MOVES2014

Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection and Maintenance Adjustments

U.S. Environmental Protection Agency
Office of Transportation and Air Quality
Assessment and Standards Division

Table of Contents

List of Tables

List of Figures

Glossary of Acronyms

A/C	Air Conditioning
ACCF	Air Conditioning Correction Factor
ASM	Acceleration Simulation Mode
CO	Carbon Monoxide
EPA	Environmental Protection Agency
F	Fahrenheit
FID	Flame Ionization Detection
FTP	Federal Test Procedure
g/mi	Grams per Mile
GVWR	Gross Vehicle Weight Rating
HC	Hydrocarbons
HLDT	Heavy Light Duty Truck
I/M	Inspection and Maintenance
LDT	Light Duty Truck
LDV	Light Duty Vehicle
LLDT	Light Light Duty Truck
MDPV	Medium Duty Passenger Vehicle
MOVES	MOtor Vehicle Emission Simulator
MSAT	Mobile Source Air Toxics
NMHC	Non-Methane Hydrocarbons
NOx	Oxides of Nitrogen
OBD	On-Board Diagnostic
PM	Particulate Matter
RSD	Remote Sensing Data
SFTP	Supplemental Federal Test Procedure
THC	Total Hydrocarbons (FID detection)
VIN	Vehicle Identification Number
VOC	Volatile Organic Compounds

1 Introduction

The emission rates in the MOVES model database represent a single (base) scenario of conditions for temperature, humidity, air conditioning load and fuel properties. MOVES is designed to adjust these base emission rates to reflect the conditions for the location and time specified by the user. MOVES also includes the flexibility for adjusting the base emission rates to reflect the effects of local Inspection and Maintenance (I/M) programs. This report describes how these adjustments for temperature, humidity, I/M and air conditioning were derived. Adjustments for fuel properties are being addressed in a separate report.

This report describes adjustments that affect running exhaust, start exhaust and extended idling emissions. The crankcase emission processes are chained to running exhaust, engine start and extended idling emissions, and thus are similarly affected by the temperature adjustments described in this report. The impact of fuels, temperatures and I/M programs on vapor venting, permeation and liquid leaks is addressed in a separate report on evaporative emissions.

2 Temperature Adjustments

In EPA's previous emissions model (MOBILE6), exhaust emissions from passenger cars and light-duty trucks were adjusted relative to their base rates at 75 degrees Fahrenheit based on:

1. Ambient temperature[1]
2. An adjustment based on the length of the soak time, for start emissions[2],[3]

In MOVES, we take a similar approach, but incorporate updated temperature adjustments based on the most recent data available. Only the effect of ambient temperature is discussed in this report. Additionally, latent engine heat from a previous trip also affects start emissions. The scope of which is discussed in the Light-Duty Emission Rates report3.

2.1 Data Sources for Temperature Effects

For the analysis of start emissions, the data consists of Federal Test Procedure (FTP) and LA-92 tests. For running emissions, analysis includes the bag 2 emissions of FTPs as well as US06 tests (without engine starts). We used the difference of Bag-1 minus Bag-3 emissions to estimate the cold-start emissions (in grams) for each test. Measurements from both the Federal FTP and California Unified Cycle (3-phase / 3-bag tests) are used to determine the effect of temperature on vehicle emissions. Within each test cycle, the first and third phases are identical driving cycles, but the first phase begins with a cold-start (cold engine and emission control equipment) while the third phase begins with a hot-start (relatively warm engine and control equipment). The difference between Bag 1 and Bag 3 are the emissions attributed to the cold start of the vehicle.

Some second-by-second test data were also used but only to validate the effects of temperature on running emissions (HC, CO, and NOx). The data used in these analyses are from the following sources:

- **MSOD -** EPA's Mobile Source Observation Database (MSOD) as of April 27, 2005. Over the past decades, EPA has performed or acquired data representing emissions measurements over various cycles (often the FTP) on tens of thousands of vehicles under various conditions. EPA has stored those test results in its Mobile Source Observational Database (MSOD).

For the data stored in MSOD, we limited our analysis to those tests for which vehicles were tested at two or more temperatures. The subset of tests meeting this criterion covered a temperature range from 15 to 110°F. Note that the tests acquired from MSOD were collected in aggregate or "bag" modes.

Information on EPA's MSOD is available on EPA's website:

http://www.epa.gov/otaq/models.htm

- **Kansas City** - A test program in Kansas City also yielded paired tests for a number of vehicles measured on the LA92 cycle over a range of ambient temperatures[4].
- **ORD Program-** EPA's Office of Research and Development (ORD) contracted (through the Clean Air Vehicle Technology Center, Inc.) the testing of five cars (model years 1987 through 2001). Those vehicles were tested using both the FTP and the IM240 cycles at temperatures of: 75, 40, 20, 0 and –20 ºF[5]. These five vehicles supplemented the vehicles from the MSOD and Kansas City.
- **MSAT Program -** Under a contract with EPA, the Southwest Research Institute (SwRI) tested four Tier 2 vehicles (2005 model year car and light-duty trucks) over the FTP at temperatures of: 75, 20, and 0 ºF[6]. These four vehicles also supplemented the vehicles from the MSOD and Kansas City.
- **OTAQ Cold Temperature Program** - EPA's Office of Transportation and Air Quality (OTAQ) contracted the testing of nine Tier 2 vehicles (2010 model year car and light-duty trucks). Eight of the nine vehicles were Mobile Source Air Toxics (MSAT-2) rule compliant. Vehicles were tested on the FTP and US06 at 75, 20, and 0ºF. Information on the vehicle test design is located in Appendix B. [7]

2.2 Effects of Temperature on Gasoline Start Emissions

The effects of ambient temperature on HC, CO, and NOx start emissions were modeled using the following principles:

- No adjustment for temperatures higher than 75°F.
- Additive adjustments for temperatures below 75°F.
- Calculate adjustments as either polynomial or exponential functions:

$$Additive\ Grams = A*(T-75) + B*(T-75)^2 + C*(T-75)^3$$

$$Additive\ Grams = Be^{A*(T-75)} + C$$

This approach guarantees a value of zero change for the additive adjustment at 75° F (i.e., the temperature of the federal FTP test). These coefficients are stored in the MOVES database table named *StartTempAdjustment*. This table contains coefficients pertaining to the temperature effect for each model year group and pollutant. The temperature effects in MOVES2010 only used polynomial functions and are maintained for the older model year groups. The capability to model HC, CO, and NOx additive cold start temperature adjustments with exponential functions is a new feature of MOVES2014. For MOVES2014, we used the exponential form for more recent model year vehicles for which we had new data. The data processing and the model fitting process differed for the polynomial and exponential fits, and each is described separately below.

2.2.1 HC and CO Start Emissions for Gasoline-Fueled Vehicles:

<u>Polynomial Fits</u>

The polynomial form was used for the cold start emission adjustments in MOVES2010. The polynomial model form is maintained in MOVES2014 for HC emissions for all gasoline vehicles pre-2006 model years, and all CO emissions for pre-2000 model years. The polynomial model is fit to the additive cold start data shown in Appendix A.

The polynomial fits were fit to data processed in the following steps. First, the cold start emissions (grams/start) were calculated by the difference in bag 1 and bag 3 emissions for each vehicle test. Next, the cold start emissions were stratified by model year groups. The data was initially grouped according to the following seven model year groups:

-- 1960 to 1980
-- 1981 to 1982
-- 1983 to 1985
-- 1986 to 1989
-- 1990 to 1993
-- 1994 to 1999
-- 2000 to 2005

Then, the mean emissions at 75°F were subtracted from each of the means to determine the change in emissions as functions of ambient temperature. (See Appendix A for the resulting processed data.)

Then, we modeled the changes in cold-start emissions as a polynomial function of temperature minus 75° F. The additive adjustments are set equal to zero for temperatures higher than 75° F. Thus, we did not use the changes in emissions from temperature above the FTP temperature range (68º to 86º F); however, those values are included in Appendix A. The model year groups were aggregated to larger intervals when the more disaggregated groups yielded non-intuitive results (e.g. older model year group had lower less additive cold start emissions).

The coefficients for the polynomial parameters (a, b, c) for the model year groups for HC and CO are included in Table 2-1.

Table 2-1. Polynomial Model Coefficients

	CO			HC		
Model Year Group	a	b	c	a	b	c

Pre-1981	-4.6773			-0.6307		
1981-1982	-4.6305			-0.4136		
1983-1985	-4.2444			-0.3607		
1986-1989					0.00241	
1986-1999		0.02341				
1990-2005					0.00292	

The HC test data for the 1986-1989, and 1990-2005 model year groups were as low as an ambient temperature of -20° F. However, the "best fit" HC regression curves (linear, quadratic, and cubic) all exhibited uncharacteristic fits to those data at temperatures from zero through 20° F. Deleting the test data at -20° F and performing the regressions produced an improved estimate of the cold-start HC emissions in that critical temperature range. Therefore, the proposed quadratic regression is based on the changes in cold-start emissions at only temperatures from zero through 75° F but is applied to all temperature in MOVES. This is likely due to the unbalanced nature of the analysis, with only a subset of vehicles used in the analysis that were tested at -20 F.

The CO temperature effect developed from the 1994-1999 model year data was applied to all model years from 1986-1999. The temperature effect developed for earlier 1986-1993 vehicles was excluded due to data anomalies that resulted in an uncharacteristically shaped model fit; the application of which led to older model years having substantially lower emissions than newer model years. (Base emission rates, however, are unaffected and still vary by model year group.) The quadratic model for the 1994-1999 model year groups is further supported by being consistent with the shape of the exponential model fit estimated for the 2000 and later cold start effects.

Exponential Fits

In updating the start temperature effects for MOVES2014, we focused on the most recent model year groups and implemented an improved methodology. For the updated cold temperature effects in MOVES2014, we fit models to raw data from the ORD, MSAT and OTAQ cold temperature programs. These datasets were analyzed to determine an HC temperature effect for model years 2006+ and a CO temperature effect for model years 2001+. CO temperature effects were updated for the 2001-2005 model years while HC temperature effects were not. This is because previous versions of MOVES contained an assumption that caused those newer model year vehicles to have cold start CO emissions unusually high relative to older model year vehicles.

We used linear mixed models fit to the logarithm of the start emissions. A log model was found to be the optimal fit to these data. Simpler polynomial models exhibited unnatural behavior when fitted to the data (negative values, non-monotonically increasing emissions). The model parameters were fit using linear mixed models using the function *lme* within the R statistical package *nlme*[8]. Using random effects for each vehicle, and emission certification and the temperature of each test as a fixed effect, we accounted for the paired-nature of the data set, yielding robust temperature effect estimates across the unbalanced nature of the data set (e.g. not all vehicles were tested at the same set of temperatures which is evident at -20 ° F in Figure 2-2).

The linear mixed model had the following form:

$$\log(\mathrm{y}) = \propto + \beta_1 \cdot Temp + Veh$$

Where: y = start emissions, Temp= temperature in Fahrenheit, Veh = random effect for each individual vehicle. The mean model simply removes the random vehicle effects:

$$\log(\mathrm{y}) = \propto + \beta_1 \cdot Temp$$

We then converted the mean logarithmic model, to real-space, yielding a multiplicative exponential model:

$$\mathrm{y} = e^{\propto + \beta_1 Temp}$$

We then changed the intercept to 75F, by setting $T' = 75 - Temp$, and substituting $Temp = 75 - T'$ into the above equation and rearranging. This yields equation:

$$\mathrm{y} = Be^{A(Temp-75)}$$

Where A = β_1, and B= $e^{\alpha+75\cdot\beta_1}$. B is essentially the 'Base Cold Start' at 75F, with units of (g/start). The $e^{A(Temp-75)}$ term is a multiplier which increases the cold start at lower temperatures.

To convert the model to an additive adjustment, we calculated the additive difference from the cold start: y – y(75) = $Be^{A(Temp-75)} - B$. This model form can be used in the current MOVES temperature calculator for HC and CO, by setting C = -B, such that such that :

$$Additive\ Grams = Be^{A*(T-75)} + C$$

The model fits for HC and CO start emissions using the linear mixed model are shown in Figure 2-1 and Figure 2-2. The data for different model year groups (emissions certifications) can be observed. The PFI MSAT-2 compliant vehicles (2010) tested in the OTAQ 2012 test program have consistently lower start emissions than the pre-MSAT vehicles (pre-2010).

Figure 2-1 FTP HC Start Emissions

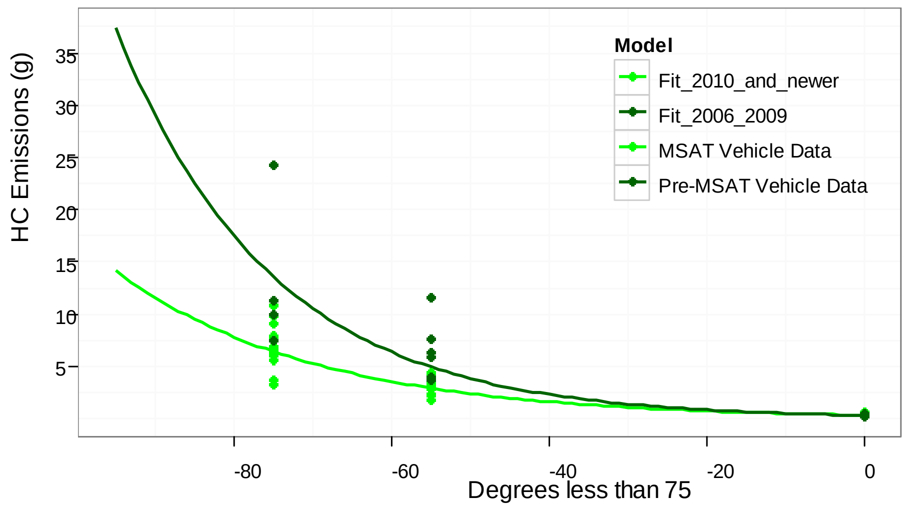
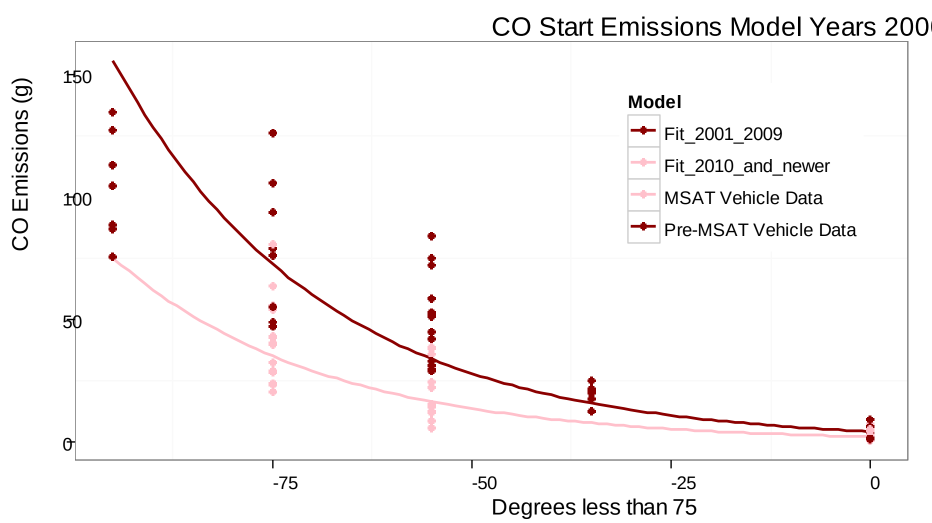


Figure 2-2 FTP CO Start Emissions



No statistical difference in the exponential impact of temperature (coefficient a) was found between the 2001-2009, and the 2010 model year groups for CO emissions. We therefore used a temperature effect of the pre-MSAT and post MSAT vehicles pooled together. The newer model year group (2010+) does have a significantly lower base cold start (coefficient b), which causes the temperatures to be lower across all temperatures for the newer model year vehicles. Table 2-3 contains the exponential temperature effects CO and HC used in MOVES. The exponential slope or CO emissions is unchanged for all the model year groups. However, the base 75° F CO cold start (coefficient b) decreases with newer model year vehicles.

For HC emissions, a significant difference was detected in the exponential temperature effect between the pre-MSAT and MSAT compliant vehicles. The MSAT compliant vehicles had a smaller temperature effect as is evident in Figure 2-1. The differences in the HC cold start temperature effect, is used to representative of the impact of the Mobile Source Air Toxic (MSAT-2) rule. The MSAT-2 rule included a limit on low temperature (i.e., at 20 ° F) non-methane hydrocarbon (NMHC) emissions for light-duty and some medium-duty gasoline-fueled vehicles6. Specifically:

- For passenger cars (LDVs) and for the light light-duty trucks (LLDTs) (i.e., those with GVWR up to 6,000 pounds), the composite FTP NMHC emissions should not exceed 0.3 grams per mile.
- For heavy light-duty trucks (HLDTs) (those with GVWR from 6,001 up to 8,500 pounds) and for medium-duty passenger vehicles (MDPVs), the composite FTP NMHC emissions should not exceed 0.5 grams per mile.

These cold weather standards are phased-in beginning with the 2010 model year, specifically:

Table 2-2 Phase-In of Vehicles Meeting Cold Weather HC Standard

Model Year	LDVs / LLDTs	HLDTs / MDPVs
2010	25%	0%
2011	50%	0%
2012	75%	25%
2013	100%	50%
2014	100%	75%
2015	100%	100%

The coefficients for the HC temperature effect equation in the *startTempAdjustment* table during the phase-in years are adjusted linearly according to the light-duty vehicle phase-in. The following equation shows how the temperature effect is calculated for model year 2010.

$$a_{2010} = a_{pre}(1 - 0.25) + a_{post}(0.25)$$

The exponential temperature effect (coefficient a) for HC emissions are reduced from 2009 to 2013. However, the base 75° F HC cold start (coefficient b) is relatively constant.

No data on the temperature effect on HLDTs/MDPVs are available, so we applied the light-duty temperature adjustments also these regulatory classes. Within the current MOVES design, temperature effects are applied by fuel types and model year vehicles, but not by regulatory class (e.g. HLDTS/MDPVs). As such, the light-duty rates, including the light-duty MSAT-2 phase in, are applied to all the gasoline-fueled vehicles in MOVES.

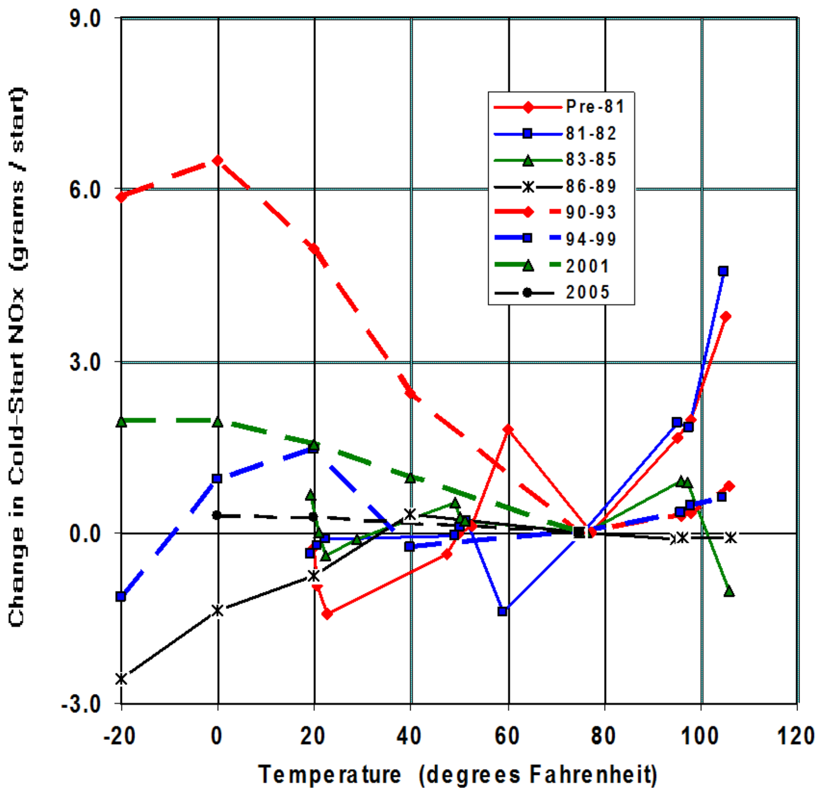
Table 2-3. Coefficients Used for Exponential Temperature Effect Equation

	CO			**HC**		
Model Year Group	a	b	c	a	b	c
2000-2009	-0.03818	4.136	-4.136			
2006-2009				-0.05052	0.308	-0.308
2010	-0.03818	3.601	-3.601	-0.04774	0.315	-0.315
2011	-0.03818	3.066	-3.066	-0.04495	0.322	-0.322
2012	-0.03818	2.531	-2.531	-0.04216	0.329	-0.329
2013 & Later	-0.03818	1.996	-1.996	-0.03938	0.336	-0.336

2.2.2 Temperature Effects on Gasoline NOx Start Emissions

For the effects on cold-start NOx emissions associated with changes in ambient temperature, we attempted the same model year stratification that we used for the HC and CO emissions. However, as is illustrated in Figure 2-3, the "by model year" temperature effects on cold-start NOx emissions did not lend themselves to linear, quadratic, or cubic regressions (possibly due to insufficient sample size). Also, not unexpectedly, most of the coefficients produced by those regression analyses were not statistically significant.

Figure 2-3 Effects of Ambient Temperature on Changes in Cold-Start NOx



A visual inspection of Figure 2-3 suggests that only three model year groups (1990-1993, 2001, and 2005) exhibited patterns that would result in meaningful regression analyses. We attempted to group the data into various other model year groups. The only grouping that produced useful regression analysis results were the ones in which we average together all of the NOx results (from Appendix A) to obtain the following table.

Table 2-4 Average NOx Emission Results by Temperature

Temp	Delta NOx (grams)	Temp	Delta NOx (grams)	Temp	Delta NOx (grams)
-20.0	1.201	31.0	-0.007	54.2	0.438
0.0	1.227	40.0	0.876	76.3	0.000
19.4	0.202	48.8	0.127	95.3	0.225
20.7	0.089	49.8	0.333	97.1	0.370

22.4	-0.155	51.0	0.325	105.8	0.543

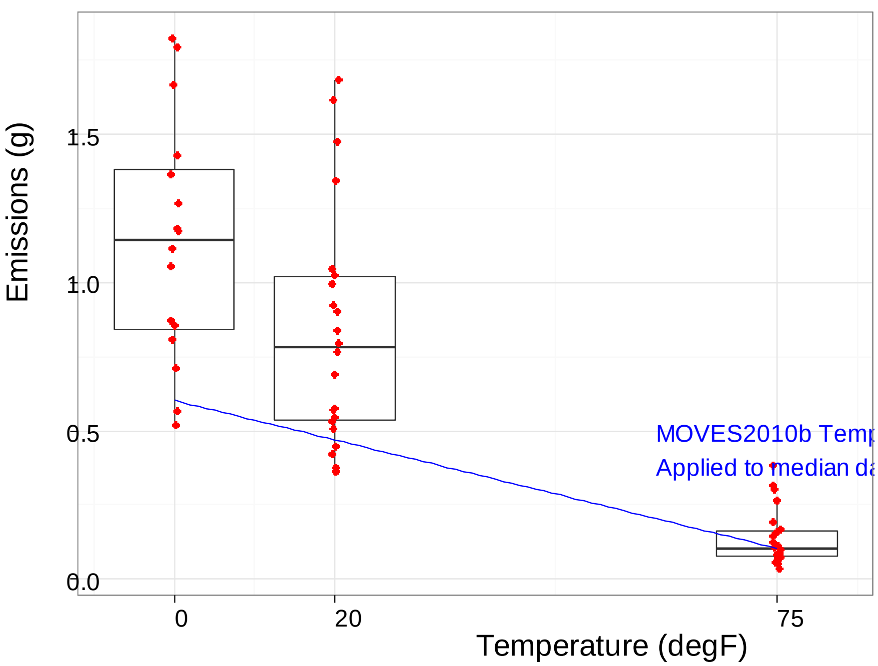
Performing regression analyses on these data (again, using only the changes in the NOx cold-start emissions for temperatures below 86º F as explained in Section 3.2), we found the "best fit" equation to be:

NOx temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.009431682 R-sqr = 0.611349

Although the value of R-squared is not as high as for the HC and CO regression equations, the coefficient is statistically significant. If we were to evaluate that equation for temperatures higher than 75° F, it would predict a negative change (i.e., a decrease) in the cold-start NOx emissions (i.e., a decrease in cold-start NOx emissions), but the actual data indicate that the cold-start NOx emissions increase as the ambient temperature rises above 90° F. Therefore (as with the previous adjustments), this additive adjustment is set to zero for temperatures higher than 75° F.

We evaluated the NOx start emissions from the 2010 model year vehicles, as shown in Figure 2-4. Both the current model estimates and data from 2010 vehicles predicts small increases in the NOx emissions at cold temperatures. We deemed the difference too minor to estimate model-year specific NOx start effects, and have maintained the NOx temperature adjustment estimated above for all model years.

Figure 2-4. FTP Start NOx Emissions, Bag 1 – Bag 3, Model years 2004+

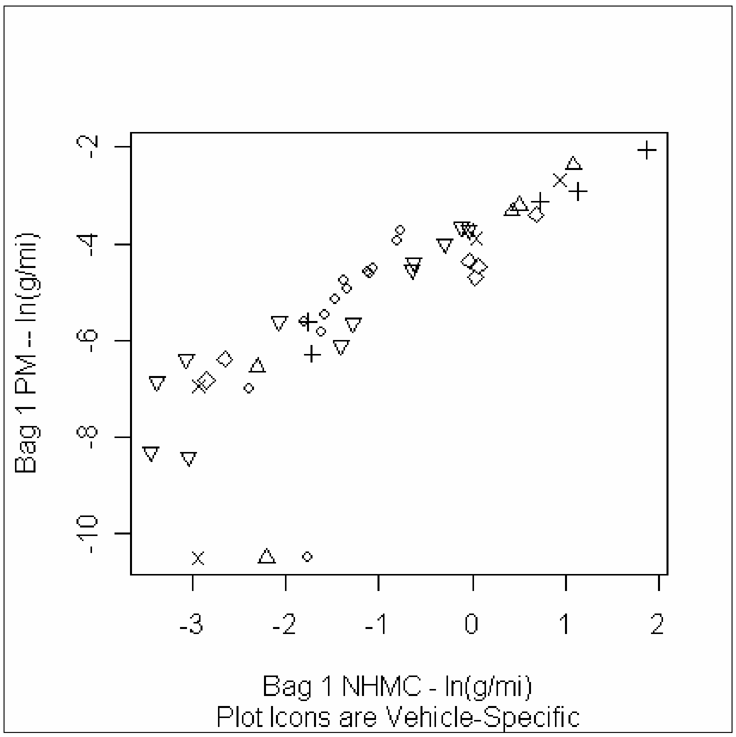


2.2.3 Temperature Effects on Gasoline PM Start Emissions

The temperature effects on particulate matter (PM) start emissions modeled in MOVES using a multiplicative (not additive) exponential (not polynomial) adjustment. This analysis is included in a separate EPA report4 and journal article[9].

The MSAT-2 rule (signed February 9, 2007) does not explicitly limit cold weather emissions of particulate matter (PM). However, the Regulatory Impact Analysis (RIA) document6 that accompanied that rule noted there is a strong linear correlation between NMHC and PM2.5 emissions. That correlation is illustrated in Figure 2-5(reproduced from that RIA) of the logarithm of the Bag-1 PM2.5 versus the logarithm of the Bag-1 NMHC (for various Tier-2 vehicles).

Figure 2-5 FTP Bag 1 PM and FTP Bag 1 NMHC for Tier 2 Vehicles



Therefore, the limitation on cold weather HC (or NMHC) emissions is expected to result in a proportional reduction in cold weather PM2.5 emissions. In the MSAT-2 RIA (Table 2.1.-9), EPA estimated that this requirement would result in a 30 percent reduction of VOC emissions at 20º F. Applying the same analytical approach that was used in the RIA means that a 30 percent reduction in VOC emissions would correspond to a 30 percent reduction in PM emissions at 20º F (for Tier 2 cars and trucks).

EPA's earlier analysis (for MOVES)4,9 indicated that ambient temperature affects both start and running PM emissions, and that effect (for Tier 2 vehicles) is best modeled by (exponential) multiplicative adjustments of the form:

Multiplicative factor = $e^{\mathbf{A}*(72-t)}$, where "t" is the ambient temperature

and where **A** = 0.0463 for cold-starts and
0.0318 for hot running
(See Table 12 in Reference **[**4**]**, page 46.)

Therefore, for Tier 2 vehicles <u>not</u> affected by the MSAT-2 requirements, as the temperature decreases from 72º to 20º F, EPA expects PM emissions to increase by factors of:

- 11.10727 for cold-starts, and

Applying the 30 percent reduction for vehicles affected by the MSAT-2 requirements implies a PM increase as the temperature decreases from 72º to 20º F of:

- 7.77509 for cold-starts and

Combining this information with the MSAT-2 phase-in schedule from Table 2-3 leads to the following (multiplicative) increases as the temperature decreases from 72º to 20º F:

Table 2-5 Multiplicative Increase in Cold Start PM from 72º to 20° Fahrenheit

Model Year	LDVs / LLDTs	HLDTs / MDPVs
2008	11.10727	11.10727
2009	11.10727	11.10727
2010	10.27423	11.10727
2011	9.44118	11.10727
2012	8.60814	10.27423
2013	7.77509	9.44118
2014	7.77509	8.60814
2015	7.77509	7.77509

Solving for the corresponding constant terms so that the preceding exponential equation will yield these increases, gives us these "A" values:

Table 2-6 Exponential Temperature Effect for Start $PM_{2.5}$ emissions (Coefficient A)

Model Year	LDVs / LLDTs	HLDTs / MDPVs
2008	0.046300	0.046300
2009	0.046300	0.046300
2010	0.044801	0.046300
2011	0.043175	0.046300
2012	0.041398	0.044801
2013	0.039441	0.043175
2014	0.039441	0.041398

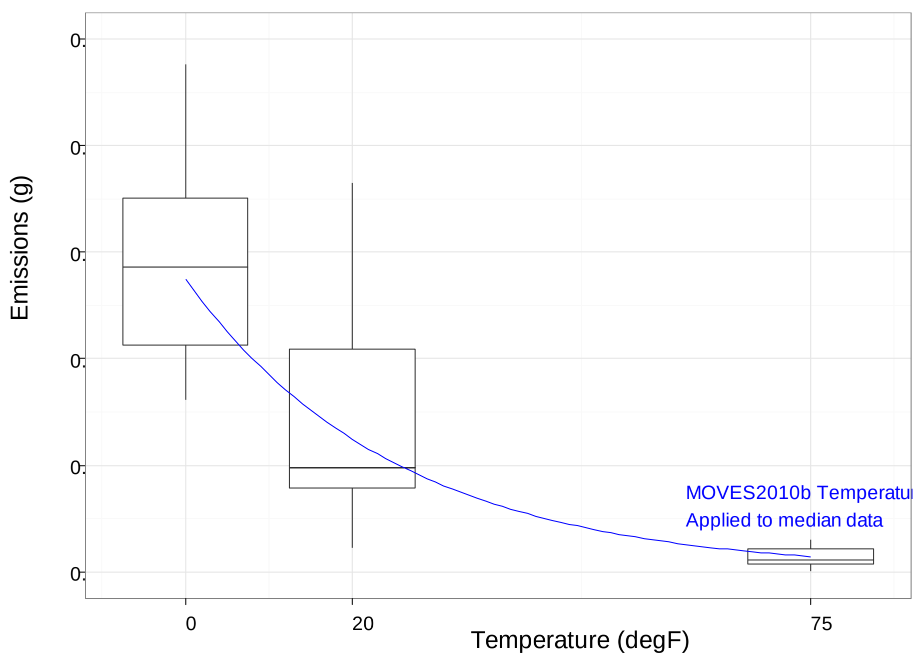
2015	0.039441	0.039441

We assume that the increases in the $PM_{2.5}$ emissions apply proportionally to each component of the PM emissions, including elemental carbon (EC), organic carbon, sulfate and other species. We applied the same temperature adjustment to each species because the $PM_{2.5}$ speciation profile for gasoline vehicles did not change significantly between the winter and summer rounds of the Kansas City Light-duty vehicle emissions study.[10]

Although the factors used to assign start emissions to operating modes based on soak time were not developed for PM emissions from gasoline-fuel vehicles[3], the finding that Tier 2 PM emissions are proportional to HC emissions supports our decision to apply the HC soak adjustments to the start PM emissions.

We compared the PM start temperature effects estimated for MSAT-2 compliant vehicles with a trend estimated from the additional data more recently collected on MY2010 MSAT-2 compliant vehicles. The temperature effect previously developed and applied in MOVES fits the most recent data collected by OTAQ quite well, as shown in Figure 2-6. Due to the good agreement, we retain the PM start temperature effects estimated for the MSAT-2 rule in MOVES2014.

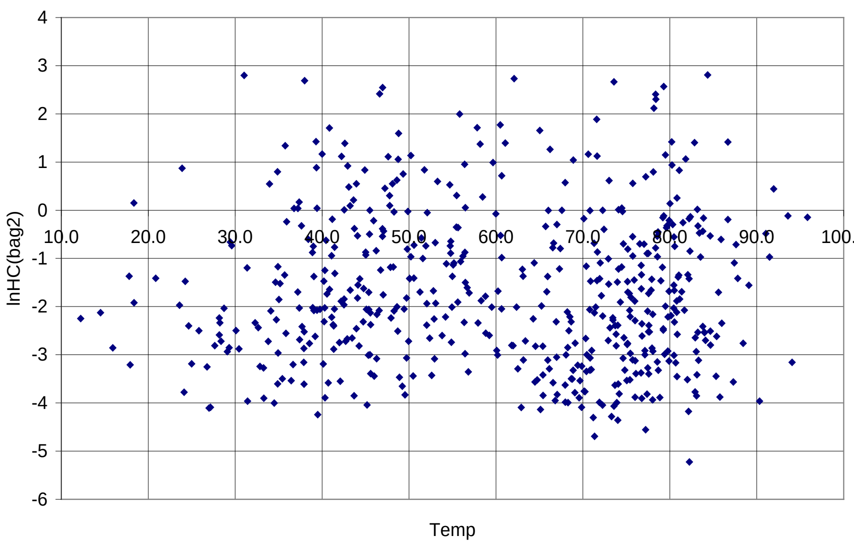
Figure 2-6. FTP PM Start Emissions, MSAT Compliant Vehicles



2.2.4 Temperature Effects on Running-Exhaust Emissions from Gasoline vehicles

Hot-running temperature effects were developed using the same data as the start temperature effects. These test data suggest that there is very little effect of temperature on running emissions of HC, CO, or NOx. Regression analyses found that the coefficients (slopes) were not statistically significant (that is, the slopes were not distinguishable from zero). This finding is consistent with what we found in our analysis of the Kansas City data[4]. This lack of correlation between running emissions and ambient temperature is illustrated (as an example) in Figure 2-7:

Figure 2-7 Logarithm of Bag-2 HC Versus Temperature from the Kansas City Study



In this plot, each point represents a single LA-92 Bag-2 test result from the Kansas City program. A visual inspection of this plot of the natural logarithm of the LA-92 Bag-2 HC emissions suggests no strong relationship between the hot-running HC emissions and the ambient temperature.

The CO and NOx plots are similar in that they also do not indicate a significant trend.

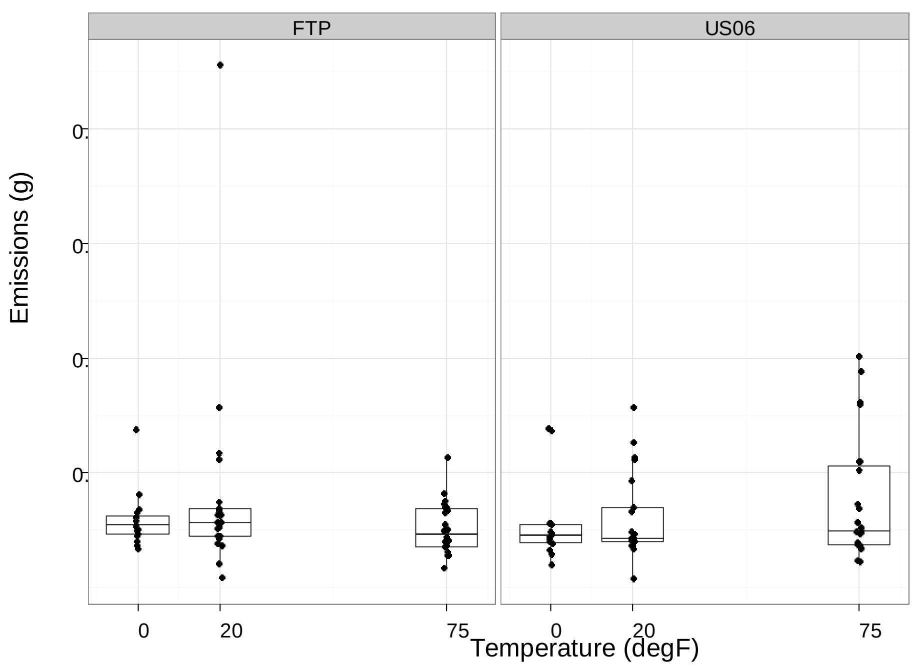
As an additional test, we examined a set of continuous data collected on the IM240 cycle in the Chicago I/M program. To avoid potential confounding due to variable levels of conditioning vehicles experienced in the queues at the I/M stations, we used only second IM240s when back-to-back IM240s were performed, and for single IM240s we examined only the 120 seconds of full duration IM240s. Based on this analysis, we found no evidence of a temperature effect between 5 and 95°F.

The effect of temperature on hot running HC, CO, and NOx emissions is coded in MOVES using polynomial functions as multiplicative adjustments. In this version of MOVES, we propose to set all of those adjustments equal to 1.0, that is, no change in running emissions with temperature.

This was not the case for PM emissions. Previously, analysis of the results of the Kansas City program appeared to show a temperature effect for running emissions of particulate matter. As with start emissions, the temperature effects on PM running emissions were modeled in MOVES using a multiplicative (not additive) exponential (not polynomial) adjustment. This analysis is detailed in as Chapters 7 and 8 of the "Analysis of Particulate Matter Emissions from Light-Duty Gasoline Vehicles in Kansas City[4]").

For MOVES2014, we re-evaluated the PM temperature effect for running emissions for Tier 2 and MSAT-compliant vehicles. Experimental data collected in the 2012 OTAQ program[7] involved measurement of PM emissions on both the FTP (by phase) and the US06 cycles temperatures of 0, 20, and 75°F. The results from these programs are plotted against temperature in Figure 2-8. No significant temperature effect is detected on either cycle. The recent test programs conducted on Tier 2 vehicles suggests that PM emissions are not influenced by ambient temperature when the engines are fully warmed up. These findings are consistent with results reported for modern PFI vehicles by Mathis et al. (2004)[11].

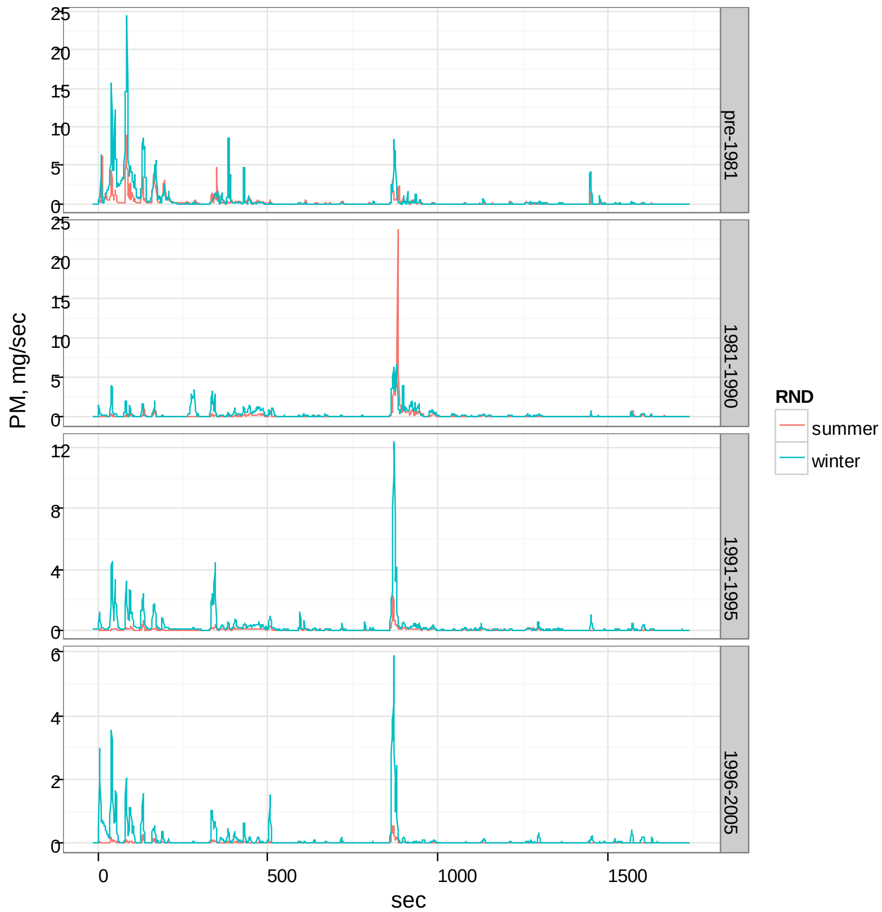
Figure 2-8. Hot-Running PM Emissions Measured on Two Cycles (FTP Bag 2, US06) on MSAT-2 compliant MY 2010 gasoline vehicles.



A significant PM running temperature effect was detected for bag 2 emissions in the Kansas City Study. The temperature effect observed in bag 2 emissions in this dataset may have been due in part to the short duration of the cold-start phase of the LA92 cycle, which is only 310 sec (1.18 mi) in length. In contrast, the cold-start phase of the FTP, used in the more recent studies, is 505 seconds (3.59 miles) in length. One interpretation of the trend observed in the Kansas City results is that vehicles were not fully conditioned at the end of the first phase of the LA92. The implication is that emissions observed in the early portion of the hot-running phase could have reflected "start" rather than "running" emissions[9], which could have explained the apparent presence of a temperature effect for hot-running emissions.

To reassess this question, the continuous (second-by-second) data from the Kansas City program were re-analyzed. Three sets of time series were considered, including second-by-second measurements of PM (DustTrak measurements normalized to the Teflon filter measurements), black carbon (photoacoustic analyzer) and hydrocarbon emissions (flame ionization detector). The second-by-second measurements were analyzed to evaluate whether an effect of ambient temperature could be observed only during the first portion of hot-running phase in the LA92. An aggregate time series for PM emissions, averaged for the set of paired measurements (20 vehicles measured in both the summer and winter) are graphed in Figure 2-9. Except for model-year group 1981-1990, the winter time measurements are noticeably higher than the summer measurements even beyond 1,000 seconds.

Figure 2-9 Average PM emissions for paired vehicle tests in Kansas City Study.



The exponential temperature effect was analyzed for bag 1, bag 1 + bag 2, and varying segments of each of the bags. These model results are shown in Table 2-7 for both a pooled sample (419 vehicles), and the paired sample (20 vehicles). The pooled data includes all the vehicles measured in Kansas City that had valid second-by-second measurements. The statistical models confirm the observations made in Figure 2-9. The PM emissions in bag 2 were influenced by temperature even after removing the first 570 seconds (bag 2 >570 s) and first 1,025 seconds (bag 2 >1,025 s). The temperature effect is largest for the segment of emissions closest to the cold start (bag 1), and decreases as the engine warms up with time.

Table 2-7 Exponential Temperature Influence measured in the KCVES

	PM		BC		HC	
Model	pooled	paired	pooled	paired	pooled	paired
bag 1	-0.047	-0.051	-0.047	-0.050	-0.018	-0.020
bag 1 + bag 2 < 570 s	-0.039	-0.048	-0.045	-0.049	-0.017	-0.019
bag 1+bag 2	-0.029	-0.041	-0.036	-0.044	-0.014	-0.017
bag 2	-0.020	-0.035	-0.015	-0.033	-0.003 **	-0.006
bag 2 > 570 s	-0.017	-0.032	-0.012	-0.030	-0.001**	-0.004**
bag 2 >1,025 s	-0.008	-0.020	-0.004**	-0.022	-0.003**	-0.005*

*p-value > 0.05 ,** p-value >0.10

The re-analysis of Kansas City study suggested that much of the running temperature effect apparent in bag 2 is due to the short warm-up in bag 1 of the LA-92. However, it also suggested that a temperature effect on bag 2 emissions persists even after 1,025 seconds (17 minutes) of operation on the LA-92 cycle. One of the difficulties in reconciling the results from the cold temperature PM test programs is that both the driving cycles and the vehicle technologies differ between test programs (i.e. driving cycle and vehicle technologies are confounding variables). This makes it difficult to determine if the differing temperature effects observed for running conditions are due to technology differences, driving cycle, or both.

Based on the available data, in MOVES2014, we have retained the PM running temperature effect estimated from Kansas City for all 2004 and earlier model year vehicles. This step was taken for several reasons:

1. Kansas City was conducted in 2004/2005 and includes measurements from 1960's era vehicles to 2005 model year vehicles. The temperature effect estimated in MOVES is applicable to the vehicle technologies tested in Kansas City. Kansas City only tested a few 2005 vehicles, none of which were compliant with the Tier 2 standards.
2. A large portion of the PM running temperature estimated in Kansas City appears to be due to the short length of bag 1 in the LA-92 cycle. However, the temperature effect was found to still be significant at the end of bag 2. The trip length for light-duty gasoline vehicles used in MOVES ranges from 2 to 9 miles. This length is less than the combined length of bag 1 and bag 2 of the LA-92 (9.81 miles). Therefore, we believe that retaining the running temperature effect in MOVES will not lead to an overestimation of PM emissions during hot-stabilized running conditions.

For 2005 and later model year vehicles, the running temperature effect is removed. This step was taken for the following reasons:

1. The available data on Tier 2 light-duty gasoline vehicles did not show a temperature effect on bag 2 of the FTP cycle or the US06. Because the light-duty gasoline phase-in of Tier 2 standards began with model year 2005, we have removed the running temperature effect for 2005 and later model year vehicles.
2. MOVES PM start effects used to model the Tier 2 MSAT-2 vehicles provides a relatively good fit to the start emission data as shown in Figure 2-6. We appear to be capturing the

magnitude of PM emissions from the cold start and associated warm-up period from these vehicles with the cold start temperature effects alone.

2.3 Effects of Temperature on Diesel Fueled Vehicles

We were able to identify only 12 diesel-fueled vehicles with FTPs at multiple temperatures (nine passenger cars and 3 light-duty trucks). However, only two of those 12 vehicles were tested at temperatures within the normal FTP range (68º to 86º F). None of these diesel trucks were equipped with after-treatment devices. The Bag-1 minus Bag-3 emissions for those tests are shown in Table 2-8. We stratified the test results into four temperature bands which yielded the following emission values (grams per start) and average temperature value:

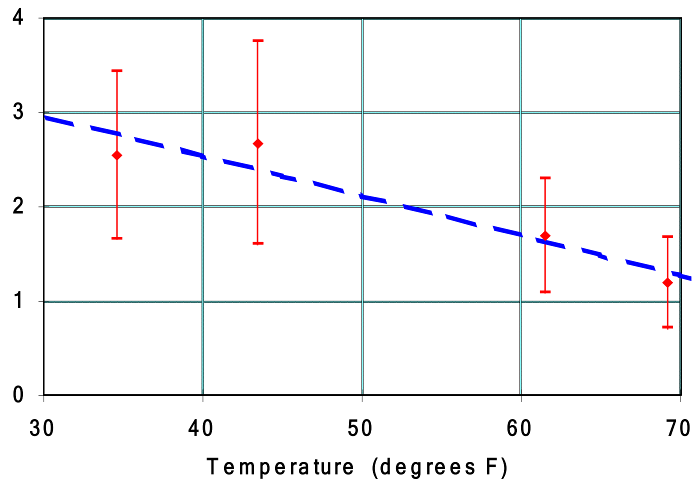
Table 2-8 Diesel Vehicle Emissions by Temperature

(grams per start)

Temperature	Count	HC	CO	NOx
34.6	6	2.55	2.44	2.6
43.4	7	2.68	2.03	0.32
61.5	10	1.69	3	0.67
69.2	2	1.2	1.91	0.36

When we plotted the mean HC start emissions (above) versus temperature, we obtained the following graph (where the vertical lines represent 90 percent confidence intervals and the "dashed" line represents a linear regression through the data).

Figure 2-10 Cold-Start HC Emissions (in grams) with Confidence Interval



The dashed (blue) line in Figure 2-10 is a linear regression line having as its equation:

HC = (-0.0420985982 * Temperature) + 4.22477812 R-sqr = 0.9040467

Transforming this equation into an equation that predicts the (additive) change/adjustment in the cold-start HC emissions from light-duty diesel-fueled vehicles (in the MOVES format), we obtain:

HC temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = -0.0420985982

The coefficient associated with this temperature adjustment term is statistically significant although its coefficient of variation is relatively large (23.04 percent).

Again, this HC adjustment factor represent the difference of Bag-1 minus Bag-3 and must be adjusted to estimate the cold-start HC emissions.

It proved more difficult to estimate a diesel light-duty vehicle temperature effect for CO and NOx. because the cold-start CO and NOx emissions did not exhibit a clear trend relative to the ambient temperature. Plotting the mean CO and NOx cold-start emissions versus ambient temperature (with 90 percent confidence intervals) produced the following two graphs:

Figure 2-11 Bag-1 minus Bag-3 CO Emissions (in grams) with Confidence Interval

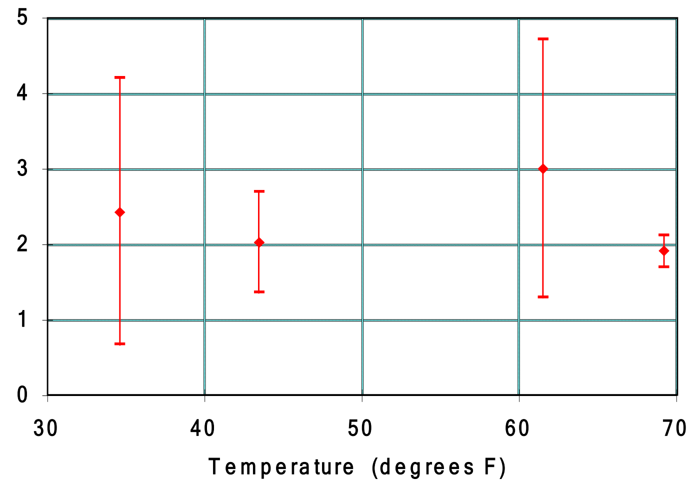
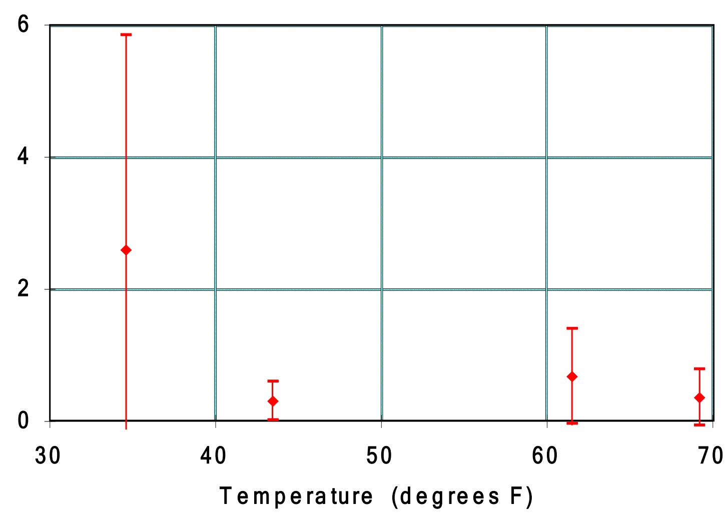


Figure 2-12 Bag-1 minus Bag-3 NOx Emissions (grams) with Confidence Intervals



Statistical analyses of both the diesel cold-start CO and NOx emissions failed to produce coefficients that were significantly different from zero. Therefore, for both cold-start CO and NOx adjustments from light-duty diesel-fueled vehicles, we propose to set the temperature adjustment for start emissions to zero:

CO temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = 0.0
NOx temperatureAdjustment = tempAdjustTermA * (Temp. – 75)
where: tempAdjustTermA = 0.0

Since gasoline adjustments were set to zero, the temperature effects for diesel running exhaust were also set to zero.

Because temperature effects data was not available for heavy duty trucks, the light duty results were extrapolated to these vehicles including the extended idling emission process for heavy duty long haul diesel trucks. Because of a lack of data no attempt has been made to adjust the effects of temperature on emissions to account for the introduction of after-treatment devices (such as diesel particulate filters or oxidation catalysts) that will become more common on future diesel fueled vehicles.

MOVES2014 does not include any temperature effects for particulate matter emissions from diesel vehicles. Conventional diesel engines do not exhibit strong temperature dependencies, like catalyst-controlled light-duty gasoline emissions. Limited data exists on temperature effects for diesel engines controlled with diesel particulate filters (DPFs). Mathis et al. (2004)[11] evaluated particulate matter emissions from a conventional light-duty diesel vehicle, and a DPF-equipped light-duty diesel. As expected, Mathis et al. (2004)[11] did not observe a significant temperature impact on the emissions from the conventional diesel. The DPF-equipped diesel vehicle did exhibit a cold start effect, with the majority of the emissions occurring at the beginning of the test cycle. However, the start emissions from the DPF-equipped diesel engine were still two-orders of magnitude smaller than the conventional diesel vehicle emissions measured at -20C. The data are limited, but suggests that the temperature effect on DPF-equipped engines may exist, but if included, would have a minor impact on the PM inventories. For now, MOVES does not include PM temperature effects for any diesel technologies.

3 Compressed Natural Gas

No data were available on temperature impacts of compressed natural gas emissions. As such,the start and running emissions in MOVES2014 are insensitive to temperature.

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34 Humidity Adjustments

In EPA's previous emissions model, MOBILE6, only gasoline vehicle exhaust NOx emissions were adjusted for humidity. MOVES adjusts both gasoline and diesel vehicle exhaust NOx emissions. The base exhaust emission rates for NOx in all modes and all processes are multiplied by a humidity adjustment. This factor is calculated using the following formula:

K = 1.0 – ((Bounded Specific Humidity – 75.0) * Humidity Correction Coefficient)

The bounded specific humidity is in units of grains of water per pound of dry air. The specific humidity is not allowed to be lower than 21 grains and is not allowed to be larger than 124 grains. If the specific humidity input exceeds these limits, the value of the limit is used to calculate the humidity adjustment. Appendix C shows how the hourly relative humidity values are converted to specific humidity used in this equation using temperature and barometric pressure.

Table 3-9 Humidity Correction Coefficients Used by MOVES

Fuel Type	Humidity Correction Coefficient
Gasoline	0.0038
Diesel Fuel	0.0026

The diesel humidity correction coefficient is taken directly from the Code of Federal Regulations[12]**[]**. The gasoline humidity correction coefficient is carried over from the coefficient used in the MOBILE6 model.

45 Air Conditioning Adjustments

The air conditioning adjustments in MOVES are based on the same data as was used in the previous MOBILE6 model, but the adjustments themselves were recalculated to be consistent with the MOVES methodology.

The proposed factors are based on a test procedure meant to simulate air conditioning emission response under extreme "real world" ambient conditions. These factors predict emissions which would occur during full loading of the air conditioning system, and will then be scaled down in MOVES according to ambient conditions in a modeling run. The second-by-second emission data were analyzed using the MOVES methodology of binning the data according to vehicle characteristics (source bins in MOVES) and vehicle specific power bins (operating modes in MOVES). The results of the analysis showed statistically significant and consistent results for three bin combinations (deceleration, idle and cruise/acceleration) and the three primary exhaust pollutants (hydrocarbon, carbon monoxide and nitrous oxides). This report shows the results of the analysis for the air conditioning adjustments used in MOVES for HC, CO, NOx and energy consumption.

MOVES will make adjustments to total energy consumption and exhaust running HC, CO and NOx emissions separately for each operating mode. The criteria pollutants (HC, CO and NOx) are only affected for passenger car, passenger truck and commercial light truck source types. Energy consumption is affected for all source types. The same adjustment values are used for all source use types affected within a pollutant type.

4.15.1 Air Conditioning Effects Data

The data for the MOVES A/C Correction Factor (ACCF) was collected in calendar year 1997 and 1998 in specially designed test programs. In the programs the same set of vehicles were tested at standard FTP test conditions (baseline) and at a nominal temperature of 95 F. Use of the same set of vehicles and test cycles should eliminate most of the vehicle and test procedure variability and highlight the difference between a vehicle operating at extreme ambient conditions and at a baseline condition.

The data used to develop the MOVES ACCF consisted of 54 individual cars and light trucks tested over a variety of test schedules. Overall the database consisted of a total of 625 test cycles, and 1,440,571 seconds of emission test and speed / acceleration data. Because of the need to compute vehicle specific power on a modal basis, only test results which consisted of second by second data were used in the analysis. All second by second data were time aligned and quality controlled checked.

The distribution of test vehicles by model year is shown in Table 4-1. Model years 1990 through 1999 were included. The data set consists of 30 cars and 24 light trucks. No test data were available on other vehicle types (i.e., motorcycles, heavy trucks, etc). The individual test cycles which the vehicles were run on are shown with the test counts in Table 4-2. The data shows a nice balance between different test cycles, and cars and trucks. Unfortunately, the study does not contain any pre-1990 model years. A complete list of the individual vehicles and a basic description is shown in Appendix C.

Only vehicles which were coded as having an emission test with the A/C system on were selected. The A/C On tests and the A/C Off (default for most EPA emission tests in general) were matched by VIN, test schedule and EPA work assignment. The matching ensured that the same vehicles and test schedules were contained in both the A/C On sample and the A/C Off sample.

Table 4-10 Distribution of Test Vehicles by Model Year

Model Year	Count
1990	5
1991	5
1992	6
1993	5
1994	7
1995	5
1996	13
1997	4
1998	3
1999	1
TOTAL	54

Table 4-11 Distribution of Tests by Test Cycle

Schedule Name	Count
ART-AB	36
ART-CD	36
ART-EF	36
F505	21
FTP	21

FWY-AC	57
FWY-D	36
FWY-E	36
FWY-F	36
FWY-G	36
FWY-HI	36
LA4	23
LA92	35
LOCAL	36
NONFRW	36
NYCC	36
RAMP	36
ST01	36
TOTAL	625

~~4.2~~5.2 *Mapping Data to VSP Bins*

The overall dataset consisted of a sample of vehicle tests with the A/C system on and a sample of vehicle tests with the A/C system off. Both samples consisted on the same vehicles and all tests were modal with a data sampling of 1 hertz (second-by-second data collection). Prior to analysis the data for each vehicle / test cycle combination was time aligned to insure that the instantaneous vehicle operating mode was in-sync with the emission collection system. Following time alignment, the vehicle specific power (VSP) was calculated for each vehicle test / second combination. This was done using Equation 1.

VSP = 985.5357 * Speed * Acoeff / Weight +
440.5729 * Speed^2 * Bcoeff / Weight +
196.9533 * Speed^3 * Ccoeff / Weight +
0.19984476 * Speed * Accel + GradeTerm   Eq 1

Where

VSP is the vehicle specific power for a given second of operation in units of KW / tonne.
Speed is the instantaneous vehicle speed for a given second in units miles / hour.
Accel is the instantaneous vehicle acceleration for a given second in unit of miles/hr-sec
Weight is the test vehicle weight in pounds.

Acoeff = 0.7457*(0.35/(50*0.447)) * ROAD_HP
Bcoeff = 0.7457*(0.10/(50*50*0.447*0.447)) * ROAD_HP
Ccoeff = 0.7457*(0.55/(50*50*50*0.447*0.447*0.447)) * ROAD_HP

Where

ROAD_HP = 4.360117215 + 0.002775927 * WEIGHT (for cars)
ROAD_HP = 5.978016174 + 0.003165941 * WEIGHT (for light trucks)

GradeTerm (KW/tonne) = 4.3809811 * Speed * Sin(Radians(GradeDeg))

Where

GradeDeg is the road grade in units of degrees. This term is zero for dynamometer tests.

4.3809811 (m^2 * hr / (s^3 * miles) =
9.80665(m/s^2) * 1609.34(m/mile) / 3600(secs/hr)

KW / tonne = m^2 / s^3

9.80665(m/s^2) is the gravitation constant.

After computing the VSP for each vehicle test / second combination, we assigned the individual seconds to the MOVES VSP bins. These VSP bins are defined in Table 4-3. VSP bins 26 and 36 were not defined because bins 27-30 and bins 37-40 overlap them.

Table 4-12 VSP Bin Definitions

VSP Label	Definition
0	Braking
1	Idling
11	Low Speed Coasting; VSP< 0; 1<=Speed<25
12	Cruise/Acceleration; 0<=VSP< 3; 1<= Speed<25
13	Cruise/Acceleration; 3<=VSP< 6; 1<=Speed<25
14	Cruise/Acceleration; 6<=VSP< 9; 1<=Speed<25
15	Cruise/Acceleration; 9<=VSP<12; 1<=Speed<25
16	Cruise/Acceleration; 12<=VSP; 1<=Speed<25
21	Moderate Speed Coasting; VSP< 0; 25<=Speed<50
22	Cruise/Acceleration; 0<=VSP< 3; 25<=Speed<50
23	Cruise/Acceleration; 3<=VSP< 6; 25<=Speed<50
24	Cruise/Acceleration; 6<=VSP< 9; 25<=Speed<50
25	Cruise/Acceleration; 9<=VSP<12; 25<=Speed<50
26	Cruise/Acceleration; 12<=VSP; 25<=Speed<50
27	Cruise/Acceleration; 12<=VSP<18; 25<=Speed<50
28	Cruise/Acceleration; 18<=VSP<24; 25<=Speed<50
29	Cruise/Acceleration; 24<=VSP<30; 25<=Speed<50
30	Cruise/Acceleration; 30<=VSP; 25<=Speed<50
33	Cruise/Acceleration; VSP< 6; 50<=Speed
35	Cruise/Acceleration; 6<=VSP<12; 50<=Speed
36	Cruise/Acceleration; 12 <= VSP; 50<=Speed
37	Cruise/Acceleration; 12<=VSP<18; 50<=Speed
38	Cruise/Acceleration; 18<=VSP<24; 50<=Speed
39	Cruise/Acceleration; 24<=VSP<30; 50<=Speed
40	Cruise/Acceleration; 30<=VSP; 50<=Speed

An average emission result for each pollutant (HC, CO and NOx) with and without A/C operation was computed for each VSP Bin. This resulted in 69 (23 VSP bins x 3 pollutants) pairs of emission averages. However, preliminary analysis of the data grouped into the 23 bins (defined in Table 4-3) showed unsatisfactory statistical results. In the general, no trends were evident across VSP bins or within similar subsets of VSP bins. The trends were highly erratic and the results were generally not statistically significant. In addition, most of the bins labeled 30 or higher had very few data members. An analysis of cars versus trucks was also performed, and showed no statistical difference between the two.

To produce more consistent results, the individual VSP bins were collapsed down to three principal bins. These are the Braking / Deceleration bin, the Idle bin and the Cruise / Acceleration bin. These large bins are quite different in terms of engine operation and emissions performance. The Braking bin consisted of VSP Bin 0 in Table 4-3, the Idle bin was VSP Bin 1 and the Cruise / Acceleration bin contained the remaining 21 bins.

~~4.3~~5.3 Air Conditioning Effects on Emissions

~~4.3.1~~5.3.1 A/C Adjustments for HC, CO and NOx Emissions

Full A/C adjustments were generated for each of the nine VSP Bin and pollutant combinations. This was done by dividing the mean "With A/C" emission factor by the mean "Without A/C" emission factor for each of the VSP Bin / pollutant combinations. The Full A/C adjustments are shown in Table 4-4. Measures of statistical uncertainty (coefficient of variation of the mean) were also computed using the standard error of the mean. They are shown in Table 4-4 as "Mean CV of CF."

Table 4-13 Full Air Conditioning Adjustments for HC, CO and NOx

Pollutant	Operating Mode	Full A/C CF	Mean CV of CF
HC	Braking / Decel	1.0000	0.48582
HC	Idle	1.0796	0.74105
HC	Cruise / Accel	1.2316	0.33376
CO	Braking / Decel	1.0000	0.31198
CO	Idle	1.1337	0.77090
CO	Cruise / Accel	2.1123	0.18849
NOx	Braking / Decel	1.0000	0.19366
NOx	Idle	6.2601	0.09108
NOx	Cruise / Accel	1.3808	0.10065

Note the higher emissions of NOx at idle. These results are consistent with those obtained from Nam et al. (2000)[13] who showed that at low load conditions, A/C greatly increased NOx emissions due to reduced residual gas fractions in-cylinder.

~~4.3.2~~5.3.2 Full A/C Adjustments for Energy Consumption

The use of a vehicle's A/C system will often have a sizeable impact on the vehicle's energy consumption. This was found statistically by analyzing the available second by second data on CO2 and other gaseous emissions, and converting them to an energy basis using standard EPA vehicle fuel economy certification equations. The vehicle emission data were binned by VSPBin (see above). A mean value was computed for each combination of VSPBin. Separate analysis was done as a function of sourcebinid (combination of vehicle type, fuel type and model year), and the results were not statistically different versus sourcebinid given the relatively small sample sizes. As a result, the A/C adjustments for energy are a function of only VSPBin. The resulting A/C adjustments are shown in Table 4-5.

Table 4-14 Full Air Conditioning Adjustments for Energy

VSPBin	A/C Factor	VSPBin	A/C Factor	VSPBin	A/C Factor
0	1.342	21	1.294	30	1.294
1	1.365	22	1.223	33	1.205
11	1.314	23	1.187	35	1.156
12	1.254	24	1.167	37	1.137
13	1.187	25	1.157	38	1.137

VSPBin	A/C Factor	VSPBin	A/C Factor	VSPBin	A/C Factor
14	1.166	26	1.127	39	1.137
15	1.154	27	1.127	40	1.137
16	1.128	28	1.127		
		29	1.127		

Only very small amounts of data were available for VSPBins 26 through 29 and VSPBins 37 through 40. As a result, the data from these bins was averaged together and binned into two groups. The resulting group averages were used to fill the individual VSPBins. This averaging process has the effect of leveling off the effect of A/C at higher power levels for an engine. This is an environmentally conservative assumption since it is likely that the engine power devoted to an A/C compressor probably continues to decline as the overall power demand of the engine is increased. In fact, in some newer vehicle designs the A/C unit will be shut off by an engine controller if the driver demands a very high level of power from the vehicle. If and when new or additional data become available on this issue, EPA will re-evaluate the assumption of a constant A/C factor for the high VSPBins.

~~4.3.3~~5.3.3 Uncertainty Analysis

Measures of statistical uncertainty as indicated by the coefficient of variation of the mean (mean CV) were calculated using the following formula. The same set of equations were used for each of the three pollutants (although the equations are shown only once). The values of X and Y represent second by second emissions from either HC, CO or NOx. The variable "X" represents emissions with the A/C On and "Y" represents emission with the A/C Off.

Given:

$Z = X / Y$

$\text{Mean CV} = SEz / Z$

Where Z is the ratio of A/C On emissions (X) to A/C Off emissions (Y)
SEz is the standard error of Z
Mean CV is the coefficient of variation of the mean

$Vz2 = (\delta Z/\delta X)2 * Vx2 + (\delta Z/\delta Y)2 * Vy2$

Where Vz is the variance of Z, Vx is the variance of X and Vy is the variance of Y
$\delta Z/\delta X$ is the partial derivative of Z with respect to X
$\delta Z/\delta Y$ is the partial derivative of Z with respect to Y

$(Vz / Z)2 = ((1/Y2)*Vx2) / (X2/Y2) + ((X2/Y4) * Vy2) / (X2/Y2)$

This equation reduces to:

$(Vz / Z)2 = (Vx / X)2 + (Vy / Y)2$

And ultimately to:

SEz / Z = SQRT [(SEz / X)2 + (SEz / Y)2]

The variance term is defined as:

Vz = (1/Y)2 * Sy2x + (-X/Y2) * (-X/Y2) * Sy2y;

Where

X = A/C On emissions
Y = A/C Off emissions

The term V_z represents a contribution from both the X and Y emissions terms (A/C On and A/C Off). The terms Sy2x and Sy2y also include variance contributions of the "across sample variance" and the "within a given vehicle test" variance. The "across sample variance" is the standard variance of the sample and is computed within a given sourcetype (vehicle type such as car, light truck, heavy truck, etc) and operating mode bin (one of the 23 VSP bin types – See Table 4-3). The "within a given vehicle test" variance is the additional variance due to the fact that each vehicle test contributes hundreds or even thousands of test data elements. Because two data elements may come from the same vehicle, they are not strictly independent of each other.

Sy2x = SA2x / nVeh + SB2x / nCell
Sy2y = SA2y / nVeh + SB2y / nCell

SA2x = (1 / (nVeh-1)) * Sum1x
SB2x = (1 / (nCell – nVeh)) * Sum2x

SA2y = (1 / (nVeh-1)) * Sum1y
SB2y = (1 / (nCell – nVeh)) * Sum2y

And

Sum1x = $\Sigma (YbarVeh_x – YbarCell_x)^2$
Sum2x = $\Sigma (varVeh_x – (nMeas – 1))^2$

Sum1y = $\Sigma (YbarVeh_y – YbarCell_y)^2$
Sum2y = $\Sigma (varVeh_y – (nMeas – 1))^2$

Where

The sums (Σ) are across sourcetype and operating mode.

nMeas Count of data elements within a given sourcetype, operating mode and vehicle test.
nVeh Count of data elements within a given vehicle test
nCell Count of data elements within a given sourcetype and operating mode
varVeh Variance for each vehicle test. Separate values for both X and Y are calculated.

YbarVeh Mean emission rate for each vehicle test. Separate values for both X and Y are calculated.
YbarCell Mean emission rate for each sourcetype and operating mode. Separate values for both X and Y are calculated.

For HC, CO and NOx, detailed VSP was not found to be an important variable in regards to A/C adjustment and A/C usage. However, Full A/C adjustments greater than one were found for all pollutants for both Idle and Cruise / Acceleration modes. For NOx Idle mode, a fairly large multiplicative adjustment of 6.2601 was obtained. This large factor reflects the relatively low levels of NOx emissions during idle operation. A moderately high multiplicative A/C adjustment of (2.1123) for CO cruise / Accel was also obtained. These adjustments will double CO emissions under extreme conditions of A/C usage. A/C adjustments of less than or equal to one were found for the Braking / Deceleration mode for all three pollutants. These were set to one for use in the MOVES model.

~~4.4~~5.4 Adjustments to Air Conditioning Effects

The adjustments for each operating mode are weighted together by the operating mode distribution calculated from the driving schedules used to represent the driving behavior of vehicles. Average speed, road type and vehicle type will affect the operating mode distribution.

weightedFullACAdjustment = SUM(fullACAdjustment*opModeFraction)

Since not all vehicles are equipped with air conditioning and air conditioning is normally not on all of the time, the full air conditioning effect on emissions is adjusted before it is applied to the emission rate. The SourceTypeModelYear table of the MOVES database contains the fraction of vehicles in each model year that are equipped with air conditioning[14].

Table 4-15 Fraction of Vehicles Equipped with Air Conditioning

(ACPenetration)

Model Year	Passenger Cars	All Trucks and Buses
1971*	0.592	0.287
1972	0.592	0.287
1973	0.726	0.287
1974	0.616	0.287
1975	0.631	0.287
1976	0.671	0.311
1977	0.720	0.351
1978	0.719	0.385
1979	0.694	0.366
1980	0.624	0.348
1981	0.667	0.390
1982	0.699	0.449
1983	0.737	0.464
1984	0.776	0.521
1985	0.796	0.532

Model Year	Passenger Cars	All Trucks and Buses
1986	0.800	0.544
1987	0.755	0.588
1988	0.793	0.640
1989	0.762	0.719
1990	0.862	0.764
1991	0.869	0.771
1992	0.882	0.811
1993	0.897	0.837
1994	0.922	0.848
1995	0.934	0.882
1996	0.9484	0.9056
1997	0.9628	0.9292
1998	0.9772	0.950
1999	0.980	0.950
2000**	0.980	0.950
* 1971 model year fractions are applied to all previous model years. ** 2000 model year fractions are applied to all later model years. Motorcycles are not adjusted for air conditioning.		

The fraction of vehicles whose air conditioning is operational varies by age of the vehicle and is stored in the SourceTypeAge table of the MOVES database.

Table 4-16 Fraction of Air Conditioning Units Still Functioning By Age

Age	Functioning	Age	Functioning	Age	Functionin g
1	1.00	11	0.98	21	0.95
2	1.00	12	0.98	22	0.95
3	1.00	13	0.96	23	0.95
4	0.99	14	0.96	24	0.95
5	0.99	15	0.96	25	0.95
6	0.99	16	0.96	26	0.95
7	0.99	17	0.96	27	0.95
8	0.98	18	0.95	28	0.95
9	0.98	19	0.95	29	0.95
10	0.98	20	0.95	30	0.95

An equation is used to predict the fraction of those vehicle owners who have air conditioning available to them that will turn on the air conditioning based on the ambient temperature and humidity (heat index[14]) of the air outside their vehicles. The heat index values are stored in the ZoneMonthHour table of the MOVES database.

ACOnFraction = ACActivityTermA
+ heatIndex*(ACActivityTermB + ACActivityTermC*heatIndex)

Table 4-17 Effect of Heat Index on Air Conditioning Activity

-3.63154	ACActivityTermA
0.072465	ACActivityTermB
-0.000276	ACActivityTermC
Heat Index	**AC On Fraction**
67.44	0.000
70	0.089
75	0.251
80	0.399
85	0.534
90	0.655
95	0.762
100	0.855
105	0.934
110	1.000

The fraction of vehicles equipped with air conditioning, the fraction of operational air conditioning and the fraction of air conditioning use are used to adjust the amount of "full" air conditioning that occurs in each hour of the day.

ACAdjustment = 1+ ((weightedFullACAdjustment-1)
* ACPenetration*functioningACFraction*ACOnFraction)

The air conditioning adjustment is a multiplicative adjustment applied to the emission rate after it has been adjusted for fuel effects.

Air conditioners are employed for defogging at all temperatures, particularly, at lower temperatures. This secondary use of the A/C along with associated emission effects is not addressed in MOVES2010.

~~5~~6 Inspection and Maintenance Programs

Inspection and Maintenance (I/M) programs are generically any state-run or locally mandated inspection of highway motor vehicles intended to identify those vehicles most in need of repair and requires repairs on those vehicles. Since these programs are locally run, there is great variability in how these programs are designed and the benefits that they generate in terms of emission reductions from highway motor vehicles.

~~5.1~~6.1 *Inspection & Maintenance in MOBILE6*

Because MOVES draws heavily on the approaches developed for MOBILE6.2 to represent the design features of specific I/M programs, it is useful to briefly review these methods. Readers interested in a more thorough treatment of the topic are encouraged to review the relevant MOBILE documentation[15].

The MOBILE6.2 model used a methodology that categorized vehicles according to emitter status (High emitters and Normal emitters), and applied a linear growth model to project the fraction of the fleet that progresses from the Normal emitter to the High emitter status as a function of age. Average emission rates of High and Normal emitters were weighted using the High emitter fraction to produce an overall average emission rate as a function of age, model year group and vehicle type. The emissions generated represented the emissions of the fleet in the absence of I/M (the No I/M emission rate).

A similar approach was used to generate I/M emission rates. In this case the initial starting point for the function (where age=0) was the same as the No I/M case. However, the effects of I/M programs and associated repairs were represented by reductions in the fraction of high emitters, which consequently affected the average emission level of the fleet. Balancing these emissions reductions due to I/M repairs were the re-introduction of high emitters in the fleet due to deterioration of vehicle emission control systems after repairs. The underlying I/M and non-I/M deterioration rates were assumed to be the same.

With the passage of time, the non-I/M and I/M emission cases diverged from each other with the I/M rates being lower. The percentage difference between these two rates is often referred to as the overall I/M reduction or I/M benefit.

~~5.2~~6.2 Inspection & Maintenance in MOVES

The MOVES emission rates contain estimates of emission levels as a function of age, model year group and vehicle type for areas where no I/M program exists (the mean base rate, or the non-I/M reference rates) and for an area representing the "reference I/M program" (the I/M reference rates). The I/M reference rates were derived using data from the enhanced I/M program in Phoenix, Arizona, and represent the design features of that program. The difference between the non-I/M and I/M reference rates are assumed to represent the I/M benefit of the Phoenix program design assuming perfect compliance. Equation 1 shows this relationship in a mathematical form.

Standard I/M difference = $E_{nonIM} - E_{IM}$ Eq 1

where $E_{non\text{-}IM}$ and E_{IM} are the non-I/M and I/M reference rates, respectively.

The Phoenix program design was selected as the reference program because virtually all of the underlying data for MOVES came from this source. The selection does not imply any judgment on the strengths or weaknesses of this specific program. In MOVES, it is this general I/M design which is the model, not the actual Arizona I/M program as it is operated.

The object of this process is to generate a general model which can be used to represent all I/M programs in the United States. This goal was achieved by comparing individual program designs against the reference program for purposes of developing adjustment to the "standard I/M difference" representing design features differing from those in the reference program This concept is shown mathematically in Equation 2,

$$E_{\mathrm{p}} = RE_{\mathrm{IM}} + (1-R)E_{\mathrm{nonIM}} \quad \text{Eq 2}$$

where E_p is the adjusted emission rate for a "target" I/M program, E_{IM} is the reference rate, E_{nonIM} is the non-I/M reference rate, and R is an aggregate adjustment representing the difference in average emission rates between the target program and the reference program. Depending on the value of R, E_p may be greater than E_{nonIM}, fall between E_{nonIM} and E_{IM}, or be less than E_{IM}. Thus this framework can represent target programs as more effective or less effective than the reference program. In MOVES, R is referred to as the "IMFactor."

Re-arranging Equation 2 and solving for R gives leads to Equation 3. This equation shows the I/M adjustment as the ratio of the emission difference between a proposed I/M program design and the Standard I/M Difference

$$R = \frac{E_p - E_{nonIM}}{E_{IM} - E_{nonIM}} \qquad \text{Eq 3}$$

~~5.3~~6.3 Development of MOVES I/M Factors

Early in the MOVES development process it was decided that developing the I/M adjustment factors based on a completely new analysis would prove infeasible. A major obstacle was a lack of suitable emissions and I/M program data representing the full range of program designs. Data sets for certain I/M programs (i.e., transient test based programs) were generally quite complete and robust. However, mass emission results and random vehicles samples were quite scarce for other test types such as the Acceleration Simulation Mode (ASM), steady-state, idle tests and OBD-II scans. This situation was particularly true for old model years at young ages (i.e., a 1985 model year at age five). As a result, EPA decided to develop I/M adjustment factors based on the information incorporated in MOBILE6.2. Mechanically, this step was achieved by running the MOBILE6.2 model about 10,000 times over a complete range of pollutant–process combinations, inspection frequencies, calendar years, vehicle types, test types, test standards, and model year group / age combinations. The mean emission results for each combination were extracted from the output and utilized. The IMFactor table includes the following fields:

- Pollutant / Process
- Test Frequency
- Test Type
- Test Standard
- Regulatory Class
- Fuel Type (Only gasoline/ethanol fuels have IMFactors)
- Model Year Group
- Age Group
- IMFactor

The IMFactor value was computed for each combination of the parameters listed in the IMFactor table. A separate MOBILE6.2 run was done for each parameter combination (Target design, E_p), and a second set of runs were done describing the reference program (Reference design, E_R). The IMFactor is the ratio of the mean emission results from these two runs. Equation 4 illustrates the simple formula.

$$R_p = \frac{E_p}{E_R} \qquad \text{Eq 4}$$

The Reference program has inputs matching the Phoenix I/M program during the time in which the data used in the MOVES emission rate development were collected (CY 1995-2005). The Reference design represents a biennial frequency with an exemption period for the four most recent model years.. It uses three different I/M test types (basic idle test for MY 1960-1980, transient tailpipe tests for MY 1981-1995 (IM240, IM147), and OBD-II scans for MY 1996 and late). Each of these test types became the Reference for the respective model year groups.

The specific combinations of MOBILE6.2 runs performed are shown in Table 5-1 below. Each of these runs represents a particular test type and test standard design which was expressed as a ratio to the standard reference tests. The first four runs represent the Non I/M reference and the three Phoenix I/M references. A set of these runs were done for each calendar year 1990 through 2030, for cars, light trucks and heavy-duty gasoline vehicles and for pollutants HC, CO and NOx.

Table 5-18 MOBILE6.2 Runs Used to Populate the MOVES I/M Adjustment Factor

RUN #	Description	Type
1	Non I/M Base	Non I/M Reference
2	IM240 Base (Biennial IM240/147)	I/M Reference
3	OBD Base (Biennial OBD Test)	I/M Reference
4	Basic Base (Loaded – Idle Test)	I/M Reference
5	Biennial - IM240 - Phase-in Cutpoints	Target I/M Design
6	Annual - IM240 - Phase-in Cutpoints	Target I/M Design
7	Biennial - IM240 - Final Cutpoints	Target I/M Design
8	Annual - IM240 - Final Cutpoints	Target I/M Design
9	Biennial - ASM 2525/5015 - Phase-in Cutpoints	Target I/M Design
10	Annual - ASM 2525/5015 - Phase-in Cutpoints	Target I/M Design
11	Biennial - ASM 2525/5015 - Final Cutpoints	Target I/M Design
12	Annual - ASM 2525/5015 - Final Cutpoints	Target I/M Design
13	Biennial - ASM 2525 - Phase-in Cutpoints	Target I/M Design
14	Annual - ASM 2525 - Phase-in Cutpoints	Target I/M Design
15	Biennial - ASM 2525 - Final Cutpoints	Target I/M Design
16	Annual - ASM 2525 - Final Cutpoints	Target I/M Design
17	Biennial - ASM 5015 - Phase-in Cutpoints	Target I/M Design
18	Annual - ASM 5015 - Phase-in Cutpoints	Target I/M Design
19	Biennial - ASM 5015 - Final Cutpoints	Target I/M Design
20	Annual - ASM 5015 - Final Cutpoints	Target I/M Design
21	Annual - OBD -	Target I/M Design
22	Annual - LOADED/IDLE	Target I/M Design
23	Biennial - IDLE	Target I/M Design
24	Annual - IDLE	Target I/M Design
25	Biennial - 2500/IDLE	Target I/M Design
26	Annual - 2500/IDLE	Target I/M Design

The MOBILE6.2 database output option was chosen for all runs. This step produced large sets of results which were further stratified by facility-cycle / start process and age. This output format necessitated additional processing of the facility rates into composite running and start factors (in MOVES the IMFactor is a function of running and start processes).

In addition to the IMFactor, MOVES adjusts rates for particular programs by applying an additional multiplicative "Compliance Factor" (IMCompliance). The IMFactor (*R*) represents the theoretical effectiveness of a specific I/M program design, relative to the reference design, as described above.

Values of the IMComplianceFactor (*C*) are specific to individual programs and represent its overall operational effectiveness and efficiency, aside from the effectiveness inherent in its design. Variables which impact the IMCompliance factor include waiver rates, compliance rates and overall operational efficiency. Default IMComplianceFactors are provided in the MOVES database, but alternate values may be entered by the user for specific analyses. The default factors were taken from the 2005 EPA National Emission Inventory (NEI)[16], and are based on data submitted by individual states in their State Implementation Plan (SIP) processes. The vast majority of the default IMCompliance factors are greater than 90 percent.

~~5.4~~6.4 Development of MOVES I/M Compliance Inputs

The default I/M Compliance inputs are contained in the IMCoverage table in the MOVES database. The structure of the table is:

- Pollutant / Process
- State / County
- Year
- Source Use Type
- Fuel Type (only gasoline fuels)
- Beginning Model Year of Coverage
- Ending Model Year of Coverage
- InspectFreq
- IMProgramID
- I/M Test Type
- I/M Test Standards
- Ignore I/M toggle (user control variable)
- Compliance Factor

The IMCoverage table structure shows that the IM Compliance Factor is a function of numerous variables that include geography, time, vehicle type / fuel / coverage factors, program test frequency and specific I/M test / I/M test standards types.

For state SIPs, it is expected that the state will enter their own set of Compliance Factors which reflect current and expected future program operation. The data in the default MOVES table is likely out of date (i.e., 2005 NEI), and has not been cross referenced or updated with recent state I/M program designs / changes.

The underlying data used to construct the default Compliance Factors were taken from MOBILE6.2 input files used in the NMIM model to compute the National Emission Inventory of 2005. The data files listed in Table 5-2 were extracted and processed into the various fields in IMCoverage table.

Table 5-19 I/M Coverage Table Data Sources

NMIM Data Source	MOVES I/M Coverage Parameter
MOBILE6 Compliance Rate	Used in the MOVES Compliance Rate Calculation
I/M Cutpoints	Used to determine MOVES I/M Test Standards
MOBILE6 Effectiveness Rate	Used in the MOVES Compliance Rate Calculation
Grace Period	Used in MOVES to Determine Beginning Model Year of Coverage
Model Year Range	Used in MOVES to Determine Ending Model Year of Coverage
Test Type	Used to determine MOVES I/M Test Type
Vehicle Type	Used to determine MOVES Regulatory Class input
MOBILE6 Waiver Rate	Used in the MOVES Compliance Rate Calculation

As seen in Table 5-2, MOBILE6.2 and MOVES do not have exactly compatible parameter definitions. Extraction and processing of the MOBILE6.2 inputs for all of the individual states was required. The MOBILE6 compliance rate, waiver rate and Effectiveness rate were used to determine the MOVES Compliance Rate. The new MOVES Compliance Rate is a broader concept that incorporates three separate MOBILE6.2 inputs. Equation 5 shows the relationship.

$$C = \text{M6 Compliance Rate} \times \text{M6 Effectiveness Rate} \times (1 - \text{M6 Waiver Rate}) \qquad \text{Eq 5}$$

MOVES does not have separate inputs for the effect of waivers on I/M benefits. Section 3.10.6.2 of the document, “Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity” describes how to calculate the MOVES compliance rate to include the effect of waivers.

In MOVES, it is assumed that any repairs attempted on vehicles receiving waivers are not effective and do not result in any reduced emissions.

Other fields in the IMCoverage table complete the description of the I/M program in effect in each county. The MOBILE6.2 I/M Cutpoints data were used only to determine level of stringency of a state’s IM240 program (if any). The MOBILE6.2 Test Type inputs provided a description of the specific I/M tests performed by the state and test standards for the ASM and Basic I/M tests. The MOBILE6.2 inputs of Grace Period and Model Year Range were used to determine the MOVES Beginning and Ending model year data values for each I/M program. The MOBILE6.2 Vehicle type input was mapped to the MOVES regulatory class. The Ignore I/M toggle is a user feature that allows the user to completely disable the effects of I/M for one or more of the parameter combinations.

67 References

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~~7~~8 Appendix A – Mean Start Emission by Temperature

Table A-20 Change in Mean Start Emissions at Various Temperatures

By Model Year Group

Relative to 75° F

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
Pre-81	19.75	36.090	226.941	-0.274
Pre-81	20.67	33.018	254.386	-0.925
Pre-81	22.63	30.560	276.341	-1.445
Pre-81	47.55	18.569	129.472	-0.380
Pre-81	49.78	15.252	120.931	-0.034
Pre-81	52.52	18.099	115.776	0.101
Pre-81	60.14	11.120	53.617	1.790
Pre-81	77.31	0	0	0
Pre-81	95.36	-2.122	-58.656	1.640
Pre-81	98.06	-1.755	-67.555	1.975
Pre-81	105.06	-4.935	-86.689	3.769

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
81-82	19.36	21.120	231.180	-0.374
81-82	20.69	23.363	242.806	-0.252
81-82	22.33	25.496	253.865	-0.135
81-82	49.20	7.782	109.851	-0.066
81-82	50.31	8.202	120.239	0.065
81-82	51.43	9.209	132.360	0.194
81-82	59.15	6.432	135.063	-1.416
81-82	75.73	0	0	0
81-82	95.22	-4.659	-144.116	1.915
81-82	97.75	-5.450	-174.532	1.814
81-82	105.00	-9.958	-343.847	4.568

APPENDIX A Continued

Table A-21 Change in Mean Start Emissions at Various Temperatures

By Model Year Group

Relative to 75° F

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
83-85	19.32	23.299	218.857	0.665
83-85	21.00	17.755	218.151	-0.017
83-85	22.48	14.599	216.439	-0.414
83-85	28.80	20.594	186.549	-0.126
83-85	48.99	5.213	94.414	0.513
83-85	50.33	5.946	93.032	0.250
83-85	51.30	6.490	95.495	0.183
83-85	76.20	0	0	0
83-85	95.81	-1.044	-29.275	0.903
83-85	97.19	-1.209	-35.995	0.868
83-85	105.79	-1.124	-25.407	-1.010

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
86-89	-20	27.252	178.536	-2.558
86-89	0	25.087	147.714	-1.360
86-89	20	14.011	104.604	-0.749
86-89	40	8.316	78.525	0.312
86-89	75	0	0	0
86-89	95.03	-0.127	-4.257	-0.137
86-89	96.43	-0.139	-5.354	-0.091
86-89	106.29	-0.729	-1.017	-0.084

Model Yr Group	Temp	HC (grams)	CO (grams)	NOx (grams)
1990-2005	-20	38.164	143.260	1.201
1990-2005	0	16.540	92.926	1.227
1990-2005	20	8.154	56.641	1.082
1990-2005	40	4.872	33.913	0.876
1990-2005	75	0	0	0

Appendix B – OTAQ Light-duty gasoline 2012 Cold Temperature Program

Vehicle Name	Model Year	Injection	Emissions Std	MSAT?	Odometer	Displ (L)	Cyl.
Buick Lucerne	2010	PFI	Tier 2/Bin 4	MSAT	22000	3.9	V-6
Honda Accord	2010	PFI	Tier 2/Bin 5	MSAT	24000	2.4	I-4
Hyundai Sante Fe	2010	PFI	Tier 2/Bin 5	MSAT	18000	2.4	I-4
Jeep Patriot	2010	PFI	Tier 2/Bin 5	MSAT	22000	2	I-4
Kia Forte EX	2010	PFI	Tier 2/Bin 5	MSAT	25000	2	I-4
Mazda 6	2010	PFI	Tier 2/Bin 5	MSAT	24000	2.5	I-4
Mitsubishi Gallant	2010	PFI	Tier 2/Bin 5	MSAT	38000	2.4	I-4
Cadillac STS	2010	GDI	Tier 2/Bin 5	MSAT	21000	3.6	V-6
VW Passat	2006	GDI	Tier 2/Bin 5	pre-MSAT	103000	2	I-4

Tested at 0°F

Appendix C – Calculation of Specific Humidity

Equations to convert relative humidity in percent to specific humidity (or humidity ratio) in units of grains of water per pound of dry air (ref. CFR section 86.344-79, humidity calculations).

Inputs:

T_F is the temperature in degrees F.

P_b is the barometric pressure.

H_{rel} is the relative humidity

$$T_K = \left(5/9\right)\left[T_F - 32\right] + 273$$

$$T_0 = 647.27 - T_K$$

$$H_{ratio\ or\ specific\ humidity} = 4347.8 * P_V / (P_b - P_V)$$

$$P_V = \left(H_{rel}/100\right) P_{db}$$

$$P_{db} = 29.92 * 218.167 * 10^{\left(-T_0/T_K\right)\left[\frac{\left(3.2437 + 0.00588 T_0 + 0.0000000117 T_0^{\,3}\right)}{1 + 0.00219 T_0}\right]}$$

$$= 6527.557 * 10^{\left(-T_0/T_K\right)\left[\frac{\left(3.2437 + 0.00588 T_0 + 0.0000000117 T_0^{\,3}\right)}{1 + 0.00219 T_0}\right]}$$

89 Appendix D– Air Conditioning Analysis Vehicle Sample

Table C-22 Vehicle Sample for the Air Conditioning Analysis

Model Year	Make	Model	Vehicle Class	Weight
1990	DODGE	DYNA	CAR	3625
1990	NISSAN	MAXI 0	CAR	3375
1991	CHEVROLET	CAVA 0	CAR	2750
1991	FORD	ESCO GT	CAR	2625
1992	CHEVROLET	CAVA	CAR	3000
1992	CHEVROLET	LUMI	CAR	3375
1992	MAZDA	PROT	CAR	2750
1992	SATURN	SL	CAR	2625
1992	TOYOTA	CORO	CAR	2500
1993	CHEVROLET	CORS	CAR	3000
1993	EAGLE	SUMM 0	CAR	2500
1993	HONDA	ACCO 0	CAR	3250
1993	TOYOTA	CAMR 0	CAR	3250
1994	CHRYSLER	LHS	CAR	3750
1994	FORD	ESCO	CAR	2875
1994	HYUNDAI	ELAN	CAR	3000
1994	SATURN	SL	CAR	2750
1995	BUICK	CENT	CAR	3995
1995	BUICK	REGA LIMI	CAR	3658
1995	FORD	ESCO	CAR	2849
1995	SATURN	SL	CAR	2610
1995	SATURN	SL	CAR	2581
1996	CHEVROLET	LUMI 0	CAR	3625
1996	HONDA	ACCO	CAR	3500
1996	HONDA	CIVI	CAR	2750
1996	PONTIAC	GRAN PRIX	CAR	3625
1996	TOYOTA	CAMR	CAR	3625
1997	FORD	TAUR	CAR	3650
1998	MERCURY	GRAN MARQ	CAR	4250
1998	TOYOTA	CAMR LE	CAR	3628
1990	JEEP	CHER	LDT1	3750
1990	PLYMOUTH	VOYA	LDT1	3375
1991	CHEVROLET	ASTR 0	LDT1	4250
1991	PLYMOUTH	VOYA	LDT1	3750
1992	CHEVROLET	LUMI	LDT1	3875
1993	CHEVROLET	S10	LDT1	2875
1994	CHEVROLET	ASTR	LDT1	4750
1994	PONTIAC	TRAN	LDT1	4250

Model Year	Make	Model	Vehicle Class	Weight
1996	FORD	EXPL	LDT1	4500
1996	FORD	RANG	LDT1	3750
1990	CHEVROLET	SURB	LDT2	5250
1991	FORD	E150 0	LDT2	4000
1994	FORD	F150	LDT2	4500
1996	FORD	F150	LDT2	4500
1996	DODGE	DAKO PICK	TRUCK	4339
1996	DODGE	D250 RAM	TRUCK	4715
1996	DODGE	GRAN CARA	TRUCK	4199
1996	DODGE	CARA	TRUCK	4102
1996	FORD	F150 PICK	TRUCK	4473
1997	DODGE	GRAN CARA	TRUCK	4318
1997	DODGE	DAKOT	TRUCK	4382
1997	PONTIAC	TRANSSPOR	TRUCK	4175
1998	DODGE	CARA GRAN	TRUCK	4303
1999	FORD	WIND	TRUCK	4500

~~9~~10 Appendix E – Toros Topaloglu, Comments

Peer Review of US EPA's

"Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection & Maintenance Adjustments"

September 29, 2009

As part of the MOVES2010 Peer Review process, EPA solicited comments from Toros Topaloglu, Ph.D., P.Eng. on the August 2009 draft of report Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection & Maintenance Adjustments.

Dr. Topaloglu is an Environmental Systems Specialist at the Ministry of Transportation Ontario, Canada.

Dr. Topaloglu's comments are copied below, with EPA response in italics.

1. Introduction

The development of MOVES and its predecessor, MOBILE, represent enormous achievements: estimating past, present and future emissions of an infinitely diverse and variable vehicle/driver population under highly variable and ever changing conditions. The US EPA deserves our sincere gratitude for this unparalleled effort, which continues to deliver ever more powerful and user-friendly emission simulators.

It has not been easy to think of a few meaningful comments on the above captioned report that describes various adjustments employed in MOVES. I have limited myself to "constructive criticism", assuming that this is what you expect from me and that this will be viewed in a positive vein coming from someone who has a direct and genuine interest in making MOVES as useful as possible. Where I am silent, I fully concur with the adopted approach and its presentation. This happens to be the case for over 99% of the report.

In this review, I relied primarily on my personal experience and knowledge but consulted also the relevant MOBILE6 documentation and a few specific publications listed under Section 5 (references).

2. General Comments

2.1. I agree with the empirical/statistical approach adopted in the derivation of the adjustments - given the imprecise nature of cars and the near infinite variability in their population. Some scientist and engineers may feel more comfortable with relations that have a theoretical basis; however, even with the "best" data `the multitude of mechanisms involved in each adjustment make a mechanistic approach very difficult to implement.

2.2. Adjustments for greenhouse gas emission factors may not have been uniformly addressed. The vehicle emissions certification process does not automatically yield adjustments for CO_2, CH_4 and N_2O emissions. Given the urgency to address Climate Change, MOVES will be called upon frequently to derive more accurate GHG emission factors.

2.3. Adjustments for individual air toxic emission factors may not have been fully addressed. It is conceivable that adjustments for NMHC may not apply equally to each and every air toxic, since they are not formed by identical physical and chemical mechanisms.

2.4. It is not clear that the US EPA adjustments deal fully with up-and-coming technologies such as hybrid, plug-in hybrid and battery-powered electric vehicles. Emissions of these vehicles, where they exist, are less sensitive to variations in ambient conditions, air-conditioning (A/C), and inspection and maintenance (I/M). In fact, they are generally exempt from I/M. The number of electric hybrids in the US fleet exceeds one million already and is expanding rapidly. Hence, it will become progressively more important to account for their characteristics.

2.5. In future updates of MOVES, it may be worthwhile to try and correlate adjustments with major vehicle technologies and fuel types – beyond what is in place. This may improve the ability of the model to simulate future emissions. Vehicle manufacturers often have this information and might share it with the US EPA.

2.6. The accuracy of the adjustments depends, in part, on the representativeness of the test vehicle sample. It is obvious that the US EPA has spent enormous effort to achieve a high degree of representativeness. However, limitations with the test data and, to a lesser extent, unexpected but deliberate efforts to alter the vehicle population such as the recent "cash for clunkers" program of the US government may have somewhat thwarted this effort. Given these factors, it is rather difficult for a regular MOVES user to judge the adequacy of the proposed adjustments.

3. Specific Comments

3.1 Ambient Temperature

3.1.1. I concur with the observation that the principal influence of ambient temperature (T_{amb}) on emissions is during the warm-up phase of cold-starts. Its influence on warmed-up vehicle running emissions is relatively small – albeit not nil, particularly, under extremely cold conditions when steady-state temperatures of vehicle components (lubricants, tires, etc.) may stay below their "normal" values.

3.1.2. It is not certain that the difference in emissions between Bags 1 and 3 of the FTP cycle can fully account for cold-start emissions under extremely cold conditions (below 32°F) when it takes extended periods of time to reach stead-state. Hence, adjustments based on these data will probably result in underestimates.

EPA has seen increased emphasis by manufacturers on decreasing the amount of time it takes to light off the catalytic convertor in order to address tighter emission standards, and since the 1990's vehicles have had to meet emission standards even at low temperatures. Once the catalytic convertor is fully operational, any small effects from the ambient temperature on emission formation in the engine are easily lost in the catalyst.

EPA believes that any temperature effects not captured in the first bag (505 seconds) of the FTP are negligible and existing data bears that out.

3.1.3. The decision to neglect adjustment for ambient temperatures above 75°F is a reasonable but not a perfect one. Reference (1) provides some evidence for less fuel consumption and CO_2 emissions at higher ambient temperatures – perhaps due to less throttling (higher volumetric efficiency). Other emissions are probably also affected, but the test data do not seem to allow for these smaller effects - as noted on page 7 of the report, in the discussion of the T_{amb} adjustment for NO_x emissions.

3.1.4. Part of the difficulty with adjusting for T_{amb} in the general fleet may be due to the many vehicle parking options: outdoors, unheated indoors, heated indoors or with a plugged-in block heater. If a vehicle is parked outdoors, the wind chill factor might also influence cold-start emissions. The test data do not seem to account for all of these factors.

The temperature adjustments in MOVES are intended to represent the effects on vehicle emissions when the ambient temperature to which the vehicle is subjected is known. There may be factors that cause difficulty in determining the appropriate temperature to apply to the fleet, such as the variation of ambient temperature over the area you wish to model. However, these are issues for guidance on how best to use the model for specific scenarios.

3.2. <u>Humidity</u>

3.2.1. One would expect a weak dependence of carbon dioxide emissions on ambient humidity, as reported for NO_x. The EPA certification humidity adjustments should, however, account for this effect.

3.2.2. I expect that the EPA certification humidity adjustments are sufficient for inventory work.

3.3. <u>Air Conditioning</u>

3.3.1. The US EPA report indicates that all emission tests with the A/C on were carried out at 95°F only. This implies that the A/C adjustments are not based on emission data obtained at the same temperature, with A/C on and A/C off. If so, according to Reference 1, a significant "error" may have been incurred by not accounting for the co-existing effect of T_{amb} on some emissions such as those of CO_2.

On the contrary, because the MOVES model does not apply temperature adjustments to running emissions (except for particulate matter), the comparison of A/C on emissions at high temperature and A/C off emissions at low temperature allows the A/C correction to incorporate any necessary temperature effect. However, as discussed in Section 2.3.2. our data suggests such effects are not significant.

3.3.2. A/Cs are employed for defogging at all temperatures – particularly, at lower temperatures. This secondary use of the A/C along with associated emission effects do not seem to have been accounted for (according to Ref. 1, defogging costs a 1.5 – 7% in CO_2 emissions at 55°F - depending on driving cycle).

MOVES does not account for the A/C effects at low temperatures from the use of A/C for defogging. The text has been updated to describe this omission.

3.3.3. Many modern vehicles are equipped with climate control systems, which are usually set by drivers to maintain automatically a preset optimum compartment temperature. The A/C systems of these vehicles switch on when this temperature set-point is exceeded – irrespective of humidity (as is the case with house thermostats). The conditioned air is cold and dry (often reheated with engine coolant). Hence, in these modern vehicles the compressor usage may be largely independent of humidity. The compressor load and hence energy use and some emissions are however very dependent on ambient air humidity.

Modeling the behavior of modern A/C systems can be very tricky. As a first cut, MOVES simply addresses the need for A/C based on how comfortable humans will be based on the combination of temperature and humidity. This should adequately capture the need for A/C and the extra loads that result for inventory estimates. A better A/C load model may be developed as our understanding of these systems improves.

3.4. Inspection and Maintenance

3.4.1. The repeated application of MOBILE 6 to predict the relative emission consequences of various I/M program design features appears to involve certain assumptions; viz., all vehicles at a given age have the same odometer reading, are subject to the same deterioration rates, and, if repaired, experience the same emission improvements. It may be worthwhile to test the benefits of replacing these point assumptions with appropriate distributions or variables.

Even with the use of distributions, the average impact of I/M programs on fleet emissions would be the same. We believe the added complexity of using distributions would only add to the complexity of our already complex modeling and provide very limited insight into the benefits of I/M repairs.

3.4.2. Future failure rates will likely be smaller than current ones – largely due to incremental improvements in vehicle technology but also due to the observed shift to inherently low emission vehicles.

All modeling of future model years is fraught with uncertainty. EPA has taken the position that improvements in emission performance will only occur if there is an incentive to improve, such as new emission standards. As such, it is reasonable that the existing failure rate, which is already very small, will continue into the future unless there is some regulatory reason why manufacturers would take the time and money to develop solutions that would significantly reduce their failure rates. Even without reductions in failure rates, the benefits of I/M programs will decrease as the emission impact of failure grows smaller on vehicles with new (lower) emission standards.

3.4.3. MOBILE 6 apparently assumed that waived vehicle emission rates are invariably 20% lower than those of failed vehicle emissions (see Ref, 2). Is this assumption carried through in MOVES? If so, it may be worthwhile to re-examine it.

In MOVES, vehicles which receive waivers are assumed not to have been repaired at all. The text has been updated to include this information. Waived vehicles are typically a small fraction of the fleet and are difficult to study. Given the limited impact that these vehicles will have on total fleet emissions, determining a more precise impact from waiver vehicles will not be a high priority.

3.4.4. The National Research Council (Ref. 2) raised a number of additional I/M related concerns with MOBILE 6: (a) assumption that vehicles with and without I/M deteriorate at the same rate; (b) no explicit allowance for those vehicles that are repaired before or after inspection but rapidly revert to high-emitter status; and (c) no I/M credit for high emitters that are scrapped or shipped outside of the region. It would be helpful to explain how these concerns were addressed in MOVES.

The description of the I/M program effects in the report has been revised to more explicitly address the concerns of the National Research Council.

3.4.5. Another concern in the I/M community, namely the effectiveness of OBD systems and OBD based I/M programs, deserves also a fuller discussion.

4. Editorial Comments

EPA has made many changes to the text of the report to address the following editorial comments.

4.1. The term “adjustment”, as used in the title of the report, expresses the goal of the effort clearly and concisely. The terms “correction factor” and “adjustment factor”, as used in the body of the report, are less clear. First, a correction is not an adjustment. Second, the word “factor” implies a multiplication whereas most of the proposed adjustments are additive. I recommend that the report stick to the term “adjustment” throughout the report.

4.2. This is not a free-standing report. Its contents cannot be fully understood without referring to a series of other reports (at least, the documentation of MOBILE 6). It would have been preferable to have a free-standing report – not for the sake of peer reviewers but for younger MOVES users who haven’t witnessed the evolution of MOBILE.

4.3. A Table presenting the principal assumptions made and the resulting effectiveness estimates for major I/M program types would add to the value of the report.

4.4. I am assuming that the final report will include lists of acronyms (with explanations), tables, figures as well as equation numbers, etc. - all the usual pieces that make a report a bit more accessible.

4.5. Minor notes:

- Last sentence on page 8 refers to Section 4.1.3, which does not exist.
- Section 4.1 apologizes for lack of data with A/C on MC. Do you really mean motorcycles?

- Section 4.1, third paragraph, refers to Appendix A for a list of vehicles and their description. It should instead refer to Table 4-1. Also, I don't see any description of the vehicles.
- The title of Section 4.3.2 reads "Energy Emissions". It should probably read "Energy Consumption".
- On page 30, "OBD" is spelled "OBC".

5. Response to Specific Questions Posed in the US EPA Letter to Me

5.1 <u>The Clarity of the Presentation</u>

- The report is well written and very clear to individuals with a technical background in the subject area. It may however require some editing to make it more easily accessible to a wider audience – if this were necessary.

5.2 <u>The Integration of Information from Multiple Areas</u>

- The report is based on an enormous volume of previous work and the resulting information. Given the difficulty of condensing this vast volume of information into a relatively compact report, the author(s) have done very well. The information is well integrated. However, as noted in my general comments (Section 1 above), the report is not a stand-alone document. It cannot be fully understood without reading its references.

5.3 <u>The Appropriateness and Completeness of the Literature Discussed</u>

- The literature referenced in the report is highly appropriate and sufficiently complete.

5.4 <u>Appropriateness of the Resulting Adjustments</u>

- In spite of the inherent complexity of the subject and the limitations of the available data, the author(s) have succeeded in:
    - Identifying those effects that call for adjustments
    - Eliminating those effects (variables) that are too insignificant to adjust for
    - Deriving robust adjustments that reflect the totality of the empirical evidence available and also conform to theory
- In my opinion, the adjustments are highly appropriate. The few comments provided in this review are intended to contribute to any future effort to update MOVES and make it as useful as possible to all potential users.

6. References

(1) Weilenmann, M.F.; Vasic A-M; Stettler P.; and Novak, P. Influence of Mobile Air-Conditioning on Vehicle Emissions and Fuel Consumption: A Model Approach for Modern Gasoline Cars Used in Europe. Environ. Sci. Technol. 2005, 39, 9601-9610.

(2) National Research Council. Evaluating Vehicle Emissions Inspection and Maintenance Programs. The National Academies Press, Washington, DC. 2001.

(3) Eisinger D.S. and Wathern, P. Policy Evolution and Clean Air: The Case of US Motor Vehicle Inspection and Maintenance. Transportation Research Part D. 2008, 13, 359-368.

Toros Topaloglu, Ph.D., P.Eng.

Thank you.

~~10~~11 Appendix F – ENVIRON International Corporation, Comments

ENVIRON Review of EPA Draft Report:

"MOVES Temperature, Humidity, Air Conditioner, and Inspection and Maintenance Adjustments"

As part of the MOVES2010 Peer Review process, EPA solicited comments from Christian E. Lindhjem of ENVIRON International Corporation on the August 2009 draft of report Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection & Maintenance Adjustments.

Chris Lindhjem has a PhD. in Chemical Engineering from Rensselaer Polytechnic Institute and has more than 15 years of experience in automotive issues with particular focus on emissions from highway and non-road vehicles, engines, and engine fuels.

Dr. Lindhjem's comments are copied below, with EPA response in italics.

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30 September 2009

Introduction

This report appears to gather all of the adjustments to the MOVES basic emission rates into one document despite the seeming unrelated topics discussed. Temperature and humidity are ambient conditions that affect the engine and after-treatment control effectiveness. Air condition loads are influenced by ambient conditions, but in fact are only one of many potential loads. New engine standards and inspection and maintenance programs are primarily emission reduction program credit assessments.

Yet despite the varied types of adjustments, it is reasonable to include all adjustments if indeed all adjustments to the model are included in this document. However, as new data or new approaches are required, updating the document could be more difficult or confusing to the reader because the document addresses so many issues. And if this document does not include all such adjustments, it might be confusing to understand all such adjustments split over many documents.

Gasoline Vehicle Temperature Adjustments

To the extent that temperature adjustments presented here differ from the official test procedures, EPA should make sure that the original data is free of temperature adjustments that the original researchers might have used on the reported data. Often researchers will follow the official test procedures to the letter and adjust the reported values to account for unique test conditions.

Overall the method for temperature adjustments seem sound with a few comments noted here that might help the explanation for the reader. EPA correctly separated the start and running temperature adjustments to account for the likely different effects when the engine and after-treatment are at operating temperature.

For gasoline vehicle start emissions, hydrocarbon and carbon monoxide effects are presented sufficiently to understand the results. The NOx results were considerably more complex, and there may be reasons for the observed start NOx emission with regard to technology by model year grouping. However, given that the effect is more predominant with older model years, the NOx effect may be less important for most uses of MOVES. For all cases, it would be helpful to put the adjustment estimates in perspective of the base emission rates to demonstrate the relative importance of the temperature adjustment effect, such as inclusion of a description of the percentage effect.

For gasoline vehicle running emissions, I agree with the assessment that ambient temperature has little effect on emissions. It might be helpful to note several same-vehicle tests at different ambient temperatures in Figure 2-2, such as by symbol and/or lines, to demonstrate that a temperature effect is not observed with the same equipment. Mixing vehicle tests and temperature conditions tests may mask an effect that could be observed in same vehicle tests.

Diesel Vehicle Temperature Adjustments

The diesel vehicle start emissions are presented, and I have no dispute with the results for start emissions determined. But this discussion could use some context in terms of vehicle types and applicability. For instance, based on the use of the FTP test cycles to determine the start emissions, I suspect that these 12 vehicles were pickup trucks, light heavy-duty vehicles, so EPA should discuss the relevance of using these vehicles to represent all diesel vehicles.

The text of this document describing the temperature adjustments to diesel start emissions has been updated to better address the types of vehicles in the samples used.

EPA makes no claim about particulate matter or running emissions temperature adjustments for diesel vehicles, so the report approach is inconsistent to that for gasoline vehicles. In addition, there was no discussion of whether these vehicles used after-treatment devices (either diesel particulate filters (DPF) or oxidation catalysts (OC) or future systems expected for 2010 model years and beyond) and how that might affect the results as was done to incorporate the cold weather CO and HC requirements for gasoline vehicle temperature adjustments.

Less is known about the effects of temperatures on diesel particulate matter emissions. The text of this document describing the temperature adjustments to diesel particulate matter emissions has been updated to better address the technologies in the samples used.

Cold Weather CO and HC Requirements

The methodology to estimate the benefits credited to the light-duty cold weather regulations appears to be a reasonable approach as presented. However, it is questionable if the cold weather regulation adjustments should be applied to high emitters given that the control systems might not be functioning. To the extent that MOVES identifies high emitters, independent temperature adjustments should be applied to high emitters.

Since MOVES does not identify high emitting vehicles during calculations, independent temperature adjustments for high emitters cannot be applied.

Humidity

Without performing additional testing, it is reasonable to use the Federal Register humidity corrections. Because these adjustments would be multiplicative, they would be applicable to the lower emission rates of later model years.

Air Conditioning

The air conditioning adjustment approach appears to be counterintuitive to approach of MOVES defining power bins to reflect the engine loads. There may be some reasons for this approach given that idle and coasting\braking bins would not otherwise incorporate the auxiliary air conditioner loads. Another reason could be that air conditioner loads would oscillate between VSP bins when the compressor is engaged and disengaged unrelated to the driving demands.

The approach presented is easy to follow in concept, but there should be more description of the overall air conditioning effect for sample vehicle types. To help the reader understand how important the air conditioning adjustment is, EPA should plot of the effect with respect to the humidity index, noting the heat index below which there is no air conditioning adjustment. The "ActivityTerm" coefficients for the 'ACOnFraction' estimates should be presented in the document.

The text of this document describing the air conditioning adjustments has been updated to better display the effects of the activity adjustments versus the humidity index.

Inspection and Maintenance (I/M)

Using the I/M benefits from the MOBILE6 analysis is a reasonable approach without an extensive reanalysis of the benefits under the MOVES modeling framework. As with the assessment of new vehicle emission standards, the emission credits estimated for various programs may not be entirely based on a quantitative assessment of each program. Therefore, because the credits assigned have been well vetted under the MOBILE6 plan, it becomes a more accepted approach to use for MOVES as well.

Because the MOBILE6.2 benefits only include HC, CO, and NOx and the Figure 2-6 was given as evidence of a relationship between PM and HC emission, PM benefits for I/M programs should also be considered. It would stand to reason, even without direct evidence, that emission reductions of the primary pollutions evaluation would also lead to PM emission reductions when malfunctioning vehicles are repaired.

EPA does not yet have sufficient data to estimate PM emission reductions for I/M programs without further evidence that repairs that reduce HC, CO and NOx emissions will significantly affect PM emissions.

Errata

Numerous changes to the text have been made to address these minor edits.

Page 12 above Figure 2-4; “adjustments” has an extra “s”

Page 25 below Table ?4-5? (label missing), just above section 4.3.3, “If and when ...”

Page 27 above Section 4.4: “A/C correction factors of less than unity or unity were found for…”

Some Tables have headings and some table headings are missing and references for those tables in the text are not clear.

Section 5, Eq. 1, 2, 3 and variable description of nonIM emissions should read the same, such as “EnonIM” in all equations and descriptions.

Equation 6 or should it be Equation 5? label on last page is incomplete

~~11~~12 Appendix G – Julio Vassallo, Comments

Review of US EPA's

"Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection & Maintenance Adjustments"

September 25, 2009

Additional comments, not part of the formal MOVES2010 Peer Review process, were submitted by Julio E. Vassallo on the August 2009 draft of report Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection & Maintenance Adjustments.

Julio Vassallo is a Chemical Engineer and the Technical Manager of Area new vehicles Approval and Certification in the the Laboratory of Vehicle Gaseous Emission Control (LCEGV) of the Ministry of Environment and Sustainable Development (SAyDS) in Buenos Aires, Argentina.

Julio Vassallo's comments are copied below, with EPA response in italics.

Page 6: The behavior presented for vehicles without (or deactivated) catalyst (that might be included in the group pre 1981) is different with respect to the NOx emission, those with catalyst. The vehicle can be considered as two reactors in series, combustion reactor in homogeneous phase (cycle Otto engine) and oxidation-reduction catalytic reactor (catalytic converter). The generation of NOx in the engine is principally a function of temperature in the cylinder and the partial pressures of nitrogen and oxygen. Therefore when the engine is cold the issue (without catalyst) is the lowest and increases as the engine warms up (example in doc "Start Emission" vehicles without catalytic converters, emissions IM240 consecutive test series). In contrast to an engine with catalyst but also emissions start to increase with increasing temperature once you reached the temperature catalyst "light off" decreases again (example in doc "Cold Emission" vehicles with catalyst) Moreover, the emission of NOx is also heavily dependent on power (VSP)

Then, depending on which portion of the emission is correlated is provable that the temperature hasn't the same effect (function) for vehicles with catalyst and without catalyst.

I think that the start NOx emission (FTP NOx emission Bag3 minus Bag1) of the vehicles without catalyst are highest than those with catalyst and has different start temperature dependence.

With CO an HC start emission is different, because both reactors (engine and catalyst) the emission decreases with temperature (example in doc "Start Emission" vehicles with and without catalytic converters, emissions IM240 consecutive test series).

The behavior of catalyst and non-catalyst vehicles is handled in MOVES by having separate temperature adjustments by model year group.

Page 7: I think that is provably if you correlate taking account VSP and the vehicles with catalyst in other group that those without catalyst the R-square coefficient will be better.

In MOVES, since the temperature adjustments are grouped by model year, some model year groupings will include catalyst and some non-catalyst vehicles in the correlations. Unless MOVES is redesigned to accommodate separate technologies in addition to model years, a separate correlation for each technology is not possible.

Page 8: I agree that to reach working temperature (running) both the emission generated in the engine and removed by the catalyst that should not be so sensitive to the test temperature such as the start

While the supply air temperature should influence the reactions of improving combustion efficiency at higher temperatures of income, is provable that the high working temperatures of engine determine less sensibility for that purpose, on the other hand those vehicles with catalyst in the regime temperature will have to be less sensibly since over 90% of the pollutants are converted and that masks any engine inefficiency specially to low exhaust flow (low rpm / VSP).

Page 11: The analysis of diesel engine emissions are different from that of Otto cycle, in the case of CO are not as significant and therefore may be more affected by the measurement uncertainty when it comes to a small population, such as that of the reporter. For NOx, in this case normally pre 2007 alone technologies are oxidation catalysts (remove only CO and HC) therefore in this case has only effect the engine and NOx emissions should increase, ie emissions Bag 1 Bag minus 3 should be negative. For example the mean value obtained to 34.6 ° F will have to be negative -2.6? I haven’t studies with a diesel emission test series to different ambient temperature in the start, but you have studies for example that about humidity and temperature effects how I adjunct (in page 7 HUMIDITY AND TEMPERATURE CORRECTION FACTORS FOR NOx EMISSIONS FROM DIESEL ENGINES SwRI Project No. 03.30.10.06599).

Page 13: as you get this value? This increasing of cold start emission (value 0,5611592) will be in grams per mile?. My doubt is because I think that if you have a total increase of 2.086 g NMHC = 0,43 (M Bag1+MBag2) + 0,57 (MBag2 + MBag3); then the value in grams of the cold start (M NMHC Bag 1) should be higher than 0,5611592.

The effects of the MSAT rule on the cold temperature adjustment for HC emissions of engine starts will need to be revisited once vehicles compliant with these standards are available for testing. The current adjustment is based solely on the emission standard values.

~~12~~13 Appendix H – Coordinating Research Council Project E-68a Comments

December 3, 2009

Additional comments regarding the adjustments described in the report, "Draft MOVES2009 Highway Vehicle Temperature, Humidity, Air Conditioning, and Inspection & Maintenance Adjustments , that were not part of the formal MOVES2010 Peer Review process, were submitted as part of the Coordinating Research Council (CRC) Project E-68a.

Comments from the report that are relevant to the topics covered in the EPA report are copied below, with EPA response in italics. Readers are encouraged to obtain the entire CRC Project E-68a report in order to fully understand the comments in their full context.

Correction Factors (Fuels and Temperature)

Regarding temperature correction factors, EPA examined recent data and found that cold start HC, CO, and NOx emissions should be adjusted for temperature, but there is no ambient temperature effect on running exhaust emissions. EPA developed additive cold start increments for HC, CO, and NOx that increase with lower temperatures.

One concern with the temperature increments is that there is no analysis of how these may change as vehicles age, and the available data seemed to omit the CRC E-74b testing program, which was completed in May of 2009. EPA could utilize the Kansas City temperature data to determine whether the temperature relationships change with vehicle age. Also, the CRC E-74b testing program data could be used to further check the MOVES cold start correction factors.

EPA believes that studies, such as the Kansas City study and CRC E-74, which include vehicles of different ages, but do not follow the vehicle fleet over time, are inadequate to conclude that the effects of temperature vary by vehicle age. EPA in cooperation with others, is planning a study specifically designed to follow the vehicle fleet over time and should produce the type of information needed to determine the effects of vehicle age on temperature effects.

A second concern is that the method used to develop HC temperature increments for the MSAT rule (which requires lower HC standards at cold temperatures) assumes a compliance margin with respect to the HC standards at 75° F, but no compliance margin with respect to the HC standards at 20° F. As a result, the HC increments for vehicles meeting the MSAT requirements are over-estimated. The method should be revised to include a compliance margin at 20° F to be consistent with the margin currently being utilized at 75° F.

EPA believes that any compliance margin at 20 degrees Fahrenheit will likely differ significantly from the margin observed at 75 degrees. Further testing will be needed on vehicles compliant with the MSAT standards to determine the appropriate margin.

A third concern is that vehicles subject to the lower MSAT HC standards will very likely have much lower CO emissions as well. Once vehicles are certified to the MSAT cold HC standards, an analysis should be conducted of certification or other data to determine how much the CO increments change for these vehicles as well.

CO emission rates already assume the impact of explicit standards for CO emissions at low temperatures. EPA believes that strategies to reduce HC emissions at low temperatures will likely have minimal further impacts on CO emissions at low temperatures.

Particulate Matter Emissions for Gasoline Vehicles

Temperature correction factors were estimated from the matched vehicle pairs. Unlike HC, CO, and NOx emissions, where the temperature correction factors were only for cold start emissions, EPA found an increase in running PM emissions with decreasing ambient temperatures, albeit lower than for the cold start.

The first concern is that the combined MSAT and Kansas City data on matched pairs does not appear to support a cold temperature adjustment for running emissions. Results from other studies such as NFRAQS should be included in the analysis, with special regard to high PM emitters.

It is true that data from the matched pairs in the combined MSAT and Kansas City was inconclusive in determine the temperature effect on running emissions. However, using other analysis techniques, EPA was satisfied that a significant temperature effect could be determined.

A third concern is that in the draft model, vehicles meeting lower HC standards in response to the MSAT rule currently are not assumed to have lower PM emissions. Since HC and PM emissions seem to correlate well, we believe there will be lower PM emissions with a lower HC standard at cold temperature. In the section on correction factors, we recommend evaluating certification data or other data to examine the effect of cold HC standards on HC and CO emissions. This should be extended to PM as well if possible.

EPA has not been able to establish a clear correlation between HC emissions and PM measurements that would support assuming that PM emissions at low temperatures would be significantly affected by changes in the HC standard. EPA will be updating the emission estimates in future versions of MOVES as new data on vehicles certified to the new standards are tested.

Summary of Recommendations

EPA should utilize the Kansas City data to determine whether temperature correction factors change with vehicle age. Also, the CRC E-74b testing program data could be used to further check the MOVES cold start correction factors.

As stated above, we believe the Kansas City data is inadequate for this purpose, but we hope to collect appropriate data to do this analysis in the future..

The Tier 2 cold temperature response should be lower than for Tier 1 vehicles. In addition, the MSAT rules should reduce CO emissions as well as HC emissions.

The method used to develop HC temperature correction factors for the MSAT rule should be revised to include margin at 20° F to be consistent with the margin currently being utilized at 75° F.

We don’t believe these changes are justified based on currently available data. Now that MSAT vehicles are entering the fleet, we hope to gather in-use data on vehicles meeting these standards.

The combined MSAT and Kansas City data on matched pairs does not support a cold temperature adjustment for running emissions. Results from other studies such as NFRAQS should be included in the analysis, with special regard to high PM emitters.