Evaluation of MOBILE Vehicle Emission Model

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Evaluation of MOBILE
Vehicle Emission Model

prepared for:

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U.S. Department of Transportation

under subcontract to:

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PREFACE

With the passage of the Clean Air Act Amendments (CAAA) of 1990, renewed efforts to properly account for emissions from on-road motor vehicles were initiated. To that end, the U.S. Environmental Protection Agency's (EPA's) motor vehicle emission factor model, MOBILE4, has subsequently been revised three times (i.e., MOBILE4.1, MOBILE5, and MOBILE5a) to improve the predictive capability of the model and to incorporate the effects of CAAA directives aimed at reducing emissions from on-road motor vehicles. Because of the speed at which EPA had to make revisions to the model, documentation of those changes was often limited. In addition, the CAAA and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) call for a more active role from the U.S. Department of Transportation (DOT) in reviewing local area transportation plans and making conformity determinations. EPA's MOBILE model is the analytical tool with which those determinations are to be made. Thus, this report was prepared to provide DOT a better understanding of the structure and operation of MOBILE and to document the changes that have occurred among the model revisions since the release of MOBILE4.

Evaluation of MOBILE Vehicle Emission Model was structured so that individuals with little background related to motor vehicle emissions modeling could familiarize themselves with the basic parameters that make up the MOBILE models. For that reason, Sections 2 and 3, which provide a summary of MOBILE components and describe motor vehicle emission modes (e.g., exhaust versus evaporative emissions), can be skipped by those possessing prior knowledge of motor vehicle emission modeling without a loss of continuity. The remainder of the report addresses the following topics:

- the basic MOBILE modeling approach is presented with a discussion of registration distributions and travel fractions;
- exhaust emissions are discussed, including base emission rates, speed corrections, temperature corrections, operating mode corrections, and idle emissions;
- the approach to calculate evaporative emission rates, which is quite different from the exhaust methodology, is reviewed;
- the methodology to determine the impact of inspection and maintenance on both exhaust and evaporative rates is presented;
- the methodologies used by EPA to account for CAAA requirements (e.g., Tier 1 standards) are reviewed;
- the contribution of model-year groups to the fleet-average emission rate is presented; and
- effects of model changes on fleet-average emission factor estimates are presented for the MOBILE4, MOBILE4.1, and MOBILE5a revisions.

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EXECUTIVE SUMMARY

With the passage of the Clean Air Act Amendments (CAAA) of 1990, renewed effort to properly account for the emissions characteristics of on-road motor vehicles was initiated. As part of this effort, the U.S. Environmental Protection Agency's (EPA's) motor vehicle emission factor model, MOBILE4, has subsequently been revised twice (i.e., MOBILE4.1 and MOBILE5) to improve the.predictive capability of the model and to incorporate other CAAA directives aimed at reducing emissions from onroad motor vehicles. In addition, the 1990 CAAA and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 call for a more active role from the U.S. Department of Transportation (DOT) in reviewing local area transportation plans and making determinations regarding whether these plans are consistent with, and conform to, the State Implementation Plan.

Title I of the CAAA outlines the requirements for conformity determinations. Specifically, air pollutant emissions occurring as a result of changes to an area's transportation network cannot:

- cause or contribute to new violations of the national ambient air quality standards,
- increase the frequency or severity of violations, or
- delay attainment of the standards or any required interim emission reductions.

All federally funded or approved transportation projects must meet these so-called "conformity requirements," and the DOT, in conjunction with local metropolitan planning organizations, is responsible for making such a determination. EPA's MOBILE model is the analytical tool by which the emissions impacts are estimated and the conformity determination is made.

OVERVIEW

Because the MOBILE model must be used in developing the on-road motor vehicle emissions estimates required to make conformity determinations, DOT requires a better understanding of its structure and operation. To that end, Sierra Research (Sierra) was retained to document and evaluate the changes among the MOBILE4, MOBILE4.1, and MOBILE5 versions of the model. This consisted of reviewing succeeding variations to the model to identify changes to existing components (e.g., speed corrections, temperature corrections, deterioration rates, etc.), as well as to evaluate the addition of new components (e.g., modeling of oxygenated

fuels, resting loss emissions, I/M program modifications, etc.). In addition, the impacts of model changes on emission factor estimates were quantified under a variety of vehicle operating conditions (e.g., speed, temperature, hot/cold start mix, I/M, etc.).

The approach that Sierra took in performing this evaluation consisted of first identifying and defining the primary components of MOBILE4. This provided a basis of comparison from which succeeding versions of the model were compared. The information sources utilized by Sierra primarily consisted of the FORTRAN source code and the materials distributed at the workshops held by EPA prior to the release of each model version. (Three workshops were held for MOBILE4; MOBILE4.1 received a single workshop; and two workshops were conducted for MOBILE5.) For cases in which additional detail was needed, EPA's Office of Mobile Sources provided valuable assistance.

DIFFERENCES AMONG MOBILE REVISIONS

MOBILE4, MOBILE4.1, and MOBILE5 are based on the same programming structure, but new data and algorithms have been added in succeeding versions to better represent emissions from in-use motor vehicles. Generally, revisions to the model have been incorporated either (1) to account for compilation of additional test data, or (2) to add new features and options. The summary below describes some of the more substantive changes that have occurred among the three MOBILE releases investigated in this study.

MOBILE4 - This version of the model was released in February 1989, and updated the previous MOBILE3 model. Some of the added data and features included the following.

New Data

- Basic emission rates were updated.
- Tampering and misfueling rates were updated.
- Temperature and speed correction factors were updated.

New Features

- The evaporative emissions component of the model was completely revised to account for minimum temperature, maximum temperature, fuel weathering, and RVP. Further, running loss emissions were included for the first time.
- Higher deterioration rates for light-duty vehicles were assumed for mileages above 50,000.

MOBILE4.1 - Section 130 of the 1990 CAAA directed EPA to review and revise, if necessary, the methods used to estimate emissions of carbon monoxide, volatile organic compounds, and oxides of nitrogen.

As a result of this directive, MOBILE4.1 was released in November 1991. Some of the more significant changes to the model are listed below.

New Data

- Basic emission rates were updated.
- Tampering rates were updated.
- Speed correction factors were updated, particularly for speeds above 48 mph.
- Registration data were expanded from 20 to 25 model years.
- The evaporative emissions data base was substantially enhanced with data stratified according to whether EPA's functional evaporative pressure/purge test was passed.

New Features

- Modeling the effects of oxygenated fuels on CO emissions was included.
- Reporting of hydrocarbon results was expanded (i.e., THC, NMHC, VOC, TOG, or NMOG).
- Evaporative resting losses were included.
- Modeling of Tier I CO and cold-temperature CO emission standards was included.
- Modeling the effects of a transient, chassis-based I/M program was included (i.e., IM240).
- Modeling the effects of a functional evaporative test (i.e., pressure/purge) was included.

MOBILE5 - Initially released in December 1992, the MOBILE5 model included the capability to model the motor vehicle requirements called for in the 1990 CAAA. (In March 1993, MOBILE5a was released. This version was essentially the same as MOBILE5, incorporating some minor corrections to the model.) The primary features associated with MOBILE5 include the following:

New Data

- Basic emission rates were updated, but they were based on IM240 data. This represented a significant departure from EPA's historical method of developing base emission rates from surveillance program vehicles.
- Additional evaporative test data were used to update emission rates for diurnal, hot soak, resting, and running losses.

New Features

- Modeling of "industry average" and reformulated gasoline was included.
- Tier I and heavy-duty NOx emission standards were taken into account.
- Modeling of Low-Emission Vehicles (LEVs) was included.
- Modeling the effects of the new evaporative standards and test procedures was included.

COMPARISON OF MODEL OUTPUT

In general, the hydrocarbon and carbon monoxide model output from the MOBILE4 and MOBILE4.1 versions is reasonably similar for equivalent model conditions of speed, temperature, etc., but the NOx results differ. All emissions estimates from the MOBILE5 release are substantially different compared to MOBILE4 and MOBILE4.1. This is seen graphically in Figures 1, 2, and 3 for hydrocarbons, carbon monoxide, and NOx, respectively. (The model runs upon which these figures were based assumed no inspection and maintenance, an average speed of 19.6 mph, 75øF temperature, and operating mode splits based on the Federal Test Procedure.)

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Although many model changes account for the differences in fleet-average emission rates observed in Figures 1 through 3, one of the primary factors is revisions made to the base emission rate equations. These are shown for light-duty gasoline vehicles in Figures 4 to 6 for HC, CO, and NOx, respectively. These figures indicate that a much higher base emission rate is being predicted in MOBILE5 compared to the previous versions (this change is primarily the result of EPA's use of IM240 data to represent the in-use fleet). It is interesting to note, however, that the MOBILE5 emissions estimates are reduced substantially when accounting for the impact of an enhanced I/M program containing chassis based emission testing and EPA's recommended functional evaporative system check. (This point is expanded upon in Section 10.)

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Another change occurring in the MOBILE5 model that may have implications for conformity analyses is the shape of the fleet-average Nox emission rate as a function of vehicle speed. This is illustrated in Figure 7. The MOBILES emission rate, shown by the top line in the figure, is predicted to Increase as speed increases above 20 mph. Historically, emissions have been assumed to decrease throughout this range until higher speeds were obtained (e.g., refer to the MOBILE4.1 results in Figure 7). However, the MOBILE5 results indicate that traffic control programs that increase average vehicle speed (e.g., from 35 mph to 40 mph) will also increase NOx emissions.

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Finally, idle emission estimates have also changed as the MOBILE models have been revised. Although MOBILE5 and MOBILE5a were released with the idle emissions algorithm disabled, EPA has subsequently issued guidance on how to convert MOBILE5a gram per mile output into gram per hour idle emission rates. (That methodology is reviewed in Section 5.6 of this report.) A comparison of MOBILE4.1 and MOBILE5a fleet-average idle CO emission rates (at 750F and under a no-I/M scenario) is presented in Figure 8, which indicates a significant increase in idle CO emissions when using MOBILE5a, particularly beyond 1995. That increase is attributable to the same model revisions that caused increases in the running exhaust emission rates in MOBILE5a, e.g., increased base emission rates, corrections to account for in-use fuel effects, and increased mileage accumulation rates.

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Although many changes have occurred among the model revisions, there are several areas that have remained relatively constant. For example, temperature correction factors have not been revised since MOBILE4, and modeling of heavy-duty vehicle exhaust emissions has also not been significantly revised since MOBILE4.

1. INTRODUCTION

The estimation of emissions from on-road motor vehicles is important from a number of viewpoints. First, these rates are used to develop regional emission inventories which give an indication of progress made toward meeting (or maintaining compliance with) ambient air quality standards. Second, they are important in determining where efforts should be placed to control air pollution in a community. Finally, on-road motor vehicle emission estimates are used to determine if regional transportation plans and projects are consistent with, and conform to, the State Implementation Plan.

Because of the need to accurately predict motor vehicle emission rates, the U.S. Environmental Protection Agency (EPA) expends considerable resources on data collection programs that help quantify the rate at which pollutants are emitted by individual categories of motor vehicles under a variety of operating conditions. The data collected through these efforts have been used to develop and continually update a computer model that estimates emission rates from the fleet of motor vehicles in a given community. That model, termed "MOBILE", accounts for the effects of a variety of local parameters (such as vehicle mix, speed, temperature, control programs, etc.) on the mass of pollutants emitted from on-road motor vehicles .

EPA has released several versions of MOBILE over the past few years:

- MOBILE4 - released February 1989,
- MOBILE4.1 - released November 1991,
- MOBILE5 - released December 1992, and
- MOBILE5a - released March 1993.

The model has generally been updated to incorporate new data that better represent emissions from in-use vehicles; however, the

MOBILE4.1 and MOBILE5 versions also addressed motor vehicle requirements stemming from the Clean Air Act Amendments of 1990. (MOBILE5a, a variant of MOBILE5, was prepared to correct errors that were found in MOBILE5 subsequent to its release. In this report, much of the analysis was based on MOBILE5. However, in cases where MOBILE5 and MOBILE5a differ, an effort was made to present the MOBILE5a results.)

1.1 SUMMARY OF MOBILE COMPONENTS*

The primary components of the MOBILE emission factor models include the base emission factors, the effect of local conditions (e.g., temperature and vehicle speed), characterization of the vehicle fleet, the impact of fuel characteristics, and the effect of inspection and maintenance programs. None of these factors are static: technology is continually evolving, leading to changing in-use emission performance, while changes in economic conditions can lead to changes in vehicle sales and travel patterns. As alluded to above, EPA expends considerable effort to quantify and stay current with the influence of all of these factors on motor vehicle emission levels. The key factors in the MOBILE models are discussed below.

Emission Factors - Also known as "base emission rates," these factors are developed from test measurements of in-use vehicles at various odometer readings. The emission factors are represented by two components: a zero-mile level (or intercept) and a deterioration rate (or slope). The zero-mile level represents the new-vehicle emission rate, while the deterioration rate depicts emission control system deterioration that takes place as the vehicle ages.

Test Conditions - Standardized test procedures have been developed (e.g., the Federal Test Procedure, or FTP) to measure emission rates from motor vehicles. These procedures include specific driving cycles (i.e., speed versus time profiles), temperatures, vehicle load, and starting conditions. Although the test procedures were developed from data intended to represent average urban driving conditions, they do not necessarily match those that vehicles experience in each community. Therefore, EPA has developed correction factors to account for differences between the test procedures and actual operating conditions.

Fleet Characteristics - The base emission rates represent the average emission level of each model year in the vehicle fleet for each vehicle class (e.g., light-duty vehicles versus heavy-duty vehicles). A fleet average emission rate incorporating the contribution of all model years and vehicle classes is the output from the MOBILE model. The age distribution, the rate of mileage accumulation, and the mix of travel experienced by the vehicle classes considered in MOBILE can all influence the contribution of each vehicle class to the fleet average emission rate. Although the MOBILE models utilize national average data as default values for these parameters, local data can be input by the user to tailor a run for a specific community and provide a more accurate estimate of emissions.

Fuel Characteristics - Emission test measurements are normally conducted on a standardized test fuel known as Indolene. The characteristics of this fuel are well defined and ensure that test results are repeatable. However, in-use fuels are generally much different than Indolene, and

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* Much of Section 2.1 is patterned after a similar discussion contained in EPA'S, "Procedures for Inventory Preparation. Volume IV: Mobile Sources," dated July 1989.

differences in fuel volatility and other fuel parameters (e.g., oxygenate content) influence both evaporative and exhaust emission rates. All MOBILE versions reviewed in this work require fuel volatility as an input. Additionally, MOBILE4.1 provided an option to model the effects of oxygenated fuels on carbon monoxide estimates, and MOBILE5 includes the ability to model the impact of reformulated and oxygenated gasolines on hydrocarbon and oxides of nitrogen emissions as well.

Emission Control Programs - The model-year-specific emission factor equations are based on test data that do not include the effects of local emission control program (i.e., inspection and maintenance (I/M) and anti-tampering programs). These programs are intended to reduce emissions from in-use vehicles, and differences in program design (e.g., annual versus biennial testing) can have a significant impact on their effectiveness. Thus, MOBILE contains provisions for identifying the specific parameters applicable to the program being modeled.

1.2 USER INPUTS

As alluded to above, there are a number of required and optional user inputs to the MOBILE models that allow the user to account for regional differences in travel parameters, ambient conditions, enforcement programs, etc. These are listed in Table 1, and briefly described in the following discussion.

Required Inputs - To run the MOBILE models, a number of local conditions are required that describe the travel parameters, ambient conditions, and fuel parameters. These include the following:

- Volatility class - Although not required in MOBILE4.1, this parameter is required in the MOBILE4 and MOBILE5 versions. It was used in MOBILE4 as a surrogate for fuel volatility in some calculations, 1* and MOBILE5 requires it for modeling the effects of reformulated gasoline.
- Temperature - Because emissions are a strong function of ambient temperature, minimum, maximum, and average daily temperatures are required.
- Reid Vapor Pressure (RVP) - The fuel volatility (measured as RVP in pounds per square inch) also is an important parameter in emissions calculations. The RVP has a significant influence on evaporative emissions (higher fuel volatility translates into higher evaporative emissions), and it also impacts exhaust emission estimates.

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* Superscripts denote references provided in Section 11.

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- Region - The region (i.e., low or high altitude) must also be input by the user. Because vehicles (particularly older vehicles with mechanically based fuel delivery systems) generally run rich at high altitudes (i.e., more fuel is introduced into the combustion chamber than can be completely burned by the available oxygen), hydrocarbon and carbon monoxide emissions are magnified.
- Calendar year - The calendar year of evaluation must be specified by the user. Because of increasingly stringent motor vehicle emission standards, the fleet-average emission rate generally decreases as future years are specified.
- Average speed - Speed also plays an important role in estimating vehicle emissions. Because emissions are reported in grams/mile, lower speeds (i.e., below 20 mph) result in higher emissions (i.e., it takes a longer time to cover the same distance). At high speeds (above 48 mph in MOBILE4.1; above 55 mph in MOBILE5), emissions are also predicted to increase.
- Operating mode - As will be described in the next section, the condition (i.e., cold start, hot start, or stabilized) under which the vehicle is operating has a significant impact on vehicle exhaust emissions. For example, exhaust hydrocarbon emissions can be several times higher while the vehicle is warming up compared to those under stabilized operation.

Optional Inputs - In addition to the above required inputs, the MOBILE models allow for a number of optional inputs that better describe the locality being modeled; these are also shown in Table 1.

Among the more important optional inputs are the following:

- Registration distribution - Because the age of the vehicle fleet is an important parameter in determining the fleet-average emission rate, many local-level analyses make use of this option. Generally, these data are readily available from state Departments of Motor Vehicles.
- Inspection and maintenance (I/M) programs - If an area has an operating I/M program, the effects of this can, and should, be modeled. The impact can be quite significant, particularly for transient, loaded mode programs which can be modeled by MOBILE5.
- Anti-tampering programs - I/M programs often include a visual check of emission control system components to assure the vehicle owner has not disabled or otherwise tampered with the system. The MOBILE models allow for the impact of these programs to be modeled.
- Refueling emissions - Although many air pollution control districts consider refueling emissions (i.e., emissions that occur when a fuel tank is filled) to be stationary source emissions, the MOBILE models are capable of modeling this process.

- oxygenated and reformulated fuels - Fuels containing oxygenates (e.g., ethanol) result in significant reductions in exhaust hydrocarbon and carbon monoxide levels. Additionally, the reformulated gasoline requirements contained in the 1990 CAAA result in decreased hydrocarbon emissions. MOBILE4.1 is capable of modeling the impact of oxygenated fuels on carbon monoxide emissions, while MOBILE5 has the capability of modeling the effects of oxygenated fuels and reformulated gasolines on hydrocarbon, carbon monoxide, and oxides of nitrogen emissions.

1.3 MODEL OUTPUT

The MOBILE output consists of exhaust hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) emission rates (in grams/mile [g/mi]) for eight separate vehicle categories:

- LDGV light-duty gasoline vehicles (i.e., passenger cars),
- LDGTL light-duty gasoline trucks (under 6000 lbs. gross vehicle weight),
- LDGT2 - light-duty gasoline trucks (6000 to 8500 lbs. gross vehicle weight),
- HDGV - heavy-duty gasoline vehicles (over 8500 lbs. gross vehicle weight),
- LDDV - light-duty Diesel vehicles (i.e., passenger cars),
- LDDT - light-duty Diesel trucks (under 8500 lbs. gross vehicle weight),
- HDDV - heavy-duty Diesel vehicles (over 8500 lbs. gross vehicle weight), and
- MC - motorcycles.

In addition, evaporative HC emissions are reported as g/mi or grams/event (e.g., grams per hot soak).

A sample output file from a MOBILE5a run for the year 2000 is given in Figure 9. For this run, two different biennial I/M programs were specified: a 2500 rpm/idle test for 1968 to 1985 model year LDGV, LDGT1, and LDGT2; and an IM240 test (i.e., a chassis-based transient test) for 1986 and subsequent model year LDGV, LDGTI, and LDGT2. In addition, a functional check of the evaporative emission control system was specified, as was an ATP. The emission results are reported for each vehicle type separately, and a composite rate for all vehicles is also computed by the model and included in the output. Note that the "Evaporat HC" value reported in g/mi includes hot soak, diurnal, and crankcase emissions that have been converted to a g/mi basis.

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1.4 ORGANIZATION OF THE REPORT

Following this introduction, Section 3 contains an overview of motor vehicle emission modes (e.g., cold start, hot start, etc.) which introduces the reader to the processes that lead to emissions from motor vehicles. This background information serves as a basis from which modeling of these modes can be discussed. Section 4 is a summary of the standard modeling approach used by the MOBILE models. Information on fleet make-up is introduced in this section. Exhaust emissions modeling is detailed in Section 5. This includes a discussion of standard test procedures as well as the development of base emission rates and various correction factors. Considerable time is spent in comparing how these parameters have changed among revisions to the model. Evaporative emissions are treated in Section 6, which details the modeling methodologies used in the MOBILE models and makes comparisons among MOBILE revisions. Because of its increasing importance as an air pollution control.strategy, modeling of I/M programs is discussed separately in Section 7. The main focus of this discussion is on the methodology utilized in MOBILE5 to model the impact of I/M. The Clean Air Act Amendments of 1990 contained a number of features related to the control of on-road motor vehicles (e.g., more stringent emissions standards, reformulated gasoline). The methodologies by which these requirements are modeled are discussed in Section 8. Section 9 contains a summary of emissions versus vehicle age which provides insight regarding the fraction of emissions attributable to older versus newer vehicles. That fraction has ramifications in terms of determining where efforts should be placed to control emissions from motor vehicles (i.e., should the focus be on new vehicle standards or in-use control programs). Finally, Section 10 summarizes how the changes incorporated in MOBILE4, MOBILE4.1, and MOBILE5 resulted in differing emissions estimates for on-road motor vehicles. (MOBILE5a was used in making these comparisons.)

2. DEFINITION OF MOTOR VEHICLE EMISSION MODES

Motor vehicle emissions consist of a large number of chemical species that primarily result from combustion within the engine and from fuel evaporation at various locations throughout the fuel delivery and storage system. Three particular emission components are modeled by the MOBILE models: hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). These are the emission components that result in the two major nonattainment pollutants related to mobile sources: ozone and carbon monoxide.

The quantification of emissions involves determining emission rates for two fundamentally different types of emission-producing processes: emittance from the vehicle's exhaust system, and evaporation from the fuel storage and delivery system. Emissions from each of these basic types of emission-producing processes, exhaust and evaporative, can be further categorized, as discussed below.

2.1 EXHAUST EMISSIONS

Cold Start - Under cold start conditions, the vehicle engine has been turned off for some time and the catalytic converter (if the vehicle is so equipped) is cold. HC and CO emissions are higher when a cold engine is first started than after the vehicle is warmed up. This is because catalytic emission control systems do not provide full control until they reach operating temperature (i.e., light-off), and a richer fuel air mixture must be provided to the cylinders under cold operating conditions to achieve satisfactory engine performance (e.g., startability and driveability). (EPA considers a cold start for a catalyst-equipped vehicle to occur after the engine has been turned off for one hour. For non-catalyst vehicles, a four-hour engine-off period distinguishes a cold start.) Rich mixtures are necessary to achieve smooth combustion during warmup because gasoline does not fully vaporize and mix with the air in a cold engine. Extra fuel is added to ensure that an adequate amount of fuel is vaporized to achieve a combustible mixture. Complete vaporization eventually occurs in the engine cylinder as a result of the high temperatures created by combustion. However, the excess fuel that was needed to ensure adequate vaporization to start the combustion process cannot be completely burned due to a lack of sufficient oxygen in the cylinder. The result is that partially burned fuel and unburned fuel are emitted in relatively high concentrations from a cold engine. Elevated emissions of these pollutants in this cold transient phase occur from the time a cold engine starts until it is fully warm. While engine-out NOx emissions tend to be low during rich operation of a cold

engine, the lack of catalyst activity to control this pollutant results in elevated cold start NOx emissions as well.

Hot Start - Under hot start conditions, the vehicle engine has been turned off for such a short time that the catalyst has not had time to cool to ambient temperature. Thus, the warm-up period is shorter (if present at all) than that required under cold start conditions. For that reason, HC and CO hot start emissions are significantly lower than under cold start operation. Under the standard test procedure used by EPA, a "hot start" is a test that begins exactly 10 minutes after a fully warmed up engine has been shut off. After only 10 minutes, no mixture enrichment is required to achieve a reliable re-start and the catalyst is usually still above its "light-off" temperature.

Hot Stabilized - After warmup has occurred, and the engine and emission control systems have reached full operating temperatures, the vehicle is considered to be in the hot stabilized mode. Generally, emissions are relatively low (compared to cold start emission rates) under hot stabilized conditions. However, emissions are also highly dependent on vehicle speed and engine load. Recent analysis by Sierra2 has revealed that varying off-cycle load conditions (i.e., under conditions not tested on the standard automotive driving cycle used for vehicle certification purposes) can have a dramatic impact on emissions.

Idle Emissions - Although not generally considered for inventory purposes, idle emissions may need to be considered for certain transportation-related analyses. The MOBILE models report idle emissions in terms of grams/hour, and emissions are a function of operating mode (i.e., stabilized or cold start) and temperature. Because many of the changes incorporated into the MOBILE5 model (e.g., incorporation of Tier I emission standards, reformulated gasoline, low emission vehicles) resulted in unreliable estimates of idle emissions, the idle subroutines have been temporarily disabled in MOBILE5. When MOBILE5 was released, EPA recommended continued use of MOBILE4.1 to estimate idle emission rates. However, EPA has recently developed a methodology to convert MOBILE5a gram/mile running exhaust emission rates to gram/hour idle rates. (This approach is discussed in Section 5.6.)

2.2 EVAPORATIVE EMISSIONS

Evaporative emissions consist entirely of hydrocarbon emissions. These emissions can be categorized into the six groups discussed below.

Hot Soak - When a hot engine is turned off, fuel exposed to the engine (e.g., in carburetor float bowls or in fuel injectors) may evaporate and escape to the atmosphere. These so-called "hot soak" emissions are modeled by MOBILE as grams/event, which are then converted within the model to a g/mi basis.

Diurnal - Diurnal temperature fluctuations occurring over a 24-hour period cause "breathing" to occur at the gasoline tank vent. To prevent the escape of fuel vapor, the vent is routed to a charcoal canister where the vapor can be adsorbed and later purged into the running

engine. These emissions are calculated by the MOBILE models in terms of grams/event, and, as with hot soak emissions, are then converted to a g/mi basis.

Running Losses - Running loss emissions are those resulting from vapor generated in gasoline fuel tanks during engine operation.

Running losses are especially a problem on vehicles that have exhaust systems in close proximity to the gasoline tank. Running loss emissions occur when the vapors emitted from the tank vent exceed the rate at which they are being purged from the canister by the engine. This HC emission category had long been assumed to be insignificant, but research over the past several years has shown this assumption to be incorrect, and running losses have been included in EPA's emission factors models since the MOBILE4 version (published in 1989). These emissions are calculated by the MOBILE models in terms of g/mi.

Resting Losses - Resting losses have only recently been included in the MOBILE models, with the MOBILE4.1 version (published in 1991) including resting losses for the first time. EPA considers resting losses to be "those emissions resulting from vapors permeating parts of the evaporative emission control system (e.g., rubber vapor routing hoses), migrating out of the carbon canister, or evaporating liquid fuel leaks."3 EPA also states that a portion of what are now considered resting losses was previously included in the hot soak and diurnal categories. Resting losses are dependent upon temperature and the type of carbon canister that is used in the evaporative emission control system (i.e., open-bottom versus closed-bottom). These emissions are calculated as grams/hour and are then converted to g/mi.

Refueling Losses - There are two components of refueling emissions: vapor space displacement and spillage. As a fuel tank is being refueled, the incoming liquid fuel displaces gasoline vapor that has established a pseudo-equilibrium with the fuel in the tank, effectively "pushing' the vapor out of the tank. Spillage simply refers to a small amount of fuel that is assumed to drip on the ground and subsequently evaporate into the ambient air. Refueling emissions are calculated in terms of grams/gallon of dispensed fuel and are converted to a g/mi basis.

Crankcase Emissions - Although not a true "evaporative" source, crankcase emissions are generally considered in the evaporative emissions category. They are the result of defective positive crankcase ventilation (PCV) systems that allow blow-by from the combustion process (which is normally routed to the vehicle's intake manifold) to escape to the atmosphere. These emissions are modeled as grams/mile.

3. STANDARD MOBILE MODELING APPROACH

Emissions from each of the processes outlined in Section 3 are estimated by EPA's MOBILE models separately for the eight vehicle classes included in the models (i.e., LDGV, LDGTI, LDGT2, HDGV, LDDV, LDDT, HDDV, and MC). The emissions estimate is performed by first determining the emission rate of each model year making up the vehicle class, weighting the model-year-specific emission rate by the fractional usage experienced by that model year (i.e., travel fraction or VMT fraction), and summing over all model years that comprise the vehicle class. In addition, a variety of corrections are applied to the base emission rates to account for conditions that are not included in the standard test cycles used to develop the base emission rates (e.g., exhaust emission rates may be corrected for non-standard speeds, evaporative emissions may be corrected for non-standard temperatures, etc.).

In equational form, the calculation can be described by:

$$EFi,j,k = \overset{n}{\underset{m-1}{\text{ä}}}\ Tpm * (BERj,k,m * CFj,k,m...) \qquad [4-1]$$

where EFi,j,k = fleet-average emission factor for calendar year i, pollutant j, and process k (e.g., exhaust, evap);
TFm = fractional VMT (i.e., travel fraction) attributed to model year m (the sum of TFm over all model years n is unity);
BERj,k,m = base emission rate for pollutant j, process k, and model year m;
CFj,k,n = correction factor(s) (e.g., temperature, speed) for pollutant J, process k, model year m, etc;

and the sum is carried out over the n model years making up the vehicle class (e.g., 20 years for LDGV-in MOBILE4, 25 years in

MOBILE4.1 and MOBILE5).

3.1 REGISTRATION DISTRIBUTION AND TRAVEL FRACTION

The registration distribution and resulting travel fraction has an important impact on the calendar-year-specific, fleet-average emission factors. This is particularly apparent for cases in which the model year emission factors undergo significant changes from one year to the next (e.g., when new emission standards are implemented). A higher proportion of the travel fraction being allocated to newer vehicles (with presumably lower emission rates) will result in a lower fleetaverage emission rate, and thus, lower inventory calculations.

The methodology to calculate travel fractions has not changed among the three versions of the MOBILE models being evaluated in this work. It is based on applying an estimated annual mileage accumulation rate by vehicle age (determined from National Purchase Diary data) to an estimated registration distribution (from Polk data) for the number of model years assumed to comprise the fleet (i.e., 20 model years for MOBILE4; 25 model years for MOBILE4.1 and MOBILE5). The travel fraction for each model year (TFm) is calculated from:

$$TFm = \frac{REGm * MILESm}{\sum_{m=1}^{n} (REGm * MILESm)}$$

where MILESm represents the annual mileage accumulation for model year m, REGm. represents the registration fraction for model year m, and n is the total number of model years in the fleet. Prior to performing the calculation, however, the registration and mileage accumulation data ' are modified to reflect a January 1 analysis date. (MOBILE4 and MOBILE4.1 calculated emissions on January 1 of the calendar year of evaluation, whereas MOBILE5 also allows the option of a July 1 evaluation date. However, the MOBILE5 July 1 methodology simply interpolates between two consecutive January 1 evaluations. Thus, the VMT distribution is still based on a January 1 evaluation date, regardless of whether a July evaluation is requested.)

The registration distributions used to calculate the travel fractions for LDGV in MOBILE4, MOBILE4.1, and MOBILE5 are shown in Figure 10. (Note that the registration distributions hard-coded in the models are on a July 1 basis. Thus, optional area-specific registration distributions, which can be input by the user, must also be on a July 1 basis.) As seen, the registration distribution for light-duty vehicles (which includes Diesels in this figure) was substantially modified for the MOBILE4.1 version. The uneven distribution for MOBILE4.1 and MOBILE5 reflects EPA's choice to use data that depict actual sales fractions through the 1980s, rather than develop a more generic curve that assumes a steady decline in population as vehicles age. Such an approach provides more reliable estimates of emissions, as long as the historical sales peaks and valleys move as the evaluation year changes. This is not the case with MOBILE4.1 and MOBILE5, as the same registration distribution is used for all evaluation years. Thus, future-year projections made with MOBILE4.1 and MOBILE5 assume an historical registration distribution. (EPA understands this concern and is considering an alternative approach to project future-year registration distributions that could be used in conjunction with the model.)

Figure 11 illustrates the mileage accumulation rates used in the MOBILE models. As seen, mileage accumulation by vehicle age was assumed to increase between MOBILE4.1 and MOBILE5, and the same relative increase (i.e., 9.7 percent) was assumed for all vehicle ages. This change was made to update the MOBILE4 and MOBILE4.1 mileage accumulation rates, which were based on 1984 National Purchase Diary (NPD) data, with 1990 data. The methodology employed by EPA consisted of comparing data from

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the Federal Highway Administration on total vehicle miles in 1984 and 1990.4 The results indicated a 9.7% increase in miles per vehicle between 1984 and 1990. Thus, this factor was applied to the mileage accumulation rates.

Finally, Figure 12 shows the calculated travel fraction for the three MOBILE versions. MOBILE4.1 and MOBILE5 attribute a higher fraction of VMT to newer vehicles than does MOBILE4. As discussed above, this can be important in terms of estimating the benefits of new control measures.

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4. EXHAUST EMISSION METHODOLOGIES

The cornerstone of exhaust emissions estimates using the MOBILE models is the model-year-specific base emission rates. For light-duty vehicles, these emission rates (in grams/mile) are determined by testing vehicles over a standardized test cycle on a chassis dynamometer. Because the standard test cycle does not include all operating conditions that can be encountered, correction factors have been developed that adjust the base emission rates for operating mode fractions (i.e., percent of VMT spent in cold start, hot start, and stabilized modes), temperatures, and speeds not represented by the test cycle. Presented below is an overview of the test cycle used to generate exhaust emissions data, the analytical approach taken in developing the model-year-specific base emission rates, and a discussion of the various corrections that are applied to account for non-standard conditions. Although emissions modeling of heavy-duty vehicles contains many of the same elements as that of light-duty vehicles, the treatment is different enough to warrant a separate subsection. Thus, this section concludes with a review of the methodologies employed by the MOBILE models to estimate emissions from heavy-duty vehicles.

4.1 BACKGROUND

Standard Test Procedure - The basic exhaust emissions data contained in the MOBILE models are based on a standardized driving cycle called the Urban Dynamometer Driving Schedule (UDDS), or "LA4 cycle." This chassis dynamometer test cycle involves duplicating a speed-time profile from an actual road route identified in the Los Angeles area in the late 1960s and chosen to represent the typical urban area driving pattern. The driving cycle was then incorporated into EPA's Federal Test Procedure (FTP), the testing process used by all motor vehicle manufacturers to certify that their vehicles are capable of meeting federal emission standards.

The FTP consists of three distinct segments at a standard test cell temperature of 68ø to 86øF. Because the mass emissions from each of the three segments are collected in separate tedlar bags, the three operating modes are often referred to in terms of "bags." A complete FTP is comprised of:

- a cold start (or cold transient) portion ("Bag 11), which is the first 3.59 miles of the UDDS (505 seconds in length);
- a stabilized portion ("Bag 2"), which is the final 3.91 miles of the UDDS (867 seconds in length); and

a hot start (or hot transient) portion ("Bag 3"), which is the first 3.59 miles of the UDDS and follows an engine-off period of 10 minutes.

The LA4, shown in Figure 13, has been the standard driving cycle for the certification of light-duty vehicles since the 1972 model year. It is approximately 7.5 miles in length with an average speed of 19.6

mph. The cycle includes 18 segments of non-zero speed activity (at varying engine loads) separated by idle periods. Since the 1975 model year, the initial 505 seconds of the cycle have been repeated following a 10 minute hot soak. It is believed that after cold/hot start weighting factors (i.e., 43 percent of the starts are assumed to be cold starts, 57 percent are assumed to be hot starts) are applied to the Bag 1 and Bag 3 results, the test provides a more accurate reflection of typical customer service than running just one 7.5 mile cycle from a cold start.5 This change was incorporated because a significant fraction of vehicle starts do not occur with the vehicle in a completely cold condition, and running the first 505 seconds of the LA4 with the vehicle in a warmed-up condition gives an indication of stabilized emissions over a higher speed cycle than represented by Bag 2. The FTP composite emission rate is calculated from the bag-specific emissions results according to the following formula:

$$BER = \frac{3.59 * (0.43 *BAG1 + 0.57 *BAG3)}{7.5} + \frac{3.91 *BAG2}{7.5} \qquad [5\text{-}1]$$

which reduces to

$$BER = 0.206 *BAG1 + 0.521 *BAG2 + 0.273 *BAG3 \qquad [5\text{-}2]$$

where BER = composite FTP base emission rate (g/mi),
BAG1 = bag 1 emission rate (g/mi),
BAG2 = bag 2 emission rate (g/mi), and
BAG3 = bag 3 emission rate (g/mi).

Corrections for Nonstandard Conditions - Because the emissions test is performed over the same standard operating conditions for all vehicles, the MOBILE emission factor models make use of a variety of correction factors to tailor the FTP results to the specific local conditions being modeled. For example, operating mode correction factors (also referred to as bag correction factors) are applied to the FTP composite emission rate to determine the emission rate of a vehicle in the cold start mode, stabilized mode, or hot start mode. Because emission rates from motor vehicles are much higher at very low temperatures, temperature correction factors are used to account for this effect. Finally, a vehicle's emission rate is also a strong function of its average speed. Thus, speed correction factors modify the FTP results to account for speeds different from the FTP average of 19.6 mph.

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The overall emission rate from a vehicle is the product of the basic emission rate (determined from the FTP results) and a number of correction factors that are specific to the conditions being modeled. Although the actual modeling procedure is very complex, this can be simply represented by:

$$EF = BER * BCF * TCF * SCF \qquad [5\text{-}3]$$

where EF = emission factor (g/mi) corrected for operating mode, temperature, and speed;
BER = composite FTP base emission rate (g/mi);
BCF = bag (or operating mode) correction factor;
TCF = temperature correction factor; and
SCF = speed correction factor.

Each of these parameters is described below.

4.2 DATA USED FOR DEVELOPING BASE EMISSION RATES

As outlined above, the base emission rates form the foundation upon which all ensuing calculations are based. The base emission rate equation is a linear function of vehicle mileage, with emissions increasing as the vehicle ages. Thus, the BER is described by two components: a zero-mile (ZM) level and a deterioration rate (DR). For some model years, pollutants, and vehicle types, however, EPA has determined that the deterioration rate increases beyond 50,000 miles. In some cases, therefore, the BER equation has two deterioration rates, termed DR1 and DR2.

There are many factors that must be considered when developing the base emission rate equations, but primary among these is the necessity that the base emission rates truly represent emissions from in-use vehicles for the vehicle class and model year being analyzed. Because it is often not possible to test enough vehicles to obtain a representative data set upon which the base emission rate equations can be developed, various modeling strategies have been developed to improve the predictive capability of these equations. The following discussion addresses some of the details that must be considered when analyzing data for the development of the base emission rate equations.

Data Sources - The raw data used to determine the base emission rates (often referred to as "emission factors") are generally derived from routine surveillance programs and occasional special studies conducted by EPA. The extent to which the data are adjusted prior to their use can have a significant effect on the emission factors. For example, vehicles tested in surveillance programs are sometimes subjected to pre-screening criteria that can "filter" the resulting data set. For example, CARB's practice of rejecting vehicles that are considered "unsafe" for testing can eliminate a valid fraction of the vehicle population that includes a relatively high fraction of gross emitters. (However, EPA does not believe this to be a problem with their data bases.) The selection of the results of a particular test (or series of tests) for analysis can affect the final emission factors.

Treatment of Gross Emitters - There is a clearly identifiable subset of the vehicle population consisting of vehicles that, for a variety of reasons, exhibit emission levels many times above the applicable emissions standards. Depending upon how this subset is defined (e.g., vehicles with emissions more than ten times the standard), the frequency of these vehicles in the overall population can be relatively small. If the frequency of these gross emitters is less than 1 percent, then a total surveillance data set of even 5000 vehicles will include only 50 gross emitters spanning a wide range of model years, emission control technologies, and age/odometer levels. The use of typical mobile source analytical techniques (such as linear regressions of emissions vs. mileage, or population size vs. mileage) can result in conclusions that depend heavily on the tests of just a few vehicles. That is because these vehicles exert a disproportionately large influence on the fleet average emission factors that are ultimately developed.

An alternative approach to estimating emissions from these vehicles is to conduct a controlled series of tests on a small group of vehicles, deliberately introducing component malfunctions and determining their effect on vehicle emissions. These data can then be used with larger data sources (such as data from I/M programs) that determine the frequency of these malfunctions to establish emission factors for this small but important segment of the vehicle population. However, this

approach can result in inaccuracies regarding synergistic and antagonistic effects of multiple malfunctions.

For 1981 and subsequent model year vehicles, EPA utilizes a variant of the latter approach by stratifying vehicles according to emission level (i.e., 'emitter categories') and estimating the emission rate and occurrence of each category as a function of vehicle mileage. This approach, embodied by the Tech IV6 and subsequent emission factors models, is discussed in detail below.

Tampering - The portion of the vehicle fleet that has had some or all of its emission control capabilities deliberately de-activated also has a large effect on fleet emissions. While the effect on emissions is identical regardless of whether an EGR valve fails in the closed position (no flow) or is disconnected, the different causal factors can influence assumptions regarding the frequency of occurrence of these events. In addition, some components are more prone to deliberate tampering (EGR valves, air injection pumps, catalysts), while other components have problems that are more typically associated with excessive wear or improper maintenance (evaporative control systems, PCV valves, fuel system components).

The problems with the treatment of tampering are similar to those of other gross emitters: a small number of vehicles can exert a disproportionately large influence on fleet average emissions. The options for analyzing these vehicles include:

- implicitly including the vehicles in the overall surveillance population, with no separate explicit analysis;
- segregating the vehicle population based on whether tampering appears to have occurred, separately analyzing the two classes of vehicles, and combining the results of the analyses using assumed (or computed) frequencies; and
- eliminating vehicles that have been subjected to tampering from the surveillance vehicle population, and developing emission factors and frequency distributions for these vehicles based on special test programs and assumed (or computed) frequency distributions.

For the MOBILE models, EPA has chosen the third option and has developed a "tampering offset" that is added to the base emission rate equation prior to the application of correction factors.

4.3 TECH IV EMISSION FACTORS MODEL

As long as the data base used to develop the BER equations is representative of the in-use fleet of vehicles, a simple regression technique adequately models emissions as a function of vehicle mileage. However, EPA has found that the technology used to control emissions from 1981 and later vehicles results in the random occurrence of

high-emitting vehicles that would not necessarily be properly accounted for using the above methodology.6 In addition, a means to account for the impact of an inspection and maintenance (I/M) program was needed. Thus, a separate model was developed that generates base emission rates and I/M benefits for 1981 and later light-duty vehicles. This model is termed the 'Tech IV Credit Model" and is described below. (This modeling procedure was used to determine only HC and CO BER equations for MOBILE4 and MOBILE4.1, while NOx emissions were determined by a simple weighting of regression equations. To estimate effects of I/M programs on NOx emissions, MOBILE5 used the more complex process to calculate the NOx BER equations as well.)

A flow chart outlining the Tech IV model, as it was applied in developing the MOBILE4 base emission rate equations, is illustrated in Figure 14. (The Tech IV model was modified in subsequent revisions to the MOBILE model; however, the basic methodology as described here has remained essentially unchanged.) In summary, the methodology calls for stratification of FTP emissions data by model year, technology group, and emission level (or 'regime"). The emission rate (g/mi) for each emission regime (which is a function of accumulated mileage and differs according to technology type) is then multiplied by the fraction of the regimes making up the fleet (also a function of vehicle mileage and technology type). These values are summed to arrive at the technology specific emission rates as a function of mileage. Model-year-specific emission rates (at each mileage interval) are determined by weighting each technology group by the anticipated sales fraction for each technology for the model year of interest. The above calculation is carried out at the mileage intervals corresponding to 20 model years (25 model years for MOBILE4.1 and MOBILE5), and the ZM, DR1, and DR2 components of the base emission rate equation are determined from the resulting emission values.

The 1981 and subsequent model year BER equations developed for MOBILE4 were based on segregating the FTP emissions data into two model-year groups (1981-1982 and 1983+), while three distinct technology types were considered: carbureted closed-loop, fuel-injected closed-loop, and open-loop (both carbureted and fuel-injected). These stratifications were chosen because, from an engineering perspective, vehicles within each group should exhibit similar emissions characteristics. (Note that in succeeding versions of the model, the closed-loop fuel-injected category was further stratified into multipoint (MPFI) and throttle-body (TBI) fuel injection.)

The emission regimes utilized for the MOBILE4 BER equations were defined as follows:

- "Normals" - emissions at or below the FTP certification level;
- "Marginals" - fail either HC or CO, but are not "Highs" or "Supers";
- "Highs" - either HC or CO emissions more than two standard deviations above the mean among vehicles with less than 50,000 miles; and

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- "Supers" - emissions either above 10 g/mi HC or 150 g/mi CO for all model year groups and technology types.

The emission regime cutpoints are listed in Table 2 for the 1983+ model year group, and the HC emission rates for each regime (as a function of mileage) are summarized in Table 3. As outlined in Table 3, the emission rate of the Super regime is the same for the

		Emission Level (g/mi)	
Regime	Technology	HC	CO
Normal	All	< 0.41	< 3.4
Moderate	All	>0.41; < High	> 3.4; 0.815; 10.398; 0.965; 10.558; 0.837; 10.139; 10
	Closed-Loop, FI		

*No Supers are assumed for open-loop technology in TechIV.

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closed-loop technologies and is independent of vehicle mileage accumulation. (Because very few data points make up the Super regime, the emissions were averaged and applied to both carbureted and fuel-injected vehicles.) On the other hand, the remaining regime emission rates differ according to technology and increase linearly with mileage. The zero-mile and deterioration rates for the Normal and Marginal regimes were determined by performing least squares regressions on data that fell within the regimes. EPA assumed that the Highs deteriorated at the same rate as the Marginal regime.

Once the emission rates of each regime are established as a function of mileage, the incidence of emitter regimes (also as a function of mileage) must be determined. Data developed by EPA though its emission test programs indicate that the fraction of non-Normal regimes increases linearly with vehicle age (i.e., more vehicles are in the high remitting regimes at higher mileages). Thus, the incidence of Moderates, Highs, and Supers is described by a zero-mile level and a deterioration rate, while the Normal regime is determined through subtraction (i.e., Normals = 1 - Moderates - Highs - Supers). Further, growth rate of the High emission category (expressed as the fraction of vehicles expected in the fleet per 10,000 miles) is assumed to increase by a factor of 3.103 beyond 50,000 miles.

The incidence of emitter regimes (i.e., the fraction of the total fleet) is shown graphically in Figures 15 and 16 for 1983+, closed-loop, carbureted and fuel-injected vehicles, respectively. As seen in the figures, the assumed fraction of Highs in the fleet increases very rapidly beyond 50,000 miles, and the percentage of Highs at a given mileage interval is greater for carbureted vehicles than for fuelinjected vehicles. This last point is consistent with the expectation that fuel-injected vehicles are more durable, from an emissions perspective, than carbureted vehicles. (Note that the Normal regime disappears beyond 70,000 miles. At this point, the Marginal regime growth equation is neglected, and the Marginal regime is determined by subtracting the Highs and Supers, i.e., Marginals - 1 - Highs - Supers. This approach avoids the sum of regime fractions being greater than unity.)

Multiplying the emission rates - of each regime (Table 3) by the regime size (Figures 15 and 16) results in a technology-specific composite emission rate at each mileage interval. This calculation was performed for the 1983+, closed-loop, carbureted and fuel-injected vehicles, and the results are presented in Figures 17 and 18. As seen in the figures, the Normal regime is the largest contributor to the overall emission rate at very low mileage, but at high mileages, Highs and Supers are the predominant contributors. This is expected, given the greater emission rate and higher incidence of these emission regimes as mileage increases. It is interesting to point out, however, that the contribution of the Super regime is very significant, considering that it makes up such a small fraction of the fleet (only 2.2 percent at 100,000 miles). Thus, errors in estimating the emission rate or regime size for the Super emission category can have a dramatic impact on the overall emission factor estimated by the Tech IV model.

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Finally, the model-year-specific emission rates (as a function of mileage) are determined by weighting the technology-specific emission rates by the appropriate technology split for the model year of interest. For MOBILE4, the technology splits shown in Table 4 were used to establish the model-year-specific BER equations. As an example, the 1990 model-year HC BER equation was determined for passenger cars using the methodology outlined above. The emission rate was determined at each mileage interval corresponding to vehicle age. This is depicted in Figure 19. As seen, there is a change in slope at 50,000 miles, which corresponds to the increase in the High regime growth rate at 50,000 miles. The data points shown in the figure are used to determine the ZM, DR1, and DR2 values through a regression technique.

Table 4. Technology Distribution by Model Year Used in MOBILE4 (Passenger Cars, LDGV)

	Technology Type*			
Model Year	CLP-MPFI	CLP-TBI	CLP-CARB	OPLP
1981	0.057	0.027	0.635	0.281
1982	0.062	0.109	0.499	0.330
1983	0.086	0.195	0.478	0.241
1984	0.104	0.289	0.552	0.055
1985	0.280	0.265	0.393	0.062
1986	0.391	0.279	0.260	0.070
1987	0.483	0.264	0.239	0.014
1988	0.576	0.235	0.189	0.000
1989	0.594	0.243	0.163	0.000
1990	0.656	0.207	0.137	0.000
1991	0.742	0.174	0.084	0.000

1992+	0.785	0.172	0.043	0.000

*CLP-MPFI: Closed-Loop, Multiport Fuel-Injection
CLP-TBI: Closed-Loop, Throttle-Body Fuel-Injection
CLP-CARB: Closed-Loop, Carbureted
OPLP: Open-Loop, All Fuel Systems

4.4 FINAL BASE EMISSION RATE EQUATIONS

Although the Tech IV methodology described above was specific to the development of base emission rate equations for MOBILE4, the same methodology was applied in developing base emission rates for MOBILE4.1 and MOBILE5. (The subsequent revisions to the Tech IV model have been named "Tech4.1" and "Tech5" to be consistent with the MOBILE revision numbers.)

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To illustrate the effect of vehicle mileage on emission rate, the MOBILE5 HC and NOx BER equations for light-duty gasoline vehicles are shown in Figures 20 and 21, respectively. In addition to the fact that emissions increase with vehicle age, it is obvious from these figures that emissions are progressively lower for later model year vehicles. This is the result of more stringent emission standards as well as the use of more durable technology (e.g., fuel injection). According to the data shown in the figures, however, the implementation of more stringent emission standards on late-model vehicles has a very small impact on the base emission rate. For example, comparing the 1990 and 1998+ modelyear HC emissions, only a slight decrease in the base emission rate is observed even though the BERs reflect a reduction in the HC emission standard from 0.41 to 0.25 g/mi. It should be noted that the BER equations depicted in Figures 20 and 21 do not include the effects of an inspection and maintenance (I/M) program, nor do they include tampered vehicles. (Both I/M benefits and the impact of tampered vehicles are accounted for separately in the MOBILE models.)

A summary of the base emission rate equations for MOBILE5 is given in Table 5. In comparing the uncontrolled 50,000-mile emission levels (i.e., pre-1968 model year) to the 1998 and subsequent model year, decreases of 93 percent, 90 percent, and 83 percent are observed for HC, CO, and NOx, respectively. Again, this indicates the significant level of emission control that vehicles have been subjected to over the years. As an example, Table 6 lists the federal LDGV emission standards with a summary of the predominant emission control systems used to comply with those standards. (Similar tables for the LDGTI and LDGT2 classes are contained in Appendix A.)

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Comparison of Base Emission Rate Equations - Figures 22 through 24 compare the HC, CO, and Nox base emission rates from MOBILE4, MOBILE4.1, and MOBILE5 for 1990 model year LDGVS. As seen, the base emission rate equations for MOBILE4 and MOBILE4.1 are reasonably similar, while the MOBILE5 emission rate equations are dramatically higher, particularly for HC and CO. This is primarily the result of EPA's decision to use data collected at an operating I/M program to develop base emission rates for MOBILE5. These data were based on transient, loaded mode I/M testing (i.e., IM240) from Indiana's I/M program, which were then converted to "FTP-equivalent" values, utilizing correlations developed from vehicles tested over both the FTP and IM240 procedures. According to EPA, the main reason for the use of IM240 data is that the data allow for the compilation of a much more robust data set that better represents the in-use fleet. In addition, biases in test vehicle selection are eliminated because all vehicles in the fleet must undergo I/M testing.

Although Figures 22 through 24 illustrate the change in base emission rates among the MOBILE revisions for a single model year, it is also interesting to compare the differences for all model years. This is cumbersome to present as a series of base emission rate equations, so specific mileage intervals were chosen to make the comparison. Figures 25 through 30 show HC, CO, and NOx emission rates, respectively, for LDGVs at 50,000 and 100,000 miles for each of the three model revisions. These figures indicate only moderate differences in the 50,000-mile emission rates among MOBILE versions. However, the 100,000-mile

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emission rates predicted by MOBILE5 are much higher than MOBILE4 and MOBILE4.1 for 1980 and later model years. This difference reflects the much higher deterioration rates developed by EPA for MOBILE5 at mileages greater than 50,000 (i.e., the DR2 values). It should be noted that the emission rates shown in Figures 25 through 30 do not include the effects of an inspection and maintenance (I/M) program. Applying I/M credits to the MOBILE5 results dramatically reduces the non-I/M deterioration. (This point is discussed in greater detail in Section 7.) This same pattern is also observed for light-duty trucks, and figures similar to those presented above are contained in Appendix A.

Pre-1981 Base Emission Rates - For model years prior to 1981, the Tech IV modeling methodology described above was not used. Instead, surveillance program vehicles were divided into groups according to their certification emissions standards. Linear regressions of emissions vs. mileage were developed for each group to predict zero mile emissions and deterioration rates. The emission factors for most of these pre-1981 vehicles have remained essentially unchanged since MOBILE2 was released in early 1981. These factors were verified through a test program conducted by EPA in 1987. Emission data from that program, which consisted of 1972 to 1977 model years, indicated very close agreement with the base emission rates developed previously.

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4.5 CORRECTION FACTORS

As discussed above, a number of correction factors are needed to tailor the base emission rates to the specific conditions of speed, temperature, etc. being modeled. These are detailed below.

Operating Mode Corrections - Also referred to as bag correction factors, the operating mode correction factors adjust the FTP composite base emission rates to account for the mode under which the vehicle is operating (i.e., cold start, stabilized, hot start). Because the mass emission rate during the cold start mode is typically much higher compared to during stabilized and hot start modes, the BCF for Bag 1 is greater than unity. On the other hand, the BCFs for Bags 2 and 3 are generally less than one (with the exception of Bag 3 NOx). MOBILE predicts that the bag correction factors for catalyst-equipped vehicles are a function of vehicle mileage, with a decrease in weight for Bags I and 3 as the vehicle ages. This is seen graphically for HC, CO, and NOX in Figures 31 through 33 for 1990 model year LDGVs based on the MOBILE5 bag correction factor coefficients.

Note that at any mileage point, the equation

$$0.206 *BCF1 + 0.\ 521 *BCF2 + 0.273 *BCF3 = 1 \qquad [5\text{-}4]$$

is valid. This occurs because the base emission rate for a vehicle operating according to the FTP bag weightings (which were derived in equations 5-1 and 5-2) does not need to be corrected for non-FTP operating mode fractions, and the sum of the FTP-weighted BCFs is unity.

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Temperature and RVP Corrections - Under the Federal Test Procedure, emissions tests are performed within a temperature window of 680 to 860F, in order to ensure consistency and repeatability of the test results. However, many air quality problems are associated with temperatures that lie far outside this range, and the performance of different emission control components can vary substantially with temperature as well. For example, at cold temperatures common in CO nonattainment areas, catalyst warm-up times are far longer than at the standard temperature conditions. On the other hand, when temperatures are above 860F, evaporative emission control system purges can take longer (because more HC vapors have been stored in the canister), resulting in higher exhaust HC and CO emissions. Consequently, the MOBILE models contain factors to adjust the base emission rates to reflect the temperature for which the model is being run.

The impact of fuel volatility, measured as Reid Vapor Pressure (RVP), on vehicle emissions is closely related to temperature. Thus, there also is an RVP adjustment contained in the MOBILE models. The RVP adjustment at temperatures below 750F is a simple multiplicative factor; however, at temperatures above 750F, the temperature and RVP adjustment is combined into a single correction factor. (It should be noted that RVP impacts exhaust emissions primarily by its influence on vapor storage in the evaporative emission control system.)

The MOBILE models calculate a correction factor to adjust the base emission rate for fuel volatility and temperature according to two basic vehicle groups. Group 1 consists primarily of non-catalyst and open-loop technology vehicles. Group 2 consists primarily of vehicles using closed-loop three-way catalyst technology. The model-year breakdown of these groups is:

Group 1	Group 2
1970 - 1979 LDGV	1980 + LDGV
1970 - 1980 LDGT1	1981 + LDGT1
1978 - 1980 LDGT2	1981 + LDGT2
All HDGV	

Low-Temperature Correction Factors - Because temperature affects emissions differently for each operating mode, temperature correction factors (TCFS) are derived separately for Bags 1, 2, and 3. In addition, emissions at lower temperatures are dependent on the type of fuel delivery system with which the vehicle is equipped (i.e., carburetion, throttle-body fuel-injection, or multipart fuel-injection). For example, the Bag 1 HC low-temperature correction factors for the three fuel delivery systems are shown in Figure 34. The figure shows that as the fuel delivery system is improved (resulting in better atomization and fuel distribution among cylinders), cold-temperature emissions are improved.

The temperature correction factors (TCFS) by fuel delivery system remained unchanged among the MOBILE4, MOBILE4.1, and MOBILE5 revisions; however, slight changes to model-year-specific TCFs have occurred because of changes to the fuel delivery system technology mix. Using

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Using the MOBILE4 assumptions on technology mix, TCFs (by bag) were calculated for HC, CO, and NOx, and the results are presented in Figures 35 through 37 for 1992 and subsequent model year LDGVS. As seen in the figures, the impact of temperature is greatest on cold start emissions, increasing the HC emission rate by a factor of almost 4 at 20øF. For stabilized and hot start operation, the HC emission rate is increased by roughly 50 percent at 20øF. A very high emission rate during cold start at low temperatures is simply the result of a magnification of the factors that lead to high emissions during cold start at standard temperature, i.e., incomplete fuel vaporization and an increased warm-up period for the emission control system.

Modeling of low-temperature CO emissions for Bag 1 is handled somewhat differently in the MOBILE models. Instead of being a multiplicative correction factor, the Bag 1 CO temperature correction is an offset which is added to the base emission rate before corrections for speed, fuel, etc. are applied. This offset is a linear function of temperature and varies according to fuel delivery system. As an example, the cold start CO offset for a 1982 model year LDGV at 30øF is roughly 60 grams per mile. (Recall, however, that this only contributes to the cold start operating mode, and the impact on the composite emission factor would be correspondingly less.)

Low-Temperature RVP Correction - The RVP correction factors for low-temperature operation are calculated independently from the temperature correction factors and are developed for each operating mode separately.

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(For 1971 to 1979 model years, the RVP correction is not bag specific. Further, it is not applied to vehicles older than the 1971 model year.) Figures 38 and 39 illustrate the low-temperature HC and CO RVP correction factors for a series of fuel RVPS. Note that the impact falls as the temperature declines, and no correction is applied at temperatures below 45øF. While not shown, there is also an RVP correction applied to NOx; however, its magnitude is very small.

High-Temperature Combined RVP and Temperature Correction - At high temperatures, the temperature and RVP correction factor is combined. Figures 40 and 41 show the MOBILE5 RVP/temperature correction factors for HC and CO, respectively. Although the model calculates these factors independently for each operating mode, they have been composited in the figures to reflect the FTP operating mode fractions. As seen, the correction factors increase with increasing temperature and with increasing RVP. (Although not shown, NOx is also corrected; however, the correction factor is much smaller for NOx.)

Speed Corrections - Emission factors are very sensitive to the average speed that is assumed. In general, emissions tend to increase as average speeds decrease from the 19.6 mph value employed in the FTP. The MOBILE models do not assume an average speed: it is a requirement that an estimate of the speed experienced by vehicles operating in the area of analysis be specified. MOBILE adjusts the emission factors for speeds other than 19.6 mph through the use of speed correction factors. These multiplicative adjustments to the base emission factors follow a non-linear relationship that increases the emission levels as speeds decline.

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There are several forms of speed correction factors contained in the MOBILE models:

SCF - exp(A + B*S + C*S2 + D*S3 + E*S4 + F*S5) (Form 1)

SCF - (A + B*S + C*S2 + D*S3 + E*S4 + F*S5) (Form 2)

SCF - (A/S + B) / (A/FTPS + B) (Form 3)

SCF - (exp(A + B*S + C*S2)) / (exp(A + B*FTPS + C*FTPS2)) (Form 4)

where:

SCF = speed correction factor,
FTPS = operating mode adjusted FTP speed,
S = vehicle speed in mph,
A,B,.. = constants specific to each pollutant, model year group, and vehicle category.

The exponential equation (Form 1) is the form that was used in EPA's MOBILE2 emission factor model for HC and CO emissions. The second form of the equation is used for NOx emissions. These forms are still generally applicable to older model year vehicles. The third and fourth forms were introduced with MOBILE4, and are generally used for 1979 and later model vehicles. Form 3 is used for HC and CO emissions, while Form 4 is used for NOx emissions.

The data used to develop the speed correction factors are based on a number of different test cycles in which the speed-time profile is changed to reflect different average speeds. A total of eight different test cycles are used by EPA in modeling the effect of speed on emissions:

☐	EPA Low Speed #3	2.5 mph
☐	EPA Low Speed #2	3.6 mph
☐	EPA Low Speed #1	4.0 mph
☐	New York City Cycle	7.1 mph
☐	EPA Speed Cycle 12	12.1 mph
☐	FTP	19.6 mph
☐	EPA Speed Cycle 36	35.9 mph
☐	Highway Fuel Economy Test	47.9 mph

In addition to these cycles, EPA has used data from CARB's high-speed testing to develop the high-speed (i.e., over 48 mph) correction factors. The speed-time traces for all of the above speed correction cycles are contained in Appendix B.

The impact of speed on emissions is observed in Figures 42 through 44. These figures present the speed correction factors (SCFS) calculated by MOBILE4, MOBILE4.1, and MOBILE5 for HC, CO, and NOx, using 19.6 mph as the reference point. There are three speed regimes modeled in MOBILE: low speed (under 19.6 mph), mid-speed (19.6 to 48 mph) and high speed (48 to 65 mph).

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The low-speed regime results in the highest SCFs (and thus emissions) for HC and CO, with MOBILE4 predicting an SCF of over 8 for HC at 2.5 mph, while MOBILE4.1 and MOBILE5 estimate an SCF of over 4 for this speed. (MOBILE4.1 and MOBILE5 speed correction factors are equivalent for the low-speed regime.) On the other hand, low-speed NOx emissions are predicted to increase by only about 50 percent from the reference speed. Higher emissions at these very low speeds occur because the vehicle is operating over a longer time period to cover the same distance, and the test cycles used to develop the low-speed corrections have a higher fraction of time spent under acceleration modes.

The mid-range HC and CO SCFs are very similar among the MOBILE revisions, steadily decreasing from 19.6 to 48 mph. The results for NOx, however, are quite different for the three MOBILE revisions, with MOBILE5 showing a steady increase throughout the mid-speed regime. Finally, MOBILE4.1 and MOBILE5 incorporated SCF revisions that resulted in a significant increase at high speed. High-speed data developed by the CARB were used in developing the high-speed correction factors.

Additional Correction Factors - Before the basic emission factors for the contributing model years can be summed, they must be further corrected for area-specific air conditioner use, trailer towing, and extra load. Although the MOBILE models contain the option to include this correction factor, it is generally based on few data and typically it is not utilized.

Tampering - Tampering effects are also accounted for in MOBILE. When basic emission rates are developed from surveillance vehicles, the effects of tampering are removed by deleting tampered vehicles from the test sample. An additive emissions impact (in g/mi) and a rate of occurrence have been developed by EPA for each tampered component (including air pump, fuel inlet restrictor and EGR system disablement, catalyst removal and misfueling), based on tests of tampered vehicles and EPA surveys. Although MOBILE contains default tampering rates, these rates can be changed by the user to reflect area-specific tampering rates and antitampering programs. The estimated increase in emissions due to tampering is adjusted to reflect the reduced tampering rates expected under an antitampering program in the development of the tampering offset.

4.6 IDLE EMISSION RATES

Although not generally used for inventory preparation purposes, idle emission rates are sometimes needed for more specialized analyses (e.g., intersection modeling). Idle emissions are not calculated by MOBILE5, but idle rates are estimated by MOBILE4 and MOBILE4.1. Because the interactions of some of the new features included in MOBILE5 (e.g., Tier I emission standards, reformulated gasoline, low-emission vehicles) with the idle emission calculations resulted in uncertain estimates, the idle algorithm was disabled in MOBILE5. EPA initially recommended continued use of MOBILE4.1 for idle emission estimates; however, EPA has recently issued guidance proposing a method to convert MOBILE5a exhaust emission rates to idle rates.* The methods used to calculate idle emission rates in MOBILE4 and MOBILE4.1, as well as the MOBILE5a procedure, are described below.

MOBILE4 - Idle emission rates are calculated by the MOBILE models in units of grams per hour (g/hr). As with running exhaust emission estimates, a fleet-average idle emission rate is calculated by weighting the model-year-specific idle emission rates by each model year's travel fraction. The sum of these VMT-weighted idle rates gives the fleetaverage idle emission rate for the calendar year of interest. The idle rates calculated by MOBILE4 assume that the vehicle is warmed-up and that the ambient temperature is 750F.

The methodology used to generate model-year idle emission rates in MOBILE4 varies according to vehicle class and model year. For the older model years (i.e., pre-1977 for LDGVS, pre-1979 for LDGT1s and LDGT2s),

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* EPA will allow the continued use of MOBILE4.1 for one year. However, EPA intends to use the method developed for MOBILE5a in the future.

the model employs a relatively simple algorithm. Idle emission factors, which were based on "bagged" idle data, are stored in the model in terms of a zero-mile component (g/hr) and deterioration rate (g/hr/10,000 mi). An idle emission rate is computed by multiplying the deterioration rate and the assumed mileage for the model year being analyzed, and adding the results to the zero-mile component. As an example, consider a 1975 model-year LDGV in 1990. Such a vehicle would have accumulated an estimated 135,705 miles; thus, its CO idle emission rate would be:

$$Idle\_CO1975MY = 360.00 \text{ g/hr} + (51.00 \text{ g/hr/10,000 mi} * 135,705 \text{ mi})$$
$$Idle\_CO1975MY = 1,052.10 \text{ g/hr}$$

This rate is then corrected for I/M (if specified) and a tampering offset is added. For this model year and vehicle age, the tampering offset (under a no-I/M scenario) is calculated to be 90.02 g/hr. (The tampering offset accounts for catalyst removal, air pump tampering, and misfueling.) Thus, the total CO idle rate estimated by MOBILE4 for this model year is 1,052.10 + 90.02 = 1,142.12 g/hr.

For 1977 and subsequent model years, a significantly different method is used to generate g/hr idle emission rates. That method is based on the g/mi running exhaust emission rate which is converted to g/hr. The calculation is somewhat complicated and is best illustrated with an example, which is provided below.

Consider a 1986 model-year LDGV in calendar year 1990. It would have accumulated 45,572 miles; its running exhaust CO base emission rate is described by the following ZM and DR values:

ZM: 2.764 g/mi
DR: 0.771 g/mi/10,000 mi;

and the CO emission rate is calculated to be:

CO1986 = 2.764 g/mi + (0.771 g/mi/10,000 mi * 45,572 mi) - 6.28 g/mi.

(Because the vehicle has under 50,000 miles, a second DR is not necessary to calculate the running exhaust emission rate.)

The 6.28 g/mi value above is based on FTP operating mode fractions (i.e., 20.6% cold start, 52.1% stabilized, and 27.3% hot start). However, EPA chose to calculate idle emissions for MOBILE4 only under stabilized conditions. Thus, operating mode correction factors (or "bag correction factors") are applied to the FTP-based base emission rate so that it represents stabilized operation. For the purposes of calculating idle emission rates, the bag 2 (stabilized) correction factor is weighted 52.1% and the bag 3 (hot start) correction factor is weighted 47.9%. For this example (i.e., a 1986 model year LDGV in 1990), the bag correction factor applied to the exhaust CO emission rate is:

COBCF = 0.521*BCF2 + 0.479*BCF3
COBCF = 0.521*0.666 + 0.479*0.864 - 0.761,

and the corrected running exhaust emission factor is 6.28 * 0.761 = 4.78 g/mi.

The next step in the process is to transform the g/mi emission rate calculated above to a g/hr basis. This is accomplished by multiplying the 4.78 g/mi value by 19.6 mi/hr, the average speed of the FTP. For this example, the calculation results in an idle CO rate of:

Idle_CO1986MY = 4.78 g/mi * 19.6 mi/hr - 93.69 g/hr.

An offset is then added to the above result so that the calculated values match observed "bagged" idle data. In this example, the offset is -42.13 g/hr, and the idle CO rate is:

Idle_CO1986MY = 93.69 g/hr - 42.13 g/hr - 51.56 g/hr.

If an I/M program is specified, the I/M credits are applied at this point in the calculation. (I/M was not specified for this example.) Finally, a tampering offset is added, which in this case is 4.46 g/hr. Thus, the final CO idle emission rate is 51.48 + 4.46 - 55.94 g/hr.

MOBILE4.1 - MOBILE4.1 uses a methodology very similar to that employed in MOBILE4 to calculate idle emission rates. Several modifications were made, however, so that the idle rates from MOBILE4.1 reflect user-input operating mode fractions, temperature, RVP, and fuel oxygen content. For the most part, these corrections are based on data collected over the FTP. In some cases, modifications are made within MOBILE4.1 to get the corrections on an idle basis (e.g., the cold-temperature CO offset, which is calculated in units of g/mi, is converted to g/hr), while others (e.g., the RVP correction factor, which is a multiplicative correction factor) are used directly to adjust the idle emission rate. It is unclear that idle emission rates and running exhaust emission rates will react the same to changes in some of these model input parameters. However, there appears to be an acute lack of data to develop idle-specific emission rates and correction factors.*

As an example of the above corrections, the impact of temperature and operating mode on idle CO emission rates for the 1996 calendar year is shown graphically in Figure 45 for the LDGV vehicle class. As with running exhaust emission rates, the idle CO rates increase with decreasing temperature, particularly during cold start operation.

It is also interesting to compare idle emission rates computed by MOBILE4.1 to the running exhaust emission rates estimated by that model. This is illustrated in Figure 46, which shows the LDGV 50,000-mile running exhaust and idle CO emission rates for pre-1968 to 1995 and subsequent model years. (Similar charts for LDGTls and LDGT2s are in Appendix C, which also contains HC and NOx results.) As shown, the idle

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*Although it would appear that idle emission rates could be easily obtained from the numerous I/M programs operating throughout the U.S., those data are collected in concentration units (e.g., percent CO, ppm HC), which are not directly transferrable to a mass per unit time basis.

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rates generally track the decrease in running exhaust rates as new standards and technologies have been implemented.

MOBILE5a - As outlined above, the idle emissions algorithm was disabled in MOBILE5 (and MOBILE5a) because the addition of new features (e.g., Tier I emission standards, reformulated gasoline, low-emission vehicles) resulted in uncertain idle emission estimates from the algorithm utilized in MOBILE4.1. When MOBILE5 was released, EPA recommended the continued use of MOBILE4.1 for calculating idle emission rates. Recent EPA guidance, however, provides a method to convert MOBILE5a running exhaust emission rates to idle emission rates, and EPA recommends that approach for all future emission estimates requiring idle emission rates.

EPA's recommended method to convert MOBILE5a g/mi running exhaust emission rates to g/hr idle emission rates is somewhat similar to the approach already used within MOBILE4 and MOBILE4.1 to develop idle emission rates for 1977 and subsequent model ears. The MOBILE5a method requires the user to run MOBILE5 at 2.5 mph and then multiply the resulting g/mi running exhaust rates by 2.5 mph to obtain idle rates in terms of g/hr. (The 2.5 mph speed is utilized because it represents the lowest speed modeled by MOBILE5a, and the test cycles used to develop speed correction factors for low speeds contain the highest fraction of idle operation.) Developing idle rates in this manner inherently accounts for all of the corrections (e.g., I/M, temperature, fuel, etc.) that are applied to the running exhaust emission rates. The idle CO emission rates calculated according to the methodology outlined above are compared to running exhaust emission rates in Figure 47 for LDGVS. As with the MOBILE4.1 results, the idle rates generally track the running exhaust emission rates as new standards are implemented. (This is not unexpected since the idle rates are based on the running exhaust emission rates.) However, there is a slight discontinuity in the idle results for the 1975 and 1976 model years. That is because the 2.5 mph speed correction factor for those model years is lower than the SCF for the 1977-1979 model years, while the FTP-based emission rates are roughly the same. (Charts similar to Figure 47 for LDGTls and LDGT2s are in Appendix C, which also contains the HC and NOx results.)

Comparison of MOBILE4.1 and MOBILE5a Idle Emission Rates - A comparison of model-year-specific idle CO emission rates calculated with MOBILE4.1 and MOBILE5a is illustrated in Figure 48 for LDGVs at 50,000 miles. This figure shows reasonable agreement between the models, with the MOBILE5a results being slightly higher for later model years. Some of this difference is attributable to the in-use fuel correction applied in MOBILE5 (explained in Section 8.5) and the differences in methodologies used to develop the idle emission rates. The comparison made in Figure 48, however, is based on vehicles with 50,000 miles. The difference for late-model vehicles at higher mileages will be greater because of the higher emission deterioration rates assumed in MOBILE5 for those vehicles. Thus, comparisons of fleet-average idle emission rates will show greater differences, as demonstrated in Figure 49 for LDGVS. This is particularly true of future-year analyses (e.g.,

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calendar year 2010), where the MOBILE5a idle CO predictions are twice those calculated by MOBILE4.1.

4.7 HEAVY-DUTY VEHICLES

Heavy-duty vehicles consist of vehicles that exceed 8500 lbs. gross vehicle weight (GVW). This general class is further segregated into specific classes according to GVW. The additional segregation is necessary because of the differing characteristics of engines making up these classes.

Standard Test Procedure - Because of the large number of applications for which heavy-duty engines are utilized, emissions testing is normally engine-specific and is performed on an engine dynamometer. Additionally, the heavier GVW rating of heavy-duty vehicles precludes testing on most chassis dynamometers. Therefore, transient engine dynamometer test cycles have been developed that simulate average urban driving for gasoline and Diesel heavy-duty engines. These test cycles specify RPM and torque by second and are roughly 20 minutes long. The test procedure, outlined in 40CFR86, calls for a "cold start" portion which is initiated after the engine temperature is stabilized at 68ø to 86øF. (This can be accomplished through an extended "cold soak" period or with a "forced cool-down" procedure.) A "hot start" portion, commencing 20 minutes after the end of the cold start test, is also required and follows the same dynamometer test cycle. The test results are reported in units of grams per brake-horsepower-hour (g/Bhp-hr), and

the composite emission rate is determined by weighting the cold portion of the test by 1/7 and the hot portion of the test by 6/7. The test procedure is diagrammed in Figure 50.

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Figure 50. Heavy-Duty Engine Test Procedure

The transient test cycles developed for heavy-duty gasoline and Diesel engines are the result of a significant effort by EPA and industry to simulate heavy-duty vehicle operation in urban areas. The data used to develop the cycles were collected from instrumented heavy-duty trucks that operated in New York City and the Los Angeles Basin in the mid1970s.8 The complete 20-minute cycles were formulated from four separate 5-minute cycles that represented freeway driving in New York City, non-freeway driving in New York City, freeway driving in Los Angeles, and non-freeway driving in Los Angeles.9,10 An optional chassis dynamometer test cycle was also developed in this program which covers 5.73 miles at an average speed of 19.45 mph.9

Basic Emission Rates - The basic emission rates developed for the MOBILE models are based on engine dynamometer test results. For MOBILE4, data from a cooperative test program with engine manufacturers formed the basis of the g/Bhp-hr emission estimates (for 1979 and later model years). For heavy-duty Diesel vehicles, a total of 30 engines were tested that were representative of the 1979 to 1984 model years. For heavy-duty gasoline emission rates, 18 engines were tested by EPA. These were from the 1979 to 1982 model years. Unfortunately, heavy-duty engine testing is very expensive, so data are generally sparse. No new data since the MOBILE4 effort have been developed with which to update heavy-duty emission factors.

Conversion Factors - Because the exhaust emission test procedure results in emissions reported in units of g/Bhp-hr, it is necessary to convert the results into g/mi units to be consistent with available travel information. Therefore, conversion factors (in Bhp-hr/mi) are developed to represent the emission results obtained from engine dynamometer testing in units appropriate for inventory purposes. The derivation of heavy-duty conversion factors is described in a 1984 EPA technical report11 which was updated in 1988.12 Only a summary of the methodology is presented here.

Because it is difficult to measure Bhp-hr/mi directly, a methodology was developed to calculate this parameter with available data. In equational form, the conversion factor is represented by:

$$CF = \frac{P}{BSFC \times FE}$$

where CF = conversion factor (Bhp-hr/mi),
p = fuel density (lb/gal),
BSFC = brake-specific fuel consumption (lb/Bhp-hr), and
FE = fuel economy (mi/gal).

Thus, by obtaining estimates of fuel density, brake-specific fuel consumption, and fuel economy, it is possible to estimate CF. Once the values of CF are obtained for each GVW class, a fleet composite CF is established by weighting the class-specific values by an estimated VMT mix. These calculations are carried out separately for gasoline and Diesel vehicles.

The data sources used in developing the conversion factors for 1982 and previous model years are summarized as follows:

- Fuel Density - Gasoline fuel density was based on data published by the National Institute for Petroleum and Energy Research (NIPER), and Diesel fuel density was based on surveys by the Motor Vehicle Manufacturers Association (MVMA). (The same value for fuel density was used for all model years.)
- Fuel Economy - Estimates for heavy-duty trucks were obtained from the Department of Commerce's "1982 Truck Inventory and Use Survey" (TIUS), while bus data came from documents published by the Federal Highway Administration (FHWA).
- Brake-Specific Fuel Consumption (BSFC) - The pre-1978 heavy-duty truck data came from a 1983 report prepared by Energy and Environmental Analysis (EEA) for the MVMA. For model years 1978 to 1982, the BSFC values were interpolated from the above 1977 estimates and more recent data submitted to EPA by manufacturers for 1987 model year engines. Bus data were based on EPA testing of high sales-volume bus engines.

The 1983 and subsequent conversion factors were developed by incorporating fuel economy improvements into the 1982 class-specific conversion factors. (Because engine-related fuel economy improvements also result in decreased BSFC (which cancels the overall impact on the CF), only non-engine-related fuel economy improvements were considered.) Specific improvements accounted for in the analysis included weight reduction, radial tires, aerodynamic add-on devices, drive-train lubricants, improved fan drives, overdrive, electronic transmission controls, and speed controls.

The sales and VMT estimates used to composite the class-specific conversion factors for each model year were based on information contained in various publications authored by MVMA, the Department of Energy, the American Public Transit Association, and FHWA, as well as data in the TIUS.

Speed and Temperature Adjustment - As with light-duty vehicles, the heavy-duty emission rates are corrected for average speed and temperature outside of those encountered in the test procedure. (Gasoline vehicles are corrected for both speed and temperature, while Diesel vehicles are corrected only for speed. The effect of nonstandard temperature on Diesel emissions is assumed to be negligible.) For speed corrections, the basic emission rate is multiplied by the appropriate speed correction factor that is calculated from the speed correction coefficients according to the following formula:

$$SCF = \exp (a + bs + cs2)$$

where a,b,c = coefficients,
s = vehicle speed, and
exp = exponential function.

Figures 51 through 53 show a graphical representation of the heavy-duty Diesel and gasoline speed correction factors for HC, CO, and NOx, respectively. (The same speed correction factors apply to all model year vehicles.)

Temperature correction is only applied to heavy-duty gasoline vehicles. Further, this correction is not operating-mode specific, which is a departure from the light-duty gasoline vehicle methodology. In equation form, the temperature correction factor is represented by:

$$TCF = \exp(a * (T - 75))$$

where a = coefficient,
T = temperature (øF), and
exp = exponential function.

The value of the coefficient for a particular model year group differs, depending upon whether the temperature range being modeled is above or below 75øF. The heavy-duty gasoline vehicle temperature correction factors for 1985 and later model years are depicted in Figure 54 for

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HC, CO, and NOx for temperatures below 75øF. As seen, the influence of temperature is greatest for HC at low temperatures.

Changes from MOBILE4 to MOBILE4.1 to MOBILE5 - Since MOBILE4, very little work has gone into updating the parameters that make up the heavy-duty emission factors. The only substantive revision was the incorporation of the Clean Air Act requirements for a 4.0 g/Bhp-hr Nox emission standard beginning with the 1998 model year. This change was introduced into the model by simply scaling the 1998 and subsequent zm component of the basic emission rate equation by the ratio of the proposed-to-existing standard (i.e., 4.0/5.0).

5. EVAPORATIVE EMISSION METHODOLOGIES

Evaporative emissions are treated quite differently than exhaust emissions in the MOBILE models, with six separate categories of evaporative emissions being considered: hot soak, diurnal, running losses, resting losses, refueling, and crankcase emissions. Only hot soak, diurnal, and crankcase emissions are currently regulated by EPA. Refueling losses, if controlled, are regulated by local air pollution control agencies through Stage II vapor recovery requirements.* Running and resting loss emissions will require control in response to the recently revised evaporative test procedures.

5.1 EMISSION STANDARDS AND TEST PROCEDURES

Evaporative emissions from gasoline-fueled, light-duty vehicles have been controlled since the 1971 model year. (Heavy-duty vehicles were first controlled beginning in 1985.) Evaporative emission standards, listed in Table 7, are based on the sum of diurnal and hot soak emissions through 1995, while vehicles built after 1995 will also be required to meet a running loss standard. The standards summarized in Table 7 are based on three different test procedures: the 'carbon trap" method, the "SHED' method, and an enhanced evaporative test procedure that is a modification of the original SHED method. Each of these procedures has required an increased level of emission control.

The discussion that follows summarizes the basic function of the evaporative emission control system used to meet the standards in Table 7. In addition, each of the test procedures used to certify vehicles to those standards is briefly described.

Evaporative Emission Control Systems - The evaporative emission control system generally consists of a series of hoses that direct hydrocarbon vapors to a canister filled with activated carbon. The carbon adsorbs these vapors during periods of vapor generation (i.e., diurnal emissions resulting from heating of the fuel tank during the day; hot soak

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*The 1990 Clean Air Act Amendments (CAAA) require the implementation of Stage II vapor recovery in all areas of the country that are classified as moderate, serious, severe, and extreme nonattainment with respect to the National Ambient Air Quality Standards for ozone. These requirements should be fully implemented by November 15, 1995. Further, the CAAA direct EPA to develop regulations requiring the use of on-board refueling vapor recovery systems on new light-duty vehicles. Although EPA has not yet promulgated these requirements, it appears that it will do so in 1994, and ORVR systems are likely to first appear with the 1998 model year.

Table 7. Light-Duty Vehicle Evaporative Emission Standards

Model Year	Diurnal + Hot Soak (g/test)	Running Loss (g/mi)	Test Procedure
1971	6.0	-	Carbon Trap
1972-77	2.0	-	Carbon Trap
1978-80	6.0	-	SHED

1981-95	2.0	-	SHED
1996a	2.0	0.05	Enhanced Evap

aThese standards are phased-in beginning with the 1996 model year.

emissions resulting from evaporation of fuel exposed to a hot engine after the engine is turned off). When the engine is running, the canister is "purged" of these stored vapors by drawing fresh air through the canister and routing these vapors back into the engine's fuel intake system where the vapors are burned in the combustion process. Although evaporative emission standards and test procedures have changed through the years, the basic method of control has remained essentially the same. To meet increasingly stringent evaporative standards, manufacturers have relied on better materials (e.g., less permeable vapor hoses) and larger carbon canister storage capacity (e.g., more adsorptive activated carbon or increased canister volume).

"Carbon Trap" Method - The first evaporative emission standards were based on a test procedure known as the "carbon trap" method. That method of measuring evaporative emissions utilized activated carbon traps connected to the fuel system at selected locations where vapors would be expected to escape. The traps adsorbed vapor emitted at those locations, and the increased weight of the carbon traps represented evaporative emissions. Emissions were measured during a one-hour diurnal test, over a running loss test designed to represent evaporative losses during urban driving, and during a one-hour hot soak test following engine shut-off. The sum of these measurements represented the total evaporative emission rate.

After implementing this procedure for several years, it became apparent that it was deficient in several ways. Most notably, the carbon trap method did not accurately measure evaporative emissions from all possible sources. Using the Sealed Housing Evaporative Determination (SHED) method (described below), both EPA and the California Air Resources Board found that vehicles certified according to the carbon trap method greatly exceeded the emission standards to which they were certified. 13 Thus, both agencies adopted evaporative emission

regulations based on the SHED procedure beginning with the 1978 model year.

SHED Procedure - The evaporative test procedure by which manufacturers have certified their vehicles since the 1978 model year is based on emissions measurements conducted in an enclosed test cell (SHED) and consists of two parts: a diurnal test and a hot soak test. (The original SHED-based standards did not include running loss measurements as these were, at the time, considered to be negligible.) These evaporative tests are conducted in conjunction with the FTP exhaust emissions test. The diurnal test is performed prior to the exhaust test and consists of first draining and filling the fuel tank (to a 40 percent fill level) with standard test fuel that is at a temperature of 60øF. The vehicle is then placed in the SHED, and the temperature of the fuel is raised from 60ø to 84øF in a one-hour time period. (A heat blanket is placed on the outside of the fuel tank to effect the temperature increase.) Emissions are collected during that time period, and test results are reported in terms of grams/test.

The hot soak test is performed after the FTP exhaust emissions test. Immediately following the exhaust test (i.e., within two minutes of engine shutdown and within seven minutes of the completion of the exhaust emissions test), the vehicle is placed in the SHED for a period of one hour. Emissions are collected during this time, and results are reported in grams/test (i.e., grams/trip).

Enhanced Evaporative Test Procedures - Through a variety of test programs, EPA found that the above SHED test procedure does not adequately describe evaporative emissions under all conditions. This was also recognized by Congress in the 1990 Clean Air Act Amendments, which directed EPA to promulgate a new evaporative test procedure to better represent evaporative emissions under in-use, summertime conditions. These requirements were finalized in March 199314 and include an extended, multi-day diurnal period with a more severe temperature rise (72ø to 96øF) and a requirement for evaporative emissions measurement while the vehicle is operating on a chassis dynamometer (i.e., a running loss test). MOBILE5a models the effects of the new evaporative emissions test procedure on vehicles certified under the new requirements, which are to be phased-in beginning with the 1996 model year. (For 'a discussion of how MOBILE5a models the effects of these regulations, refer to Section 8.3.)

5.2 EVAPORATE EMISSIONS DATA

MOBILE4 - The evaporative emission factors used in MOBILE4 were derived from the results of EPA's in-use emission factor test program. For the development of the emission factors, the test vehicles were divided into two categories: tampered and non-tampered.

The vehicles that had evaporative emission control system malfunctions attributed to deliberate tampering were placed in the category of tampered vehicles. The remaining vehicles were placed in the non-tampered vehicle category. Within each of the above categories, the vehicles were also separated into carbureted and fuel-injected vehicles. In the MOBILE4 evaporative emissions calculations, the fuel-injected vehicles were further divided into throttle-body-injected (TBI) vehicles and multipart fuel-injected (MPFI) vehicles. The non-tampered emissions estimates are based on the emissions of the vehicles in the emission factor database. Tampered emissions estimates were developed based on a separate testing program in which vehicles were tested in a tampered state.

For calculating hot-soak and diurnal emissions, the light-duty vehicles were divided into the following model year categories based on the different evaporative emission standards for these model years:

- 1970 and earlier,
- 1971,
- 1972-1977,
- 1978-1980, and
- 1981+.

The estimates for 1981+ vehicles are the most refined as they are based on the largest amount of data. The emissions estimates for older years become increasingly less accurate because the earlier data were based on less stringent test procedures and performed on a smaller sample of vehicles. This issue is of lesser importance for the future years as the population of the pre-1981 vehicles becomes smaller.

MOBILE4.1 and MOBILE5 - With the release of MOBILE4.1, the methodology used to calculate evaporative emission estimates changed. Although the data were still stratified according to fuel delivery system and model year, the distinction between non-tampered and tampered vehicles was not made. Rather, the data were stratified according to whether the vehicle passed an evaporative system functional check. This test, which was developed by EPA for use in inspection and maintenance programs, consists of two parts: a pressure test and a purge test. The pressure test is designed to assess the integrity of the fuel tank (including the gas cap) and vapor line leading from the fuel tank to the evaporative canister. Under this procedure, the fuel tank vapor line is disconnected at the canister, a pressure gauge is connected, and the tank is pressurized with nitrogen (through the vapor line) to 14 inches of water. If the pressure drops below 8 inches of water in a two-minute period, the system is considered to be defective. As the name implies, purge testing is intended to identify defects in the evaporative purge system. EPA's procedure consists of placing a flow meter in the vapor purge line between the canister and the engine, and monitoring cumulative flow (in liters) over a dynamometer-based test cycle (i.e., EPA's IM240 test). If the cumulative flow during the test is less than 1.0 liter, the system fails.

It is very difficult to detect evaporative control system defects based on a visual inspection (which was the basic approach in defining tampered and non-tampered vehicles for the MOBILE4 methodology), and the functional checks outlined above provide a much better indication of malfunctioning systems. For that reason, EPA opted to stratify data according to three failure regimes in MOBILE4.1 and MOBILE5: pass pressure/purge, fail pressure, and fail purge. (Vehicles that fail both pressure and purge tests are treated as pressure failures in the model because emissions from pressure failures are generally higher than emissions from purge failures.) The emission data collected for use in MOBILE4.1 and MOBILE5 were, therefore, tested according to the pressure/purge procedure prior to emissions measurements.

5.3 PRESSURE/PURGE FAILURE RATES

Model-year-specific evaporative emission rates are calculated within MOBILE4.1 and MOBILE5 by weighting the emission rates of the three failure regimes according to the expected occurrence of failures in the fleet. Thus, it was necessary for EPA to develop estimates of the fraction of vehicles failing these tests. The failure rates estimated by MOBILE4.1 and MOBILE5 are a function of vehicle age, and were based on data collected from the Hammond, Indiana, I/M program. The fraction of pressure and/or purge failures predicted in MOBILE4.1 and MOBILE5 are compared in Figure 55. As demonstrated in the figure, a substantial fraction of vehicles are expected to have malfunctioning evaporative control systems beyond about 10 years of age. (As explained in Section 7, segregating emissions according to pressure/purge failure status facilitates estimates of pressure/purge check effectiveness in I/M program modeling.)

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5.4 HOT SOAK AND DIURNAL EMISSION MODELING

MOBILE4 - Both non-tampered and tampered emission estimates for hot-soak and diurnal emissions are based on EPA's emission factor data and EPA data on special studies of RVP and temperature effects. These data are from tests conducted by EPA at Ann Arbor and at Automotive Testing Labs in Ohio. The hot-soak emissions are based on the one-hour soak test following the driving portion of the Federal Test Procedure (FTP). The diurnal test is performed before the driving portion of the FTP when the temperature of the fuel tank is increased from the minimum temperature to the maximum temperature (i.e., 60ø to 84øF) over a one-hour time period.

EPA has analyzed these data to establish relationships in MOBILE that calculate hot-soak and diurnal emissions on a gram per test basis as a function of RVP, temperature (minimum and maximum for diurnal), and fuel tank level. The diurnal estimate is a function of the Uncontrolled Diurnal Index (UDI).

The UDI is based on the Wade equation. This equation estimates the uncontrolled diurnal emissions from a tank depending on the atmospheric pressure, the RVP of the fuel, the size of the vapor space in the tank, and tank temperature.' The Wade estimate is first calculated for standard conditions of 9.0 psi RVP fuel, 60ø-84øF diurnal temperature, and 40 percent tank fill level. The UDI is then calculated as a ratio of the Wade estimate for the selected conditions of RVP, temperature, and tank level, and the Wade estimate for the standard conditions. Hotsoak emissions are calculated as a function of RVP and then corrected for temperature.

Table 8 gives the various estimates for non-tampered hot-soak and diurnal emissions used in MOBILE4 for 1981+ LDGVS. The RVP value used in evaporative emissions estimates is assumed to have weathered (i.e., lowered) from the RVP at the fill level to the in-use tank level. Fuel weathering is based on the fill-up RVP level and ambient temperature. The tampered estimates for hot-soak and diurnal emissions are also based on functions of RVP and temperature. The tampering rates were calculated for fuel cap removal and canister disconnection in MOBILE4.

Table 8. 1981 + LDGV Non-Tampered Emission Equations
Used in MOBILE4

Fuel System	Hot Soak	Diurnal
Carb	-4.51 + 0.72 x RVP	2.35 x UDI
TBI	-2.04 + 0.32 x RVP	2.10 x UDI

MPFI	-2.26 + 0.39 x RVP	1.75 x UDI

once the gram/trip hot-soak and full-day diurnal emissions are calculated as described above, daily values are estimated. These are required because the daily estimates correct the emissions for driving effects. These effects are based on driving pattern data from NPD diary data.

In MOBILE4, daily hot-soak emissions are calculated as:

$$HS = HS * TPD * 0.76$$

where TPD = trips per day (function of vehicle age).

The factor of 0.76 is used because EPA estimates that no trips are taken on 24 percent of all days. Therefore, if there are no trips, then there can be no hot-soak emissions, so only 76 percent of the vehicle days have hot-soak emissions.

The daily diurnal emissions are calculated in three components:

- full diurnals,
- partial diurnals, and
- multiple diurnais.

Full diurnals occur as vehicles experience the entire diurnal increase in temperature. They are calculated as:

$$FDI = DI * 0.34$$

where 0.34 is the frequency of occurrence of these days.

Partial diurnals are caused as vehicles experience diurnal temperature increases between trips. EPA assumes that these occur between specific times of the day and are calculated as:

$$PDI = (D1 \times 0.32) + (D2 \times 0.071) + (D3 \times 0.037)$$

where D1 = Diurnal from 8 a.m. to 11 a.m.,
D2 = Diurnal from 10 a.m. to 3 p.m., and
D3 = Diurnal from 8 a.m. to 2 p.m.

Multiple diurnals occur as vehicles experience successive days without a trip, resulting in canister overloading and higher emissions. In MOBILE4, these are calculated as:

$$MDI = TPDI * 0.8 * 0.16$$

where TPDI = tampered diurnal emissions.

The factor of 0.8 is used because EPA assumed that the second day diurnals are 80 percent of the tampered emission level. The 0.16 factor

is the EPA estimate for the frequency of occurrence of these type of diurnals.

The total diurnal emission rate is the sum of FDI, MDI, and PDI. It should be noted that the fractions of FDI, MDI, and PDI do not sum to 1. That is because a certain fraction of vehicles are assumed not to be parked long enough to undergo a diurnal emission cycle (e.g., delivery vehicles).

Although MOBILE calculates diurnal and hot soak emissions independently, it reports these emission categories as a combined gram per mile "evaporative" emission rate. (Also included in the gram per mile "evaporative" rate are crankcase emissions.) To generate these gram per mile estimates, the following formula is used:

$$\frac{\{(HS(g/trip) * trip\ fraction * trips/day)+DI(\&/day))}{mi/day} + CC(g/mi) \quad [6-1]$$

where CC represents crankcase emissions in g/mi.

MOBILE4.1 and MOBILE5 - To model hot soak emissions, MOBILE4.1 and MOBILE5 also segregate the vehicle fleet according to fuel delivery system (i.e., carbureted, throttle-body fuel-injected, and multipart fuel-injected). However, rather than defining non-tampered and tampered vehicles, the distinction is made as to whether the vehicle has passed the pressure/purge functional evaporative system check. The baseline emission estimates are calculated by determining the emission rate of the passing and failing vehicles separately, and then weighting the results by the expected occurrence in the fleet.

Hot soak emissions are adjusted to account for the input RVP and temperature. (The RVP used in determining emission rates is also adjusted downward to account for fuel tank weathering, and the temperature used to determine hot soak emissions is a function of the input minimum and maximum daily temperature.) As an example, the MOBILE5 hot soak emission rate for "passing' multipart fuel-injected vehicles as a function of RVP is shown in Figure 56, while the multiplicative temperature correction factor is illustrated in Figure 57.

As an example of the weighting procedure, MOBILE5a was run for the 1995 calendar year under typical summer conditions (i.e., 70ø - 95øF; 7.8 RVP fuel). For a 1992 model year LDGV, the model predicts 0.3% would be carbureted, 20.2% would have TBI, and 79.5% would be equipped with MPFI. Emission rates from vehicles passing the pressure/purge test are predicted to be as follows:

Carb - 1.996 g/trip
TBI - 0.824 g/trip
MPFI - 0.283 g/trip

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Thus, the composite hot soak emission rate for passing vehicles is calculated as:

```
HSpass       = 1.966 g/trip * 0.003                 (Carb)
             + 0.824 g/trip * 0.202 * 0.88          (TBI)
             + 0.283 g/trip * 0.795 * 0.88          (MPFI)

HSpass       = 0.350 g/trip
```

Note that the TBI and MPFI vehicles include a correction factor of 0.88. This accounts for the difference in average fuel tank fill level observed in-use (55%) versus the test procedure fill level (40%). Lower emissions are predicted from the higher fuel tank level because there is less vapor space in the tank, and therefore less vapor generation.

For the hot soak estimates, failed pressure and failed purge emission rates are not stratified according to fuel delivery system. Under the temperature and RVP conditions specified above for this MOBILE run, the hot soak rates are:

HSfail purge = 4.305 g/trip, and
HSfail pres = 4.357 g/trip.

Finally, the above emission rates are composited according to the expected fraction of pass, fail purge, and fail pressure vehicles in the fleet. In this example (i.e., a 1992 model year vehicle analyzed in 1995), the pass/fail regime sizes are:

Pass = 93.15%
Fail Purge = 2.11%
Fail Pressure = 4.74%

Thus, the 1992 model-year hot soak emission rate is:

```
HS1992MY     = (0.9315 0.350 g/trip) + (0.0211 * 4.305 g/trip)
```

(0.0474 4.357 g/trip) = 0.623 g/trip.

In modeling diurnal losses, MOBILE4.1 and MOBILE5 also segregate the fleet according to fuel delivery system and whether the vehicle has passed the pressure/purge functional system check. Emissions are determined as a function of temperature (minimum and maximum, input by the user) and fuel RVP in a manner similar to that described above for MOBILE4. The model calculates diurnal rates for "partial" diurnals (i.e., diurnals that are not completed before the vehicle is driven again), full diurnals, and "multiple" diurnals (i.e., cases in which a vehicle sits idle for more than one day). These values are weighted according to their expected occurrence in the fleet to arrive at a single diurnal emission rate in grams/day.

For MOBILE4.1 and MOBILE5, the fraction of vehicles undergoing partial, full, and multiple diurnals was modified to reflect changes in this distribution as a function of vehicle age. This is illustrated in Figure 58, which shows the fractional occurrence of diurnal episodes as a function of vehicle age. As seen in the figure, the fraction of fullday and multi-day diurnals increases with vehicle age as these vehicles are used less.

To illustrate, the diurnal emission rates (already weighted for fuel delivery system and pressure/purge failure status) and fraction of each diurnal episode are summarized below for the 1992 model-year LDGV considered in the above example:

Diurnal Episode	Fraction	Emission Rate (g/event)
Full-Day	0.3325	2.180
8 a.m. - 11 a.m.	0.3408	0.398
10 a.m. - 3 p.m.	0.0747	0.547
8 a.m. - 2 p.m.	0.0390	0.718
Multi-Day	0.1423	7.554
Composite:	0.9293	2.004

It is interesting to note that for this example, the multi-day diurnal episode is the largest contributor to the composite daily emission rate, representing 54% of the composite rate. (Recall that the sum of the diurnal episodes does not equal 1.)

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As with the MOBILE4 methodology, MOBILE4.1 and MOBILE5 combine hot soak and diurnal emissions with crankcase emissions into a single "evaporative" gram per mile emission rate. This is accomplished by multiplying the hot soak emission rate by the number of trips per day and the daily trip fraction; adding this daily hot soak rate to the daily diurnal rate; dividing this sum by the miles per day; and adding the crankcase emissions. This calculation, represented by equation 6-1, is shown below for the example presented above (i.e., a 1992 model year LDGV in 1995), and the average trips per day and miles per day assumed in MOBILE5a are illustrated graphically in Figure 59.

$$\frac{\{(O.623\ \text{g/tr}*0.802*4.48\ \text{tr/day}) + 2.00\ \text{9/day})}{34.8\ \text{mi/day}} + 0.006\ \text{g/mi} = 0.128\ \text{g/mi}$$

The above calculation is carried out over the 25 model years comprising the fleet. The fleet-average "evaporative' emission rate is then calculated by weighting the model-year-specific values by the assumed travel fraction for each model year.

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5.5 RUNNING LOSSES

Running losses, in g/mi, are calculated by MOBILE with a comparatively simple algorithm. Although a distinction is not made by fuel delivery system, vehicles are stratified according to whether they pass the functional pressure/purge test. (In MOBILE4, the distinction was made between non-tampered and tampered.) Emissions are determined by interpolating among data tables that list running loss emission rates (in g/mi) at four temperatures (80ø, 87ø, 95ø, and 105øF) and four different fuel RVP levels (7.0, 9.0, 10.4, and 11.7). Once emission rates are derived for the two emissions categories, these are weighted according to their expected occurrence in the fleet.

MOBILE4 - Figure 60 shows the MOBILE4 non-tampered running loss estimate for 1981+ light-duty vehicles at various RVP and temperatures. These data are used to estimate running losses at other RVPs and temperatures by linear interpolation. No running losses are calculated for temperatures below 40øF. RVP values of 7.0 psi and 11.7 psi are used as extreme ranges for allowable RVPs. RVPs below or above this range are considered to be equal to end points of the range. Similarly, temperatures above 105øF are considered to be equal to 105øF.

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A comparison of MOBILE4 non-tampered running loss emissions for LDGV by model year is given in Figure 61. This figure demonstrates a significant reduction in running loss emissions (for non-tampered evaporative emission control systems) as a result of the SHED-based 2.0 gram/test emission standard that became effective with the 1981 model year.

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In MOBILE4, the tampered running losses are calculated for two tampering categories: gas cap removal and canister disconnection. Table 9 shows the tampered emissions used for all vehicle types at various RVP and temperature levels. The tampering rates for gas cap removal and canister disconnect are calculated as a function of vehicle miles based on EPA's tampering data. Figure 62, which shows a comparison of tampered to non-tampered running loss emissions, graphically illustrates the large impact of gas cap and canister removal.

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MOBILE4.1 and MOBILE5 - The basic methodology used to estimate running loss emission rates remained the same between MOBILE4 and the MOBILE4.1 and MOBILE5 models. However, rather than segregating emissions according to tampering status, MOBILE4.1 and MOBILE5 segregate emission rates by pressure/purge failure status. Running loss emission rates from the MOBILE5 model are shown in Figures 63 and 64 for vehicles passing and failing the pressure/purge test, respectively. (For running losses, pressure failures and purge failures are assumed to have the same emission rate.) These figures indicate that higher temperatures and RVPs result in higher running loss emissions.

A comparison of MOBILE5 running loss predictions for 'passing" and "failing' vehicles is presented in Figure 65 for 9.0 RVP fuel. As seen, the emission rates from vehicles failing the pressure/purge test are much higher (by nearly an order-of magnitude) than emissions from those passing the test.

Finally, in comparing the MOBILE5 results to those obtained with MOBILE4, the following is observed:

- The "passing' emission rates in MOBILE5 are slightly lower than the "untampered" rates estimated by MOBILE4.

- The MOBILE5 "failing" emission rates are similar to the MOBILE4 gas-cap-tampered estimates at temperatures below 95øF, and lower at temperatures above 95øF.

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- The MOBILE5 "failing" emission rates are higher than the MOBILE4 canister-tampered emission rates.

The above emission differences are not unexpected, given the different methods used to identify the MOBILE4 "tampered" and MOBILE5 "failing' vehicles.

5.6 RESTING LOSSES

Resting losses were incorporated into the MOBILE model with the MOBILE4.1 release. The model calculates resting losses in grams/hour, and emissions are a function of temperature and the type of canister in the evaporative control system (i.e., open bottom versus closed bottom). As an example', MOBILE5 estimates resting loss emissions for a vehicle with an open bottom canister to be 0.29 grams/hour at 100øF, while the value for a closed bottom canister under the same conditions is 0.13 grams/hour. Resting losses are also converted to an equivalent g/mi value by summing emissions throughout the day and dividing by miles/day.

5.7 REFUELING LOSSES

Two components of refueling emissions are considered in the MOBILE models: vapor space displacement and spillage. Vapor space displacement is a function of fuel tank temperature, dispensed fuel temperature, and dispensed fuel RVP, and emissions are reported as grams/gallon (g/gal). Spillage is considered a constant at 0.31 g/gal. The user has the option of specifying uncontrolled rates or including the impact of a vapor recovery system in the output. EPA has chosen to model the impact of an on-board vapor recovery system by assuming a 98 percent reduction in uncontrolled displacement emissions and a 50 percent reduction in spillage. Stage II vapor recovery is modeled by applying a user-specified percent reduction in uncontrolled displacement emissions (no benefit is assumed for spillage). The g/gal values are then converted to g/mi by dividing by the average fuel economy for the vehicle class and model year being considered.

5.8 CRANKCASE EMISSIONS

Crankcase emissions are largely controlled by positive crankcase ventilation (PCV) systems that have been installed on new vehicles since the early 1960s. Crankcase emissions, therefore, are the result of tampered or defective PCV systems. MOBILE models crankcase emissions by assuming a certain tampering rate (which increases with vehicle age) and multiplying that value by an uncontrolled crankcase emission rate. Overall, crankcase emissions are very small, generally contributing only a few hundredths of a gram per mile to the HC emission rate.

6. MODELING OF I/M PROGRAMS

On-road motor vehicles have been required to meet increasingly stringent emission standards when new for over 25 years, but they still are significant contributors of ozone precursors and carbon monoxide in most urban areas. Much of this contribution is attributed to vehicles that exceed certification standards in customer service. Although EPA has implemented programs to improve in-use emission control system durability (e.g., in-use recall, 100,000-mile certification standards), a properly designed inspection and maintenance (I/M) program remains one of the most effective means of ensuring that high-emitting vehicles are identified and repaired. Congress recognized the importance of I/M programs in reducing vehicular emissions in urban areas when drafting the Clean Air Act Amendments of 1990, and directed EPA to develop performance requirements and other standards for basic and enhanced I/M programs. These guidelines were published in November 1992,15 and specify a number of features associated with both program types.

The methodology by which MOBILE accounts for I/M benefits differs between exhaust and evaporative emissions. The exhaust procedure follows from the discussion of the Tech IV model contained in Section 5, and I/M credits (by model year) are estimated by recalculating the emitter regime emission levels as a result of an I/M repair. The emission reductions calculated by MOBILE are a function of I/M program type (i.e., centralized versus decentralized), I/M test type (i.e., idle versus loaded mode), inspection frequency (annual versus biennial), and I/M emission cutpoints. The overall effectiveness of a particular program is strongly influenced by assumptions made by EPA regarding how well a program identifies and repairs a failing vehicle. (Although the calculation methodology is similar among MOBILE revisions, the discussion that follows has utilized information from MOBILE5/Tech5.)

An I/M benefit for evaporative emissions can be calculated by the MOBILE4.1 and MOBILE5 versions of the model, and it is applied according to whether or not the functional pressure and purge tests are in place. (For MOBILE4, a small evaporative benefit is calculated if the evaporative system is included in an ATP program.) The evaporative emissions benefit is calculated in MOBILE4.1 and MOBILE5 by changing the fraction of vehicles passing and failing the pressure/purge test and recomputing the evaporative emission rate. That process follows from the discussion of pressure/purge failure and emission rates contained in Section 6.

The discussion below summarizes the methodologies used in MOBILE5 to estimate emission benefits (both exhaust and evaporative) from I/M programs. In addition, EPA's performance standards for basic and enhanced I/M programs are reviewed.

6.1 EXHAUST EMISSION I/M MODELING

When an I/M program option is invoked in a MOBILE run, the base emission rate ("BER" in equation 4-1) is adjusted to reflect the presence of that program. The adjustment takes into account the features of the I/M program being modeled, such as:

- program type (centralized or decentralized),
  inspection frequency (annual or biennial),
- test type (idle, idle/2500, loaded idle, or IM240),
- emission cutpoints (for IM240),
- waiver rate, and
- compliance rate (i.e., the fraction of vehicles subject to the program that complete the process to the point of receiving a certificate of compliance or a waiver).

To perform the I/M adjustment on the BER, the following methodology is employed:

BERI/M = BERNon-I/M * {1 - [CREDI/M * (1 WVR)] * ADJcomp1}

where CREDI/M is the I/M credit for the test type, cutpoints, frequency, model year, and vehicle age being considered; WVR is the user-input waiver rate; and ADJcomp1 an adjustment that accounts for the user input compliance rate. The above calculation is valid for centralized program types; if a decentralized program is specified, the calculation includes an adjustment that reduces the overall effectiveness of the program by 50%.

As an example, consider a calendar year 2000 MOBILE5a run in which an annual, centralized IM240 program is specified with 0.8 g/mi HC and 20.0 g/mi CO cutpoints. Further, assume that the I/M compliance rate is 96% and the waiver rate is 3%. (These are the MOBILE parameters that EPA has chosen for developing the enhanced I/M performance standards.) The non-I/M HC base emission rate for a 1992 model-year LDGV (analyzed in the year 2000) is 2.153 g/mi, and the base emission rate including the effects of the above I/M program is:

BERI/M = 2.153 * {1 - [0.476 * (1 - 0.03)] * 0.92)
BERI/M = 2.153 * {1 - 0.425) = 1.238 g/mi.

Several items are worth noting in the calculation above. First, the I/M credit is reduced from 47.6% to 42.5% when accounting for the effects of the waiver rate and the compliance rate. Second, the adjustment performed to account for the compliance rate is nonlinear (i.e., although the compliance rate was 96% in the above example, the I/M benefits are reduced by 8% rather than 4%). This adjustment inherently assumes that the I/M failure rate of non-complying vehicles will be -higher than that of the rest of the fleet.16

The I/M credits (i.e., CREDI/M in the above equation) are stored in data matrices that are read by MOBILE. For 1981 and later model years, these credits are developed by EPA's "Tech" models, and are a function of test type, inspection frequency, model year, and vehicle age. A summary of how the Tech models develop the I/M credits is provided below.

Tech5 Model - The Tech5 model was used to generate the I/M credits (i.e., "CREDI/M in the above equation) for use in MOBILE5. To develop those credits, Tech5 compares emission rates under no I/M program to the emission rates that would occur in the presence of an I/M program (neglecting compliance and waiver rates, which are accounted for within MOBILE). The emission rates for a particular I/M case are calculated by Tech5 (by technology class and emitter regime) according to the following approach:

Emission RateIM - {(1-IDRATE)*EMIS} + (IDRATE*EMIS*(1-REF))

where IDRATE is the identification rate specific to the I/M test type, emitter group, and technology group; EMIS is the baseline emission rate of the emitter group being analyzed; and REF is the assumed repair effectiveness.

As with the Tech IV model, emissions data are stratified by certification standard, technology (i.e., closed-loop multipart fuel-injection, closed-loop throttle-body injection, closed-loop carbureted, and open-loop), and emitter group (or "regime"). The emitter groups utilized in the Tech5 model are:

- Normal: ó 2 x HC Std. and ó 3 x CO Std.
- High: > 2 x HC Std. or > 3 x CO Std.
- Very High: > 4 x HC Std. or > 4 x CO Std.
- Super: > 10 g/mi HC or > 150 g/mi CO

In addition, NOx emissions are stratified into low and high NOx regimes, with high NOx emitters being greater than 2.0 g/mi.

Baseline Emission Rates - Once the emission data are stratified as outlined above, the baseline emission rates (as a function of vehicle mileage or age) are determined by multiplying the emission rate of each regime by the fraction of each regime making up the fleet at the mileage intervals corresponding to vehicle age. As an example, the incidence of emitter groups in the fleet is illustrated in Figure 66 for 1983 to 1993 model year multipart fuel-injected (MPFI) light-duty gasoline vehicles, and the exhaust HC emission rate of each regime (as a function of vehicle age) is shown in Figure 67. Combining the data illustrated in Figures 66 and 67 results,in the baseline HC emission rate shown in Figure 68.

After-I/M Emission Rates - The Tech5 model then determines an "after-I/M" emission rate (for each vehicle age) that is based on the identification rate and repair effectiveness of the specific I/M program

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type (e.g., IM240) and cutpoints being modeled. The identification rate and repair effectiveness developed by EPA are a function of emitter category, with the identification of failing vehicles being close to 100 percent for the Super and Very High categories for most cutpoints. As an example, the identification rates assumed for 1983 to 1993 model year vehicles by emitter group and technology are shown in Figure 69 based on 0.8/15.0 HC/CO cutpoints (i.e., vehicles with an emission rate of over 0.8 g/mi HC or 15.0 g/mi CO on the IM240 test are considered failing vehicles under these cutpoints).

The after-repair emission rates are variable, according to I/M test type and model year, but for 1983 to 1993 model years, the after-repair HC rates (based on IM240 testing) are generally about 0.5 g/mi for Normals, 0.8 g/mi for Highs, 1.0 g/mi for Very Highs, and 0.9 g/mi for Supers. The after-repair emission rates are depicted graphically in Figure 70 for this model year group.

The after-repair composite emission rates from the Tech5 model for light-duty MPFI vehicles are shown in Figure 71 as a function of emitter category (based on IM240 testing and 0.8/15.0 HC/CO cutpoints). The figure indicates a significant reduction in emission level as a result of an I/M program, and most of the reduction is from the Super and Very High emitter categories.

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To develop model-year specific emission rates and I/M program benefits, the above calculations are performed for each standard group and technology group. These results are then weighted according to the expected fraction of each group in the fleet. As an example, the baseline and after-I/M emission rates as a function of vehicle age are given in Figure 72 (again based on IM240 testing and 0.8/15.0 HC/CO cutpoints). The I/M credit matrices developed for use in the MOBILE models are determined from these two lines through an algorithm that applies the non-I/M deterioration rate (i.e., the slope of the top line) to the I/M emission rate at each vehicle age (for an annual program) to arrive at the final I/M emission rate. This results in the traditional "stair-case" emission rate normally associated with modeling of I/M programs.

6.2 EVAPORATIVE EMISSIONS I/M MODELING

Pressure/Puree Testing - EPA's recommended evaporative system functional test procedure consists of two distinct test types: a pressure test and a purge test. The pressure test is designed to assess the integrity of the fuel tank (including the gas cap) and vapor line leading from the fuel tank to the evaporative canister. Under this procedure, the fuel tank vapor line is disconnected at the canister, a pressure gauge is connected, and the tank is pressurized with nitrogen (through the vapor

Click HERE for graphic.

line) to 14 inches of water. If the pressure drops below 8 inches of water in a two-minute period, the system fails. As the name implies, purge testing is intended to identify defects in the evaporative purge system. EPA's test procedure consists of placing a flow meter in the vapor purge line between the canister and the engine, and monitoring the cumulative purge flow (in liters) over the 4-minute IM240 transient test. If the cumulative flow during the test is less than 1.0 liter, the system fails.

Benefits of Evaporative System Functional Tests - Section 6 described the process used in MOBILE4.1 and MOBILE5 to generate baseline (i.e., no pressure/purge test in effect) evaporative emission rates. That method relies on estimates of the fraction of vehicles (by vehicle age) passing the pressure/purge test, failing the pressure test, and failing the purge test. Those fractions are then applied to the emission rates applicable to each of the three failure categories to arrive at a composite model-year-specific emission rate. Under an I/M program, the benefits of pressure/purge testing are estimated by modifying the distribution of vehicles expected to pass, fail purge, or fail pressure, and then re-computing the model-year emission rate.

The effect of vehicle repair on pressure/purge failure rates as a function of vehicle age is depicted graphically in Figure 73. It shows the MOBILE5a baseline failure rate (from Figure 55) and the after-repair failure rate as a result of an annual pressure/purge check. This figure demonstrates the classical saw-tooth pattern associated with inspection

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and maintenance cycles (i.e., failing vehicles are repaired, but in the next cycle there are additional failures). It is assumed that the failure rate between inspections will increase at the same rate as that observed for the same-age vehicles under the baseline case, and the after-repair failure rate is 5 percent of the before-repair failure rate (i.e., 95 percent identification and repair effectiveness is assumed). This can be thought of as translating the slope of the top line of Figure 73 (e.g., between years 10 and 11) onto the after-repair failure rate depicted by the lower points of the bottom line in Figure 73 (e.g., at year 10).

Note that Figure 73 indicates that there is a cyclical nature to the pressure/purge failure rate under an I/M scenario. That is because EPA assumes that a certain fraction of vehicles repaired early in their lives fail again at a later date. However, this approach was incorrectly applied in the MOBILE5 version, which resulted in near-zero failure rates at years 14 and 23. Conversations with EPA staff revealed that this error has only a small impact on the MOBILE5 results, and it will likely be corrected in the next revision to the model.

6.3 EPA'S I/M PERFORMANCE STANDARDS

EPA's performance standard for enhanced I/M programs is commonly reported to be 28% for HC, 31% for co, and 9% for NOx, the emission reductions cited in the I/M final rule.15 However, these percentages were based on the MOBILE4.1 version of EPA's emission factor model and reflect the reduction in emissions for the entire on-road motor vehicle fleet when compared to a non-I/M case. The actual performance standards for both basic and enhanced I/M programs are to be calculated for each nonattainment area using the latest version of the MOBILE model run under a very specific set of I/M input parameters. The performance standard, calculated as g/mi (or tons/day), is then compared to the MOBILE results that reflect the proposed local I/M program being modeled. If emission rates from the proposed program equal or fall below the performance standard, the program can be approved by EPA.

This approach allows nonattainment communities the flexibility to develop an I/M program different from the "model" programs set forth by EPA in the I/M final rule. For example, although the "model" programs specify annual testing, the benefits from biennial testing are nearly as great at a substantially reduced cost. Thus, if a biennial program is chosen, the reduced benefits can be made up by expanding.the I/M program to include additional vehicle classes (e.g., HDGVS) or extending the model year coverage for some test types (e.g., require pressure testing on 1971 and later vehicles rather than 1983 and later vehicles as specified in the "model" program).

MOBILE Input Parameters - Although the I/M final rule lists the I/M program inputs to be used in establishing I/M performance standards, some of these inputs (e.g., 1.4 g/mi IM240 NOx standard for Tier I vehicles under enhanced I/M) cannot be used with the MOBILE model. Subsequent guidance 17 , however, has established the proper inputs for communities to use in developing I/M performance standards for basic and enhanced programs. These inputs are summarized in Table 10, which shows that only 1968 and later model-year LDGVs subject to an idle-based emissions test are considered in developing the performance standards for the basic program. On the other hand, LDGVS, LDGTls, and LDGT2s are included in the enhanced I/M requirements. These requirements also specify IM240 testing for 1986 and later vehicles, evaporative system pressure testing for 1983 and later, and evaporative purge testing for 1986 and later.

In addition to the parameters listed in Table 10, the MOBILE input files prepared to establish the I/M performance standard should include area specific inputs for the following:

- registration distributions by vehicle class;
- VMT mix (i.e., percent travel by vehicle class);
- minimum and maximum temperature;
- ASTM class (used to model the effects of reformulated gasoline);
- fuel RVP;

Table 10. MOBILE5a Parameters Used to Model the Performance Standard
Targets for Basic and Enhanced I/M Programs

Input Parameter	Basic I/M	Enhanced I/M
Network:	Centralized	Centralized
Frequency:	Annual	Annual
Model Years:	1968+	1968+
Vehicle Types:	LDGV	LDGV,LDGT1,LDGT2
Emission Test(s):	Idle on 1968+	Idle on 1968-80 Idle/2500 on 81-85 IM240 on 1986+a
Start Date:	1983/1994b	1983/1995b
Pressure Test:	None	1983+
Purge Test:	None	1986+
Visual Check:	None	Catalyst & Fuel Inlet
Pre-81 Stringency:	20%	20%
Pre-81 Waiver Rate:	0%	3%
Post-80 Waiver Rate:	0%	3%
Compliance Rate:	100%	96%

a IM240 cutpoints: 0.8 g/mi HC, 20.0 g/mi CO, 2.0 g/mi NOx.
b1983 is used for areas with existing I/M programs, 1994 or 1995 is used for areas newly subject to I/M under the 1990 CAAA.

- altitude; and
- all other mobile source programs modeled by MOBILE that are applicable for the case being analyzed (e.g., oxygenated fuels, Stage II vapor recovery).

I/M Performance Standards - The MOBILE input parameters specified in Table 10 were used to generate I/M performance standards for basic and enhanced I/H programs based on national default MOBILE5a runs - for the year 2000. The MOBILE5a output for HC and CO is summarized in Table 11, which indicates an 8% reduction in on-road motor vehicle HC emissions under the basic program and a 34% reduction in HC emissions under an enhanced program. The CO benefits are 11% and 36% for basic and enhanced programs, respectively.

Table 11. Basic and Enhanced I/M Performance Standards Based on MOBILE5a (Year 2000, 750F, 9.0 RVP, 19.6 mph)

	Hydrocarbonsa		Carbon Monoxide	
I/M Scenario	g/mi	Reduction	g/mi	Reduction
No I/M	2.47	-	21.62	-
Basic I/M	2.28	8%	19.28	11%
Enhanced I/M	1.64	34%	13.83	36%

a Includes exhaust and all evaporative components except refueling losses.

7. CLEAN AIR ACT REQUIREMENTS

The Clean Air Act Amendments (CAAA) of 1990 included a number of new requirements for on-road motor vehicles. In addition, Section 130 of the CAAA directed EPA to review and revise emission factors used to estimate emissions of VOC, CO, and NOx. Thus, many of the revisions included in MOBILE4.1 (released November 1991) and MOBILE5 (released December 1992) were in direct response to the directives of the CAAA. Among the requirements necessitating revisions to the model are heavy-duty truck emission standards, light-duty vehicle cold CO emission standards, revised evaporative emission test procedures, more stringent ("Tier I") emission standards for light-duty vehicles, and reformulated and oxygenated gasolines. The following describes how the model was revised to account for the effects of these CAAA requirements. (Although not a CAAA requirement, a description of how the California Low-Emission Vehicle program is modeled in MOBILE5 is also included in this section.)

7.1 HEAVY-DUTY TRUCK EMISSION STANDARDS

Promulgation of new NOx emission standards for heavy-duty gasoline and Diesel vehicles is required by the CAAA. Beginning with the 1998 model year, the NOx standard will be changed from 5.0 grams per brake horsepower-hour (g/bhp-hr) to 4.0 g/bhp-hr. This new standard was modeled in MOBILE5 by simply applying the ratio of the standards (i.e., 4.0/5.0) to the zero-mile component of the 1998 model year base emission rate equation.

7.2 COLD CO EMISSION STANDARDS

Section 204 of the CAAA directs EPA to promulgate low-temperature CO standards for light-duty vehicles and light-duty trucks beginning with the 1994 model year. The regulations are to be phased-in, with 40 percent compliance in 1994, 80 percent in 1995, and full compliance with the 1996 model year. Under these requirements, light-duty vehicles must comply with a 10.0 g/mi CO emission level at 200F while operating over the three-bag FTP. Light-duty trucks will comply with a 12.0 g/mi standard.

To model the impact of the cold temperature CO emission standards, EPA assumed that all of the benefit of the regulation would occur during the cold start portion of the exhaust emission test. Therefore, the Bag 1 cold temperature CO offset (discussed in Section 5) was modified, while the stabilized and hot start modeling procedure remained unchanged. Recall that the CO emission factor (EFCO) is represented by:

$$\mathrm{EFCO = BER*BCF + COoff] * CFn} \qquad [8\text{-}1]$$

where BER is the basic emission rate, BCF is the bag (or operating mods) correction factor, COoff is the cold temperature CO offset, and CFn represents the various multiplicative correction factors included in the model (e.g., speed, in-use fuel, etc.). The cold CO standard is modeled by decreasing the CO offset by an amount that varies linearly with ambient temperature. The offset correction, OFFcor' is specified as:

```
OFFcor = (75-T *   fcncs ) * (13. 2 -  2.7* STD)                 [8-2]
         ( 55       0.206)   (         3.4     )
```

where T is the temperature at which the exhaust emission factor is being calculated, fcncs' is the VMT fraction occurring in the cold start mode, and STD is the numerical cold CO standard applicable to the particular vehicle type being modeled (i.e., 10.0 g/mi for light-duty vehicles and 12.0 g/mi for light-duty trucks).

As a numerical example, a 1997 model year LDGV was considered in the year 2000. Further, the vehicle was assumed to be operating 100 percent in the cold start mode at a temperature of 30øF. The emission rate (neglecting CF. in equation (8-1]) is therefore calculated as:

EFCO = [(BER * BCF) + (COoff - OFFcor)]
EFCO = [(7.60 *1.59) + (34.83 -20.89)]
EFCO = 26.02 g/mi

Thus, the effect of the cold CO standard is to reduce the CO emission level of this vehicle at 30øF from 46.91 g/mi to 26.02 g/mi (a 45 percent reduction) during cold start operation. The overall impact of the standard is reduced when including hot start and stabilized operating modes in the composite emission factor.

7.3 REVISED EVAPORATE TEST PROCEDURE

The CAAA directed EPA to promulgate new evaporative standards and test procedures to control running loss emissions and multi-day diurnal emissions under summertime, ozone conditions (i.e., elevated temperatures). Although the CAAA were not explicit in terms of actual requirements or implementation schedule, the new procedures and standards will be effective with the 1996 model year and will be phased in over a four-year period (i.e., 20 percent compliance in 1996, 40 percent compliance in 1997, 90 percent compliance in 1998, full compliance in 1999).

A review of the MOBILE5a code indicates that the following methodology is used to model these requirements for vehicles passing the pressure/purge functional test:

- An 80 percent reduction is applied to the baseline running loss emission rate;

- Resting losses are reduced by 75 percent;
- Hot Soak emissions are reduced by 50 percent; and
- Partial and full diurnals are reduced by 50 percent, two- to three-day diurnals are reduced by 75 percent, and diurnals beyond three days are reduced by 40 percent.

For vehicles failing the functional pressure/purge test, the benefits from the new test procedures are substantially reduced. (A review of the MOBILE5 code indicates that no diurnal benefit is ascribed to failing vehicles, while failing vehicle running loss and hot soak emissions are reduced by about 20 to 30 percent. However, the actual reductions for running loss and-hot soak emissions are dependent upon RVP and temperature.)

7.4 TIER I EMISSION STANDARDS

The CAAA call for more stringent (i.e., "Tier I") exhaust emission standards for light-duty vehicles (LDVS) and light-duty trucks (LDTS) beginning with the 1994 model year. The standards are to be phased in, with 40 percent compliance in 1994, 80 percent compliance in 1995, and full compliance in 1996. (Intermediate in-use compliance standards are also included in the requirements.) LDVs and LDTs under 3750 lbs. loaded vehicle weight (LVW) would comply with 0.25 g/mi NMHC, 3.4 g/mi CO, and 0.4 g/mi NOx, while LDTs from 3751 to 5750 lbs. LVW would meet 0.31 g/mi NMHC, 4.4 g/mi CO, and 0.7 g/mi NOx. (All standards above are 50,000 mile requirements; the CAAA also specifies corresponding 100,000 mile standards.)

To model the effects of the Tier I standards, EPA adjusted the ZM component of the base emission rate equation. This adjustment was based on the ratio of the Tier I standard to the existing standard for the vehicle class being modeled. For example, the LDGV zero-mile level for NOx was multiplied by 0.4/1.0 to model the effects of the 0.4 g/mi NOx standard (the current NOx standard is 1.0 g/mi). No changes were made to the deterioration rates.

7.5 REFORMULATED AND OXYGENATED GASOLINE

Modeling the effects of oxygenated fuels was first included in MOBILE4.1. That version of the model, however, only estimated the impacts on exhaust CO and evaporative emissions (evaporative emissions are impacted by virtue of the change in RVP from commingling effects). MOBILE5 extended the modeling of oxygenated fuels to also include HC emissions. MOBILE5 can model the effects of oxygenated fuels on NOx emissions, but at the time of the MOBILE5 release, the impact of oxygenated fuels on NOx was estimated to be negligible.

The MOBILE5 subroutine that estimates the exhaust emission benefits from oxygenated fuels first calculates a factor that increases the base emission rate to account for the differences in certification (i.e., Indolene) and in-use fuels. This correction for HC and CO is applied to all catalyst-equipped vehicles, whereas a correction for NOX is only applied to vehicles equipped with three-way catalysts. (No in-use correction is applied to non-catalyst vehicles.) These correction factors are:

- HC = 1.157 (applied to all catalyst vehicles),
- CO = 1.087 (applied to all catalyst vehicles), and
- NOx = 1.160 (applied to three-way catalyst vehicles).

These factors were calculated from data collected in EPA's Phase I Reformulated Gasoline Study.

The exhaust emission benefits of oxygenated fuels modeled in MOBILE4.1 and MOBILE5 are a function of fuel oxygen content, emission rate, and model year. (Imbedded in the model-year-specific corrections are assumptions regarding vehicle technology. These data matrices were developed from a subroutine contained in the TECH5 model.) For HC emissions, the model has been structured to account for a difference in benefits between ether and alcohol blends; however, MOBILE5 assumes the same exhaust HC effects for ether and alcohol blends.

To illustrate the magnitude of the projected impact of oxygenated fuels determined by MOBILE5, Figures 74 and 75 show the calculated benefits (as a percent reduction from the base emission rate) for CO and HC for 1990 model year light-duty vehicles. The benefits increase with increasing fuel oxygen content and with increasing base emission rate, resulting in a maximum benefit of approximately 18 percent for HC and 29 percent for CO at an oxygen content of 2.7 weight percent. (Note that MOBILE5 does not calculate HC benefits for fuels with an oxygen content above 2.7 percent. For cases in which a higher oxygen content is input by the user, a value of 2.7 percent is utilized in the calculation.)

The changes in CO benefits estimated by the MOBILE4.1 and MOBILE5 versions of the emission factors model are relatively minor as illustrated in Figure 76. The data contained in the figure indicate a slightly higher benefit at lower emission rates for MOBILE4.1. What is more interesting about this figure, however, is the fact that the maximum CO emission rate predicted by MOBILE5 is nearly 3 times that predicted by MOBILE4.1. Again, this demonstrates the impact of changes to the methodology and data used in TECH5 to develop the exhaust base emission rate equations for MOBILE5.

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7.6 CALIFORNIA LOW-EMISSION VEHICLE PROGRAM

Because of interest by a variety of states in adopting the California Low-Emission Vehicle (LEV) standards (notably the northeast states), EPA included an algorithm in MOBILE5 to model the effects of those emission standards (including the capability to specify an alternative start date). Basically, EPA has taken two approaches in modeling emission rates from LEVS:

- Standard (or No) I/M: In this case, the only adjustment made to the emission factor equation that accounts for the standard change was to the zero-mile level. EPA has argued for many years that more stringent emission standards do not impact emission control system deterioration rates. Thus, under this scenario, the zero-mile level for the various LEV classes (i.e., TLEVS, LEVS, ULEVS) was developed from the existing Tier I zero mile levels by applying the ratio of the LEV to Tier I standards. (Also included in this methodology were a variety of adjustments to account for NHOG versus NMHC differences, reactivity differences, and certification versus in-use fuel differences).

- "Appropriate I/M": As an alternative for those users that want more emission benefit associated with the LEV program, EPA has

developed a second methodology to estimate its benefits. Under this "Appropriate I/M" approach, it is assumed that these vehicles meet their certification standards in customer service due to the presence of a very strong I/M program (i.e., the maximum possible I/M benefits). Thus, the deterioration rates of the LEV emission factor equations were also adjusted downward so that emission standards are met in-use. Although this results in significant LEV benefits, historical in-use data have never indicated that standards are met in customer service for an entire fleet of vehicles.

The difference in the emission factor equation for LEVs developed through these two methodologies is quite dramatic, as illustrated in Figure 77. Clearly, the presence of just a fraction of a percent of high-emitting vehicles could cause a significant change in the emission rate depicted by the bottom line in Figure 77.

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8. EMISSIONS VERSUS VEHICLE AGE

There has been considerable interest recently in the fraction of emissions attributable to older vehicles versus newer vehicles. This fraction has ramifications in terms of where efforts should be placed to control emissions from motor vehicles (i.e., should the focus be on new vehicle standards or on in-use control programs). For example, many communities are considering vehicle scrappage programs in which owners of older vehicles (e.g., pre-1975 model year) are offered a bounty for their vehicle. These vehicles, which have high emissions relative to the fleet average, are then removed from service (i.e., they are destroyed). Presumably, such vehicles are replaced by lower-emitting vehicles resulting in a net reduction in emissions.

The emission reduction potential of such measures depends on the fractional contribution to the fleet-average emission rate of the model year groups included in the program. That contribution, in turn, depends on the vehicle class (e.g., passenger cars versus light trucks) and the type of I/M program in place (I/M programs may have a different impact on different model years). This section presents results from MOBILE4.1 and MOBILE5a depicting the contribution of specific model year groups to the fleet-average emission rate. The calculations were performed for the light-duty gasoline vehicle classes (i.e., LDGV, LDGT1, LDGT2) for calendar years 1985 through 2010 under no I/M, "basic" I/M (assumed to be idle/2500 rpm testing for this analysis), and enhanced" I/M (i.e., IM240 and pressure/purge testing) cases.

8.1 ANALYTICAL APPROACH

MOBILE Model-Year Output - The MOBILE4.1 and MOBILE5 versions of the model offer the user an option to specify output on a model-year-specific basis, and an example of this output format is contained in Figure 78. This output also contains the estimated travel fraction for each of the 25 model years making up the fleet. (Section 4 of this report describes how the travel fraction is determined.) To generate the fleet-average emission rate, the model-year-specific emission rates are multiplied by the corresponding travel fraction and summed over all model years.

For this analysis, it was necessary to process the model-year output in a series of spreadsheets that combined the emission rates and travel fractions (i.e., VMT fractions) associated with certain model-year groups. In this way, the fractional contribution of model-year groups to the fleet-average emission rate was determined.

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Model-Year Groupings - The model-year groupings chosen for this analysis were based on the emission standards to which the vehicles were certified, as well as the expected emission control technology used to meet those standards. This was discussed previously in Section 5.4, and Table 6 lists the emission standards and predominant emission control technologies for LDGV as a function of model year. (Similar tables for LDGT1s and LDGT2s are contained in Appendix A.) Based on this table, the model year groupings chosen for analyzing LDGV emission rates are as follows:

- pre-1968,
- 1968-1971,
- 1972-1974,
- 1975-1980,
- 1981-1993, and
- 1994+.

The same approach was also used to develop the model year groupings for LDGT1s and LDGT2s.

MOBILE Inputs - Because the comparisons presented in this section are intended to reflect differences in emission rates, FTP conditions were used when developing the input files for the MOBILE runs (i.e., 75øF, 19.6 mph, FTP operating mode fractions, 9.0 RVP fuel). For cases in which an I/M program was specified, a waiver rate of 3% and a compliance rate of 96% was assumed. For the Purposes of this analysis, "basic" I/M was considered to be an idle/2500 test and "enhanced" I/M was assumed to be an IM240 test. (An enhanced I/M program was only modeled with MOBILE5a in this analysis.) An evaporative system functional check was included under the "enhanced" I/M scenarios (pressure testing was assumed for 1971 and later model years, purge testing was assumed for 1981 and later model years). Finally, all I/M programs were assumed to be conducted on an annual, centralized basis.

8.2 MOBILE4.1 RESULTS

The analysis described above was performed on MOBILE4.1 output for a no I/M case and a basic I/M case. The results of that analysis are presented below.

No I/M - Figures 79 and 80 illustrate the fleet-average LDGV emission rate by model year group for exhaust HC and CO, respectively, for calendar years 1985 to 2010 (in five-year increments). As seen, the overall fleet-average emission rate drops dramatically between 1985 and 2000 and then levels off beyond that point. This is the result of fleet turnover (i.e., higher-emitting, older model years disappearing from the 25-year fleet considered in MOBILE4.1) and the fact that emission rates beyond the 1981 model year are substantially similar. (Recall that MOBILE4.1 does not include the effects of Tier

I vehicles.)

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It is also interesting to compare the fractional contribution of each model year group to the fleet-average emission rate versus that group's VMT fraction. This is depicted in Figures 81 and 82 for exhaust HC and CO, respectively, for the 1995 calendar year. Those figures indicate that although pre-1981 LDGVs account for only 5.1% of the VMT in 1995, they contribute 29.8% and 26.3% of the exhaust HC and CO emissions, respectively. (The spreadsheets used to develop these figures are contained in Appendix D, which also includes results for LDGTls and LDGT2s.)

Basic I/M - Under the "basic" program modeled in this section, the MOBILE4.1 results are very similar to those presented above for the no I/M case, but the relative contribution of the pre-1981 model years is slightly less. This is the result of I/M being more effective, on a percentage basis, for older vehicles than newer vehicles. The results for this I/M case are summarized for LDGVs, LDGT1s, and LDGT2s in Appendix D.

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8.3 MOBILE5a RESULTS

The analysis presented above was also carried out using MOBILE5a as the basis for the emission calculations, and the results from that evaluation are summarized below. Only results for the no I/M case are presented in this section, as the I/M scenarios revealed similar trends. (Results from the I/M cases are contained in Appendix D.)

The model-year contributions to the fleet-average LDGV exhaust HC and CO emission rates calculated by MOBILE5a under a no I/M case are illustrated in Figures 83 and 84, respectively. As with the MOBILE4.1 results, the overall fleet-average emission rates decline substantially between 1985 and 2010. However, with the MOBILE5a estimates, the exhaust HC emission rates continue to decrease beyond 2000 because of the Tier I emission standards that are phased-in beginning in 1994. Figures 85 and 86 show the travel fraction and the emission contribution of the model-year groups for exhaust HC and CO, respectively, for a 1995 analysis year. Again, the pre-1981 emission contribution is much greater than indicated by this group's travel fraction.

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8.4 COMPARISON OF MOBILE4.1 AND MOBILE5a

Table 12 compares the emission contribution of pre-1981 and 1981+ modelyear groups for LDGVs for a 1995 analysis year computed with MOBILE4.1 and MOBILE5a. As seen, MOBILE5a is predicting a higher contribution from the newer (1981+) vehicles. This is primarily the result of the changes to the base emission rate equations in MOBILE5a that predict much higher deterioration rates beyond 50,000 miles.

Table 12. Comparison of Model Year Contribution to the Fleet-Average LDGV Emission Rate for Calendar Year 1995
(MOBILE4.1 Versus MOBILE5a)

	MOBILE4.1		MOBILE5a	
Pollutant/ I/M Scenarioa	Pre-1981	1981+	Pre-1981	1981+
HC				
No I/M	0.297	0.703	0.214	0.786
Basic I/M	0.262	0.738	0.192	0.808
Enhanced I/M			0.224	0.776
CO				
No I/M	0.285	0.715	0.183	0.817
Basic I/M	0.244	0.756	0.151	0.849
Enhanced I/M			0.176	0.824
NOx				
No I/M	0.222	0.778	0.135	0.865
Basic I/M	0.226	0.774	0.137	0.863
Enhanced I/M	0.168	0.832		

For this analysis, "basic" I/M refers to an idle/2500 RPM test; enhanced" I/M refers to an IM240 test.

9. EFFECT OF MODEL CHANGES ON EMISSION FACTOR ESTIMATES

This section presents a comparison of the fleet-average emission rates calculated by MOBILE4, MOBILE4.1, and MOBILE5a. The baseline emissions estimates are presented first, followed by an investigation of changes made to individual parameters while holding the remaining parameters constant. Included in this comparability analysis are changes in operating mode fractions; the effect of temperature on emissions; the effect of speed on emissions; the impact of RVP control, oxygenated fuel, and reformulated gasoline; and the impact of inspection and maintenance programs.

As detailed in the preceding sections, many parameters go into the fleet-average emissions estimates provided by the MOBILE model, and many of these have changed among revisions to the model. This is further complicated by the fact that not all vehicle types included in the emissions estimates are treated in the same manner. For example, gasoline vehicles are corrected for temperatures outside the standard FTP temperature of 750F, whereas Diesel vehicles are not; and multiple day diurnals are calculated for LDGV, LDGT1, LDGT2, and HDGV, but not for motorcycles or Diesel vehicles. (A summary of the various model parameters and the applicability to each vehicle class is given in Table 13.)

When comparing the following fleet-average g/mi output from MOBILE4, MOBILE4.1, and MOBILE5a, it must be recognized that each vehicle class contributes to the overall emission rate, with LDGVs generally having the most significant impact because of their large numbers in the fleet. Thus, changes that have occurred to LDGVs are most noticeably reflected in the fleet-average emission rate. On the other hand, changes to the heavy-duty vehicle classes have a relatively smaller impact on fleetaverage emissions. In addition, measures that impact all model years generally have a larger impact on fleet-average emissions than a measure that is applied to new vehicles and must wait for fleet turnover before it is fully implemented. Thus, measures such as the more stringent NOX standard for HDGV and HDDV coming from the 1990 CAAA have a relatively minor impact on the fleet-average emission rate, whereas measures such as oxygenated and reformulated fuels have a significant effect on fleet-average emissions.

9.1 BASELINE EMISSIONS

The fleet-average baseline emissions estimates for MOBILE4, MOBILE4.1, and MOBILE5a are illustrated in Figures 88 through 90 for HC, CO, and NOx, respectively. No I/M or ATP programs were specified for these

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estimates, and they were conducted at an average speed of 19.6 mph and a temperature of 75øF (diurnal emissions assumed a 60ø to 84øF temperature rise), and the FTP operating mode fractions (i.e., "bag splits," 20.6 percent cold start, 27.3 percent hot start, 52.1 percent stabilized) were utilized. The large differences in the baseline emissions estimates observed in these figures are the result of modifications to the base emission rate equations made among the model revisions, the use of an in-use fuel correction in MOBILE5, and higher mileage accumulation rates assumed in MOBILE5. This is especially noticeable for HC and CO, where the MOBILE4 and MOBILE4.1 estimates are fairly close, but the MOBILE5a results are much higher. For NOx, the emission rates have increased by about the same amount between the release of MOBILE4 and MOBILE4.1, and the release of MOBILE4.1 and MOBILE5.

The HC emissions estimates depicted in Figure 87 include exhaust and evaporative emissions. Figure 90 shows a breakdown of HC emissions for the 1995 and 2005 calendar years. As seen, the increase in the HC emission rate observed with MOBILE5a is primarily the result of an increase in exhaust emissions (at least for the 75øF case modeled here), although an increase in running loss emissions also occurred with the release of MOBILE5a.

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9.2 OPERATING MODE FUNCTIONS

Differences in operating mode have significant impacts on the emission rates calculated by the MOBILE models. This difference is limited, however, to light-duty vehicles, as no operating mode correction is applied to the HDGV and HDDV vehicle classes. Differences in cold start, hot start, and stabilized operation are shown in Figures 91 through 93 for HC, CO, and NOx emissions, respectively. This comparison is made for the year 2000, and only exhaust HC emissions are presented since operating mode does not impact non-exhaust HC components.

As seen in the figures, the relative difference in emission rates between cold start, hot start, and stabilized operation remained fairly constant among the MOBILE revisions. As expected, cold start operation results in the highest g/mi emissions for all pollutants, followed by hot start and stabilized operation. The higher emission rates observed for MOBILE5a are again the result of higher estimates of base emission rates.

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9.3 TEMPERATURE

The ambient temperature used in a MOBILE run also plays a critical role in the fleet-average emission rate. As temperature decreases (below 75øF), emissions increase. The increase in emissions is explained by increased cold start emissions as the engine and emission control system take longer to warm up and additional fuel enrichment is necessary for smooth combustion. Additionally, as the temperature rises above the standard 75øF point, an increase in HC and CO emissions is observed, but the increase is not as severe. This increase is primarily the result of increased vapors being purged from the evaporative emission control system, leading to rich operation.

The impact of temperature on the year 2000 fleet-average emission rate is shown in Figures 94 through 96 for exhaust HC, CO, and NOx, respectively. The general shape of the curves is very similar, which was expected since no substantive differences in the temperature correction factors exist among the MOBILE4, MOBILE4.1, and MOBILE5a versions of the model. The relative differences among the emission estimates are again the result of higher base emission rates predicted for MOBILE5a.

The comparison of emission estimates for non-exhaust HC was performed with a slightly different basis for each of the evaporative components modeled. Figure 97 displays the year 2000 diurnal emission rate (in

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grams/day, not accounting for multiple-day diurnals) for a diurnal temperature swing of 25øF with a variety of different maximum temperatures. (Note that only the LDGV class is shown in the figure.) The general shape of the curve is similar for each of the MOBILE revisions, and the values of the results are also very close. As expected, an increase in emission rate is observed for higher maximum temperatures. Hot-soak emissions for the year 2000 (in grams/trip) are illustrated in Figure 98. Widely varying results among the model revisions are seen, particularly at the higher temperatures. Finally, a comparison of running loss emissions is given in Figure 99. The results for MOBILE5a and MOBILE4.1 are very close, while the MOBILE4 estimates are much lower at higher temperatures. The differences in the evaporative component emission estimates are primarily the result of new data incorporated by EPA, however, the MOBILE5a estimates also include the effect of the new evaporative standards and test procedures.

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9.4 SPEED

Figures 100 through 103 illustrate the impact of speed on the year 2000 MOBILE4, MOBILE4.1, and MOBILE5a emission estimates for exhaust HC, CO, and NOx, respectively. Because the speed correction factors have not changed dramatically among the MOBILE revisions, the shape of the curves is very similar. However, the MOBILE5a results are higher in terms of absolute g/mi values. This is the result of the higher base emission rates assumed for the MOBILE5a model. It is interesting to note, however, that the NOx emissions depicted in Figure 103 may have significant implications for conformity analyses. Because NOx emissions are projected to increase beyond 20 mph, any transportation measure that increases speed by reducing congestion increases the NOx inventory. This result is counter to historical thinking that assumed as speed increased, emissions decreased.

9.5 FUEL EFFECTS

There are three fuels-related inputs to the MOBILE models that impact emission estimates: Reid vapor pressure (RVP), oxygenate content, and the presence or absence of reformulated gasoline. RVP, which is a measure of the fuells volatility, most significantly impacts evaporative emissions, but it also affects exhaust emission estimates. Oxygenated

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fuels are now required in many communities as a cold-weather CO control strategy, and the capability to model the effects of oxygenated fuels was first included with MOBILE4.1. Finally, an option included in MOBILE5 is modeling of reformulated gasoline. As part of the Clean Air Act Amendments of 1990, reformulated gasoline will be required in ozone nonattainment areas classified as "severe" and "extreme" beginning in 1995.

RVP - As discussed above, the impact of RVP is most pronounced on evaporative emission estimates. This is evidenced in Figure 103, which illustrates MOBILE5a nonexhaust hydrocarbon emission rates for a series of RVPs ranging from 15.0 psi down to 7.0 psi. (Included in these estimates are hot soak, diurnal, running loss, and resting loss emissions.) Substantial emission reductions can be achieved by controlling fuel RVP, and EPA has promulgated fuel volatility regulations that limit summertime RVP to 9.0 and 7.8 psi, depending on state and month, beginning in 1992.18 (This represents Phase II of EPA's fuel volatility regulations; Phase I, which had less stringent RVP requirements, was implemented in 1989.) As demonstrated in the figure, nonexhaust HC emissions from 9.0 psi fuel are roughly 50% lower than 11.0 psi fuel under typical summertime conditions. (Figure 103 is based on a 70ø to 95øF diurnal temperature rise.)

Although not as significant, RVP level also impacts exhaust emission estimates calculated by MOBILE. At higher RVP, HC and CO emissions

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increase. That is because higher volatility fuel leads to more hydrocarbon vapors being stored in the evaporative control system canister. This, in turn, causes rich operation during canister purge which elevates HC and CO emission rates. Figures 104 and 105 illustrate this effect for HC and CO, respectively.

Figure 104 shows MOBILE5a exhaust HC results for RVPs ranging from 12.5 to 7.0 psi. (The maximum RVP chosen for this figure was 12.5 psi because MOBILE does not correct for RVP above that point.*) This figure indicates a 10% to 20% reduction in exhaust HC emission rates as a result of changing RVP from 11.0 to 9.0 psi. Also of note in Figure 104 is the very small change in emission rate when RVP is lowered to 7.0 from 9.0. This is because MOBILE does not allow the exhaust RVP correction factor to fall below 1.0, which would occur under these ambient conditions at just below 9.0 psi. (This is shown in Figures 40 and 41.)

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* In actuality, MOBILE considers the maximum RVP for purposes of exhaust corrections to be 11.7 psi. However, MOBILE has an algorithm that decreases the user-input RVP to account for RVP loss as fuel sits in vehicle fuel tanks (this phenomenon is known as 'fuel tank weathering'). Under the ambient conditions specified in Figure 104 (i.e., 70ø to 95øF), the 12.5 psi fuel has been "weathered" to 11.7 psi; thus, 12.5 represents the maximum RVP for a 70ø to 95øF case.

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The effect of RVP on CO emission estimates from MOBILE5a is illustrated in Figure 105. Because CO is typically a wintertime problem, these runs were performed for a diurnal temperature rise of 45ø to 65øF. (Because MOBILE does not calculate an RVP correction at temperatures below 45øF, this was chosen as the lower temperature for developing Figure 105. Also note that at temperatures below 75øF, no RVP correction is calculated for RVPs below 9.0 psi.) The results shown in Figure 105 indicate fairly significant CO reductions (e.g., 30% for the year 2000, although the reduction would be slightly diminished if an I/M program was specified) from lowering RVP from 11.0 to 9.0 psi. Although it is clearly not an option for many CO nonattainment areas, some of the warm weather CO nonattainment areas (e.g., Phoenix, Arizona) are investigating wintertime RVP limits as a CO control strategy.

Oxygenated Fuels - As discussed in Section 8, the capability to model oxygenated fuels for cold-temperature CO control was included in MOBILE4.1 and MOBILE5a. The impact of oxygenated fuels on cold-temperature CO emissions is shown in Figure 106 for MOBILE5a run at an ambient temperature of 30øF. (Because modeling of oxygenated fuels is very similar between MOBILE4.1 and MOBILE5a, only the MOBILE5a results are shown in the figure.) A considerable decrease in CO emissions is observed when comparing the oxygenated fuels case to the baseline case. As expected, the effects are roughly linear as a function of oxygen content (i.e., higher oxygen content results in a higher benefit).

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Reformulated Gasoline - The capability to model the effects of reformulated gasoline was included with the MOBILE5 version, and the effect of reformulated gasoline on HC emissions is shown in Figure 108. In this analysis, the MOBILE5a model was run at a relatively high temperature (i.e., a diurnal temperature swing of 70ø to 95øF, with 90øF serving as the exhaust analysis temperature), which roughly corresponds to the ambient conditions required for the baseline modeling analysis contained in the notice of proposed rulemaking on reformulated gasoline.19 The relative difference between the 1995 estimate and the 2000 and subsequent calendar years reflects the difference between Phase 1 and Phase 2 of the regulations.

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9.6 INSPECTION AND MAINTENANCE

Inspection and maintenance programs remain an attractive motor vehicle pollution control option for many local communities. Because all model years can fall under inspection requirements, the impact on fleet emissions is much faster compared to new vehicle regulations that take many years to become fully effective.

Exhaust Emissions - Figures 108 through 110 illustrate the baseline and after-I/M LDGV exhaust HC emission factors for MOBILE4, MOBILE4.1, and MOBILE5a, respectively. Because MOBILE4 did not model a transient I/M program (i.e., EPA's IM240) and the MOBILE4.1 IM240 credits were based on little IM240 data, only a single I/M program is shown in Figures 108 and 109. The program modeled for these figures is an annual, centralized, idle program. This program was also modeled by MOBILE5a and is shown in Figure 110; however, Figure 110 also contains an estimate for an annual, centralized, transient chassis dynamometer based program (IM240 based on 0.8/15.0/2.0 HC/CO/NOx cutpoints). Significant reductions are predicted for I/M programs, particularly the IM240 program shown in Figure 110. Applying the IM240 program to the MOBILE5a emission factors results in estimates similar to the MOBILE4 and MOBILE4.1 non-I/M cases.

The I/M results for CO are shown in Figures 111 to 113 for MOBILE4, MOBILE4.1, and MOBILE5a, respectively. As with HC, significant reductions are also predicted as a result of I/M. In fact, MOBILE5a estimates that the LDGV CO emission rate beyond 1995 will be roughly cut in half as a result of the IM240 program modeled in this analysis.

Finally, the NOx benefits ascribed to IM240 are shown in Figure 114. Although the NOx benefits are not as large as HC and CO, this still represents a significant reduction in in-use emissions. (Because idlebased programs result in only minor changes to NOx emissions, the impact of I/M on NOx emissions for MOBILE4 and MOBILE4.1 was not shown.)

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Evaporative Emissions - In conjunction with the transient, loaded-mode exhaust emissions test, EPA is strongly encouraging states to adopt functional testing of evaporative emission control systems. This check consists of a pressure test in which the fuel tank is pressurized with nitrogen to a preset limit, and a significant fall in pressure over time indicates a defective system. A purge test has also been developed which consists of placing a flow meter in the purge line. If the flow registered is not sufficient to properly purge the charcoal canister, the vehicle fails the test.

MOBILE5a has been structured to estimate the benefits of a pressure/purge test, and the LDGV baseline and after-test results are given in Figures 115 and 116 for evaporative emissions (i.e., hot soak, diurnal, and crankcase emissions) and running loss emissions. The test modeled was an annual, centralized program including 1981 and later model year vehicles. Significant emission reductions are estimated as a result of this program, with reductions on the order of 50 percent being ascribed for the later calendar years.

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APPENDIX A

Emission Control Technologies and Comparison of Base Emission Rates at 50,000 and 100,000 Miles for the LDGTI and LDGT2 Vehicle Classes

This appendix presents a summary of emission standards and emission control technologies used to most those standards for the LDGT1 and LDGT2 vehicle classes. It also contains a series of illustrations that show a comparison of LDGT1 and LDGT2 base emission rates at 50,000 and 100,000 miles computed by the MOBILE4, MOBILE4.1, and MOBILE5a models.

LDGT1

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LDGT2

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APPENDIX B

Speed-Time Profiles of Cycles Used in Speed Correction Factor Development

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APPENDIX C

Comparison of Running Exhaust and Idle Emission Rates
Computed with MOBILE4.1 and MOBILE5a

This appendix presents a series of illustrations that show a comparison of running exhaust emission rates and idle emission rates computed by the MOBILE4.1 and MOBILE5a models. (Note that the MOBILE5a model does not calculate idle emission rates directly. EPA's recommended procedure to convert g/mi running exhaust emission rates to g/hr idle rates, which is described in the text, was used to develop the MOBILE5a idle rates for these figures.)

MOBILE4.1; LDGV

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MOBILE4.1; LDGT1

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MOBILE4.1; LDGT2

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MOBILE5a; LDGV

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MOBILE5a; LDGT1

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MOBILE5a; LDGT2

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APPENDIX D

Contribution of Model Year Groups to the fleet-Average Emission Rates Computed with MOBILE4.1 and MOBILE5a

This appendix presents a series of spreadsheets that summarize the contribution (in grams per mile) of model-year groups to the HC, CO, and NOx fleet-average emission rates. The calculations were carried out with the MOBILE4.1 and MOBILE5a models under a series of I/M cases and include the LDGV, LDGT1, and LDGT21 vehicle classes. For this analysis, "basic" I/M refers to an idle/2500 rpm test, while "enhanced" I/M refers to the IM240 procedure and includes pressure/purge testing. (Recall, however that MOBILE assumes an idle test for pre-1981 vehicles, regardless of the I/M test applied.to the 1981 and later model years.)

The spreadsheets are organized in the following manner:

1. MOBILE4.1; No I/M
2. MOBILE4.1; "Basic" I/M
3. MOBILE5a; No I/M
4. MOIBLE5a; "Basic" I/M
5. MOBILE5a; "Enhanced" I/M

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1. MOBILE4.1; No I/M

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-185-

2. MOBILE4.1; "Basic" I/M

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-189-

MOBILE5a; No I/M

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-192-

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-193-

2. MOBILE4.1; "Basic" I/M

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5. MOBILE5a; "Enhanced" I/M

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