US Department of Transportation
Federal Highway Administration

Sensitivity Analysis of MOBILE6 Motor Vehicle Emission Factor Model

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INTRODUCTION

On January 29, 2002, the US Environmental Protection Agency (EPA) officially released the latest motor vehicle emission factor model - MOBILE6. This release represents significant achievements in understanding both motor vehicle performance and driver behavior when estimating motor vehicle emissions. The model also establishes routines to compute and analyze fuel and vehicle certification standards, state programs and different highway facilities as related to vehicle emission factors. Significant efforts by US EPA were also carried out to establish a national default database used by the computer model. Along with the MOBILE6 release, more than 48 technical papers related to MOBILE6 development were also released. Overall, MOBILE6 model predicts higher emission rates in near future years and lower emission rates in out years when compared to MOBILE5 series models.

MOBILE6 is the approved US EPA motor vehicle emission factor model for estimating volatile organic compounds (VOC), nitrogen oxides (NOx), and carbon monoxide (CO) from different vehicles. State and local air quality and transportation agencies outside of California are required to use MOBILE6 in State Implementation Plan (SIP) development, and transportation conformity determination. The official release of MOBILE6 on January 29, 2002 started the 2-year grace period before MOBILE6 is required for new conformity determinations in most areas. As the end of the grace period approaches, transportation as well as air quality agencies are gaining an understanding of the model behavior, especially in impacts of using localized data as compared to EPA's national default data. Understanding the behavior of the model under various conditions becomes more critical as the tasks of collecting local data is time and resources intensive. The purpose of this paper is to provide a basic evaluation of the MOBILE6 model behavior under various conditions. Through the understanding of the model's behavior, state and local agencies can prioritize costly data collecting efforts and ultimately initiate emission control strategies according to parameter sensitivity.

METHODOLOGY

The MOBILE6 model utilized in this sensitivity analysis was the official version released by the EPA on January 29, 2002. All modeling runs were conducted on a Gateway X86-based PC with a GenuineIntel 600 Mhz microprocessor under the Windows 2000 Professional operating system.

During the sensitivity analysis, input parameters other than those being tested, were based on EPA national default data. For all scenarios, the calendar year used for modeling was 2005. For both VOC and NOx emission factor modeling, the evaluation month was July. For CO emission factor modeling, the analysis month was January. Temperatures used in all NOx and VOC analyses, unless otherwise noted, were 72.0° F and 98.0° F for the daily minimum and maximum. For analysis of CO emission, the daily minimum and maximum temperatures used were 20.0° F and 60.0° F. Fuel Reid Vapor Pressure (RVP) was 8.5 psi throughout all runs except for fuel RVP testing. Emission factors obtained and cited in this analysis are composite vehicle emission factors (VOC: start + running+ evaporative; NOx and CO: start + running) unless otherwise noted.

The least significant digit of the MOBILE6 emission factor output is the thousandth digit. When the emission factor is multiplied by vehicle miles traveled, which is typically in millions, the thousandth digit of the emission factor becomes very significant. In this sensitivity analysis, when an emission factor experiences a change in the least significant digit (the thousandth digit) as a result of one unit change in the parameter being tested, the term "sensitive" is used to describe the effect of the parameter on the emission factor.

PARAMETERS EVALUATED

Ramp Vehicle Miles Traveled

Since freeway ramps are directly associated with freeway mainlines, two different cases were created here for evaluation. The first case simulates a freeway mainline with an average speed of 55 miles per hour (mph). The second case simulates a freeway mainline with an average speed of 30 mph. A total percentage of vehicle miles traveled (VMT) between a freeway mainline and ramp is 100% for both cases. The effects of ramp vehicle miles traveled on vehicle emission rates are evaluated through the average speed command.

As shown in Fig. 1, the VOC emission rate is very sensitive to the ramp VMT percentage in the 55 mph mainline average speed case. The VOC emission rate is not sensitive to the ramp VMT percentage at the 30 mph mainline average speed. The average increase of VOC emission rate is 0.0028 g/mi per 1% ramp VMT percentage increase at the 55 mph mainline average speed case.

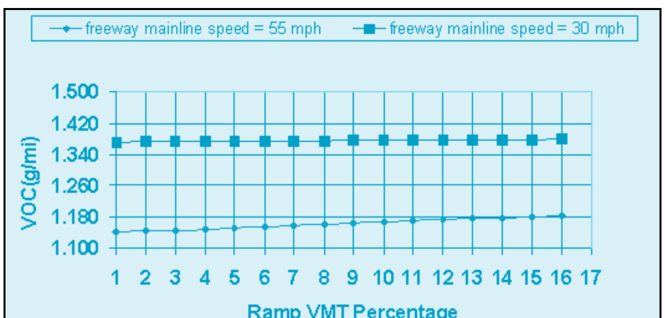

Figure 1. VOC Versus Ramp VMT Percentage

NOx emission rates are inversely related to ramp VMT percentages. In the case of 55 mph mainline freeway average speed, the ramp VMT reduces the NOx emission rate at an average of 0.0036 g/mi per one percent of ramp VMT percentage increase. For the 30 mph case, NOx emission rates are not sensitive to ramp VMT percentages (Fig. 2).

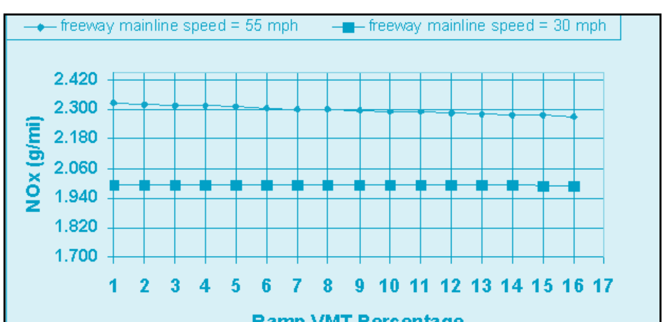

Figure 2. NOx Versus Ramp VMT Percentage

CO emission rates are exceedingly sensitive to ramp VMT percentages in both cases. The average increases in CO emission rates are 0.0489 g/mi and 0.0731 g/mi per 1% increase of ramp VMT percentage with a mainline freeway speed of 55 mph and 30 mph (Fig. 3).

A highway ramp speed of 34.6 mph is coded in

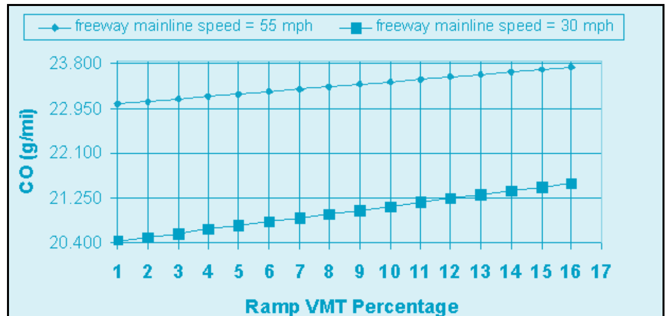

Figure 3. CO Versus Ramp VMT Percentage

MOBILE6 by US EPA as the default. Other than driving cycle differences between a freeway mainline and ramp, the facility speed is the dominant factor in explaining effects of ramp VMT percentage on all emission rates.

Vehicle Miles Traveled By Facility

Two different cases were evaluated here for vehicle miles traveled among freeway, arterial and local facilities. The first case is to assign 100% VMT between a mainline and an arterial/collector. The second case is to assign 100% VMT between an arterial and a local facility. The objective is to evaluate effects from roadway facility types on vehicle emission rates.

As indicated in Fig. 4, as the VMT ratio between a freeway mainline and arterial changes from 20/80 to 80/20, changes in VOC emission rates are minimal. The average

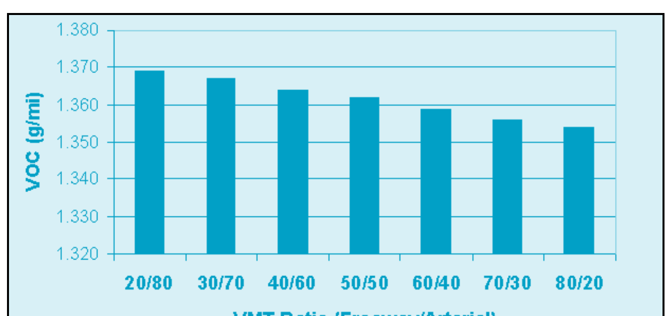

Figure 4. VOC Versus VMT by Facility

decrease in VOC emission rate is less than 0.00026 g/mi per 1% increase in the freeway VMT percentage . It is concluded that VOC emission rates are not sensitive toVMT ratios between a freeway mainline and an arterial.

NOx emission rates that are affected by the VMT ratio between a freeway mainline and an arterial is shown in Fig. 5. Unlike VOC emission rates, NOx emission rates are sensitive to VMT ratio. As the freeway mainline/ arterial VMT ratio increases, NOx emission rates increase dramatically, with an average increase of 0.0043 g/mi per 1% increase of VMT ratio.

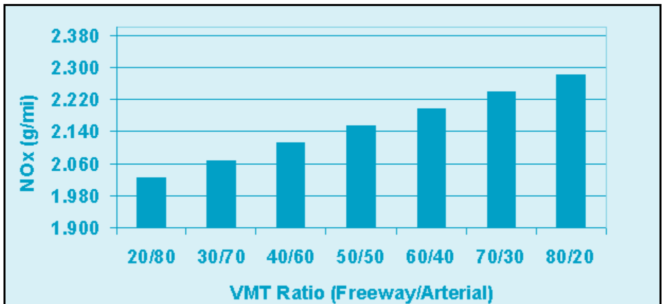

Figure 5. NOx Versus VMT by Facility

The CO emission rate, as affected by the VMT ratio, exhibits the same trend as the NOx. The average increase in the CO emission rate is 0.0228 g/mi per 1% increase in the VMT ratio (Fig. 6).

Figs. 7, 8, and 9 depict the effect of arterial and local facility VMT ratio on VOC, NOx, and CO emission rates, respectively. Both VOC and CO emission rates are

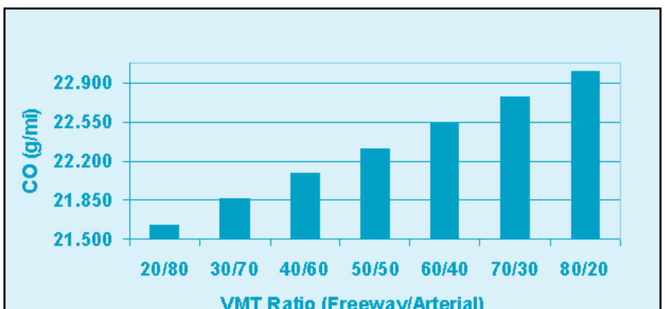

Figure 6. CO Versus VMT by Facility

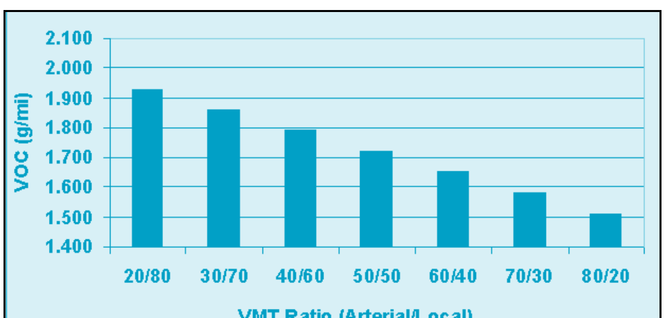

Figure 7. VOC Versus VMT by Facility

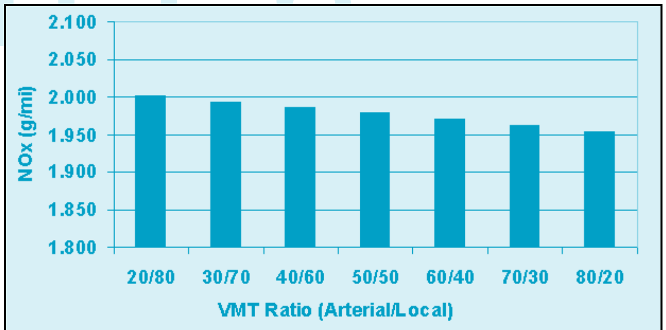

Figure 8. NOx Versus VMT by Facility

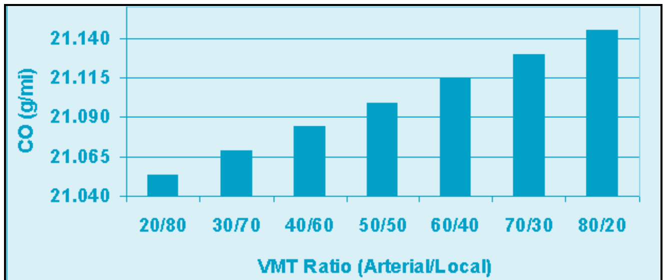

Figure 9. CO Versus VMT by Facility

sensitive to changes in the VMT ratio. For every 1% increase in local facility VMT ratio, emission rates decrease 0.0069 g/mi for VOC and increase 0.0015 g/mi for CO. NOx emission rates are not sensitive to VMT ratio between arterial and local facilities. The average decrease in NOx emission is less than 0.0008g/mi per 1% increase in local VMT ratio.

Based on driving cycles used for freeway, arterial and local roadway facilities in the MOBILE6 model, one of the most significant differences among all driving characteristics is speed. The effects of VMT allocation among roadway types on emission rates can be attributed principally to speed differences.

Roadway Facility Speed

The average speed command was used to test roadway speeds in two different VMT cases. The first case assigns 100% VMT to a freeway mainline. The second case assigns 100% VMT to an arterial/collector roadway.

As indicated in Figs. 10 (a & b), 11 (a & b), and 12 (a & b), emission rates for all three pollutants are exceedingly sensitive to speed changes. As speed increases, VOC emission rate decreases rapidly in a linear fashion within the range of 2.5 mph and 7.5 mph. Between 10.0 mph and 65.0 mph, VOC emission rates decrease in a pseudo-linear trend. When speed reaches 30 mph and higher, VOC emission rates are the same for freeway mainline and arterial facilities.

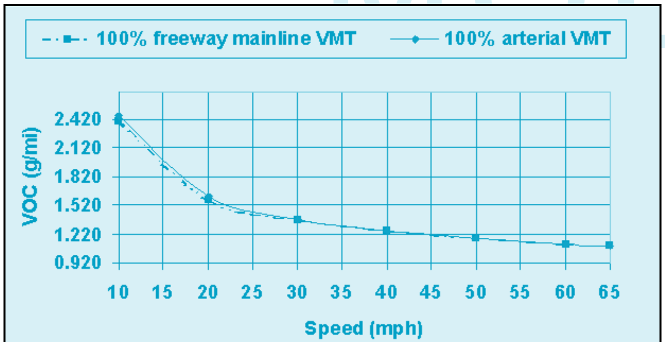

Figure 10a. VOC Versus Facility Speed

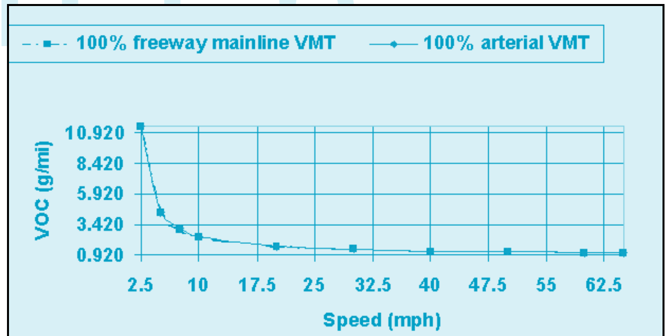

Figure 10b. VOC Versus Facility Speed

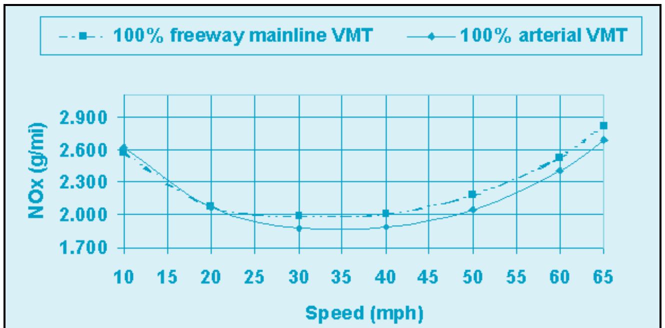

Figure 11a. NOx Versus Facility Speed

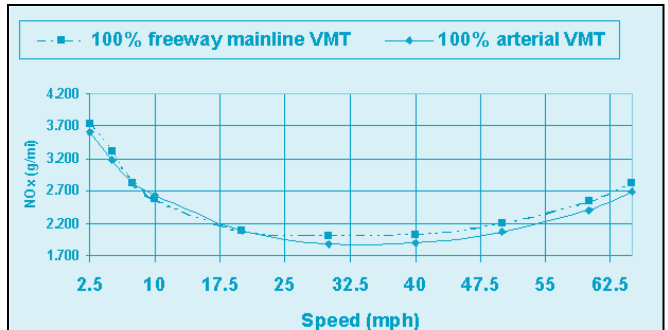

Figure 11b. NOx Versus Facility Speed

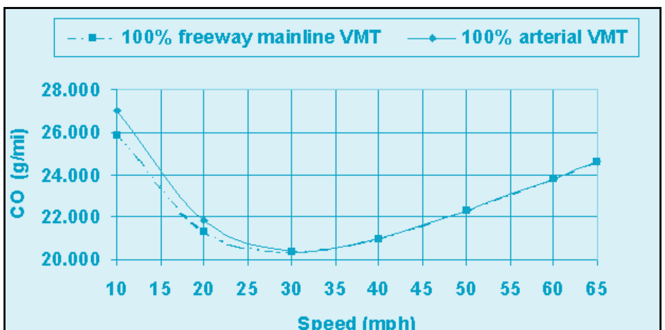

Figure 12a. CO Versus Facility Speed

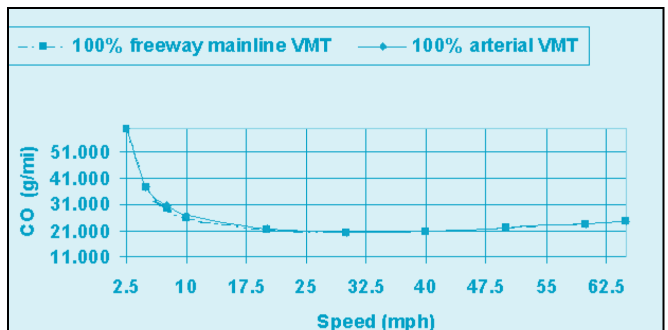

Figure 12b. CO Versus Facility Speed

NOx and CO emission rates exhibit a third order polynomial relationship with facility speeds. Between 10 mph and 35 mph, the NOx emission rate decreases as speed increases. Within the 35 mph to 65 mph range, the NOx emission rate increases as speed increases. CO emission rates decrease as speed increases in the range of 2.5 to 25 mph and increase in the range of 25 to 65 mph. Within the range of 2.5 mph to 10 mph (Figs. 10b and 12b), both CO and VOC emission rates increase dramatically as the facility speed drops to the 2.5 mph idle speed.

CO emission rates for freeway mainline and arterial facilities are identical when the facility speed exceeds 30 mph.

Humidity

The absolute humidity used in the testing ranged from 20 grains/lb to 118.0 grains/lb. At a temperature of 75.0° F, the 118.0 grains/lb represents 100% relative humidity. As indicated in Fig. 13, as humidity increases, VOC emission rates increase. However, the emission rate of VOC is not especially sensitive to changes in humidity level. NOx emission rates are sensitive to humidity level changes. The NOx emission rate increases approximately 0.0030 g/mi per one grains/lb humidity decrease (Fig. 14). The higher the humidity level, the less NOx is produced. Humidity does not appear to have any effects on CO emissions (Fig. 15).

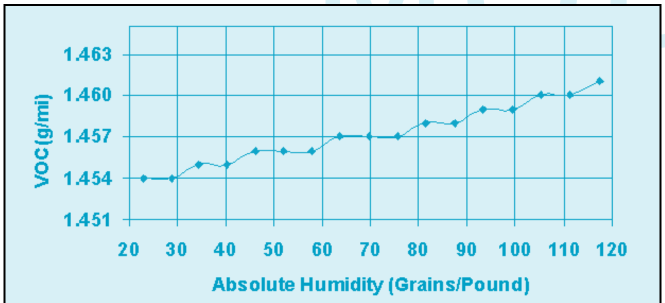

Figure 13. VOC Versus Humidity

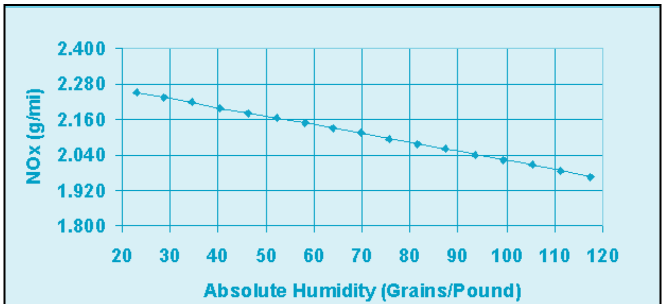

Figure 14. NOx Versus Humidity

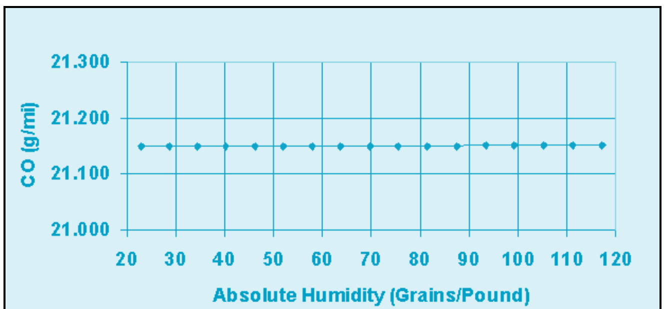

Figure 15. CO Versus Humidity

Percentage of Cloud Cover

The percentage of cloud cover evaluated is between 1% and 100%. As the cloud coverage increases, emission rates of VOC and NOx decrease (Figs. 16 and 17).

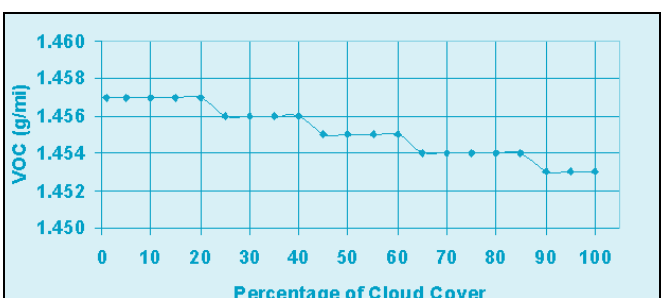

Figure 16. VOC Versus Cloud Cover

With every 10 % increase in cloud coverage, the rate of NOx reduction is 0.0022 g/mi. VOC emission rates appear to be in a stepwise decrease as the cloud cover increases (Fig 16). CO emission rates are not sensitive to cloud cover (Fig. 18).

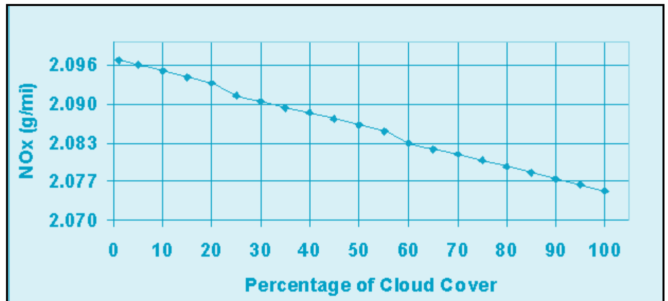

Figure 17. NOx Versus Cloud Cover

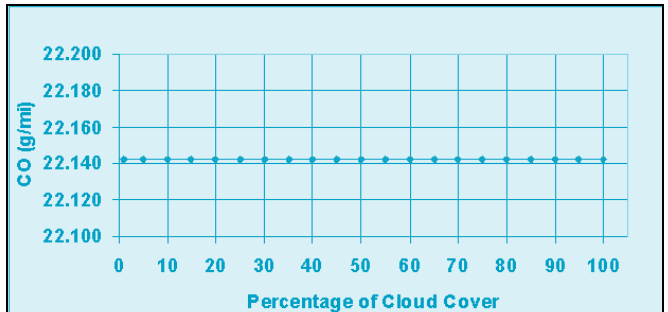

Figure 18. CO Versus Cloud Cover

Fuel Reid Vapor Pressure

Fuel Reid Vapor Pressure is one of the few parameters that a user must provide to a MOBILE6 input file. The RVP tested here ranges from 6.0 to 12.0 psi.

VOC emission rates are exceedingly sensitive to the RVP changes within the entire testing range. VOC emission rates increase 0.2543 g/mi per 1.0 psi RVP increase (Fig. 19).

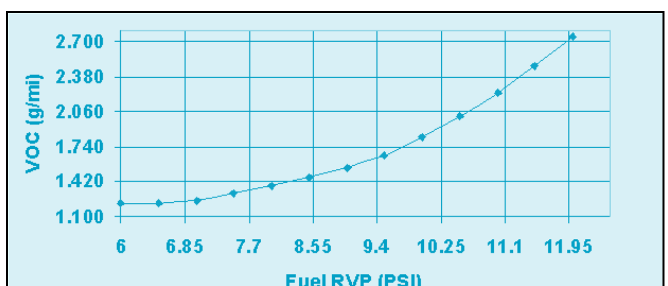

Figure 19. VOC Versus Fuel Reid Vapor Pressure

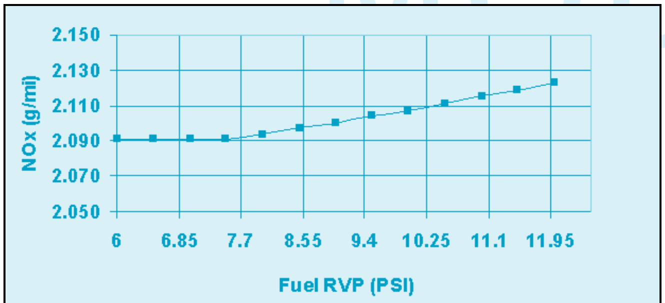

Figure 20. NOx Versus Fuel Reid Vapor Pressure

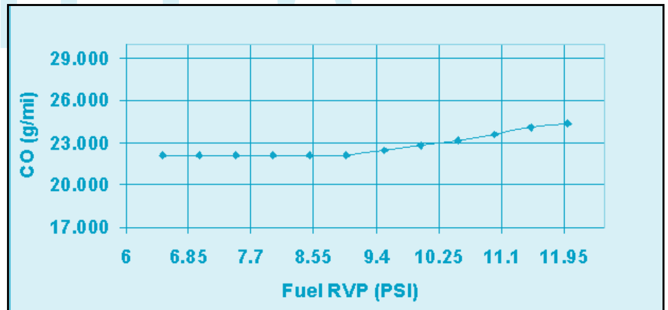

Figure 21. CO Versus Fuel Reid Vapor Pressure

As indicated in Fig. 20, NOx emission rates are not sensitive to RVP between the range of 6.0 and 7.5 psi. However, between 7.5 and 12.0 psi, NOx emission rates become sensitive to RVP changes with an average increase of 0.0071g/mi per 1.0 psi increase.

The effect of RVP on CO emission rates as depicted in Fig. 21, between 6.0 and 9.0 psi, is very limited. However, when the RVP moves into the range of 9.0 to 12.0 psi, the CO emission rate becomes sensitive to the RVP changes with an average increase of 0.7679 g/mi per 1.0 psi RVP increase.

Temperature Effects

Like the Absolute Humidity command, Min/Max Temp is another required input (Twenty-four hourly temperatures may be supplied as an alternative) that a user must supply. To evaluate temperature sensitivity, the command MIN/MAX TEMP was used by specifying the same minimum and maximum temperature for each testing scenario. The temperature tested in the analysis ranges from 7.5.0° F to 100.0° F.

As indicated in Figs. 22, 23, and 24, all emission factors are exceedingly sensitive to temperature changes.

VOC emission rates, as affected by temperature, exhibits a relatively complicated pattern. Within the range of 7.5° F to 40.0° F, the VOC emission rate decreases linearly at a rate of 0.0159 g/mi per one-degree temperature drop. When the temperature exceeds 40.0° F, the emission rate of VOC experiences a sudden jump (Fig. 22). Between 42.5° F and 100.0° F, the emission rate, as affected by temperature changes, is best described by a third order polynomial equation. The temperature effect on NOx emissions is essentially the same as on CO emissions. The emission of NOx decreases at a rate of 0.0074 g/mi per one-degree temperature drop when the temperature is between 67.5° F and 7.5° F. When the temperature exceeds 70.5° F, the NOx emission rate increases at a rate of 0.0048 g/mi per one-degree temperature increase.

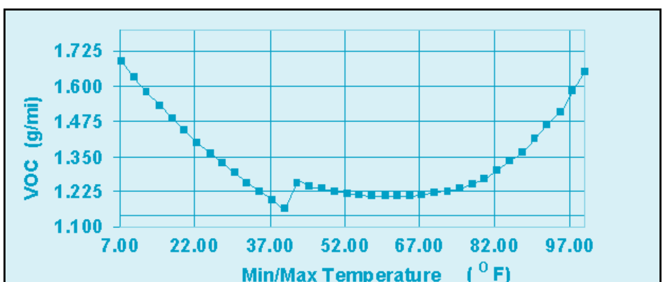

Figure 22. VOC Versus Temperature

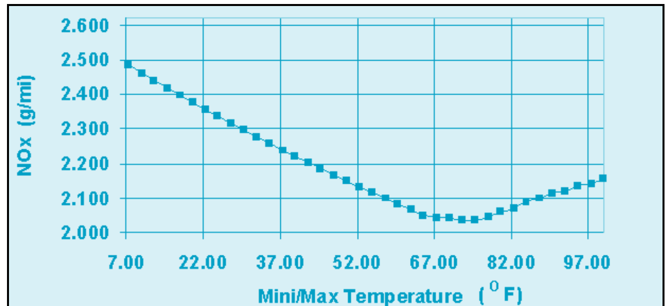

Figure 23. NOx Versus Temperature

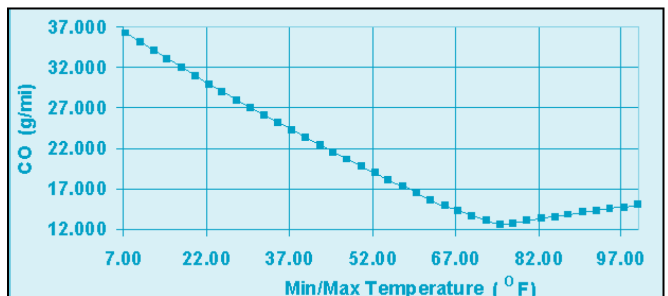

Figure 24. CO Versus Temperature

The CO emission rate decreases linearly at a rate of 0.3602 g/mi per one-degree temperature drop in the range of 72.5° F to 7.5° F; it increases at a rate of approximately 0.0956 g/mi per one-degree temperature increase within the range of 75.0° F and 100.0° F. Temperature exerts the most significant effect on CO emission.

Fraction of Vehicle Miles Traveled at Each Hour of The Day

VMT by hour of the day, in the default national database, clearly depicts typical morning and evening hourly traffic peaks for urban commuter routes on weekdays. Five additional VMT databases by hour of the day were created to gauge the sensitivity of hourly travel patterns (Fig. 25). The first two sets of data shift the travel pattern one hour to two hours ahead the national default. The other two sets delay the travel patterns one hour to two hours as compared to the national default. The last data set contains a single peak VMT distribution by hour of the day.

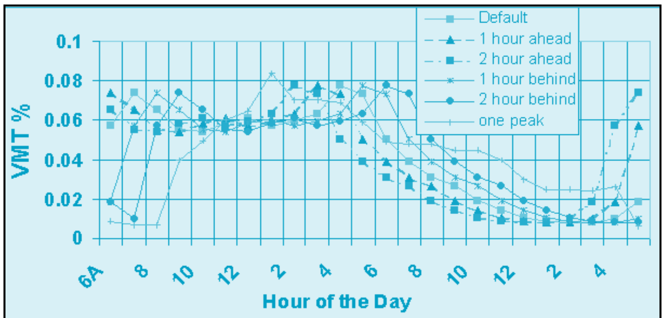

Figure 25. VMT By Hour of the Day

As indicated in Figs. 26, 27 and 28, all three-emission rates (VOC, NOx, and CO) are sensitive to the hour of the day that travel occurs. The sensitivity of all emission factors to the VMT by hour of day is also tied to VMT distribution by speed. To effectively evaluate hourly distributions of VMT by hour, VMT distributions by speed should also be analyzed. The use of VMT by hour and VMT by speed should be coordinated and used in combination.

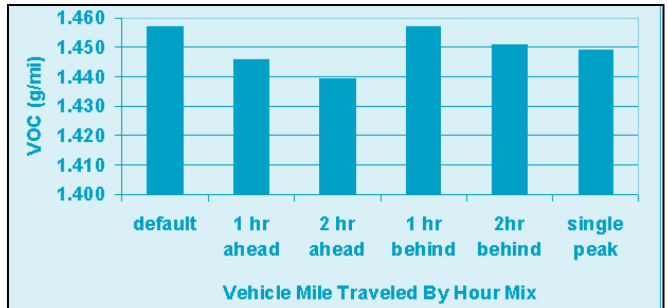

Figure 26. VOC Versus VMT By Hour of the Day

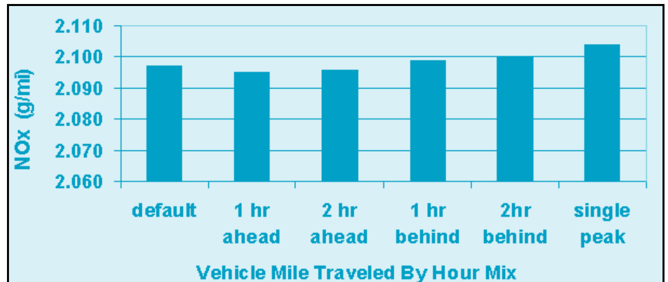

Figure 27. NOx Versus VMT By Hour of the Day

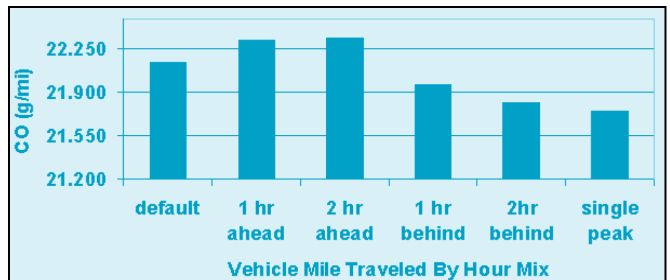

Figure 28. CO Versus VMT By Hour of the Day

Fraction of Vehicle Mile Traveled by Speed

Since speeds for both freeway ramp and local facility are fixed, only freeway mainline and arterial/collector facilities possess variable speed characteristics. VMT traveled on both freeway mainline and arterial facilites are allocated to 14 different speed bins. To test the effect of VMT allocation by speed on emission rates, five additional speed VMT distributions, in addition to the default, were created (Table 1) and tested.

Table 1. Vehicle Mile Traveled by Speed (Speed VMT) Mix

SVMT Mix*	Speed Bin 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Default	d**	d	d	d	d	d	d	d	d	d	d	d	d	d
SVMT1	d	d	d	d	d	d	d	1[a]	-1[b]	d	d	d	d	d
SVMT2	d	d	d	1	d	d	d	d	d	-1	d	d	d	d
SVMT3	d	d	d	d	d	d	d	d	d	-1	1	d	d	d
SVMT4	d	d	d	d	d	d	-1	d	d	1	d	d	d	d
SVMT5	d	d	d	d	d	d	2	d	d	d	-2	d	d	d

*: Name of speed VMT mix group
**: Default Speed VMT.
a: VMT % by speed at bin 8 increased 1%
b: VMT % by speed at bin 9 decreased 1%

It is clear from Figs. 29, 30, and 31 that emission rates for all three pollutants (VOC, NOx, and CO) are sensitive to changes of VMT occurring at various speeds. It reinforces the fact that vehicle emission rates are highly sensitive to speed changes.

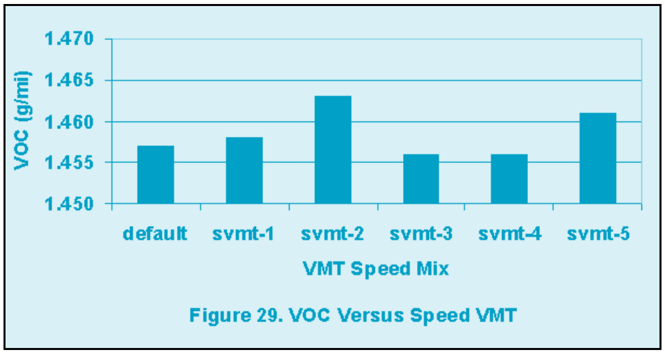

Figure 29. VOC Versus Speed VMT

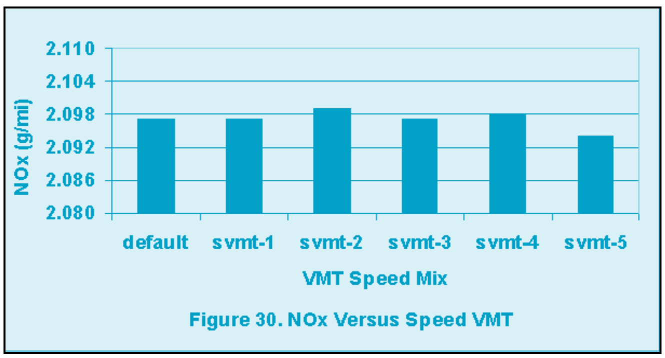

Figure 30. NOx Versus Speed VMT

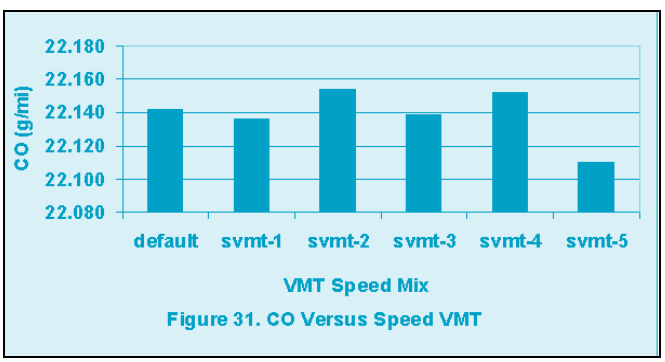

Figure 31. CO Versus Speed VMT

Fraction of Vehicle Mile Traveled by Vehicle Types

The VMT Fraction command utilizes the VMT distribution among 16 vehicle types. In this sensitivity analysis, VMT fractions of the HDV8B and HDV8A are modified from the default. However, the sum of the VMT fractions from these two vehicle types is the same as default. The same strategy is carried out for the LDT4 and HDV2B vehicles.

As indicated in Figs. 32(a), 33(a) and 34(a), emission rates for all three-pollutant emission rates are exceedingly sensitive to changes in VMT traveled by the HDV8A and HDV8B vehicles. This phenomena indicates that VMT allocation even between closely related HDVs is still critical in the emission rate modeling. Figs. 32(b), 33(b), and 34(b) show the results from VMT allocation changes between LDT4 and HDV2B. It is clear that VMT allocation between LDV and HDV is critical to successfully model all emission factors.

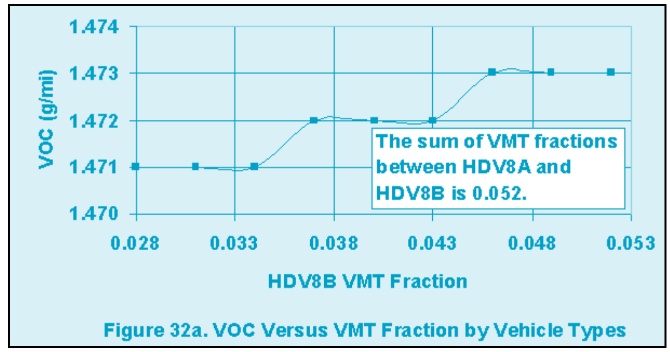

Figure 32a. VOC Versus VMT Fraction by Vehicle Types

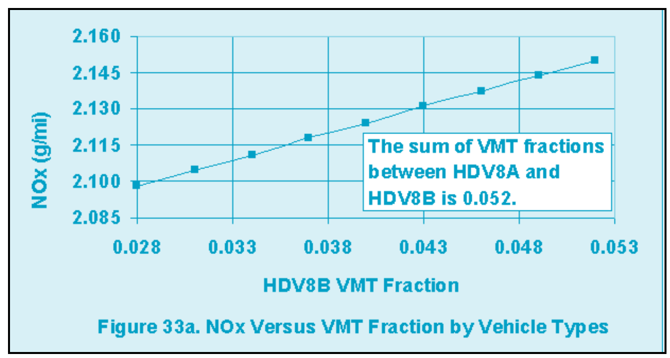

Figure 33a. NOx Versus VMT Fraction by Vehicle Types

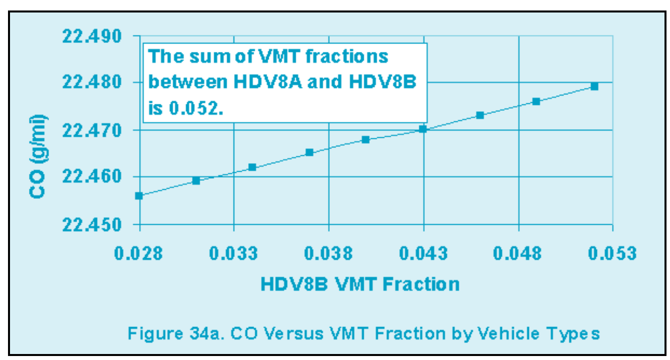

Figure 34a. CO Versus VMT Fraction by Vehicle Types

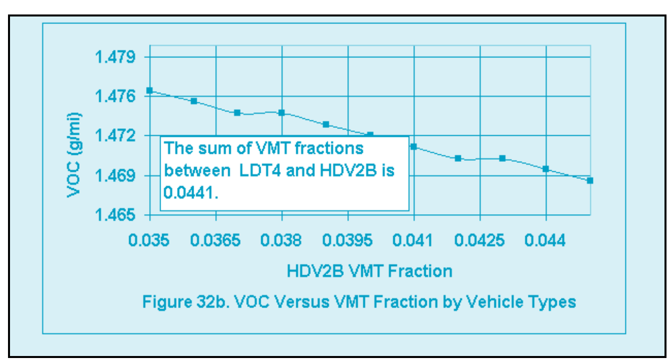

Figure 32b. VOC Versus VMT Fraction by Vehicle Types

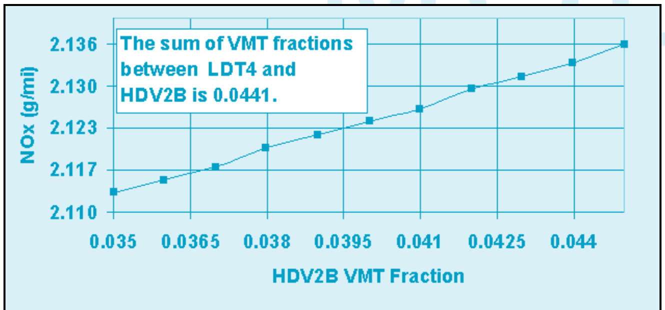

Figure 33b. NOx Versus VMT Fraction by Vehicle Types

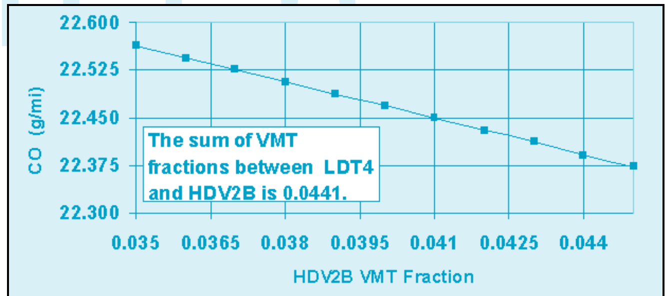

Figure 34b. CO Versus VMT Fraction by Vehicle Types

Vehicle Age Distribution

For each of the 28 vehicle types, age distribution is established for all 25 age categories. For the purposes of this sensitivity analysis, in addition to the default age distribution, another four distributions were created for the LDG vehicle class. Two newer fleet mix and two older fleet mixes (as compared to the national default fleet mix) were analyzed. The specific distribution pattern is shown in Fig. 35.

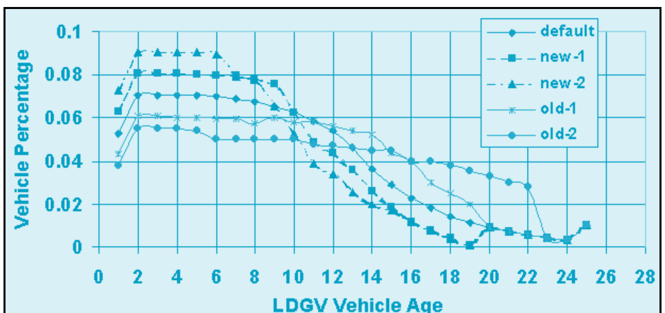

Figure 35. LDGV Vehicle Age Distribution

As indicated in Figs. 36, 37, and 38, all three-emission rates are exceedingly sensitive to age changes in the fleet mix. The newer the fleet, the lower the emission rates.

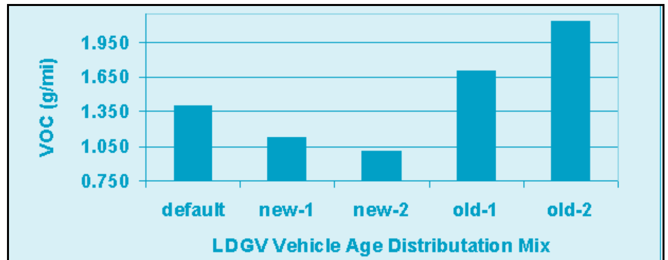

Figure 36. LDGV VOC Versus Vehicle Age Distributation

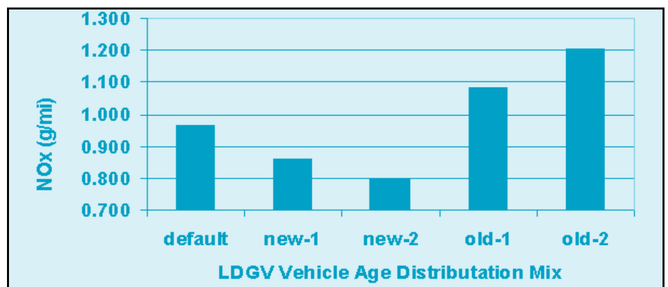

Figure 37. LDGV NOx Versus Vehicle Age Distributation

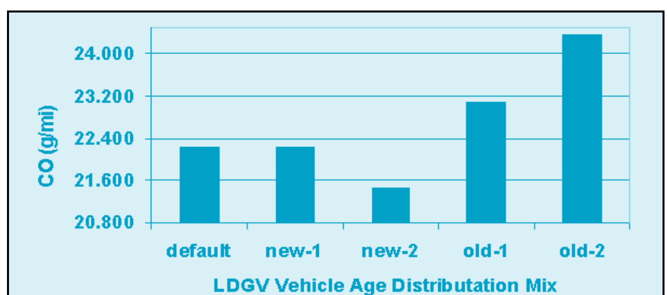

Figure 38. LDGV CO Versus Vehicle Age Distributation

Vehicle Starts Per Day

Vehicle starts per day include starts for each of the 28 vehicle types for each of the 25 vehicle age categories. A complete database for vehicle starts per day encompasses 450 entries for weekday and 450 for weekend. During this sensitivity analysis, five additional databases in addition to the national default were created for the LDGV class under weekday conditions.

As indicated in Figs. 39, 40, and 41, all three-pollutant emission rates (VOC, NOx, and CO) are exceedingly sensitive to the number of starts per day changes. The average decreases in emission rates are 0.0605 g/mi, 0.0205 g/mi, and 0.5733 g/mi per one fewer start for VOC, NOx and CO, respectively.

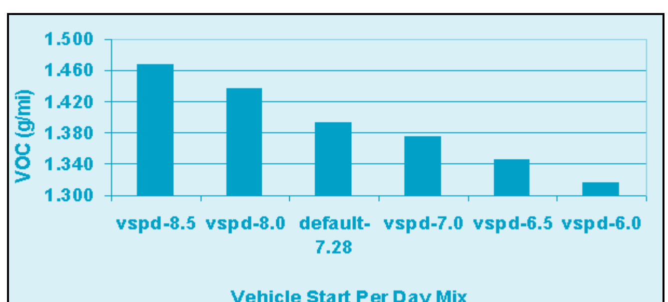

Figure 39. VOC Versus Vehicle Starts Per Day

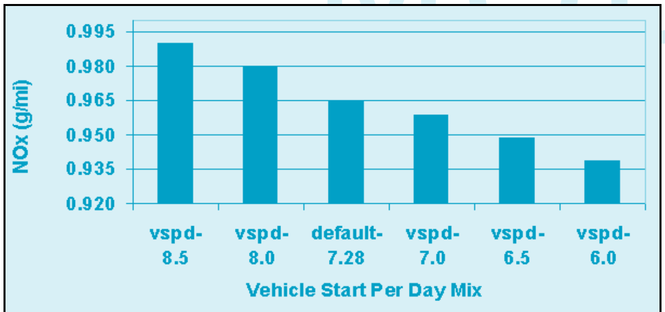

Figure 40. NOx Versus Vehicle Starts Per Day

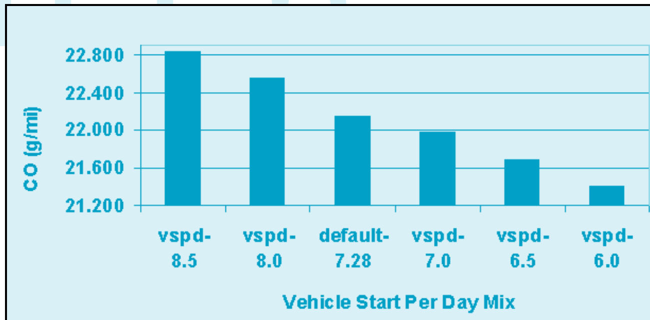

Figure 41. CO Versus Vehicle Starts Per Day

Vehicle Trip Length Distribution

Vehicle trip length distribution is characterized by fractions of VMT that occurs in each of the 6-trip length (in minutes) for each of the 14 time periods. There are 84 entries for a full weekday trip length distribution. Four additional weekday vehicle trip length distribution datasets in addition to the national default data were created (Table 2).

Table 2. Vehicle Trip Length (Duration) Percentage during Weekday Mixes

Trip* Mix	Trip Duration (minutes)					
	< 10	11-20	21-30	31-40	41-50	51+
default	d**	d	d	d	d	d
tl-1	d	-3%[a]	+3%[c]	d	d	d
tl-2	d	-6%	+6%	d	d	d
tl-3	d	-3%	d	d	+3%	d
tl-4	d	-6%	d	d	+6%	d

*: Name of Trip Mix group
**: Default
a: The 11-20 minutes long vehicle trip percentage decreased 3%.
b: The 21-30 minutes long vehicle trip percentage increased 3%

As indicated in Figs. 42, 43 and 44, there are no apparent affects from vehicle weekday trip length on any of the emission factors tested. Vehicle emission factors are not sensitive to weekday vehicle trip length distributions.

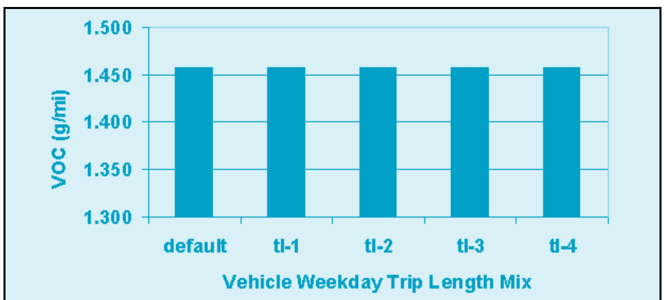

Figure 42. VOC Versus Vehicle Weekday Trip Length

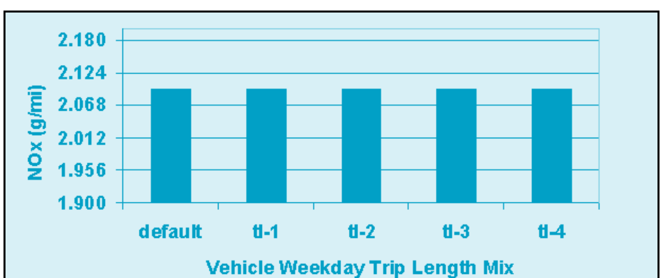

Figure 43. NOx Versus Vehicle Weekday Trip Length

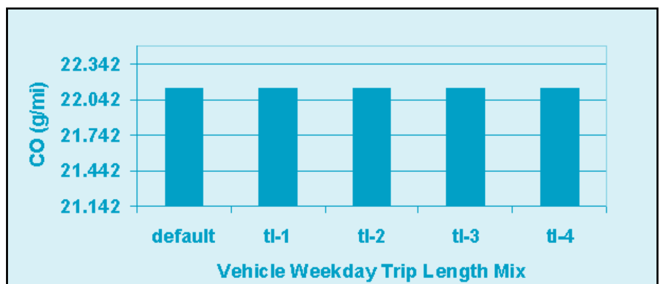

Figure 44. CO Versus Vehicle Weekday Trip Length

Vehicle Mile Accumulation Rate

The vehicle mile accumulation rate database contains the annual vehicle mile accumulation rates by vehicle age for all 28 vehicle types. During the present sensitivity analysis, six additional datasets were created in addition to the national default data. In the new database, vehicle miles accumulated for the LDGV type are 1000, 2000, and 3000 miles more and less for each corresponding data point in the national default data set.

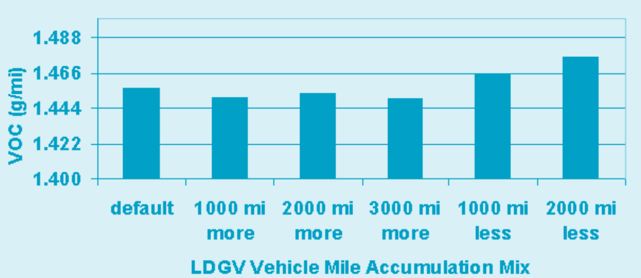

Figure 45. VOC Versus Annual Vehicle Mile Accumulation Rate

As indicated in Figs. 45 and 46, as annual vehicle mile accumulation rates go up, both the VOC and NOx emission rates go down. Contrary to the VOC and NOx trend, CO emission rates increase as the vehicle annual mile accumulation rate increases (Fig. 47). As shown in Figs. 45, 46, and 47, all three-emission factors are sensitive to the annual vehicle mile accumulation rate changes.

Vehicle mile accumulation rate, trip length and starts per day are all inter-related. When one of these data groups is changed, assessment of its effects on the remaining parameters is necessary.

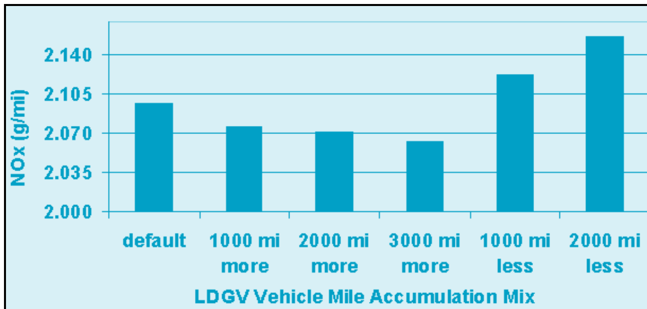

Figure 46. NOx Versus Annual Vehicle Mile Accumulation Rate

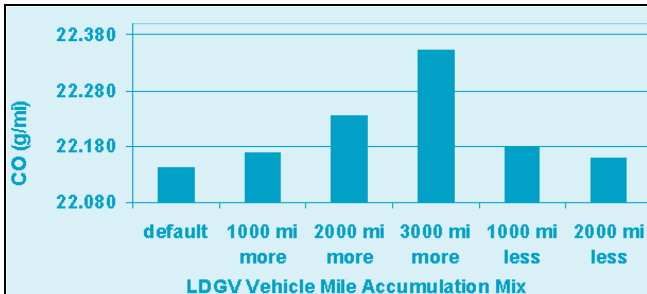

Figure 47. CO Versus Annual Vehicle Mile Accumulation Rate

SUMMARY

The MOBILE6 sensitivity analysis provides valuable information in gauging the overall model behavior under various conditions. As indicated by the testing results, all tested parameters affected the model outputs. However, the amount of influence on all three-pollutant emission rates (CO, NOx, VOC) from different inputs varied greatly in magnitude. This observation demonstrates that the model is very responsive to condition changes.

Vehicle speeds associated with all roadway facility types exert the most significant and sensitive effects on all emission rates. The relationships between vehicle speeds and pollutant emission rates for both NOx and CO can be adequately described by third order polynomial equations. The relationship between VOC emission rates and vehicle speeds is pseudo-linear.

Percentages of vehicle miles traveled among local, arterial/collector, and freeway facilities have a significant effect on all three-pollutant emission rates. This observation indicates that the allocation of vehicle miles traveled among all roadway facilities is critical. This conclusion is also applicable to the VMT allocation between freeway ramps and freeway mainlines.

Environmental factors such as temperature, humidity, and cloud cover affect one or all three-pollutant emission rates. The NOx emission rate decreases at a rate of more than 0.0030 g/mi per 1-grain/pound humidity increases. The minimum temperature increases the CO emission at rates ranging from 0.0856 to 0.3602 g/mile per 1-degree temperature drops.

All three-pollutant emission rates are very sensitive to changes in travel behaviors such as vehicle miles traveled by hour of the day, vehicle travel speeds, and vehicle types. Among the three parameters, VMT by vehicle type exerts the most significant and sensitive affect on both NOx and CO emissions. The correct allocation of VMT traveled by HDV is also critical.

Among other tested parameters such as vehicle starts per day, annual vehicle miles accumulation, vehicle weekday trip lengths, and vehicle ages, the vehicle age has the most influence on the three-pollutant emission rates. Vehicle weekday trip length has the least influence on all emission rates.

RVP was the only fuel parameter tested. CO emission rates increase as RVP increases in the range of 6.0 to 12.0 psi. Between 6.0 and 7.5 psi, NOx emission rates are constant. However, as the RVP exceeds 7.5 psi, NOx emission rates increase linearly with fuel RVP. CO emission rates are at a constant when fuel RVP is less than 9.0 psi. When fuel RVP exceeds 9.0 psi, CO emission rates experience significant increases with higher RVP.

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