United States
Environmental Protection
Agency

Research and Development

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

EPA/600/S8-91/032 July 1991

EPA

Project Summary

MOBILE4 Sensitivity Analysis

Mark G. Smith and Terry T. Wilson

The purpose of this analysis is to identify the MOBILE4 input variables that can have significant impacts on highway vehicle emissions inventories and to develop priorities for the development of improved guidance for specifying MOBILE4 inputs. Two major factors are considered: (1) the likelihood and potential range of variability in values for each MOBILE4 input; and (2) the potential magnitude of the effect of these variations, in terms of impact on typical mobile source inventories. This exercise uses ranges that illustrate: misinterpretation of guidance; use of MOBILE4 defaults where local conditions are significantly different; and use of assumptions about local conditions which may not accurately reflect actual conditions.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This analysis updates previous work based on MOBILE3 by using MOBILE4 for the sensitivity analysis and by adding new MOBILE4 variables. The approach used in previous work is modified to address the specific concerns of this project (the state implementation plan [SIP] and National Emissions Data System [NEDS] inventory/guidance context). An additional level of detail is included for two critical variables (speed and temperature). Sensitivity to basic inspection/maintenance (I/M) program specifications (waiver and compliance rate) is also considered.

The primary sensitivity analysis presented here is structured around two base cases representing ozone and carbon monoxide (CO) season conditions. Table 1 summarizes the protocol for the primary sensitivity analysis, including all relevant MOBILE4 input variables. In general, the base cases and primary ranges were chosen to be parallel to the previous sensitivity analysis and to relate to specific cities or national averages from available work by the EPA Office of Mobile Sources (OMS). The pollutants, regions, and calendar years were chosen to cover the areas, periods, and pollutants of interest in SIP inventories and other typical inventory applications. To provide additional data about the importance of accuracy in estimating key variables, secondary sensitivity ranges were tested around the base cases as well as around the primary speed and temperature ranges specified in the protocol.

MOBILE4 Input Values for the Base Cases

Emissions of hydrocarbons (HC), nitrogen oxides (NO_x), and CO were analyzed for the summer ozone season situation. Only CO was considered for the winter CO season base case. Both low and high altitude situations were included. The years 1990 and 2005 were selected as typical base and projection years for SIP inventories, to provide some perspective on the relative importance of the individual variables over time. Both base cases and all sensitivity runs include a typical basic I/M program. The individual program specifications were selected to be typical of current programs.

MOBILE4 Input Values for Sensitivity Analysis

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Table 1. Protocol for MOBILE4 Sensitivity Analysis

	Base Case 1: Ozone Season	Base Case 2: CO Season	Ozone Season Ranges[a]	CO Season Ranges[a]
Pollutant	HC, CO, NO_x	CO only	--	--
Region	Low + high altitude	Low + high altitude	--	--
Calendar Year	1990, 2005	1990, 2005	--	--
Avg. Speed (mph) [b]	19.6	19.6	7.1 (low) - 35 (high)	7.1 (low) - 35 (high)
Avg. Temperature (°F) [c]	78.1	43.2, no diurnal	86.0 (low) - 91.7 (high) [d]	11.3 (low) - 66.1 (high)
Hot/Cold Start [e]	20.6/27.3/20.6	20.6/27.3/20.6	5.0/5.0/5.0 (low) - 5.0/55.0/5.0 (high)	57.0/0/57.0 (low) - 5.0/5.0/5.0 (high)
VMT Mix and Mileage Accumulation	MOBILE4 Default	MOBILE4 Default	Fairbanks - California	Fairbanks - California
Vehicle Age Distrib.	MOBILE4 Default	MOBILE4 Default	Fairbanks - Phoenix	Fairbanks - Phoenix
ASTM Class	C	E	C or B [c]	--
Diurnal Temp. (°F)	60-84°F	No diurnal	72-90; 62-102 [d]	No diurnal
Base RVP (psi)	10.5	13.7	10.5; 9.0 [d]	--
In-use RVP (psi)	9.0 in 1992	13.7	9.0; 7.8 [d]	--
I/M Program [f]	Basic I/M	Basic I/M		
Compliance	95%	95%	90-100% [g]	90-100% [g]
Waivers	8%	8%	0-16% [g]	0-16% [g]

[a] In addition, secondary ranges of 5 mph and 5°F around the base cases and ranges for speeds and temperatures were simulated.
[b] Readers more familiar with metric units may use the factors listed at the end of this project summary.
[c] These are trip- and emission-weighted average temperatures as calculated by MOBILE4.
[d] Temperature, ASTM class, diurnal range, and RVPs varied jointly for Muskegon and Sacramento cases.
[e] Percent of VMT accumulated by: non-catalyst vehicles in cold-start mode/catalyst vehicles in hot-start mode/catalyst vehicles in cold-start mode--other fractions calculated by MOBILE4.
[f] Inspection/maintenance.
[g] Ranges for I/M combined into two cases: 100% compliance with 0% waivers (high); 90% compliance with 16% waivers (low).

gested urban traffic. The high speed of 35 mph is based on the highest-speed urban driving cycle used by OMS. Since temperature and RVP are interrelated, two cases based on recent OMS analyses for Muskegon and Sacramento were used to create two logical joint scenarios for the CO and ozone season primary sensitivity analyses. Muskegon represents a case in which the diurnal temperature range is 18°F rather than the 24°F of the Federal Test Procedure (FTP) (with corresponding trip- and emission-weighted MOBILE4 average temperature of 86.0°F rather than the 78.1°F FTP average). The RVP-related parameters for Muskegon are unchanged from the base case (10.5 psi in 1990). Sacramento is in a different ASTM region, and has incrementally lower RVPs (9.0 in 1990), as well as a larger diurnal range and higher trip- and emission-weighted average temperature.

Variations in the hot/cold start fractions were selected to be parallel to the previous MOBILE3 sensitivity analysis. For the ozone season, the set of input fractions labeled as "low" represents low levels of both cold and hot starts (5%), resulting in a high level of stabilized emissions. The set labeled "high" represents a high level of hot starts (55%) and low levels of cold starts. For CO season, the "low" input set includes 57% cold starts and the "high" set has a minimum level of hot and cold starts (5%), resulting in a high percentage of stabilized emissions. These designations were used to be consistent with the previous MOBILE3 analysis and the "high" and "low" terms do not refer to the resulting emissions levels.

Ranges for VMT mix, mileage accumulation, and vehicle age distribution were based on input variable sets used in the previous MOBILE3 analysis to represent significant variations from the MOBILE3 defaults. Fairbanks, Alaska, was selected for its high proportion of light duty trucks, low mileage accumulation, and relatively low numbers of older vehicles. The VMT mix and mileage accumulation for California were chosen for the relatively high proportion of cars in the California fleet and the higher levels of mileage accumulation reported. The vehicle age distribution for Phoenix was used as an example of an area where vehicles have relatively long lives.

Sensitivity of MOBILE4 to I/M program parameters was limited to joint variation of compliance and waiver rates from the base case (95% compliance, 8% waivers). The "low" case used 16% waivers and 90% compliance, and the "high" case used 100% compliance and 0% waivers (an ideal program with respect to these variables).

A second set of sensitivity runs was made to illustrate the effects of smaller changes in speed or temperature. These runs were made to illustrate the potential effects of inaccuracies in these two critical variables across their potential ranges. These secondary sensitivity analyses were made by varying temperature and speed for each of the high, low, and default cases in Table 1 by 5°F and 5 mph, respectively.

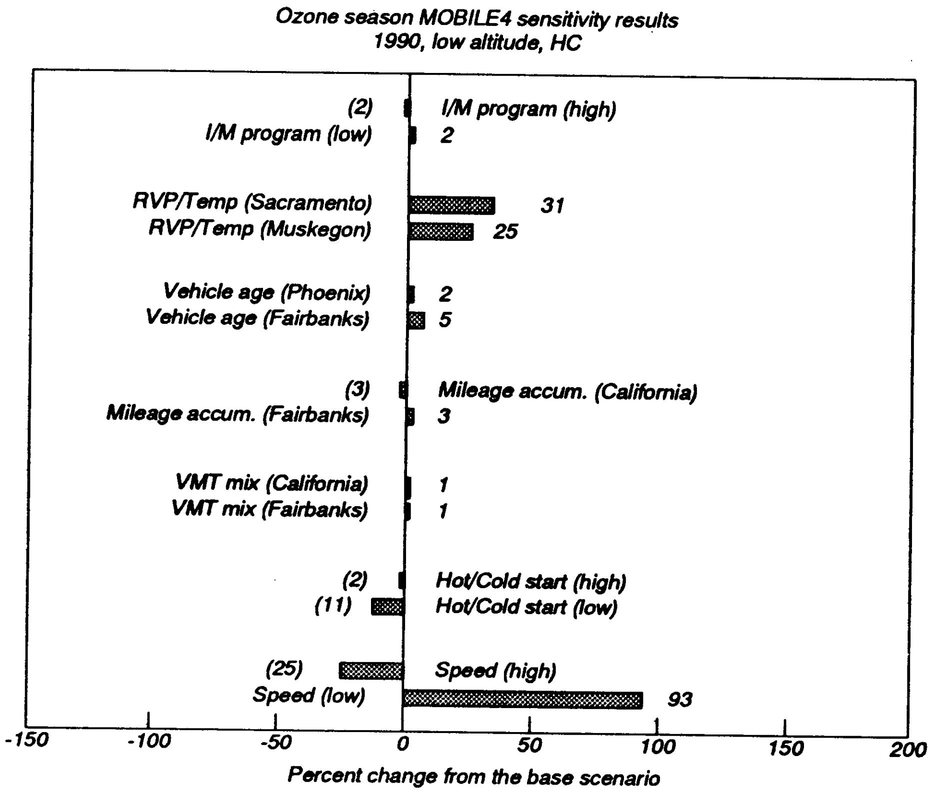
Sensitivity Analysis Results

Figure 1 presents the results of the sensitivity analysis for the primary ozone and CO season cases for 1990 at low altitude. Figure 2 presents the results of the secondary sensitivity runs for speed and temperature, also for 1990 and low altitude.

Results for Low Altitude in 1990

Ozone Season

The first three graphs in Figure 1 show that speed and the combination of RVP and temperature have the largest and most consistent effects. CO is the pollutant most affected by speed, followed by HC, and then NO_x. The joint variation of temperature and RVP to simulate Muskegon and Sacramento resulted in very significant increases in HC and CO for both cases, with NO_x being reduced slightly. This overall effect is due primarily to the differences in temperature, with the HC and CO results for Sacramento being tempered by the lower RVP.



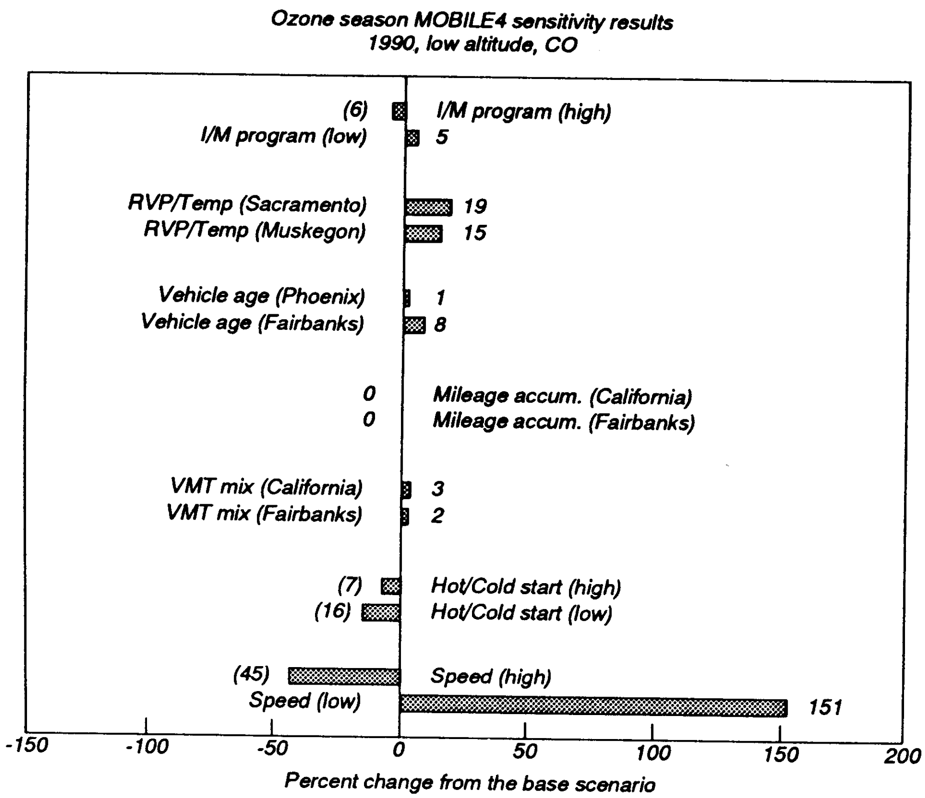
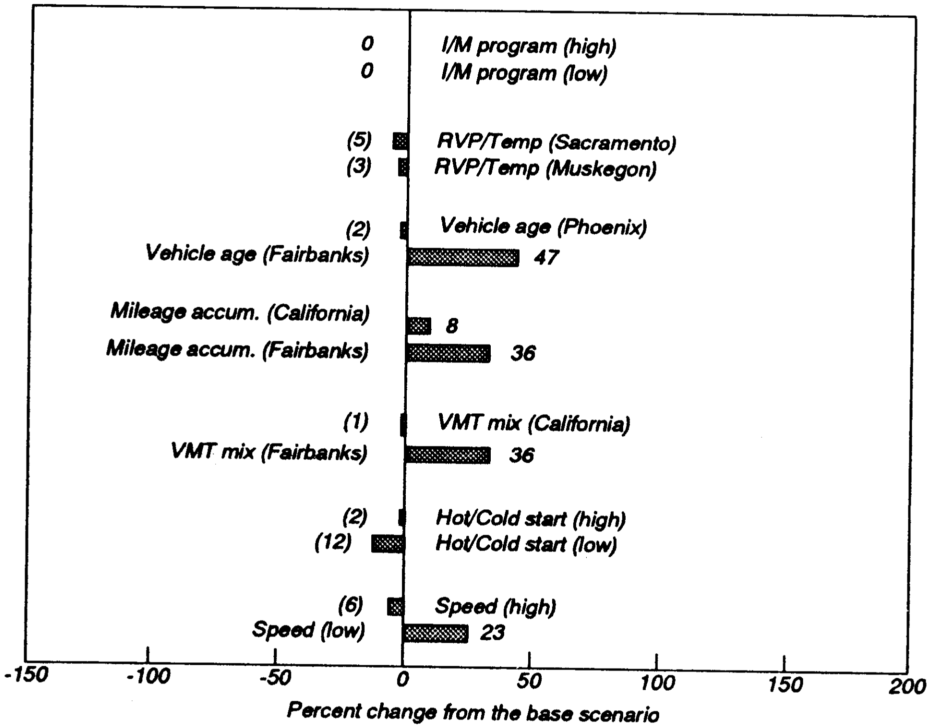


Figure 1. *Primary MOBILE4 sensitivity analysis results (low altitude - 1990).*

Ozone season MOBILE4 sensitivity results
1990, low altitude, NO_x



CO season MOBILE4 sensitivity results
1990, low altitude, CO

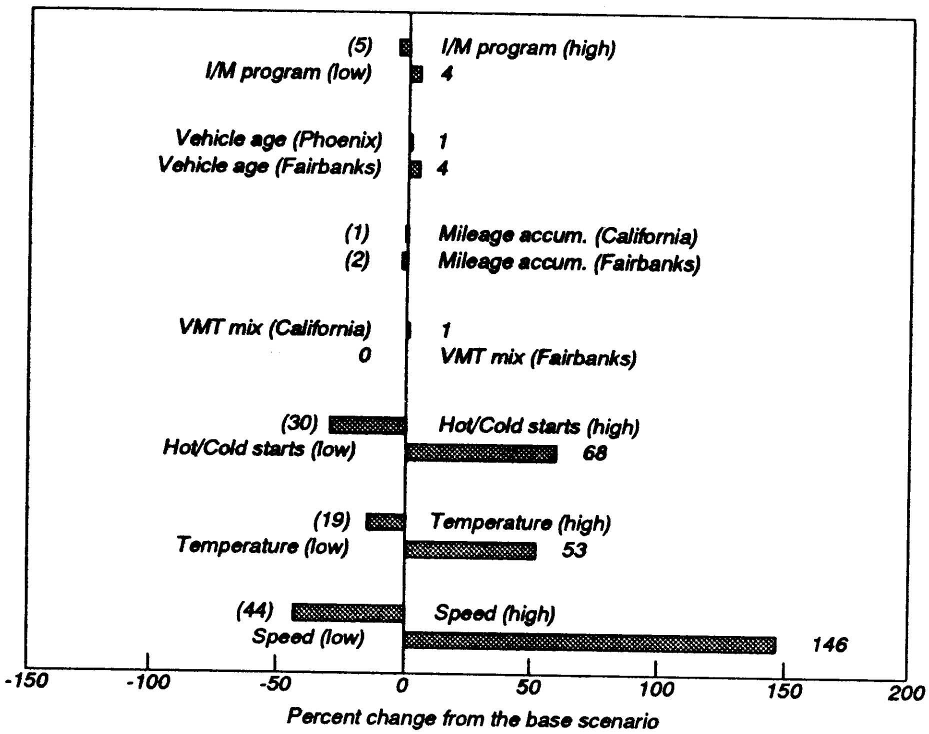
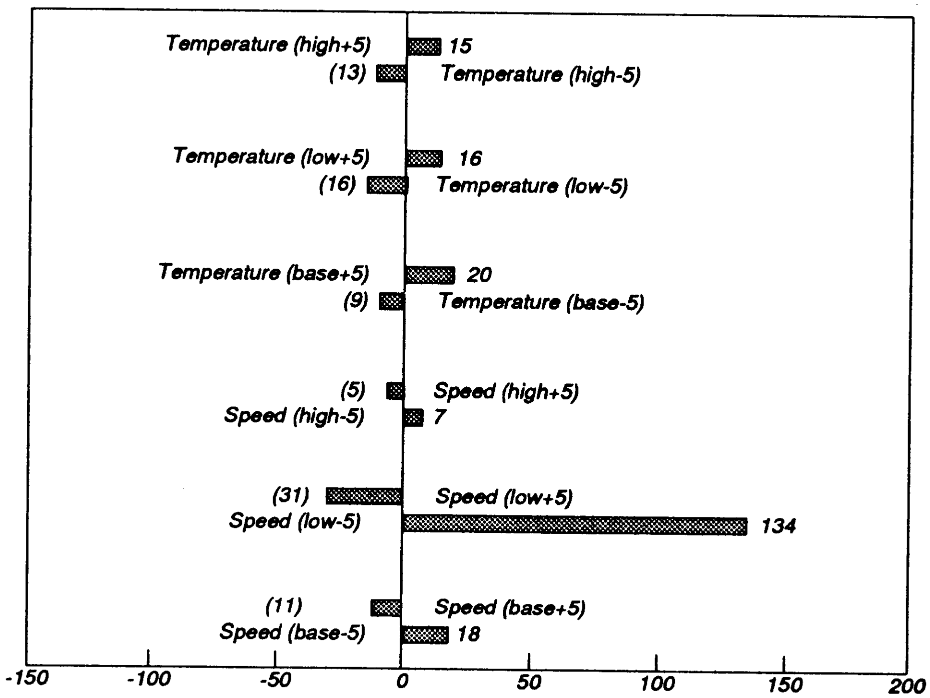


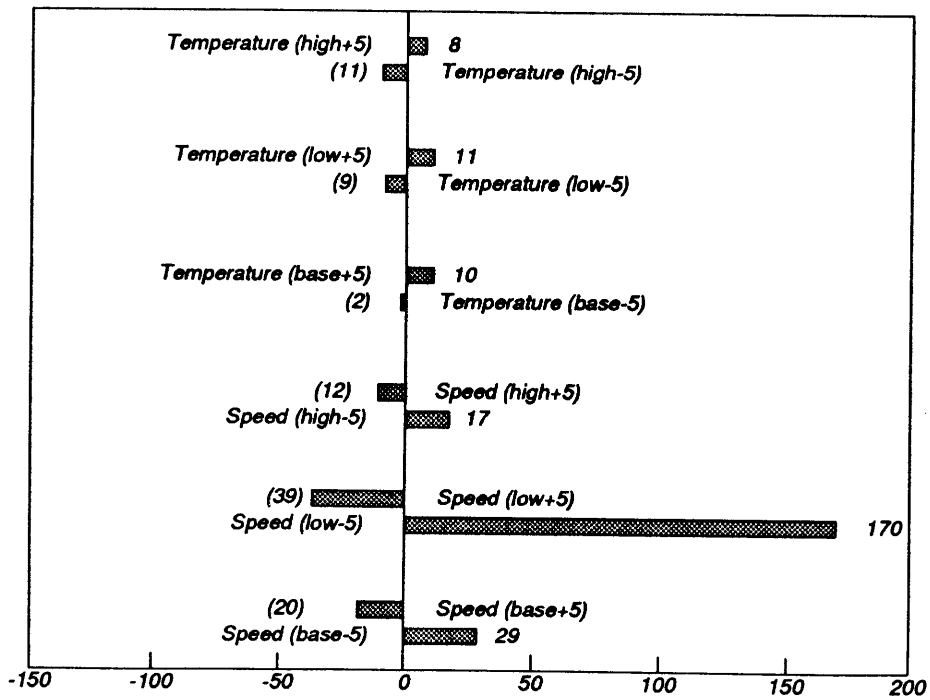
***Figure 1.** (Continued)*

Ozone season MOBILE4 sensitivity results
Secondary temperature and speed ranges for HC



Percent change from the base scenario

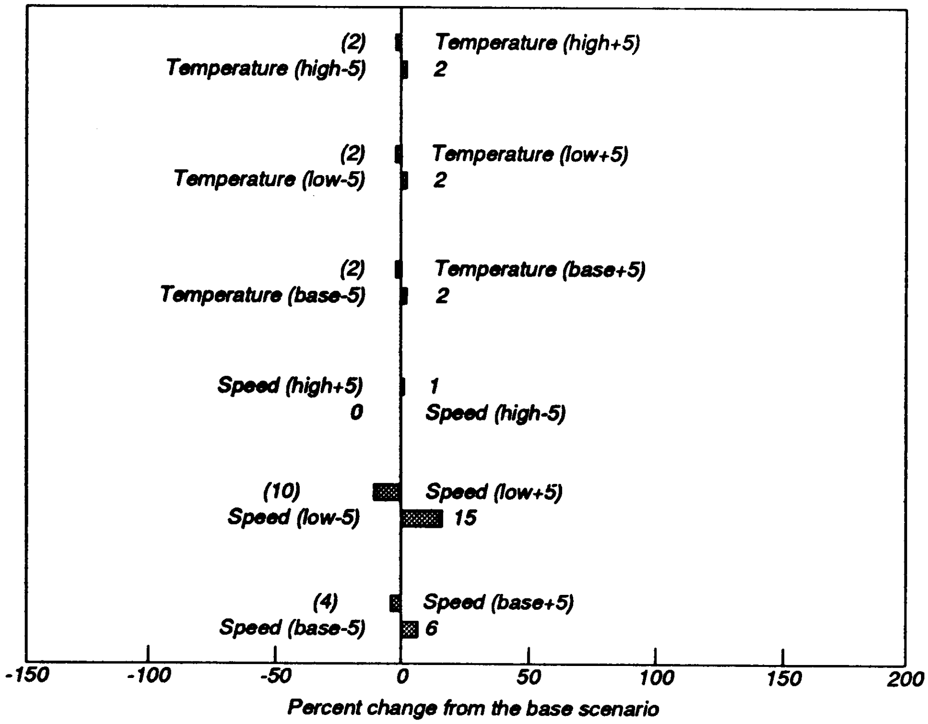
Ozone season MOBILE4 sensitivity results
Secondary temperature and speed ranges for CO



Percent change from the base scenario

Figure 2. Secondary MOBILE4 sensitivity analysis results (low altitude - 1990).

Ozone season MOBILE4 sensitivity results
Secondary temperature and speed ranges for NO_x



CO season MOBILE4 sensitivity results
Secondary temperature and speed ranges for CO

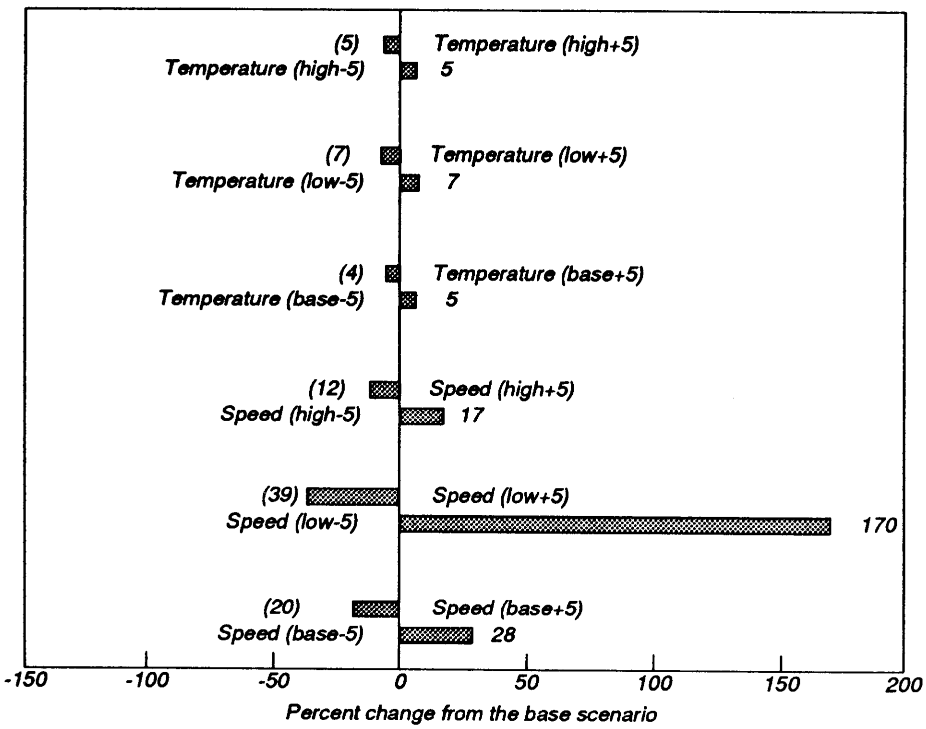


Figure 2. *(Continued)*

Both of the alternate ozone season hot/cold start ratios reduced start emissions for all pollutants. Changes in the I/M program waiver and compliance rates have a relatively small effect on HC emissions, a slightly larger effect of CO emissions, and no effect on NO_x emissions (typical I/M programs are not intended to reduce NO_x).

The three variables associated with local vehicle fleet characteristics (VMT mix, mileage accumulation, and vehicle age distribution) show relatively little effect on overall emissions in 1990. The major exception is the effect of the Fairbanks VMT mix on NO_x emissions, which is mainly due to an increase in heavy duty diesel VMT of 130% over the base case. The Fairbanks VMT mix was also used in conjunction with the Fairbanks vehicle age and mileage accumulation cases, so the NO_x results for these cases are affected similarly. The net result is that the Fairbanks mileage accumulation appears to have no effect and the Fairbanks vehicle age distribution has about 9% additional effect on NO_x emissions. Of the other fleet-related variables, the only results over 5% are the effect of the Fairbanks vehicle age distribution on HC and CO emissions and the effect of the California mileage accumulation on NO_x emissions. The effects of fleet-related variables can vary among pollutants. For example, the California mileage accumulation reduces HC by 3%, increases NO_x by 8%, and has no effect on CO.

CO Season

The last graph in Figure 1 shows the variation of CO fleet composite emission factors from the CO season base case inputs to the CO season ranges shown in Table 1. For the cooler CO season temperatures, speed remains a major variable, and the temperatures and hot/cold start ranges for the CO season also have dramatic effects on CO emissions. Effects are especially pronounced for low speed (7.1 mph), low temperature (11.3°F), and the cold-start-dominated hot/cold start mix. The I/M program ranges have slightly less effect at CO season temperatures than at ozone season temperatures. The vehicle-fleet-related variables also have less effect at CO season temperatures.

Secondary Sensitivity Runs for Speed and Temperature

Figure 2 shows the results of further variation of speed and temperature around the base case and ranges described in Table 1. Secondary ranges of 5°F and 5 mph were used around both the ozone and CO season base cases and the cited primary ranges. This exercise illustrates the sensitivity of MOBILE4 results to small potential errors in these key variables.

In general, the results in Figure 2 indicate that relatively small differences in average speed and temperature can have significant effects on the MOBILE4 composite fleet emission factors for ozone season HC and for CO in both seasons. NO_x is much less sensitive to speed and temperature.

Results for 2005 and for High Altitude

The main purpose of these runs was to identify situations in which the basic conclusions obtained for low altitude in 1990 might change in the future or in the few areas considered high altitude for MOBILE4 modeling. For all future year and high altitude cases, the effect of changing I/M program compliance and waiver rates is marginally less than for low altitude in 1990. For 2005 at low altitude, the following ozone season parameters showed some significant variation from the 1990 base year:

- Effect of the specified RVP/temperature combinations is somewhat smaller for HC and their slightly negative effects for NO_x in the base year become slightly positive for 2005.
- Effects of vehicle fleet parameters and hot/cold start ratios are marginally larger for HC and CO, and are mixed for NO_x.
- Effects of the speed range become a little larger for HC and NO_x, but are reduced for CO.

For the CO season, the results of the specified variations in vehicle fleet parameters are mixed, and results for hot/cold start mix, temperature, and speed are marginally smaller than in 1990.

Going from low to high altitude for the two analysis years results in only a few noticeable changes. The general effects of the vehicle fleet characteristics on ozone season HC and CO at high altitude are somewhat greater for 1990 and are considerably greater in 2005. The Fairbanks VMT mix appears to be responsible for the biggest changes, resulting in roughly double the changes seen for HC at low altitude. Sensitivity to speed is slightly lower in 2005, for ozone season HC and CO emissions as well as for CO emissions in the CO season.

Conclusions

The following general conclusions can be drawn from this analysis:

The most consistently significant variables identified in this analysis are speed and the combination of Reid vapor pressure (RVP) and temperature (temperature alone for the CO season). This is true for current and future years, and for high and low altitudes.

The increasing sensitivity of emissions at lower speeds indicates that methods of incorporating speeds in inventories should be oriented toward better reflection of the true distribution of speeds.

The combinations of RVP and temperature used for the ozone season cases can cause significant variations between areas (about 20 to 30% difference in HC and CO). The effect of RVP is less pronounced in future years due to Federal RVP control mandates.

The overall results for the CO season point out the need for explicit consideration of speed, temperature, and vehicle starts in analyses of CO exceedance situations and for the development of better methods and more accurate data for these variables if possible.

Secondary sensitivity analyses around the base and primary ranges for temperature and speed indicate that relatively small differences in these variables can have significant effects on the MOBILE4 emission factors for ozone season HC and for CO in both seasons.

Results for vehicle fleet characteristics and VMT mix were significant in only a few of the cases in this analysis. The most dramatic result was a 36% increase in NO_x due to a 130% increase in heavy duty diesel VMT in the VMT mix for Fairbanks. The specific fleet-related variables were taken from a previous analysis and no independent attempts were made to determine whether they actually represent appropriate alternative cases for the 1990 and 2005 analysis years. More detailed study of this area could provide inventory managers a better perspective on the value of developing area-specific inputs for these variables and on methods for their development.

Metric Conversions

Readers more familiar with metric units may use the following factors to convert to that system.

Nonmetric	Times	Yields Metric
°F	0.556 (T-32)	°C
gm/mi	1.609	gm/kg
lb	0.454	kg
mph	1.609	km/h
psi	6.895	kPa

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