	0.007
53	0.38	1.49	3.46	1045.20	0.19	0.07	3.94	0.35	353.08	0.007
54	0.38	1.47	3.42	1033.19	0.18	0.07	3.91	0.35	351.00	0.007
55	**0.37**	**1.45**	**3.37**	**1021.18**	**0.18**	**0.07**	**3.89**	**0.35**	**348.92**	**0.007**
56	0.37	1.43	3.32	1006.71	0.18	0.07	3.87	0.35	347.45	0.007
57	0.36	1.41	3.27	992.23	0.18	0.07	3.86	0.35	345.99	0.007

58	0.36	1.39	3.23	977.76	0.17	0.07	3.84	0.35	344.53	0.007
59	0.35	1.37	3.18	963.28	0.17	0.07	3.83	0.35	343.07	0.007
60	**0.35**	**1.35**	**3.13**	**948.81**	**0.17**	**0.07**	**3.82**	**0.35**	**341.61**	**0.007**
61	0.34	1.33	3.14	950.69	0.17	0.07	3.82	0.35	341.97	0.007
62	0.34	1.32	3.15	952.58	0.17	0.07	3.82	0.35	342.33	0.007
63	0.33	1.30	3.17	954.46	0.16	0.07	3.83	0.36	342.69	0.007
64	0.33	1.28	3.18	956.34	0.16	0.07	3.83	0.36	343.05	0.006
65	**0.32**	**1.27**	**3.20**	**958.23**	**0.16**	**0.07**	**3.83**	**0.36**	**343.41**	**0.006**
66	0.32	1.25	3.21	960.72	0.16	0.07	3.91	0.37	345.28	0.006
67	0.31	1.24	3.23	963.20	0.16	0.07	3.99	0.37	347.15	0.006
68	0.31	1.23	3.24	965.69	0.16	0.07	4.06	0.38	349.02	0.006
69	0.30	1.21	3.26	968.18	0.16	0.07	4.14	0.38	350.89	0.006
70	**0.30**	**1.20**	**3.27**	**970.67**	**0.15**	**0.07**	**4.22**	**0.39**	**352.76**	**0.006**

Model Outputs in Grams and Pounds of Pollutant per Vehicle Type and Total per Analysis Period

		BASE				
AM		**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
	PC	9,227	521,019	48,846	48,061,666	878
		20.3	1148.6	107.7	105957.8	1.9
	HGV	4,627	17,776	43,391	12,993,698	2,228
		10.2	39.2	95.7	28646.2	4.9
	Total	**13,854**	**538,795**	**92,237**	**61,055,364**	**3,106**
		30.5	**1,187.8**	**203.3**	**134,604.0**	**6.8**
Mid						
	PC	8,018	461,269	43,371	41,809,623	772
		17.7	1016.9	95.6	92174.4	1.7
	HGV	3,692	14,393	35,472	10,644,493	1,812
		8.1	31.7	78.2	23467.1	4.0
	Total	**11,710**	**475,663**	**78,843**	**52,454,116**	**2,585**
		25.8	**1,048.7**	**173.8**	**115,641.5**	**5.7**

PM

	THC	CO	NOx	CO2-Atm	PM 2.5
PC	9,624	552,784	51,690	50,207,856	937
	21.2	1218.7	114.0	110689.4	2.1
HGV	4,761	18,498	44,857	13,487,255	2,322
	10.5	40.8	98.9	29734.3	5.1
Total	**14,385**	**571,282**	**96,548**	**63,695,111**	**3,259**
	31.7	**1,259.5**	**212.9**	**140,423.7**	**7.2**

	Speed on Lockwood (Scenario 1)				
AM	**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
PC	9,264	528,756	49,263	48,186,014	903
	20.4	1165.7	108.6	106232.0	2.0
HGV	4,527	17,475	42,551	12,762,813	2,190
	10.0	38.5	93.8	28137.2	4.8
Total	**13,790**	**546,231**	**91,814**	**60,948,827**	**3,093**
	30.4	**1,204.2**	**202.4**	**134,369.2**	**6.8**
Mid					
PC	8,008	463,678	43,459	41,722,681	782
	17.7	1022.2	95.8	91982.8	1.7
HGV	3,672	14,355	35,364	10,619,883	1,808
	8.1	31.6	78.0	23412.8	4.0
Total	**11,680**	**478,033**	**78,823**	**52,342,564**	**2,590**
	25.8	**1,053.9**	**173.8**	**115,395.6**	**5.7**
PM					
PC	9,639	556,373	51,775	50,202,293	953
	21.2	1226.6	114.1	110677.1	2.1
HGV	4,757	18,499	44,759	13,466,206	2,320
	10.5	40.8	98.7	29687.9	5.1

		THC	CO	NOx	CO2-Atm	PM 2.5
	Total	**14,396**	**574,873**	**96,534**	**63,668,499**	**3,273**
		31.7	**1,267.4**	**212.8**	**140,365.0**	**7.2**

		Wallisville (Scenario 2)				
AM		**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
	PC	9,420	532,692	49,843	49,033,344	902
		20.8	1174.4	109.9	108100.0	2.0
	HGV	4,701	18,067	44,011	13,185,238	2,263
		10.4	39.8	97.0	29068.5	5.0
	Total	**14,121**	**550,759**	**93,854**	**62,218,583**	**3,165**
		31.1	**1214.2**	**206.9**	**137168.5**	**7.0**
Mid						
	PC	8,174	468,966	44,046	42,590,600	786
		18.0	1033.9	97.1	93896.2	1.7
	HGV	3,803	14,789	36,360	10,908,176	1,861
		8.4	32.6	80.2	24048.4	4.1
	Total	**11,977**	**483,755**	**80,406**	**53,498,776**	**2,647**
		26.4	**1066.5**	**177.3**	**117944.6**	**5.8**
PM						
	PC	9,778	560,330	52,439	51,018,584	948
		21.6	1235.3	115.6	112476.7	2.1
	HGV	4,882	18,942	45,845	13,783,863	2,377
		10.8	41.8	101.1	30388.2	5.2
	Total	**14,660**	**579,273**	**98,284**	**64,802,447**	**3,325**
		32.3	**1277.1**	**216.7**	**142864.9**	**7.3**

		Liberty (Scenario 3)				
AM		**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
	PC	9,365	533,751	49,838	48,751,517	909
		20.6	1176.7	109.9	107478.7	2.0
	HGV	4,600	17,783	43,323	12,998,156	2,231
		10.1	39.2	95.5	28656.0	4.9
	Total	**13,965**	**551,535**	**93,162**	**61,749,673**	**3,140**
		30.8	**1215.9**	**205.4**	**136134.7**	**6.9**
Mid						
	PC	8,164	468,549	44,047	42,559,151	784
		18.0	1033.0	97.1	93826.9	1.7
	HGV	3,852	14,988	36,862	11,059,966	1,886
		8.5	33.0	81.3	24383.1	4.2
	Total	**12,016**	**483,537**	**80,909**	**53,619,117**	**2,670**
		26.5	**1066.0**	**178.4**	**118209.9**	**5.9**
PM						
	PC	9,796	557,760	52,250	51,106,221	940
		21.6	1229.7	115.2	112669.9	2.1
	HGV	5,000	19,323	46,703	14,030,512	2,422
		11.0	42.6	103.0	30932.0	5.3
	Total	**14,797**	**577,083**	**98,953**	**65,136,733**	**3,362**
		32.6	**1272.3**	**218.2**	**143601.9**	**7.4**

		Both Added Roads (Scenario 4)				
AM		**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
	PC	9,423	528,737	49,526	49,035,423	892
		20.8	1165.7	109.2	108104.6	2.0
	HGV	4,797	18,352	44,751	13,388,300	2,298
		10.6	40.5	98.7	29516.1	5.1
	Total	**14,221**	**547,090**	**94,277**	**62,423,723**	**3,190**
		31.4	**1206.1**	**207.8**	**137620.8**	**7.0**
Mid						
	PC	8,167	468,885	44,087	42,585,813	785
		18.0	1033.7	97.2	93885.6	1.7
	HGV	3,821	14,873	36,610	10,983,796	1,872
		8.4	32.8	80.7	24215.1	4.1
	Total	**11,989**	**483,758**	**80,697**	**53,569,608**	**2,657**
		26.4	**1066.5**	**177.9**	**118100.8**	**5.9**
PM						
	PC	9,795	561,114	52,492	51,096,100	950
		21.6	1237.0	115.7	112647.6	2.1
	HGV	4,951	19,206	46,579	13,998,870	2,410
		10.9	42.3	102.7	30862.2	5.3
	Total	**14,746**	**580,320**	**99,072**	**65,094,971**	**3,361**
		32.5	**1279.4**	**218.4**	**143509.8**	**7.4**

		Both Added Roads and Speed (Scenario 5)				
AM		**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
	PC	9,447	535,791	50,007	49,136,313	912
		20.8	1181.2	110.2	108327.0	2.0
	HGV	4,693	18,055	43,995	13,183,219	2,262
		10.3	39.8	97.0	29064.0	5.0
	Total	**14,140**	**553,846**	**94,002**	**62,319,531**	**3,174**
		31.2	**1221.0**	**207.2**	**137391.0**	**7.0**
Mid						
	PC	8,153	471,074	44,157	42,480,645	794
		18.0	1038.5	97.3	93653.8	1.8
	HGV	3,803	14,835	36,508	10,959,775	1,867
		8.4	32.7	80.5	24162.2	4.1
	Total	**11,956**	**485,909**	**80,665**	**53,440,420**	**2,661**
		26.4	**1071.2**	**177.8**	**117816.0**	**5.9**
PM						
	PC	9,781	564,030	52,570	50,976,328	963
		21.6	1243.5	115.9	112383.6	2.1
	HGV	4,900	19,050	46,102	13,868,957	2,390
		10.8	42.0	101.6	30575.8	5.3
	Total	**14,682**	**583,080**	**98,672**	**64,845,285**	**3,353**
		32.4	**1285.5**	**217.5**	**142959.4**	**7.4**

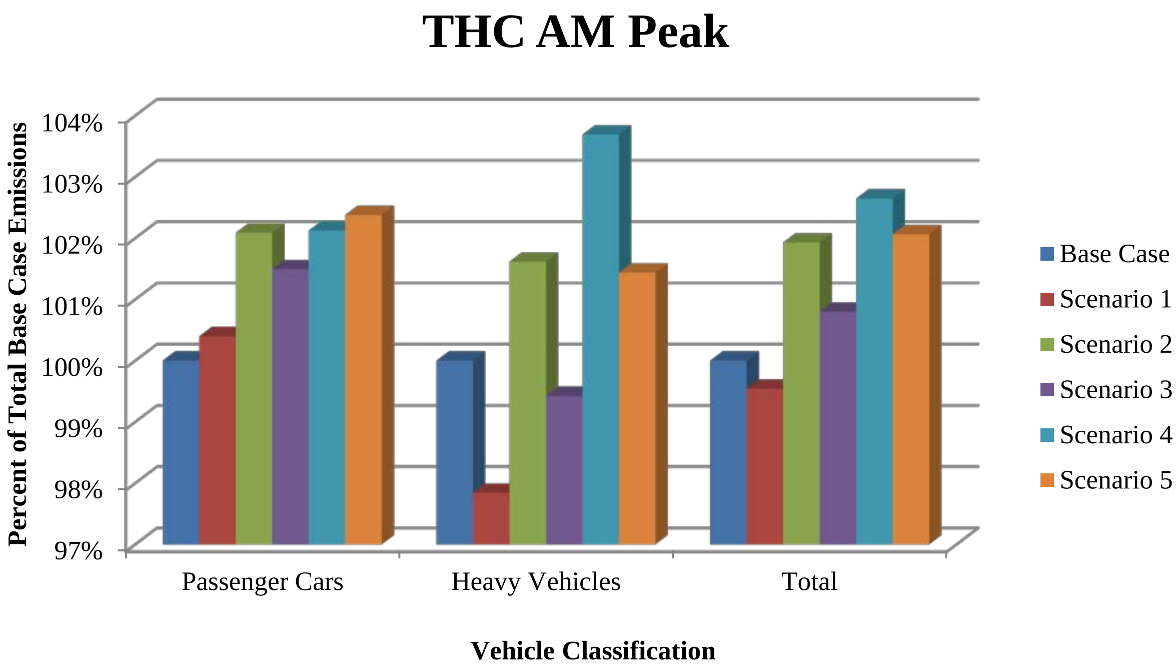
Scenario Pollutant Percent Comparison

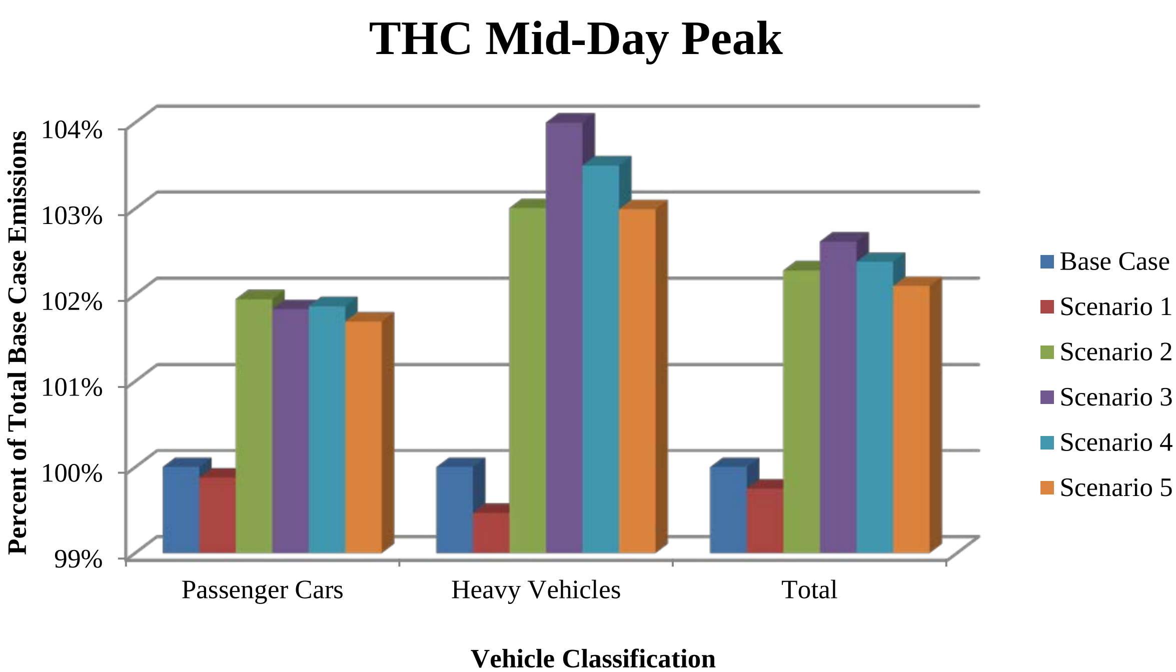
(Analysis Periods Averaged for Passenger Cars and Heavy Vehicles)

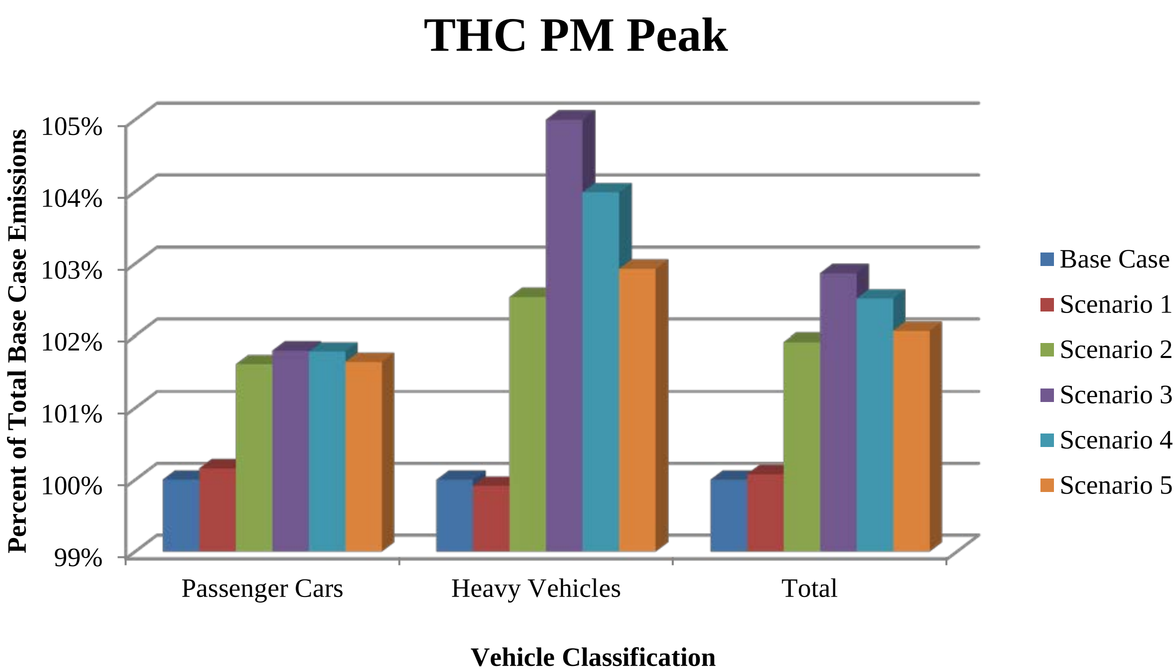
	Pollutant	**THC**	**CO**	**NOx**	**CO2-Atm**	**PM 2.5**
Scenario 1	PC	-0.14%	-0.89%	-0.41%	-0.01%	-1.94%
	HV	0.93%	0.65%	0.82%	0.72%	0.69%
Scenario 2	PC	-1.88%	-1.76%	-1.68%	-1.83%	-1.88%
	HV	-2.39%	-2.26%	-2.04%	-2.05%	-2.21%
Scenario 3	PC	-1.71%	-1.64%	-1.56%	-1.67%	-1.79%
	HV	-2.92%	-2.88%	-2.63%	-2.66%	-2.84%
Scenario 4	PC	-1.92%	-1.55%	-1.53%	-1.88%	-1.53%
	HV	-3.73%	-3.47%	-3.39%	-3.34%	-3.41%
Scenario 5	PC	-1.90%	-2.33%	-1.96%	-1.79%	-3.15%
	HV	-2.45%	-2.54%	-2.36%	-2.42%	-2.48%

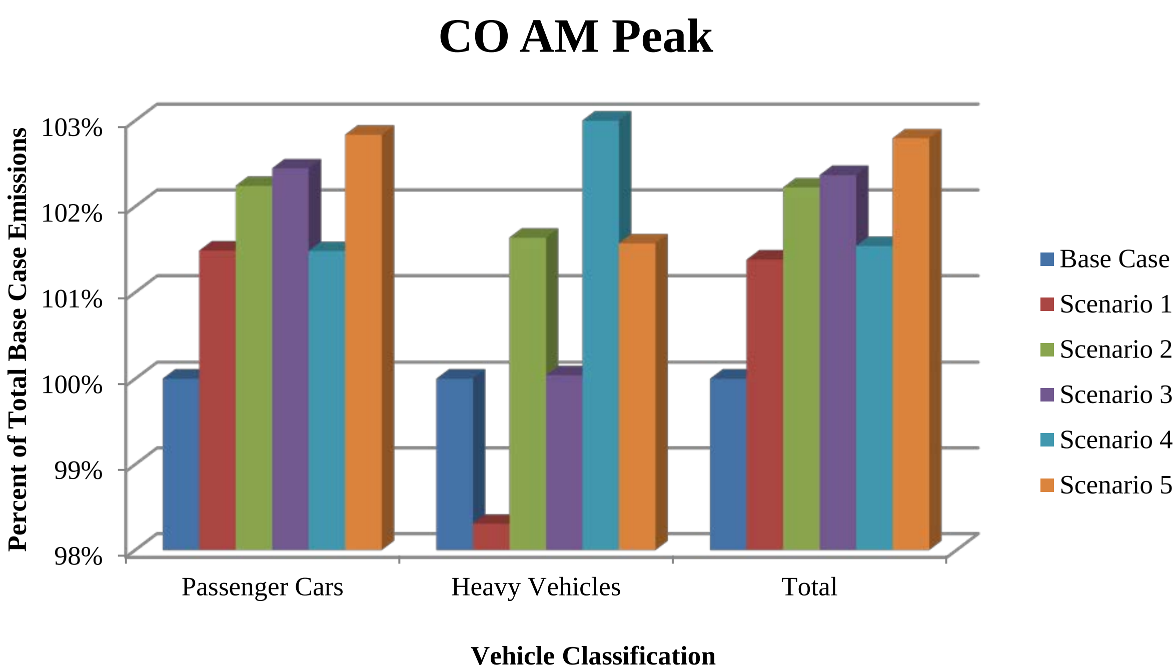
(These percentages show the amount of *decrease* in emissions, thus a negative number is an increase in emissions)

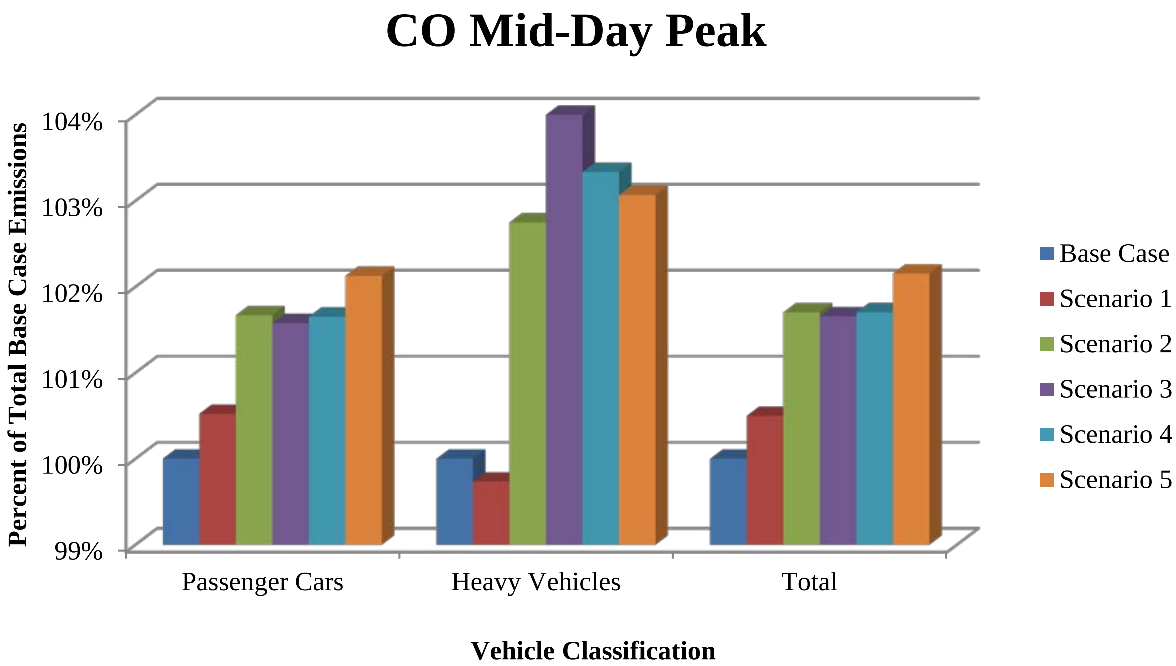
Scenario Pollutant Percent Comparison

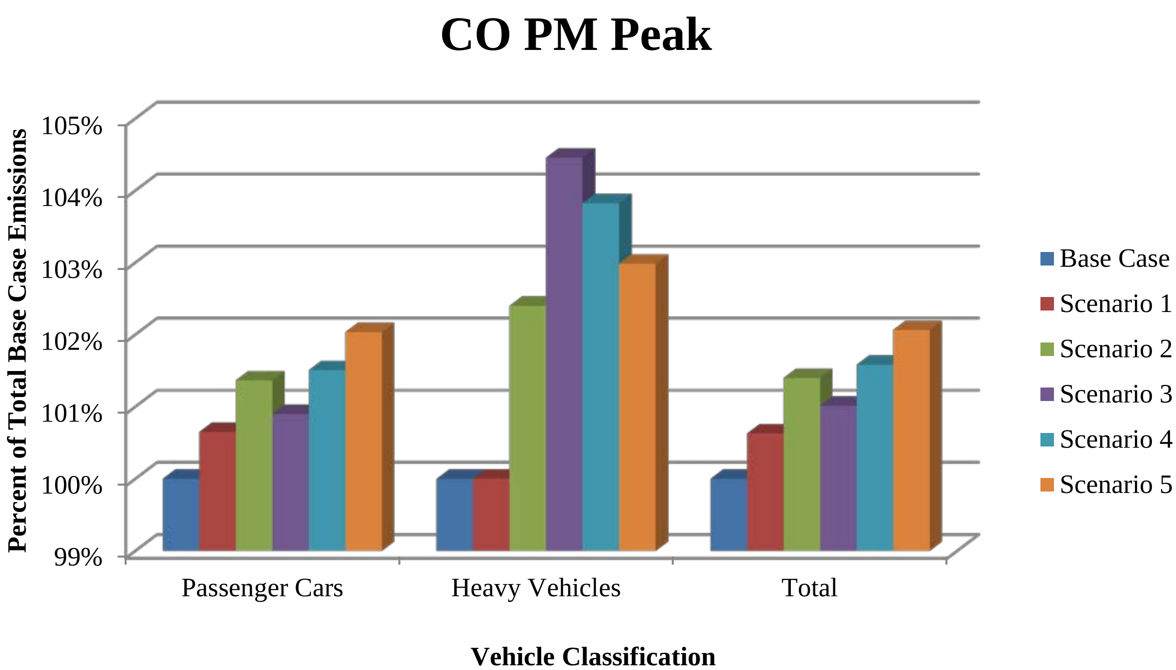


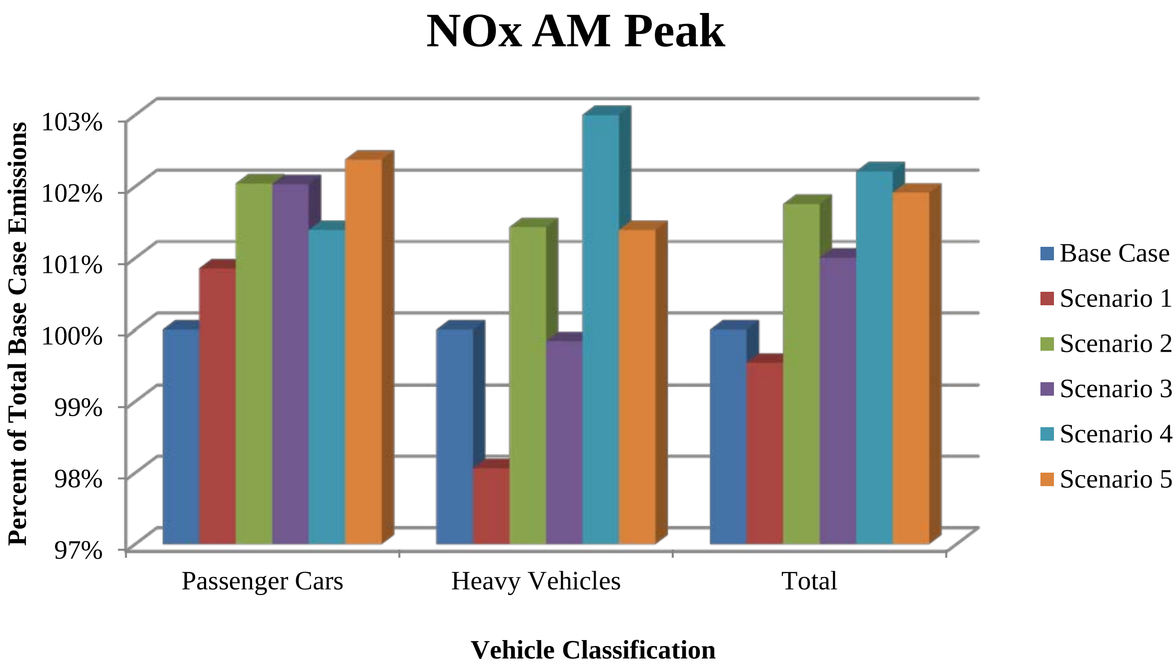


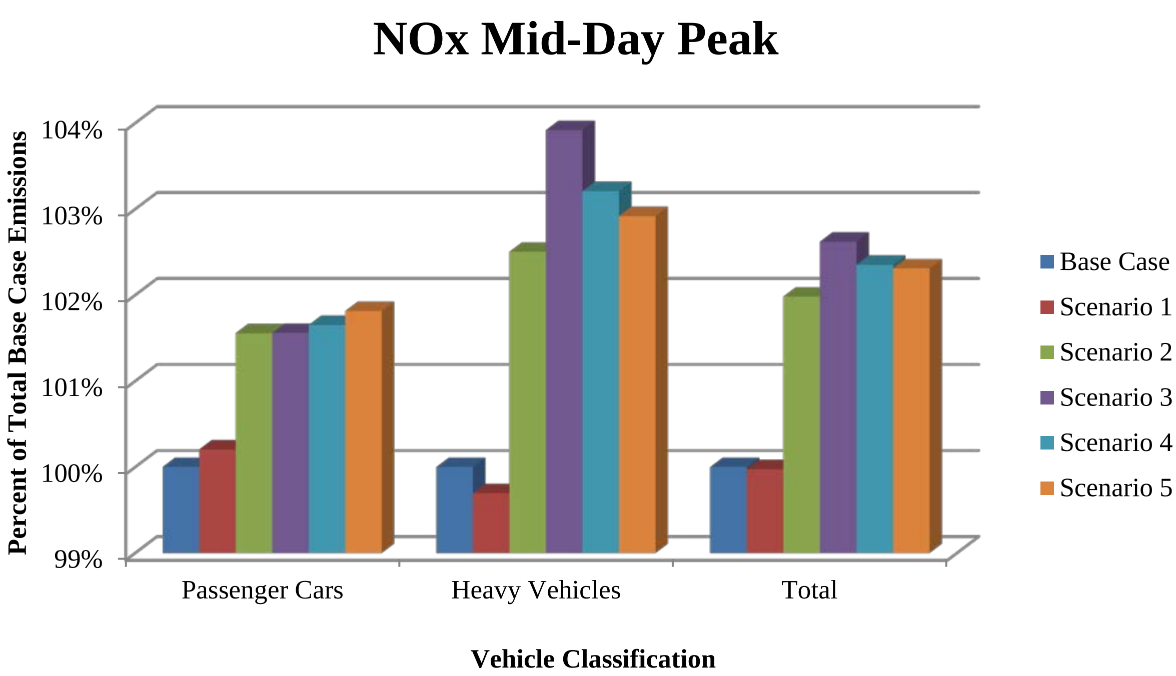

THC PM Peak
Percent of Total Base Case Emissions
105%
104%
103%
102%
101%
100%
99%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

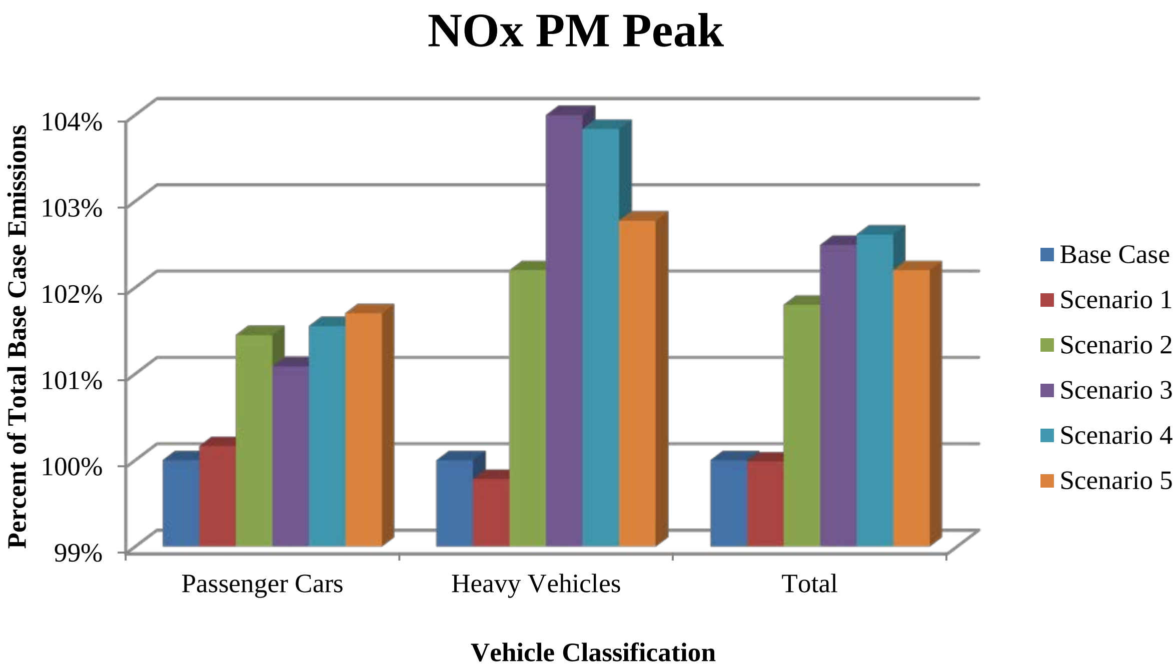

CO AM Peak
Percent of Total Base Case Emissions
103%
102%
101%
100%
99%
98%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

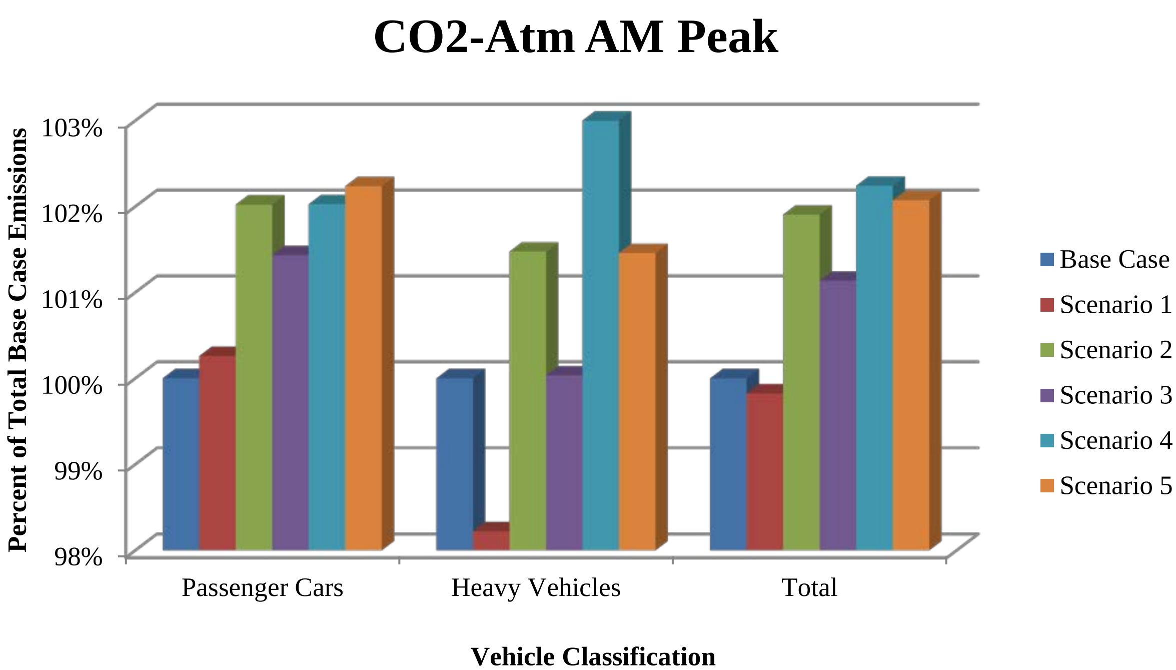

CO Mid-Day Peak
Percent of Total Base Case Emissions
104%
103%
102%
101%
100%
99%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


CO PM Peak
Percent of Total Base Case Emissions
105%
104%
103%
102%
101%
100%
99%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

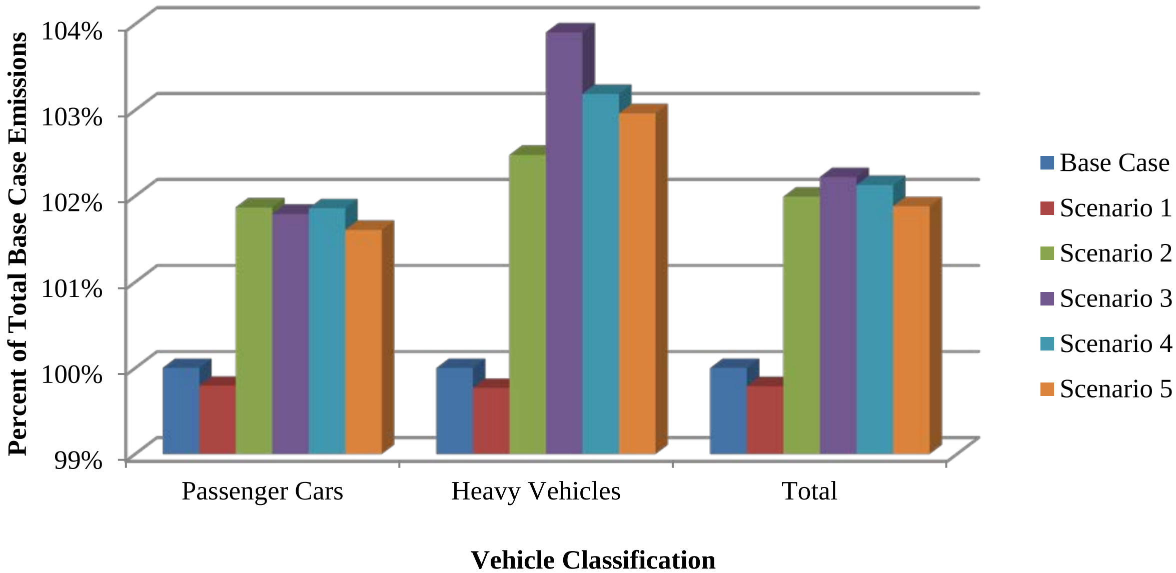

NOx AM Peak
Percent of Total Base Case Emissions
103%
102%
101%
100%
99%
98%
97%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


NOx Mid-Day Peak
Percent of Total Base Case Emissions
104%
103%
102%
101%
100%
99%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

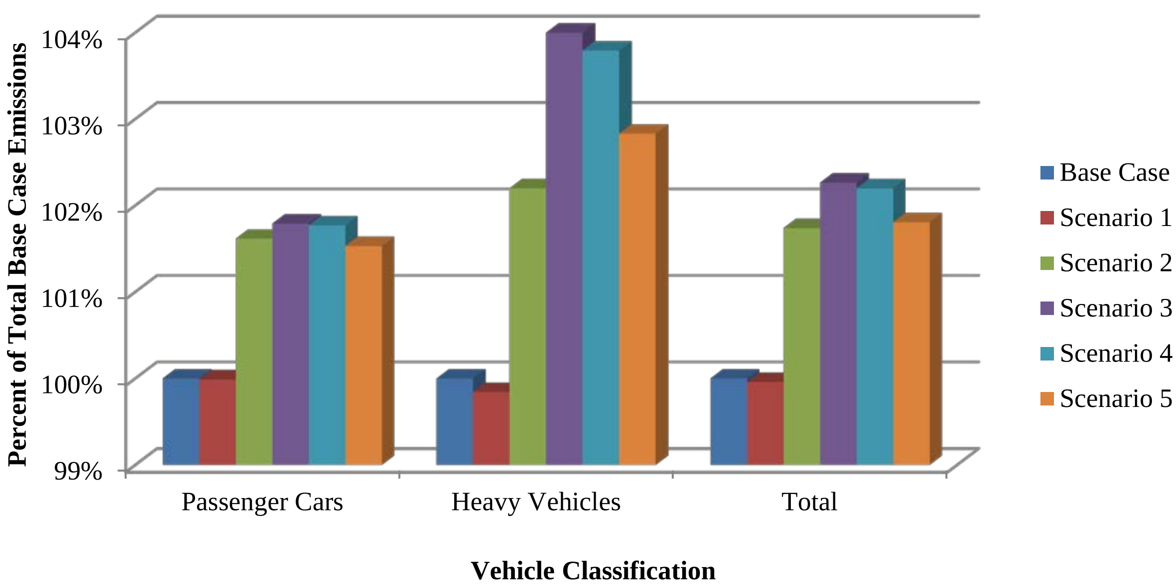

NOx PM Peak
Percent of Total Base Case Emissions
104%
103%
102%
101%
100%
99%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

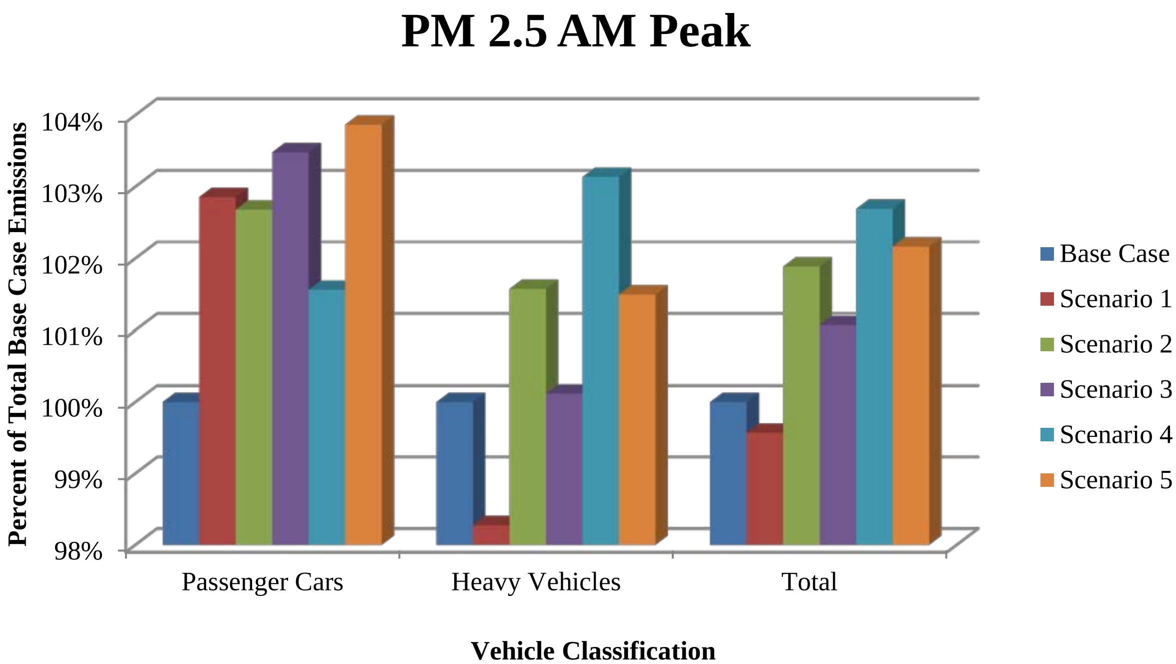

CO2-Atm AM Peak
Percent of Total Base Case Emissions
103%
102%
101%
100%
99%
98%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

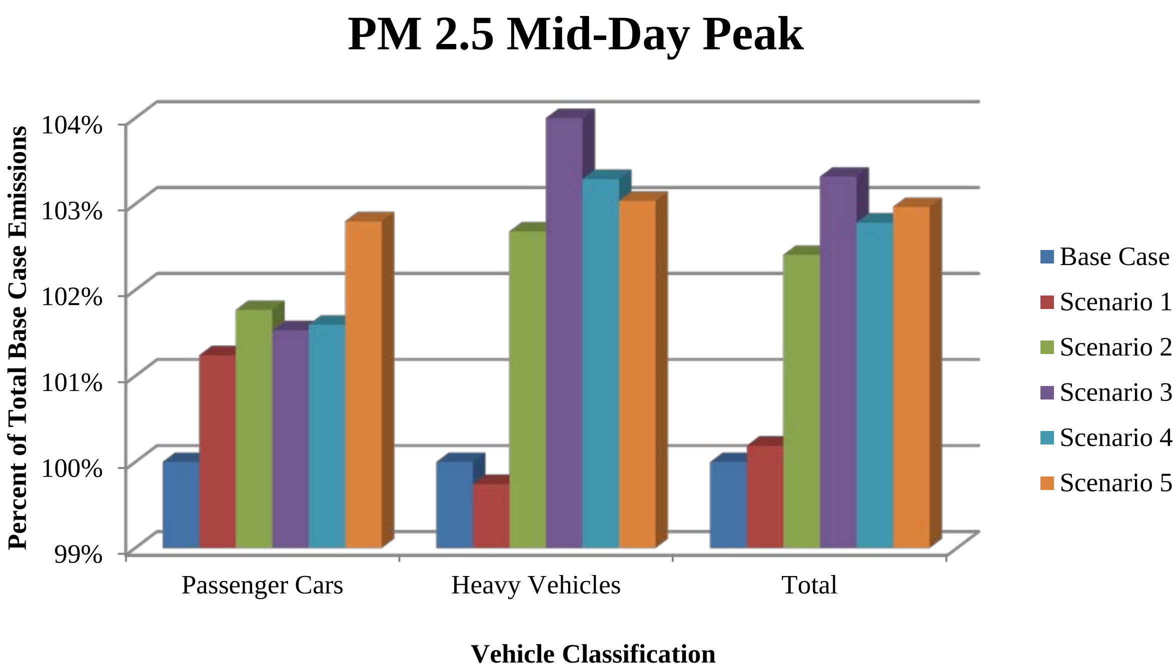
CO2-Atm Mid-Day Peak

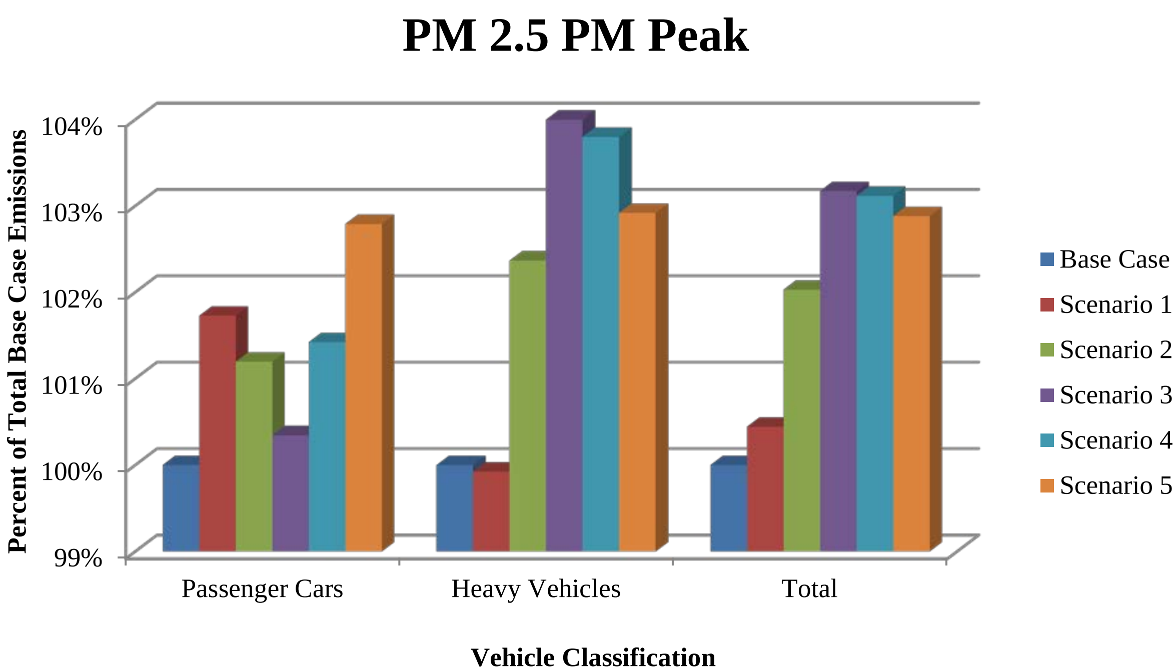


CO2-Atm PM Peak




PM 2.5 AM Peak
104%
103%
102%
101%
100%
99%
98%
Percent of Total Base Case Emissions
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


PM 2.5 Mid-Day Peak
104%
103%
102%
101%
100%
99%
Percent of Total Base Case Emissions
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5


PM 2.5 PM Peak
Percent of Total Base Case Emissions
104%
103%
102%
101%
100%
99%
Passenger Cars
Heavy Vehicles
Total
Vehicle Classification
Base Case
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Scenario 5

		THC			CO			NOx			CO2-Atm			PM 2.5		
		AM	**MD**	**PM**	**AM**	**MD**	**PM**	**AM**	**MD**	**PM**	**AM**	**MD**	**PM**	**AM**	**MD**	**PM**
Base	PC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	HV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Scenario 1	PC	100.4%	99.9%	100.2%	101.5%	100.5%	100.6%	100.9%	100.2%	100.2%	100.3%	99.8%	100.0%	102.9%	101.2%	101.7%
	HV	97.8%	99.5%	99.9%	98.3%	99.7%	100.0%	98.1%	99.7%	99.8%	98.2%	99.8%	99.8%	98.3%	99.7%	99.9%
	Total	99.5%	99.7%	100.1%	101.4%	100.5%	100.6%	99.5%	100.0%	100.0%	99.8%	99.8%	100.0%	99.6%	100.2%	100.4%
Scenario 2	PC	102.1%	101.9%	101.6%	102.2%	101.7%	101.4%	102.0%	101.6%	101.4%	102.0%	101.9%	101.6%	102.7%	101.8%	101.2%
	HV	101.6%	103.0%	102.5%	101.6%	102.7%	102.4%	101.4%	102.5%	102.2%	101.5%	102.5%	102.2%	101.6%	102.7%	102.4%
	Total	101.9%	102.3%	101.9%	102.2%	101.7%	101.4%	101.8%	102.0%	101.8%	101.9%	102.0%	101.7%	101.9%	102.4%	102.0%
Scenario 3	PC	101.5%	101.8%	101.8%	102.4%	101.6%	100.9%	102.0%	101.6%	101.1%	101.4%	101.8%	101.8%	103.5%	101.5%	100.3%
	HV	99.4%	104.3%	105.0%	100.0%	104.1%	104.5%	99.8%	103.9%	104.1%	100.0%	103.9%	104.0%	100.1%	104.1%	104.3%
	Total	100.8%	102.6%	102.9%	102.4%	101.7%	101.0%	101.0%	102.6%	102.5%	101.1%	102.2%	102.3%	101.1%	103.3%	103.2%
Scenario 4	PC	102.1%	101.9%	101.8%	101.5%	101.7%	101.5%	101.4%	101.7%	101.6%	102.0%	101.9%	101.8%	101.6%	101.6%	101.4%
	HV	103.7%	103.5%	104.0%	103.2%	103.3%	103.8%	103.1%	103.2%	103.8%	103.0%	103.2%	103.8%	103.1%	103.3%	103.8%
	Total	102.6%	102.4%	102.5%	101.5%	101.7%	101.6%	102.2%	102.4%	102.6%	102.2%	102.1%	102.2%	102.7%	102.8%	103.1%
Scenario 5	PC	102.4%	101.7%	101.6%	102.8%	102.1%	102.0%	102.4%	101.8%	101.7%	102.2%	101.6%	101.5%	103.9%	102.8%	102.8%
	HV	101.4%	103.0%	102.9%	101.6%	103.1%	103.0%	101.4%	102.9%	102.8%	101.5%	103.0%	102.8%	101.5%	103.0%	102.9%
	Total	102.1%	102.1%	102.1%	102.8%	102.2%	102.1%	101.9%	102.3%	102.2%	102.1%	101.9%	101.8%	102.2%	103.0%	102.9%

Scenario Comparisons for Each Pollutant by Analysis Period.