LA-Plan: Virtual Co-Laboratory for Policy Analysis in the Greater L.A. Region

Vehicle Fuel Use and Emission Factors

George Scora and Kanok Boriboonsomsin

College of Engineering - Center for Environmental Research and Technology
University of California at Riverside
Riverside, CA 92507

1.0 Introduction

The estimation of emissions from on-road mobile sources (i.e., the various types of vehicles) is critical for air quality management and control. The ability to relate fuel use and emissions with vehicle activities is required for properly assessing the impact of these activities on the fuel use and emission inventory. This type of assessment is important for transportation research, planning, and policy development.

In this research, vehicle fuel use and emission factors were developed for use with the Regional Economy, Land Use and Transportation Model (RELU-Tran) [1] in the Virtual Co-Laboratory for Policy Analysis in the Greater L.A. Region ("LA-Plan"). The following sections describe the methods and calculations that were used to generate the fuel use and emission factors and provide summary results.

2.0 Method

The EMFAC2011 vehicle emission model [2] developed by the California Air Resources Board (CARB) was chosen to generate vehicle emission and fuel use factors for LA-Plan. EMFAC is the regulatory model for conformity analysis of regional air quality management plans in California as required by the U.S. Environmental Protection Agency (EPA). EMFAC2011, released in September of 2011, is the latest version of the EMFAC model. However, it is not yet officially required for conformity analysis by the U.S. EPA. The current model for conformity analysis in California is EMFAC2007. Once the U.S. EPA announces the availability of EMFAC2011 in the Federal Registrar, EMFAC2011 will supersede EMFAC2007.

The EMFAC model can generate vehicle emission factors at multiple levels of aggregation from county level to roadway link level. The base non-idle emission factors (in grams per mile) in EMFAC2011 are given by vehicle category and by vehicle speed bins. Various correction factors such as speed correction factors (SCF), deterioration rates (DR), and ambient temperature and humidity correction factors are applied by the model to the base emission factors to result in emission factors for specific vehicle categories, regions, environmental conditions, etc.

The EMFAC2011 model can be run in two ways and at multiple levels of aggregation. The standalone EMFAC2011 model has three basic modules: 1) EMFAC2011-LDV for light-duty vehicles, 2) EMFAC2011-HD for heavy-duty vehicles, and 3) EMFAC2011-SG for scenario generation and data compilation. In EMFAC2011, the urban bus and heavy truck categories have been omitted from the EMFAC2011-LDV module since they are handled exclusively by the EMFAC2011-HD module unlike in EMFAC2007 where heavy-duty categories were part of EMFAC2007-LDV. EMFAC2011 emission estimates can be produced by running the LDV and HD modules separately and then running the SG module to create the appropriate analysis results.

A new development in EMFAC2011, however, is the creation of EMFAC2011 web-based data tool which allows users to generate emission results from a web-based application that integrates results from the LDV and HD databases based on user provided criteria. The EMFAC2011 web-based data tool is available through the CARB mobile source emission inventory website [3] and is recommended by CARB for most modeling applications. In this research, the EMFAC2011 web-based data tool was used to generate EMFAC2011 emission factors for various vehicle categories. The web-based data tool has the advantage of compiling data across the LDV and HD databases according to user defined criteria. A screen shot of the EMFAC2011 web-based data tool is given in Figure 1.

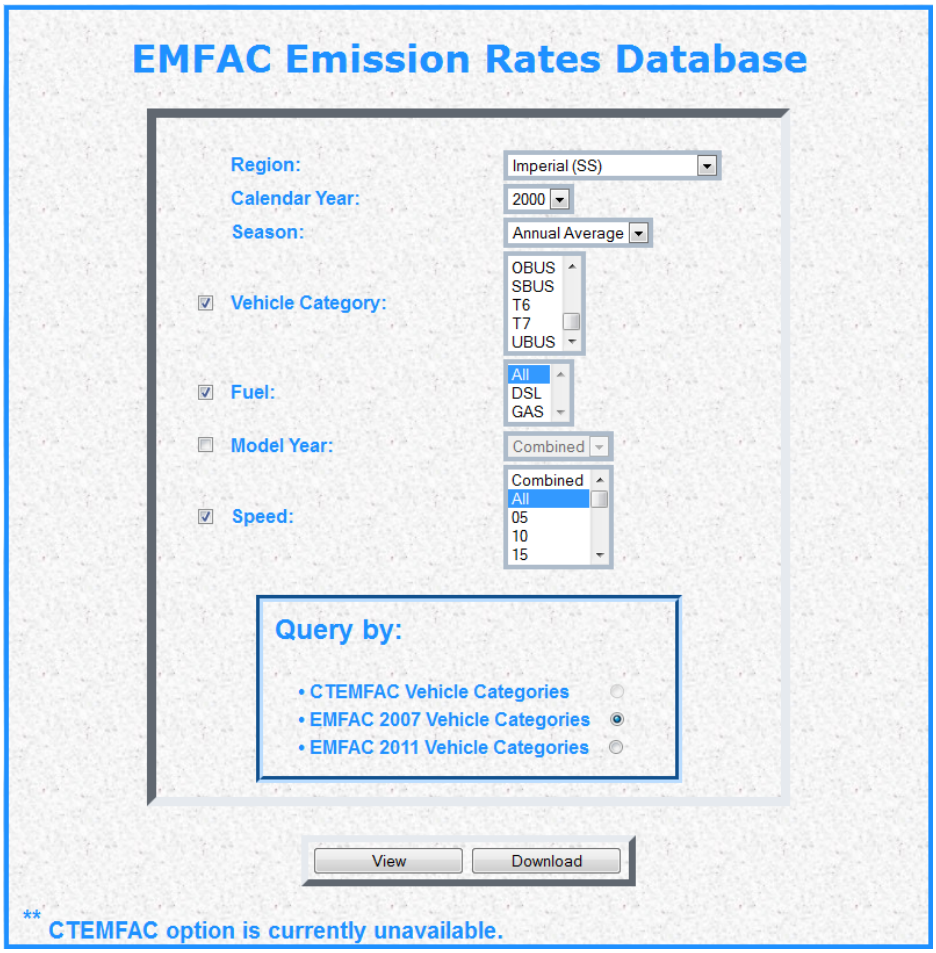


Figure 1. EMFAC2011 web-based data tools.

Emission and fuel use factors were generated for the vehicle categories in Table 1. This table presents the modeled vehicle categories and the corresponding EMFAC categories from which they were determined. EMFAC2011's newly defined vehicle categories were not used since they further categorize the T7 heavy-duty truck category into 16 separate heavy-duty truck categories which would have to be combined for the purpose of this research. In contrast, the EMFAC2011web-based tool retains EMFAC2007 vehicle category definitions including the combined heavy-duty diesel vehicle category (T7). The modeled light-duty vehicle category was a combination of three separate EMFAC vehicle categories (LDA, LT1, and LT2) which were weighted based on vehicle miles traveled (VMT) in each area, calendar year, and vehicle speed bin.

Table 1 Vehicle Categories

Modeled Category	EMFAC2011 Category
Light Duty Vehicle	Light-Duty Auto (LDA)
	Light-Duty Truck 0-3750 lbs. (LT1)
	Light-Duty Truck 3751-5750 lbs. (LT2)
Heavy-Duty Diesel Truck	Heavy-Duty Diesel Truck (T7)
Urban Bus	Urban Bus (UBUS)

Emission and fuel use factors for the vehicle categories in Table 1 were determined for the areas listed in Table 2. Areas in EMFAC are defined by county and air basin.

Table 2 Selected EMFAC2011 Areas

County	Air Basin
Ventura	South Central Coast
Los Angeles	South Coast
Orange	South Coast
Riverside	South Coast
San Bernardino	South Coast
Imperial	Salton Sea
Riverside	Salton Sea
Riverside	Mojave Desert/MDAQMD
Riverside	Mojave Desert/SCAWMD
Los Angeles	Mojave Desert
San Bernardino	Mojave Desert

Emission and fuel use factors were determined from the EMFAC2011 model for the standard conditions of 70 degree Fahrenheit ambient air temperature and 40% humidity. Emission factors were determined for the pollutants and greenhouse gases

listed in Table 3. The carbon dioxide (CO_2) emission factors account for reductions due to the adoption of the Pavley I regulation and Low Carbon Fuel Standard (LCFS). The description of emission and fuel use data processing is presented in the following section.

Table 3 Pollutants and Greenhouse Gases Considered

Pollutants and Greenhouse Gases Considered
Hydrocarbons in the form of Total Organic Gases and Reactive Organic Gases
Carbon Monoxide
Nitrogen Oxides
Carbon Dioxide (including reductions from adoption of Pavley I regulation and Low Carbon Fuel Standard)
Particulate Matter < 10 µm
Particulate Matter < 2.5 µm
Fuel Use

3.0 Emission Factor Processing

The EMFAC2011 web-based data tool, described in the precious section, was used to generate annual average emission factor by area, calendar year, vehicle category, fuel type, and vehicle speed bins across all model year vehicles. The EMFAC2011 web-based data tool combines individual vehicle model year data into a composite result based on vehicle age in a given calendar year and deterioration rates.

Output data from the EMFAC2011 web-based application was further processed to fit the criteria of this research. There are four processing steps: 1) compositing light-duty vehicle emission factors from those of the LDA, LDT1, and LDT2 categories (see Table 1), 2) combining emission factors from gasoline and diesel vehicles into composite emission factors, 3) Converting total organic gases and reactive organic gases to hydrocarbons, and 4) calculating fuel use factors based on CO_2 emission factors. These steps are described below.

3.1 Compositing LDV Category

A composite LDV category is a combination of three vehicle categories in EMFAC2011 as shown in Table 1. Emission and fuel use factors of the three vehicle categories in EMFAC2011 were weighted based on VMT to result in emission and fuel use factors for the composite LDV category.

3.2 Combining Emission Factors from Gasoline and Diesel Vehicles

For each vehicle category in EMFAC2011, emission and fuel use factors are available separately for gasoline and diesel vehicles. Therefore, these emission and fuel use factors need to be aggregated into composite emission and fuel use factors for each vehicle category. In this research, the aggregation was based on VMT.

3.3 Converting TOG and ROG to HC

Hydrocarbon emission data from mobile sources are typically measured as total hydrocarbon (THC) using a Flame Ionization Detector (FID) calibrated with propane. FID measures compounds with hydrogen and carbon atoms only and does not include compounds with oxygenated hydrocarbons such as alcohols and aldehydes. Because these oxygenated hydrocarbons are commonly found in engine exhaust and are chemically reactive in forming ozone and Secondary Organic Aerosol (SOA), CARB uses the emission category Total Organic Gases (TOG) to include them. CARB also uses the emission category Reactive Organic Gases (ROG) which is a portion of TOG that is reactive and does not include non-regulated emissions such as methane, ethane, and acetone.

The EMFAC2011 web-based data tool does not output THC values; rather they output TOG and ROG. In order to determine THC, Equations 1 and 2 could be used [4]. Equation 1 is for diesel vehicles while Equation 2 is for gasoline vehicles.

$$THC_{Diesel} = \frac{TOG}{1.4417} \quad (1)$$

$$TOG = 0.0115168 + 1.05894 \times THC_{Gasoline} - \frac{0.00129204}{THC_{Gasoline}} + \frac{5.66768e-5}{THC_{Gasoline}^{\ 2}} \quad (2)$$

where

THC = Total Hydrocarbons
TOG = Total Organic Gases

3.4 Calculating Fuel Use from CO_2

Fuel use data are not a direct output of the EMFAC2011 web-based data tool. Since almost all of the carbon in fuel is converted to CO_2 during the combustion process, the fuel consumption rate is proportional to CO_2 production, and the distance-based CO_2 emission factors can easily be converted to fuel economy (in miles per gallon, MPG) and fuel use values. These calculations are presented in Equations 3 and 4.

$$MPG = \frac{\rho_{fuel}}{(0.273 \times CO_2) + (0.429 \times CO) + (0.866 \times HC)} \quad (3)$$

where

ρ_{fuel} = Carbon content of fuel
Gasoline ~ 2,421 grams carbon/gallon fuel [5]
Diesel ~ 2,778 grams carbon/gallon fuel [5]
CO_2 = CO_2 emission factor in grams/mile

$$fuel\ (g/m) = CO_2 \times 0.273 \times \frac{1}{CWF} \quad (3)$$

where

CO_2 = CO_2 emission factor in grams/mile
CWF = Carbon weight fraction of fuel
Gasoline ~ 0.865 grams carbon/grams fuel [6]
Diesel ~ 0.87 grams carbon/grams fuel [6]

4.0 Emission and Fuel Use Factors

Emission and fuel use factors are presented in a database format. The data fields included in the emission and fuel use factor database are presented in Table 4.

Table 4 Data Fields in the Emission and Fuel Use Factor Database

Column Header Name	Units	Description
Area	-	Area (county and air basin)
CalYr	year	Calendar year (1990, 2000, 2010)
Veh	-	Vehicle type (LDV, T7, UBUS)
Speed (mi/hr)	miles/hour	Speed bin (5 to 70 in 5 mph increments)
VMT (mi/day)	miles/day	Vehicle miles traveled
ROG_RUNEX (g/mi)	grams/mile	Reactive organic gas running emissions
TOG_RUNEX (g/mi)	grams/mile	Total organic gas running emissions
CO_RUNEX (g/mi)	grams/mile	Carbon monoxide running emissions
NOX_RUNEX (g/mi)	grams/mile	Nitrogen oxides running emissions
CO2_RUNEX(Pavley I+LCFS) (g/mi)	grams/mile	Ccarbon dioxide running emissions including reductions from Pavley I regulation and Low Carbon Fuel Standard
PM10_RUNEX (g/mi)	grams/mile	Particulate matter < 10um running emissions
PM2_5_RUNEX (g/mi)	grams/mile	Particulate matter < 2.5um running emissions
MPG	miles/gallon	Fuel economy value
Fuel (g/mi)	grams/mile	Fuel use value

Emission and fuel use factors by calendar year, vehicle category, and speed bin for each of the 11 areas listed in Table 2 were also weighted by VMT to result in composite emission and fuel use factors for the region. The composite emission and fuel use factors for light-duty vehicles are presented in Figure 2through Figure 9. Similar figures for heavy-duty diesel trucks and buses categories are presented in Appendices A and B, respectively. These composite emission and fuel use factors can be applied to aggregate vehicle activity output (in terms of VMT by speed bin) from the LA-Plan model to create emission and fuel use inventory for the region. Alternatively, the emission and fuel use factors for each area can be applied to VMT by speed bin with the area to create emission and fuel use inventory for the area. Then, the emission and fuel use inventory of each area can be aggregated to result in the total emission and fuel use inventory for the region.

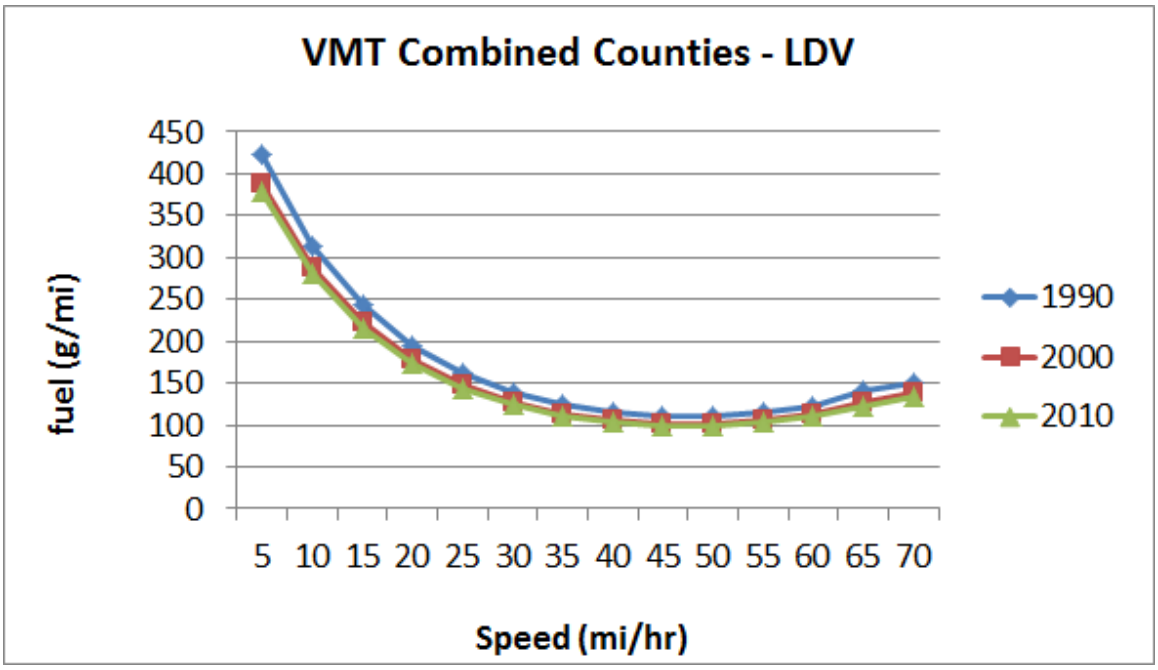


Figure 2 LDV fuel use factors by speed bin for the Greater L.A. region.

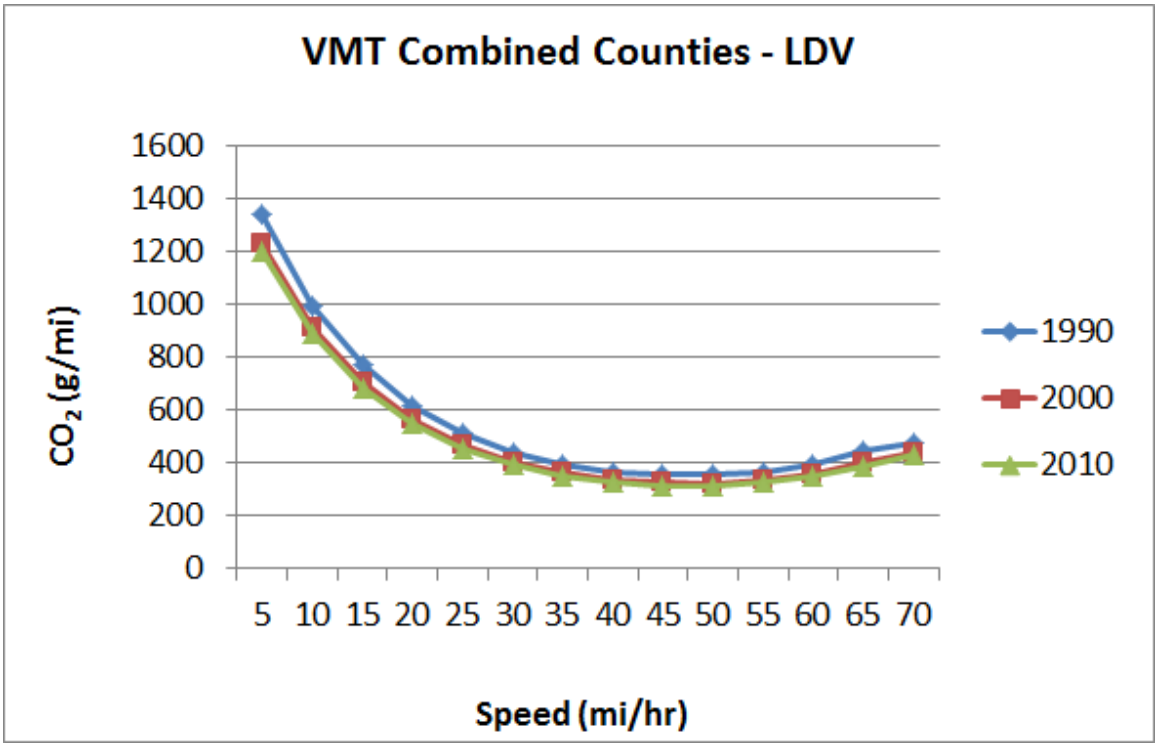


Figure 3 LDV CO_2 emission factors by speed bin for the Greater L.A. region.

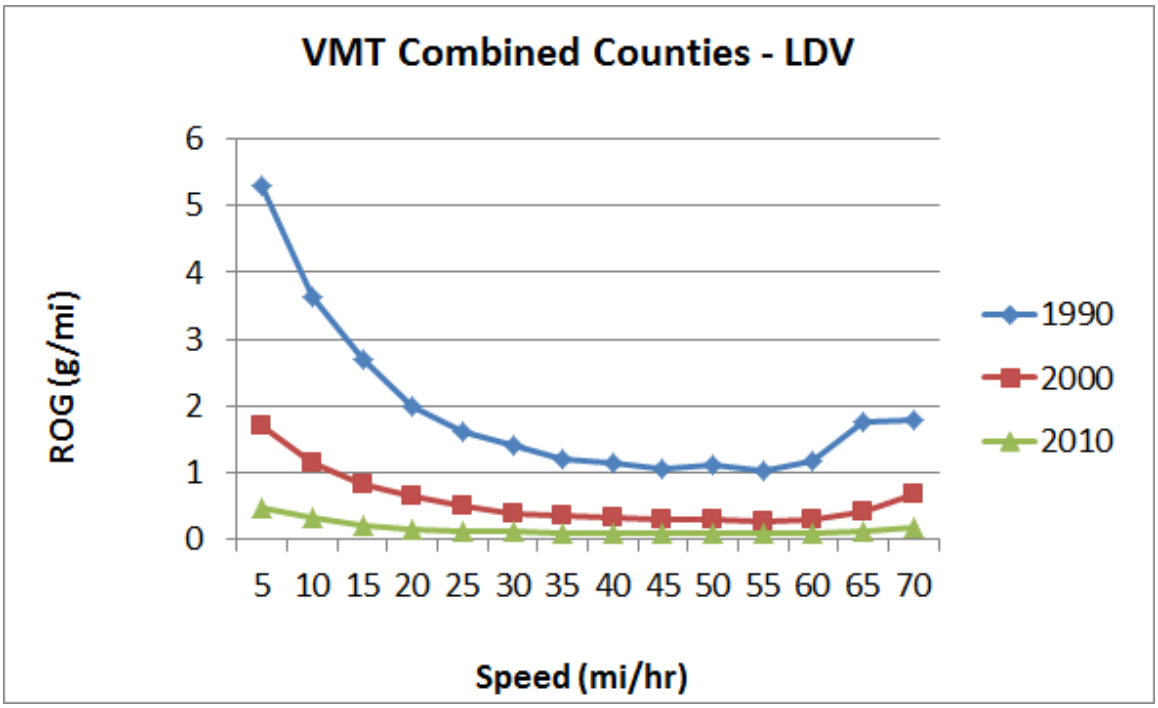


Figure 4 LDV ROG emission factors by speed bin for the Greater L.A. region.

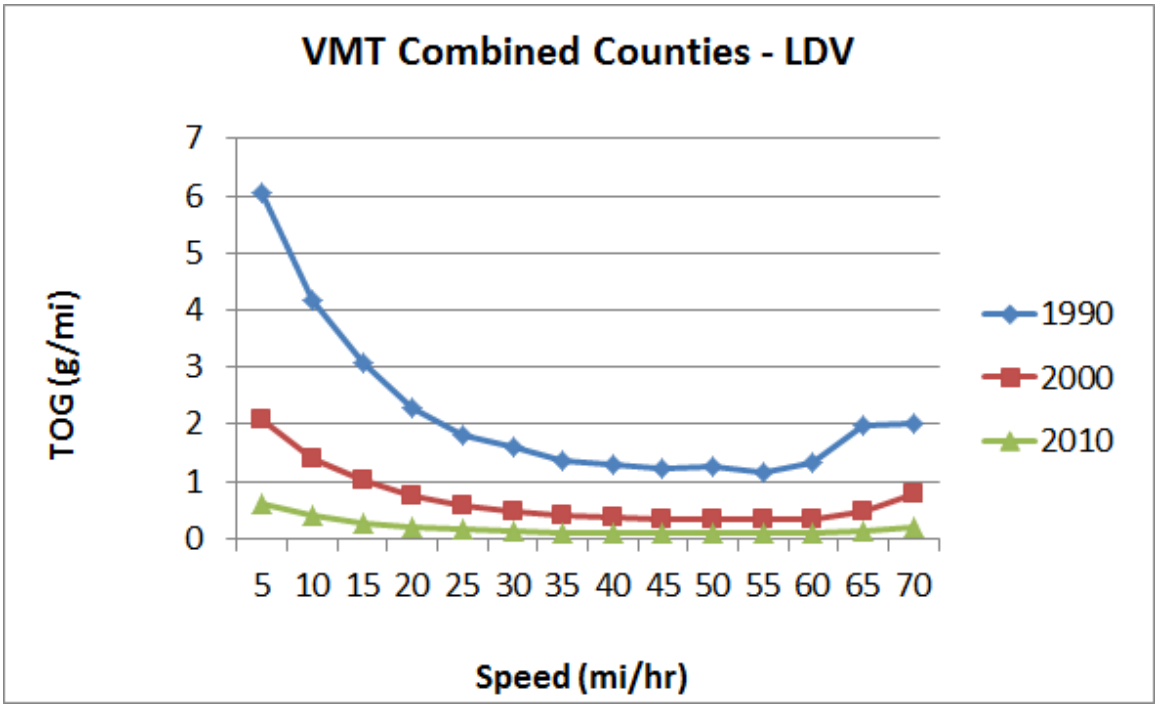


Figure 5 LDV TOG emission factors by speed bin for the Greater L.A. region.

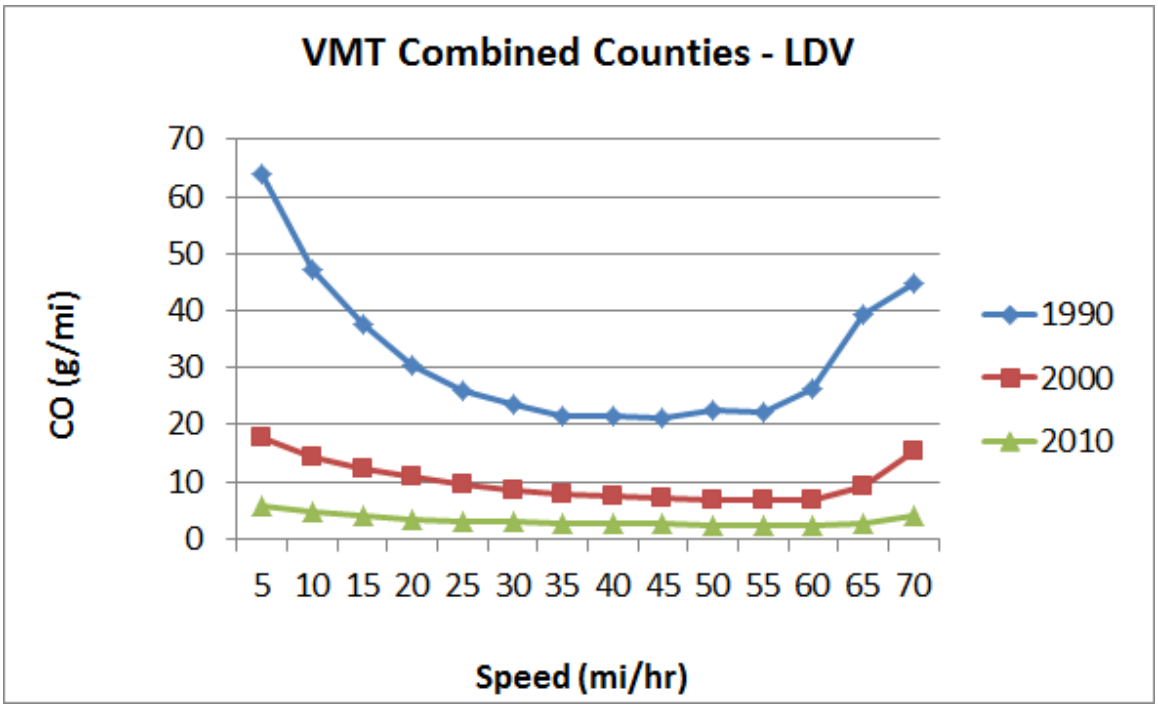


Figure 6 LDV CO emission factors by speed bin for the Greater L.A. region.

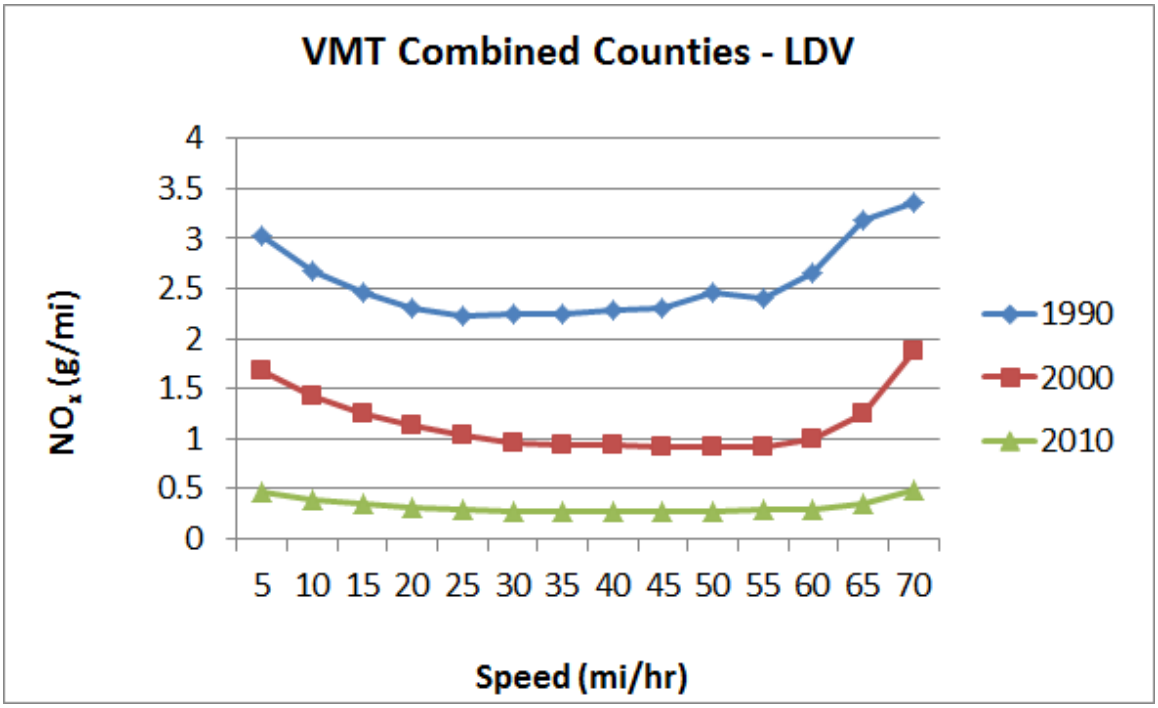


Figure 7 LDV NO_x emission factors by speed bin for the Greater L.A. region.

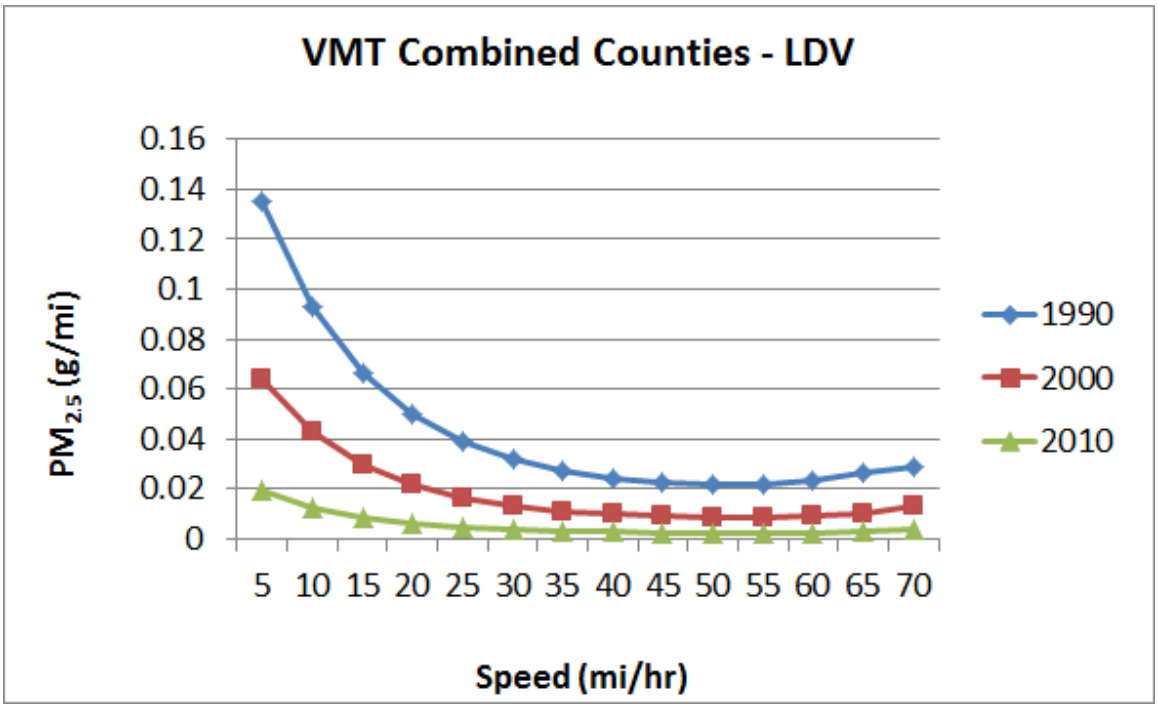


Figure 8 LDV $PM_{2.5}$ emission factors by speed bin for the Greater L.A. region.

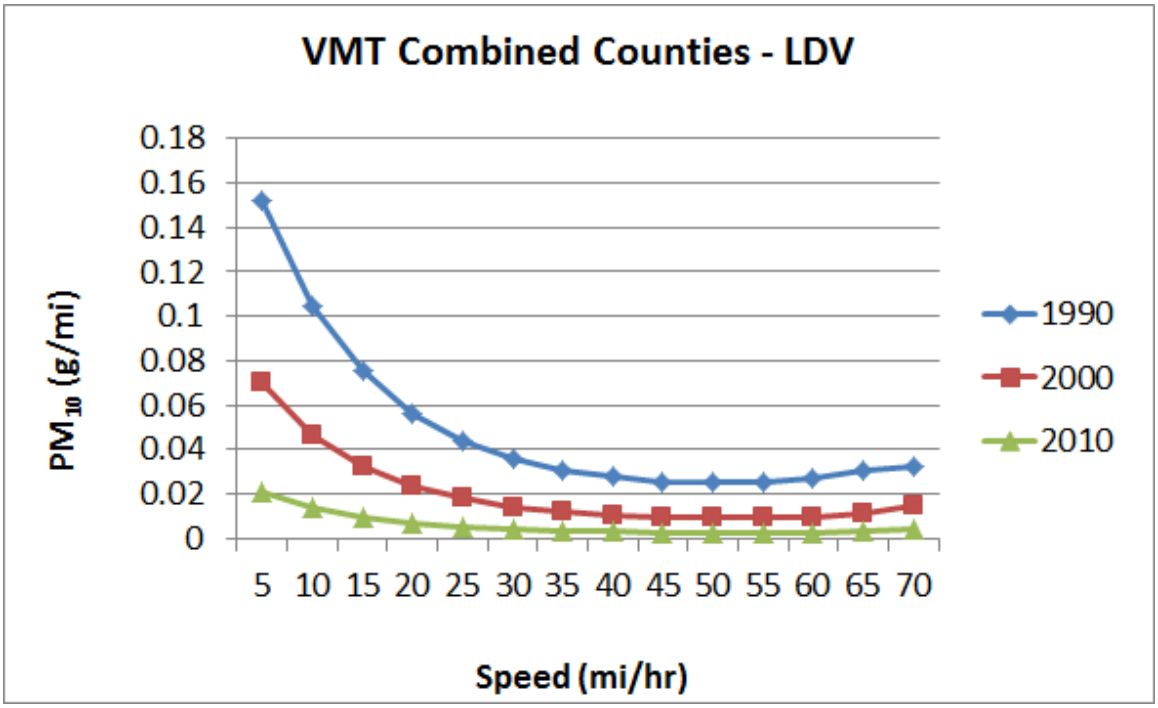
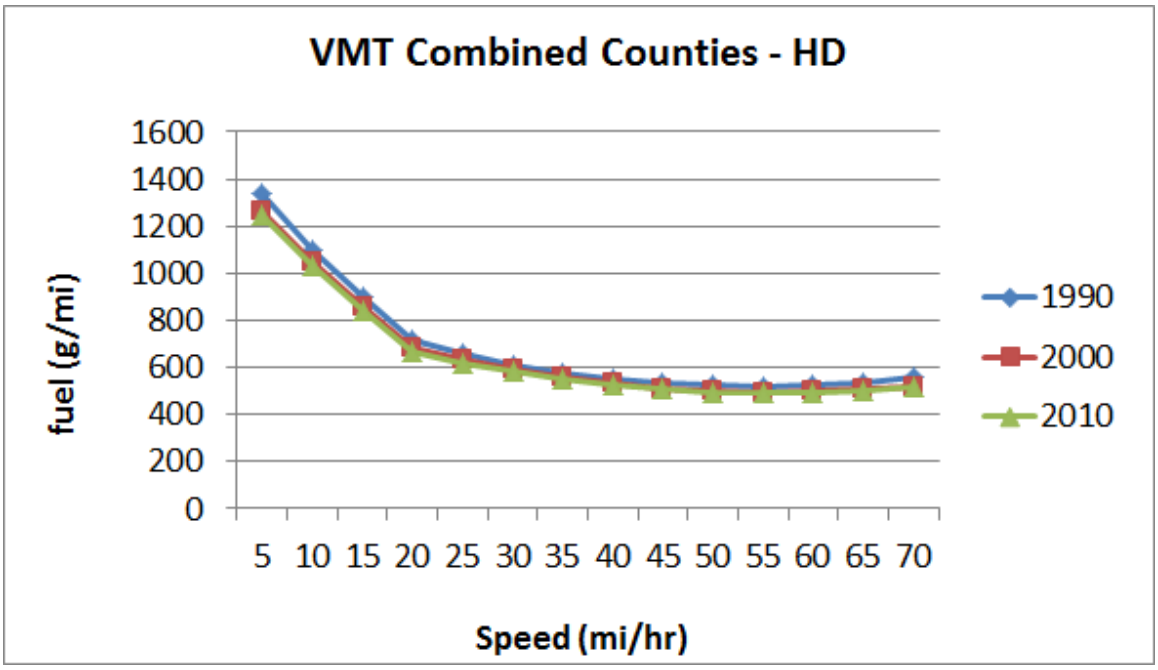


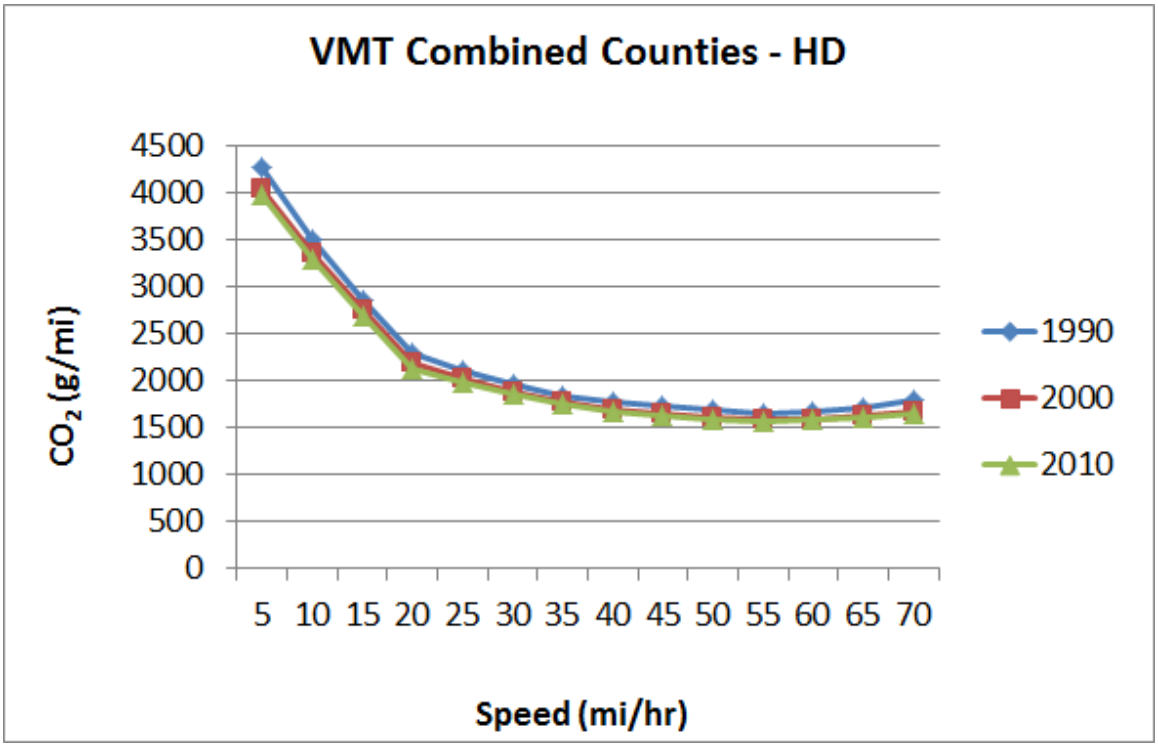
Figure 9 LDV PM_{10} emission factors by speed bin for the Greater L.A. region.

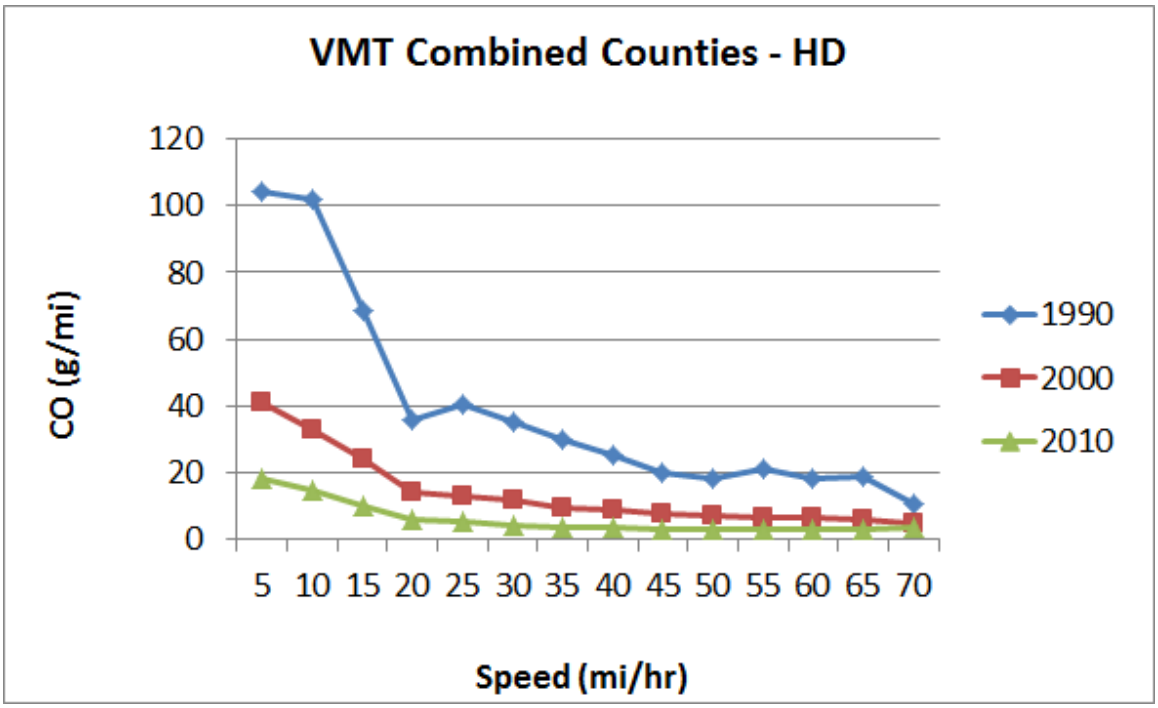
References

1. Anas, Alex and Liu, Yu, A Regional Economy, Land Use, and Transportation Model (Relu-Tran©): Formulation, Algorithm Design, and Testing. Journal of Regional Science, Vol. 47, No. 3, pp. 415-455, August 2007.
2. CARB, EMFAC2011 Technical Documentation, September 19, 2011.
3. CARB, EMFAC2011 Web based Data Tools, http://www.arb.ca.gov/msei/msei.htm
4. CARB, Public Meeting to Consider Approval of Revisions to the States's On-Road Motor Vehicle Emission Inventory – Technical Support Document, May 2000.
5. Code of Federal Regulations (40 CFR 600.113).
6. Heywood, J. B., Internal Combustion Engine Fundamentals, McGraw-Hill, New York, 1988.
7. CARB, EMFAC2011 User's Guide, September 19, 2011, http://www.arb.ca.gov/msei/emfac2011-ldv-users-guide-final.pdf

Appendix A – HDDT Emission and Fuel Use Factors






VMT Combined Counties - HD
CO (g/mi)
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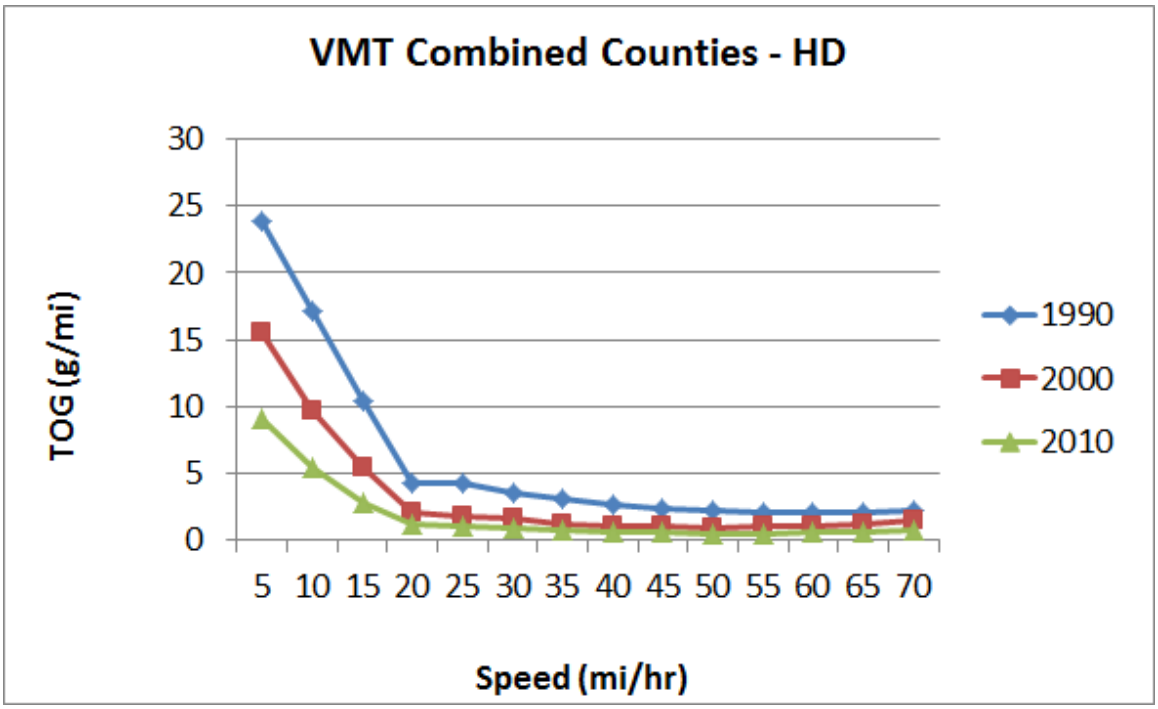
100
80
60
40
20
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - HD
TOG (g/mi)
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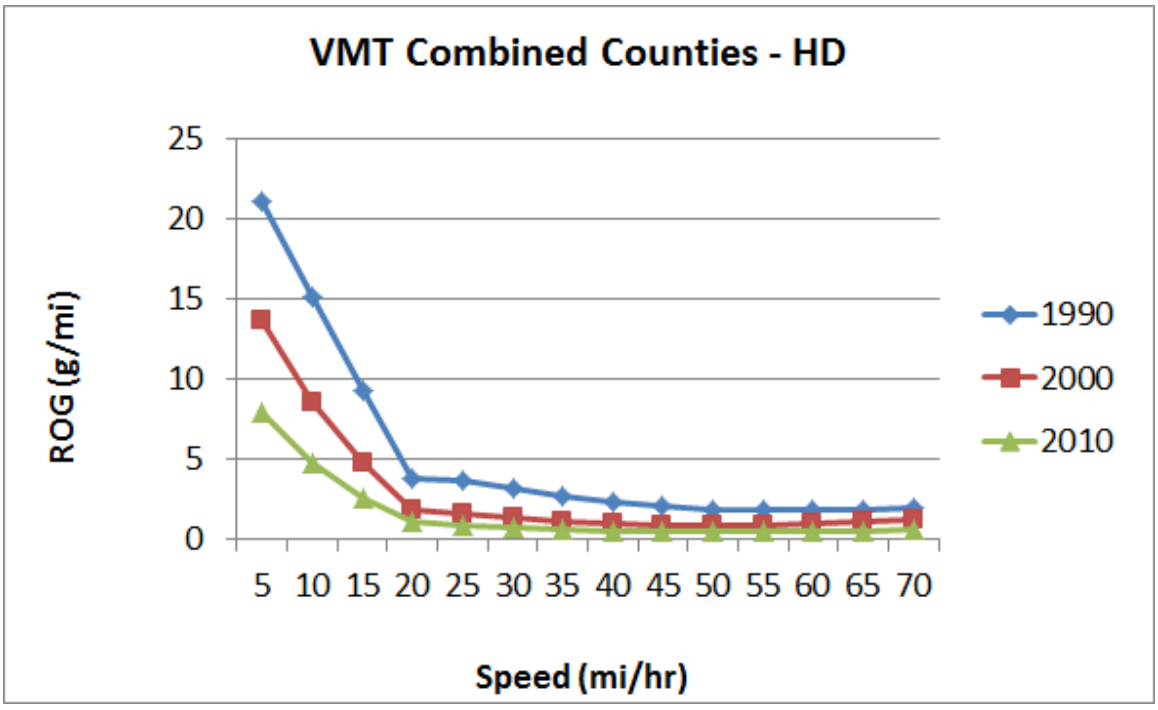
25
20
15
10
5
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - HD
ROG (g/mi)
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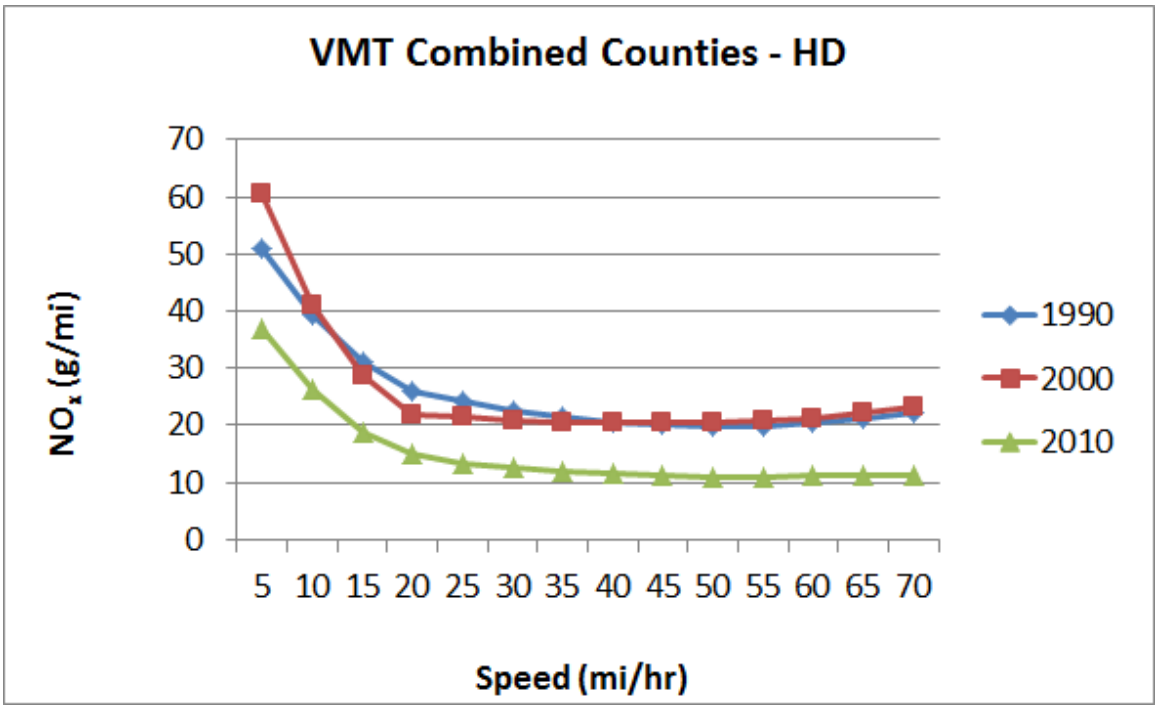
20
15
10
5
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Speed (mi/hr)
1990
2000
2010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NOx (g/mi)
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30
20
10
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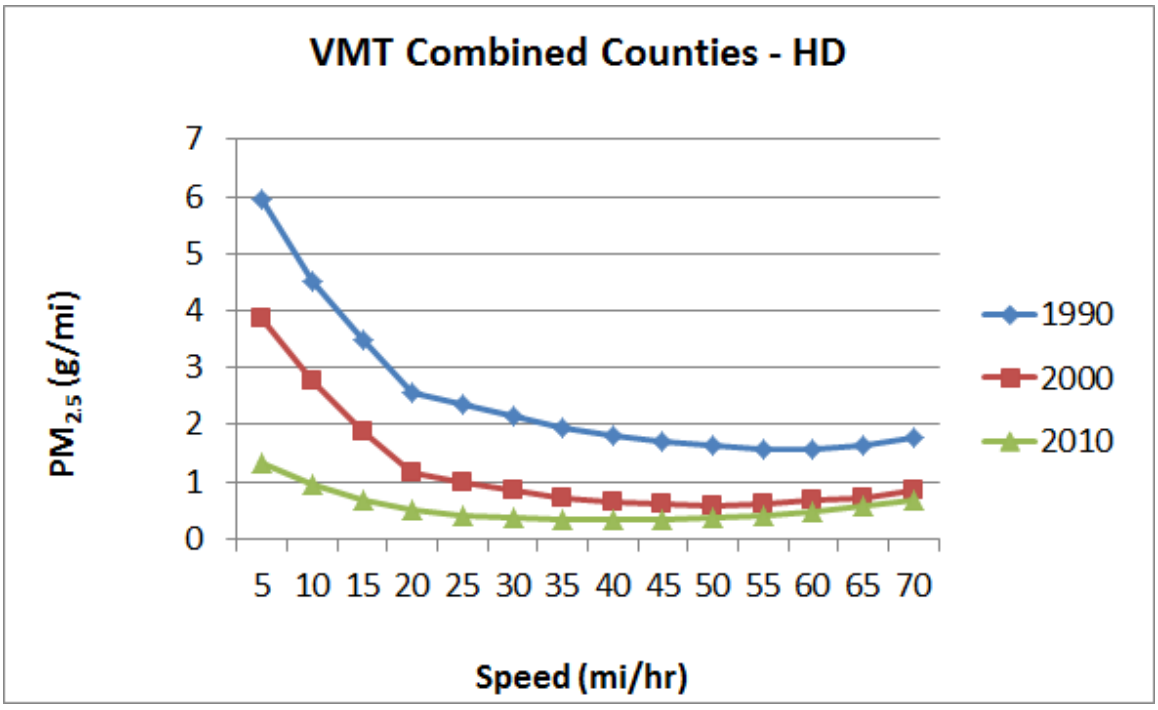
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - HD
PM2.5 (g/mi)
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2
3
4
5
6
7
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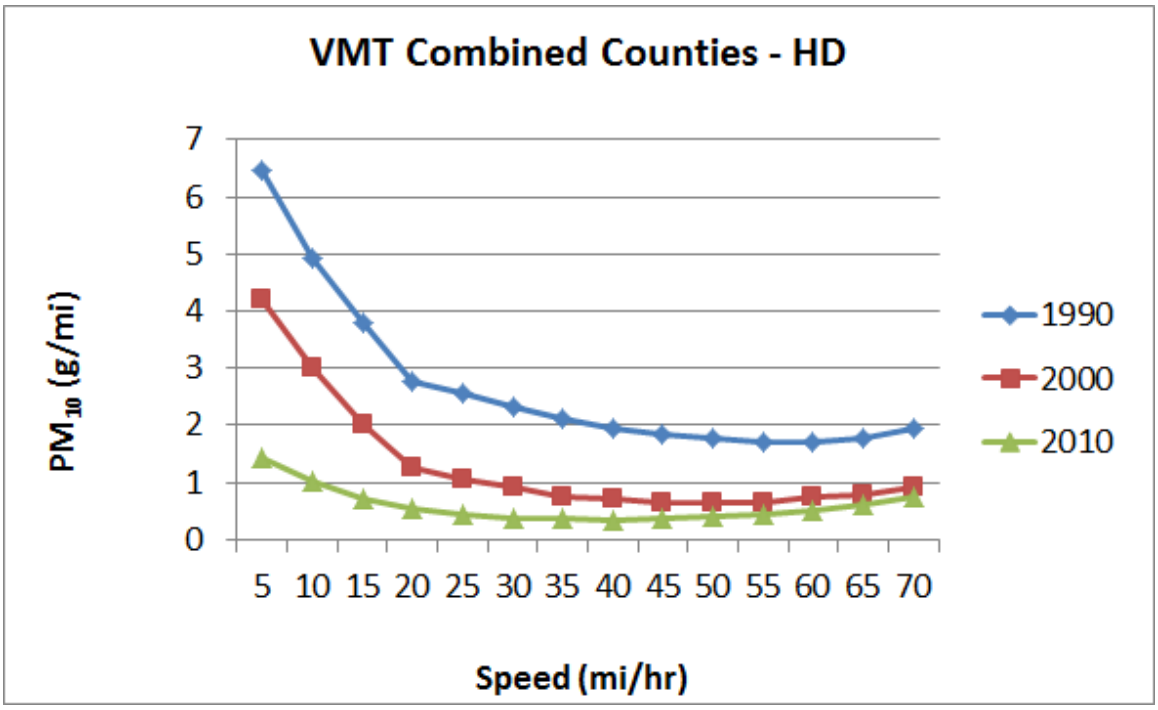
Speed (mi/hr)
1990
2000
2010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PM10 (g/mi)
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1
2
3
4
5
6
7
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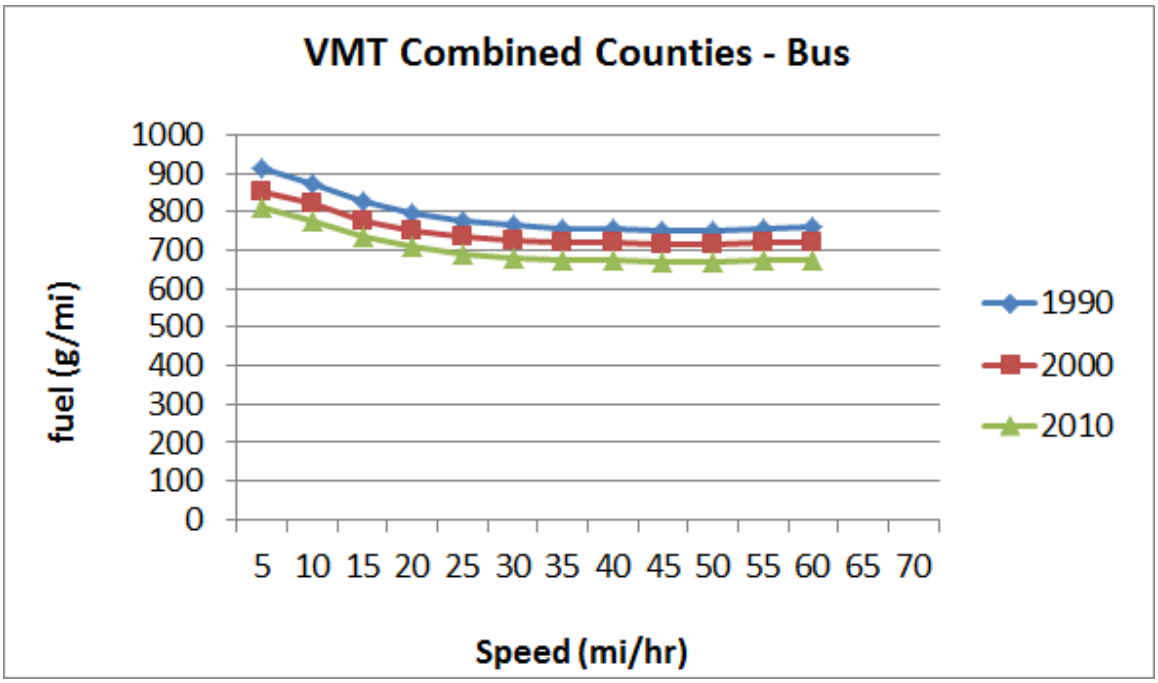
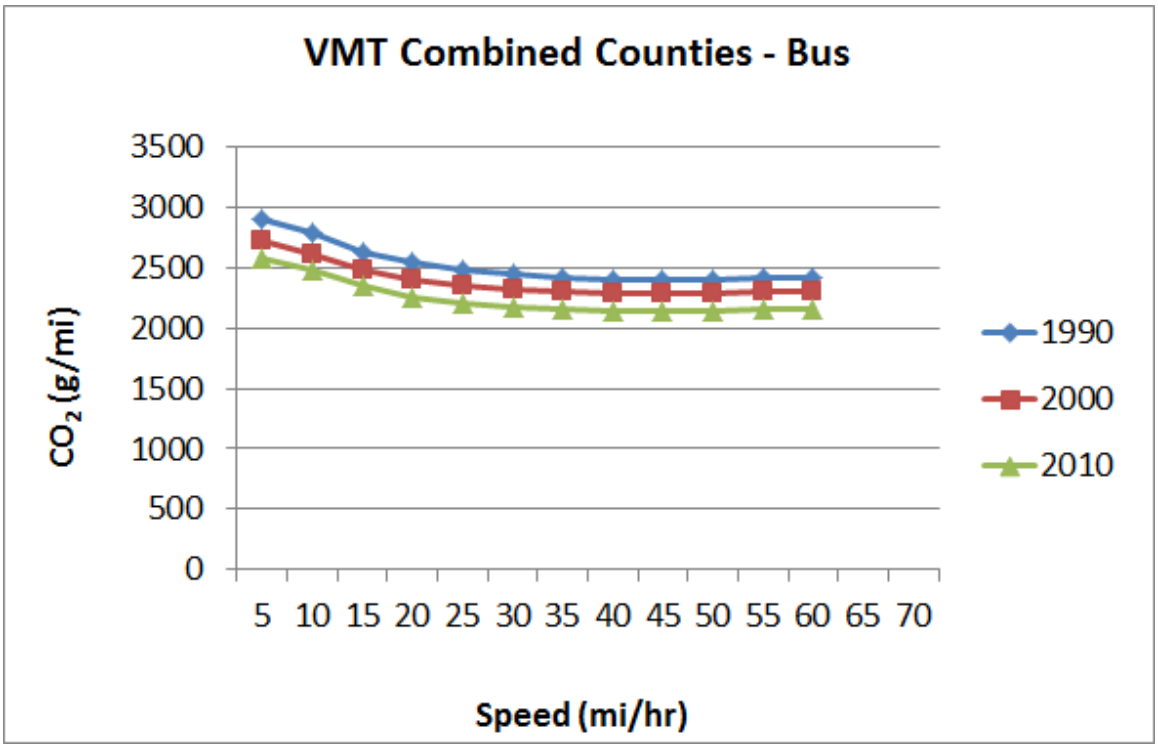
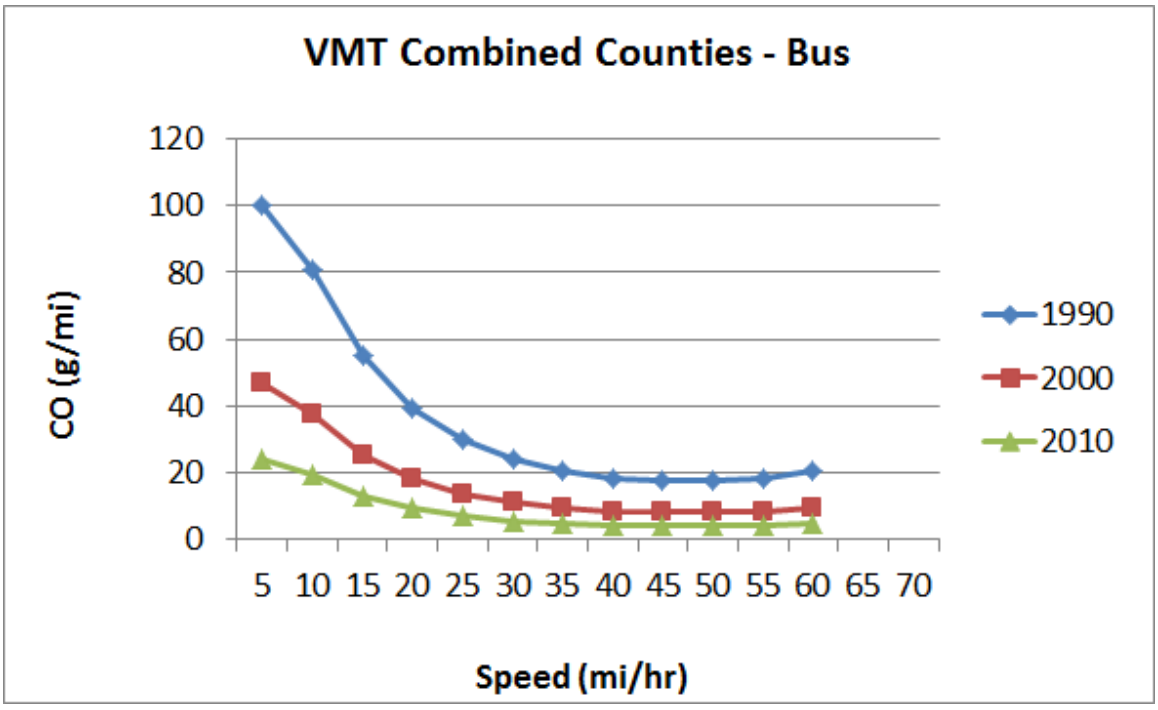
Speed (mi/hr)
1990
2000
2010

Appendix B – Urban Bus Emission and Fuel Use Factors






VMT Combined Counties - Bus
CO (g/mi)
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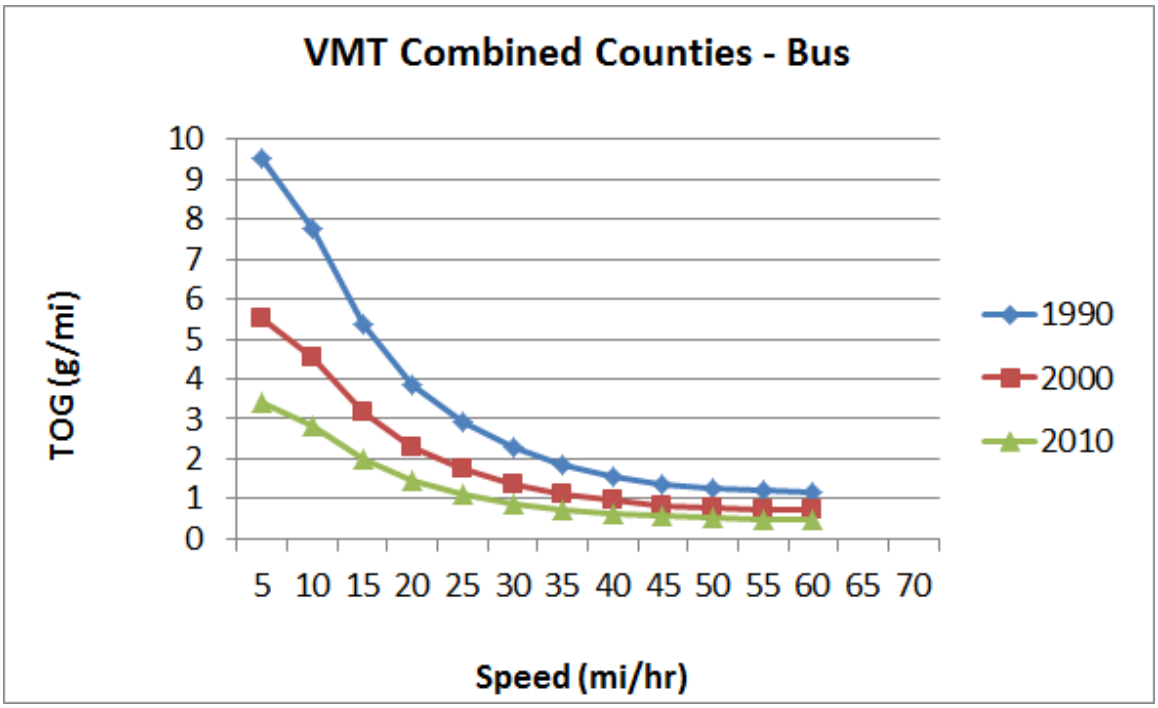
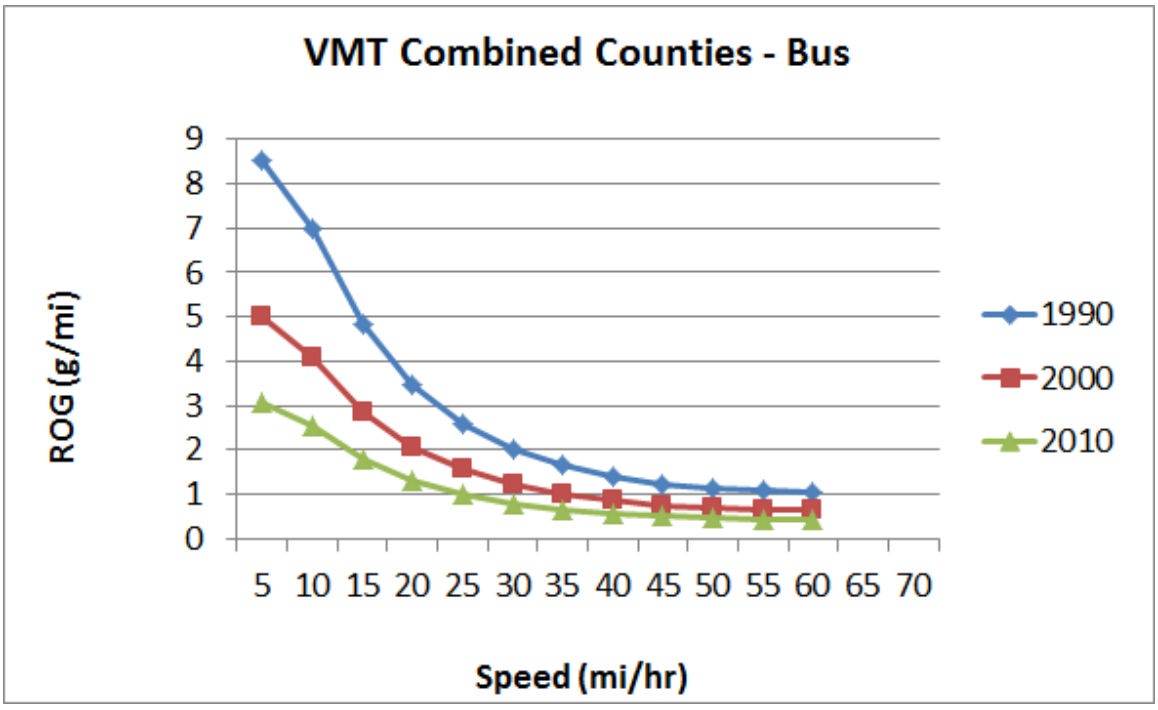
80
60
40
20
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - Bus
TOG (g/mi)
10
9
8
7
6
5
4
3
2
1
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - Bus
ROG (g/mi)
0
1
2
3
4
5
6
7
8
9
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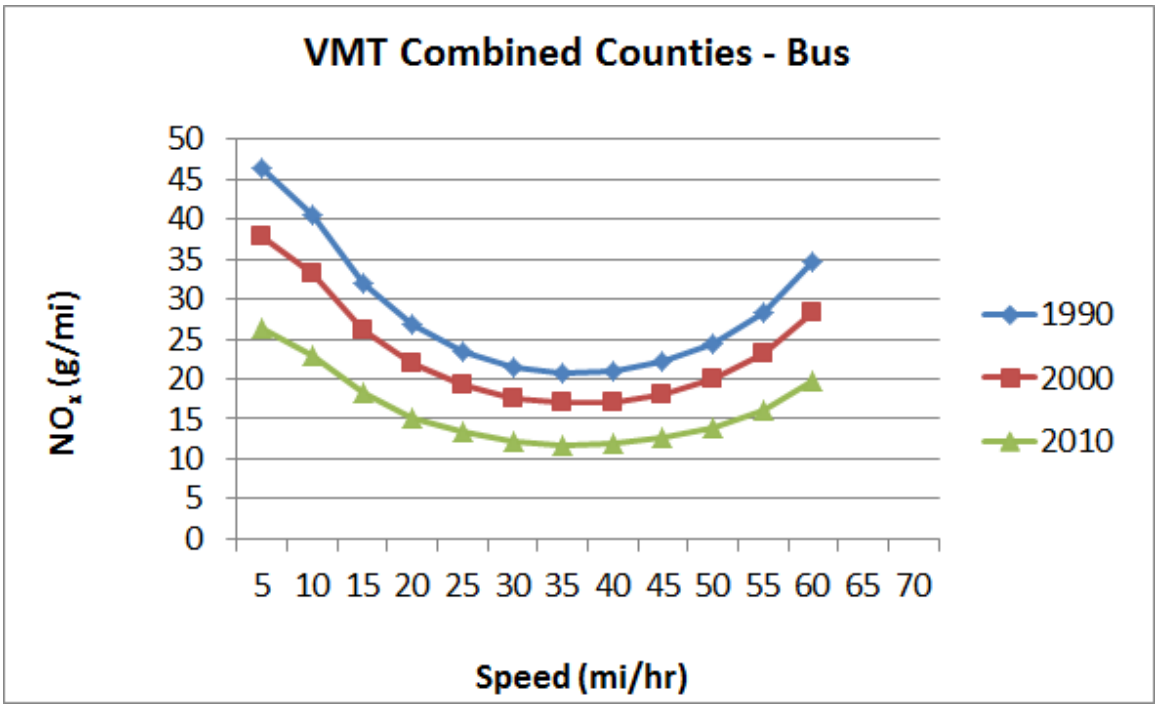
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - Bus
NOx (g/mi)
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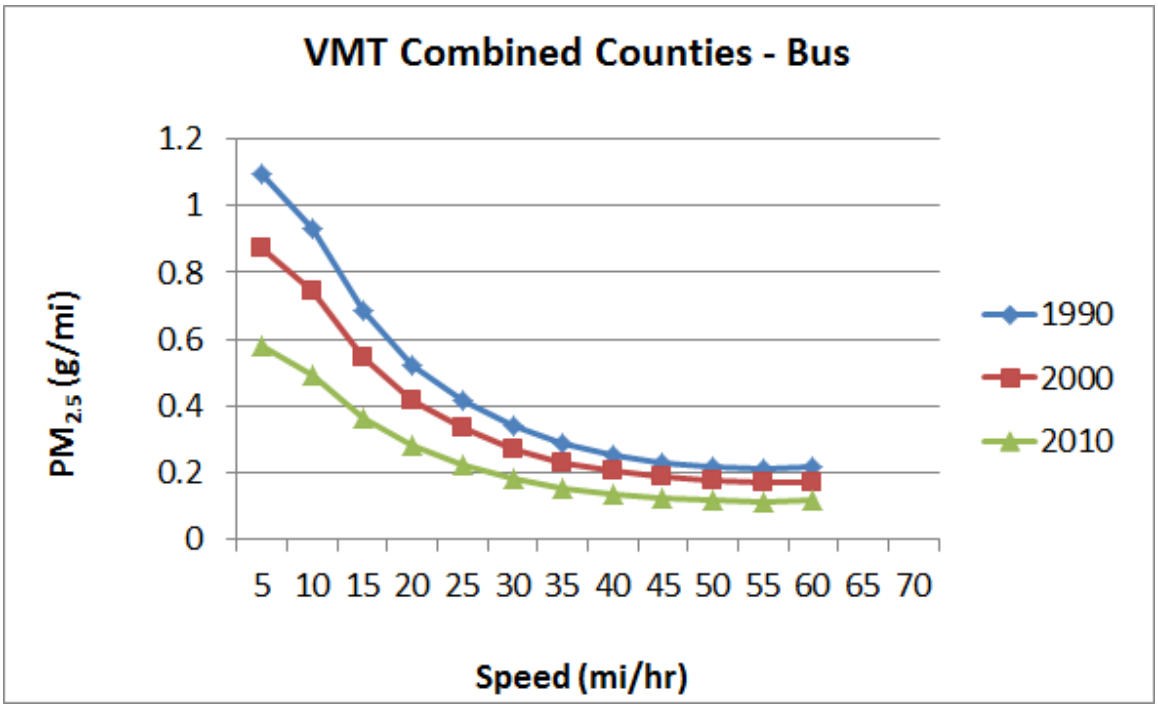
Speed (mi/hr)
1990
2000
2010


VMT Combined Counties - Bus
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0.4
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0
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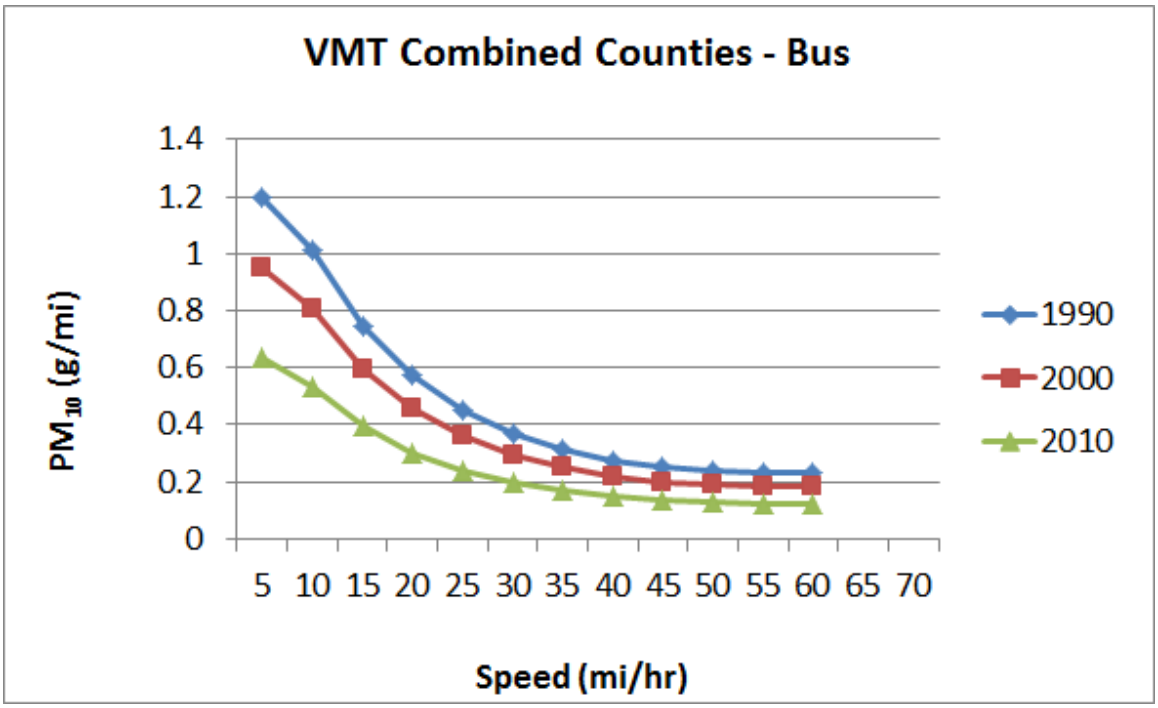
Speed (mi/hr)
1990
2000
2010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0.6
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0.2
0
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Speed (mi/hr)
1990
2000
2010