A Methodology for Evaluating Mobile Source Air Toxic Emissions Among Transportation Project Alternatives

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ABSTRACT

With the final update to its on-road mobile source emission factor model, MOBILE6.2, the U.S. Environmental Protection Agency (EPA) added capabilities of predicting emission factors for a select number of mobile source air toxics (MSAT), commonly referred to as the six priority MSATs. These are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter, and formaldehyde. This presentation describes a methodology for computing and evaluating emissions of MSATs among a group of transportation project alternatives. The suggested scale of analysis is the affected transportation network, defined as those links where the annual average daily traffic is expected to change by ± 5% or more as a result of the project. This analysis scale is considered reasonably representative of the regional scale emission factors predicted by MOBILE6.2. To gauge how emissions could change over an affected transportation network, provided are calculation ranges of MSAT emission factors produced by the model due to changes in a variety of input parameters. These include calendar year, ambient temperature, fuel Reid vapor pressure, and vehicle speed. Finally, a technique is presented for assessing MSAT emissions from the affected transportation network considering their relative toxicities. The technique allows a way to gauge the importance of increases and decreases in individual MSAT species amid proposed transportation alternatives and/or mitigation measures.

INTRODUCTION

This paper provides the results of an analysis of air toxic emissions due to mobile sources for a hypothetical transportation project designed to mitigate traffic congestion. The example project involves the expansion of an existing urban freeway, plus upgraded arterial/collectors and freeway ramps to improve vehicular access. It is assumed that the freeway corridor extends 10 miles and that arterials cross the freeway every 2 miles with freeway/arterial access provided by freeway ramps. A No-Action Alternate was evaluated for the calendar year 2005 (present); the No-Action and two Build alternates were evaluated for calendar years 2010 (estimated time of completion) and 2030 (design year). The following notation/description is used in referring to the alternatives:

- 6-lane No-Action Alternate – no upgrades to the existing 6-lane freeway and 4-lane crossing arterials;
- 6- to 8-lane Build Alternate – upgrade the existing 6-lane freeway and 4-lane crossing arterials by adding 2 travel lanes; and

- 6- to 10-lane Build Alternate – upgrade the existing 6-lane freeway by adding 4 travel lanes and upgrade the 4-lane crossing arterials by adding 2 travel lanes.

The underlying purpose of this effort is to provide a practical example of how a mobile source air toxics analysis may be applied to a planned project. This exercise offers additional insight into the technical challenges involved, including the formulation of analysis techniques; the types and sources of data required to complete such an analysis; the assumptions that may need to be made; the data forecasting routines and issues involved; and the comparative results likely to be obtained.

ANALYSIS METHODOLOGY

Fundamentals

The basic procedure for conducting an emissions analysis or emissions inventory for on-road mobile sources is to calculate emission factors using the Environmental Protection Agency's (EPA) MOBILE model (EPA, 2003), then multiply by the vehicle-miles of travel (VMT) for each affected roadway link. The EPA's current version of the model, MOBILE6.2 (dated November 2003), is capable of predicting composite emission factors of the six priority mobile source air toxics (acetaldehyde, acrolein, benzene, butadiene, diesel particulate matter, and formaldehyde) in units of g/VMT. Most MOBILE6.2 emission factors are sensitive to changes in vehicle activity parameters so that the appropriate emission factors for a link are matched to the corresponding VMT/day. The sum product (g/VMT × VMT/day) for all affected links is obtained to provide emissions by pollutant on a ton per day or ton per year basis.

The mobile source emission factors predicted by the MOBILE6.2 model are applicable to a regional scale not an individual project corridor. Consequently, an emissions analysis for a project should include links beyond the project corridor and evaluated with respect to its effect on the transportation system. The affected transportation network can be defined as those links where the annual average daily (AADT) traffic is expected to change by more than ±5% as a result of a project.

Key Assumptions

The core assumption made in developing the traffic data for the emissions analysis is that the existing freeway and crossing arterials are operating at capacity (e.g., the volume-to-capacity ratio, V/C = 1) during the peak hour. Lanes are added to relieve the traffic congestion anticipated in future years. A growth rate of 1.5% per year in hourly traffic volumes on the freeway and crossing arterials was assumed for the No-Action Alternates based on Bureau of Transportation Statistics data (BTS, 2003) for the most recent 5-year record available (1998 through 2002). A higher growth rate (i.e., 1.75% per year) in hourly volumes was assumed for the upgraded projects to account for redirected trips from the surrounding area that may be diverted to a new, more efficient facility. The maximum hour-by-hour V-to-C ratios allowed on the facilities were 1.25 for the freeway and 1.15 for the crossing arterials. These are the major assumptions used to establish traffic volumes and speeds for the hypothetical upgrading projects.

In practice, a systems-level analysis would be required to adequately account for the redistribution of traffic on the upgraded project and on other parts of the affected transportation network as previously recommended. Or for projects located in relatively undeveloped areas, there is the potential for changes in surrounding land use and associated implications with respect to affected growth rates in traffic volumes. An actual systems-level analysis would need to account for this as well.

Traffic Data

Traffic activity data were developed based on methodology formulated by the Texas Transportation Institute (TTI) as provided in the National Highway Institute (NHI) course "Estimating Regional Mobile Source Emissions" and national data built into the MOBILE6.2 model. The capacity of the urban freeway is assumed to be 2100 vehicles per hour per lane (vphpl) (NHI, 2003; TRB, 2000) and the capacity of the urban crossing arterials is assumed to be 673 vphpl (NHI, 2003). Traffic volumes are assumed to vary hourly according to EPA's (2003) VMT fraction by hour of the day. For the 2005 existing condition, the roadways (i.e., freeway and crossing arterials) are assumed to be operating at capacity during the peak-hour traffic condition of 4 to 5 pm. Traffic volumes for the remaining hours are distributed based on the assumed capacity multiplied by a ratio of the VMT fraction for each hour divided by the VMT fraction for the peak hour. Total hourly volumes were determined considering the number of lanes associated with the existing condition, i.e., 6-lane freeway with 4-lane crossing arterials. A 50/50 directional split was employed. No distinction for weekend travel was made.

Traffic volumes for future years were determined by applying the assumed annual growth rate of 1.5% per year for the No-Action Alternate and 1.75% per year for the Build Alternates, limited to 1.25 × V/C for the freeway and 1.15 × V/C for the crossing arterials during any one hour. Capacity-limited volumes were only applicable for the 2030 No-Action Alternate. The resulting hourly traffic volumes are provided in Figure 1.

One reason for computing hourly traffic volumes is to determine hourly travel speeds, which vary according to the V-to-C ratio. The TTI method (NHI, 2003) for predicting congested speeds was applied. The basis for the methodology is calculating a congested speed (in mph) accounting for the effects of delay (min/mi) on the free-flow speed (in mph):

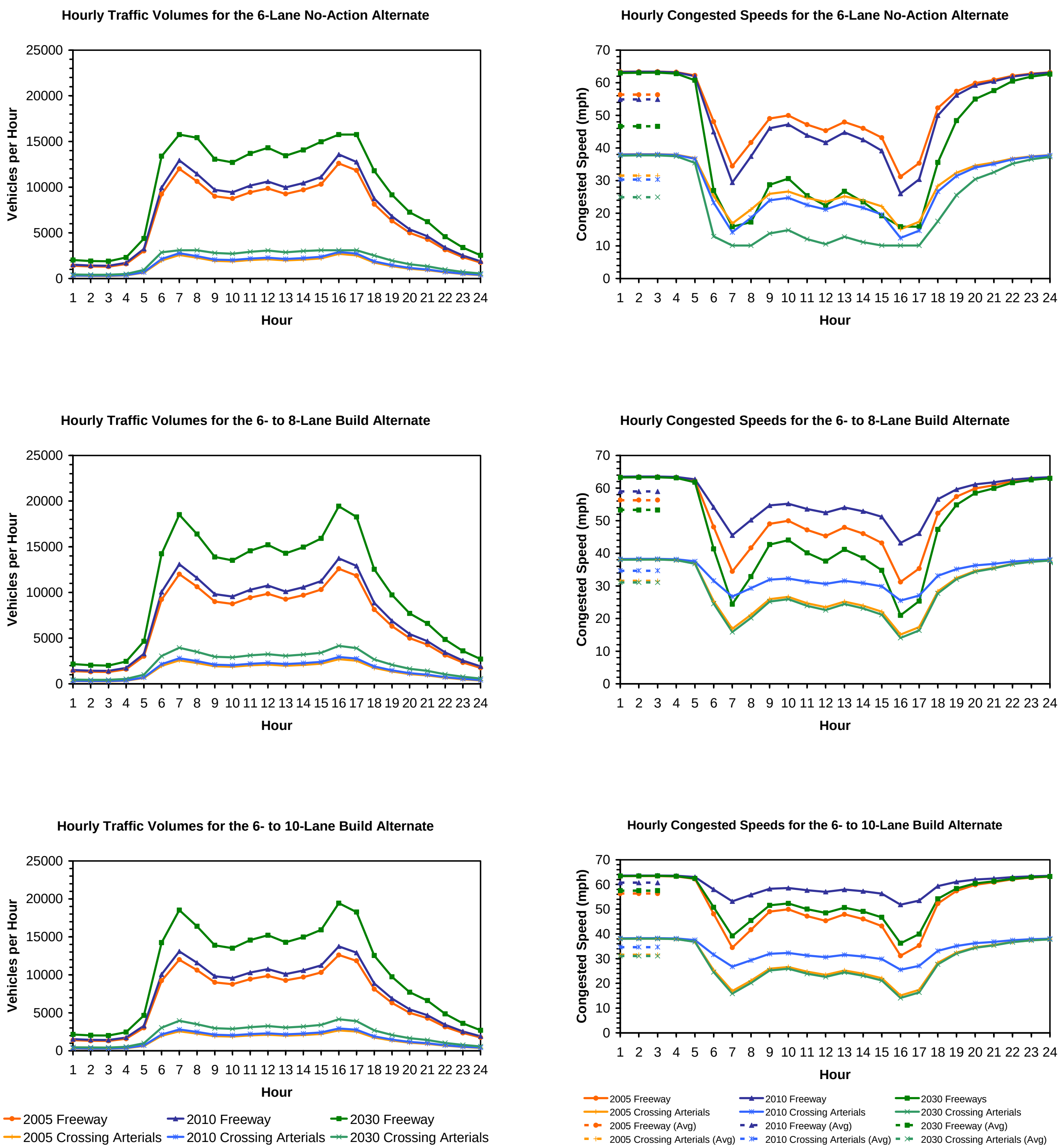
$$\text{Congested Speed} = \frac{60}{\dfrac{60}{\text{Freeflow Speed}} + \text{Delay}}$$

Default free-flow speeds are provided as a function of area type and roadway functional classification defined in the FHWA Highway Performance Monitoring System (HPMS). The default free-flow speeds for urban freeways and urban other principal arterials are 65 mph and 40 mph, respectively. The formula for calculating delay is:

$$\text{Delay} = \text{Minimum}\left[A \times e^{B\left(\frac{V}{C}\right)}, M \right]$$

where A and B are volume/delay equation coefficients and M is the maximum minutes of delay per mile. Default values are provided: A = 0.015, B = 3.5, and M = 5 for high-capacity facilities; A = 0.05, B = 3, and M = 10 for low-capacity facilities. Default capacities are also provided as a function of area type and roadway functional classification: C = 2100 vphpl for urban freeways and C = 673 vphpl for urban other principal arterials. Locale-specific parameters should be derived and used in calculating congested speeds for most applications.

Figure 1. Hourly Traffic Volumes and Congested Speeds.



The resulting travel speeds are given in Figure 1 as previously referenced. An average hourly congested speed for the day was also computed to determine if it may be used as a surrogate for an hour-by-hour variation in speeds. The average hourly congested speeds illustrated in the figure are applicable to all hours of the day, but only a portion of each series is presented so that the hourly congested speeds can be more clearly shown. The hourly congested speeds predicted encompass the average speeds of the test cycles used in developing the speed correction factors in MOBILE6.2, i.e.:

- For freeways, low speed – 13.1 mph; level of service (LOS) F – 18.6 mph; LOS E – 30.5 mph; LOS D – 52.9 mph; LOS A-C – 59.7 mph; and high speed – 63.2 mph, as well as
- For arterial/collectors, LOS E-F – 11.6 mph; LOS C-D – 19.2 mph; and LOS A-B – 24.8 mph.

The daily VMT is the product of the Annual Average Daily Traffic (AADT) and the facility length. The hourly volumes by facility type were summed to obtain the AADT as provided in Table 1 by alternate. The facility lengths assumed are 10 miles for the freeway and 6 miles for the crossing arterials (i.e., 6 arterials of 1 mile in length each). The resulting daily VMT for each alternate are also presented in Table 1.

Identical hourly traffic volumes, AADT, and daily VMT are realized for the 6- to 8-Lane and 6- to 10-Lane Build Alternates. Even so, there are differences in the capacities and predicted congested speeds for the build alternates that may affect the respective MSAT emission totals. In contrasting the No-Action and Build Alternates, differences in hourly traffic volumes, AADT, and daily VMT are observed due to the AADT growth rates and V-to-C ratio limits implemented.

MOBILE6.2 Inputs

The MOBILE6.2 model was run using EPA’s national default data built into the program with the following exceptions. Parameters for which there are no default values include calendar year; minimum and maximum temperature; gasoline fuel Reid vapor pressure (RVP); average diesel fuel sulfur level and maximum particle size cutoff (for diesel particulate matter); and specifications of the gasoline fuel used (for acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde). Parameters for which national defaults were not used include month of evaluation and average speeds. Emission reductions that may be realized from a local inspection/maintenance program were not taken into account.

The calendar years evaluated include 2005 as the baseline year; 2010 as the estimated time of completion; and 2030 as the design year. When conducting annual emissions inventories, EPA recommends that monthly emission factors be developed via mathematical interpolation between January and July and summing the monthly emissions results. To simplify this analysis, the parameters that would vary by month are represented by a single value as the basis for the annual emissions inventory. An evaluation of the variability of MOBILE6.2 emission factors is provided to gauge how changes in certain assumptions would affect emission factors representative of freeway and arterial operation.

The MOBILE6.2 model was run assuming no temperature variation over the day simulated (i.e., minimum temperature = maximum temperature) using a temperature of 55 ºF to represent an annual average. The median of the annual average daily minimum and maximum temperatures measured in the U.S. are 43.3 ºF and 63.6 ºF, respectively; 55 ºF is about midway

Table 1. Travel Characteristics of Each Alternate.

Annual Average Daily Traffic (vpd)

Alternate	2005 Freeway	2005 Arterials	2005 Total	2010 Freeway	2010 Arterials	2010 Total	2030 Freeway	2030 Arterials	2030 Total
6-Lane No-Action	162162	34646	196808	174695	37324	212018	229669	47963	277632
6- to 8-Lane Build				176857	37786	214642	250213	53458	303671
6- to 10-Lane Build				176857	37786	214642	250213	53458	303671

Daily Vehicle-Miles of Travel (VMT per day)

Alternate	2005 Freeway	2005 Arterials	2005 Total	2010 Freeway	2010 Arterials	2010 Total	2030 Freeway	2030 Arterials	2030 Total
6-Lane No-Action	1621622	207876	1829498	1746947	223942	1970889	2296691	287779	2584470
6- to 8-Lane Build				1768567	226713	1995281	2502131	320749	2822880
6- to 10-Lane Build				1768567	226713	1995281	2502131	320749	2822880

between these values. The median of the normal daily minimum temperatures measured in the U.S. during the coldest month of the year (January) is 23.5 ºF and the median of the normal daily maximum temperatures measured in the U.S. during the warmest month of the year (July) is 86.1 ºF. The fuel RVP would change over the course of a year from the switching of winter fuel blends to summer fuel blends and back again. The range of fuel RVP in some locales can be expected to encompass the volatility of class AA (7.8 psi) through class E (15.0 psi) fuels prescribed by the American Society of Testing Materials (ASTM). A fuel RVP of 12.5 psi (Class C/D) was assumed for this analysis. The evaluation month selected was July.

Emission factors of diesel particulate matter include the organic carbon, elemental carbon, and sulfate portions of diesel exhausts for a maximum particle size cutoff of 10 µm. The diesel fuel sulfur levels used are consistent with the 49-state average values reflecting more stringent federal controls (i.e., 11 ppm for 2010 and 2030). For the baseline year of 2005, an average diesel fuel sulfur level of 350 ppm was assumed. Emission factors for the hydrocarbon MSATs were based on the 2007/2020 30 ppm fuel specifications for the northeastern states during summer and no reformulated fuel program (RFP).

The emissions analysis was conducted by accounting for the vehicle emission types specific to the operation of the facility, e.g., exhaust running and evaporative running loss emissions for vehicles operating on the freeway and crossing arterials. The national defaults for start and soak emissions built into the MOBILE6.2 model are not applicable to a project-level analysis as most of the starts and ends of vehicle trips would not occur on the upgraded project or on the affected transportation network. Start and soak emissions need to be accounted for if a project would significantly increase the number of trips above the No-Action Alternate, not just a redistribution of existing trips.

PRESENTATION OF RESULTS

Project-Level Emissions

Traffic data representative of a congestion-mitigation highway project was formulated; the most-recent official version of the MOBILE6.2 model (dated November 2003) was run; and the resulting emission inventory for the six priority mobile source air toxics was compiled as summarized in Table 2. The relative amount of total MSAT emissions attributable to the freeway and the crossing arterials and the emissions of each individual MSAT are also provided in Table 2.

Variability of MOBILE6.2 Emission Factors

MSAT emission factor predictions produced by the MOBILE6.2 model vary substantially over the typical evaluation period of a transportation project. The MSAT emission levels attributable to a group of transportation alternatives will be governed by project-specific and locale-specific circumstances such as external conditions, vehicle fleet characteristics, vehicle activity, and vehicle fuel specifications. Recognizing the importance of these factors, the EPA (2004) recommends which MOBILE6.2 input parameters should be based on locally-derived data in preparing emission inventories. Tianjia Tang (2003) of the FHWA Resource Center conducted an in-depth trend and sensitivity analysis of the air toxic function of the MOBILE6.2 model.

Table 2. Project-Level MSAT Emissions (tons per year).

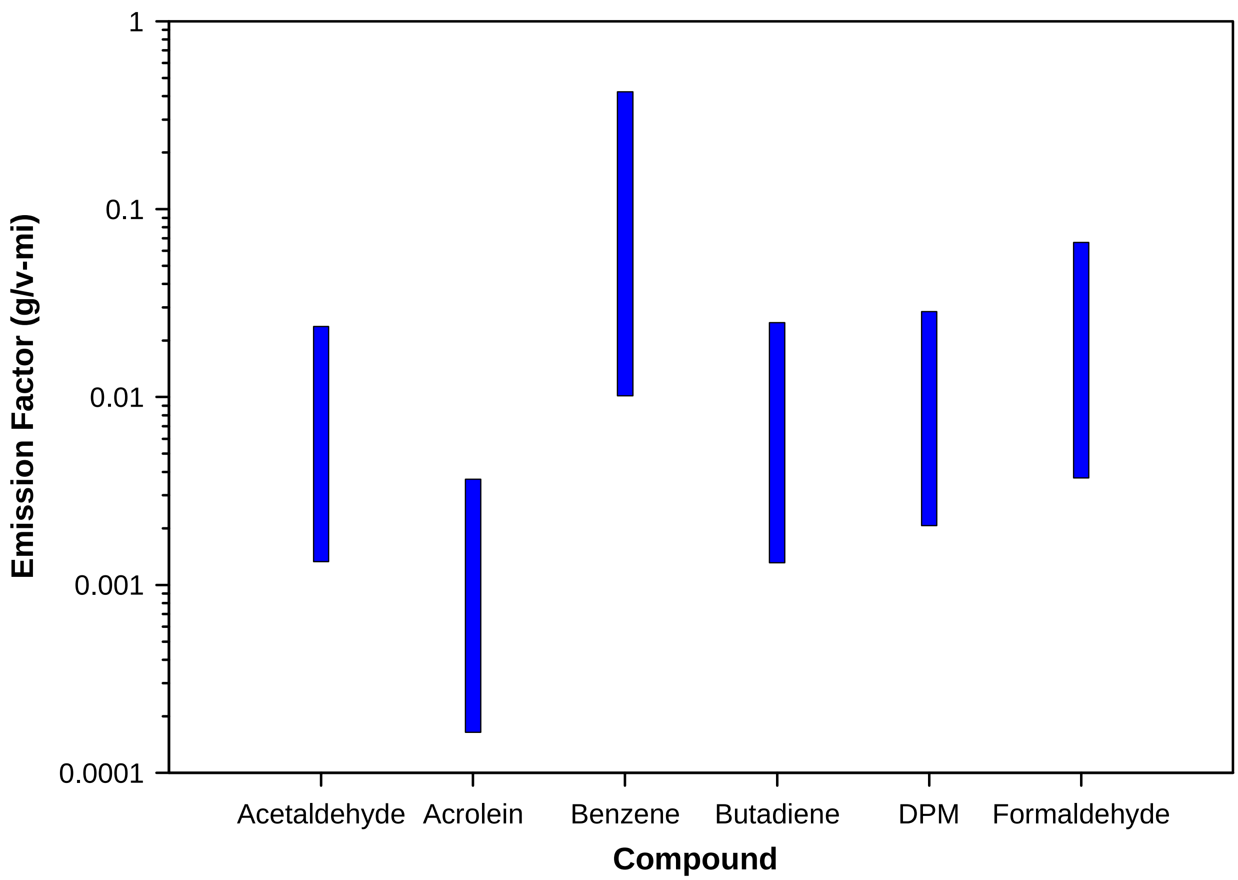
Total MSAT Emissions			
	Year		
Alternate	2005	2010	2030
6-Lane No-Action	63.3	41.9	27.7
6- to 8-Lane Build		40.3	27.1
6- to 10-Lane Build		40.0	26.0

MSAT Emissions by Facility Type						
	Year / Facility Type					
	2005		2010		2030	
Alternate	Freeway	Arterials	Freeway	Arterials	Freeway	Arterials
6-Lane No-Action	55.1	8.16	36.3	5.53	23.7	4.00
6- to 8-Lane Build			35.4	4.94	23.6	3.50
6- to 10-Lane Build			35.0	4.94	22.5	3.50

MSAT Emissions by Alternate							
	Year / Alternate						
	2005	2010			2030		
Compound	6-Lane No-Action	6-Lane No-Action	6- to 8-Lane Build	6- to 10-Lane Build	6-Lane No-Action	6- to 8-Lane Build	6- to 10-Lane Build
Acetaldehyde	3.4	2.5	2.3	2.3	2.3	2.1	2.0
Acrolein	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Benzene	25.6	18.6	17.7	17.5	15.0	14.7	14.2
Butadiene	3.3	2.4	2.3	2.3	1.9	1.9	1.8
Diesel Particulate Matter	21.0	11.4	11.5	11.5	2.4	2.6	2.6
Formaldehyde	9.5	6.6	6.1	6.1	5.9	5.5	5.1

Offered as a supplement is an evaluation of the range of MSAT emission factors obtained from the MOBILE6.2 model by varying the key parameters identified by Tang – calendar year, temperature, fuel Reid vapor pressure, and vehicle speed. Calendar years ranging from 2005 to 2050 in 5 year increments were considered. No temperature variation over the day simulated was assumed; however, various temperatures were assessed where the minimum was set to the maximum to gauge the effects of discrete temperatures, ranging from 35 ºF to 95 ºF in 10 ºF increments. The effects of fuel RVP were calculated for four selected values: 7.8 psi (Class AA), 10.0 psi (Class B), 12.5 psi (Class C/D), and 15.0 psi (Class E). The effects of vehicle speeds for the freeway and arterial/collector roadway scenarios were evaluated in increments defined by the 14 speed bins established in MOBILE6.2 (i.e., 2.5 mph, 5 mph, and in 5 mph increments thereafter to 65 mph). This represents over 47,000 emission factor values calculated for the 6 priority MSAT compounds. The results are shown in Figure 2.

Figure 2. Variability of MOBILE6.2 Emission Factors for the Priority MSATs.

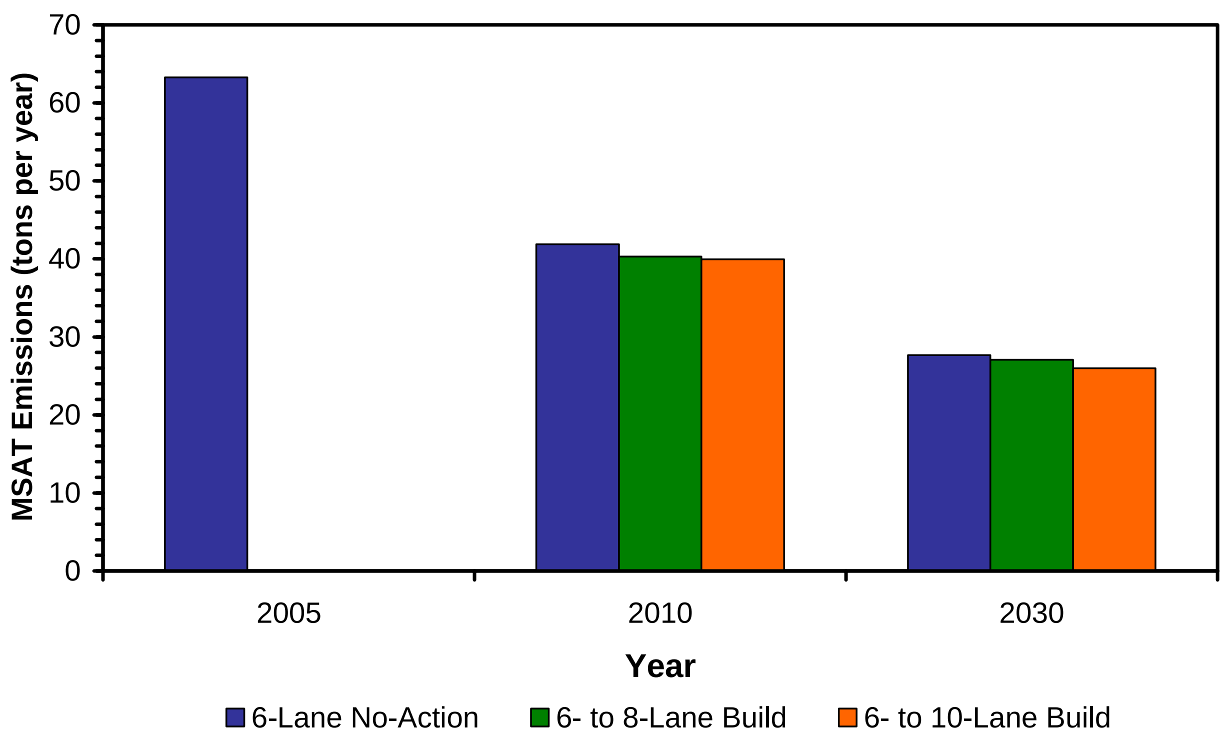


DISCUSSION OF RESULTS

Project-Level Emissions

The analysis indicates that a significant decrease in MSAT emissions can be expected for a planned congestion-mitigation transportation project from current (e.g., 2005) levels through future (e.g., 2030 design year) levels. The emission trends obtained in this analysis are illustrated in Figure 3. Emissions of total MSATs are predicted to decrease by more than 56% in 2030 compared with 2005 levels. Differences in total MSAT emissions between the Build and No-Action alternates were found. The No-Action Alternate is expected to carry less traffic than the Build Alternates, but this is offset by an over-capacity traffic condition and breakdown of travel speeds during an extended peak period. As a result, less total MSAT emissions are associated with the Build Alternates compared to the No-Action Alternate (i.e., 2.2 to 6.2% less).

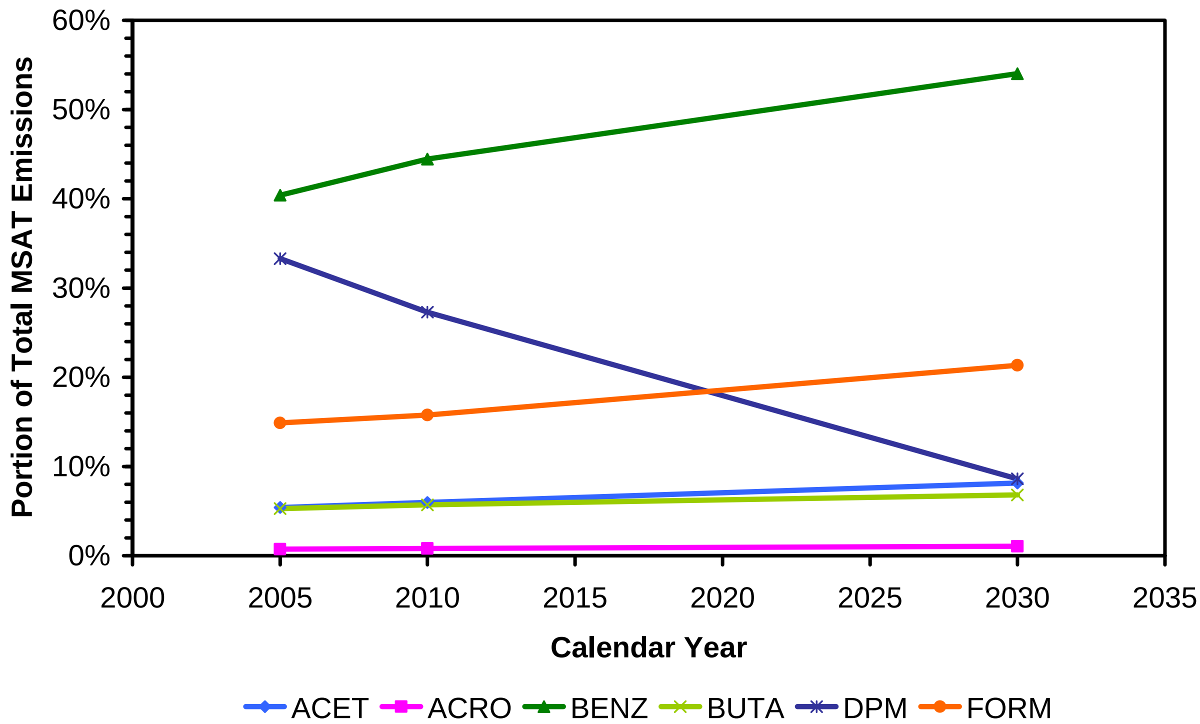
Figure 3. Predicted Changes in MSAT Emissions.



Most of the MSAT emissions are attributable to the freeway compared with the crossing arterials. But although the arterials account for only 11.1 to 11.4% of the total daily VMT; they contribute a disparate amount of the total MSAT emissions – 12.3 to 14.4%. While this may not seem significant, arterial travel accounts for 7.9 to 29.6% more MSAT emissions than indicated by its portion of the total VMT. This is attributable to the congestion reflected for the arterial facilities represented in the analysis. Since emissions are directly proportional to the assumed daily VMT, the results by facility type presented in Table may be adjusted to reflect different assumptions with respect to the length of the freeway corridor or crossing arterials and to a lesser extent, the AADT on the two facility types. Changing traffic volume assumptions would affect traffic speeds and emission factors that would not be reflected in a simple proportional adjustment of facility VMT.

Of the six priority MSAT compounds, benzene contributes the most to the emissions total. The amount of diesel particulate matter emitted in 2005 is comparable to the amount of benzene emitted – 21.0 versus 25.6 tpy for the 6-lane No-Action Alternate. But for future years, a substantial decline in benzene is anticipated (more than a 41% decrease from 2005 to 2030); and an even larger reduction in diesel particulate matter emissions is predicted (about an 88% decrease from 2005 to 2030). In 2005, the largest portion of the total MSAT emissions is due to benzene (40%) followed by diesel particulate matter (33%), formaldehyde (15%), acetaldehyde (5%), butadiene (5%), and acrolein (1%). By 2030, the rank order and proportions change as follows: benzene (54%), formaldehyde (21%), diesel particulate matter (9%), acetaldehyde (8%), butadiene (7%), and acrolein (1%). This is displayed graphically in Figure 4.

Figure 4. Changes in the Proportional Mix of MSAT Emissions.



Associated with each MSAT compound is its inherent toxicity. While huge uncertainties and inconsistencies exist in assigning absolute toxicity values, considering their relative toxicities may be an effective technique to gauge the relative importance of the magnitudes or increases and decreases in emissions among individual MSAT species, transportation alternatives, and/or mitigation measures. A sampling of acute and chronic toxicities associated with the six priority MSATs are provided in Table 3. Included in this table are short-term worker exposures provided by the National Institute for Occupational Safety and Health (NIOSH) and the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA); and short-term and long-term air quality exposures provided by the U.S. EPA and the states of New York and California. The range of variability in toxicities from the short-term to the long-term is six to eight orders of magnitude. No National Ambient Air Quality Standards (NAAQS) have been set for any of the priority MSATs. California is the only entity included in this sampling to adopt a level for diesel particulate matter.

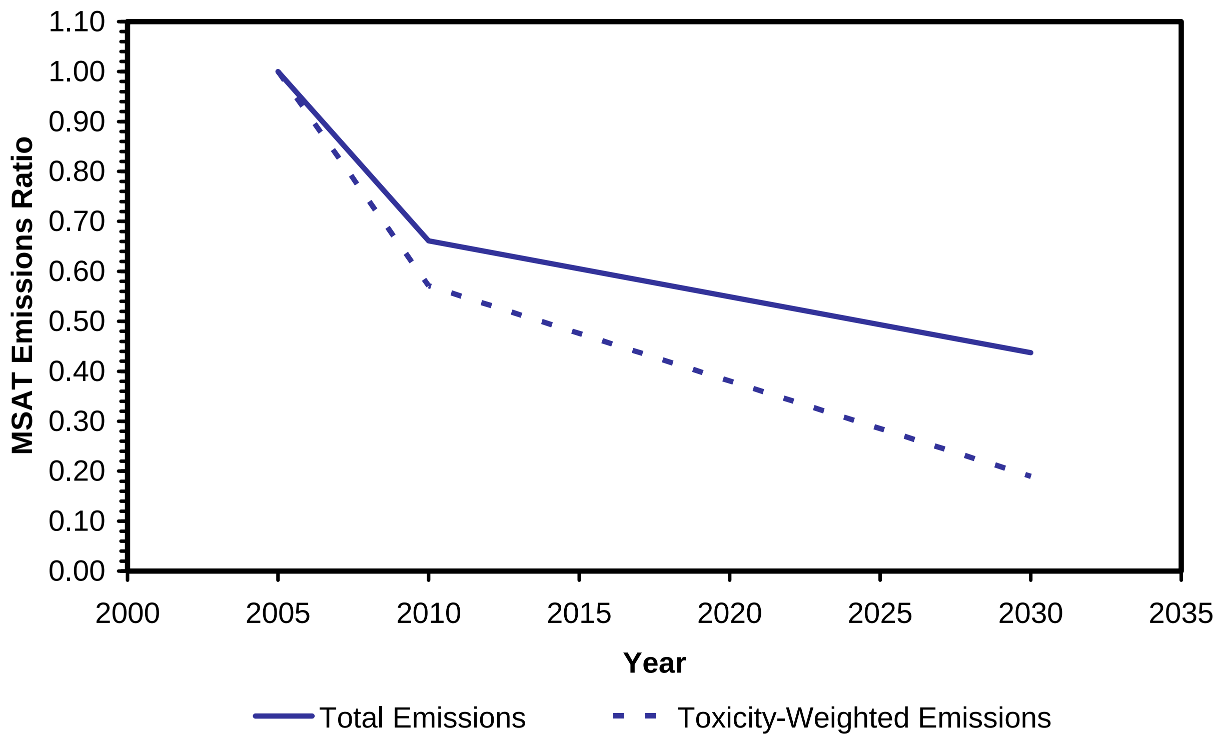
Table 3. Air Exposure Criteria (μg/m^3).

MSAT Compound	NIOSH	U.S. DoL	U.S. EPA			New York Air Guide		California		
	IDLH	OSHA PEL	NAAQS	RAC	RsD 10^{-5} Risk	SGC	AGC	Acute Inhalation	Chronic Inhalation	RsD 10^{-5} Risk
Acetaldehyde	3,610,000	360,000	None	10	None	4,500	4.5E-01	None	9.0E+00	3.7E+00
Acrolein	4,590	250	None	20	None	1.9E-01	2.0E-02	1.9E-01	6.0E-02	None
Benzene	1,600,000	3,200	None	None	1.2E+00	1,300	1.3E-01	1.3E+03	6.0E+01	3.4E-01
1,3-Butadiene	4,430,000	2,220	None	None	3.6E-02	None	3.6E-03	None	2.0E+01	5.9E-02
Diesel Particulate Matter	None	None	15 (annual)[A] 65 (24-hr)[A]	None	None	None	None	None	5.0E+00	3.3E-02
Diesel Organic Gases	None	None	None	None	None	None	None	None	None	None
Formaldehyde	24,600	921	None	None	7.7E-01	30	6.0E-02	9.4E+01	3.0E+00	1.7E+00

Notes: All Concentrations in μg/m^3.
NIOSH IDLH – National Institute for Occupational Safety and Health, Immediately Dangerous to Life or Health, 15-minute average.
OSHA PEL – U.S. Deparment of Labor, Occupational Safety and Health Administration Permissible Exposure Limits, 8-hour Time Weighted Average.
NAAQS – National Ambient Air Quality Standard.
RAC – U.S. EPA Reference Air Concentration (annual average), 40 CFR 266, Appendix IV.
RsD – Risk Specific Dose of a 10^{-5} increased cancer risk due to a lifetime exposure (70-year average) via the inhalation pathway, 40 CFR 266, App. IV.
New York State Air Guide values: SGC – Short-term Guideline Concentration (1-hour average); AGC - Annual Guideline Concentration.
California: Acute Inhalation – 1-hour average Reference Exposure Limits (except for arsenic, 4-hour average and benzene, 6-hour average);
Chronic Inhalation – Annual average Refererence Exposure Limits; Inhalation Risk Specific Dose = 1 / Inhalation Unit Risk * 10^{-5}.
[A] As PM-2.5.

While the apparent decrease in MSAT emissions projected in 2030 compared to 2005 levels is more than 56%, the effective decrease in MSAT emissions is greater on a toxicity-weighted basis. Employing the appropriate EPA air exposure criteria (e.g., RAC or RsD) and California's RsD for diesel particulate matter, emissions can be expressed on a common basis – as diesel particulate matter or benzene or any of the other priority MSATs. On a toxicity-weighted basis, the effective decrease in MSAT emissions is 81% from current to design year levels. Figure 5 provides a comparison of these emissions decreases on an un-weighted versus toxicity-weighted basis.

Figure 5. Predicted Decreases in MSAT Emissions.



Several of the findings have alluded to the significant effect that traffic congestion has on predicted MSAT emission levels. Consequently, as a practical consideration, comes a question of the required level of detail of vehicle activity data to accurately characterize the amount of congestion on an affected transportation network. One aspect of this question was examined by determining if an average hourly congested speed for the day may be used as an adequate surrogate for the hour-by-hour variation in congested speeds. For facilities operating close to and above capacity, an average hourly congested speed is a marginal to poor indicator of congestion as it relates to the prediction of emissions for all priority MSAT compounds except DPM, which is insensitive to changes in speed. Use of an average hourly congested speed results in an underestimation of MSAT emissions minus DPM for the No-Action Alternate by 6 to 7% for 2005 and 2010 to as much as 16% for 2030. In contrast, for the 2010 Build Alternates where the freeway V-to-C ratios are less than 0.82, a closer match (within 2%) is obtained. The 2030 Build Alternates operate with peak V-to-C ratios ranging from 0.93 to 1.16. Underestimations of MSAT emissions minus DPM in the range of 3 to 7% are obtained using an average hourly congested speed as a surrogate for the hourly variation.

The level of detail of the vehicle activity data employed in a project-level MSAT emission analysis extends to other factors that may either mitigate or adversely affect congestion. Factors such as variations in vehicle activity by weekday/weekend, month or season, and directional split should be considered.

Emission Factor Variability

The variability of MSAT emission factors projected for the variety of conditions that may be representative of transportation projects and locales throughout the U.S. is huge, ranging by an order of magnitude for each individual compound:

- Acetaldehyde – 0.00133 to 0.0238 g/VMT;
- Acrolein – 0.000165 to 0.00365 g/VMT;
- Benzene – 0.0102 to 0.422 g/VMT;
- Butadiene – 0.00131 to 0.0249 g/VMT;
- Diesel Particulate Matter – 0.00207 to 0.0285 g/VMT; and
- Formaldehyde – 0.00371 to 0.0665 g/VMT.

The highest emission factors are associated with the current year (2005), the minimum speed (2.5 mph), the maximum temperature (95 ºF), and the top end fuel RVP (12.5 or 15.0 psi). The lowest emission factors are associated with years extending into the future (2035 to 2050), higher speeds (55 to 65 mph), moderate temperature (75 ºF), and minimum fuel RVP (7.8 psi).

Some conditions are unlikely to occur concurrently – such as high temperatures and high volatility gasoline, low temperatures and low volatility gasoline, high vehicle speeds on arterial facilities, or minimal vehicle speeds on freeways and arterials for extended periods of time. A series of graphs were prepared to identify practical ranges of MSAT emission factors by calendar year considering the common operating speeds of vehicles on freeways and arterials and a combination of temperatures with relatively high volatility gasoline.

The vehicle operating speeds selected were 15 to 65 mph on freeways and 10 to 40 mph on arterials. These speeds were chosen considering the congested speeds calculated in the project-level emissions analysis and the average speeds of the test cycles used in developing the speed correction factors in MOBILE6.2. Temperature/fuel RVP combinations were selected considering that automotive gasoline is adjusted seasonally by manufacturers to meet EPA's volatility regulation and ASTM fuel volatility specification D-4814. Suppliers generally publish specification schedules for their gasoline shipments. Typically, high volatility gasoline is supplied during the winter months when high temperatures are unlikely to occur and low volatility gasoline is supplied during the summer months when low temperatures are unlikely to occur. The spring and fall months may be more representative of the minimum/maximum temperature range for periods when relatively high volatility gasoline (Class C or D) is in use. A temperature range of 35 to 95 ºF in combination with a fuel RVP of 12.5 psi was evaluated, as well as a fuel RVP range of 7.8 to 15.0 psi in combination with a temperature of 55 ºF. Figures 6 though 9 show the variability of emission factors predicted by the MOBILE6.2 model as a function of calendar year for acetaldehyde, acrolein, benzene, butadiene, diesel particulate matter, and formaldehyde. What's represented by the floating bar graphs in each figure is the full extent of projected emission factors by calendar year considering vehicle speeds from 2.5 to

Figure 6. Variability of MOBILE6.2 Emission Factors for MSATs in the 15 to 65 mph Freeway Operating Speed Range (Temperature = 55 ºF, RVP = 12.5 psi).

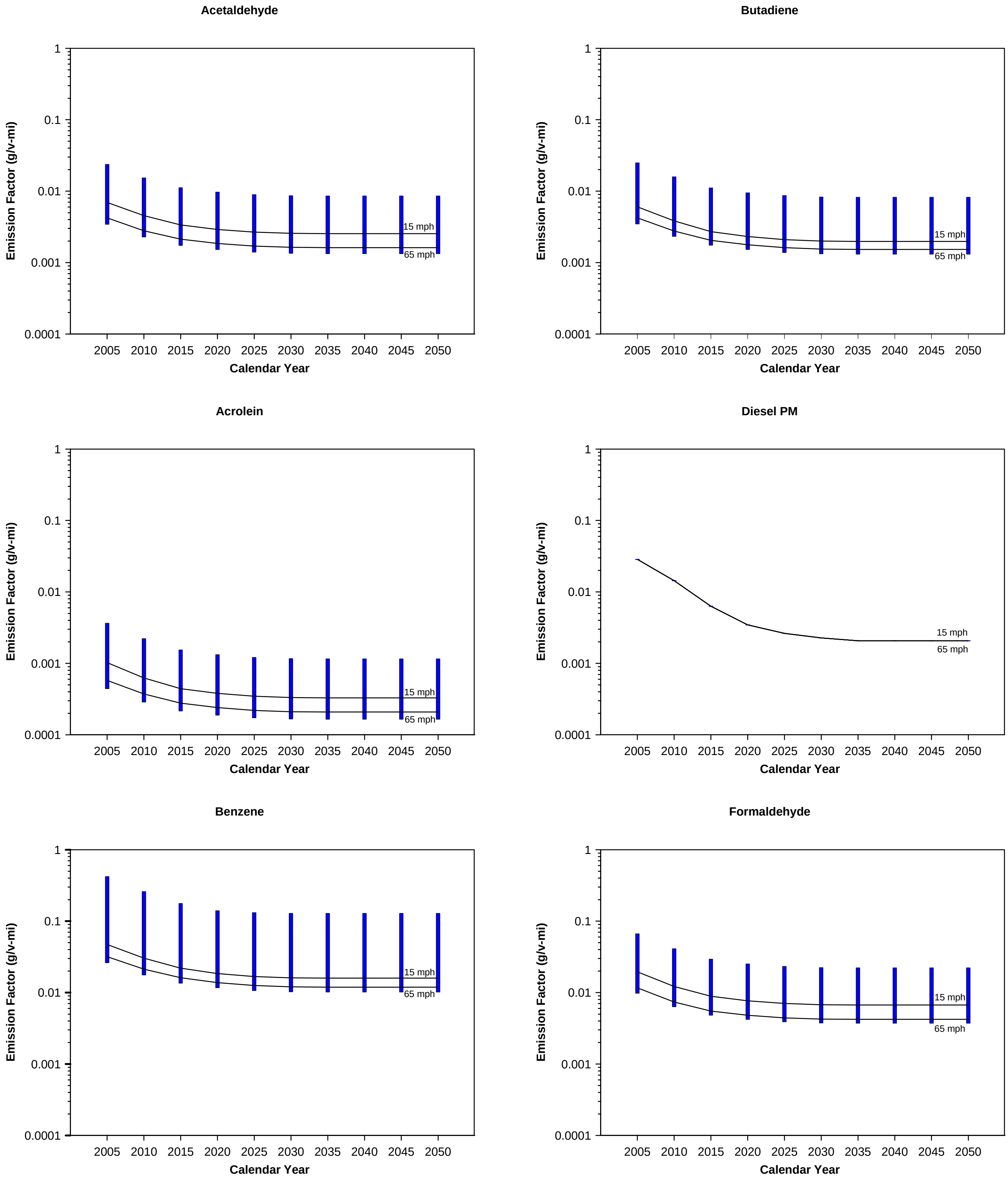


Figure 7. Variability of MOBILE6.2 Emission Factors for MSATs in the 10 to 40 mph Arterial Operating Speed Range (Temperature = 55 ºF, RVP = 12.5 psi).

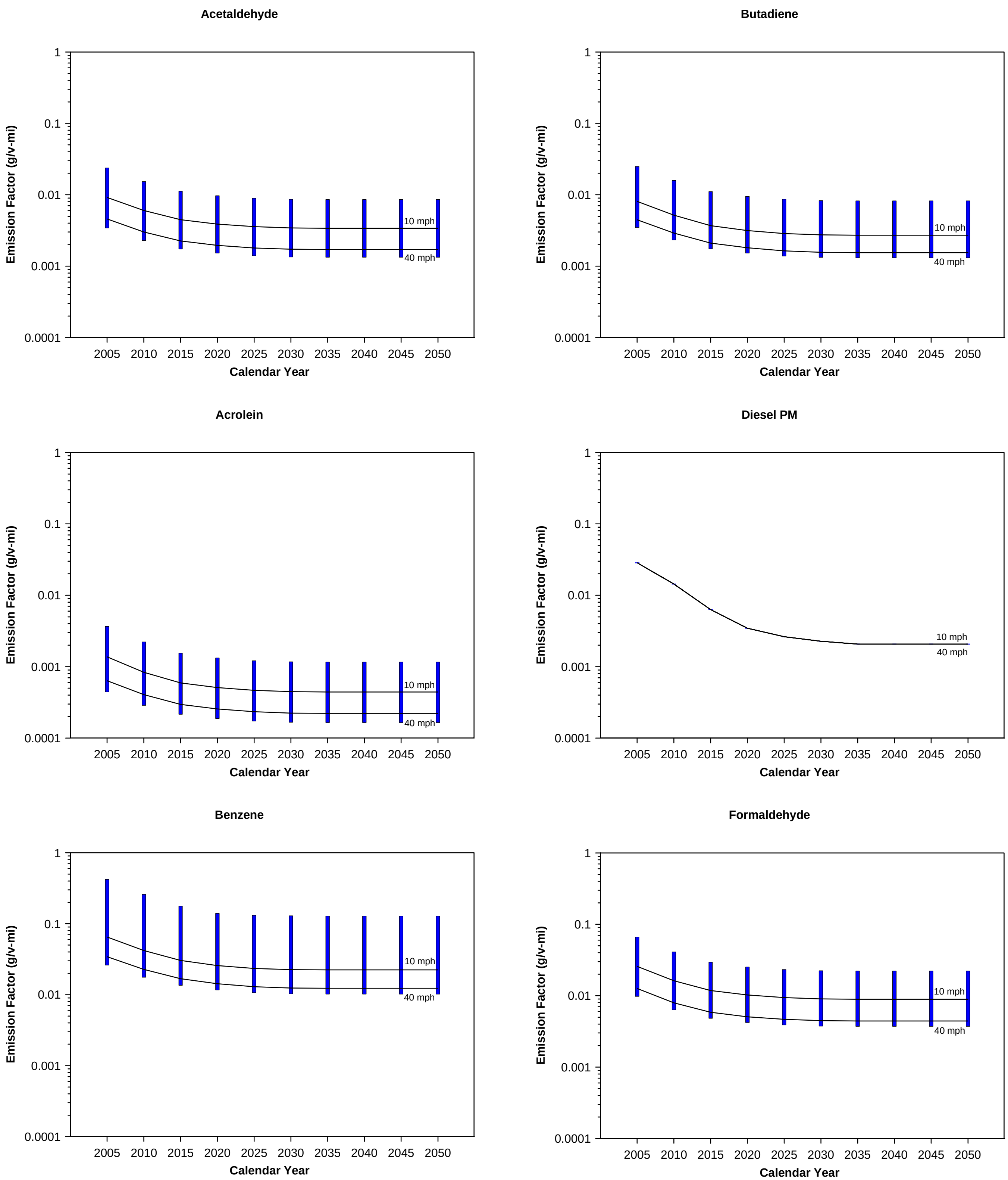


Figure 8. Variability of MOBILE6.2 Emission Factors for MSATs in the 35 to 95 ºF Temperature Range (55 mph Freeway Speed, RVP = 12.5 psi).

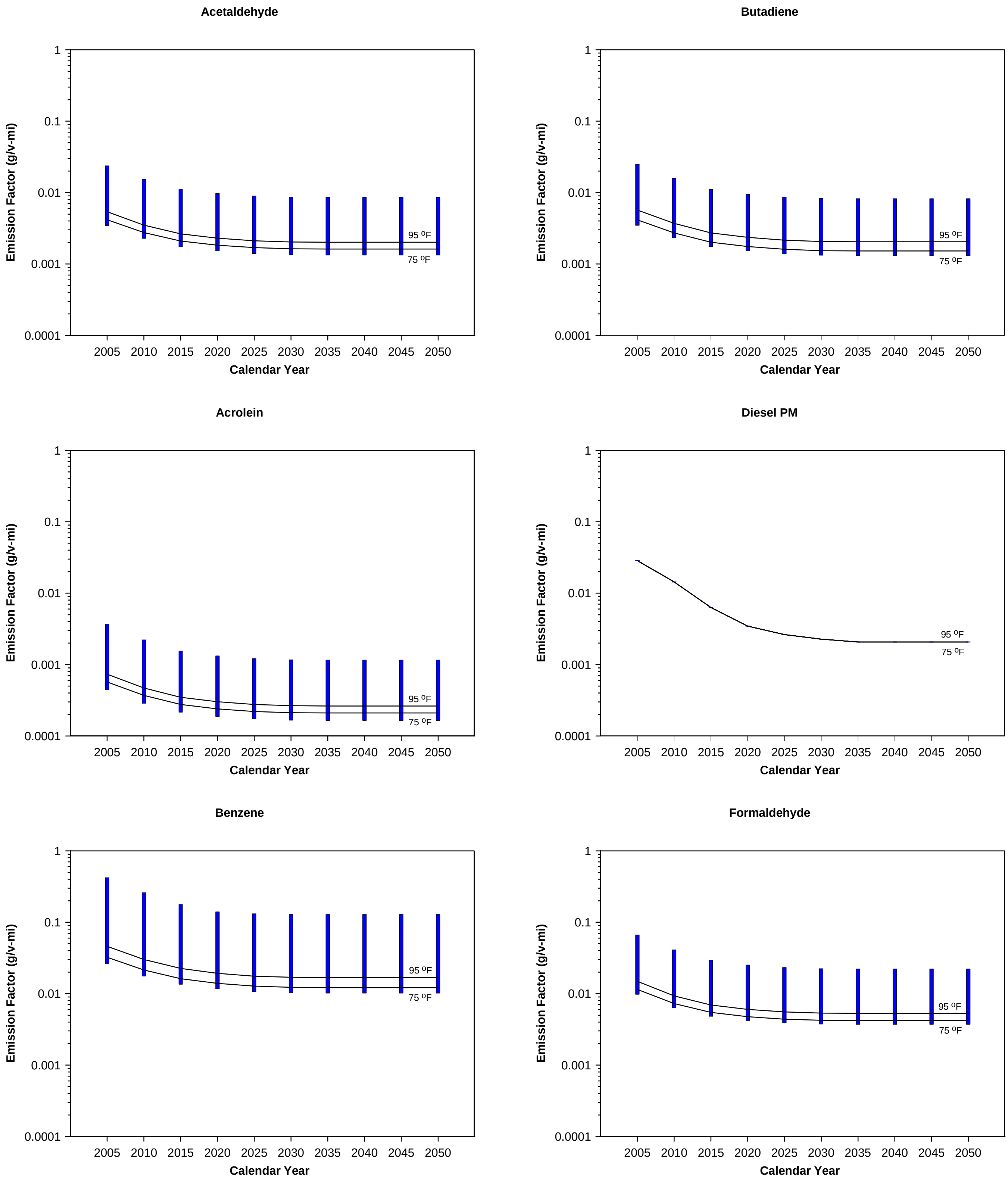
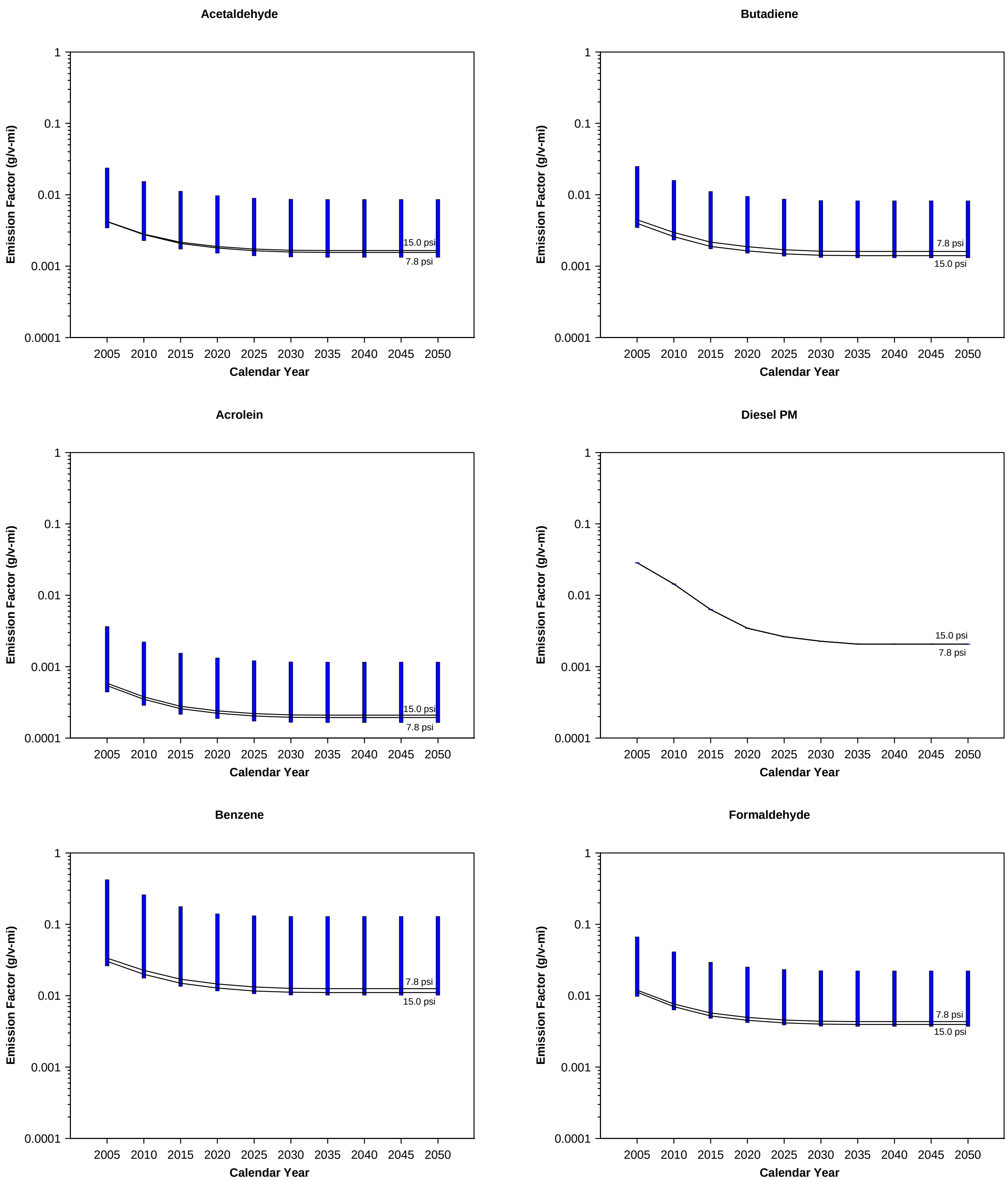


Figure 9. Variability of MOBILE6.2 Emission Factor for MSATs in the 7.8 to 15.0 psi Fuel RVP Range (55 mph Freeway Speed, Temperature = 55 ºF).



65 mph, temperatures from 35 to 95 ºF, and fuel RVP from 7.8 to 15.0 psi. Superimposed are line graphs illustrating the range of results expected considering practical assumptions of vehicle speed, temperature, and fuel RVP. Each figure consists of six panels, one for each MSAT, delineated by line graphs representing:

- The freeway operating speed range of 15 to 65 mph for a temperature of 55 ºF and fuel RVP of 12.5 psi in Figure 5;
- The arterial operating speed range of 10 to 40 mph for a temperature of 55 ºF and fuel RVP of 12.5 psi in Figure 6;
- The temperature range of 35 to 95 ºF for a fuel RVP of 12.5 psi and freeway operating speed of 55 mph in Figure 7; and
- The fuel RVP range of 7.8 to 15.0 psi for a temperature of 55 ºF and freeway speed operating of 55 mph in Figure 8.

Using parameters that reflect realistic conditions versus rare or unlikely events results in emission factors in the bottom half of the predictive range of MOBILE6.2. For the most part, these emission factors are nevertheless sensitive to changes in calendar year, congested speed, temperature, and fuel RVP. MSAT emission factors decrease with increasing calendar year, reaching their minimum during 2035 and remaining flat through 2050.

The results obtained for diesel particulate matter are not characteristic of those obtained for the HC-based MSATs (i.e., acetaldehyde, acrolein, benzene, butadiene, and formaldehyde). As illustrated in each of the figures, emission factors for diesel particulate matter are insensitive to changes in vehicle speed, temperature, and not surprisingly, fuel (gasoline) RVP. Emission factors for diesel particulate matter will only change as a function of the VMT of diesel-fueled vehicles and the diesel-fuel sulfur content, which will be set for future years by EPA regulation.

For the HC-based MSATs, higher emission factors are associated with lower operating speeds. Because a higher frequency of lower speeds is linked with traffic on arterials, higher emission factors are generally obtained for arterial versus freeway travel. The differences in drive cycles for the arterial versus freeway roadway scenarios have little to no effect. Higher emission factors are obtained for higher and lower temperatures with 75 ºF being the inflection point. Temperature and fuel-RVP effects are inter-related. Changes in fuel RVP for moderate temperatures have a minor effect on emission factors. However, the misapplication of fuels for high or low temperatures will have an effect on predicted emission factors for the HC-based MSATs. Use of high volatility gasoline with high temperatures results in higher emission factors compared with the proper match of low volatility gasoline with high temperatures. The same is true for the use of low volatility gasoline with low temperatures compared with the appropriate match of high volatility gasoline with low temperatures.

CONCLUSIONS

This study provides some insight into what may be expected when conducting an in-depth project-level mobile source air toxics emissions analysis. First, the main analytical tool for predicting emissions from on-road motor vehicles is the EPA's MOBILE6.2 model. The MOBILE6.2 model is regional in scope and has limited applicability to a project corridor. However, the effects of a major transportation project extend beyond its corridor and an evaluation within the context of an affected transportation network can be accomplished.

When evaluating the future options for upgrading a transportation corridor, the major mitigating factor in reducing mobile source air toxic emissions is the implementation EPA's new motor vehicle emission control standards. Substantial decreases in MSAT emissions will be realized from a current base-year through an estimated time of completion for a planned upgrading project and its design year some 25 years in the future. Even accounting for anticipated increases in vehicle-miles of travel and varying degrees of efficiency of vehicle operation, total MSAT emissions were predicted to decline more than 56% from 2005 to 2030. While benzene emissions were predicted to decline more than 41%, emissions of diesel particulate matter were predicted to decline more than twice this rate (i.e., 88%). On a toxicity-weighted basis, the effective decrease in total MSAT emissions is 81% from current to design year levels.

The ability to discern remarkable differences in MSAT emissions among transportation alternatives is difficult given the uncertainties associated forecasting travel activity and air emissions 25 years or more into the future. In this hypothetical congestion-mitigation project, differences in MSAT emissions between the Build and No-Action Alternates ranged from 2 to 6%. While factors such as ambient temperature, implementation of an inspection maintenance program, use of reformulated gasoline, etc., can affect the magnitude of MSAT emissions specific to a locale; these factors would be common to all project alternatives under review.

The most important factors affecting emission differences among the available options are vehicle-miles of travel and levels of traffic congestion. When evaluating transportation network alternatives operating significantly under-capacity, the difference in vehicle-miles of travel is more important than the difference in congested vehicle speeds. The excess capacity would accommodate an increase in traffic volumes without adversely affecting travel speeds and related MOBILE6.2 emission factors. At the other extreme, where one transportation network alternative is operating significantly over its capacity, then the difference in congested vehicle speeds may be more influential than the difference in vehicle-miles of travel. MOBILE6.2 emission factors are very sensitive to vehicle speeds in the slow, congested speed range. Mitigating this congestion may have more of an effect on reducing emissions than the offset due to a potential increase in vehicle-miles of travel. For transportation network alternatives operating slightly under- or over-capacity, then differences in vehicle-miles of travel and differences in congested speeds are equally significant. The level of detail required in formulating vehicle activity data is greater for congestion-mitigation projects. Factors that may mitigate or adversely affect congestion need to be accounted for and it is preferable to represent congestion by an hour-by-hour variation in traffic speeds versus an average for the day.

Applicability to Real-World Analyses

The approach used in this analysis could be applied for project-level analysis of proposed projects in the National Environmental Policy Act (NEPA) process, or for other purposes. However, the analysis needs to be tailored to reflect local conditions.

The geographic area of analysis should reflect, at a minimum, all roadways where traffic volumes are affected by the proposed project. The affected transportation network can be defined as those links where the AADT is expected to change by more than ±5% as a result of a project. Also, to better reflect total emissions of the six priority MSATs, the analysis could include not only emissions associated with the transportation facilities in question, but also emissions from the local street network, non-road mobile sources, area and point (industrial) sources. Including these other emissions sources provides a more accurate representation of the relative impact of the proposed project.

This analysis is based on assumptions regarding traffic volumes and V-to-C ratios. An actual analysis would use volumes and capacity information specific to the project. Rather than using arbitrary growth rates, future volumes should be projected using a travel demand model or other technique normally used to forecast future travel in the area. Speeds from the travel demand model can also be used, but they should be post-processed using the TTI methodology, Bureau of Public Roads (BPR) formula, or other methodology. An enhancement would be to account for the effects of lower levels of weekend travel.

This analysis is based largely on national defaults in the MOBILE6.2 model. An actual analysis would use MOBILE inputs that are appropriate to the area. To a large extent, these inputs should be consistent with those used for other modeling purposes in the area (e.g., State Implementation Plan inventories, conformity analyses). However, given the limitations of the accuracy of the MOBILE6.2 model, use of annual average inputs is probably appropriate for most analyses. Also, rather than modeling each individual speed calculated for project links, it may be more expedient to generate a speed look-up table, in 5 mph increments, and select emissions rates by rounding to the closest modeled speed. Also note previous comments regarding use of hourly speeds versus daily average speeds. In many cases, daily average speeds would be appropriate.

DISCLAIMER

The content of this paper solely represents the work of the authors and does not reflect the policy, guidance, or procedures adopted or recommended by the U.S. Department of Transportation and the Federal Highway Administration. This document is disseminated in the interest of information exchange and the U.S. Government assumes no liability for use of the information. This paper does not constitute a standard specification or regulation.

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