COMPREHENSIVE MODAL EMISSIONS MODEL (CMEM), version 3.01

User's Guide

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The Comprehensive Modal Emissions Model (CMEM) was originally developed under sponsorship of the National Cooperative Highway Research Program, Project 25-11. Since 1999, it has been enhanced and maintained with funding from the U.S. Environmental Protection Agency (EPA). The contents of this report reflect the views of the authors and do not necessarily indicate acceptance by the sponsors.

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Summary

In August 1995, the College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California-Riverside along with researchers from the University of Michigan and Lawrence Berkeley National Laboratory, began a four-year research project to develop a *Comprehensive Modal Emissions Model (CMEM)*, sponsored by the National Cooperative Highway Research Program (NCHRP, Project 25-11). The overall objective of this research project was to develop and verify a modal emissions model that accurately reflects Light-Duty Vehicle (LDV, i.e., cars and small trucks) emissions produced as a function of the vehicle's operating mode. The model is comprehensive in the sense that it is able to predict emissions for a wide variety of LDVs in various states of condition (e.g., properly functioning, deteriorated, malfunctioning). Since 1999, CMEM has been enhanced and maintained with funding from the U.S. Environmental Protection Agency (EPA). One of the major changes to the model has been the addition of a variety of heavy-duty diesel-power truck categories. With these additional categories, the model is now complete and capable of predicting second-by-second tailpipe emissions and fuel consumption for a wide range of vehicle/technology categories.

In this User's Guide, the model is briefly introduced, with a description of its purpose, its modeling approach, and a description of the project phases that were carried out in creating the model. Chapter 2 describes the large scale vehicle emissions testing program that was carried out to provide data as the foundation of the model. This rich dataset is available for analysis. Chapter 3 briefly describes the model's general structure and validation procedures that were carried out. Chapter 4 is the heart of the User's Guide, describing how to run the model in both a command-line form as well as in its Graphical User Interface (GUI) form. Chapter 5 then describes how the model can be integrated into different transportation modeling frameworks.

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Portions of this User's Guide have been extracted from the original NCHRP Project 25-11 Final Report and other related references.

Contents

1 Introduction

In order to develop and evaluate transportation policy, agencies at the local, state, and federal levels currently rely on the mobile source emission-factor models MOBILE (developed by the U.S. Environmental Protection Agency) or California's EMFAC modeling suite (developed by the California Air Resources Board). Both MOBILE and MVEI predict vehicle emissions based in part on average trip speeds and were built upon regression coefficients based on a large number of FTP (Federal Test Procedure) bag emission measurements. Since these models are intended to predict emission inventories for large regional areas, they are not well suited for evaluating operational improvements that are more "microscopic" in nature, such as ramp metering, signal coordination, and many Intelligent Transportation System (ITS) strategies. What is needed in addition to these "regional-type" of mobile source models is an emissions model that considers at a more fundamental level the *modal* operation of a vehicle, i.e., emissions that are directly related to vehicle operating modes such as idle, steady-state cruise, various levels of acceleration/deceleration, etc.

In August 1995, the College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California-Riverside along with researchers from the University of Michigan and Lawrence Berkeley National Laboratory, began a four-year research project to develop a *Comprehensive Modal Emissions Model* (CMEM), sponsored by the National Cooperative Highway Research Program (NCHRP, Project 25-11). The overall objective of this research project was to develop and verify a modal emissions model that accurately reflects Light-Duty Vehicle (LDV, i.e., cars and small trucks) emissions produced as a function of the vehicle's operating mode. The model is comprehensive in the sense that it is able to predict emissions for a wide variety of LDVs in various states of condition (e.g., properly functioning, deteriorated, malfunctioning). The model is capable of predicting second-by-second tailpipe (and engine-out) emissions and fuel consumption for a wide range of vehicle/technology categories.

1.1 MODAL EMISSIONS MODELING APPROACH

Several types of modal emission models have been developed in the past, using several different approaches. For example, a convenient method to characterize vehicle operating modes of idle, cruise, and different levels of acceleration/deceleration is to set up a speed/acceleration matrix. With such a matrix, it is possible to measure emissions associated with each "bin" or mode. This emissions matrix can then be multiplied with a similar matrix that has vehicle activity broken down so that each bin contains the time spent in each driving mode. The result is the total amount of emissions produced for the specified vehicle activity with the associated emissions matrix. The problem with such an approach is that it does not properly handle other variables that can affect emissions, such as road grade, use of accessories, etc.

Another modal emissions modeling method is to develop an emissions map that is based on engine power and speed. Second-by-second emission tests are performed at numerous engine operating points, taking an average of steady-state measurements. By basing emissions on engine power and speed, the effects of acceleration, grade, use of accessories, etc. can be taken directly into account. When creating an emission inventory, the vehicle activity parameters of engine power and speed must be derived from second-by-second velocity profiles. However, this approach can be a very time consuming and expensive process. Another problem with using such an emissions mapping approach is that it is not well suited if there is substantial time dependence in the emissions response to the vehicle operation (e.g., the use of a timer to delay command enrichment, or oxygen storage in the catalytic converter).

A problem associated with both the speed-acceleration matrix and emission mapping approaches is that they are typically based on steady-state emissions, and ignore transient operation. Further, significant errors are generated by either averaging emission rates within each bin or extrapolating/interpolating among them in the emission map grids. Without knowing the underlying relationship for emission rate versus vehicle speed and acceleration rates, or engine speed and engine load, the most widely-used methodology is to assume a simple two-dimensional linear relationship among them. Due to measurement difficulties, most speed-acceleration matrices or emission maps only have a very limited number of bins or measurement points, resulting in the repetitive use of the above procedure in real applications. The error associated with a single bin or engine operational point could be accumulated into major computing errors in the final results. The key to eliminating this kind of error is to establish a correct analytical formula among the important variables, as described below.

In order to avoid the problems associated with the methods described above, CMEM uses a physical, power-demand modal modeling approach based on a parameterized analytical representation of emissions production. In such a physical model, the entire emissions process is broken down into different components that correspond to physical phenomena associated with vehicle operation and emissions production. Each component is then modeled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary according to the vehicle type, engine, and emission technology. The majority of these parameters are stated as specifications by the vehicle manufacturers, and are readily available (e.g., vehicle mass, engine size, aerodynamic drag coefficient, etc.). Other key parameters relating to vehicle operation and emissions production must be deduced from a comprehensive testing program. The testing involved is much less extensive than creating emission maps for a wide range of vehicle operating points.

This type of modeling is more deterministic than descriptive. Such a deterministic model is based on *causal* parameters or variables, rather than based on simply observing the effects (i.e., emissions) and assigning them to statistical bins (i.e., a descriptive model). Further, the essence of the proposed modeling approach is that the major effort is up front, in the model-development phase, rather than in application. Once the model forms are established, data requirements for applications and for updating to include new vehicles are modest. This limited requirement for data in future applications is perhaps the main advantage of this modeling approach. Of comparable importance, this approach provides understanding, or explanation, for the variations in emissions among vehicles, types of driving, and other conditions. Analysts will be able to discuss “whys” in addition to providing numbers. This is in contrast to models based on statistical “surrogate” variables that are not necessarily linked to physical variables that can be measured. There are several other key features that make the physical, deterministic modeling approach attractive:

- It inherently handles all of the factors in the vehicle operating environment that affect emissions, such as vehicle technology, operating modes, maintenance, accessory use, and road grade. Various components model the different processes in the vehicle related to emissions.

- It is applicable to all vehicle and technology types. When modeling a heterogeneous vehicle population, separate sets of parameters can be used within the model to represent all vehicle/technology types. The total emission outputs of the different classes can then be integrated with their correctly weighted proportions to create an entire emission inventory.

- It can be used with both microscale and macroscale vehicle activity characteristics. For example, if a second-by-second velocity profile is given, the physical model can predict highly time resolved emissions. If average vehicle activity characteristics such as average speed, peak average speed, idle time, positive kinetic energy (PKE, a measure of acceleration) are given, the physical model can still be used based on average power requirements calculated from the activity parameters.

- It is easily validated and calibrated. Any second-by-second driving profile can be applied to the model, while simultaneously measuring emissions. Modeled results can be compared with measurements and the parameters of the model can be calibrated accordingly.

- It is not restricted to pure steady-state emission events, as is an emissions map approach, or a speed-acceleration matrix approach. Therefore, emission events that are related to the transient operation of the vehicle are more appropriately modeled.

- Functional relationships within the model are well defined. So, in contrast to a model which operates by sampling numerical data, the analytical approach avoids extrapolation and interpolation. Moreover, it will be possible to simply describe delay effects, such as with the introduction of timers for command enrichment.

- The model is transparent; results are easily dissected for evaluation. It is based on physical science, so that data are tested against physical laws and measurement errors can be identified in the model establishment phase.

- The computations performed in the model consist primarily of evaluating analytical expressions, which can be done quickly with only modest memory requirements.

There are also some potential disadvantages to such an approach. Establishment of this type of model is data intensive. There will be a large number of physical variables to be collected and/or measured for the wide variety of vehicle technology types in different states of deterioration. Because the modeling approach is based on the study of extensive emission measurements in the context of physical laws, a systematic inductive study of physical mechanisms such as energy loss and chemical equilibrium will be necessary. During the model development, it is necessary to identify a smaller set of key variables that play an important role in the generation of emissions. Models of this kind have been developed to predict fuel use, with data from the 1970s (e.g., [Feng et al., 1993a, b]). Through this process one finds that the variations in fuel use and emissions among vehicles and in different driving modes are sensitive to only a few critical parameters. Satisfactory accuracy will be achievable with publicly available parameters, and with parameters which can be obtained from brief dynamometer tests.

The statement about the degree of parameterization *which is adequate* assumes that accuracy is interpreted in absolute terms on the basis of regulatory needs. For example, analytic modeling of extremely low emissions (that can occur for short periods during moderate-power driving) with high relative accuracy might complicate the model to no purpose. We are not concerned with relative accuracy where the emissions are below those of interest for regulatory purposes. Similarly, in current second-by-second data there is some temporal variability to emissions whose study may not justify more detailed measurements and model making. For regulatory purposes, accurate prediction of emissions over modes on the order of ten seconds or more may be adequate.

Another critical component of the approach is that emission control malfunctions and deterioration have to be explicitly modeled. Problems of high deterioration rates of catalyst efficiency, imprecise fuel metering, etc., must be accounted for. Modeling components that estimate the emissions of high-emitting vehicles are also an important part of this approach.

Using this physical model approach, models must be established for different engine/emissions technologies that are represented in the national vehicle fleet. This will include the appropriate combinations of engine type (spark ignition, diesel), fuel delivery system (carbureted, fuel injection), emission control system (open-loop, closed-loop technology), and catalyst usage (no catalyst, oxidation catalyst, three-way catalyst). After the models corresponding to the different technologies have been approximately established, it is necessary to identify the key parameters in each component of the models that characterize vehicle operation and emissions production. These parameters can be classified into several categories: 1) readily available (i.e., public domain) static vehicle parameters (e.g., vehicle mass, engine size, etc.); 2) measurable static vehicle parameters (e.g., vehicle accessory power demand, enrichment power threshold, etc.); 3) deterioration parameters (e.g., catalyst aging, etc.); 4) fuel type parameters; and 5) vehicle operating parameters.

When the physical models and associated parameters are established for all vehicle/technology/year combinations, they must be combined with vehicle operating parameters that are characteristic of real-world driving. These vehicle operating parameters consist of static environmental factors such as ambient temperature and air density, as well as dynamic factors such as commanded acceleration (and resultant velocity), road loads such as road grade, and use of vehicle accessories (e.g., air conditioning, electric loads, etc.).

Combining the physical models with vehicle operating parameters results in highly time resolved emission rates. These predicted rates can then be compared directly to measured emissions data, and the parameters of the modeling components—or the modeling components themselves—can be adjusted to establish an optimal fit. This calibration/validation process occurs iteratively until the models are well developed.

As previously mentioned, factors of emission control deterioration will also be considered within this model. These deterioration factors correspond to the effects of emission equipment failure, tampering, and long-term reductions of efficiencies (e.g., catalyst aging). They can be represented as modeling components within the physical model itself, and/or as simple additional parameters with the current components. The incorporation of these components is critical to the model development since their contribution to emissions production has been shown to be significant.

The developed modal emissions model is microscale in nature, meaning it can readily be applied to evaluating emissions from specified driving cycles or integrated directly with microscale traffic simulations (e.g., TRAF-NETSIM, FRESIM, PARAMICS, etc.). However, its use for estimating larger, regional emissions is somewhat more complicated. Because microscale models typically model at the vehicle level and have high accuracy, they require extensive data on the system under study and are typically restricted in size due to the non-linear complexity gain incurred with larger networks. In order to produce emission inventories of greater scope, it is possible to develop link-level emission functions for different roadway facility types (e.g., freeway section, arterials, intersections, rural highways, freeway on-ramps, etc.) using the modal emissions model. At the microscale level, emissions can be estimated as a function of vehicle congestion on each facility type, with different degrees of geometrical variation. Statistical emission rates are then derived from the microscale components as a function of roadway facility type and congestion level. These rates are then applied to individual links of a macroscale traffic assignment model.

1.2 PROJECT PHASES

This NCHRP research project was carried out in four distinct phases:

> ***Phase 1***—The first phase of work consisted of: 1) collecting data and literature from recent related studies; 2) analyzing these data and other emission models as a starting point for the new model design; 3) developing a new dynamometer emission testing protocol to be used for the vehicle testing phase of the project (described in detail in [Barth et al., 1997]); 4) conducting preliminary testing on a representative sample of vehicles (approximately 30) with the developed dynamometer emission testing protocol. These data supplement existing data which were used for 5) the development of an interim working model (described in detail in [An et al., 1997]).

***Phase 2*—**This phase of work consisted of 1) conducting testing on a larger representative sample of vehicles (approximately 320) using the developed dynamometer testing procedure; This large collection of detailed vehicle operation and emissions data have been used to 2) iteratively refine the working model. 3) Additional testing data have been used to validate the model.

***Phase 3*—**This phase of work consisted of examining the interface between the developed modal emissions model and existing transportation modeling frameworks. The objective of this phase was to demonstrate that the emissions model is responsive to the regulatory compliance needs of transportation and air quality agencies.

***Phase 4*—**This phase of work consisted of 1) incorporating additional vehicle/technology categories in order to better estimate emission inventories into future years; 2) developing a graphical user interface (GUI) for the model, making it more user-friendly; and 3) holding a national workshop on the model, in order to help introduce the model to transportation/air quality model practitioners.

1.2.1 Phase 1 Summary

The research team has completed Phase 1 of the project in August, 1996. In Phase 1, the following tasks were accomplished:

- A literature review was performed focusing on vehicle operating factors that affect emissions. The literature was categorized into eight different groups, and over 110 documents were reviewed*.
- A wide variety of data sets were collected pertaining to vehicle emissions and activity. Several of these data sets were analyzed to help determine a testing procedure for the collection of modal emission data and to provide insight on how to best develop a comprehensive modal emission model*.
- The conventional emission models (i.e., MOBILE and EMFAC) were reviewed and evaluated in light of this NCHRP project to provide insight on how to develop the modal emission model*.
- Based on the information determined in the previous tasks, a testing protocol was designed for modal emission analysis and modeling. As part of this task, a vehicle/technology "matrix" was defined identifying the key vehicle groups that make up part of the modal model. This matrix was used to guide the recruitment of vehicles tested in Phase 2 of this project. The vehicle/technology categorization is described in Chapter 2.
- A vehicle emissions testing procedure was developed for use at the CE-CERT dynamometer facility. This procedure consists of performing second-by-second pre- and post-catalyst measurements of CO_2, CO, HC, and NO_X over three separate driving cycles: the full 3-bag FTP, EPA's SFTP Bag 4 cycle (US06), and a newly designed modal test cycle (MEC01) that focuses on specific modal events. This testing procedure is described in detail in Chapter 2.
- Using the testing procedure, one or two vehicles from each of the different vehicle/technology groups (31 total) were tested in Phase 1. Based on this preliminary testing, the vehicle testing protocol was

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* This material is summarized in [Barth et al., 1999].

evaluated and modified for Phase 2 of the project. In addition, an emissions data validation procedure was developed to ensure the quality of the pre- and post-catalyst emission data*.

- The initial mathematical formulation of the modal emission model was developed for all emissions (including CO_2) and fuel consumption. The model parameters were established for each tested vehicle. The model predictions were compared directly with actual measurements with encouraging results.

- Summary statistics of the emissions data were compiled, such as integrated bag data, average catalyst efficiency, catalyst light-off time, and emission values for 60 vehicle operating modes identified in the MEC01 modal cycle.

1.2.2 Phase 2 Summary

The research team completed Phase 2 of the project in October, 1997. In Phase 2, the following tasks were accomplished:

- In order to develop the full working modal emissions model for a variety of vehicle/technology types, test vehicles were recruited for dynamometer testing at CE-CERT's Vehicle Emissions Research Laboratory. A recruitment procedure was set up and implemented so as to fill the target vehicle numbers in each "bin" of the vehicle/technology matrix established in Phase 1. In this phase, approximately 380 vehicle were recruited (see Chapter 2).

- 296 of the recruited vehicles were tested using three primary driving cycles: 1) the FTP; 2) the US06; and 3) the MEC01 cycle. For nearly all of the vehicles tested, second-by-second tailpipe and engine-out emissions data were collected. Combined with the 31 vehicle tests of Phase 1B, 327 vehicle tests were performed in this project. Out of these 327 tests, a total of 315 tests had valid, usable data which were used in developing the working model.

- Using existing modal emissions data and the emissions data collected in this project, a working modal emissions model was developed based on our physical modeling approach. Issues dealing with model parameterization and calibration were addressed for the different vehicle/technology groups, and malfunctioning/high-emitting vehicles are addressed and characterized. See Chapter 3 for details.

- In order to determine how well the model predicts emissions, comparisons were performed between the modeled output and the measured values. This type of validation was performed at the individual vehicle level as well as the composite vehicle level. Further, the validation took place at both the second-by-second time resolution and at the integrated "bag" level. The validation is described briefly in Chapter 3.

- Preliminary analysis was completed on the emissions data, and summary statistics were compiled*.

1.2.3 Phase 3 Summary

Phase 3 of the project was completed in September, 1998. In Phase 3, the following tasks were accomplished:

- The massive amounts of data collected in Phase 2 were further analyzed. The data analysis focused on items such as vehicle enrichment effects, air conditioning effects, measurement repeatability, vehicle categorization, and model sensitivity*.

- The modal emission model developed in Phase 2 were further refined. Specifically, the calibration methodology for each vehicle/technology group was improved; the vehicle compositing methodology was refined; high-emitting vehicles were further characterized and modeled; the model was validated with additional testing data; and the uncertainty of the different model components were characterized.

- As part of the integration of the emissions model into different transportation model frameworks, vehicle category mappings were created between EMFAC/MOBILE and the modal emission model. This is a great advantage since vehicle activity set up for either MVEI or MOBILE can now be translated directly to the modal emission model's vehicle/technology categories. This is described in Chapter 4.

- A vehicle category generation methodology to go from a vehicle registration database to the modal emission model categories was created and tested using a local vehicle registration database. Details of the methodology are given in Chapter 4.

- Velocity/acceleration-indexed emissions/fuel lookup tables for the vehicle/technology categories were created. These lookup tables can be used by several types of microscopic transportation models, such as CORSIM, FRESIM, NETSIM, PARAMICS, etc. These are discussed in Chapter 4.

- Roadway facility/congestion-based emission factors for the vehicle/technology categories were generated using EPA's latest facility/congestion cycles. These emission factors can be used for mesoscopic transportation models. This is discussed in detail in Chapter 4.

1.2.4 Phase 4 Summary

Phase 4 of the project was completed in December, 1999. In this phase, the following tasks were carried out:

- In order to better estimate emission inventories into future years (e.g., 2010, 2020), additional vehicle/technology categories were incorporated into the model. These additional categories include both diesel and gasoline powered heavier trucks (>8500 gross vehicle weight); late model high-emitting vehicles; and high-mileage Tier 1 vehicles. These additional categories were tested and modeled in a similar fashion to the methodology established in Phase 2.

- The original command-line implementation of the model is somewhat rudimentary in form, and the user must be careful to structure the inputs properly. In this task, the "user-friendliness" of the model has been improved, making it much more flexible and intuitive to operate. The key milestones of this task was to create a Graphical User Interface (GUI) so that the user can easily control to model.

- In order to help introduce the modal emissions model to transportation/air-quality model practitioners, a national workshop was held in January, 2000.

1.3 CMEM ENHANCEMENTS

Since its original release as version 1.0, CMEM has undergone a variety of enhancements with sponsorship from the U.S. EPA. From 1999 to 2000, several tasks were carried out, including:

- An evaluation of the MOBILE6 facility-based cycles as part of a validation exercise (see [Barth et al., 2001]).

- The prediction of future vehicle model emissions parameters based on modifying the physical parameters of the model (see [Younglove et al., 2000]); and

- Carrying out a detailed analysis of enrichment behavior and catalyst behavior in the model. The catalytic converter component of the model was modified based on this analysis (see [Scora et al., 2000] for further details).

In late 2000, the U.S. EPA provided additional funds for the expansion and enhancement of CMEM. Four tasks were addressed, focusing on modeling emissions from Heavy-Duty Diesel (HDD) vehicles:

- Carrying out a detailed literature and data review of HDD vehicle emissions and activity;

- Developing a HDD vehicle testing procedure specifically for modal emissions analysis and modeling. This procedure consisted of a specific modal emissions test cycle that focused on specific modal events (e.g., steady-state cruise at different velocities, a variety of acceleration and deceleration events, idle, and steady-state enleanment events). The truck testing protocol also examined roadway grade effects. The testing protocol included both real-world and on-road HDD vehicle activity. The focus was placed on measuring emissions from many activity modes that are important for the model development.

- Designing a Heavy-Duty Diesel Modal Emissions Model Architecture –The objective of this task was to start with the current physical modeling approach already in place in CMEM for light-duty vehicles and modify the design for a heavy-duty diesel (Class 8 HDD) emissions (and fuel consumption) model. Issues dealing with model parameterization and calibration were addressed for the different truck technology categories identified in the project. Modifications were performed in the fuel rate module, the fuel/air module, and the engine-out emission module. Several key engine and fuel parameters were changed. Part of this task was co-funded by California PATH, which also supported model development and validation.

For the HDD vehicle fleet, seven vehicle/technology categories were created based upon emissions certification levels and engine technology. It should be noted that additional vehicle/technology groups exist within the on-road fleet. The sale of two-stroke HDD vehicles continued until 1998. In addition, Federal and California HDD certification levels were different prior to 1991, however the percentage of the on-road vehicle fleet is small and the groups were combined for modeling purposes. However, these vehicles represent a very small fraction of the on-road fleet (< 1%) and were not included because of the limited number of tests available for model building.

1.3.1. Enhancements in 2003

In late 2003, expansion and enhancements to CMEM continued. Four tasks were addressed, focusing on developing new testing and calibration methodologies that more compatible with the latest Portable Emissions Measurement System (PEMS) data sets. More specifically, a new calibration procedure was developed so that it can readily be calibrated from on-road emissions data without any prescribed driving cycle. With the enhanced calibration procedure in place, it is possible to incorporate a variety of datasets.

Further, a methodology for determining future fleet compositions of CMEM categories was developed. When CMEM was first developed, an example methodology was developed to categorize vehicle fleets into appropriate CMEM categories. This step is necessary in order to use the modal emissions model for estimating an inventory for a vehicle fleet. In this particular task, a more robust method of vehicle categorization has been developed for CMEM that works for any arbitrary inventory year, including future years.

Lastly, a preliminary ammonia (NH_3) module was developed for CMEM. The ammonia module was developed for a limited set of vehicles based on a parallel vehicle emissions test and research program.

1.3.2. Enhancements in 2004

In 2004, the CMEM modeling was expanded to include new modules for three new light-duty vehicle categories: LEV (Low Emitting Vehicle), ULEV (Ultra Low Emitting Vehicle), and SULEV (Super Ultra Low Emitting Vehicle), based on the California Air Resources Board's certification standards. These extremely low emitting vehicles are 98% to 99% cleaner than catalyst-equipped vehicles produced in the mid 1980s. To better understand the emission characteristics of these extremely low emitting vehicles as well as their potential impact on future air quality, this study consisting of: 1) an emission measurement program; 2) the development of specific emission models; and 3) the application of future emission inventories to air quality models. The model results compare very well to actual measurements.

1.3.3. Enhancements in 2005

In 2005, a new modeling effort for CMEM begun, developing a particulate matter module for CMEM. In this work, a literature and data review took place focusing on second-by-second PM emissions measured from vehicle, with an emphasis toward heavy-duty trucks. The majority of the data collected was from CE-CERT's mobile emissions laboratory. Using these initial data, an architecture was developed for the modeling of PM. Preliminary modeling has been performed using a fuel-based approach.

2 Vehicle Testing

Based on background data and literature, a vehicle testing methodology has been designed, consisting of several key components:

1) Defining the *vehicle/technology categories* that make up the modal emissions model;

2) Using the vehicle/technology categories for guidance, determining a *vehicle recruitment strategy*; and

3) Developing a *dynamometer test procedure* for the measurement of modal emissions.

These three components are described in the first three sections of this chapter. The fourth section describes the emissions testing that was performed. The last section of this chapter describes the data pre-processing that took place.

2.1 VEHICLE/TECHNOLOGY CATEGORIZATION

The conventional emission inventory models (California Air Resources Board's EMFAC and US EPA's MOBILE) are based on bag emissions data (FTP) collected from certification tests (using new car exhaust emission standards), surveillance programs, and inspection/maintenance programs. These large sets of emissions data provide the basis for the conventional emission inventory models. These conventional models aggregate vehicles into a few general classes (e.g., light-duty gas vehicles, light duty diesel vehicles, light duty trucks, etc.) which are then indexed by model year.

In developing a modal emission model using a physical load-based approach, we chose not to base the model on these "bag" data. Instead, it was determined that it was necessary to collect second-by-second emissions data from a sample of vehicles to build a model that predicts emissions for the national fleet. The choice of vehicles for this sample is crucial, since only a small sample (approximately 340 vehicles) was used as the basis for the model.

Because the eventual output of the model is emissions, the vehicle/technology categories have been chosen based on a vehicle's *emissions contribution*, as opposed to a vehicle's actual population in the national fleet. Recent results from both remote sensing and surveillance studies have shown that a small population of vehicles contribute a substantial fraction of the total emissions inventory. With this approach, more emphasis is put on high emitters than if based strictly on population numbers. High emitting vehicles are not well understood, however the data and models developed in this project have gone a long way in improving our understanding of these vehicles.

In order to guide the vehicle recruitment and testing process, we have determined a vehicle/technology category set primarily driven by total emissions contribution. Early on in this study, we analyzed existing remote sensing and surveillance data to help establish the category set, as well as to determine the appropriate sample size in each category. Details of this process are given in [Barth et al., 1999].

The vehicle/technology candidate categories underwent several iterations early on in the project. Increased importance was placed on a vehicle's certification standard, in particular, whether a vehicle was a *Tier 1 certified vehicle* (MY94 on) or a "*Tier 0" certified vehicle* (non Tier 1 certified). The Tier 1 standards for cars and trucks are shown in Table 2.1. The standards for cars were phased in over a three-year period; 40% of 1994 cars sold met the standards, while all 1996 cars must meet the standards. The last previous change in federal car emissions standards occurred in 1981.

Vehicle		New Car Standards, grams per mile				Standards Phase-In Schedule, Model Year				
Type	Emissions Standard	HC	NMHC	CO	NOx	1993	1994	1995	1996	1997
LDVs (0-6,000 GVW)										
Cars	0-3,750 LVW									
	CA	0.41	0.39	7.0	0.4	100%	60%	20%		
	Federal Tier 0	0.41		3.4	1.0	100%	60%	20%		
	Federal Tier 1		0.25	3.4	0.4		40%	80%	100%	100%
Trucks	LDT1: 0-3,750 LVW									
	CA	0.41	0.39	9.0	0.4	100%	60%	20%		
	Federal Tier 0	0.80		10.0	1.2	100%	60%	20%		
	Federal Tier 1		0.25	3.4	0.4		40%	80%	100%	100%
	LDT2: 3,751-5750 LVW									
	CA	0.50	0.50	9.0	1.0	100%	60%	20%		
	Federal Tier 0	0.80		10.0	1.7	100%	60%	20%		
	Federal Tier 1		0.32	4.4	0.7		40%	80%	100%	100%
LDTs (6,001-8,500 GVW)										
	LDT3: 3,751-5,750 ALVW									
	CA	0.50	0.50	9.0	1.0	100%	100%	100%	50%	
	Federal Tier 0	0.80		10.0	1.7	100%	100%	100%	50%	
	Federal Tier 1		0.32	4.4	0.7				50%	100%
	LDT4: Over 5,750 ALVW									
	CA	0.60	0.60	9.0	1.5	100%	100%	100%	50%	
	Federal Tier 0	0.80		10.0	1.7	100%	100%	100%	50%	
	Federal Tier 1		0.39	5.0	1.1				50%	100%

Notes:

- Standards for cars and LDT1s are identical
- 50,000 mile standards for LDT2 and LDT3 are identical; however, higher mileage standards differ slightly
- GVW = gross vehicle weight
- curb weight = unloaded weight
- LVW = loaded vehicle weight, or test weight (curb weight + 300 lbs)
- ALVW = adjusted LVW, (GVW + curb weight) / 2

Table 2.1. Vehicle Emissions Standards and Phase-Ins.

The final vehicle/technology categories used for vehicle recruitment and testing are shown in Table 2.2. There were a total of 24 categories, based on fuel and emission control technology, accumulated mileage, power to weight ratio, emission certification level, and emitter level category[*].

In this table, it can be seen that the Tier 0, 3-way catalyst, fuel-injected (FI) cars, as well as the Tier 1 cars, are divided into subgroups based on power/weight ratio and mileage, since these vehicle categories

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[*] Note that these 24 vehicle/technology categories used for recruitment are slightly different than the vehicle/technology categories used for modeling (a total of 26 categories, see Chapter 3). The main difference lies in the high emitters. Because many of the high emitting vehicles had disparate emission results when categorized by technology group, the high emitting vehicles were re-categorized into groups with similar emission characteristics. Grouping high emitters by emission profiles produced much more homogeneous groups than grouping by technology category. The modeling vehicle/technology categories are given in Table 3.1 and are described in detail in Chapter 3.

will dominate future emissions. Power/weight ratio was chosen as a discriminating variable since it plays a large role in the on set of enrichment emissions. The dividing point between low power/weight and high power/weight was set at 0.039 hp/lb. for the 3-way catalyst, FI groups and at 0.042 hp/lb. for the Tier 1 cars. Different limits were selected to reflect the increase in vehicle power to weight ratios during the time these cars were available (see [Murrell et al, 1993]).

Vehicle Technology Category	**Number Tested (Recruitment Targets)**	
Cars	**normal-emitting**	**high-emitting**
No Catalyst	5	
2-way Catalyst	10	
3-way Catalyst, Carbureted	5	10
3-way Catalyst, FI, >50K miles, low power/weight	15	25
3-way Catalyst, FI, >50K miles, high power/weight	15	
3-way Catalyst, FI, <50K miles, low power/weight	15	
3-way Catalyst, FI, <50K miles, high power/weight	15	
Tier 1, >50K miles, low power/weight	15	5
Tier 1, >50K miles, high power/weight	15	
Tier 1, <50K miles, low power/weight	15	
Tier 1, <50K miles, high power/weight	15	
Total Cars	125	55
Trucks	**normal-emitting**	**high-emitting**
Pre-1979 (<=8500 GVW)	5	
1979 to 1983 (<=8500 GVW)	10	
1984 to 1987 (<=8500 GVW)	7	8
1988 to 1993, <=3750 LVW	15	25
1988 to 1993, >3750 LVW	15	
Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)	15	5
Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)	15	
Total Trucks	67	53

Table 2.2. Final Vehicle/Technology Categories used for Phase 2 recruitment and testing, shown with recruitment targets.

Unlike emissions standards for cars, the federal truck emissions standards have changed several times since 1981. These changes were substantial for all three pollutants, reducing the allowable emissions of each by almost one-half. As the emissions standards changed, so did the classification of trucks by weight; the Tier 1 standards include four separate light-duty truck standards, based on a combination of *gross vehicle weight* (GVW, which includes maximum payload) and *loaded vehicle weight* (LVW, or test weight, which is the empty or "curb" weight plus 300 lbs.)[*]. Since the Tier 1 LDT1 standards are identical to those for cars, these trucks (up to 3,750 GVW) are included in the car Tier 1 categories. The LDT2 and LDT3 standards are nearly identical, so these categories also are combined.

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[*] Although the pre-1979 truck standards apply only to trucks up to 6,000 lbs. GVW, we expanded this technology group to include trucks up to 8,500 lbs. GVW, since most of the pre-79 trucks still in use exceed 6,000 lbs. GVW.

During the course of vehicle testing, the recruitment targets for high-emitting Tier 1 vehicles were revised downward (from 15 to 5 each for cars and trucks), due to the difficulty of obtaining these type of vehicles.

Towards the end of the project (i.e., Phase 4), it was determined that additional vehicle/technology categories should be incorporated into the model, in order to better estimate emission inventories into future years. We analyzed the high-growth vehicle markets which were not given enough emphasis during the initial categorization in Phase 1 (carried out in 1996). A total of four additional groups have been identified for testing and modeling:

Gas-powered LDTs, >8500 GVW

Both gasoline and diesel light duty trucks in the heavier categories (e.g., greater than 8500 lbs. gross vehicle weight) have experienced tremendous growth in the last few years. None of these type of vehicles were tested in Phase 3. This category was added in Phase 4.

Diesel-powered LDTs, >8500 GVW

During the previous Phase 3 testing, there weren't any diesel-powered vehicles tested. As an initial formation of a diesel modal model, we added a category for light duty trucks greater than 8500 lbs. gross vehicle weight. It is important to note that it is a major undertaking to develop a complete *diesel* modal emission model. Only a preliminary diesel modal model has been developed which hopefully can be developed more fully in the future.

Tier 1, High Mileage (>100K miles) Vehicles

During the Phase 3 testing, it was nearly impossible to find high mileage Tier 1 vehicles, because of the recent introduction of the Tier 1 standards when the testing was performed. There simply hasn't been enough elapsed time to find those type of vehicles with high mileage. As a result, several Tier 1 high mileage (>100,000 accumulated miles) vehicles were tested in Phase 4, making up this new category.

1995-1999 High Emitting Vehicles

During Phase 3 testing, it was extremely difficult to recruit and test high-emitting, newer vehicles (MY 1995 on). As a result, the high emitting categories developed in Phase 2 did not include these newer vehicles. During Phase 4, additional recent model year (MY 1995 on) vehicles that are high emitters were tested. These vehicles were included in the established high emitter categories.

2.2 TEST VEHICLE RECRUITMENT PROCEDURE

Given the recruitment targets set forth in Table 2.2, vehicles were recruited throughout California's South Coast Air Basin, with a small subset brought in from other states. Particular care was given to target 49-state certified vehicles as well as California certified vehicles, as discussed below. To prevent bias and to ensure the broad applicability of the testing results, to the best extent possible, vehicles were sampled randomly within each vehicle/technology category of Table 2.2. It was particularly challenging recruiting high-emitting vehicles and 49-state vehicles, so several additional databases were used to assist in the recruitment, such as California's Department of Motor Vehicle's registration database, and a high-emitter list developed from Arizona's inspection/maintenance program.

At the beginning of the testing phase, the majority of vehicles were randomly selected by telephone solicitation in Southern California. However, as individual categories in the recruitment matrix were filled, a variety of recruitment approaches were used to fill out the rest of the matrix.

2.2.1 High-Emitter Vehicle Identification

The recruitment of suspected high-emitting vehicles was the most problematic. For this recruitment, the following strategies were used:

- **Remote Sensing:** Using a remote sensing van, a set of remote sensing measurements were made in the local area. Vehicles that had multiple high measurements were identified by license plate. The license plate data were then matched up with the DMV database in order to get the make and model of vehicle, as well as the address of the owner. Solicitation letters were then sent out to those targeted owners.

- **Local Car Dealers:** Several local car dealerships in the area were asked to inform customers who bring their vehicles in for emissions-related repairs about our study. Prior to having their vehicle fixed by the dealer, some vehicles were recruited for testing. It was hoped that this source would provide us with some newer model year vehicles with high emissions; however only limited success was achieved.

- **Local Rental Agencies and Used Car Dealers**: Local car rental agencies and used car dealers were also contacted to identify high mileage vehicles. Candidate vehicles were brought to the testing site and driven past a remote sensing van. Vehicles that had multiple high remote sensing readings were selected for testing.

- **High Emitter List:** Using the Arizona I/M database of vehicle models with high average failure rates, a subset of the local DMV database of potential high emitting vehicle models was produced. Specific vehicles were then selected randomly from this list. Solicitation letters were sent out to the vehicle owners requesting their participation in the study. The owners would bring their vehicles to the testing site, where they were driven past the remote sensing van. If they had consistently high emissions, they were selected for testing.

2.2.2 49-State Vehicle Identification

There are differences between California and 49-state certification levels for many of the vehicle/technology groups. California and federal standards are different for all car groups except the No Catalyst and the Tier 1 technology groups. For the trucks, the differences apply to all groups except the Pre-1979 and the Tier 1 groups.

During recruitment, vehicle owners were asked the state of origin of their vehicles; however many owners of used vehicles do not know the status of the vehicles. The differences in emission control technology between 49-state and California certified vehicles varies by year and manufacturer and in some cases can determine vehicle/technology category. For example, with some manufacturers the three-way catalyst was introduced earlier in the California certified vehicles. In this case vehicles of identical year, make, and model would be split between our two-way and three-way catalyst groups depending on state of certification.

The DMV database contains limited information on whether a vehicle is 49-state or California certified. In all of the subset list generated from the DMV database, an effort was made to also select a good sample of 49-state vehicles when possible. The certification of individual vehicles could only be determined once the vehicle was brought in for testing by looking at the emissions label under the vehicle hood. Approximately 12% of all vehicles tested (18% in categories where differences exist) were 49-state vehicles.

2.2.3 Recruitment Incentive

A varying cash incentive was used to recruit vehicles for testing. Owners of vehicles that were more difficult to recruit generally were given a higher cash incentive. The incentives ranged from nothing to $400, with an average between $150 and $200 per vehicle.

2.3 VEHICLE RECRUITMENT RESULTS

After vehicles were recruited for testing, they underwent an inspection to determine if they were safe to test. During Phase 2, a total of 415 vehicles were recruited. Out of these 415 vehicles, 89 did not pass the initial safety inspection and were rejected. During Phase 4, a total of 41 additional vehicles were recruited. Out of these vehicles, 11 did not pass the safety inspection and were rejected. The primary reason for failure was due to leaks in the vehicle's exhaust system. Because the recruited vehicles are tested in a closed chamber with a driver present, major exhaust leaks cannot be tolerated. Other reasons for rejections include bald tires, bad brakes, major leaks in the oil and radiator systems, etc. The owners of the rejected vehicles were told about the problems with their vehicles; a small percentage made repairs and brought their vehicles back for testing.

After the vehicles were tested, they were categorized as normal- or high-emitting based on their bag emissions values for the FTP cycle. A variety of cut-point definitions for high-emitting vehicles, proposed by several researchers, were reviewed. For this study, high-emitting Tier 0 vehicles were defined to be those vehicles having FTP emissions in excess of two times the corresponding FTP standard for CO or HC, or 4 times the corresponding FTP standard for NOx. For Tier 1 vehicles, high-emitting vehicles have FTP emissions in excess of 1.5 times the standard for any pollutant. These cutpoints are in-line with other researchers' definitions of high (rather than very high or super) emitters.

After a particular vehicle was tested, it was placed in the appropriate category in the vehicle/technology matrix. If a suspected high emitting vehicle turned out to be normal emitting, it was put in a normal emitting category. Conversely, if a suspected normal emitting vehicle turned out to be high emitting, it was moved to the appropriate high emitting category. Because of these types of shifts, it was difficult to fulfill the target recruitment numbers exactly.

Further, the odometer readings and power to weight ratios are not confirmed for each vehicle until the vehicle was brought in for testing. Therefore, if the maximum power value or odometer turned out to be different than what was known at the time of recruitment, the vehicle's location in the vehicle/technology matrix changed. The final categorization of all vehicles tested is given in Table 2.3. This vehicle distribution has proved to be more than adequate for modeling purposes.

A total of 357 vehicle tests were performed in this project. Out of these 357 tests, a total of 343 tests had valid, usable data which were used in developing the comprehensive modal emission model.

2.3.1 High Emitting Vehicles

Out of the 343 total valid vehicle tests, 107 vehicles, or 31% of the tested fleet, were high-emitters. This is by far the largest database of second-by-second, tailpipe and engine-out emissions of high-emitting vehicles assembled to date.

2.3.2 49-State Vehicles

Out of the 343 total valid vehicle tests, 37 vehicles were 49-state emission certified vehicles. This represents 11% of the fleet. When considering only the categories where differences exist, 19% of the fleet were 49-state emission certified vehicles.

2.3.3 Repeat Vehicles

Of the 343 vehicle fleet, six of the vehicles had repeat tests performed. These vehicles were tested at different times during the testing period, and were valuable in tracking vehicle emissions variability and any influence of time.

Vehicle Technology Category	**Number of Vehicles Tested**	
Cars	**normal-emitting**	**high-emitting**
No Catalyst	8	
2-way Catalyst	13	
3-way Catalyst, Carbureted	5	11
3-way Catalyst, FI, >50K miles, low power/weight	23	24
3-way Catalyst, FI, >50K miles, high power/weight	17	
3-way Catalyst, FI, <50K miles, low power/weight	18	
3-way Catalyst, FI, <50K miles, high power/weight	8	
Tier 1, >50K miles, low power/weight	12	12
Tier 1, >50K miles, high power/weight	12	
Tier 1, <50K miles, low power/weight	16	
Tier 1, <50K miles, high power/weight	19	
Tier 1, >100K miles	6	
Total Cars	136	68
Trucks	**normal-emitting**	**high-emitting**
Pre-1979 (<=8500 GVW)	6	
1979 to 1983 (<=8500 GVW)	8	
1984 to 1987 (<=8500 GVW)	11	10
1988 to 1993, <=3750 LVW	25	17
1988 to 1993, >3750 LVW	11	
Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)	16	5
Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)	14	
gasoline-powered LDT (>8500 GVW)	9	
diesel-powered LDT (>8500 GVW)	8	
Total Trucks	94	46

Table 2.3. Vehicle/Technology categories with tested vehicle distribution.

2.4 VEHICLE TESTING PROCEDURE

During the early stages of the project, a vehicle testing procedure was developed and applied to the recruited vehicles. This vehicle testing procedure includes the following test cycles:

1) A complete 3-bag FTP test;

2) A high speed cycle (US06);

3) A modal emission cycle (MEC01) developed by the research team.

A complete FTP test is necessary for two reasons. First, it is the standard certification testing procedure, and provides baseline information about a vehicle's emissions which can be used as a reference to compare with existing tests of other vehicles. Second, FTP Bags 1 and 3 provide information on catalyst efficiency and light-off time during cold and warm starts, which are important components of the model. The primary reason for including the US06 in our test protocol is that EPA is planning to use the US06 as a supplemental Bag 4 in the supplemental FTP test. In the testing, the FTP driving cycle provides important information on the stoichiometric regime of driving. The US06, on the other hand, specifically targets high emission, non-FTP operation that is characteristic of modern driving patterns. The US06 velocity trace is shown in Figure 2.1.

Even though the US06 cycle was designed to cover off-cycle driving events, it is still not a "modal" emission cycle, i.e., it doesn't provide clear-cut modal emission results; i.e., emissions that can easily be matched to specified speeds, accelerations, or power rates. In order to capture specific modal emission events, we designed a specific modal emissions cycle, the MEC01. The MEC01, described in detail in Section 2.4.2, was developed and iteratively refined during the early stages of the testing phase. During the course of testing, the MEC01 cycle was slightly modified twice. In this project, we primarily used the FTP and MEC01 data for the modal model development and the US06 data as a validation cycle.

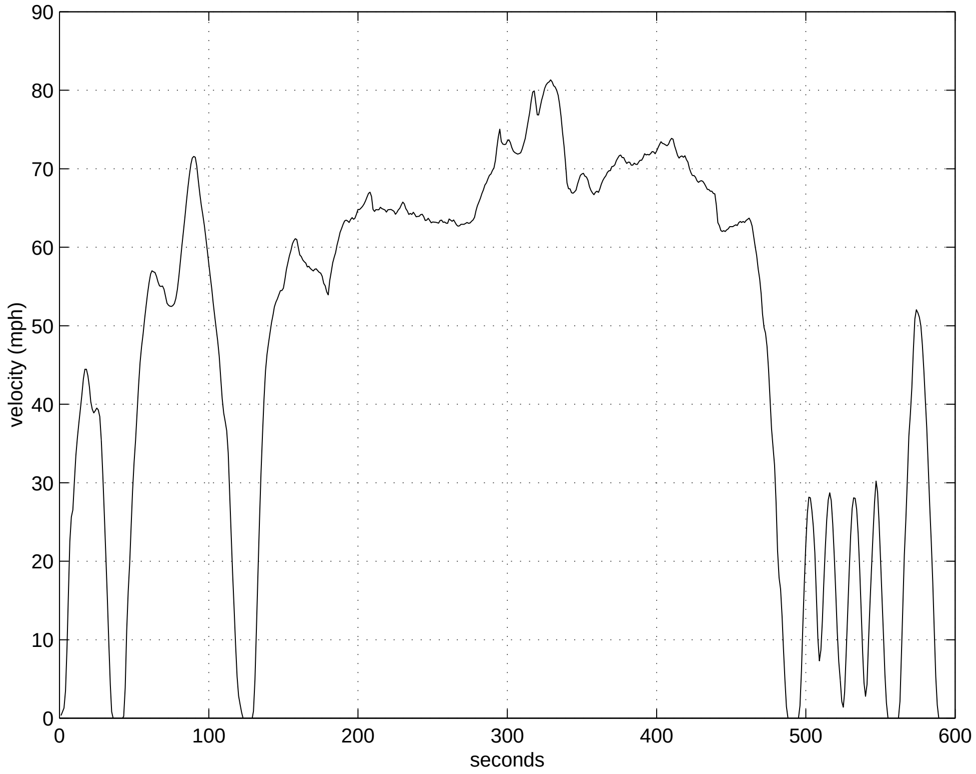

Figure 2.1. US06 velocity trace.

2.4.1 Testing Sequence

Several protocols were evaluated during the initial emission testing conducted in the testing phase. The emission measurement system was configured to simultaneously measure engine-out and tailpipe emission rates. A procedure was also developed to allow for the comparison of bag and modal emission data as an internal on-going quality assurance check. The final testing sequence is illustrated in Table 2.4.

An IM240 test and a 1-minute idle were inserted between the FTP Bag 3 and the MEC01 tests, primarily for the purpose of warming up vehicles for the ensuing MEC01 cycle. This is necessary since it takes approximately 50 minutes to perform analysis of the bag emissions (30 minutes) and to purge and prepare the analyzers for the next test cycle (20 minutes). Thus, the vehicle would be soaking for roughly 50 minutes before the MEC01 test could begin. Running an IM240 test before the MEC01 ensures that the vehicle is fully warmed up for MEC01 testing. The 1 minute idle allows the engine to stabilize and the vehicle's brakes to cool prior to the MEC01. Emissions generated during these preconditioning cycles were not measured for analysis.

During the initial vehicle testing, we had a unique opportunity to evaluate the effectiveness of these test cycles and identify areas for improvement. Initially, the biggest concern was the length of the entire test procedure for each vehicle. We evaluated each segment of the test procedure to see if any were not directly useful to project goals. After careful analysis of the 30-vehicle emission data, we concluded that each segment of the test procedure has its own merit, thus only marginal modifications were possible. As shown in Table 2.4, four different versions of the NCHRP test sequence were developed in order to minimize the testing time. The particular testing sequence used for a given vehicle depends on the characteristics of that vehicle, as described below. Because the US06 has several hard acceleration and braking events, several vehicles were not able to complete the entire US06. These vehicles were typically model year 1980 and older rear-wheel drive vehicles.

Operation	**NCHRP_A (seconds)**	**NCHRP_B (seconds)**	**NCHRP_C (seconds)**	**NCHRP_D (seconds)**
12-hour soak				
equipment preparation	1,200	1,200	1,200	1,200
FTP Bag 1	505	505	505	505
FTP Bag 2	866	866	866	866
10 minute soak	600	600	600	600
FTP Bag 3	505	505	505	505
FTP bag analysis	1,800	1,800	1,800	1,800
equipment preparation	1,200	1,200	1,200	1,200
IM240 *	240	240	240	240
1 minute idle	60	60	60	60
MEC01	1,000	1,000	1,000	1,000
Repeat Hill	460	460	460	460
AC Hill	460	-	460	-
US06	600	600	-	-
US06 & MEC01 bag analysis	1,800	1,800	1,800	1,800
Total	**11,296 (188min)**	**10,836 (180min)**	**10,696 (178min)**	**10,236 (171min)**

* for vehicle preconditioning only (emissions not collected)

Table 2.4. Four NCHRP test sequences.

Test Sequence A:

FTP 3 bag test + IM240 + 1min idle + ***MEC01 with both Repeat and AC hills + US06***

This is the default test sequence and was applied to all vehicles that both were capable of completing the US06 cycle and had air conditioners.

Test Sequence B:

FTP 3 bag test + IM240 + 1 min idle + ***MEC01 without AC hill + US06***

This test sequence was applied to all vehicles that were capable of completing the US06 cycle, but did not have operable air conditioners.

Test Sequence C:

FTP 3 bag test + IM240 + 1min idle + ***MEC01 with both Repeat and AC hills (NO US06)***

This test sequence was applied to vehicles that were not capable of completing the US06 cycle, but that did have operable air conditioners. Most of the rear-wheel drive vehicles prior to MY80 were tested under this test sequence.

Test Sequence D:

FTP 3 bag test + IM240 + 1min idle + ***MEC01 without AC hill (No US06)***

This test sequence was applied to vehicles that were not capable of completing the US06 cycle and that did not have operable air conditioners.

2.4.2 MEC01 Cycle

There were two general objectives of constructing the MEC01 cycle:

1) It should cover most speed, acceleration, and specific power ranges that span the performance envelope of most light-duty vehicles; and

2) It should be composed of a series modal events such as various levels of accelerations, deceleration events, a set of constant cruise speeds, speed-fluctuation driving, and constant power driving.

Based on feedback from a number of sources, the MEC01 cycle was iteratively refined prior to any substantial vehicle testing. The first version that was used for vehicle emissions data collection was MEC01 version 5.0, shown in Figure 2.2. The MEC01 cycle consists of five different sections: *stoichiometric cruise section*, *constant power section*, *constant acceleration section*, *air conditioning hill section*, and *repeat hill cruise section*.

Stoichiometric Cruise Section

This section or “hill” has been designed to measure emissions associated with cruises at eight constant speeds: 5, 35, 50, 65, 80, 75, 50, and 20 mph. Each of these events lasts approximately 20 seconds, except the 65 mph cruise which lasts 40 seconds. All of the acceleration rates in this section are below 3.3. mph/s, the maximum acceleration rate in the FTP. At four of the constant-speed plateaus, there are also “speed fluctuation” events which are common phenomena during in-use driving and may induce transient enrichment spikes. The speed fluctuation is simulated by initially coasting down for three seconds, followed by a mild acceleration back to the initial speed level. This is repeated three times.

It is important to note that there are two 50 mph cruises, one immediately preceded by an acceleration event, the other preceded by a deceleration event. Comparisons between the two have helped establish the impact that recent driving history has on emissions.

Constant Power Section

In this section there are five constant specific-power sub-cycles, with specific power (SP) ranging from 150 to 400 $(\text{mph})^2/\text{s}$. Specific power (SP) is approximated as two times the product of velocity (v) and acceleration (a):

$$SP = 2 * v * a.$$

The units of v are mph, a is mph/s, and SP is $(\text{mph})^2/\text{s}$. Since the specific power multiplied by the vehicle mass is the kinetic power, the specific power measures kinetic energy used during a driving episode. In the case of the FTP, the maximum SP is 192 $(\text{mph})^2/\text{s}$. In the US06, the maximum specific-power is much greater, reaching 480 $(\text{mph})^2/\text{s}$. During high power episodes, the kinetic power required to overcome vehicle inertia typically dominates the total power requirements. Thus during high power operation, a constant specific power approximately represents constant total power. The specific power levels from 200 to 300 $(\text{mph})^2/\text{s}$ represent moderately high power driving, while a level of 150 is within the power range of the FTP, and a level of 400 requires wide-open-throttle (WOT) operation in most vehicles. This section allows us to detect the thresholds at which vehicles enter a power enrichment state.

Constant Acceleration Section

Five acceleration episodes are included in this section: the first goes from 0 to 25 mph with a constant acceleration rate of 3.5 mph/s; the second from 0 to 20 mph at a constant rate of 4 mph/s. These first two acceleration rates are slightly above the FTP limit of 3.3 mph/s, again intended to capture any on-set of enrichment. The third acceleration episode is from 0 to 25 mph at 4.5 mph/s, followed by two events at wide-open throttle: one from 30 to 50 mph and another from 50 to 70 mph. The last two episodes are designed to test emissions associated with the maximum enrichment level and the application of maximum power of the vehicle.

Air Conditioning Hill Section

The stoichiometric cruise section is repeated in the cycle, this time with the air conditioner on if the vehicle is so equipped. Air conditioning usage can have a drastic effect on emission rates; this section of the cycle allows direct comparison with the initial steady-state cruise section.

Repeat Hill Cruise Section

In order to determine emissions variance for each vehicle within a single test, the stoichiometric cruise section is again repeated, this time with the air conditioning turned off. This repeat hill allows us to directly compare the modal events within the hill or the composite emissions for both hills.

The time intervals between all high acceleration/deceleration modal events in the cycle are at least 30 seconds long, allowing the catalytic converter enough recovery time. Also, there are various deceleration rates in the cycle; however these rates are rather mild in order to avoid brake over-heating during the testing.

The total duration of MEC01 version 5 (including the air conditioning and repeat hills) is 1920 seconds (1160 seconds without the air conditioning and repeat hills). MEC01v5.0 was applied to the first 43 vehicles tested. After that, slight modifications were made to the cycle based on testing results and comments from the NCHRP panel.

MEC01 version 6

Version 6.0 of the MEC01 is shown in Figure 2.3, and includes the following modifications:

Constant Power Section: Among the preliminary tested vehicles, it was found that some vehicles have power enrichment thresholds below K = 150 mph^2/s, the lowest value in the constant power section. Since the major purpose of including these hills with different K-values is to detect the power enrichment threshold, we added a K = 100 mph^2/s hill in this section.

On the other hand, we found that episodes of constant power are not easily achieved due to driver and vehicle limitations. Small speed fluctuations can cause relatively large changes in the actual power demand, especial for high power episodes. Generally, the 150 and 200 mph^2/s were achieved by most vehicles with reasonable accuracy; however, some of the older vehicles had difficulty in achieving the higher power levels. These same vehicles also demonstrated more variability during the constant power episodes. Based on these concerns, as well as to avoid further lengthening of the cycle, we eliminated the K = 250 mph^2/s hill. Thus the new constant power section includes 100, 150, 200, 300 and 400 mph^2/s hills.

Acceleration Section: After much deliberation, we decided to retain this section, since it specifies some constant acceleration modal events, which may occur in real-world driving. However, we have modified the acceleration section by combining the 3 acceleration events into a single event: 0 to 60 mph in 15 seconds, at a constant acceleration rate of 4.0 mph/s. This episode is very similar to that of a vehicle entering a highway on-ramp.

Repeat & AC Hills: Our preliminary analysis showed that CO, NOx, and CO_2 emission rates with air conditioning on were significantly higher across technology groups for normally operating vehicles; however, no significant differences were observed for the malfunctioning/high-emitting vehicles. The repeat hill had significantly higher NOx emissions and lower CO and HC emissions for normally operating vehicles. Again, malfunctioning/high-emitting vehicles did not show consistent increases (or decreases) in any pollutant for the repeat hill.

This suggests that both the AC and repeat hills produce interesting results that would be valuable in modeling emission impacts of air conditioner use and driving variability. The concern is that both hills include the low power cruise section only. Thus in version 6.0, we included two moderate constant power episodes at 150 and 200 mph^2/s. In order to avoid further lengthening this section, we retained only the first half of the cruise section. The duration of each section is now 460 seconds. Unlike version 5 of the MEC01 cycle, the Repeat Hill Section will be tested prior to the AC Hill section in version 6 of the MEC01 cycle.

MEC01 version 7

A total of 82 vehicles were tested using the MEC01v6.0 cycle. Based on further recommendations from the Panel, the repeat portion of the cycle was slightly modified to better identify potential modal history effects (see Figure 2.4). The new repeat hill cycle starts with a rapid acceleration from 0 to 65 mph with a constant acceleration rate of 4.0 mph/s^2, which is a repeat of an episode in the acceleration section. It is immediately followed by a 65 mph cruise and fluctuation driving. This sequence is designed to compare 65 mph cruise driving following a mild acceleration (as in the Cruise Section) and a hard acceleration (as in this section). This event is followed by several cruise and fluctuation driving modes at 35, 5, 20, 75, 80 and 65 mph. The order of these modes have been “scrambled”: each cruise mode follows an opposite acceleration or deceleration event from the original cruise section. For example, the 65 mph cruise follows a deceleration event from the 80 mph cruise driving mode in this repeat section, while in the cruise section, it follows an acceleration event from the 50 mph cruise driving mode. The only exception is the 80 mph cruise driving mode, which is the maximum speed in this cycle, and therefore can only be approached from an acceleration event. In this section, a K = 300 mph/s^2 constant power episode was included to accelerate from 20 mph to 75 mph, which is essentially a repeat of the constant power driving in the constant power section.

In summary, this section includes a hard acceleration event (a = 4.0 mph/s^2), a constant power event (K = 300 mph/s^2), 7 cruise driving events (v = 65, 35, 5, 20, 75, and 65 mph), and 4 fluctuation driving modes (average speed = 65, 35, 20, and 65 mph). The order of these modes is "scrambled" from the original sequence. The new design of the repeat hill allowed us to analyze the history effects of the different modes.

2.5 EMISSIONS TESTING PERFORMED

In total, 327 vehicle tests were performed over 18 months in Phase 2. Thirty additional vehicle tests were performed in Phase 4. Of the 357 total tests, 343 of the data sets turned out to be valid. A total of 14 tests were rejected due to a number of problems; the most common problem was that the vehicle failed at some point during the test. A vehicle failure in this case was typically an overheating problem. Although adequate ventilation was provided in the test chamber, several vehicles did not have very good cooling systems and thus overheated. When the car failed, the data up to the failure point were recovered; however, partial datasets are not useful for modeling. The other common vehicle failure was brake problems. The high-speed, aggressive US06 cycle required substantial braking of the vehicle. Even with brake assistance from the dynamometer, some vehicles' brakes were just too weak to maintain the cycle without damaging the brakes. All of the valid vehicle tests and their categories are listed in Appendix A.

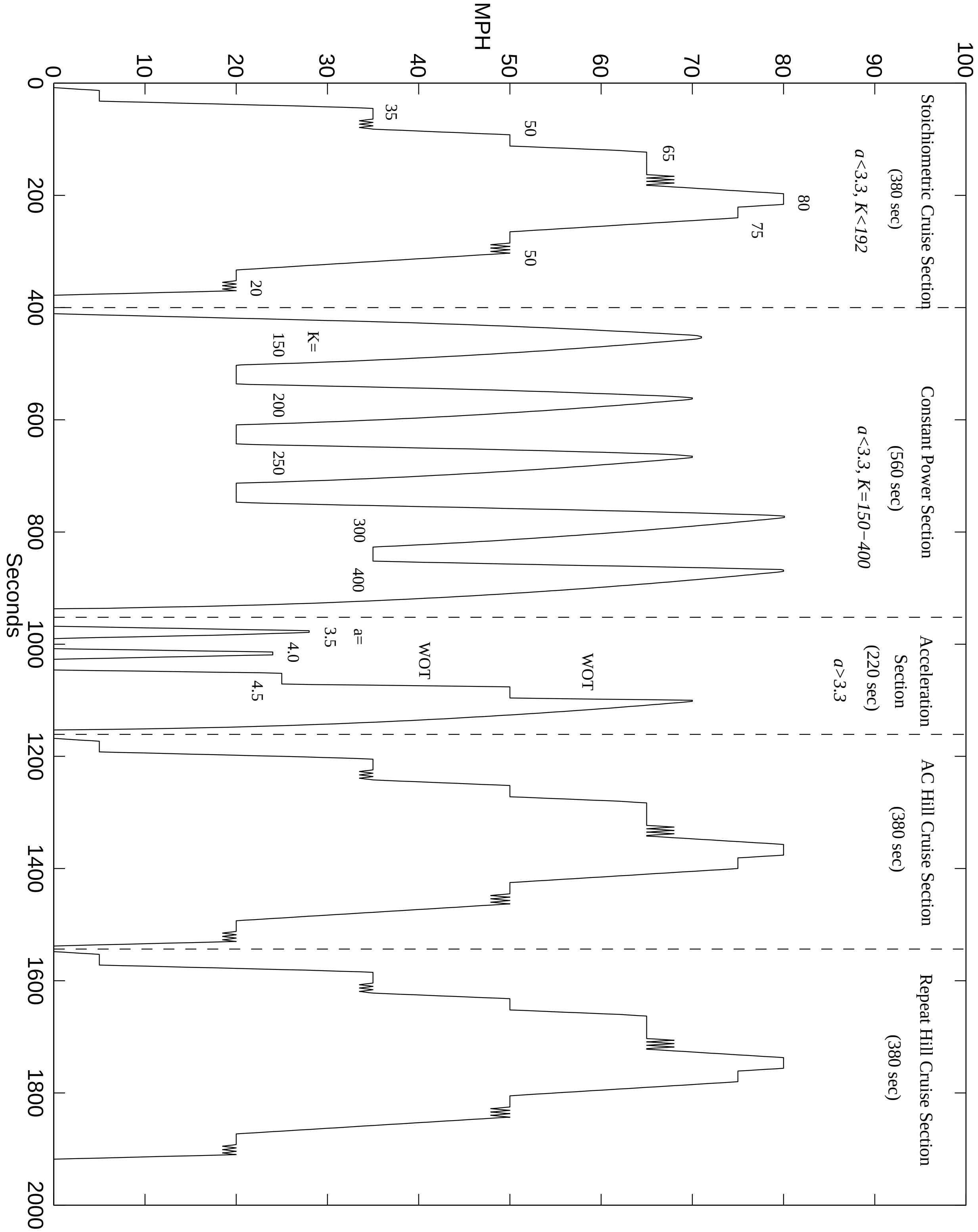

Figure 2.2. MEC01 version 5.0 modal emission cycle.

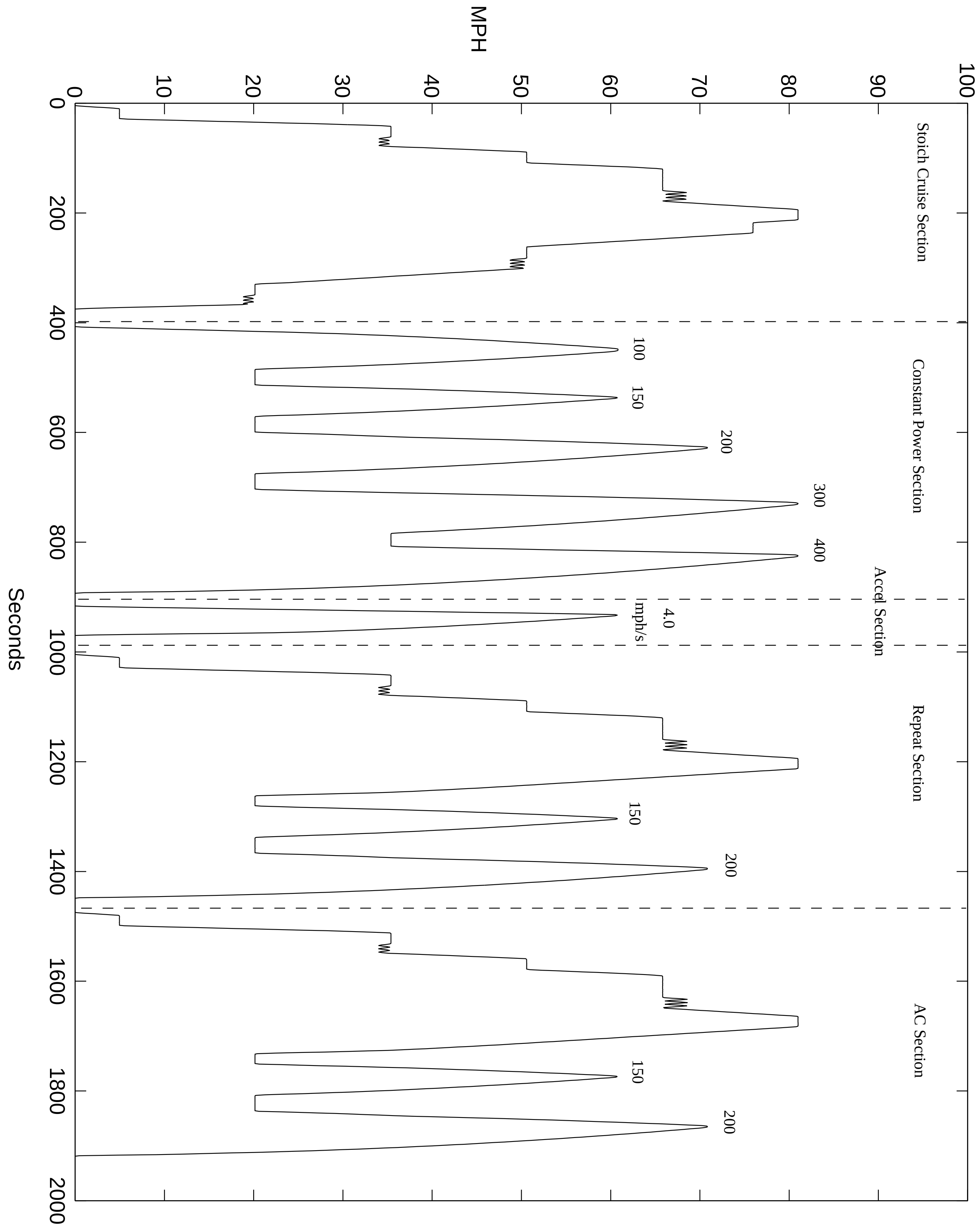

Figure 2.3. MEC01 version 6.0 modal emission cycle.

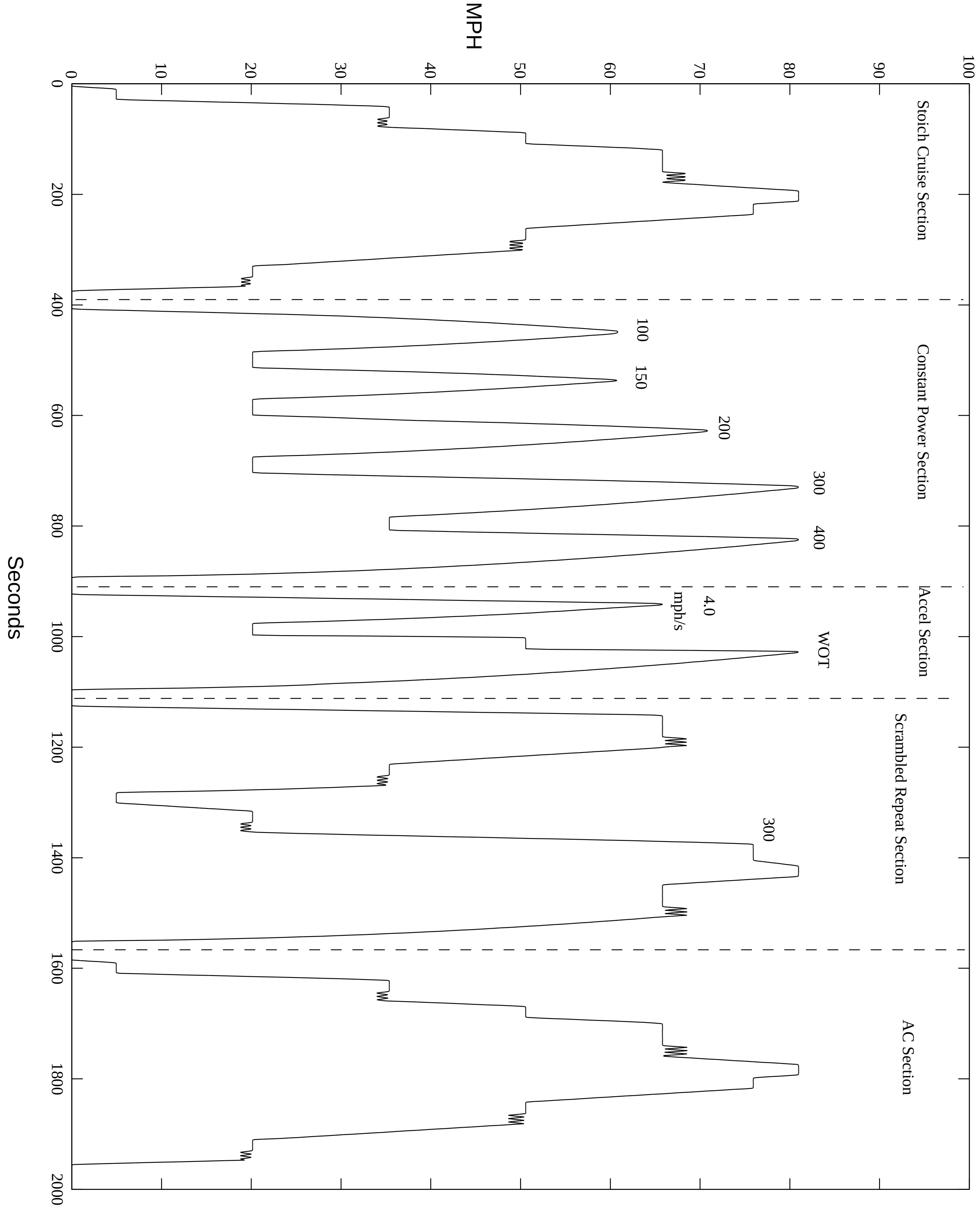

Figure 2.4. MEC01 version 7.0 modal emission cycle.

2.6 HEAVY-DUTY DIESEL VEHICLE TESTING

In order to more realistically measure on-road, real-world emissions for heavy-duty diesel trucks, UC Riverside has developed a unique Mobile Emissions Research Laboratory (MERL). This unique laboratory contains all of the instrumentation normally found in a conventional vehicle emissions laboratory, but the equipment is mounted inside a 53-foot over-the-road truck trailer. A dilution tunnel inside the trailer mixes the truck's exhaust (sampled directly from the exhaust pipe) with dilution air, and the samples are measured just as they would be in a stationary laboratory using the procedures prescribed in the Code of Federal Regulations (CFR) Parts 86 and 89 [CFR, 1986]. Both gaseous and particulate matter (PM) emissions are measured with the same levels of accuracy as measurements made in a stationary facility. The laboratory weights approximately 45,000 pounds and serves as the truck's load. Thus, we are able to sample a truck's emissions under real-world operating conditions with the accuracy and precision normally restricted to a stationary laboratory. Any class-8 tractor can pull this trailer, and the lab has gone through extensive calibration and testing to ensure accuracy and repeatability [Cocker et al., 2005]. MERL serves as an important tool for understanding how trucks pollute and for quantifying the effects of different fuels (reformulated diesel, etc.), alternative powertrains, different control strategies, and a variety of emission control equipment. Further details on MERL can be found elsewhere [Cocker et al., 2005].

In order to create the HDD instantaneous emission model, a test program was developed consisting of a vehicle recruitment process, testing the vehicles over a wide set of operating conditions on the road, and post-processing the resulting data (e.g., time alignment) so that they could be used for calibrating the model.

2.6.1. Vehicle/Technology Categorization and Vehicle Recruitment

Similar to the CMEM approach for LDVs, HDD vehicle technology and existing emissions data were examined closely and several vehicle/technology categories were derived. For each category, a different model "instance" has been developed. The vehicle/technology categories were derived based on differences in *emissions behavior,* which were given priority over factors that were more likely to affect emission levels. For example, technology factors such as fuel injection type that could result in emissions difference that were not consistent by operating mode were given priority over factors that were more likely to affect emissions level (e.g., engine displacement), but not modal behavior. The reason for this is that a composite vehicle that averages the different levels of vehicles having the same modal behavior will have lower vehicle-to-vehicle error rates across driving modes than a composite vehicle that averages trucks having different modal behaviors. Also playing a major role in selection of the vehicle/technology groups are the California state and federal emissions standards for HDD vehicles. The manufacturers have met these increasingly stringent standards through basic improvements to the combustion process (e.g., electronic fuel injection, quiescent combustion chambers, increased injection pressure, etc.) rather than through addition of exhaust after treatment or add-on controls [U.S. EPA, 1998].

After several iterations in balancing the number of vehicle/technology groups with the potential number of testing samples, the final HDD categories were chosen and are shown in Table 2.5. Fewer samples were allocated to the mechanical injection groups because of the lack of multiple operating modes made possible by electronic ignition systems. Manufacturer-to-manufacturer as well as model year-to-model year differences in timing strategies were expected to lead to higher vehicle-to-vehicle variability within the electronic injection categories so more samples were allocated to the electronic injection groups. Vehicles were recruited from used vehicle fleets in Southern California for testing using MERL. Initially, a total of 11 vehicles were recruited and tested, all in technology groups 5, 6, and 7. One vehicle was eliminated from the model development fleet because it was found to have mechanical problems with the engine. The test fleet was augmented with 23 additional vehicles from a HDD dynamometer test program [CRC E55, 2003]. The target sample size and actual sample size including the dynamometer test vehicles are listed in Table 1. Vehicles were recruited randomly within test categories by engine model year, and a balance between horsepower and between manufacturers was attempted. Since 2003, additional HDD tests have been added to enhance the model.

Model Year (Group)	Engine	Injection	Target Vehicle Count (Model Development Count)
Pre 1991 (1)	2-stroke	Mechanical FI	3 (0)
Pre 1991 (2)	4-stroke	Mechanical FI	3 (11)
1991-1993 (3)	4-stroke	Mechanical FI	3 (1)
1991-1993 (4)	4-stroke	Electronic FI	5 (4)
1994-1997 (5)	4-stroke	Electronic FI	5 (8)
1998 (6)	4-stroke	Electronic FI	5 (4)
1999-2002 (7)	4-stroke	Electronic FI	5 (6)

Table 2.5. Vehicle/Technology Categories for HDD Vehicles

2.6.2. Testing Procedure

As part of the data collection effort, a vehicle testing procedure was developed and applied to the recruited vehicles. This vehicle testing procedure includes the following test cycles:

1) a complete California Air Resources Board Heavy Duty Diesel (CARB-HDD) test, including creep mode, transient mode, and freeway mode [Maldonado et al., 2002];

2) a UDDS (Urban Dynamometer Driving Schedule) test cycle adapted for on-road use;

3) real-world driving with the flow of highway traffic; and

4) a set of modal emission cycles developed by the research team.

A complete CARB-HDD test is necessary for two reasons. First, it is the standard testing procedure used by CARB in testing of HDD vehicles, and provides baseline information about a vehicle's emissions that can be used as a reference to compare with existing tests of other vehicles. Second, the cycle provides a structured set of driving to be compared with the unstructured "real-world" driving. The primary reason for including the freeway driving without a test cycle in our test protocol is that the emissions under this driving are directly representative of in-use emissions. The UDDS cycle was included to provide a common baseline driving cycle that has been commonly used in emissions testing in the lab. The UDDS cycle is also used primarily as an independent cycle for validation purposes.

In order to capture specific modal emission events, a specific set of modal emissions cycles were designed and applied. The two general objectives of constructing these cycles were to: 1) cover the majority of speed, acceleration, and specific power ranges that span the performance envelope of most heavy duty vehicles; and 2) cover a series of modal events such as various levels of accelerations and decelerations, a set of constant cruise speeds, speed-fluctuation driving, and constant power driving. In addition to these criteria, the cycles had to conform to the lengths of the road segments, speed limits and otherwise safe driving practices of the testing area. Based on feedback from the initial tests and simulation runs, the modal cycles were iteratively refined prior to any substantial vehicle testing. The resulting three modal cycles are illustrated in Figure 2.5.

A total of 11 HDD vehicles were initially tested using this test schedule. A total of 442 individual cycles were collected on the vehicles with a total of 376,371 seconds of data. Ambient temperature and humidity were measured continuously during testing and local hourly wind measurements were obtained. All vehicles were tested using standard fuel obtained from the same source with spot testing to ensure consistency. Since this initial testing in 2003, several additional HDD vehicles have been tested and added to the modeling.

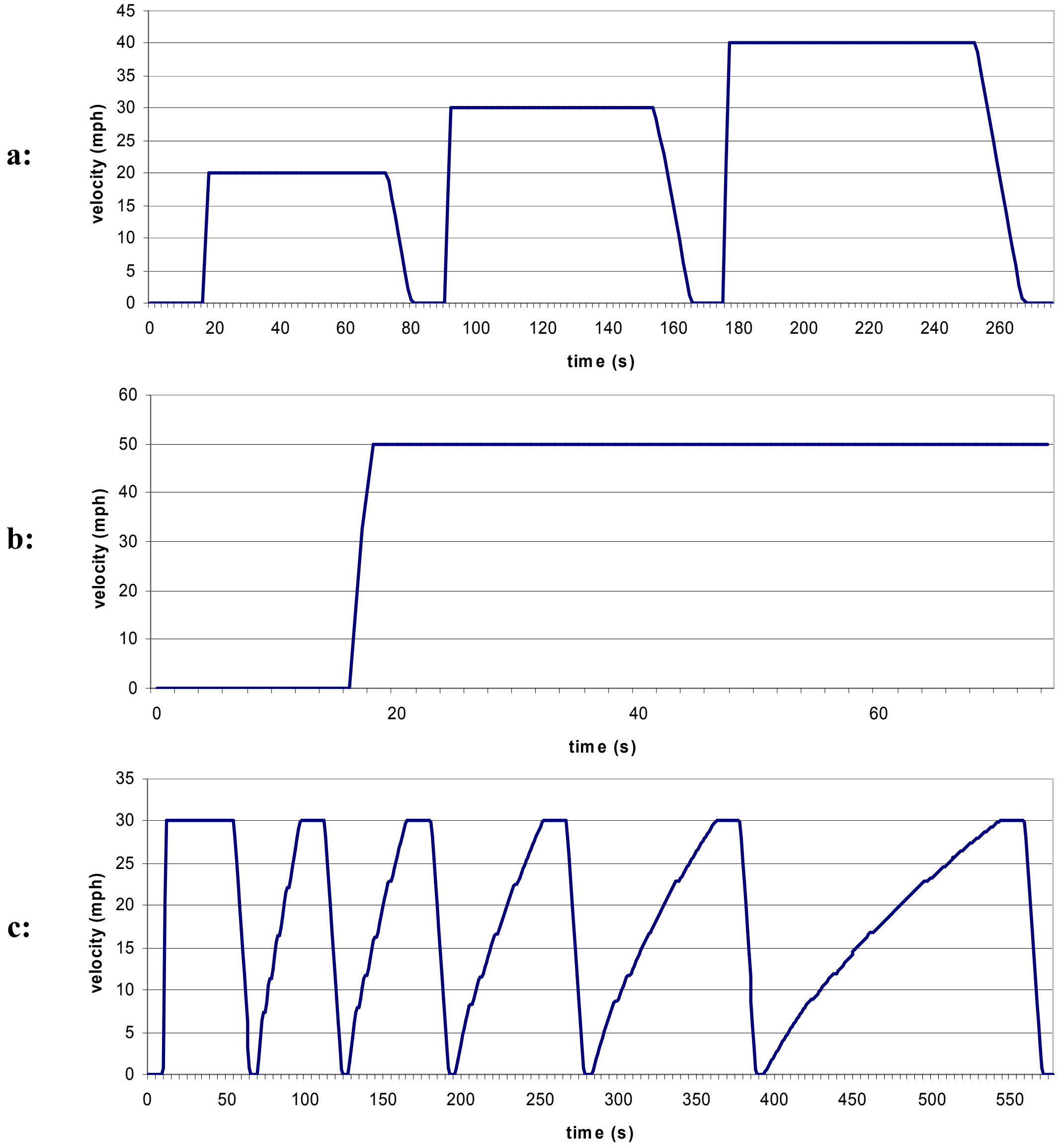

Figure 2.5. Derived modal cycles for HDD testing; a) "three hills" of acceleration/deceleration; b) "one hill" of constant speed events; and c) power mode events.

The HDD testing with MERL was carried out on seldom-used roadways in California's Coachella Valley, approximately two hours from UC Riverside. This area was chosen for its relative proximity to UC Riverside and it's long, uninterrupted stretches of road at zero grade, approximately at sea level.

Recruiting of older vehicles proved to be more difficult than anticipated so the test data were augmented with additional second-by-second data collected on 23 additional HDD vehicles in the CRC E-55 dynamometer study [CRC E55, 2003].

2.6.3. Data Conversion and Time Alignment

Emission concentrations and mass flow rates are recorded second-by-second during the testing and are stored in a database. The raw emission gas concentrations are then converted from concentrations in parts-per-million (ppm) to mass emission rates in grams per second, using algorithms for the gas analyzers which account for parameters such as emission densities, exhaust flow rates, and differences in dry and wet gas measurements. This is carried out for CO_2, CO, HC, and NOx. This is then followed by a comparison between the cumulative modal data and integrated bag results as part of Quality Assurance/Quality Control (QA/QC) procedures.

Further, an important part of post-processing is to time align all of the necessary second-by-second emission data. This step is crucial since there is a time delay inherent in each of the gas analyzer response times and between data from the analyzer and the vehicle's engine control unit (ECU). Data obtained from the ECU such as engine speed, vehicle speed, fuel use, etc., are either obtained by feedback from vehicle sensors or are calculated by the ECU itself and for our purposes are essentially time aligned and representative of real time.

The proper time shift for the emission data is determined through several steps. An initial time shift for each pollutant emission is provided by MERL as part of the validation and calibration of the emission benches. The second step is to analyze the time shifts for each pollutant emission relative to the ECU data. Since the ECU fuel data shows a strong relationship with the emission data and is the basis for much of the later regression work, it is used to determine alignment between the ECU and emission data sets. Alignment of these two data sets is done via a cross correlation analysis using a cross correlation estimate function to calculate correlation values for a range of lag times between the emission and the ECU fuel data. The lag times with the highest correlations are then compared with MERL's expected time shifts and with the optimal lag times of other tests in the series to determine the proper lag times for a range of tests.

2.7. LOW EMITTING VEHICLE TESTING

Because the emission levels of the low emitting vehicles are so low, standard off-the-shelf measurement equipment could not be used. Instead, specialized on-board emissions measurement instrumentation was developed that could measure at the very low ranges of these vehicles. The on-board instrumentation is centered around a Fourier Transform Infra-Red (FTIR) spectrometer that had custom-built sample extraction and conditioning systems. As part of the overall system, data are also gathered from the vehicle's On-Board Diagnostics (OBD II) port, a Global Positioning System (GPS) receiver, and ambient condition data acquisition system. Power for all sampling and data acquisition equipment is provided by a battery pack and inverter system that allows for approximately 2 hours of operation and imposes no load on the vehicle battery and charging system. The vehicles tested for the low emitting vehicle modules are listed in Table 2.6.

Undiluted raw exhaust is withdrawn from the tailpipe through a heated line maintained at 75°C. The sample passes through a quartz filter also heated to 75°C, into a Nafion permeation drier, through the sample pump, and into a second Nafion permeation drier. The first drier is warm due to the heated sample, and rapidly removes the bulk of the water from the sample stream. The second drier is thermoelectrically cooled, which allows it to achieve a low final water content having a dewpoint of about –30°C. The dried sample is then passed to an FTIR gas cell, where pressure is maintained at 900 torr and temperature is maintained at 50°C. The sample leaving the gas cell is combined with nitrogen from a small gas bottle carried on board and used as the purge flow for the Nafion driers. The purge gas is then vented to the atmosphere.

The FTIR and sample gas cell consists of an interferometer that is operated with a wavenumber resolution of 0.5 cm^{-1} through a wavenumber range of 450 to 4000 cm^{-1}, and collects one scan per 1.4 seconds. The gas cell is a white cell design with a path length of 8.28 meters, which for pollutants of interest gives sub-ppm sensitivity. The raw FTIR data are stored during an on-road test, and is post processed using software to generate absorbance spectra which are then quantified. At the sample flow rate provided by the sample conditioning system, the gas cell has a residence time of 15 seconds. This results in a smoothed out concentration signal, too slow to characterize exhaust concentration transients. However, the gas cell is basically a well-mixed flow reactor, which results in an exponential impulse response function. The 15-second exponential time constant can be mathematically compensated for using a digital filter algorithm.

Vehicle speed, engine operating characteristics, and geographic position are obtained and logged by the data acquisition system. The engine operating data are used to estimate vehicle exhaust flow rate. Exhaust flow rate is combined with exhaust concentration data to estimate pollutant mass emission rates. Further details on the measurement system are provided in [Truex et al., 2000].

2.7.1. Vehicle Testing Procedure

Each low emitting vehicle was tested once on a vehicle chassis dynamometer using specific driving cycles. Initially, the standard Federal Test Procedure was applied that consists of a cold start portion[1], a hot-stabilized running portion, and a warm-start portion. This was followed by a more aggressive US06 driving cycle, which is now used to supplement the FTP for certification purposes. Finally, an in-house designed driving cycle was applied, called the MEC01. The MEC01 cycle was developed to exercise the vehicle across its full performance envelope, making it straightforward to extract its modal characteristics. The MEC01 cycle is described in a previous section.

Following the laboratory dynamometer tests, each vehicle was tested extensively on the road. A specific driving course was used that included an initial start, followed by driving on residential roadways, arterial roadways, and freeways. The tests occurred over a three-day period and took place during different times of the day. For the on-road testing, the vehicle carried one driver and the measurement system. The resulting vehicle weight exceeded the certification Equivalent Test Weight (ETW) by 200 to 400 pounds. The same route was driven every time, but the traffic varied from congested to free flowing.

Certification	Year	Make	Model	Odometer
LEV	2001	Chevrolet	Malibu	11,324
ULEV	1999	Honda	Accord LX	80,124
ULEV	2000	Dodge	Neon	87,608
ULEV	2001	Ford	Focus	35,089
ULEV	2001	Honda	Accord LX	5,500
ULEV	2001	Mazda	Protégé	27,114
ULEV	2001	Volkswagen	Jetta GLS	88,790
ULEV	2002	Acura	3.2TL	32,344

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[1] Prior to a “cold start” vehicles are soaked indoors using specific temperature limits as specified by the Code of Federal Regulations for the Federal Test Procedure. The soak period for each vehicle was typically 18 hours.

ULEV	2002	Buick	Regal	21,184
ULEV	2002	Ford	Mustang	23,894
ULEV	2002	Honda	Civic	26,632
ULEV	2002	Mitsubishi	Galant	22,350
ULEV	2002	Mitsubishi	Lancer	13,300
ULEV	2002	Nissan	Altima	13,747
ULEV	2002	Saturn	L200	14,888
ULEV	2002	Toyota	Camry LE	13,098
ULEV	2003	Honda	Civic Hybrid	13,700
ULEV	2003	Toyota	Corolla	21,835
SULEV	2000	Honda	Accord EX-L	7,000
SULEV	2001	Nissan	Sentra CA	3,863
PZEV	2003	Honda	Accord EX	7,731
PZEV	2003	Honda	Civic GX	15,191
PZEV	2003	Honda	Civic Hybrid	1,502
PZEV	2003	Toyota	Camry LE	2,600

Table 2.6. List of Vehicles tested in program

3 Modal Emission Model Structure and Validation

This chapter provides a brief description of the developed modal emissions model. In general, the model is a physical, power-demand model based on a parameterized analytical representation of emissions production. In this model, the emission process is broken down into different components or modules that correspond to physical phenomena associated with vehicle operation and emissions production. Each component is then modeled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary based on several factors, such as vehicle/technology type, fuel delivery system, emission control technology, vehicle age, etc. Because these parameters typically correspond to physical values, many of the parameters are stated as specifications by the vehicle manufacturers, and are readily available (e.g., vehicle mass, engine size, aerodynamic drag coefficient, etc.). Other key parameters relating to vehicle operation and emissions production must be determined from a testing program, described in the model calibration procedure.

The main purpose of the comprehensive modal emission model is to predict vehicle tailpipe emissions associated with different modes of vehicle operation, such as idle, cruise, acceleration, and deceleration. These modes of operation may be very short (i.e., a few seconds) or may last for many seconds. Moreover, the model must deal with the following operating conditions:

1) variable starting conditions (e.g., cold start, warm start);

2) moderate-power driving (i.e., driving for the most part within the FTP performance envelope);

3) "off-cycle" driving (i.e., driving that falls outside the FTP performance envelope; this typically includes enrichment and enleanment events).

As discussed previously, we are concerned with a variety of in-use vehicles that vary by model, age, and condition (i.e., emissions control system deterioration or malfunction). Therefore, one needs to consider both temporal and vehicular aggregations:

Temporal Aggregation:	*second-by-second → several seconds (mode) → driving cycle or scenario*
Vehicle Aggregation:	*specific vehicle → vehicle/technology category → general vehicle mix (fleet)*

Using a bottom-up approach, the basic building block of our physical-based emissions model is the individual vehicle operating on a fine time scale (i.e., second-by-second). However, the model itself does not focus on modeling specific makes and models of vehicles. Our primary goal is the prediction of emissions in several-second modes for average, *composite vehicles* within each of the vehicle/technology categories specified in Table 3.1. Modeling at a higher level of detail is of limited value for two reasons:

1) At the second-by-second level, there can be major fluctuations in driving patterns, with large short-term emissions consequences. Major fluctuations in throttle position are common in dynamometer tests using standard driving cycles, as the driver corrects for overshooting or undershooting the target speed trace. Information on the frequency and intensity of throttle fluctuations in actual driving is not readily available, as they depend on specific road and traffic conditions. Therefore in our present view, some time-averaging process is desirable in the model.

2) It would be difficult (and outside the scope of the project) to attempt to develop a separate formalism for all vehicle models based on measured parameters describing engine and emission control system (ECS) behavior, including rates of ECS deterioration and failure for each vehicle. Instead, we are developing the generic characterization of a composite vehicle within each vehicle/technology category specified in Table 3.1. The composite vehicle (in each category) is determined based on an appropriately weighted emissions average of all vehicles tested in the category. Generic parameters are then modeled as part of the composite vehicle emissions model. Using this generic approach, one obtains good modal-emissions predictions for composite cars. Model accuracy also improves considerably with temporal aggregation.

Category #	Vehicle Technology Category
	Normal Emitting Cars
1	No Catalyst
2	2-way Catalyst
3	3-way Catalyst, Carbureted
4	3-way Catalyst, FI, >50K miles, low power/weight
5	3-way Catalyst, FI, >50K miles, high power/weight
6	3-way Catalyst, FI, <50K miles, low power/weight
7	3-way Catalyst, FI, <50K miles, high power/weight
8	Tier 1, >50K miles, low power/weight
9	Tier 1, >50K miles, high power/weight
10	Tier 1, <50K miles, low power/weight
11	Tier 1, <50K miles, high power/weight
24	Tier 1, >100K miles
	Normal Emitting Trucks
12	Pre-1979 (<=8500 GVW)
13	1979 to 1983 (<=8500 GVW)
14	1984 to 1987 (<=8500 GVW)
15	1988 to 1993, <=3750 LVW
16	1988 to 1993, >3750 LVW
17	Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)
18	Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)
25	Gasoline-powered, LDT (> 8500 GVW)
40	Diesel-powered, LDT (> 8500 GVW)
	High Emitting Vehicles
19	Runs lean
20	Runs rich
21	Misfire
22	Bad catalyst
23	Runs very rich

Table 3.1. Vehicle/Technology modeled categories. Note diesel vehicles start at category 40; "blank" categories are user programmable from category #60.

Table 3.1 comes directly from the vehicle/technology categories developed and specified in Section 2.3 (Table 2.3), with the following exception. Because many of the high emitting vehicles had disparate emission results when categorized by technology group, the high emitting vehicles were re-categorized into groups with similar emission characteristics. Grouping high emitters by emission profiles produced much more homogeneous groups than grouping by technology category. These characteristics are described in detail in Section 3.5, and include running lean, running rich, misfiring, having a bad catalyst, and running very rich.

Separate sub-models for each vehicle/technology category listed in Table 3.1 have been created. All of these sub-models have similar structure; however the *parameters* used to calibrate each sub-model are very different. Each calibrated sub-model corresponds to a composite vehicle representing the characteristics of a particular vehicle/technology category.

In developing these sub-models, it is important to strike a balance between achieving high modeling accuracy and reducing the number of model input parameters. Because the design, calibration, and in-use conditions of vehicles vary greatly, there is always the temptation to add more input parameters for special situations of different vehicles to improve modeling accuracy. In order to control the number of independent input parameters, focus has been placed on the most common emission mechanisms, rather than trying to accommodate every special vehicle case.

3.1 GENERAL STRUCTURE OF THE MODEL

In the developed modal emissions model, second-by-second vehicle tailpipe emissions are modeled as the product of three components: fuel rate (FR), engine-out emission indices ($g_{\text{emission}}/g_{\text{fuel}}$), and time-dependent catalyst pass fraction (CPF):

$$\begin{array}{c}\text{tailpipe}\\ \text{emissions}\end{array} = \text{FR} \bullet \left(\frac{g_{\text{emission}}}{g_{\text{fuel}}}\right) \bullet \text{CPF} \tag{3.1}$$

Here FR is fuel use rate in grams/s, engine-out emission index is grams of engine-out emissions per gram of fuel consumed, and CPF is the catalyst pass fraction, which is defined as the ratio of tailpipe to engine-out emissions. CPF usually is a function primarily of fuel/air ratio and engine-out emissions.

The complete modal emissions model is composed of six modules, as indicated by the six square boxes in Figure 3.1: 1) engine power demand; 2) engine speed; 3) fuel/air ratio; 4) fuel-rate; 5) engine-out emissions; and 6) catalyst pass fraction. The model as a whole requires two groups of input (rounded boxes in Figure 3.1): A) input operating variables; and B) model parameters. The output of the model is tailpipe emissions and fuel consumption.

There are also four operating conditions in the model (ovals in Figure 3.1): a) variable soak time start; b) stoichiometric operation; c) enrichment; and d) enleanment. Hot-stabilized vehicle operation encompasses conditions b) through d); the model determines in which condition the vehicle is operating at a given moment by comparing the vehicle power demand with two power demand thresholds. For example, when the vehicle power demand exceeds a power enrichment threshold, the operating condition is switched from stoichiometric to enrichment. The model does not inherently determine variable soak time; rather, the user (or integrated transportation model) must specify the time the vehicle has been stopped prior to being started. The model does determine when the operating condition switches from a cold start condition to fully warmed-up operation. Figure 3.1 also shows that the operating conditions have direct impacts on fuel/air ratio, engine-out emissions, and catalyst pass fractions.

The vehicle power demand (1) is determined based on operating variables (A) and specific vehicle parameters (B). All other modules require the input of additional vehicle parameters determined based on dynamometer measurements, as well as the engine power demand calculated by the model.

The fuel/air equivalence ratio (which is the ratio of stoichiometric air/fuel ratio, roughly 14.7 for gasoline) to the instantaneous air/fuel ratio), ϕ, is approximated only as a function of power, and is modeled separately in each of the four operating conditions a) through d). The core of the model is the fuel rate calculation (4). It is a function of power demand (1), engine speed (2), and fuel/air ratio (3). Engine speed is determined based on vehicle velocity, gear shift schedule and power demand.

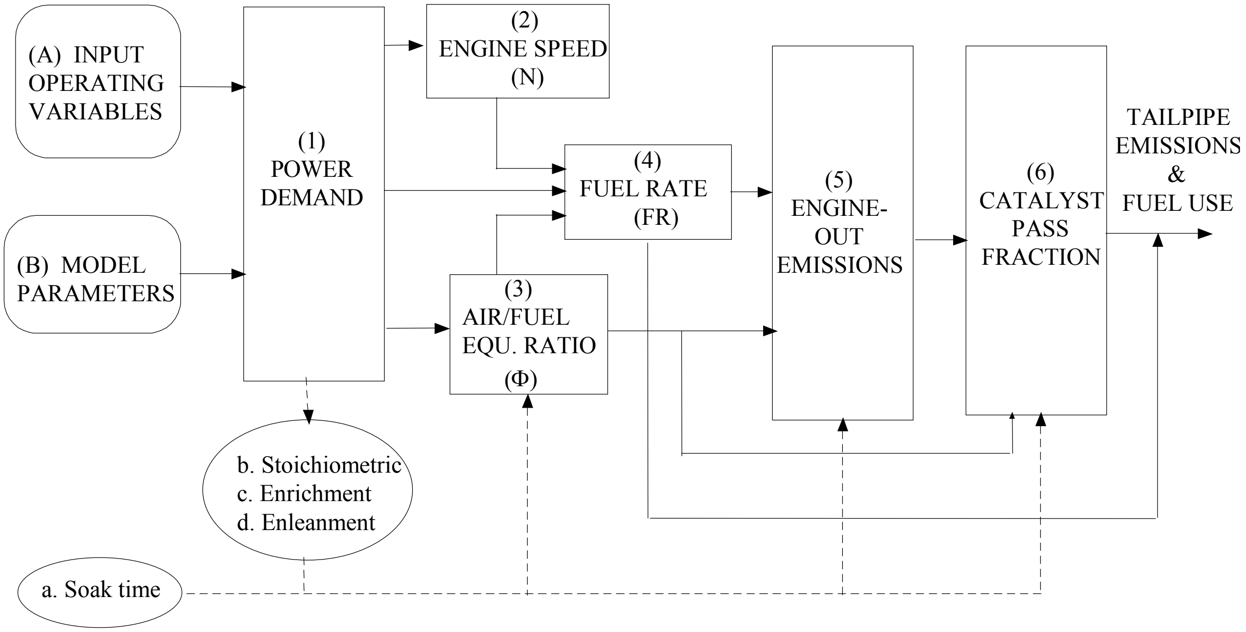

Figure 3.1. Modal Emissions Model Structure

The details of the six modules are described elsewhere (see, e.g., [Barth et al., 1999], [Feng et al., 1997]). It is important to note that the generic model shown in Figure 3.1 applies to the 26 different vehicle/technology categories defined in Table 3.1. Differences between the sub-models show up only in their defining parameters.

3.2 SUMMARY OF MODEL PARAMETERS AND VARIABLES

As discussed previously, separate sub-models for each vehicle/technology category have been created. The sub-models all have similar structure (as described in the previous section), however they differ primarily in their parameters.

Each sub-model uses three dynamic operating variables as input. These variables include second-by-second speed (from which acceleration can be derived; note that acceleration can be input as a separate input variable), grade, and accessory use (such as air conditioning). In many cases, grade and accessory use may be specified as static inputs or parameters.

In addition to these operating variables, each sub-model uses a total of 55 static parameters in order to characterize the vehicle tailpipe emissions for the appropriate vehicle/technology category. A summary list of the parameters and operating variables is given in Table 3.2. Table 3.2 gives the name and a brief definition of each parameter.

In Table 3.2, the model input parameters are first divided into two large categories: 13 *Readily Available Parameters* and 42 *Calibrated Parameters*. The *Readily Available Parameters* represent model input parameters which can be either obtained externally from public sources (e.g., sources of automotive statistics, datasets compiled by EPA, etc.), and are further divided into *specific vehicle parameters* and *generic vehicle parameters*. The *generic vehicle parameters* are ones that may not necessarily be specified on a vehicle-by-vehicle basis, but are rather specified generically for entire vehicle classes.*

The *Calibrated Parameters* cannot be directly obtained from publicly available sources; rather they are deduced (i.e., calibrated) from the testing measurement data. This group of parameters is further divided into two sub-sets: an *Insensitive Set* (23 parameters) and a *Sensitive Set* (19). In the *Insensitive Set*, the model parameters are either approximately known in advance (e.g., fuel and engine-out emission parameters) or have relatively small impacts on overall vehicle emissions (e.g., enleanment parameters). The parameters in the *Sensitive Set* need to be carefully determined. There are three sub-sets of *Sensitive Parameters*:

1) *Cold-Start subset*, consisting of 7 model input parameters describing both cold-start catalyst performance and engine-out emissions;

2) *Hot Stabilized Catalyst subset*, consisting of 10 parameters that determine the relationships between catalyst efficiencies and engine-out emissions and fuel/air ratios under hot stabilized conditions; and

3) *Enrichment Parameters subset*, consisting of 2 parameters defining enrichment: the maximum enrichment fuel/air equivalence ratio ϕ_0 at wide open throttle (WOT), and the enrichment power threshold P_{scale}.

3.3 MODEL CALIBRATION PROCESS

As the model was developed, each test vehicle was individually modeled by determining all of the parameters described in the previous section. The *Readily Available Parameters* of the test vehicles (e.g., mass, engine displacement, etc.) have been obtained for each vehicle. The *Calibration Parameters* were determined through a detailed calibration procedure, using the measured emissions results for each test vehicle. Depending on the specific parameter, the calibration values are determined either: 1) directly from measurements; 2) based on several regression equations; or 3) based on an optimization process.

3.3.1 Measurement Process

Nine parameters are determined directly from the dynamometer emission measurements:

- maximum hot-stabilized catalyst efficiencies for CO, HC, and NO_x emissions (Γ_{CO}, Γ_{HC}, and Γ_{Nox});

- maximum fuel/air equivalence ratio (ϕ_0);

- maximum lean HC emission rate during long deceleration events (hc_{max});

- maximum lean HC emission rate during transient events (hc_{trans});

---

[*] In the current model implementation, these generic vehicle parameters are programmed into the model and cannot be modified by the user (see Chapter 4).

MODEL EMISSIONS MODEL PARAMETERS AND VARIABLES		
Readily-Available Parameters	**Calibrated Parameters**	
Specific Vehicle Parameters	***(Insensitive)***	***(Sensitive)***
M - vehicle mass in lbs.	***Fuel Parameters***	***Cold-Start Parameters***
V - engine displacement in liters	k_0 - eng. fri. factor in kJ/(lit.rev)	β_{CO}, β_{HC}, β_{NOx} - cold start catalyst coefficients for CO, HC, and NOx respectively
Idle – idle speed of engine	$\varepsilon_{1,}\varepsilon_3$ - drivetrain eff. coefficients	
Trlhp - coastdown power in hp	***Engine-out Emission Parameters***	
S - eng spd./veh spd. in rpm/mph		ϕ_{cold} - cold F/A equi. ratio
Q_m - max torque in ft.lbs	C_0 - CO enrich. coef.	T_{cl} - surrogate temp reach stoich
N_m - eng spd. in rpm @ Q_m	a_{CO} - EO CO index coef.	CS_{HC} - cold EO HC multiplier
P_{max} - max power in hp	a_{HC} - EO HC index coef.	CS_{NO} - cold EO NO multiplier
N_p - eng spd. in rpm @ P_{max}	r_{HC} - EO HC residual value	
N_g - number of gears	a_{1NOx} - NO_x stoich index	***Hot Catalyst Parameters***
	a_{2NOx} - NO_x enrich index	Γ_{CO}, Γ_{HC}, Γ_{NOx} - hot max CO, HC, and NO_x catalyst efficiencies
Generic Vehicle Parameters	FR_{NO1}, FR_{NO2} - NO_xFR threshold	
η - indicated efficiency	***Enleanment Parameters***	
ε_1 - max. drivetrain eff.	hc_{max} - max. HC_{lean} rate in g/s	b_{CO}, b_{HC}, b_{NO} - hot Cat CO, HC, and NOx coefficient
R(L) - gear ratio	hc_{trans} - trans. HC_{lean} rate in g/SP	
	δSP_{th} - HC_{lean} threshold value	c_{CO}, c_{HC}, c_{NO} - hot cat CO, HC and NOx coefficient
Operating Variables	r_R – HC_{lean} release rate in 1/s	
	r_{O2} - ratio of O_2 and EHC	
	ϕ_{min} – lean fuel/air equ. ratio	
θ - road grade	***Soak-time Parameters***	id - NOx Cat tip-in coefficient
P_{acc} – accessory power in hp	C_{soak_CO}, C_{soak_HC}, C_{soak_NO}– soak time engine coef. for CO, HC, NO_x	***Enrichment Parameters***
v - speed trace in mph		ϕ_0 - max F/A equi. ratio
Tsoak – soak time (min)	α_{soak_CO}, α_{soak_HC}, α_{soak_NO}– soak time Cat. coef. for CO, HC, NO_x	P_{scale} – SP threshold factor
SH – specific humidity (grains H_20/lb.)		

Table 3.2. Modal emissions model input parameters.

- minimum fuel/air equivalence ratio (f_{min}) during enleanment operation;
- ratio of oxygen and engine-out HC emissions (r_{O2}) during enleanment operation; and
- maximum cold-start fuel/air equivalence ratio (ϕ_{cold}).

The first eight parameters are derived directly from the MEC01 cycle emissions traces. The maximum cold-start fuel/air equivalence ratio (ϕ_{cold}) is based on data from the FTP bag 1 cycle.*

3.3.2 Regression Process

All seven parameters used to model engine-out emissions (C_0, a_{CO}, a_{HC}, r_{HC}, a_{1NOx}, a_{2NOx}, and FR_{NOxth}) are determined through a regression process. Emission measurements from the MEC01 cycle are used to determine these parameters. These parameters are determined by regressing engine-out emissions against rate of fuel use.

3.3.3 Optimization Processes

The remaining 26 calibration parameters are determined using an optimization process. Several optimization processes are used to calibrate the model parameters by minimizing the differences between the integrated modeled and measured emissions data. The optimization procedure is based on golden section and parabolic interpolation. During the optimization process, one parameter is optimized at a time while all remaining parameters are held constant. Parameters are optimized in a specific order such that they are dependent only on previously optimized parameters.

3.4 VEHICLE COMPOSITING

Each of the vehicles tested during the testing phase with sufficient and acceptable data has been modeled, using the calibration process described above. However, the primary modeling goal is to predict detailed emissions for each average, *composite* vehicle that represents the vehicle/technology categories listed in Table 3.1. Thus, a *compositing procedure* has been developed to construct a composite vehicle to represent each of the 26 different vehicle/technology modeled categories. The compositing procedure is as follows:

1. *Determine input model parameters for each vehicle tested*—As discussed, the first step is to establish all of the readily available model parameters for each vehicle tested in the program. The resulting vehicle parameter database is then used in subsequent steps. As described in Section 3.3, the calibration process involves the usage of both second-by-second engine-out and tailpipe emissions under both the FTP 3 Bag and MEC01 cycles. Therefore, only those vehicles that were completely tested under these conditions can be used for composite calibration. There were a number of vehicles that could not be used since the full engine-out and tailpipe-out data were not always measured.

2. *Establish composite emission traces for each technology group*—Using the vehicles that are grouped in each vehicle/technology category, an average composite vehicle emission trace is constructed for the MEC01, FTP, and US06 cycles. This was done by averaging the second-by-second emissions over the FTP three bags, MEC01 and US06 cycles for all vehicles in each vehicle/technology category.

3. *Establish composite parameters*—A subset of the composite parameters are directly established based on their average values within each vehicle/technology category, i.e., primarily the *Readily-Available Parameters*. The remaining calibrated parameters for the composite vehicles are

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* FTP bag 1 cold-start tests are carried out at 75° F, therefore this model is not well suited for evaluating emissions at cold ambient temperatures.

determined using the same calibration process described earlier, using the average of the calibrated parameters of the vehicles in the category as the starting point. Based on this procedure, the parameter sets of the 26 composite vehicles are given in Appendix B.

3.5 HIGH EMITTING VEHICLES

As discussed in Chapter 1, several independent analyses have found that about half of the on-road emissions by automobiles may be from the small fraction of vehicles that are high-emitters [Stedman, 1989; Lawson, 1990; Stephens, 1994; CARB, 1994]. Although there are many potential technical causes of failed or malfunctioning emissions controls, there has been relatively little study of the distribution of these technical causes in the fleet of in-use vehicles [CARB, 1996; McAlinden, 1994; Soliman, 1994]. In the nature of investigations of high-emitters, the emphasis has been on carbureted vehicles and early-model fuel-injected vehicles. In this project, we primarily focused on newer model years, i.e., vehicles with sophisticated computer-controlled fuel-injected engines.

3.5.1 Characterizing High Emitters

As specified in Chapter 2, suspected high-emitting vehicles were recruited and tested based on a number of different methods. Based on their FTP bag emission results, the vehicles were classified either as high emitting or normal emitting using a set of cutpoints. The high-emitting vehicles were classified into different categories, based on the same approximate characteristics used in classifying normal emitters, such as emission/fuel control technology and emission certification level (e.g., Tier 0, Tier 1). However, these categories did not work well, simply because the vehicles in the groups had very different emission characteristics. It made more sense to regroup the vehicles based on the physical mechanisms of emission control system (ECS) failure. (Note that careful inspection of the tested vehicles by a professional mechanic was not a part of the NCHRP project.)

To address the issue of real-world frequency of the high emitters, we categorized the several types of high emitters measured in the project according to their emissions characteristics, and made a correspondence between these types of high emitter and the distribution of high emitters with similar tailpipe-emission profiles observed in Arizona's on-going I/M program. The Arizona program covers essentially all light-duty vehicles in the Phoenix area (although the number of high emitters may be underestimated because there is a tendency for people to not register their vehicles, or register them elsewhere, if they think that they won't pass the I/M test [Stedman, 1997]). We thus determine weights to assign to the NCHRP high-emitter types which may reasonably reflect the representation of those kinds of high emitters on the road.

We focus our study on vehicles which are high emitters in low- to moderate-power driving. An example of what we call moderate power is a 50 mph cruise on a level road without unusual load, but with throttle fluctuations. Such a power level requires a fuel rate of about 0.7 grams per second for small sedans, and about twice that for large sedans and most light trucks. This power level is characteristic of the IM240 driving cycle used in the Arizona I/M program and the 505-second cycle used for bags 1 and 3 of the FTP.

For the newer model year vehicles, accurate control of the fuel-air ratio in closed-loop operation is critical to effective emissions control. It is likely that most high emitters among MY1990 and later vehicles are caused or created by some form of fuel-air ratio control problem. In closed-loop operation with a three-way catalyst, the electronic control module manages the injection of fuel so as to essentially maintain stoichiometry (the optimum ratio of air to fuel, about 14.7:1) to maintain combustion while minimizing emissions. For proper operation the fuel-air ratio oscillates around stoichiometric:

$$|\langle\phi\rangle - 1| < \Delta\phi. \quad (3.2)$$

Here, ϕ is the fuel-air ratio compared to its stoichiometric value. In fact, it should hold with substantial overlap. For many vehicles with malfunctioning ECS the fuel-air management isn't working properly, so this inequality doesn't hold, even at moderate power. In these conditions, the vehicle is likely to be a high emitter. We distinguish three fuel-air ratio regions: *stoichiometric*, where eq (3.2) is satisfied; *rich*, where $\phi > 1$ is beyond the window of stoichiometry; and *lean*, where $\phi < 1$ is beyond the window of stoichiometry.

3.5.2 High-Emitter Types

Based on the high emitting vehicles tested in this NCHRP 25-11 project, four types of high emitters were determined based on their emission characteristics and the fuel-air ratio regions described above. For each, a profile has been determined in the form of tailpipe CO/HC/NOx levels. Two cutpoints are used (low and high) for each, with L, M, and H standing for: below a low cutpoint, medium, or in-between, and above a high cutpoint, respectively.

Type 1. Operates Lean at Moderate Power

In the first type of high emitter, the fuel-air ratio is chronically lean or goes lean in transient operation calling for moderate-power. An average 2% or more lean is likely to saturate the catalyst with oxygen. For this type of high emitter, CO and HC emissions are typically low, but the NOx emissions are high, relative to emissions of clean vehicles. The CO/HC/NOx profile for this type of high emitter is LLH or MHH.

A physical failure mechanism leading to Type 1 behavior is not so easy to pinpoint. Improper signal from the oxygen sensor or improper functioning of the electronic engine control are possibilities.

Type 2. Operates Rich at Moderate Power

In the second type of high emitter, the fuel-air ratio is chronically rich or goes rich in transient moderate-power operation. The engine-out hydrocarbons typically remain normal. Under these conditions, the CO emission index and catalyst pass fraction are high, resulting in high tailpipe CO emissions. The CO/HC/NOx profile for this type of high emitter is HML, HMM, or HLL.

There are many possible failure mechanisms resulting in enrichment during closed loop operation[*]; however the mechanism here must also leave the engine-out HC emissions index in its normal range of 0.01 to 0.02. Thus there can be enrichment but not misfire. One example which meets the characteristics is a leaking exhaust line which brings in oxygen before the oxygen sensor, resulting in the sensor calling for more fuel from the injectors.

Type 3. High Engine-Out Hydrocarbon Emissions Index

The third type of high emitter involves a high engine-out emission index for HC and mild enrichment, as evidenced by high engine-out CO and high CO catalyst pass fraction. Catalyst performance is also poor. The profile for this type of high emitter consists of moderate to slightly-high tailpipe CO, very high HC,

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[*] One of the primary mechanisms is that rich operation is the default mode for many kinds of malfunctions detected by the on-board computer.

and moderate to low NOx relative to properly-functioning vehicles. The key aspect of the profile is the very high HC. The CO/HC/NOx profiles include MHM, HHL, and HHM.

Excess engine-out HC is probably caused by incomplete combustion in one or more cylinders (i.e., misfire), from a physical mechanism such as a bad spark plug or partial obstruction of an injector resulting in too little fuel injected into the cylinder. There are many possible mechanisms. Oxygen levels in the engine-out exhaust are observed to be correspondingly high (2.5 grams of excess oxygen per gram of excess engine-out fuel). Catalyst performance is also poor, and not only when hydrocarbons are high. This is likely due to catalyst deterioration caused by the combination of high engine-out HC emissions (which is essentially unburned gasoline) and high oxygen levels. This mixture readily burns in the catalyst, causing very high temperatures and catalyst deterioration.

Type 4. Poor Catalyst Performance for All Three Pollutants at Moderate Power

High tailpipe emissions of all pollutants typifies Type 4 high emitters. This type involves more than one behavior, with 1) chronically poor catalyst performance, due to burned-out or missing catalyst, or 2) transiently poor catalyst performance, e.g. a catalyst pass fraction of 0.3 or more in moderate-power driving. Type 4 malfunction is distinguished from Type 3 because engine-out HC is normal, or only slightly high, and from Type 2 because there is no or only slight enrichment at moderate power. For this type, in almost all cases all three pollutants are high, relative to clean car levels. The CO/HC/NOx profiles consist of HHH, HMH, and MHH.

This type of high emitter may be associated with a burned-out catalyst, as observed in several of the tested vehicles; but transiently bad catalyst performance is also observed. It is difficult to distinguish between two possible basic causes of the latter. The first involves greatly deteriorated performance of the catalyst, presumably due to severe operating conditions in the past. A second possible cause is poor closed-loop control of the fuel-air ratio, such that it doesn’t conform to the needed pattern but at a level of failure too detailed to be observed directly here.

Summary

The CO/HC/NOx tailpipe-emissions profiles for the high-emitters measured in the NCHRP project are shown in Table 3.3. We include MMH vehicles as both Type 1 and Type 4 high emitters.

High-Emitter Type	CO/HC/NOx profile
1: lean	LLH, LMH, (MMH)
2: rich	HML, HMM
3: misfire	HHL, MHM, MHL, HHM
4: catalyst problem	HHH, MHH, (MMH)

Table 3.3. High-Emitter types by FTP bag 3 profile.

An essential point is that these are general categories. Each “type” identified corresponds to more than one detailed behavior; for example, we observe both transient and chronic behavior for each type. And each type covers more than one disparate *physical* malfunction.

3.5.3 Emission Profiles in the Arizona IM240 Data

Because the number and distribution of the high emitting vehicles recruited for testing under the NCHRP 25-11 project are not representative of the in-use fleet, we analyzed data from the Arizona I/M program to get a sense of the prevalence of each type of high emitter.

The IM240 test was recently introduced in several non-attainment areas, including the Phoenix area, as part of an enhanced inspection and maintenance (I/M) program. The test involves a 4-minute dynamometer cycle with speeds up to 57 mph, with an average speed of 30 mph. The IM240 power levels are similar to those in FTP bag 1 or 3, and involve the same maximum specific power. To reduce costs and waiting, the 240-second test is terminated early by the Arizona contractor for vehicles with relatively low or high emissions. For short tests, we calculate an adjusted gpm; our adjustment is different than that used in Arizona [Wenzel, 1997].

Using the IM240 data, we create CO/HC/NOx profiles based on high, medium and low categories for each pollutant, as we did with measurements on the sample of NCHRP high-emitting vehicles. The profiles again depend on choice of low-emitter and high-emitter cutpoints. (Because of differences between the two measurement programs, as discussed below, these IM240 cutpoints are not the same as those for the NCHRP 25-11 measurements.)

Almost all of the Arizona IM240 high emitters occur in eight profiles, depending on the choice of cutpoints. The profile distributions found are shown in Table 3.4. With three pollutants and three emissions levels, H, M and L, there are nineteen possible profiles of high emitters (i.e. vehicles with at least one H). Just eight in Table 3.4 have an incidence of 5% or more; only 10% of the vehicles fall in the other eleven profiles. A characteristic of most of the missing profiles is that they do not obey a tight correlation between CO and HC (independent of the NOx level).

Profile: CO/HC/NOx	**percent high emitters**
HHH	1
HHM	5
HMH	0
MHH	11
HMM	2
MHM	17
MMH	20
HHL	10
HML	11
HLM	0
MHL	6
MLH	2
LHM	1
LMH	4
HLH	0
LHH	0
HLL	0
LHL	0
LLH	7

Table 3.4. Distribution of High-Emitters by profile: Arizona IM240, MY1990-1993.

By examining the boundaries for the IM240 profiles for the four types of high emitter identified among the NCHRP vehicles, we can assign about one-third of IM240 category MMH to Type 4 and two-thirds to Type 1, all of LMH to Type 1, and all of MHL to Type 3. The resulting frequencies as percentages of all high emitters are shown in Table 3.5. These frequencies or weights are used in formulating the contribution of high emitters in the modal model.

High Emitter Type	Profile	Percent of High Emitters	Percent of All Cars
1: Runs Lean	LLH, LMH, (MMH)	24	2.4
2: Runs Rich	HML, HMM	13	1.3
3: Misfire	HHL, MHM, MHL, HHM	38	3.8
4: Bad Catalyst	HHH, MHH, (MMH)	19	1.9
Other high emitters		5	0.5

Table 3.5. Distribution of IM240 profiles of MY90-93 cars.

3.6 MODEL VALIDATION

An essential step in the modeling process is performing *model validation*, as well as examining the *model uncertainty*, and analyzing *model sensitivity*. Much effort was spent examining these issues, with the results detailed in [Barth et al., 1999] and [Schulz et al., 1999]. A summary of the model validation is given below.

Model validation is the assessment of how well the model performs on independent input data, when compared to some ground truth data. For model validation, the key question to answer is whether or not the model predicts with reasonable accuracy and precision. These general questions lead to several other questions, such as what statistics or functions will properly describe accuracy and precision. Large-scale CMEM validation has been conducted by comparing composite vehicle bag numbers for CO_2, CO, HC, and NO_x for the FTP, MEC, and US06 test cycles using linear regression. Of these, the FTP Bag 3 (excluding the first 100 seconds) and the US06 are the most important because they were not directly used in model development and thus provide independent test data. For this validation, we use the slope and intercept of the regression of observed values against predicted values to measure model accuracy. Precision is measured using the r-square of the regression. High r-square values alone do not indicate a good model, because a consistent but highly biased model is not good for prediction.

The emissions of tailpipe CO_2, CO, HC, and NO_x for the 26 composite vehicles were calculated for the three bags of the FTP, the MEC, and the US06 test cycles. These composited vehicle driving and measured emission traces are used in this validation for comparison to the modeled results. The measured values of emissions serve as the *observed* data set (plotted on the X-axis) and the modeled emission values serve as the *predicted* data set (plotted on the Y-axis). A regression was run comparing the predicted results against the observed results for each emission and driving trace. A joint statistical test [Draper and Smith, 1966] was used to test the joint hypothesis that the intercept equals zero and the slope equals one. Significant p-values ($p<0.01$) indicate that there is a significant bias in the model for the regression being tested. If the model were perfect, the slope would be one and the intercept would be zero and all points would fall on the line (r-square = 1.0). It should be noted that for high r-square values (low variability about the regression), the joint probability test is sensitive to smaller slope and intercept differences. The slope and r-square are summarized in Table 3.6. Further details and plots of these regressions are presenting in [Barth et al., 1999].

Overall, the composite vehicle validation results are very good. Several conclusions from the analysis of the composite car results can be summarized:

- The tailpipe emissions for the independent FTP Bag 3 results show no significant bias in HC ($p>0.01$) and a significant bias for CO_2, CO, and NO_x primarily due to one or two high emitting categories.

- The tailpipe emissions for the independent US06 results show no significant bias in HC ($p>0.01$) and a significant bias for CO_2, CO, and NO_x.

- The tailpipe emission results for FTP Bag 1 are excellent for HC and CO, having no significant bias and very low variability. There is a significant bias in the NO_x results, primarily due to five high emitting groups. The results are biased for CO_2 but with low variability.

- The tailpipe emission results for FTP Bag 2 are excellent for HC and CO_2, having no significant bias and very low variability. There is a significant bias in the NO_x results, with low variability. The results are biased for CO primarily due to three high emitter groups.

- With the exception of an occasional individual composite vehicle, the engine-out results have either no significant bias or very small bias for FTP Bag 1 except for CO_2 which is predicted low, FTP bag 2 except for NO_x, FTP Bag 3 except for NO_x the MEC except for NO_x which has one problem category, and the US06 test cycle except for HC and NO_x.

Cycle	Emission	Slope	Y-Intercept	R-Square
FTP Bag 1	TP CO	1.017	0.019822	0.993
	TP HC	0.971	-0.060948	0.995
	TP NOx	1.126	-0.119060	0.986
	TP CO2	0.940	-17.0036	0.970
FTP Bag 2	TP CO	0.900	-0.058601	0.966
	TP HC	1.019	-0.077000	0.977
	TP NOx	1.151	-0.048714	0.995
	TP CO2	0.989	1.907500	0.992
FTP Bag 3	***TP CO***	***0.845***	***0.344860***	***0.955***
	TP HC	***0.973***	***-0.009146***	***0.963***
	TP NOx	***0.896***	***0.032673***	***0.956***
	TP CO2	***0.935***	***10.3265***	***0.986***
MEC	TP CO	1.014	2.19700	0.995
	TP HC	1.009	0.025411	0.999
	TP NOx	0.977	0.064148	0.992
	TP CO2	0.942	8.02000	0.971
US06	***TP CO***	***1.162***	***0.11068***	***0.721***
	TP HC	***1.041***	***-1.12330***	***0.976***
	TP NOx	***0.826***	***0.30714***	***0.897***
	TP CO2	***0.862***	***45.7556***	***0.866***

***FTP Bag 3 and US06 Are Independent Test Cycles.**

Table 3.6. Summary of composite vehicle validation regression slope, Y-intercept, and R-Square.

A second validation was conducted on measured and modeled *second-by-second* CO_2, CO, HC, and NO_x emissions for individual vehicles. The model was not intended for use as a second-by-second model for prediction of individual vehicles, however the second-by-second evaluation provides insight into bias and variability of the model. In this validation case, bias was measured by taking the mean observed value minus the mean predicted value over the entire distribution of vehicles. Variability was assessed using standard Mean Square Error (MSE) and the Normalized Mean Square Error (NMSE) measures. For this analysis, bootstrap re-sampling was used (see [Efron and Tibshirani, 1986]). Individual vehicles were used for this analysis to ensure that the population used for bootstrapping was sufficiently large. Bootstrapping on a small population such as the 26 composite vehicles can cause problems in the results. Using this technique, it is desired to generate plots of bias vs. time, MSE vs. time, and NMSE vs. time, where time is the second-by-second time range over a given cycle for a particular emission. For each second, point estimates are helpful, but of more use would be 95% confidence intervals for the appropriate statistics, since they indicate how variable the estimates are. However, it is not really known if this data is normal, and so the distributions of bias, MSE and NMSE are not known. In short, the usual confidence intervals may not be appropriate. However, the bootstrap method will result in confidence limits for the statistics of interest (bias, MSE, NMSE) that do not depend on the form of the distribution. The bootstrap procedure is applied to the normal emitting and high emitting vehicles separately to identify possible differences in model performance.

The second-by-second bias, MSE, and NMSE were calculated for the FTP Bag 3 and US06 test cycles for this model validation. The first 100 seconds of data were left out of the validation for the FTP Bag 3 cycle. The remainder of the FTP Bag 3 cycle provides an independent data set with mild driving conditions. The US06 cycle was used because it also is not used in the development of the model, and is a difficult test cycle for model prediction. For these calculations, the confidence limits were determined using the percentiles of the bootstrapped results, which do not require any assumptions about the distribution of the second-by-second emissions. The MSE and NMSE results were similar to the bias results. The average emissions and bias results are presented in Table 3.7.

Cycle	Emissions	Average g/sec.	Average Bias	Maximum Bias	Minimum Bias
FTP Bag 3	CO_2	3.5146	0.5298	2.9049	-1.6718
	CO	0.0732	0.0186	0.1538	-0.5111
	HC	0.0053	0.0015	0.0136	-0.7750
	NO_x	0.0069	0.0025	0.0199	-0.0077
US06	CO_2	5.0568	0.2156	4.3302	-3.1592
	CO	0.2809	0.0027	1.4295	-1.6395
	HC	0.0081	0.0016	0.0250	-0.0272
	NO_x	0.0136	0.0048	0.0136	-0.579

Table 3.7. Average emissions, average bias, maximum bias, and minimum bias for FTP bag 3 and US06.

The second-by-second model validation bias, MSE, and NMSE results in brief are:

- Tighter confidence limits (lower vehicle-to-vehicle variability in bias) are found on the decelerations and the cruise events for both normal emitters and high emitters.

- Second-by-second bias results show the majority of the seconds of the FTP Bag 3 cycle and the US06 cycle to have no significant bias for normally operating vehicles

- Normally operating vehicles do show a pattern of overprediction of emissions at the start of acceleration events followed by underprediction of emissions at the end of acceleration events. This results in a slightly low bias for the acceleration mode on average.

- Second-by-second bias results show a tendency to underpredict NOx emissions slightly on the cruise sections of both driving cycles for high emitting vehicles.

- Second-by-second model MSE on the US06 test cycle is highest on the acceleration events.

- Second-by-second model NMSE is lower for CO_2 than for CO, HC, and NO_x.

- Second-by-second model NMSE is higher on the deceleration events for CO, HC, and NO_x and higher on the acceleration events for CO_2.

3.7. HDD MODEL STRUCTURE

The HDD truck emissions model has been developed using very similar principles as other models in the CMEM program. As discussed earlier, the emissions process is broken down into different components or modules that correspond to physical phenomena associated with vehicle operation and emissions production. With the heavy-duty vehicles, similar to the light–duty vehicles, each component is then modeled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary based on several factors, such as vehicle/technology type, vehicle age, etc. Because these parameters typically correspond to physical values, many of the parameters are stated as specifications by the vehicle manufacturers, and are readily available (e.g., vehicle mass, engine size, gear ratios, etc.). Other key parameters relating to vehicle operation and emissions production must be determined from a testing program, as part of the model calibration procedure.

Using a bottom-up approach, the basic building block of our physics-based emissions model is the individual truck operating on a fine time scale (i.e., second-by-second). However, the HDD model, like the light-duty CMEM models, does not focus on modeling specific makes and models of trucks. Our primary goal is the prediction of emissions in several-second modes for average, *composite trucks* for each of the truck categories. Thus, separate sub-models for each composite truck category have been created. All of these sub-models have similar structure; however the *parameters* used to calibrate each sub-model are different.

3.7.1. General Structure of the Model

In the developed HDD emissions model, second-by-second tailpipe emissions are modeled as the product of three components: fuel rate (FR), engine-out emission indices ($g_{emission}/g_{fuel}$), and an emission after-treatment pass fraction:

$$tailpipe\ emissions = FR \bullet \left(\frac{g_{emissions}}{g_{fuel}} \right) \bullet after - treatment\ pass\ fraction$$

Here FR is fuel use rate in grams/s, engine-out emission index is grams of engine-out emissions per gram of fuel consumed, and the after-treatment pass fraction is defined as the ratio of tailpipe to engine-out emissions. To date, no HDD vehicles with after-treatment devices have been tested or are commonly available, so the after-treatment pass fraction for all of the current truck categories are being modeled as 100%*.

The complete HDD emissions model is composed of six modules, as indicated by the six square boxes in Figure 3.2: 1) engine power demand; 2) engine speed; 3) fuel-rate; 4) engine control unit; 5) engine-out emissions; and 6) after-treatment pass fraction. The model as a whole requires two groups of input (rounded boxes in Figure 3.2): A) input operating variables; and B) model parameters. The output of the model is tailpipe emissions and fuel consumption. The vehicle power demand (1) is determined based on operating variables (A) and specific vehicle parameters (B). All other modules require the input of additional vehicle parameters determined based on on-road measurements, as well as the engine power demand calculated by the model. The core of the model is the fuel rate calculation (3). It is a function of

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* It is important to note that a variety of after treatment devices can be modeled separately and integrated into this model structure without extensive retesting.

power demand (1) and engine speed (2). Engine speed is determined based on vehicle velocity, gear shift schedule and power demand.

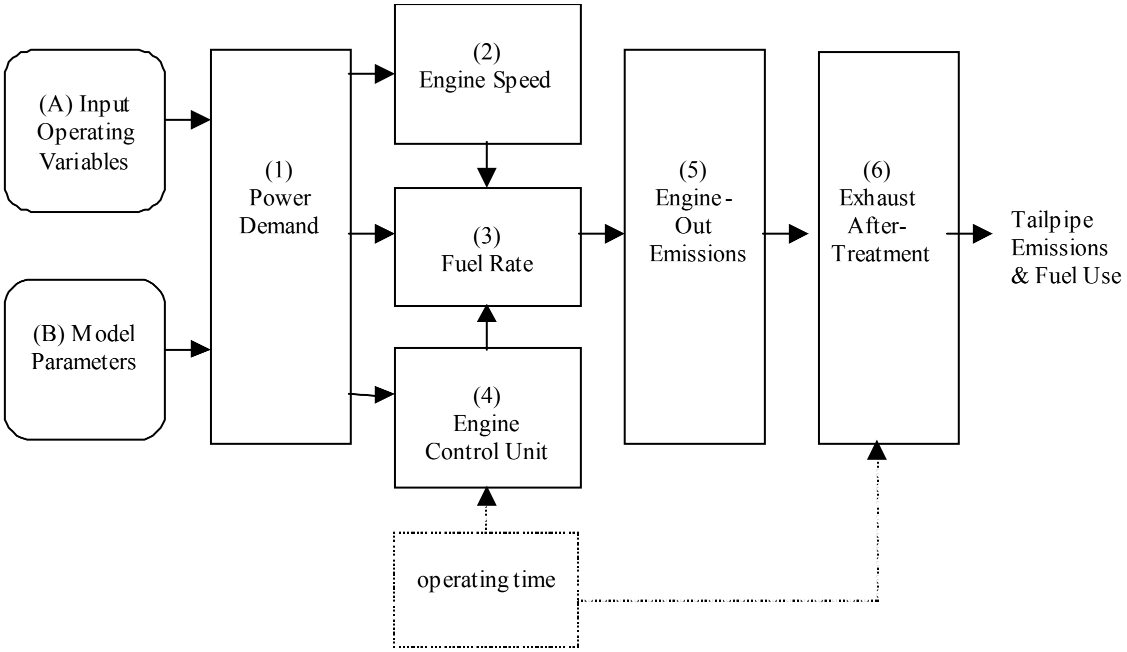


Figure 3.2. HDD Emissions Model Structure.

3.7.2. Engine Power Demand Module

The establishment of a power demand function for each truck is straightforward. The total tractive power requirements (in kW) placed on the truck (at the wheels) is given as:

$$P_{tract.} = (M \cdot a + M \cdot g \cdot sin\theta + \tfrac{1}{2} Cd \cdot A \cdot \rho \cdot v + M \cdot g \cdot Cr \cdot \cos\theta) \cdot v / 1000$$

where M is the truck mass with appropriate inertial correction for rotating and reciprocating parts (kg), v is speed (meters/second), a is acceleration (meters/second^2), g is the gravitational constant (9.81 meters/s^2), and θ is the road grade angle in degrees, Cd is the coefficient of drag, A is the frontal surface area (meters^2), ρ is the air density (kg/m^3) and Cr is the coefficient of rolling resistance. The terms in parentheses represent resistance due to acceleration, grade, wind, and rolling friction. To translate the tractive power requirement to demanded engine power requirements, the following relationship applies:

$$P = \frac{P_{tract.}}{\varepsilon} + P_{acc}$$

where P is the second-by-second engine power output in kW, ε is vehicle drivetrain efficiency, and P_{acc} is the engine power demand associated with running losses of the engine and the operation of vehicle accessories such as air conditioning usage. As the model was developed, we performed intermediate engine power validation with actual "load" values provided by the engine control unit (ECU).

3.7.3. Engine Speed Module

Engine speed is approximated in terms of vehicle speed:

$$N(t) = S \cdot \frac{R(L)}{R(L_g)} \cdot v(t)$$

where: *N(t)* = engine speed (rpm) at time *t*, *S* is the engine-speed/vehicle-speed ratio in top gear L_g (known as N/v in units rpm/mph), *R(L)* is the gear ratio in L^{th} gear, L = 1,...,Lg, and *v(t)* is the vehicle speed (mph) at time *t*. Gear ratio is selected from a given set of shift schedules. Under certain circumstances, especially for high-power events, down-shifting is required as determined by a wide-open-throttle (WOT) torque curve. The general relationship between torque and power output of the engine is:

$$Q(t) = \frac{P(t) \cdot 5252}{N(t)}$$

where *Q(t)* = engine torque in ft-lb. at time t and *P(t)* is engine power in horsepower. The engine torque at any engine speed must not exceed the WOT torque, $Q_{WOT}(t)$. The latter is based on an approximation of the manufacturer's supplied torque curve. When the calculated Q(t) is greater than $Q_{WOT}(t)$, the vehicle downshifts to the next lower gear. New values of engine speed, torque, and the WOT torque are calculated based on the equations above and a representation of the vehicle's torque curve. If necessary, this process is repeated (i.e., a second downshift is considered) to satisfy the operating conditions.

3.7.4. Fuel Rate Module

Modeling the fuel rate in any driving cycle for any vehicle has been previously developed. The basic diesel fuel consumption module is as follows:

$$FR \approx (k \cdot N \cdot V + \frac{P}{\eta})\frac{1}{43.2} \cdot (1 + b_1 \cdot (N - N_0)^2)$$

$$K = K_0 \cdot (1 + C \cdot (N - N_0))$$

$$N_0 \approx 30 \cdot \sqrt{\frac{3.0}{V}}$$

where *FR* is fuel use rate in grams/second, *P* is engine power output in kW, *K* is the engine friction factor, *N* is engine speed (revolutions per second), *V* is engine displacement (liter), and $\eta \approx 0.45$ is a measure of indicated efficiency for diesel engines. $b_1 \approx 10^{-4}$ and $C \approx 0.00125$ are coefficients; 43.2 kJ/g is the lower heating value of a typical diesel fuel.

Alternate fuel injection timing strategies are often used to improve fuel economy at the expense of NOx emissions. For modeling purposes, a fuel-use reduction factor has been introduced to account for these alternative fuel injection timing strategies:

$$FR_{off} = FR \cdot (1 - \mathrm{f}_{\mathrm{Red}})$$

where FR_{off} is the off cycle fuel rate in grams/second and f_{Red} is the fuel use reduction factor associated with off cycle fuel injection timing strategies.

3.7.5. Engine-Out Emissions Module

CO emissions are a product of incomplete combustion and are greatly dependent on the air-fuel ratios occurring during combustion. Since fuel rich combustion leads to increased CO, diesel engines, which run lean, typically have extremely low CO emissions unlike spark ignition engines. Our analysis shows that there is a linear correlation between fuel use and engine-out CO, however, it is not a particularly strong one. The following equation is used for modeling CO:

$$ECO = a_{CO} \cdot FR + r_{CO}$$

where ECO is the engine-out emission rate in g/s and a_{CO} and r_{CO} are the CO emission index coefficients.

HC emissions from diesel engines are unburned hydrocarbons resulting primarily from combustion inefficiencies. Incomplete fuel-air mixing in the combustion chamber results in portions of the combustion mixture not supporting combustion. Similar to CO, our analysis shows that there is a linear correlation between fuel use and engine-out HC:

$$EHC = a_{HC} \cdot FR + r_{HC}$$

where EHC is in g/s and a_{HC} and r_{HC} are the HC emission index coefficients.

NO_x emissions along with particulates are the diesel pollutants of primary concern. The formation of NO_x emissions in diesel engines is well understood and is dependent mainly on the presence of sufficient oxygen and high temperatures. NO_x emissions exhibit a strong linear relationship with load or fuel use. The following equation is used for basic NO_x emission modeling:

$$NO_x = a_{NO} \cdot FR + r_{NO}$$

where FR is fuel rate, a_{NO} is the NO_x emission index coefficient in grams-emission/grams-fuel, and r_{NO} is a small residual value.

NO_x emissions may be controlled by reducing in-cylinder temperatures which can be accomplished with retarded fuel injection timing at the expense of increased particulate emissions and reduced fuel economy. This is commonly referred to as the NO_x, particulate, fuel “trade-off”. For this reason fuel injection timing strategies are critical to the formation of NO_x.

It has also been noted that the fuel injection timing strategies of many existing electronic controlled HDD vehicles do not always remain consistent with those used during engine certification testing. It has been determined that under certain modes of operation, many of the HDD vehicles found in today’s vehicle fleet utilize off-cycle fuel injection timing strategies which results in higher NO_x emission rates in favor of increased fuel economy. Figure 3.3 illustrates dual NO_x/fuel emission rates as a result of off cycle fuel injection timing strategies.

These off-cycle strategies are not publicly documented and are to be eliminated in the future. Nevertheless, it is important to model this effect when dealing with the current and (short-term) future vehicle fleet. In an effort to model these off-cycle fuel injection strategies, an off cycle NO_x–fuel relationship is used

$$NO_x = a_{NOh} \cdot FR + r_{NOh}$$

where a_{NOh} is the off cycle NO_x emission index coefficient in grams emission/ grams fuel, and r_{NOh} is a small residual value associated with off cycle NO_x emissions. The determination of NO_x emission factors for use with normal injection timing strategies and off-cycle fuel injection strategies is relatively straightforward and usually result in strong least squares fits (see Figure 3.3). The difficulty lies in determining when, in a given cycle, each strategy is used. It was observed that the off-cycle timing strategies appear to have a history effect and in some cases show a moderately predictable pattern across similar cycles. For our modeling purposes, off-cycle fuel injection strategies are being characterized as a function of time and velocity in which these strategies occur after 80 seconds above 30 mph and then normal operation resumes once the vehicle speed drops below 30 mph. The off-cycle timing strategies appear to vary by manufacturer, model year, and sometimes from test cycle-to-test cycle during a single day of testing. Determining the best overall model formulation of the off-cycle strategy is therefore highly dependent upon the vehicle test fleet. Because of the difficulty in determining the best overall strategy with the current data set, a generic speed and time method was used for this initial version of the model, pending collection of more data[*].

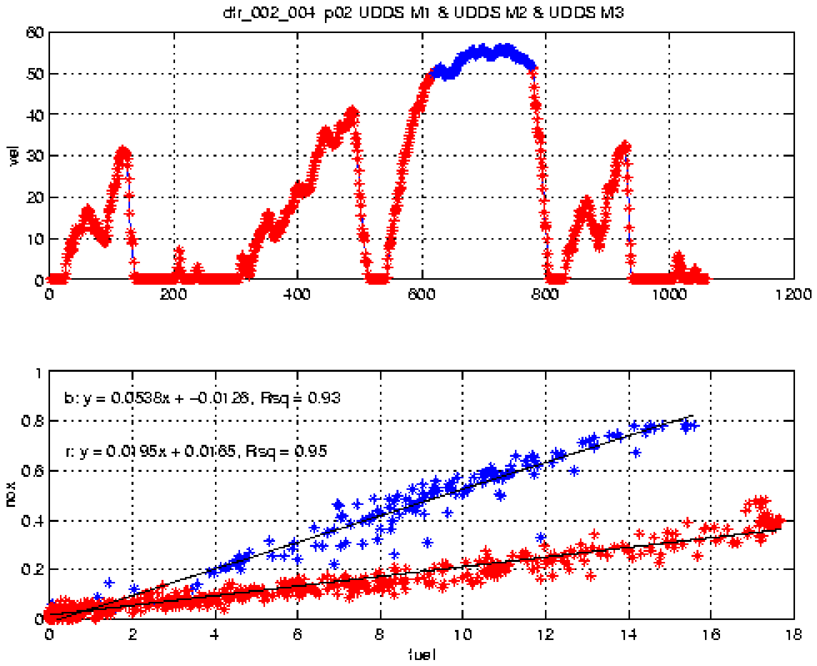


Figure 3.3. a) Velocity (mph) vs. Time (seconds) and b) NOx (grams) vs. fuel rate (grams) with corresponding symbols/colors and associated regression lines. The high-speed cruise, off-cycle blue activity has higher NOx/lower fuel compared to the on-cycle red activity.

3.7.6. Model Calibration and Vehicle Compositing Procedures

As discussed previously, separate sub-models for each truck category have been created. The sub-models all have similar structure (as described in the previous section), however they differ primarily in their

---

[*] The model strategy is not intended to represent a particular manufacturer's truck but rather give a good approximation of the fleet behavior.

parameters. Each sub-model uses three dynamic operating variables as input. These variables include second-by-second vehicle speed (from which acceleration can be derived; note that acceleration can be input as a separate input variable), grade, and accessory use (such as air conditioning). In many cases, grade and accessory use may be specified as static inputs or parameters. In addition to these operating variables, each sub-model uses a total of 31 static parameters in order to characterize the vehicle tailpipe emissions for the appropriate vehicle/technology category. As the sub-models were developed, each test vehicle was individually modeled by determining all of the parameters. Readily available parameters of the test vehicles (e.g., mass, engine displacement, etc.) have been obtained for each vehicle. Next, a set of calibration parameters was determined through estimation procedures, using the measured emissions results for each test vehicle. Depending on the specific parameter, the values are determined either: 1) directly from measurements; or 2) based on several regression equations.

Each test vehicle has been individually modeled, however, the primary modeling goal is to predict detailed emissions for each average, *composite* vehicle that represents the vehicle/technology categories. Thus, a compositing procedure has been developed to construct a composite vehicle to represent each of the different HDD vehicle/technology modeled categories. The compositing procedure is relatively straightforward. In previous CMEM work, compositing light duty vehicles involved first averaging second-by-second emission values in time across all vehicles in the category. The modeling procedure was then carried out on the averaged emission traces. This was possible since every vehicle was tested very closely following the prescribed driving cycles. For the on-road HDD testing, it was impossible to follow each target trace exactly due to wide differences in the vehicle's power/weight ratio. Therefore, the previous emission trace averaging technique does not work. Instead, each test vehicle is individually modeled, resulting in an individual vehicle parameter set. The parameter sets from all the vehicles in the category are then averaged appropriately to provide a representation of a composite vehicle. Influential factors such as emissions rate and vehicle weight have roughly symmetric distributions so that the mean is a good estimator of the central value of the distribution. For parameters such as number of gears where the mean value does not make physical sense, the mode was used.

3.8. LOW-EMITTING VEHICLE MODEL STRUCTURE

As described previously, second-by-second vehicle tailpipe emissions are modeled as the product of three components: fuel rate (FR), engine-out emission indices ($g_{emission}/g_{fuel}$), and time-dependent catalyst pass fraction (CPF):

$$\text{Tailpipe Emissions} = \mathbf{FR} \bullet (g_{emission}/g_{fuel}) \bullet \mathbf{CPF}$$

Here **FR** is fuel use rate in grams/s, engine-out emission index is grams of engine-out emissions per gram of fuel consumed, and **CPF** is the catalyst pass fraction, which is defined as the ratio of tailpipe to engine-out emissions. **CPF** usually is a function primarily of fuel/air ratio and engine-out emissions. As shown in Figure 3.4, the generalized model consists of six distinct modules that individually predict: 1) engine power; 2) engine speed; 3) air/fuel ratio; 4) fuel use; 5) engine-out emissions; and 6) catalyst pass fraction.

For each sub-model, there are a number of vehicle parameters and operating variables that are considered. The vehicle parameters used are divided into two groups: 1) parameters that are obtained from the public domain (or determined generically), and 2) parameters that need to be calibrated based on the second-by-second emission measurements. Examples of the first group include vehicle mass, engine displacement, rated engine power and torque, etc. Examples of the second group include engine friction factor, enrichment threshold and strength, catalyst pass fraction, etc.

Emission modeling of different vehicle/technology categories within this architecture requires category specific calibration of the second group of model parameters mentioned above. For each vehicle/technology category, a different model "instance" or sub-model has been created using a parameterized physical approach.

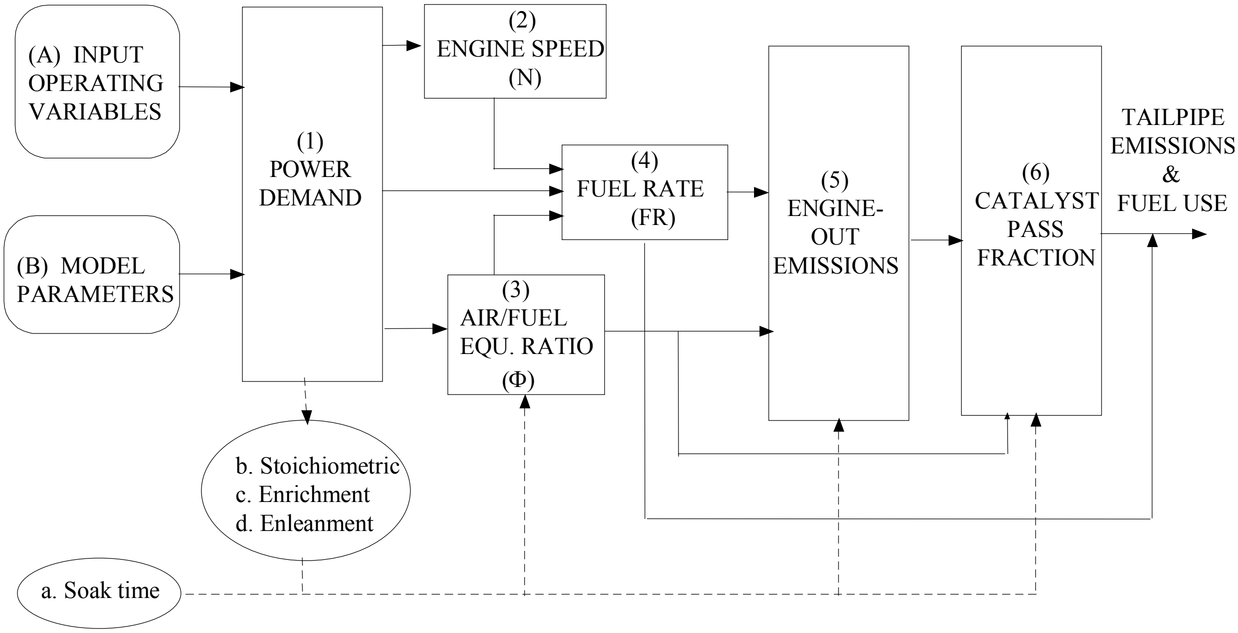


Figure 3.4. Modal emissions model architecture for low-emitting light duty vehicles.

Based on the results of this SELEV program, two new vehicle/technology categories have been added to CMEM. One of the categories corresponds to ULEV-certified vehicles, the other corresponds to SULEV and PZEV-certified vehicles. For these two vehicle/technology categories, major architectural changes were not required and modeling of these new extremely low emitting vehicle categories resulted in new sets of calibration parameters.

There are several factors that contribute to low ELEV emissions. One of the most important is catalyst performance. The most relevant catalyst characteristics, from a modeling perspective, are catalyst light-off-times and hot running catalyst efficiencies. Test data show that for extremely low emitting vehicles most of the emissions are generated during the startup period (cold- and warm-starts). For this reason, the light-off-time parameter has one of the largest impacts on total emissions. Based on measured light-off data illustrated in Figure 3.5, ELEV emission control systems will have increasingly shorter light off times. This is one of the biggest parameter changes in the CMEM LDV modeling.

In addition to shorter light-off-times, ELEV vehicles exhibit very high stabilized catalyst efficiency during hot running operation. For the ELEV CMEM modeling, catalyst efficiency parameters are significantly different when compared to Tier 0 and Tier 1 vehicles.

ELEV emission values are also a result of improvements in the control of engine operating conditions, most notably in fuel enrichment and enleanment. Enleanment is generally associated with increases in NOx and in some cases HC emissions. Enrichment results in increased CO emissions. CMEM estimates open loop or fuel-enrichment operation based on a power threshold level, which has been steadily increasing with newer vehicles. In CMEM, this power threshold level is a calibrated parameter and is significant higher for ELEVs when compared to other vehicle/technology categories. CMEM estimates when significant enleanment occurs based on a calibrated enleanment parameter and engine-out emissions. Differences have been noted in the enleanment parameters between ELEVs and other vehicle types.

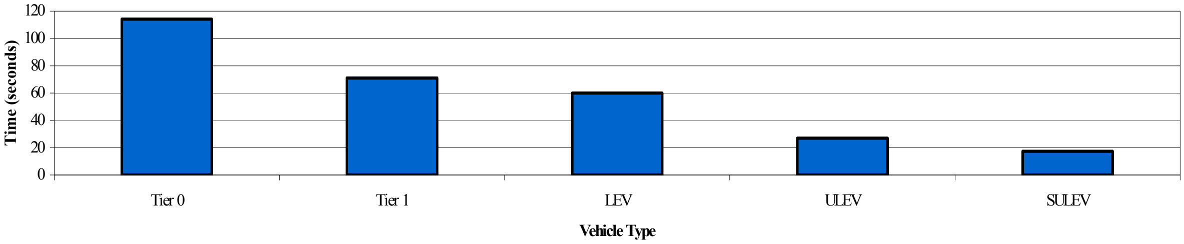


Figure 3.5. Average Time to Reach Optimum HC Catalyst Efficiency During FTP Cycle

With the exception of hydrocarbon absorbers, the major improvements in ELEV emission control technology can be represented well with the existing CMEM architecture. CMEM has sophisticated cold-start and catalyst efficiency sub-models with several parameters that can be calibrated to give quicker catalyst light off times and stabilized hot running catalyst efficiencies. Catalyst efficiency is based on a calibrated maximum catalyst efficiency which is near 100 for ELEV vehicles, cumulative fuel use used as a surrogate for catalyst temperature, and a calibrated cold start catalyst coefficient specific to each pollutant. Additionally, catalyst warm start is also modeled based on cumulative fuel use and several calibrated cold start catalyst parameters. Calibration of vehicle category parameters is automated using an optimization routine that minimizes measured and modeled differences for variations in selected parameters across selected data sets.

Hydrocarbon absorption is another means of obtaining extremely low tailpipe emissions and was clearly identified in at least one of the test vehicles. However, not all ELEV vehicles had this characteristic and therefore it was not specifically modeled. A future modeling task may be to create a sub-category of ELEV vehicles that specifically utilize hydrocarbon absorption. This phenomenon can be modeled in much the same way that unburned hydrocarbon emissions are modeled in the existing CMEM architecture.

Model validation is an essential step in the modeling process. As an example of how the modeled predictions match the measurements, Figure 3.6 shows second-by-second emissions for modeled (red) and measured (blue) for tailpipe CO_2, CO, HC and NOx emissions for a single vehicle (ULEV08). The numbers to the right of the plot from top to bottom are total measured emissions over the cycle, total modeled emissions over the cycle, and the percent difference between the two. This particular vehicle above was generally well behaved although there are a few NOx emission events that the model was unable to capture.

The validation of CMEM's SELEV categories presented in this paper is not completely independent of the calibration data. Calibration was done based on portions of the MEC and FTP cycles selected to represent specific modes of operation. One set of parameters for each vehicle category was optimized to best predict emissions for the various driving cycle portions. Results for both cycles in their entirety were then calculated and combined as a measure of validity.

From a larger perspective, Figure 3.7 shows composite comparison results for all the vehicles by technology category. These data include both the dynamometer test (FTP and MEC01 drive cycles) as well as a portion of the on-road data. This figure shows that there are some discrepancies between modeled and measured ELEV emissions, particularly for NOx and CO. However, these differences are no greater than +/- 5% for ULEVs and +/- 15% for SULEVs. A likely cause for the SULEV discrepancy is the fact that these vehicle's cumulative emissions across the cycles are so small that even small fluctuations in emissions predictions can result in large errors.

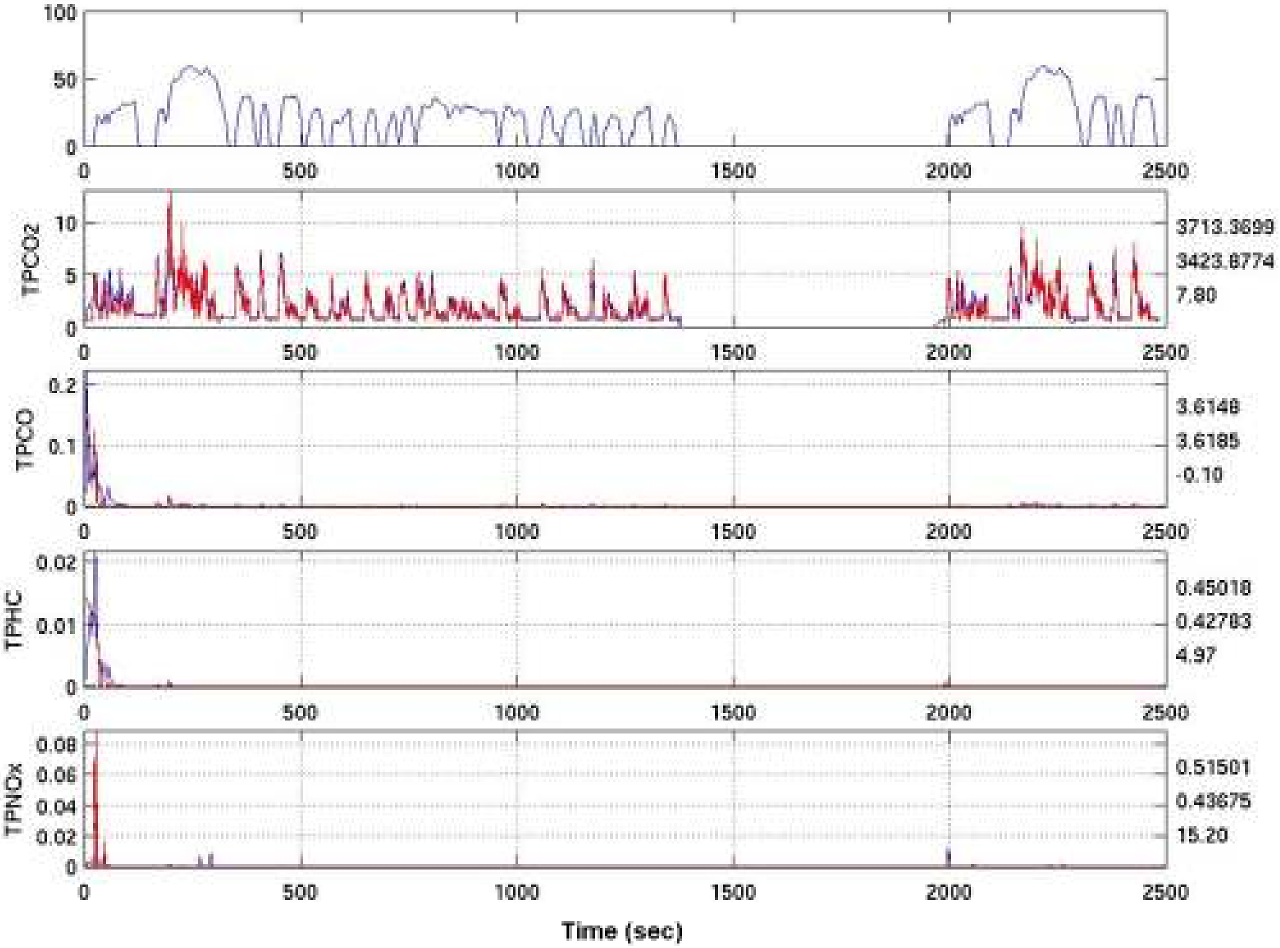


Figure 3.6. Second-by-second comparison of measured (blue) and modeled (red) emissions for vehicle ULEV08 operating over the FTP driving cycle.

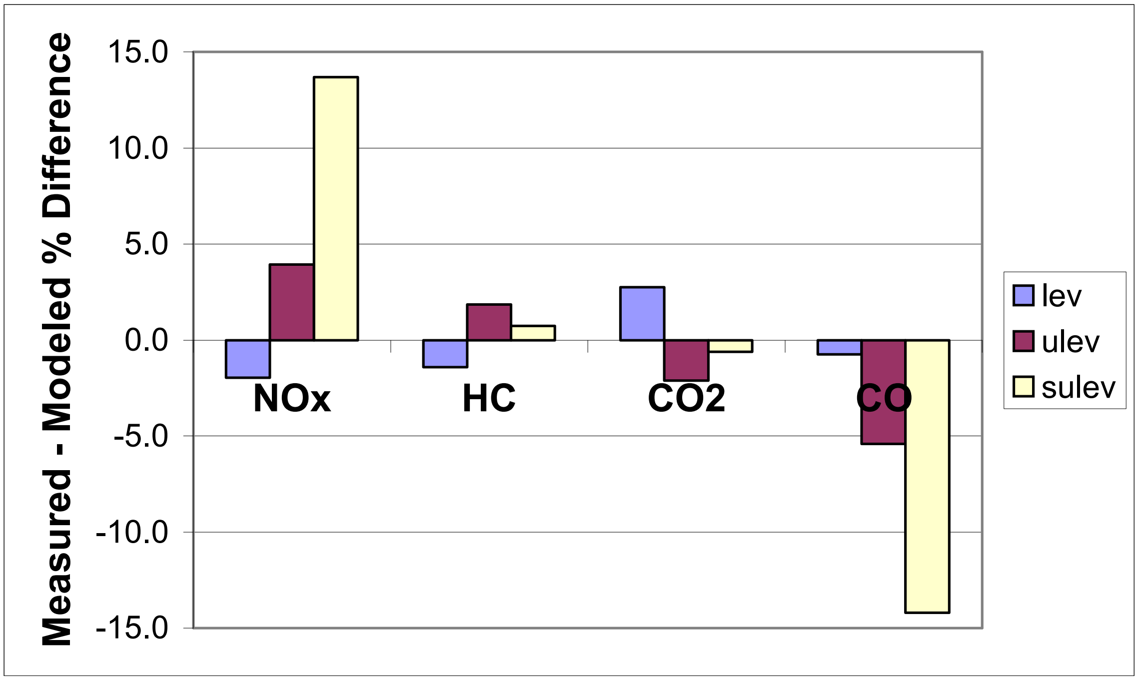


Figure 3.7. Composite comparison results between measured and modeled ELEVs.

3.9. CURRENT LIST OF VEHICLE/TECHNOLOGY CATEGORIES

The current list of CMEM vehicle/technology categories is given in Table 3.8.

Category #	Vehicle Technology Category
	Normal Emitting Cars
1	No Catalyst
2	2-way Catalyst
3	3-way Catalyst, Carbureted
4	3-way Catalyst, FI, >50K miles, low power/weight
5	3-way Catalyst, FI, >50K miles, high power/weight
6	3-way Catalyst, FI, <50K miles, low power/weight
7	3-way Catalyst, FI, <50K miles, high power/weight
8	Tier 1, >50K miles, low power/weight
9	Tier 1, >50K miles, high power/weight
10	Tier 1, <50K miles, low power/weight
11	Tier 1, <50K miles, high power/weight
24	Tier 1, >100K miles
50	LEV PC
51	ULEV PC
52	PZEV
	Normal Emitting Trucks
12	Pre-1979 (<=8500 GVW)
13	1979 to 1983 (<=8500 GVW)
14	1984 to 1987 (<=8500 GVW)
15	1988 to 1993, <=3750 LVW
16	1988 to 1993, >3750 LVW
17	Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)
18	Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)
25	Gasoline-powered, LDT (> 8500 GVW)
40	Diesel-powered, LDT (> 8500 GVW)
41	Pre 1991, 2-stroke HDDT
42	Pre 1991, 4-stroke HDDT
43	1991 to 1993, 4-stroke, Mech. FI HDDT
44	1991 to 1993, 4-stroke, Elect. FI HDDT
45	1994 to 1997, 4-stroke, Elect. FI HDDT
46	1998, 4-stroke, Elect. FI HDDT
47	1999 to 2002, 4-stroke, Elect. FI HDDT
	High Emitting Light Duty Vehicles
19	Runs lean
20	Runs rich
21	Misfire
22	Bad catalyst
23	Runs very rich

Figure 3.8. CMEM Vehicle/Technology Categories.

4 Running CMEM

CMEM was designed to be a flexible modeling tool that can be used for many different applications. In this chapter we first describe how to run the fundamental command-line executable code for CMEM. Later in the chapter, we describe a more friendly, graphical user interface for CMEM, implemented using the Java programming language. In the next chapter, we describe the integration issues between transportation and emission, as well as other alternative forms of the model.

4.1 COMMAND-LINE INTERFACE

During development, the comprehensive modal emissions model was carried out in a research environment, using MATLAB modeling/analysis tools [Mathworks, 1999]. In order to use the model outside the development environment, executable code was created from the finalized source code. For this executable code, a command-line interface (CLI) for the user was developed. CMEM's Light Duty Vehicle (LDV) model and Heavy Duty Diesel (HDD) model exist in two separate CLI models. The CLI executables for both have been developed for the PC environment (running from a DOS command line) and the UNIX environment (compiled for Linux). Running from the command line, the executables read in specific input files and produces specific output files, as described in detail below.

The CMEM command-line executables takes on two forms:

Core Model—the core executable code is available for both the CMEM LDV and HDD code. It allows the user to obtain emission data for a single specified vehicle category and a given vehicle activity file. As illustrated in Figure 4.1, the core model uses two input files and outputs two emission files. One input file is used to control the parameters of the model, the other input is a second-by-second vehicle activity file. One resulting output file provides tailpipe emissions and fuel consumption on a second-by-second basis. The other output file is a vehicle summary file. The control input file specifies the vehicle category to be modeled and the soak time prior to the model run. Default parameters to the model can be overridden with specific entries in the control input file. The vehicle activity file consists of column-oriented data vectors. The minimum vectors that are required are time (in seconds) and vehicle velocity (in MPH or KPH depending on control file). Optional data vectors in the vehicle activity input file include acceleration (if directly measured and not derived from velocity differentiation), grade, and secondary load activity (such as AC use). The emissions output file also consists of column-oriented data vectors, including time, velocity, HC, CO, NOx, and fuel use.

Batch Model—the batch executable code is available for the CMEM LDV model only. It allows the user to obtain emission data for multiple vehicles (from a variety of categories) with different trajectories specified in the vehicle activity file. As illustrated in Figure 4.6, the batch model requires three input files: a parameter control file, a definition file, and a time-ordered vehicle activity file. Three output files are available: a second-by-second, time-ordered vehicle emissions file, a vehicle integrated emissions file and a model run file. The control file is similar to that described above, however it also includes a matrix correlating vehicle ID (*vehid* of the activity file) and the vehicle type (*vehtyp*). The control file also specifies whether a soak time file exists. An optional soak time file specifies how long each vehicle has been stopped prior to the model application. The vehicle activity file is similar to that described above, except it has an additional column vector specifying particular vehicles (*vehid*). Several transportation models output vehicle trajectories in this format. The second-by-second time-ordered vehicle emissions file is similar to that used in the core model, except again it has an added column specifying vehicle ID. The vehicle integrated emissions file provides the integrated emission results of the velocity patterns for each vehicle. The model run file contains information for the current run such as the names of the files associated with that run, the parameter values used for each vehicle ID for that run, and any errors or comments generated from processing the control, activity and definition files for that run.

Both forms of the executable code are written in C++, and dynamically allocate memory. The core form of the model has been tested with up to 50,000 seconds of trajectory data on a SGI workstation. The batch form of the model has been tested up to 100 vehicles, each having approximately 25,000 seconds of trajectory data. The maximum number of seconds and vehicles that can be evaluated by the model is system specific and will depend on available memory of the workstation being used.

In addition to the executable code, demo input and output files for the CMEM LDV and HDD model are provided. These files are named `sample-ctr` (sample core input control file), `sample-act` (sample core input vehicle activity file), `sample-ctb` (sample batch input control file), `sample-atb` (sample batch input vehicle activity file), and `sample-def` (sample batch input definition file). The first two files mentioned are read by the core form of the model and the batch form of the model reads the latter three files. To execute the model using these files as input, simply make sure the executable code (`cmemCore or hddCore`) and sample files are in the same directory, and type:

```
“cmemCore sample” or “hddCore sample”
```

from the command line to execute the core form of the models. Note that on a Windows machine, the executables have .exe extensions (e.g. cmemCore.exe or hddCore.exe), but .exe extensions are understood and typically do not have to be typed when executing the commands.

For the batch form, again make sure the executable code (`cmemBatch`) and sample files are in the same directory, and type:

```
cmemBatch sample
```

from the command line. Demo results for the core form of the model are presented in the files `sample-sbs` (sample second-by-second emissions output) and `sample-sum` (sample summary output). Demo results for the batch form of the model are presented in the files `sample-ssb` (sample second-by-second batch emissions output), `sample-smb` (sample batch summary output) and `sample-rnb` (sample model run file).

The various forms of the command line-model, how to run them, and appropriate input and output files are described in further detail in the following sections.

4.1.1 LDV Core Model

Again, the core model predicts emission data for a vehicle from a single vehicle category and a given vehicle activity file (i.e., the speed trajectory of the vehicle). The core model executable name is `cmemCore.exe`. The executable code only requires command line arguments for the input file names. As illustrated in Figure 4.1, the core model uses two input files:

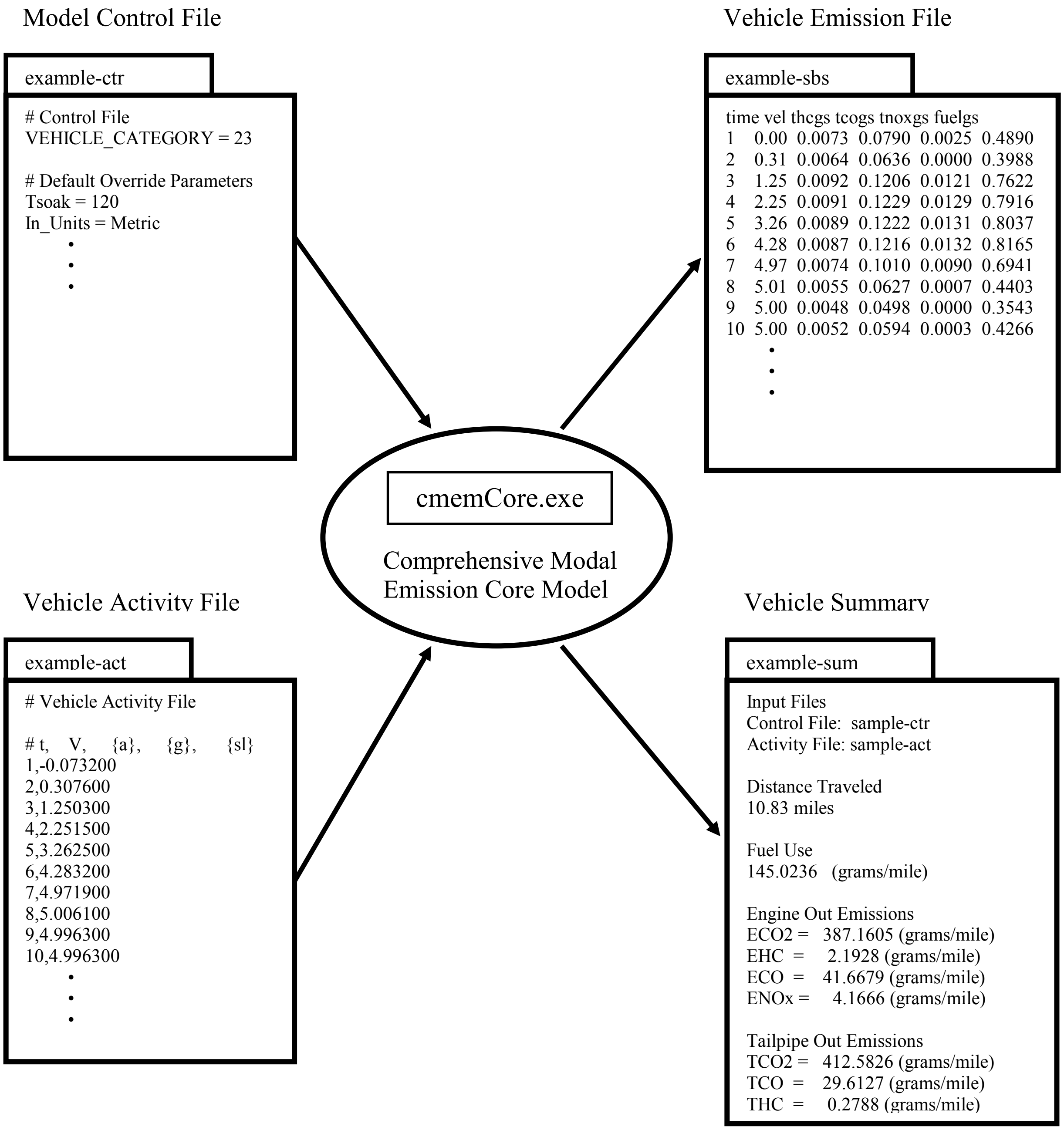
- control file
- vehicle activity file

and produces two output files:

- vehicle emission file

- summary file

File names are passed to the core model as command line arguments in one of two ways. The first method is to list the input file names on the command line after the executable name, starting with the control file name first followed by the activity file name. For the executable file `cmemCore.exe`, the control file `sample-ctr` and the activity file `sample-act`, the core model can be run by typing the following statement:



example-ctr

```
# Control File
VEHICLE_CATEGORY = 23

# Default Override Parameters
Tsoak = 120
In_Units = Metric
      •
      •
      •
```

example-sbs

```
time vel thcgs tcogs tnoxgs fuelgs
1    0.00  0.0073  0.0790  0.0025  0.4890
2    0.31  0.0064  0.0636  0.0000  0.3988
3    1.25  0.0092  0.1206  0.0121  0.7622
4    2.25  0.0091  0.1229  0.0129  0.7916
5    3.26  0.0089  0.1222  0.0131  0.8037
6    4.28  0.0087  0.1216  0.0132  0.8165
7    4.97  0.0074  0.1010  0.0090  0.6941
8    5.01  0.0055  0.0627  0.0007  0.4403
9    5.00  0.0048  0.0498  0.0000  0.3543
10   5.00  0.0052  0.0594  0.0003  0.4266
        •
        •
        •
```

example-act

```
# Vehicle Activity File

# t,    V,    {a},    {g},    {sl}
1,-0.073200
2,0.307600
3,1.250300
4,2.251500
5,3.262500
6,4.283200
7,4.971900
8,5.006100
9,4.996300
10,4.996300
      •
      •
      •
```

example-sum

```
Input Files
Control File:  sample-ctr
Activity File: sample-act

Distance Traveled
10.83 miles

Fuel Use
145.0236   (grams/mile)

Engine Out Emissions
ECO2 =   387.1605 (grams/mile)
EHC  =     2.1928 (grams/mile)
ECO  =    41.6679 (grams/mile)
ENOx =     4.1666 (grams/mile)

Tailpipe Out Emissions
TCO2 =   412.5826 (grams/mile)
TCO  =    29.6127 (grams/mile)
THC  =     0.2788 (grams/mile)
```

Figure 4.1. Core form of the modal emission model executable.

```
cmemCore sample-ctr sample-act
```

The output files generated from this run will use the base name from the control file with a `-sbs` extension for the core model vehicle emission file and a `-sum` extension for the core model summary file.

The second more abbreviated method of running the core model requires that the control file and the activity file both have the same base name and have a `-ctr` and `-act` extension respectively. In this case, the only command line argument required is the common base name for both files. For the executable `cmemCore.exe`, the control file `example-ctr` and the activity file `example-act`, the core model can be run by typing the following statement:

```
cmemCore example
```

With this method, the common base name is also used as the base name for the output files. In this case, the core model vehicle emission file would be named `example-sbs` and the core model summary file would be named `example-sum`.

Core Model Control File

The control file controls various running parameters of the model and allows a user to override the default parameters of the model. The running parameters specify the format of the input and output data. The running parameters and specific vehicle parameters are listed in Table 4.1.

The first three control parameters specify file input and output formats. They are described as follows.

`IN_UNITS:`	Specifies which units input data are given in. This value may be `METRIC` or `ENGLISH`. The default `IN_UNITS` value is `ENGLISH`. All input values are converted to `ENGLISH` units and all model calculations are carried out in `ENGLISH` units.
`OUT_UNITS:`	Specifies which units output data will be reported in. This value may be `METRIC` or `ENGLISH`. The default `OUT_UNITS` value is `ENGLISH`. All results are calculated in `ENGLISH` units and converted if necessary.
`CO2_OUT:`	Adds tailpipe CO_2 data to the second-by-second output file in column format. This value may be `on` or `off`. The default value for `CO2_OUT` is `off`.

The next four parameters define the vehicle category, the vehicle soak time, the default secondary load, and specific humidity:

`VEHICLE_CATEGORY:`	Defines the vehicle category. The value can be from 1 to 69. These category numbers correspond to the numbers listed in Table 3.1. Note that categories 26 – 39 have been reserved for future light duty gasoline vehicle technologies. Also, categories 41 – 59 have been reserved for future diesel vehicle technologies. Category numbers 60 – 69 are "blank" categories that can be utilized by the user for any purpose. These blank (and reserved) category numbers have no default parameter values, they must be defined by the user. The default value for `VEHICLE_CATEGORY` is set to `5` which represents a Tier 0, high mileage, high

power-to-weight car. (category 5 was chosen as the default since this type of vehicle is one of the most common in California in 1998.)

`Tsoak:` Defines a vehicle's soak time in minutes. This value can range from zero to 1440 where zero represents hot stabilized operation and 1440 (24 hours) represents cold start as defined by the FTP. Any value greater than 1440 gives the same results as the 1440 input value. The default `Tsoak` value is zero.

Parameter Name	Symbol from Table 3.2	Accepted Value	Default Value	Parameter Description
IN_UNITS		METRIC, ENGLISH	ENGLISH	Specifies which units input data are given in.
OUT_UNITS		METRIC, ENGLISH	ENGLISH	Specifies which units output data will be reported in.
CO2_OUT		on, off	off	Adds tailpipe CO_2 data to the second-by-second output file.
VEHICLE_CATEGORY		1 – 69	5	Defines vehicle category.
Tsoak	Tsoak	0-1440	0	Defines a vehicle's soak time in minutes.
Sload	P_{acc}	Positive Real Number	Category Dependent	Secondary load such as AC use in hp.
Specific Humidity (see [Manos etal., 1972])	SH	Positive Real Number	75	Specific humidity in grains of H20/lb. of dry air.
Masslb	M	Positive Real Number	Category Dependent	Vehicle mass in lbs.
Masskg	M	Positive Real Number	Category Dependent	Vehicle mass in kg.
Ed	V	Positive Real Number	Category Dependent	Engine displacement in liters.
Trlhp	Trlhp	Positive Real Number	Category Dependent	Coast down power in hp.
S	S	Positive Real Number	Category Dependent	Engine speed / Vehicle Speed in rpm/mph.
Nm	N_m	Positive Real Number	Category Dependent	Engine speed in rpm @ maximum torque.
Qm	Q_m	Positive Real Number	Category Dependent	Maximum torque in ft.lb.
Zmax	P_{max}	Positive Real Number	Category Dependent	Maximum power in hp.
Np	N_p	Positive Real Number	Category Dependent	Engine speed in rpm @ maximum power.
Idle	Idle	Positive Real Number	Category Dependent	Idle speed in rpm.
ng	N_g	3, 4, 5	Category Dependent	Number of gears.

Table 4.1. Recognized core model control file parameters, their description, accepted values, and default values.

`Sload:` Overwrites a vehicle's secondary load such as AC use in horsepower. This value is predetermined specifically for each of the vehicle categories based on measured AC emissions. The model will refer to this number if the secondary load column in the activity file is set to 1 (described in the next section). This value can be overwritten by defining the `Sload` value in the control file. `Sload` is typically in the range of 1 to 10 hp, but the model will accept greater positive real numbers.

`SH:` The majority of the testing was carried out under test conditions spelled out in the Code of Federal Regulations (CFR), i.e., 75 degrees F. and 40% humidity (75 grains of water per pound of dry air). Because NOx emissions are greatly effected by humidity, a correction factor has been introduced that is a function of the specific humidity. The default specific humidity is 75 grains of water per pound of dry air; by entering a different specific humidity here, the NOx emissions are corrected, based on equations spelled out in [Manos et al., 1972].

The following 11 parameters are specific vehicle parameters that a user can set to override the default model parameters that were determined for the composite vehicles representing each vehicle/technology category. It is highly recommended that the user does not change these parameters from their default values unless he/she understands the context for the specific parameter changes.

`Masslb:` Overwrites a vehicle's mass in lbs. A vehicle mass value is derived for each vehicle category based on averaged weight for vehicles in that category. This value is automatically incorporated in the model run for the vehicle category being used. The mass parameter is a readily available parameter and can be overwritten by defining `Masslb` in the control file. Defining the `Masslb` parameter in lbs. is equivalent to defining the `Masskg` parameter in kg. (see `Masskg` parameter below). In instances where both the `Masslb` and the `Masskg` parameter are defined, or where either of these parameters are defined multiple times, the last mass definition will be used for the model run.

`Masskg:` Overwrites a vehicle's mass in kilograms. This parameter is a variation of the `Masslb` parameter defined above (see `Masslb`).

`Ed:` Overwrites a vehicle's engine displacement in liters. The `Ed` parameter is determined for each vehicle category based on average engine displacements for that category and is automatically incorporated in the model run for the vehicle category being used. This is a readily available parameter and can be overwritten by defining `Ed` in the control file. The model will accept positive real numbers for the `Ed` value.

`Trlhp:` Overwrites a vehicle's coast down power in horsepower. The `Trlhp` parameter is determined for each vehicle category based on the average `Trlhp` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. An experienced user may choose to overwrite this value by defining `Trlhp` in the control file. `Trlhp` usually falls in the range of 5 to 30, but the model will accept positive real numbers outside of this range.

`S:` Overwrites a vehicle's engine speed over vehicle speed ratio in rpm/mph. The `S` parameter is determined for each vehicle category based on the average `S` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. An experienced user may choose to overwrite this value by defining `S` in the control file. The model will accept any positive real numbers for `S` values.

`Nm:` Overwrites a vehicles engine speed in rpm at maximum torque value. The `Nm` parameter is determined for each vehicle category based on the average `Nm` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. An experienced user may choose to overwrite this value by defining `Nm` in the control file. The model will accept any positive real numbers for `Nm` values.

`Qm`: Overwrites a vehicle's maximum torque value in ft.lb. The `Qm` parameter is determined for each vehicle category based on the average `Qm` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. An experienced user may choose to overwrite this value by defining `Qm` in the control file. The model will accept any positive real numbers for `Qm` values.

`Zmax`: Overwrites a vehicle's maximum power value in horsepower. The `Zmax` parameter is determined for each vehicle category based on the average `Zmax` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. This parameter is readily available and can be overwritten by defining the `Zmax` parameter in the control file. `Zmax` typically ranges between 70 to 300 hp. The model will accept any positive real numbers for `Zmax` values.

`Np`: Overwrites a vehicle's engine speed in rpm at maximum power value. The `Np` parameter is determined for each vehicle category based on the average `Np` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. An experienced user may choose to overwrite this value by defining `Np` in the control file. The model will accept any positive real numbers for `Np` values.

`Idle`: Overwrites a vehicle's idle speed value in rpm. The `Idle` parameter is determined for each vehicle category based on the average `Idle` values for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. This parameter is readily available and can be overwritten by defining the `Idle` parameter in the control file. `Idle` values typically ranges between 700 and 1200 rpm, but the model will accept any positive real numbers for this value.

`ng`: Overwrites a vehicle's number of gears value. The `ng` parameter is determined for each vehicle category based on the average number of gears rounded to the nearest integer for vehicles in that category and is automatically incorporated in the model run for the vehicle category being used. This is a readily available parameter and can be overwritten by defining `ng` in the control file. `ng` values are typically either three, four or five which are the only values the model will accept for `ng`.

In addition to the specific vehicle parameters, it is also possible (although not recommended) to overwrite the calibrated parameters of each category. The calibrated parameters are defined in Table 3.2, and listed again in Table 4.2. An example calibrated parameter that one might modify is Pscale:

`Pscale`: Overwrites a vehicle's specific power threshold scaling factor. The `Pscale` parameter is calibrated specifically for each vehicle category and is automatically incorporated in the model run for the vehicle category being used. An experienced user may choose to overwrite this calibrated value by defining

`Pscale` in the control file. `Pscale` usually falls in the range of 0.1 to 2, but the model will accept greater positive real numbers.

Entries in the control file must be written in the following format:

```
ParameterName = ParameterValue
```

where `ParameterName` is a recognized parameter and `ParameterValue` is an accepted alphanumeric value for `ParameterName` as listed in Table 4.2. There must be at least one space following the variable `ParameterName` and the equal sign. Entries in the control file may appear in any order and may or may not end with a comma, semi-colon or colon. Control files may be commented using the pound symbol in the beginning of a line to declare that line as a comment line. Empty lines in the control file are not interpreted. A portion of a control file is given in Figure 4.2 as an example.

```
# Sample Control File for core
# form of the model.

VEHICLE_CATEGORY = 4
IN_UNITS         = ENGLISH
OUT_UNITS        = ENGLISH
Tsoak            = 3;
# Override Parameters
Masslb           = 3000
Pscale           = 1.2
Ed               = 5.2
Trlhp            = 11.2
Zmax             = 150
Idle             = 800
ng               = 5
```

Figure 4.2. Example control file for core model.

Parameter name	Symbol from Table 3.2	Definition
`Ed`	V	engine displacement in liters
`Masslb`	M	vehicle mass in lbs. (or kg)
`Trlhp`	Trlhp	coastdown power in hp
`S`	S	eng spd./veh spd. in rpm/mph
`Qm`	Q_m	max torque in ft. lbs.
`Nm`	N_m	eng spd. in rpm @ Q_m
`Zmax`	P_{max}	max power in hp
`Np`	Np	eng spd. in rpm @ P_{max}
`Idle`	Idle	idle speed of engine in RPM
`Ng`	N_g	number of gears
`K_0`	K_0	eng friction factor in kJ/(lt. rev)
`Edt1`	ε_1	drivetrain efficiency coefficient
`Edt3`	ε_3	drivetrain efficiency coefficient
`C0`	C0	CO enrichment coefficient
`aCO`	a_{CO}	engine-out CO index coefficient
`aHC`	a_{HC}	engine-out HC index coefficient
`rHC`	r_{HC}	engine-out HC residual value
`aNO1`	a_{NO1}	NOx stoichiometric index 1
`aNO2`	a_{NO2}	NOx stoichiometric index 2
`FRNO1`	FR_{NO1}	NOx fuel rate threshold 1
`FRNO2`	FR_{NO2}	NOx fuel rate threshold 2
`maxhc`	hc_{max}	max HC_{lean} rate in g/s
`hc_jk`	hc_{trans}	trans HC_{lean} rate in g/SP
`r_R`	r_R	HC_{lean} release rate in 1/s
`lam_m`	ϕ_{min}	lean fuel/air equ. ratio
`spd_th`	δSP_{th}	HC_{lean} threshold value
`ro2`	r_{O2}	ratio of O2 and EHC
`Csoak_co`	C_{soak_co}	soak time engine coef. for CO
`Csoak_hc`	C_{soak_hc}	soak time engine coef. for HC
`Csoak_no`	C_{soak_no}	soak time engine coef. for NOx
`Bcat_co`	α_{CO}	soak time catalyst coef. for CO
`Bcat_hc`	α_{HC}	soak time catalyst coef. for HC
`Bcat_no`	α_{NO}	soak time catalyst coef. for NOx
`COB1`	β_{CO}	cold start catalyst coefficients for CO
`HCB1`	β_{HC}	cold start catalyst coefficients for HC
`NOB1`	β_{NO}	cold start catalyst coefficients for NOx
`Tlamb`	T_{cl}	surrogate temp reach stoich
`lam_cold`	ϕ_{cold}	cold F/A equivalence ratio
`csHC`	CS_{HC}	cold engine-out HC multiplier
`csNO`	CS_{NO}	cold engine-out NOx multiplier
`MAXCO`	Γ_{CO}	hot max CO catalyst coefficient
`MAXHC`	Γ_{HC}	hot max HC catalyst coefficient
`MAXNO`	Γ_{NO}	hot max NOx catalyst coefficient
`bCO`	b_{CO}	hot catalyst CO coefficient
`cCO`	c_{CO}	hot catalyst CO coefficient
`bHC`	b_{HC}	hot catalyst HC coefficient
`cHC`	c_{HC}	hot catalyst HC coefficient
`bNO`	b_{NO}	hot catalyst NOx coefficient
`cNO`	C_{NO}	hot catalyst NOx coefficient
`id`	Id	NOx catalyst tip-in coefficient
`Lamb_0`	ϕ_0	max fuel/air equivalence ratio
`Pscale`	P_{scale}	specific power threshold factor

Table 4.2. Parameter name, symbol from Table 3.2, and parameter definition.

Core Model Activity File

The activity file defines a vehicle's second-by-second velocity/acceleration trajectory and optionally a vehicle's second-by-second grade and secondary load (such as AC use). This file consists of column-oriented and comma delimited vectors and must contain at least two columns: time (in seconds) and velocity (in mph or kph depending on the units specified in the control file). Optional data vectors in the activity file include acceleration (if directly measured and not obtained from velocity differentiation), road grade angle (in degrees), and a secondary load flag (this value is 1 for on and 0 for off). The secondary load value is predefined for each vehicle category and may be overwritten in the control file (see Table 4.1). Optional columns that are left empty must be represented with commas if subsequent columns are to be defined. A portion of a vehicle activity file is presented in Figure 4.3 as an example.

Core Model Vehicle Emission File

The model outputs second-by-second emission and fuel data in column format in this file. This file is presented without a header line so that it may be incorporated more easily into some database programs, spreadsheet programs and other programs such as MATLAB. The default output data is time, velocity, HC, CO, NO_x and fuel use. Another second-by-second parameter, which may also be selected for output via the control file, is CO_2. This is done by setting the control flag for CO_2 (`CO2_OUT`) in the control file to `on` (Table 4.1). The second-by-second emission file name is determined using the base name of the control file with a `-sbs` extension. For the control file name `sample-ctr`, the vehicle emission file name would be `sample-sbs`. An example of output data from a vehicle emission file is presented in Figure 4.4.

Core Model Summary File

The summary file presents summarized second-by-second data. The units used in the summary file are set in the control file via the `UNITS_OUT` flag (see Table 4.1). Data included in the summary file are total distance traveled, total mass of tailpipe emissions per unit distance (grams/mile) including tailpipe CO_2 and mass or volume of fuel used per unit distance.

The summary file also logs any messages that the model may generate. The model generates messages reports when parameters in the control file are not recognized or when problems with the model execution such as file reading or writing errors occur. An example of a core model summary file is presented in Figure 4.5.

```
# Sample activity file
# CMEM version 2.00
# time, vel, acc, grade, sload
1, 0.024400
2, 0.024400
3, 0.024400
4, 0.024400
5, 0.024400
6, 0.024400
7, 0.024400
8, 0.024400
9, 0.024400
10, 0.024400
11, 0.024400
12, 0.024400
13, 0.024400
14, 0.024400
15, 0.024400
16, 0.024400
17, 0.024400
18, 0.024400
19, 0.024400
20, 0.371100
21, 2.393100
22, 4.942600
23, 8.122100
24, 10.925500
25, 13.113500
26, 15.189200
27, 16.849800
28, 17.807000
29, 19.267300
30, 21.030500
31, 21.875400
32, 22.129400
33, 22.251500
34, 22.041500
35, 21.421200
36, 20.805800
37, 20.063400
38, 17.899800
39, 15.770400
40, 14.783800
41, 14.656800
42, 15.638500
43, 16.654400
44, 17.479800
45, 18.647100
46, 20.190400
47, 21.782600
48, 22.798500
49, 22.901000
50, 22.754500
```

Figure 4.3. Example vehicle activity file for the core form of the model.

```
       1   0.00     0.07   0.11   0.01   0.58
       2   0.00     0.07   0.11   0.01   0.58
       3   0.00     0.07   0.11   0.01   0.58
       4   0.00     0.07   0.11   0.01   0.58
       5   0.00     0.07   0.11   0.01   0.58
       6   0.00     0.06   0.11   0.01   0.58
       7   0.00     0.06   0.11   0.01   0.58
       8   0.00     0.06   0.11   0.01   0.58
       9   0.00     0.06   0.11   0.01   0.58
      10   0.00     0.06   0.11   0.01   0.58
      11   0.00     0.06   0.11   0.01   0.58
      12   0.00     0.06   0.10   0.01   0.58
      13   0.00     0.06   0.10   0.01   0.58
      14   0.00     0.06   0.10   0.01   0.58
      15   0.00     0.06   0.10   0.01   0.58
      16   0.00     0.06   0.10   0.01   0.58
      17   0.00     0.06   0.10   0.01   0.58
      18   0.00     0.06   0.10   0.01   0.58
      19   0.00     0.05   0.10   0.01   0.58
      20   0.00     0.05   0.10   0.01   0.58
      21   0.37     0.08   0.14   0.02   0.83
      22   2.39     0.13   0.27   0.05   1.29
      23   4.94     0.14   0.31   0.06   1.48
      24   8.12     0.12   0.27   0.05   1.60
      25  10.93     0.12   0.29   0.05   1.74
      26  13.11     0.12   0.32   0.05   1.97
      27  15.19     0.09   0.24   0.03   1.48
      28  16.85     0.07   0.21   0.03   1.36
      29  17.81     0.08   0.25   0.03   1.61
      30  19.27     0.08   0.28   0.04   1.83
      31  21.03     0.06   0.24   0.03   1.64
      32  21.88     0.05   0.21   0.02   1.47
      33  22.13     0.04   0.20   0.02   1.44
      34  22.25     0.04   0.18   0.02   1.32
      35  22.04     0.02   0.08   0.01   0.57
      36  21.42     0.02   0.08   0.01   0.57
      37  20.81     0.02   0.08   0.01   0.57
      38  20.06     0.01   0.08   0.01   0.57
      39  17.90     0.02   0.08   0.01   0.57
      40  15.77     0.01   0.08   0.01   0.57
      41  14.78     0.03   0.19   0.02   1.45
      42  14.66     0.03   0.23   0.02   1.80
      43  15.64     0.02   0.16   0.01   1.29
      44  16.65     0.02   0.16   0.01   1.30
      45  17.48     0.02   0.17   0.02   1.47
      46  18.65     0.02   0.19   0.02   1.69
      47  20.19     0.02   0.20   0.02   1.84
      48  21.78     0.02   0.19   0.01   1.75
      49  22.80     0.01   0.15   0.01   1.48
      50  22.90     0.01   0.14   0.01   1.38
```

Figure 4.4. Example vehicle emission file for the core form of the model.

```
*****************************************************************************
*                                                                             *
*            CCCCCCC    MMM      MMM   EEEEEEEEEE   MMM      MMM              *
*           CCCCCCCCC   MMMM    MMMM   EEEEEEEEEE   MMMM    MMMM              *
*          CCC     CC   MMMMM  MMMMM   EEE          MMMMM  MMMMM              *
*          CCC          MMMMMMMMMMMM   EEEEEEEEEE   MMMMMMMMMMMM              *
*          CCC          MMM MMMM MMM   EEEEEEEEEE   MMM MMMM MMM              *
*          CCC     CC   MMM  MM  MMM   EEE          MMM  MM  MMM              *
*           CCCCCCCCC   MMM      MMM   EEEEEEEEEE   MMM      MMM              *
*            CCCCCCC    MMM      MMM   EEEEEEEEEE   MMM      MMM              *
*                                                                             *
*                   Comprehensive Modal Emissions Model                       *
*                                                                             *
*                       Version 2.02   October 2001                           *
*                                                                             *
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*                                                                             *
*****************************************************************************
Input Files
Control File:  sample-ctr
Activity File: sample-act

Input Parameters
IN_UNITS    =    ENGLISH
OUT_UNITS   =    ENGLISH
CO2_OUT     =        off
VEHICLE_CAT =          4
Tsoak       =     3.0000
Pscale      =     1.2000
Sload       =     2.3000
Masslb      =    3000.00
Masskg      =    3000.00
Ed          =       5.20
Trlhp       =       11.2
S           =      40.44
Nm          =    3217.28
Qm          =     139.48
Zmax        =     150.00
Np          =    4909.38
Idle        =        800
ng          =          5

Distance Traveled
0.493 miles
Tail Out Emissions
CO2 =    695.793 g/m
CO  =    22.6386 g/m
HC  =     5.9578 g/m
NOx =     2.3549 g/m
```
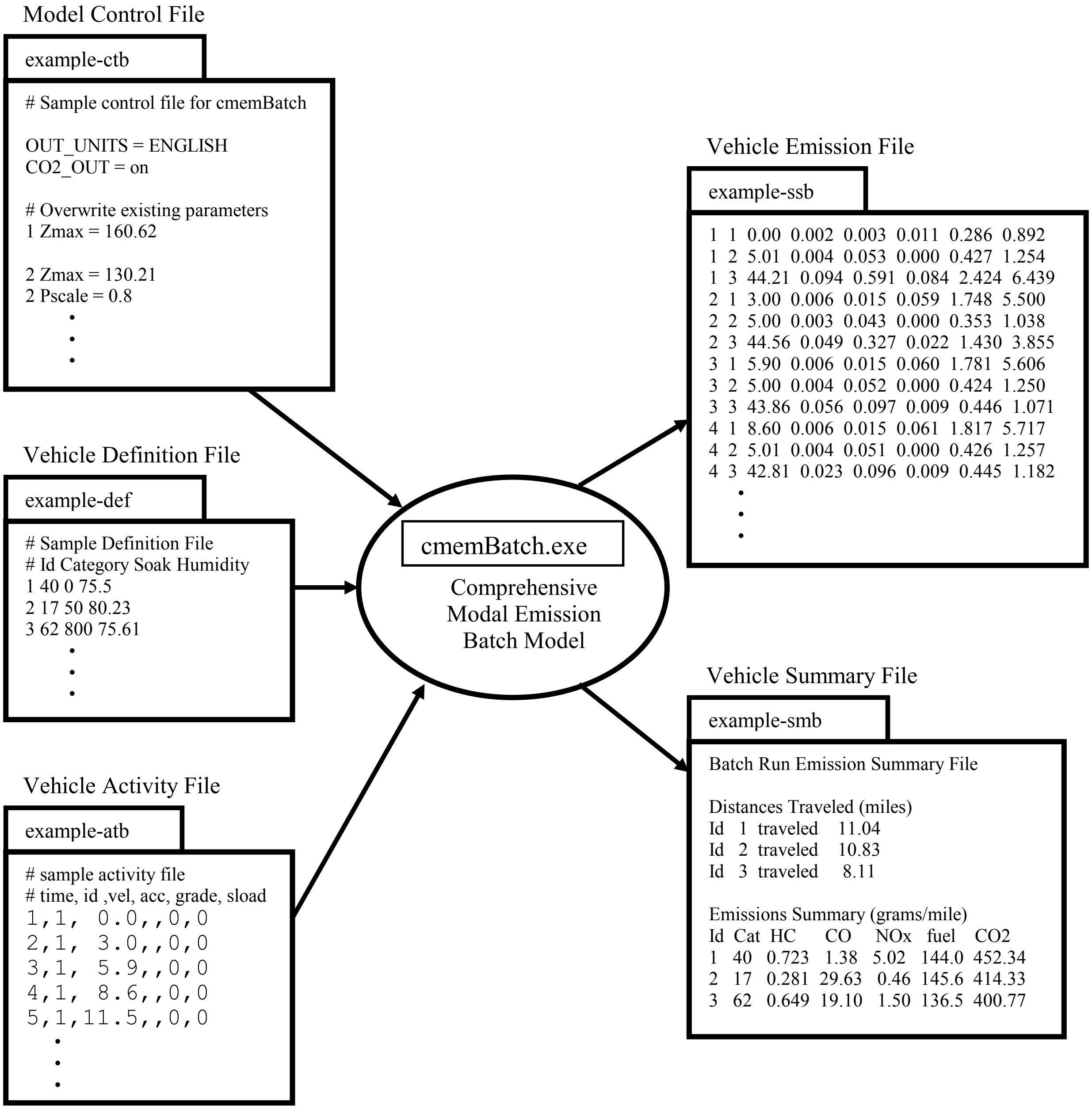

Figure 4.5. Example vehicle emission file for core model.

4.1.2 LDV Batch Model

The batch model allows the user to obtain emission data for multiple vehicles from different vehicle categories with varying trajectories. The executable name is `cmembatch.exe`. It is run from the command line (DOS or UNIX) and requires command line arguments for the input files. As illustrated in Figure 4.6, the batch model uses three input files and produces to three two output files.



```
# Sample control file for cmemBatch

OUT_UNITS = ENGLISH
CO2_OUT = on

# Overwrite existing parameters
1 Zmax = 160.62

2 Zmax = 130.21
2 Pscale = 0.8
      •
      •
      •
```

```
# Sample Definition File
# Id Category Soak Humidity
1 40 0 75.5
2 17 50 80.23
3 62 800 75.61
      •
      •
      •
```

```
# sample activity file
# time, id ,vel, acc, grade, sload
1,1, 0.0,,0,0
2,1, 3.0,,0,0
3,1, 5.9,,0,0
4,1, 8.6,,0,0
5,1,11.5,,0,0
  •
  •
  •
```

```
1  1  0.00  0.002  0.003  0.011  0.286  0.892
1  2  5.01  0.004  0.053  0.000  0.427  1.254
1  3  44.21  0.094  0.591  0.084  2.424  6.439
2  1  3.00  0.006  0.015  0.059  1.748  5.500
2  2  5.00  0.003  0.043  0.000  0.353  1.038
2  3  44.56  0.049  0.327  0.022  1.430  3.855
3  1  5.90  0.006  0.015  0.060  1.781  5.606
3  2  5.00  0.004  0.052  0.000  0.424  1.250
3  3  43.86  0.056  0.097  0.009  0.446  1.071
4  1  8.60  0.006  0.015  0.061  1.817  5.717
4  2  5.01  0.004  0.051  0.000  0.426  1.257
4  3  42.81  0.023  0.096  0.009  0.445  1.182
      •
      •
      •
```

```
Batch Run Emission Summary File

Distances Traveled (miles)
Id  1  traveled   11.04
Id  2  traveled   10.83
Id  3  traveled    8.11

Emissions Summary (grams/mile)
Id  Cat  HC      CO     NOx   fuel    CO2
1   40   0.723   1.38   5.02  144.0   452.34
2   17   0.281  29.63   0.46  145.6   414.33
3   62   0.649  19.10   1.50  136.5   400.77
```

Figure 4.6. Batch form of the modal emission model executable.

Similar to the core form of the model, the input files include a *control* file, which defines model running parameters and override-able category parameters, an *activity* file which defines multiple vehicle velocity/acceleration trajectories, and a vehicle *definition* file which defines multiple vehicle types and soak times. The output files are a vehicle *emissions* file which consists of second-by-second emission and fuel data, a vehicle *summary* file which provides integrated emission results and a model run file which provides a record of parameters used, comments and errors encountered during the run. File names are passed to the batch model as command line arguments in much the same way as the core model. For the executable `cmembatch`, the control file `sample-ctb`, the activity file `sample-atb` and the vehicle definition file `sample-def`, the batch model would be run by typing the following statement.

```
cmembatch sample-ctb sample-act sample-def
```

Executing the model in this manner does not require that the input files all have the same base file name or that they have specific extensions. The output files use the control file base name and a `-ssb` (Second-by-Second Batch) and `-smb` (SuMmary Batch) extension. For this case, the output files would be named `sample-ssb`, `sample-smb and sample-rnb`.

A second more abbreviated method of running the batch model requires that all three input files have the same base name and have a `-ctb` extension for the control file, a `-atb` extension for the activity file, and a `-def` extension for the vehicle definition file.

For the executable `cmembatch.exe`, the control file `example-ctb`, the activity file `example-atb` and the vehicle definition file `example-def`, the batch model would be run by typing the following statement:

```
cmembatch example
```

Output data following this run would be presented in files named `example-ssb`, `example-smb` and `example-rnb.`

Batch Model Control File

The control file for the batch form of the model is used to set model running parameters and overwrite category parameters for the batch model run in much the same way as the control file for the core form of the model. The control file for the batch version, however, must also specify which vehicle category the parameters are being applied to if they are specific vehicle parameters and not formatting parameters. Parameters recognized by the batch model in the control file are identical to those recognized by the core model in the control file, with the exception of `VEHICLE_CATEGORY` and `Tsoak`. Note that the parameters `VEHICLE_CATEGORY` and `Tsoak` are defined in the vehicle definition file for the batch model, not in the control file.

Entries in the batch model control file are written in one of two formats. The first format is used when defining parameters that apply to model input or output data. These parameters in particular are `IN_UNITS`, `OUT_UNITS`, `CO2_OUT`, `Sload`, and `SH`. The format used when defining these parameters is the following:

```
ParameterName = ParameterValue
```

where `ParameterName` is either `IN_UNITS`, `OUT_UNITS`, or `CO2_OUT` and `ParameterValue` is an accepted alphanumeric value for `ParameterName` (see Table 4.1). The second format is used to overwrite vehicle parameters for specified categories. The format used to do this is as follows:

`VehCat ParameterName = ParameterValue`

where `VehCat` specifies which category the overwritten parameter is being applied to (`VehCat` may be 1-69), `ParameterName` is an acceptable parameter name and `ParameterValue` is an acceptable parameter value. An example of a batch model control file is presented in Figure 4.7.

```
# Sample Control File for the Batch Model
IN_UNITS = METRIC
OUT_UNITS = ENGLISH

# Overwriting Category 1 parameters
1 Zmax = 160
1 Pscale = 0.9
1 ng = 4

# Overwriting Category 2 parameters
2 Zmax = 130
2 Pscale = 0.85
2 ng = 4

# Overwriting Category 21 parameters
21 Zmax = 123
21 Pscale = 0.95
21 ng = 4
```

Figure 4.7. Example control file for batch model.

Batch Model Vehicle Activity File

The activity file for the batch model is used to define the trajectories of multiple vehicles and optionally the acceleration, road grade angle, and secondary load flag for these vehicles. The secondary load flag is either `1` for on or `0` for off. Secondary load values are predefined for each vehicle category and may be overwritten in the control file (see Table 4.1). Input for the vehicle activity file is column-oriented, comma delimited and must contain at least three columns: time (in seconds), vehicle id, and velocity (in units specified by the batch control file). Data entered in the vehicle activity file should be time-ordered first and then vehicle-ordered as shown in the example activity file in Figure 4.8. As in the core form of the model activity file, optional columns that are left empty must be represented with commas if subsequent columns are to be defined.

```
# Sample Activity File for the Batch Model
# time, vehid, velocity,  {acceleration},  {grade},  {secondary load}
1,1,0,,0,0
1,2,0,,0,0
1,3,0,,0,1
1,4,0,,0,1
1,5,0,,0,1
2,1,0,,0,0
2,2,1.5,,0,0
2,3,2.9,,0,1
2,4,4.3,,0,1
2,5,5.8,,0,1
3,1,1.1,,0,0
3,2,3.8,,0,0
3,3,4.8,,0,1
3,4,5.4,,0,1
3,5,6.2,,0,1
```

Figure 4.8. Example activity file for batch model.

The example activity file in Figure 4.8 shows input data for five vehicles over three seconds.

Batch Model Vehicle Definition File

This file specifies categories, soak time values, and specific humidity for vehicles in a given run. Entries in the definition file must have the following format:

```
VehId  VehCat  SoakTime SH
```

where `Vehid` is a number corresponding to the vehicle id used in the activity file, `VehCat` is a number from 1-69 indicating the vehicle category to be assigned to that vehicle id, `SoakTime` is the soak time value in minutes, and SH is the specific humidity to be used with that vehicle id. The vehicle definition file may be commented using the pound symbol in the beginning of a line to indicate that the line is a comment line. Empty lines are not interpreted. An example of a vehicle definition file for the batch program is presented in Figure 4.9.

```
# Sample Vehicle Definition File for the Batch Model
# Vehicle Id,   Category,  Soak Time Value, Specific Humidity
1     23    0     74
2     12    10    89
3     9     1440  58
4     3     0     75
```

Figure 4.9. Example vehicle definition file for batch model.

Batch Model Vehicle Emissions File

This file presents second-by-second emission output data for the batch run. Data are presented in a time-ordered and vehicle-ordered fashion. The vehicle emissions file is presented without a header line so that it may be incorporated more easily into some database programs, spreadsheet programs, and other programs such as MATLAB. By default there are seven columns in the vehicle emission file. The columns in order are: time, vehicle id, vehicle velocity, tailpipe HC emissions, tailpipe CO emissions, tailpipe NOx emissions and fuel use. The units in which the data are presented are by default the English units of miles per hour for speed, grams per second for emissions, and grams per liter for fuel. The units for the output data may be otherwise defined in the control file. A portion of a vehicle integrated emissions file for a batch model run is presented in Figure 4.10 as an example.

```
1     1     0.0   0.11        0.32        0.05        1.23
1     2     0.0   0.16        0.90        0.08        1.56
1     3     0.0   0.23        0.12        0.08        1.84
2     1     0.2   0.13        0.41        0.10        2.32
2     2     0.5   0.18        0.50        0.14        2.50
2     3     1.2   0.23        0.57        0.23        2.87
3     1     1.3   0.21        0.54        0.12        3.49
3     2     2.8   0.23        0.51        0.14        2.87
3     3     3.2   0.25        0.52        0.25        2.85
```

Figure 4.10. Example vehicle emissions file for batch model.

Batch Model Summary File

This file presents integrated second-by-second emission data and optional data, such as total VMT (vehicle miles traveled). An example of a summary file for a batch model run is presented in Figure 4.11.

```
Batch Run Emission Summary File


Distance Traveled (miles)
Id   1    traveled   11.04
Id   2    traveled   10.83
Id   3    traveled    8.11


Emission Summary (grams/mile)
Id     HC       CO      NOx     fuel
1      0.896    6.45    2.19    116.4
2      1.320    7.12    1.86    125.3
3      0.736    3.28    0.62    96.4
4      1.728    4.35    1.14    103.4
```

Figure 4.11. Example summary file for batch model.

Model Run File

This file is headed with the CMEM name, the version number of the executable and the release date. The model run file provides information about the specific data which was used in the model run. It includes the names of the files associated with the run, any overwritten parameters as defined in the control file, the vehicle categories which the vehicle Id's are mapped to as defined in the definition file, along with the fuel type, humidity, soak time and the remaining vehicle and calibrated parameters. The model run file also provides a record of any error statements or comments the batch program generates during the processing of the control, activity and definition files which may be useful in analyzing or trouble shooting a batch run. An example of a summary file for a batch model run is presented in Figure 4.12.

```
   ******************************************************************************
  *                                                                             *
  *            CCCCCCC    MMM      MMM   EEEEEEEEEE   MMM      MMM              *
  *           CCCCCCCCC   MMMM    MMMM   EEEEEEEEEE   MMMM    MMMM              *
  *          CCC     CC   MMMMM  MMMMM   EEE          MMMMM  MMMMM              *
  *          CCC          MMMMMMMMMMMM   EEEEEEEEEE   MMMMMMMMMMMM              *
  *          CCC          MMM MMMM MMM   EEEEEEEEEE   MMM MMMM MMM              *
  *          CCC     CC   MMM  MM  MMM   EEE          MMM  MM  MMM              *
  *           CCCCCCCCC   MMM      MMM   EEEEEEEEEE   MMM      MMM              *
  *            CCCCCCC    MMM      MMM   EEEEEEEEEE   MMM      MMM              *
  *                                                                             *
  *                   Comprehensive Modal Emissions Model                       *
  *                                                                             *
  *                       Version 2.02   October 2001                           *
  *                                                                             *
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  *                                                                             *
   ******************************************************************************

Input Files
Control File:    sample-ctr
Activity File:   sample-act
Definition File: sample-def


Output Files
Model Run File:  sample-rnb
Summary File:    sample-smb
Sec-by-Sec File: sample-ssb


Id 1 Category set to 40
Id 2 Category set to 2
Id 3 Category set to 6
Id 1 Tsoak value set to 0
Id 2 Tsoak value set to 10
Id 3 Tsoak value set to 1440

In_Units set to Metric
Out_Units not set.  Defaulting to English.
```

```
Overwritten Parameters by Category
Cat 2 Zmax set to 160.00
Cat 2 Pscale set to 0.75

Id Categories
Id   1 Category set to 40
Id   2 Category set to 4
Id   3 Category set to 17

Id Fuel Type
Id    1 Fuel Type set to diesel
Id    2 Fuel Type set to gasoline
Id    3 Fuel Type set to gasoline

Id 1
Condition Parameters
Tsoak    =         0
SH       =     75.50

Vehicle Parameters
Ed       =      6.60
Masslb   =   6777.78
Trlhp   =   20.69
 .
 .
 .

Calibrated Parameters
K_0      =    0.1353
Edt3     =    0.2000
C0       =    0.0016
 .
 .
 .
```

Figure 4.12. Example model run file for batch model.

4.1.3 HDD Core Model CLI

Much like the LDV core model, the HDD core model predicts emission data for an HDD vehicle from a single HDD vehicle category and a given activity file (i.e., the speed trajectory of the vehicle). The core model CLI executable name is `hddCore` on Linux and `hddCore.exe` on Windows machines. The executable code only requires command line arguments for the input file names. As illustrated in Figure 4.13, the core model uses two input files:

- control file
- vehicle activity file

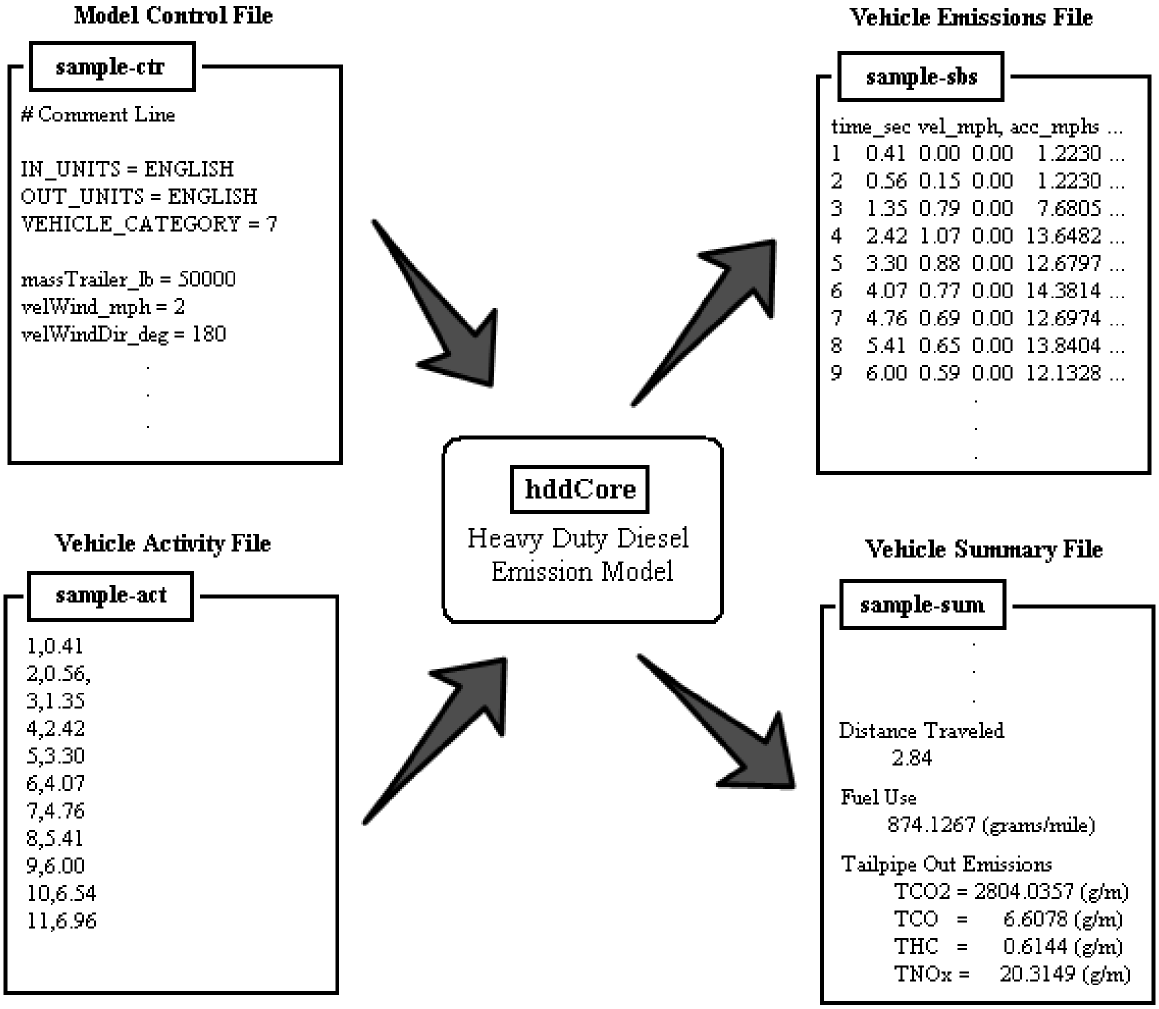
and produces two output files:

- vehicle emission file

- summary file

As in the LDV command line model, file names are passed to the `hddCore` model as command line arguments in one of two ways. The first method is to list the input file names on the command line after the executable name, starting with the control file name first followed by the activity file name. For the executable file `hddCore.exe`, the control file `sample-ctr` and the activity file `sample-act`, the core model can be run by typing the following statement:

```
hddCore sample-ctr sample-act
```



```
# Comment Line

IN_UNITS = ENGLISH
OUT_UNITS = ENGLISH
VEHICLE_CATEGORY = 7

massTrailer_lb = 50000
velWind_mph = 2
velWindDir_deg = 180
          .
          .
          .
```

```
time_sec vel_mph, acc_mphs ...
1   0.41  0.00  0.00    1.2230 ...
2   0.56  0.15  0.00    1.2230 ...
3   1.35  0.79  0.00    7.6805 ...
4   2.42  1.07  0.00  13.6482 ...
5   3.30  0.88  0.00  12.6797 ...
6   4.07  0.77  0.00  14.3814 ...
7   4.76  0.69  0.00  12.6974 ...
8   5.41  0.65  0.00  13.8404 ...
9   6.00  0.59  0.00  12.1328 ...
                  .
                  .
                  .
```

```
1,0.41
2,0.56,
3,1.35
4,2.42
5,3.30
6,4.07
7,4.76
8,5.41
9,6.00
10,6.54
11,6.96
```

```
                .
                .
                .
Distance Traveled
     2.84
Fuel Use
     874.1267 (grams/mile)
Tailpipe Out Emissions
     TCO2 = 2804.0357 (g/m)
     TCO   =      6.6078 (g/m)
     THC   =      0.6144 (g/m)
     TNOx =     20.3149 (g/m)
```

Figure 4.13. HDD core form of the modal emission model executable.

The output files generated from this run will use the base name from the control file with a `-sbs` extension for the core model vehicle emission file and a `-sum` extension for the core model summary file.

The second more abbreviated method of running the core model requires that the control file and the activity file both have the same base name and have a `-ctr` and `-act` extension respectively. In this case, the only command line argument required is the common base name for both files. For the executable `hddCore.exe`, the control file `example-ctr` and the activity file `example-act`, the core model can be run by typing the following statement:

```
hddCore example
```

With this method, the common base name is also used as the base name for the output files. In this case, the core model vehicle emission file would be named `example-sbs` and the core model summary file would be named `example-sum`.

CLI Help

The HDD model CLI has basic help features which can be accessed from the command line. These help features are designed as a quick reference when using the CLI version of the HDD model and can be viewed by typing the executable name followed by the appropriate flag on the command line. Help flags are composed of a "-" followed by a recognized help code.

For example typing

```
hddCore –help
```

returns the information shown in Figure 4.14 below, which is the basic HDD CLI help overview and shows the available help codes..

```
Usage:

  hddCore
        Runs hddCore using
        default-ctr as the control file name and
        default-act as the activity file name.

  hddCore [Prefix]
        Runs hddCore using Prefix as the common
        file prefix if the input file names follow
        the format Prefix-ctr and Prefix-act.

  hddCore [CtrName ActName]
        Runs hddCore using
        CtrName as the control file name and
        ActName as the activity file name.

  hddCore -act
        Input activity file usage information

  hddCore -ctr
        Input control file usage information

  hddCore -sbs
        Second-by-second output file usage information

  hddCore -sum
        Summary ouput file usage information

  hddCore -info

        Shows general model info.
```

Figure 4.14. HDD Model CLI Help Results

Typing `hddCore` and using the input and output file extensions as flags shows basic formatting information, information on units used, default values and/or offers a description of selected variables relevant to the input and output files.

For example typing

```
HddCore –ctr
```

reports control file related information which is abridged in Figure 4.15 below.

```
Control input file format
  -- The control file is made up of control commands in
     no particular order. Use these to set selected
     test conditions.
  -- Default values are defined for all variables.
  -- Comment lines begin with '#' in the first column.

Control command list
  General commands
     OUT_UNITS = [ENGLISH,METRIC,default = ENGLISH]
     IN_UNITS = [ENGLISH,METRIC,default = ENGLISH]

  Test condition related commands
     ambTemp_c = [default = 25]
     ambTemp_f = [default = 77]
     ambPres_mmhg = [default = 750]
     ambPres_kp = [default = 100]
     massTrailer_lb = [default = 44360.3
     massTrailer_kg = [default = 20121.5
                 •
                 •
                 •
  Vehicle related commands
     VEHICLE_CATEGORY = [5,6,7,default = 7]
     ambTemp_c = [default = 25]
     cDrag = value
     cRr1 = value
     cRr2 = value

Note:
  -- VEHICLE_CATEGORY
     5: 1994-1997, 4 Stroke, Electronic FI
     6: 1998     , 4 Stroke, Electronic FI
     7: 1999-2000, 4 Stroke, Electronic FI

  -- velWindDir_deg is relative to vehicle and
     values are any number between 0 and 360
     0:   head wind
     90:  cross wind from left
     180: tail wind
     270: cross wind from right
```

Figure 4.15. HDD Model CLI Control File Help Results

CLI Control File

The control file controls various running parameters of the model and allows a user to override the default parameters of the model. The running parameters specify the format of the input and output data.

The following is a list of control file parameters. The first two control parameters specify file input and output formats. They are described as follows.

`IN_UNITS:` Specifies which units input data are given in. Generally applies to activity file. This value may be `METRIC` or `ENGLISH`. The default value is `ENGLISH`.

`OUT_UNITS:` Specifies which units output data will be reported in. Generally applies to the -sum file and activity in the -sbs files. This value may be `METRIC` or `ENGLISH`. The default value is `ENGLISH`.

The next eleven parameters define the simulation or test conditions:

`ambTemp_c:` Defines the average ambient temperature during the simulation run in units of degrees Celsius. Default value for this parameter is 77. Used to determine air density and air drag.

`ambTemp_f:` Defines the average ambient temperature during the simulation run in units of degrees Fahrenheit. Default value for this parameter is 25. Used to determine air density and air drag.

`ambPres_mmhg:` Defines the average ambient pressure during the simulation run in millimeters of mercury. Default value for this is 750. Used to determine air density and air drag.

`ambPres_kp:` Defines the average ambient pressure during the simulation run in kilopascal. Default value for this is 100. Used to determine air density and air drag.

`massTrailer_lb:` Defines the mass of the trailer or the load on the tractor during the simulation in units of pounds. The default value is set at 44360.3 pounds.

`massTrailer_kg:` Defines the mass of the trailer or the load on the tractor during the simulation in units of kilograms. The default value is set at 20121.5 kilograms.

`powAcc_hp:` Defines the accessory load on the vehicle in units of hp. This could be used to reflect air-conditioning or similar accessory power usage. The default value for this is zero.

`powAcc_kw:` Defines the accessory load on the vehicle in units of hp. This could be used to reflect air-conditioning or similar accessory power usage. The default value for this is zero.

`velWind_mph:` Defines the wind velocity relative to the vehicle in units of miles per hour. The default value is zero.

`velWind_mps:` Defines the wind velocity relative to the vehicle in units of meters per second. The default value is zero.

`velWindDir_deg:` Defines the direction of wind velocity in units of degrees. The value can range anywhere between 0 and 360 in the following manner:

0: head wind (default value)
90: crosswind from left
180: tail wind
270: crosswind from rightThe following parameters are specific vehicle parameters that a user can set to override the default model parameters that were determined for composite vehicles representing each vehicle/technology category. Default values for these categories will depend on individual vehicle categories.

`VEHICLE_CATEGORY:` Defines the truck category to be simulated. The default truck category is category 7. The following three HDD truck categories are available:

5: 1994-1997, 4 Stroke, Electronic FI
6: 1998 , 4 Stroke, Electronic FI
7: 1999-2000, 4 Stroke, Electronic FI

`cDrag:` Defines the drag coefficient for the truck cab.

`cRr1:` Defines the first drag coefficient used for rolling resistance.

`cRr2:` Defines the second drag coefficient used for rolling resistance.

`disp_l:` Defines the vehicle's engine displacement in units of liters.

`massTractor_lb:` Defines the weight of the tractor in pounds.

`massTractor_kg:` Defines the weight of the tractor in kilograms.

`maxP_hp:` Defines the maximum engine power of the truck in units of horsepower.

`maxP_rps:` Defines the engine speed at which maximum engine power (maxP_hp) is produced in units of revolutions per second.

`maxQ_nm:` Defines the maximum engine torque produced in units of Newton-meters.

`maxQ_rps:` Defines the engine speed at which maximum engine torque (maxQ_nm) is produced in units of revolutions per second.

`spdEngVeh_rpmmph:` Defines the ratio of engine speed in units of revolutions per minute over vehicle speed in units of miles per hour.

`spdEngVeh_rpsmps:` Defines the ratio of engine speed in units of revolutions per second over vehicle speed in units of meters per second.

`numGear:` Defines the number of transmission gears excluding final drive. The range is 1-18.

`gearFinal:` Defines the final transmission gear ratio.

`gearValue1:` Defines the gear ratio for gear 1. Subsequent gear variables follow the same format so the gear variable names would be gearValue2, gearValue3, gearValue4,…,gearValue18.

Entries in the control file must be written in the following format:

```
ParameterName = ParameterValue
```

where `ParameterName` is a recognized parameter and `ParameterValue` is an accepted alphanumeric value for `ParameterName` as listed under the sub-section CLI Control File above. There must be at least one space following the variable `ParameterName` and the equal sign. Entries in the control file may appear in any order and may or may not end with a comma, semi-colon or colon. Control files may be commented using the pound symbol in the beginning of a line to declare that line as a comment line. Empty lines in the control file are not interpreted. A portion of a control file is given in the example in Figure 4.16.

```
# Example Control File for core
# form of the HDD model.

IN_UNITS         = ENGLISH
OUT_UNITS        = METRIC
VEHICLE_CATEGORY = 6

ambTemp_f = 85
massTrailer_lb = 5000.00
#massTrailer_kg = 20121.5
#powAcc_hp = 0
#powAcc_kw = 0
#velWind_mph = 0
#velWind_mps = 0
#velWindDir_deg = 0

cDrag = 0.7
#cRr1 = 0.0021
#cRr2 = 0.00005
massTractor_lb = 1500
#massTractor_kg = 8182.81
     •
     •
     •
```

Figure 4.16. HDD Model CLI Control File Example

CLI Activity File

The activity file defines a vehicle's second-by-second trajectory data, specifically velocity, acceleration and grade. This file consists of column-oriented and comma delimited vectors and must contain at least two columns: time (in seconds) and velocity (in mph or kph depending on the units specified in the control file). Optional data vectors in the activity file include acceleration (if directly measured and not obtained from velocity differentiation) and road grade angle (in radians). Optional columns that are left empty must be represented with commas if subsequent columns are to be defined. A portion of two vehicle activity files is presented in Figure 4.17 as an example.

a)

```
1,0.41
2,0.56
3,1.35
4,2.42
5,3.30
  •
  •
  •
```

b)

```
1,0.41,,0.122
2,0.56,,0.124
3,1.35,,0.121
4,2.42,,0.119
5,3.30,,0.118
  •
  •
  •
```

Figure 4.17. HDD Model CLI Activity File Example a) without grade b) with grade

CLI Second-by-Second Emission Result File

The model outputs second-by-second emission and fuel data in space delimited columns with a header line at the top.. The output data is time, velocity, HC, CO, NO_x and fuel use. The second-by-second emission file name is determined using the base name of the control file with a `-sbs` extension. For the control file name `sample-ctr`, the vehicle emission file name would be `sample-sbs`. An example of output data from a vehicle emission file is presented in Figure 4.18.

```
time_sec vel_mph acc_mphs grade_rad tco2_gs tco_gs thc_gs tnox_gs fuel_gs
1 0.41 0.00 0.00 1.223011 0.014163 0.002153 0.032143 0.390000
2 0.56 0.15 0.00 1.223011 0.014163 0.002153 0.032143 0.390000
3 1.35 0.79 0.00 7.680599 0.023536 0.002556 0.065704 2.405669
4 2.42 1.07 0.00 13.648204 0.032198 0.002929 0.096719 4.268395
5 3.30 0.88 0.00 12.679772 0.030792 0.002868 0.091686 3.966109
             •
             •
             •
```

Figure 4.18. HDD Model CLI Space Delimited Result File

This format can easily be incorporated in various database and spreadsheet programs. To load this file in Excel, open the application with Excel, select column A, and use the *Text to Columns* command under the *Data* menu to separate the data into columns using space as the delimiter

CLI Summary Result File

The summary file presents summarized second-by-second data. The units used in the summary file in part are set in the control file via the `UNITS_OUT` flag. Data included in the summary file are total distance traveled, total mass of tailpipe emissions per unit distance (grams/mile) including tailpipe CO_2 and mass or volume of fuel used per unit distance.

The summary file also logs any messages that the model may generate. The model generates message reports when parameters in the control file are not recognized or when problems with the model execution such as file reading or writing errors occur. An example of the HDD core model summary file is presented in Figure 4.19.

```
*****************************************************************************
*                 ,`     ____________________________________________         *
*            ____||_/_  |                                            |        *
*        ___/__] ||   | |                                            |        *
*       |.__|____||___| |____________________________________________!        *
*       |=(_)[___][___]==(_)(_)=|    \___________________]=(_)(_)(_)=|        *
*                                                                             *
*       HHH    HHH  DDDDDDDD      DDDDDDDD      EEEEEEEEE  MMM      MMM       *
*       HHH    HHH  DDDDDDDDDD    DDDDDDDDDD    EEEEEEEEE  MMMM    MMMM       *
*       HHH    HHH  DDD     DDD   DDD     DDD   EEE         MMMMM  MMMMM       *
*       HHHHHHHHHH  DDD      DDD  DDD      DDD  EEEEEEEE   MMMMMMMMMMMM       *
*       HHHHHHHHHH  DDD      DDD  DDD      DDD  EEEEEEEE   MMM MMMM MMM       *
*       HHH    HHH  DDD     DDD   DDD     DDD   EEE         MMM  MM  MMM       *
*       HHH    HHH  DDDDDDDDDD    DDDDDDDDDD    EEEEEEEEE  MMM      MMM       *
*       HHH    HHH  DDDDDDDDD     DDDDDDDDD     EEEEEEEEE  MMM      MMM       *
*                                                                             *
*                   Heavy Duty Diesel Emissions Model                         *
*                                                                             *
*                       Version 1.10   August   2005                          *
*                                                                             *
* Copyright (c) 2005 The Regents of the University of California.             *
            •
            •
            •
Input Files
Control File:    sample-ctr
Activity File:   sample-act

Output Files
Summary File:    sample-sum
Sec-by-Sec File: sample-sbs

Using calculated acceleration.

VEHICLE_CATEGORY = 7

Test Condition Parameters
ambTemp_f         =     77.00
ambPres_mmhg      =    760.00
            •
            •
            •
Vehicle Related Parameters
massTractor_lb    =  16450.00
fArea_f2          =    110.50
cDrag             =      0.65
cRr1              =   0.00210
            •
            •
            •
Distance Traveled
     2.84 miles

Fuel Use
     874.1267   (grams/mile)

Tailpipe Out Emissions
     TCO2 =  2804.0357 (grams/mile)
     TCO  =     6.6078 (grams/mile)
     THC  =     0.6144 (grams/mile)
     TNOx =    20.3149 (grams/mile)
```

Figure 4.19. Abridged Example of HDD Model CLI Summary File

4.2. GRAPHICAL USER INTERFACE

In order to make CMEM easier to use, we have implemented the code in a graphical user interface (GUI) using the Java programming language. Java runs on multiple platforms and was designed with the intent of making code more portable between various operating systems. To run the CMEM Java GUI, the operating system must be equipped with the Java Runtime Environment (JRE) which can be obtained at no expense from www.java.com. The Java GUI exists as a Java .jar file which should be recognized by the properly installed JRE.

The CMEM Java GUI runs both the LDV and HDDV portions of the CMEM model. The Java GUI contains 5 panels in the following order: *Activity* panel, *LD Vehicle* panel, *HDD Vehicle* panel, *Fleet* panel and *Group* panel. The panels are selectable by tabs and are ordered in the same way that a user would define and execute model runs. The *Activity* panel is used to enter various trajectories or driving cycles. The *LD Vehicle* and *HDD Vehicle* panels are used to define vehicle IDs by associating trajectory information with vehicle information, the *Fleet* panel is used to define a vehicle fleet based on vehicle IDs and to execute the model for a defined vehicle fleet. Fleets may contain only one vehicle for single vehicle runs or multiple vehicles. The *Group* panel can be used to combine and run groups of fleets. Export functions allow the user to export second-by-second emission data as well as summary data to text files. The use of the various panels and the export feature are described in more detail in the following sections.

4.2.1. Getting Started

The Java programming language is designed to be portable between various operating systems. In order to do this it does not create operating system-specific compiled executables in the common way. Instead, Java creates pre-compiled code which it stores in .class files. These .class files can be interpreted and executed by the JRE on various machines. In this manner, multiple executables do not have to be created for various operating systems. Class files can further be archived in what are known as .jar files. The CMEM GUI consist of .class files archived in a .jar file named `cmem.jar`. In addition to this .jar file, the GUI also consists of a folder named `GRAPHICS` which must accompany the `cmem.jar` file. The `GRAPHICS` folder, as its name suggests, contains all the supporting graphic files for the Java GUI. The final component of the CMEM Java GUI is a file named `CMEMdata` which is used to store saved information for the GUI. The CMEM Java GUI will create a new, empty `CMEMdata` file if one does not exist in the same directory. In order to run the CMEM Java GUI, the following items discussed above must reside in the same directory:

- `cmem.jar` file
- `GRAPHICS` folder
- `CMEMdata` file (optional to access previously stored data)

In order to run the CMEM Java GUI, the standard JRE should be installed. The JRE is available at no expense from the website www.java.com. To run the GUI from a Windows machine once the JRE is installed, simply click on the file `cmem.jar`. Windows should associate the .jar extension with Java and open the .jar file using the `javaw.exe` from the JRE. Macintosh users will be able run the CMEM GUI in a similar manner. To run the GUI on a Unix based machine such as Linux, use the command `javaw cmem.jar` or the system command for executing Java code.

Once the Java GUI is initiated, the first screen that should appear is the following screen in Figure 4.20.

version 3.0 Beta
creating activity panel

Figure 4.20 CMEM Java GUI Splash Screen

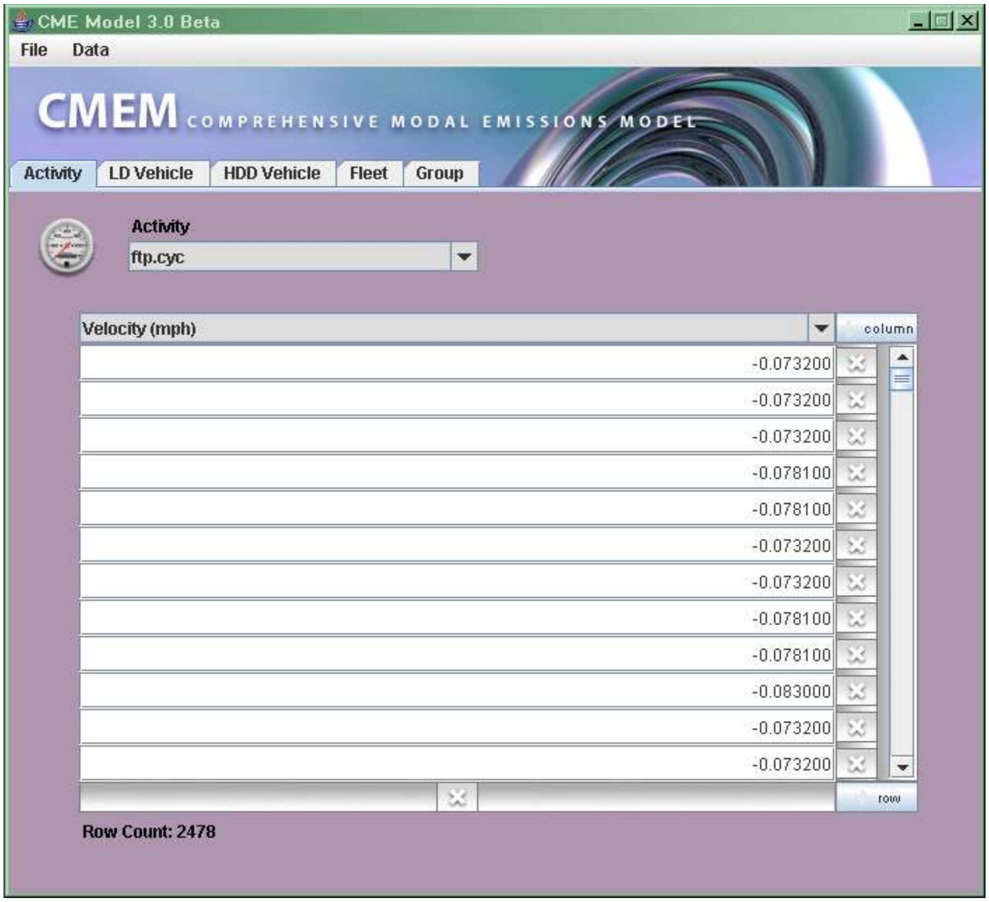
If the splash screen in Figure 4.20 is empty, the `GRAPHICS` folder is either not in the same directory as the `cmem.jar` executable or it is missing graphic files. If a warning message indicates that the `CMEMdata` file can not be found, then the `CMEMdata` file is not in the same directory as the `cmem.jar` executable. If the user continues with the Java GUI an empty `CMEMdata` file will be created. Note that the `CMEMdata` file released with the CMEM Java Model contains selected vehicle activity traces and some sample data.

4.2.2 Activity Panel

The first panel which appears following the splash screen on GUI startup is the *Activity* panel shown in Figure 4.21. This panel allows the user to define vehicle activity which can later be associated with vehicle parameters. The word activity in this case refers to second-by-second vehicle speed, acceleration and second-by-second road grade. Although a time column can be defined, the GUI assumes all activity data inputted is in one second intervals. The time column serves more as a placeholder for reference purposes. The only required activity data field is vehicle velocity in units of miles per hour. The units for acceleration data are mph/second. If no acceleration data is specified, it is calculated from velocity data. The units for grade data are degrees and if no grade data is specified, zero grade at every second is assumed.

Creating New Activity

To create a new activity under the *Activity* panel, select from the pull down menu “File → New” or use the shortcuts key “Alt-n”. This prompts for an activity name and then places this name into the activity selection pull down menu at the top of the *Activity* panel. With the activity selected , click on the column plus symbol at the right of the panel, select “Data → Add a Column” from the pull down menu or use the shortcuts key “Alt-c” to add empty activity columns. From the column heading pull down menu, select the appropriate column heading. Similarly, to create data rows, select “Data → Add a Row” from the pull down menu or use the shortcut key “Alt-r” to add an empty activity row. Repeat this for the desired number of rows. A row count at the bottom of the panel will indicate the number of rows in the activity. Data can now be manually entered into the activity array using the keyboard. Use the pull down manual at the top of the panel to select between different entered activities. Using the pull down menu under “File” at the top of the GUI, activity data can also be renamed, duplicated or deleted.



Activity
ftp.cyc

Velocity (mph)

-0.073200
-0.073200
-0.073200
-0.078100
-0.078100
-0.073200
-0.073200
-0.078100
-0.078100
-0.083000
-0.073200
-0.073200

Row Count: 2478

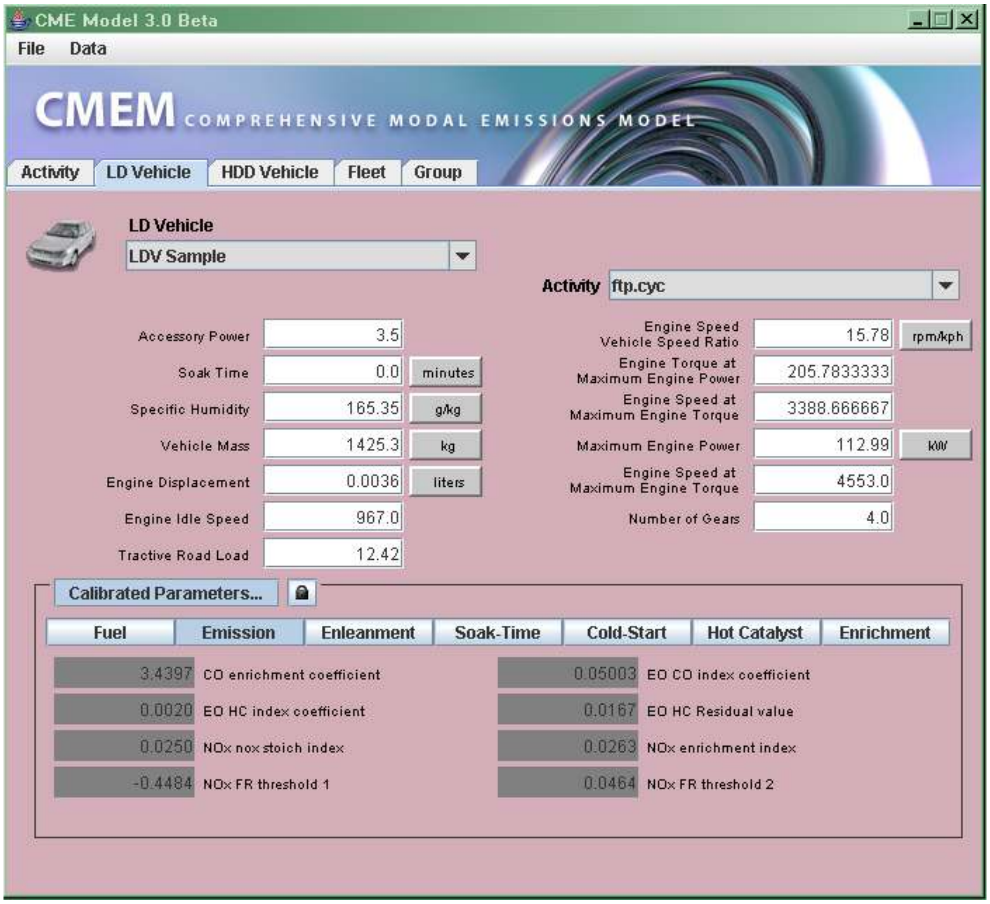
Figure 4.21. Activity panel

Importing Existing Activity

To import data into the *Activity* panel from a data file, select "File → Import" or use the shortcut keys "Alt-i". This will bring up a file browser allowing the user to search for his activity data file. The file browser will be followed by a window prompting for a data delimiter. Once the proper delimiter is chosen the data file will be imported and named based on the imported text file's name. The row count at the bottom of the *Activity* panel will indicate how many seconds of data were imported. To rename the activity entry, select "File → Rename" or use the shortcut keys "Alt-r". Also, the proper column headings must be chosen to indicate the velocity column and any other columns being specified. Use the "X" boxes to the right of the rows and under the columns to remove unwanted data.

4.2.3 LD Vehicle Panel

The *LD Vehicle* panel shown in Figure 4.22 is the first of two panels used for defining vehicle IDs. The second of these panels is the *HDD Vehicle* panel discussed later. Vehicle IDs defined on this panel will be calculated using CMEM's LDV model. Vehicle IDs are simply all the information needed to run CMEM for a single vehicle over a single trajectory. This information includes any applicable test conditions such as vehicle soak time or humidity, general vehicle parameters such as vehicle weight or maximum engine horsepower, calibrated vehicle parameters and finally activity data such as velocity and road grade. Vehicle IDs are used in the *Fleet* panel to define vehicle fleets for calculation.



LD Vehicle: LDV Sample

Activity: ftp.cyc

Accessory Power: 3.5
Soak Time: 0.0 minutes
Specific Humidity: 165.35 g/kg
Vehicle Mass: 1425.3 kg
Engine Displacement: 0.0036 liters
Engine Idle Speed: 967.0
Tractive Road Load: 12.42

Engine Speed Vehicle Speed Ratio: 15.78 rpm/kph
Engine Torque at Maximum Engine Power: 205.7833333
Engine Speed at Maximum Engine Torque: 3388.666667
Maximum Engine Power: 112.99 kW
Engine Speed at Maximum Engine Torque: 4553.0
Number of Gears: 4.0

3.4397 CO enrichment coefficient
0.0020 EO HC index coefficient
0.0250 NOx nox stoich index
-0.4484 NOx FR threshold 1
0.05003 EO CO index coefficient
0.0167 EO HC Residual value
0.0263 NOx enrichment index
0.0464 NOx FR threshold 2

Figure 4.22. CMEM Java GUI LD Vehicle Panel

Creating New LD Vehicle IDs

To create a new vehicle ID under the *LD Vehicle* panel, select the pull down menu “File → New” or use the shortcut key “Alt-n” to create a new vehicle ID. The GUI will prompt for a LD Vehicle name which will be the vehicle ID name. It is helpful to make this user defined vehicle ID name relate to the vehicle and its activity, but it should also be somewhat limited in length for ease of use with the *Fleet* panel. Vehicle parameter values both general and calibrated, as well as test condition parameter values can be manually entered on the GUI, but in most situations the supplied default parameter values should be used.

Default parameter values are loaded by selecting the “Data → Load Default Values” pull down menu and selecting the appropriate category information as shown in Figure 4.23. These values can be modified or reloaded. Some parameters have unit specifications which can be toggled.

The lock icon next to the “Calibrated Parameters” text on the *LD Vehicle* panel locks and unlocks the calibrated parameters for overwriting. Selecting the various “Calibrated Parameter” subheadings switches between calibrated parameter groups. The parameter values under this section only need to be unlocked if the are to be manually overwritten.

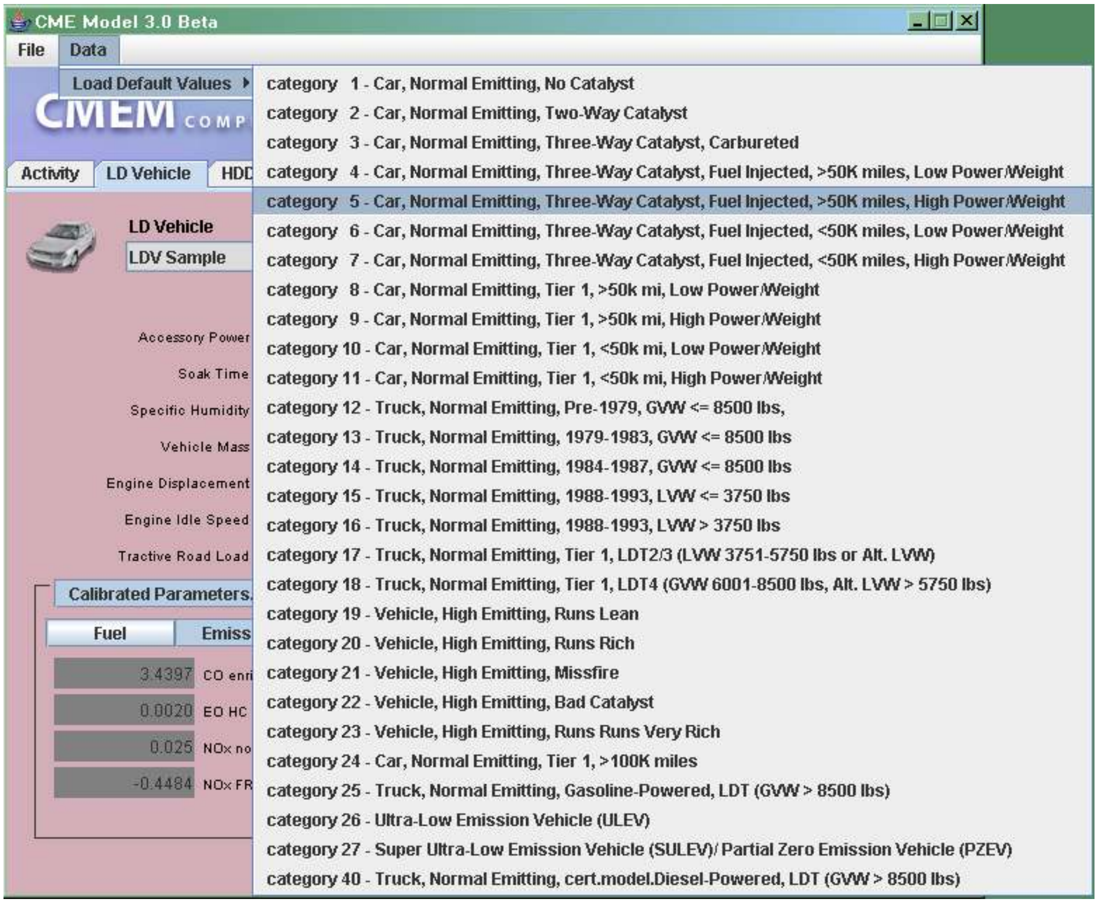


Figure 4.23. Loading default data for vehicle ID

Finally, each vehicle ID has to be associated with an activity. Only activities defined in the *Activity* panel can be associated with vehicle IDs. To associate an activity with a vehicle ID, first make sure the desired vehicle ID is active in the LD Vehicle pull-down menu on the *LD Vehicle* panel and then select the appropriate vehicle activity from the activity pull-down menu on the right side of the *LD Vehicle* panel. Vehicle IDs can also be renamed, duplicated or deleted using the options under the “File → ….” pull-down menu.

4.2.4 HDD Vehicle Panel

The *HDD Vehicle* panel shown in Figure 4.24 is the second vehicle panel used for defining vehicle IDs. Vehicle IDs defined on this panel will be calculated using the HDD portion of the CMEM model. The *HDD Vehicle* panel functions in much the same manner as the *LDV Vehicle* panel does, the most notable difference being the parameter set. Please refer to section 4.2.3 for definitions of vehicle ID and activity as they are used here and for instructions on creating new vehicle IDs.

HDD Vehicle: HDDV Sample

Activity: ARB Cruise

Mass of trailer	44360.0	lbs
Ambient air pressure	100.0	Kpa
Ambient temprature	25.0	C
Accessory load	0.0	hp
Wind velocity	0.0	mph
Wind direction	0.0	

0.00465	Engine out CO index coefficient	0.01235	Engine out CO residual value
2.0E-4	Engine out HC index coefficient	0.002075	Engine out HC residual value
0.01665	Engine out NOx index coefficient	0.02565	Engine out NOx residual value
0.04715	Engine out NOx high index coefficient	0.055125	Engine out NOx residual value

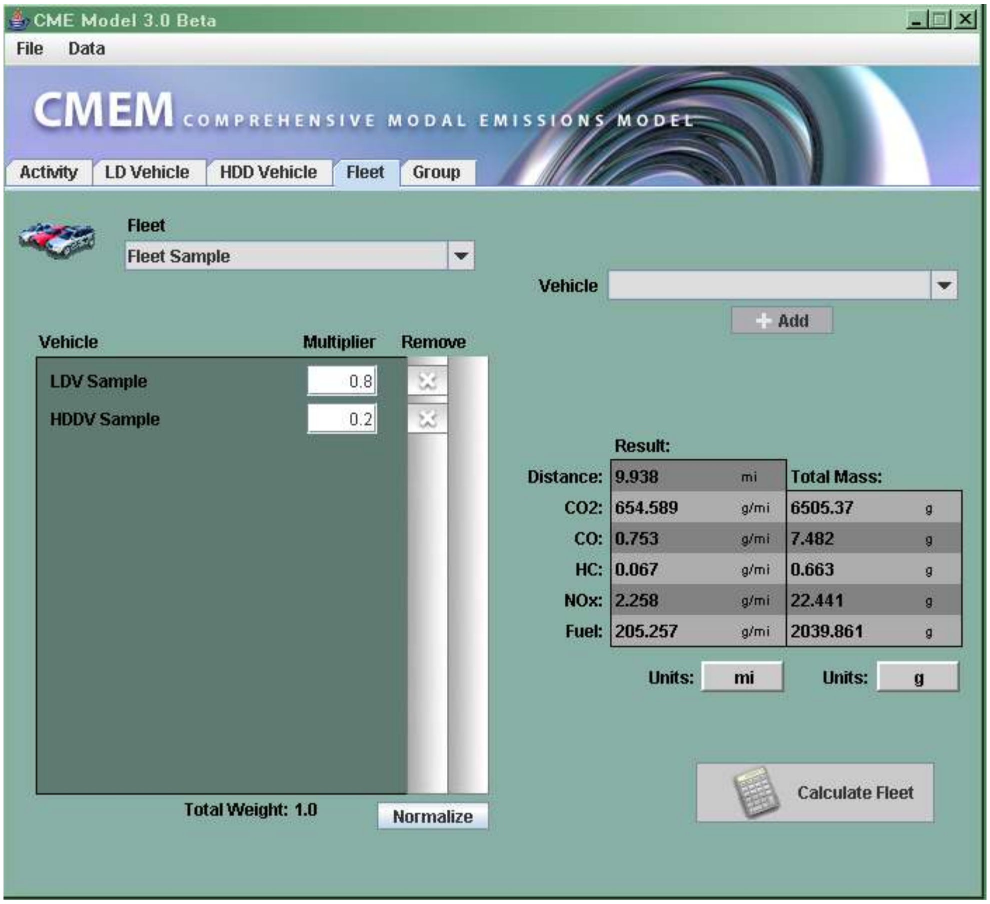
Figure 4.24 CMEM Java GUI HDD Vehicle Panel

4.2.5 Fleet Panel

The *Fleet* panel is one of two panels that initiates model calculations and reports results, the second panel with which this can be done is the *Group* panel. The *Fleet* panel, shown in Figure 4.25, is comprised of five main components: fleet selection box, fleet content box, vehicle ID selection box, result grid and calculation button. These components and their use are discussed below.

The top left of the panel is the fleet selection box which shows the name of the active fleet. To define a new fleet, use the "File → New" pull-down menu or the shortcut key "Alt-n", and enter a fleet name. This creates a new empty fleet which appears in the fleet selection box. To add vehicle IDs to the box use the vehicle selection box on the top right of the panel. The vehicle ID box contains all available vehicle IDs defined on the *LD Vehicle* and *HDD Vehicle* panels. Select the appropriate vehicle ID and click on the add button below the vehicle ID selection box. This places the vehicle ID into the fleet content box on the lower left side of the panel. Multiple vehicle IDs can be added in this way to create a fleet. Vehicle IDs may also be removed by clicking the "X" in the *Remove* column next to the appropriate vehicle ID. Note that once a vehicle ID is added to the fleet, it is removed from the vehicle ID selection box. Each vehicle ID can only be added once to the fleet.

To compensate for the rate of various vehicle ID occurrences in the fleet, weighting factors or vehicle ID multipliers should be defined. These weighting factors appear in the *Multiplier* column of the fleet content box next to each vehicle ID. The sum of the multipliers is shown following the label *Total Weight* at the bottom of the fleet content box. The multipliers can be used in one of two ways, either to reflect total vehicle counts or normalized as a percentage. To normalize vehicle ID multipliers, click on the *Normalize* button at the bottom of the *Remove* column. Normalization will not effect the mass/distance results, but will effect the total mass numbers. Normalized mass/distance results may differ slightly from total vehicle count weighted mass/distance results due to rounding errors.



Fleet: Fleet Sample

Vehicle:

Vehicle	Multiplier	Remove
LDV Sample	0.8	☒
HDDV Sample	0.2	☒

Total Weight: 1.0

	Result:		Total Mass:	
Distance:	9.938	mi		
CO2:	654.589	g/mi	6505.37	g
CO:	0.753	g/mi	7.482	g
HC:	0.067	g/mi	0.663	g
NOx:	2.258	g/mi	22.441	g
Fuel:	205.257	g/mi	2039.861	g

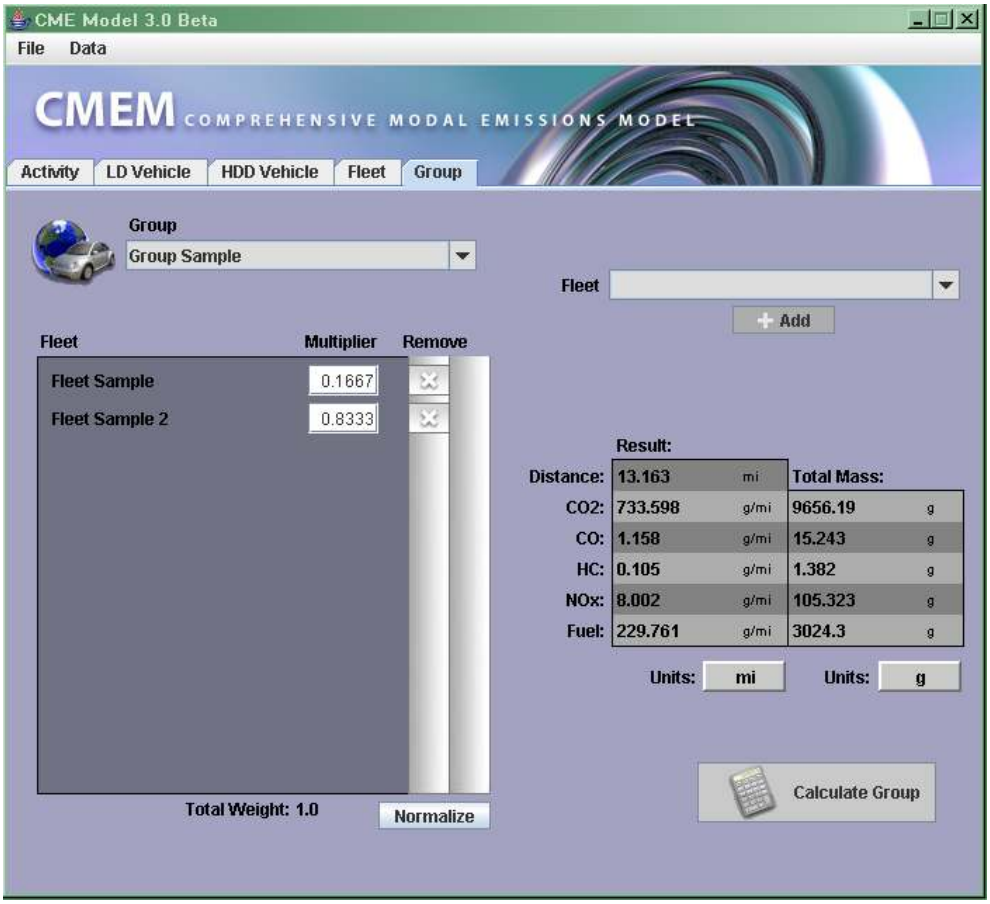
Units: mi
Units: g

Figure 4.25 CMEM Java GUI Fleet Panel

Once the fleet has been defined, calculation is initiated by clicking the *Calculate Fleet* button. This runs the model over each vehicle ID and reports the summarized weighted data in the result grid above the *Calculate Fleet* button. The unit boxes below the grid allow the user to toggle the units that the results are displayed in. To obtain second-by-second data, to export summary results or to obtain VSP binned data, the export function is required. This is discussed in more detail in section 4.27.

4.2.6 Group Panel

The *Group* panel, shown in Figure 4.26, is the second panel in which model calculations can be initiated. This panel and its functionality are identical to that of the *Fleet* panel with the exception that the *Group* panel groups fleets rather than vehicle IDs. Please refer to the previous section for instructions on defining and running fleets for use in defining and running groups. Note that fleets must be defined in the *Fleet* panel prior to being used in the *Group* panel.



Group: Group Sample

Fleet:

Fleet	Multiplier
Fleet Sample	0.1667
Fleet Sample 2	0.8333

Total Weight: 1.0

	Result:		Total Mass:	
Distance:	13.163	mi		
CO2:	733.598	g/mi	9656.19	g
CO:	1.158	g/mi	15.243	g
HC:	0.105	g/mi	1.382	g
NOx:	8.002	g/mi	105.323	g
Fuel:	229.761	g/mi	3024.3	g

Units: mi

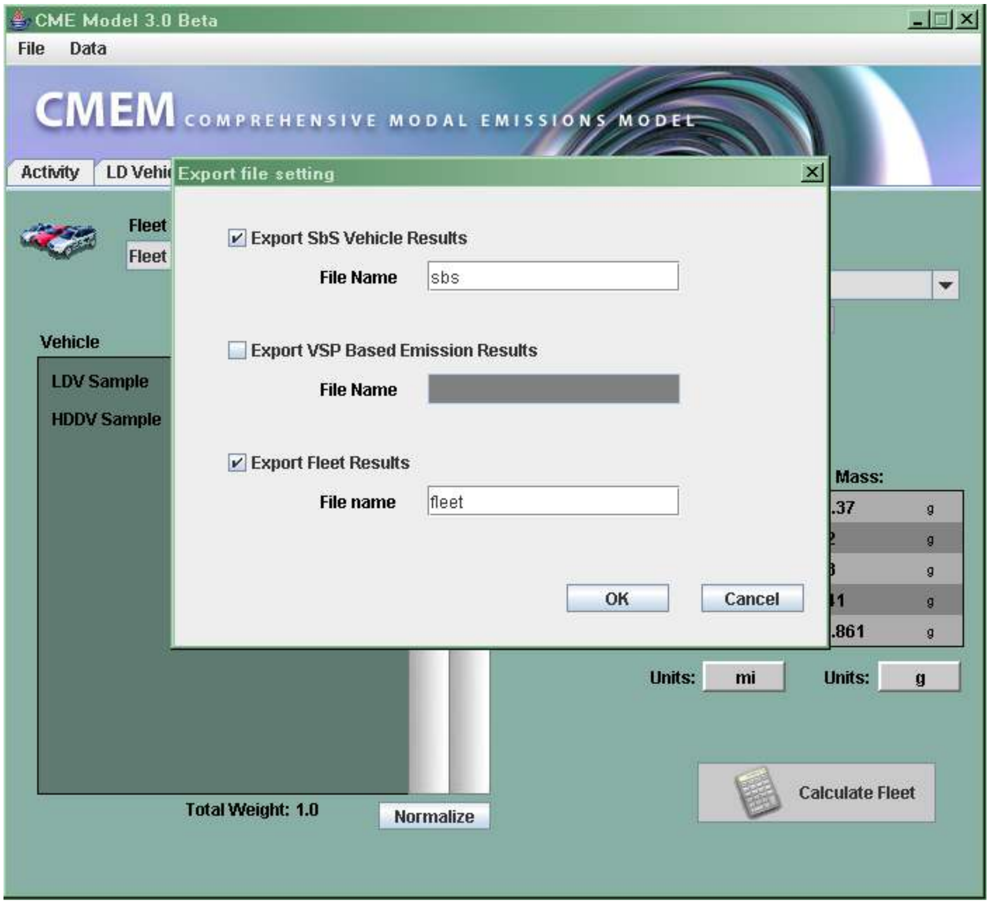
Units: g

Figure 4.26. CMEM Java GUI Group Panel

4.2.7 Exporting Data

The Java CMEM GUI has the ability to export 3 different sets of data: second-by-second vehicle data, summarized fleet results and VSP binned emission and activity data. To export data, the user needs to specify what data is exported prior to any calculation step. To specify data for exporting select the “Data → Export Results” pull down menu. This opens the *Export File Settings* window shown in Figure 4.27.

The *Export File Settings* window has three options: exporting second-by-second vehicle results, exporting VSP based emission results, and exporting fleet results. To select one, two or all of these options, check the appropriate box/boxes and specify text which will be used in part of the output file names. This will be elaborated on in the following sub-sections for each of these three options.



☑ Export SbS Vehicle Results
File Name sbs

☐ Export VSP Based Emission Results
File Name

☑ Export Fleet Results
File name fleet

Figure 4.27 Export Window

Export Second-by-Second Vehicle Results

By selecting this option and specifying text to be used with the file name, the CMEM GUI will create one vehicle ID file for each vehicle in the fleet. These files will begin with the specified text followed by an underscore and the vehicle ID name. For example the files created from the example run in Figure 4.27 would be `sbs_LDV Sample.txt` and `sbs_HDDV Sample.txt` and would look something like the example in Figure 4.28. Data in these files is given for the four pollutants: CO2, CO, HC and NOx as well as for fuel and velocity. The data is tab delimited and may not line up when opened with a text editor, but is easily imported into Excel or similar spreadsheet programs.

```
HDDV Sample
Vel    Fuel(g)      CO2(g)       CO(g)        HC(g)        NOx(g)
18.0   3.1599       10.0969      0.027        0.0027       0.0783
21.9   80.1748      256.8292     0.3852       0.0181       1.3606
25.7   92.7973      297.2679     0.4439       0.0206       1.5707
28.4   81.4884      261.0375     0.3913       0.0184       1.3824
                                   •
                                   •
                                   •
```

Figure 4.28 Second-by-Second Vehicle Results Example File

Exporting Fleet Results

By selecting this option and specifying text to be used with the file name, the CMEM GUI will create one vehicle fleet summary file for the specified fleet. This file will begin with the specified text followed by an underscore and the fleet name. For example the file created from the example run in Figure 4.27 would be `fleet_Fleet Sample.txt` and would contain data for the four pollutants: CO2, CO, HC and NOx as well as for fuel and velocity. The data file format is shown in two parts in Figure 4.29. In an actual fleet results file for a fleet containing two vehicles, these two portions of data would be contained on 5 lines. The formatting of this file may not be consistent depending on the data presented, however, the data is tab delimited and will open up easily in Excel or similar spreadsheet program.

```
Fleet: Fleet Sample
Vehicle ID  Fuel(g)     CO2(g)      CO(g)   HC(g)   NOx(g)    multiplier
LDV Sample  1196.6786   3793.894    1.0425  0.2090  0.8453    0.9091
HDDV Sample 5412.5894   17351.273   33.2378 2.4767  108.8226  0.0909
```

```
                  Fuel*m(g)   CO2*m(g)    CO*m(g)  HC*m(g)  NOx*m(g)
                  1087.9005   3449.0291    0.9477  0.1903    0.7685
                  492.0044    1577.2308    3.0213  0.2251    9.892
Weighted Total:   1579.9049   5026.2599    3.969   0.4154    10.6605
```

Figure 4.29 Export Fleet File Results. Note this is actually 5 lines of information split into two parts for viewing here.

The first line specifies the fleet name. The second line contains the header with the headings for Vehicle ID, Fuel, each of the four modeled pollutants, fleet multiplier, fuel and each of the four modeled pollutants weighted by the fleet multiplier. The lines following the header line give information for each of these headings for each vehicle ID in the fleet. The last line gives the total of the last four columns which are the weighted numbers. These numbers are comparable to the summarized results shown on the GUI.

Exporting VSP Based Emission Results

Vehicle Specific Power (VSP) binned emission rates are one method of estimating emissions. The CMEM GUI bins fleet emission and trajectory data based on the VSP bins shown in Table 4.3. The VSP definition used in this model is given by equation 4.1 and is the same definition used by CE-CERT's Integrated Vehicle Emission (IVE) model. These results are exported and can be used for comparison purposes, as an estimation tool or as inputs to other models such as transportation models.

$$VSP = 0.132 \times S + 0.000302 \times S^2 + 1.1 \times S \times dS/dt + 9.81 \times \mathrm{atan}(\sin(grade)) \qquad (4.1)$$

where:

VSP = vehicle specific power (kW/ton)
S = vehicle speed (m/second)
dS/dt = vehicle acceleration (m/second^2)
$grade$ = road grade (radians)

Power Bin VSP Values (kW/ton)					
Bin	**1**	**2**	**3**	**4**	**5**
Range	-80.0 < v < -44.0	-44.0 < v < -39.9	-39.9 < v < -35.8	-35.8 < v < -31.7	-31.7 < v < -27.6
Bin	**6**	**7**	**8**	**9**	**10**
Range	-27.6 < v < -23.4	-23.4 < v < -19.3	-19.3 < v < -15.2	-15.2 < v < -11.1	-11.1 < v < -7.0
Bin	**11**	**12**	**13**	**14**	**15**
Range	-7.0 < v < -2.9	-2.9 < v < 1.2	1.2 < v < 5.3	5.3 < v < 9.4	9.4 < v < 13.6
Bin	**16**	**17**	**18**	**19**	**20**
Range	13.6 < v < 17.7	17.7 < v < 21.8	21.8 < v < 25.9	25.9 < v < 30	30 < v < 1000

Table 4.3 VSP Power Bins (kW/ton)

In order to export VSP data, select the "Data → Export Results" pull down menu. This opens the *Export File Settings* window shown in Figure 4.27. Click on *Export VSP Based Emission Results* and specify text to be used with the output file name. This text is added to before the fleet name to create the VSP output filename. For example, entering the text "vsp" would result in the file name "vsp_Fleet1.txt" for a fleet named "Fleet1". Once the fleet name is specified, the fleet must be run to create the VSP emission files.

An example VSP output file is shown in figure 4.30. Data in this file is tab delimited. The first two lines are header lines. The first line gives the fleet name and the second line gives the column headers for the data presented in the file. The first data column is the bin number. Only bin numbers with actual activity counts are presented. The second thru fifth columns give weighted and binned emission data for the vehicle fleet. The sixth column presents frequency information for each bin as total counts or hits and the last column presents this same information as a percentage.

```
Fleet Sample
VSP bin  CO2(g)   CO(g)        HC(g)        NOx(g)       Count    Percent
6        1.223    0.0142       0.0022       0.0321       1        0.0311
7        1.198    0.0141       0.0022       0.0456       6        0.1866
8        0.9855   0.0079       0.0012       0.029        18       0.5599
9        0.9325   0.0058       9.0E-4       0.0138       59       1.8351
10       0.8563   0.0036       5.0E-4       0.0080       125      3.888
11       0.9067   0.0049       7.0E-4       0.0114       207      6.4386
12       0.9563   0.0016       3.0E-4       0.0048       1557     48.4292
                                 •
                                 •
                                 •
```

Figure 4.30 Sample VSP Result File

5 Transportation/Emissions Model Integration

The comprehensive modal emissions model was designed so that it can interface with a wide variety of transportation models and/or transportation data sets in order to produce an emissions inventory. As shown in Figure 5.1, these transportation models/data vary in terms of their inherent temporal resolution. For example, at the lowest level, microscopic transportation models typically produce second-by-second vehicle trajectories (location, speed, acceleration). Driving cycles used for vehicle testing are also specified on a second-by-second basis (speed vs. time). The CMEM implementations described in Chapter 4 are microscopic in nature.

In addition, there are other types of transportation models/data sets that aggregate with respect to time, producing traffic statistics such as average speed on a roadway facility type basis. Similar acceleration statistics may also be produced by these models. At the highest level, total vehicle volume and average speed over an entire regional network may be all that is provided.

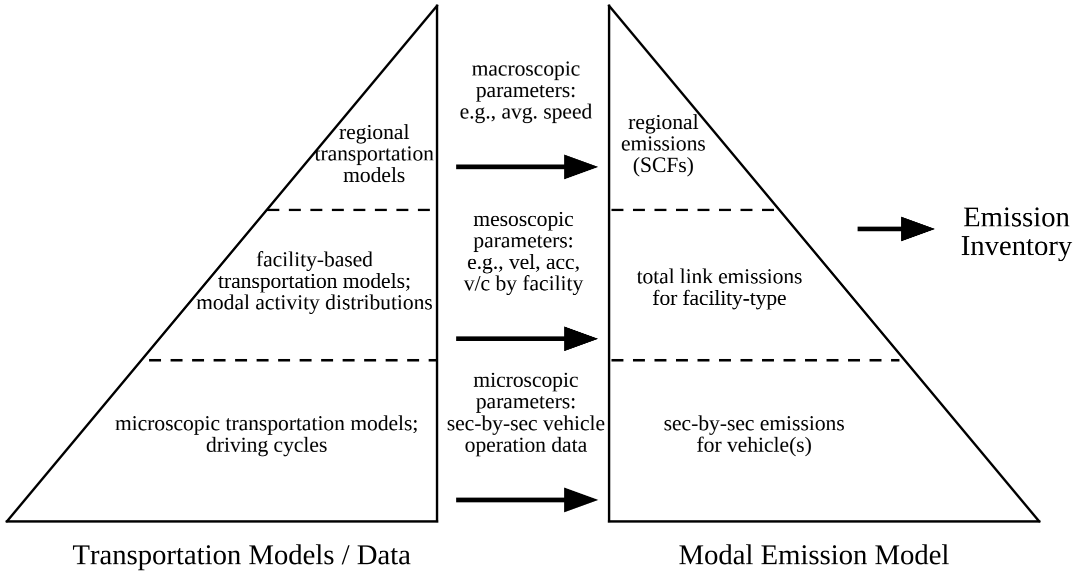


Figure 5.1. Transportation/Emission Model Interface.

In order for the fundamental emission model to be closely integrated with these different types of transportation models (with varying levels of temporal and vehicle resolution), it must be usable at various temporal resolutions. CMEM has been developed in a bottom-up fashion, concentrating first at a high temporal resolution (i.e., on the order of a few seconds) and then aggregating upwards. As illustrated in Table 5.1, emissions can be predicted second-by-second, by vehicle operating mode, or aggregate emissions can be given for a specific driving cycle (i.e., velocity profile).

Temporal Aggregation:	*second-by-second → several seconds mode → driving cycle or scenario*
Vehicle Aggregation:	*specific vehicle → vehicle/technology category → general vehicle mix*

Table 5.1. Temporal and vehicle aggregation.

In addition to temporal aggregation, vehicle aggregation must also be considered. Given an appropriate parameter set, CMEM is capable of predicting emissions for individual vehicles. However, our ultimate goal is the prediction of detailed emissions for an average *composite* vehicle within each vehicle/technology category. This composite vehicle approach is somewhat different from the approach used by traditional emission factor models. At the highest level of vehicle aggregation, the model outputs from each vehicle/technology category (i.e., composite vehicle) can be combined appropriately to represent emissions from the general vehicle population.

When considering the interface between transportation and emission models, there are primarily two key components that must be considered: 1) the vehicle fleet distribution, and 2) the vehicle operation.

Vehicle Fleet Distribution

As previously discussed, a vehicle fleet may consist of just a single specific vehicle. More than likely, however, the vehicle fleet will consist of a mixture of different vehicles. Transportation models typically aggregate similar types of vehicles into groups, based on how they operate within a transportation or traffic simulation model. In addition to the obvious divisions of vehicle types (i.e., motorcycles, passenger cars, buses, heavy-duty trucks), categories are often made based on vehicle performance (e.g., high-performance cars, low-performance cars) that can be closely related to traffic simulation parameters. For heavy-duty trucks, transportation models/datasets typically categorize their vehicles based on their configuration and number of axles. In all cases, a straightforward approach to handling the transportation/emissions model interface is to create an appropriate *mapping* between the vehicle types defined in the transportation model, and the vehicle types defined in the emission model. This is usually represented as a matrix which specifies the different categories and the percentage of each vehicle class.

Vehicle Operation

The parameters that define how vehicles operate in a transportation modeling framework are highly dependent on the fidelity level of the model. For microscopic transportation simulation models, typical vehicle operating parameters include second-by-second velocity, acceleration (which can be differentiated from velocity), and position (from which road grade can be deduced) for each individual vehicle. Other secondary variables that may be given at this fine level of resolution include load-producing accessory use (e.g., air conditioning) and front and rear vehicle spacings (which may play a role with aerodynamic drag reduction if sufficiently small).

For mesoscopic transportation models (e.g., models that still consider individual vehicles but not their dynamic operation), the vehicle/traffic operating parameters may include average velocity by roadway facility type, volume/capacity by roadway facility type, and average energy or work parameters such as Positive Kinetic Energy (PKE), or Total Absolute Acceleration Differences (TAD). For macroscopic models, the parameters average speed and VMT are typically provided.

This chapter discusses these transportation/emission modeling issues. The primary form of CMEM is either the command-line version or the Microsoft ACCESS version with an easy-to-use graphical user interface (described in the previous chapter). Another form of the model, also occurring at the microscopic level, is when the model is represented as velocity/acceleration-indexed emissions/fuel lookup tables, described below. A methodology is also given for generating mesoscopic emission factors for a more aggregated transportation modeling framework. This chapter also discusses a detailed methodology on how to generate the appropriate weights for the CMEM categories given a vehicle registration database and describes vehicle category mappings that have been made between the conventional EMFAC/MOBILE models and CMEM's vehicle/technology categories. The final section describes the CMEM API which was developed for Paramics, a set of microscopic traffic simulation software tools.

5.1 VELOCITY/ACCELERATION-INDEXED EMISSION/FUEL LOOKUP TABLES

Interfacing transportation and emission models at the microscopic level is straightforward, as shown at the bottom of Figure 5.1. Second-by-second vehicle operation data is generated on the transportation/data side and transferred straight across to the modal emissions model. The emissions data can then be integrated to provide an emissions inventory. As an example, the vehicle trajectory output file (used primarily for viewing the trajectories) of FHWA Traffic Software Integrated System (TSIS) models can be used as the second-by-second activity and input directly into CMEM as described in Chapter 4.

Another technique that can be used is to generate *velocity/acceleration-indexed lookup tables* of emission values and directly integrate those with the microscopic traffic simulation model. FHWA's TSIS suite of microscopic traffic models (i.e., FRESIM, NETSIM, CORSIM) also are capable of estimating emissions using this technique.

It is straightforward to generate these lookup tables from the core form of CMEM. All the different combinations of velocity and acceleration are input into the model and an emissions "mesh" is created as output. When inputting different sets of velocity and acceleration, the core modal emissions model also evaluates whether the input is outside the performance envelope of the vehicle. For example, if you ask a low-powered vehicle to undertake a hard acceleration at high speed, the vehicle will not be able to meet this performance demand. When vehicle operation inputs are beyond the performance envelope, emissions and fuel consumption are predicted for the maximum performance at the given speed.

The velocity/acceleration-indexed lookup tables have been generated for the 26 different composite vehicles representing the 26 modeled vehicle/technology categories. An example set of lookup tables for category 4 is illustrated in Figure 5.2, where fuel, CO, HC, and NOx are shown for this composite vehicle. For the majority of these vehicles, it is readily apparent that the emissions and fuel consumption are fairly low at low power; emissions then increase tremendously in a "cliff"-like fashion when the enrichment threshold is exceeded. The emissions levels in the enrichment region can be several orders of magnitude greater than those in the low-powered stoichiometric region. Because of this, little detail is seen at the lower emission levels. In order to see these lower emission details, it is possible to plot these velocity/acceleration-indexed graphs on a semi-log basis.

The lookup table-based emission model form is straightforward to implement, and the computational costs are very low. However there is a serious potential problem with this form of model. Using instantaneous lookup tables assumes that there is no time dependence in the emissions response to the vehicle operation. This assumption is not true for many vehicle types where vehicle operating history (i.e., the last several seconds of vehicle operation) can play a significant role in an instantaneous emissions value (e.g., the use of a timer to delay command enrichment, and oxygen storage in the catalytic converter). Further, there is no convenient way to introduce other load-producing effects on emissions such as road grade, or accessory use (e.g., air conditioning), other than introducing numerous other lookup tables, or perhaps a applying a set of corrections.

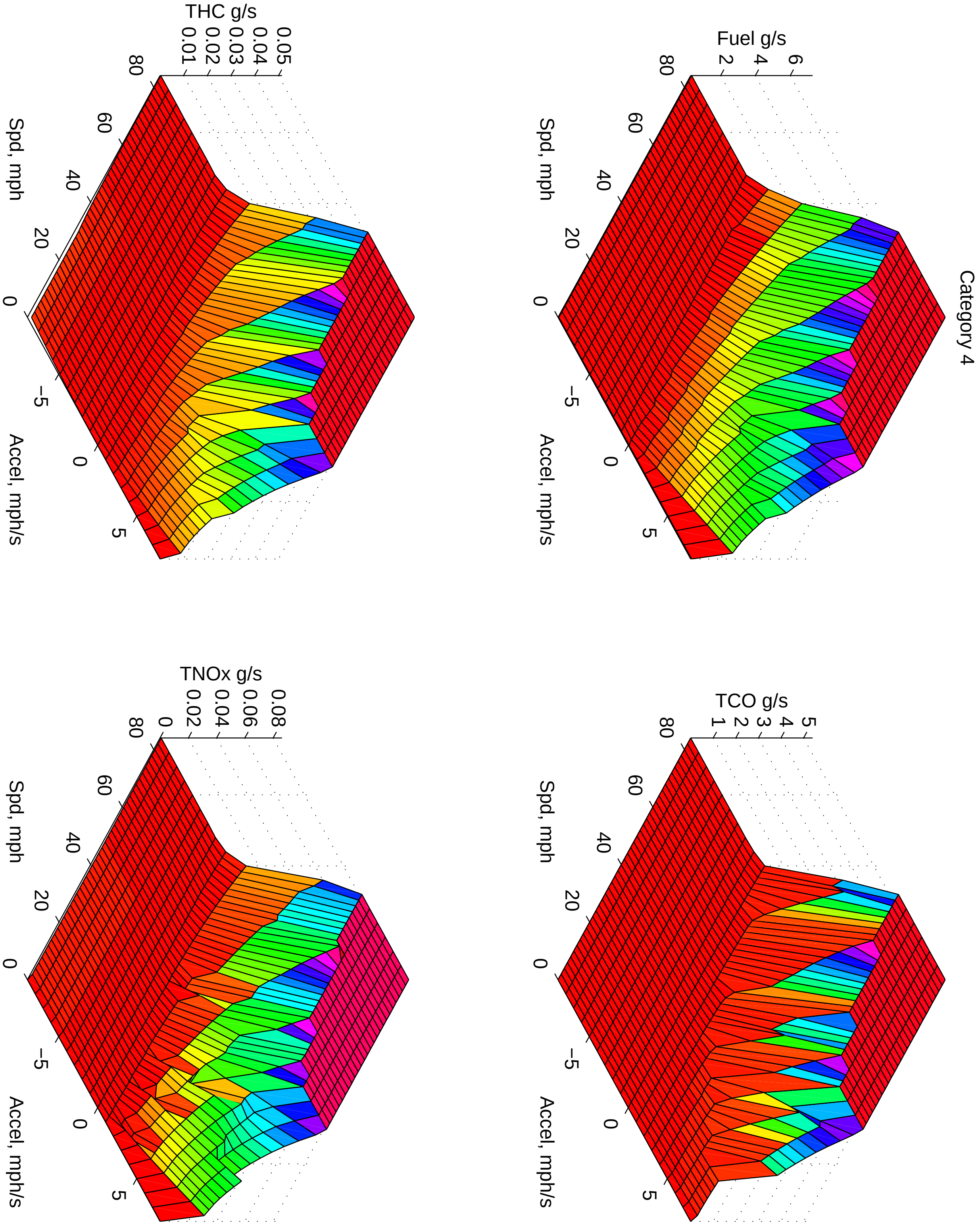


Figure 5.2. Velocity/Acceleration-index tailpipe emission lookup tables for CMEM vehicle/technology category #4.

5.2 Generating Mesoscopic Emission Factors

Interfacing transportation and emissions models at the mesoscopic level is somewhat more complicated than at the microscopic level. However, one of the key advantages of the microscopic modal emissions model is that one can estimate emissions (and fuel consumption) for any given driving cycle, without the trouble of performing expensive dynamometer testing. Therefore, it is possible to create mesoscopic emission factors, referring to Figure 5.1. Driving cycles can be generated for different roadway facility types and possibly different congestion levels (left middle section in Figure 5.1). These driving cycles can then be applied to the modal emissions model and the resulting emissions output can be integrated to provide facility-based emission factors (right middle section in Figure 5.1).

Current conventional emission models have no mechanism to produce facility-specific emissions inventories, i.e., emissions for specific roadway facilities such as highways, highway ramps, main arterials, residential roads, etc. This is a critical issue, since driving patterns vary greatly depending on road type. Two "trips" that have the same average speed can have drastically different emission results depending on whether the trip was made on free-flowing arterials or on a congested freeway.

To address these problems, the U.S. EPA is introducing into its latest version of MOBILE (MOBILE6, to be released in 2000) a new modeling methodology that uses facility-specific driving cycles for inventory development. Under contract to the EPA, Sierra Research [Sierra-Research, 1997] has created several facility-specific driving cycles based on matching speed-acceleration frequency distributions for a wide range of roadway types and congestion levels. Six driving cycles have been developed for freeway driving. These cycles range from high-speed driving (Level-of-Service A+, where vehicles have little or no interaction with other vehicles) to driving in near gridlock conditions (Level-of-Service F-). Cycle length ranges from 4 to 12 minutes and the cycles were constructed to optimally match the observed speed-acceleration and specific power frequency distributions of the on-road vehicle data [Sierra-Research, 1997]. These cycles are shown in Figure 5.3. General characteristics of these cycles are given in Table 5.2. The cycle characteristics include average speed (mph), maximum speed (mph), maximum acceleration rate (mph/second), cycle length in terms of time (seconds) and distance (miles), and *Kmax*, the maximum specific energy (defined as 2 * velocity * acceleration, in units of mph^2/second).

Cycle	Avg Speed (mph)	Max Speed (mph)	Max Accel (mph/s)	Length (seconds)	Length (miles)	Kmax (mph^2/s)
LOS A+	63.2	74.7	2.7	610	10.72	357
LOS A-C	59.7	73.1	3.4	516	8.55	307
LOS D	52.9	70.6	2.3	406	5.96	233
LOS E	30.5	63.0	5.3	456	3.86	227
LOS F	18.6	49.9	6.9	442	2.29	215
LOS F-	13.1	35.7	3.8	390	1.42	99

Table 5.2. Freeway congestion cycle characteristics (Kmax is the maximum specific energy, defined as 2 *vel * ac).

Other driving cycles have been developed for arterial driving patterns. As an example of how to create facility/congestion-based mesoscopic emission factors, these driving cycles can be applied directly to CMEM, for each composite vehicle. The resulting integrated emissions for the fleet can serve as "emission factors" within a mesoscopic transportation modeling framework. If the transportation model predicts the amount of traffic flow and congestion conditions for the different roadway segments (freeway, arterial, collector, ramp), then these factors can be appropriately applied and summed together t

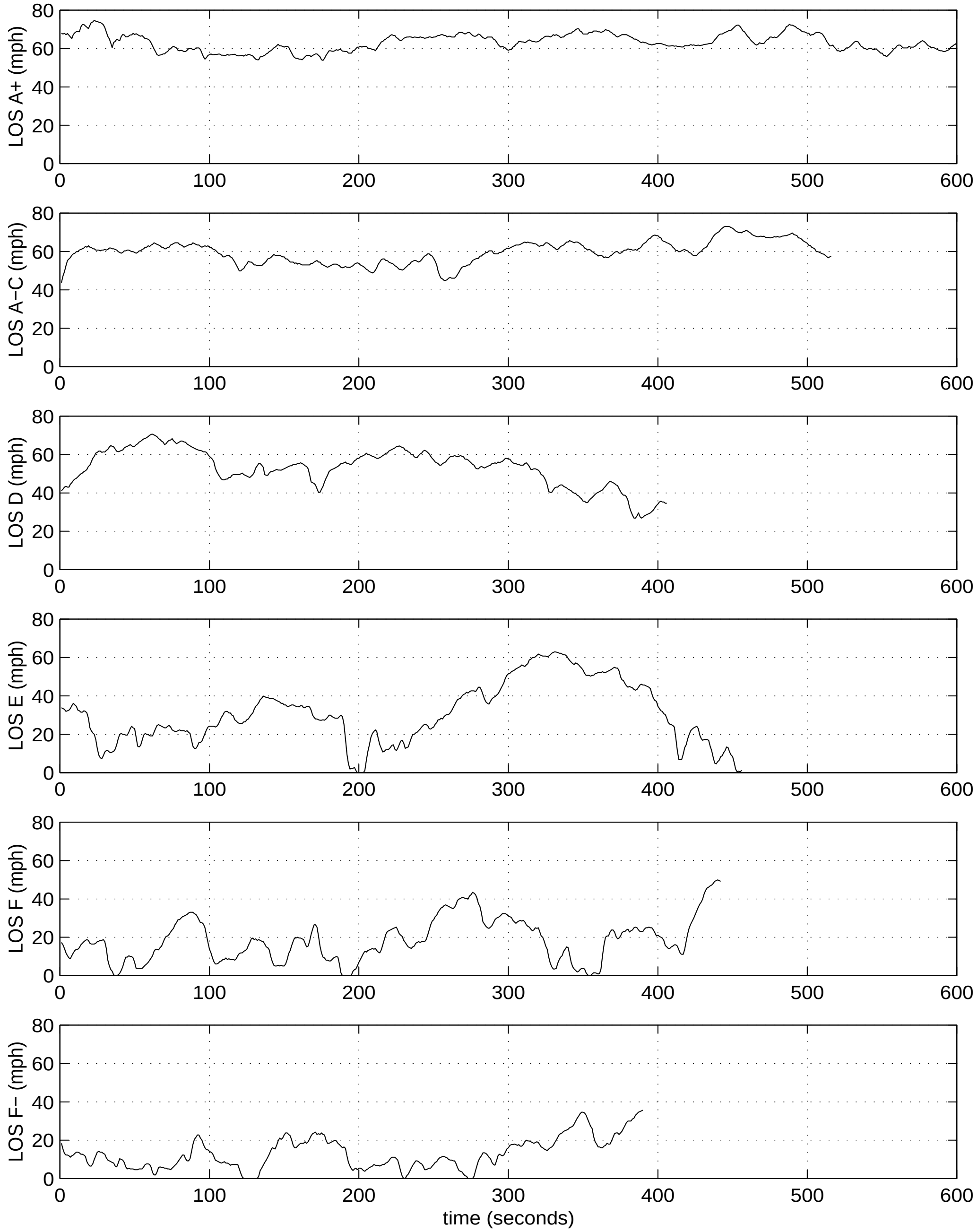


Figure 5.3. Freeway congestion cycles.

5.3 CATEGORIZATION FROM A VEHICLE REGISTRATION DATABASE

In order to use CMEM for estimating an inventory for a vehicle fleet, it is necessary to take a given vehicle database and determine the appropriate CMEM category for each vehicle. A common vehicle database will typically come from a state's department of motor vehicles (DMV) or a national database such as that assembled by the R.L. Polk & Company. A DMV vehicle registration database contains information about each registered vehicle, and with that information, each vehicle can be categorized into the appropriate CMEM vehicle/technology group. A state's entire vehicle registration database can be used, but more commonly, *regional subsets* of the database are applied. These regional subsets could be at the county level, city level, or even at the zip-code level.

A subset of a vehicle registration database can also be determined using license plate monitoring. If a set of license plate numbers are observed and recorded, the license plate numbers can be used as a filter set applied to the vehicle registration database. This is similar to creating a regional subset (by county, city, zip-code, etc.), however the license plate number is used as the filter field. Many states now use remote sensing equipment for monitoring instantaneous emissions of vehicles as they pass a particular spot on the road. With these emission measurements, the license plate is typically imaged with a video camera and registered with the measurement database.

As an example of a methodology for going from a vehicle registration database to the CMEM vehicle/technology categories, a *categorization program* has been developed, described below. This categorization program uses certain fields from a vehicle registration database and classifies each individual vehicle. Please note that this categorization program serves as an example for the local Riverside California area only and should not be applied elsewhere without changing some of its assumptions. Further, it is important to note that the VMT or fleet percentages returned by the categorization program serve as a "snapshot" in time, based on the year of the registration database.

The categorization process is illustrated in Figure 5.4. Several fields are extracted from the database, and a *decision tree* is used when categorizing each vehicle. In addition to the information provided from the vehicle registration database, additional information is necessary. For example, in order to classify a vehicle as either a high- or normal-emitter, high emitter probability distributions are necessary.

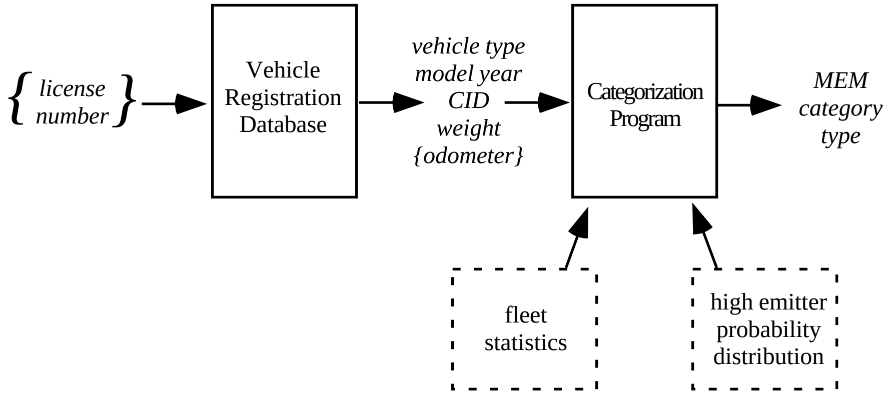


Figure 5.4. Registration Database to CMEM category type.

5.3.1 Vehicle Registration Database Fields

There are many fields in a typical vehicle registration database for each vehicle, several of which are used by the categorization program. Fields of a typical vehicle registration database are:

Owner Information—the owner's name, address, and zip-code are almost always included in a vehicle registration database. The address and zip-code information can be used to filter larger databases into smaller areas of interest;

Vehicle Type—a parameter is often given specifying what the type of vehicle. Common parameters include symbols for motorcycles, passenger vehicles, trucks, and miscellaneous;

Registration Information—information on registration is typically included in the form of registration status, expiration date, year-first-sold, and purchase price. The *year-first-sold* data field is typically the same as the *model year* field, which is a critical piece of information when categorizing vehicles;

Vehicle Make, Model—the vehicle make and model information is included, along with information on body style;

Fuel Type—another important field for categorization is the type of fuel a vehicle uses. Common parameters include symbols for gas, flex fuel, electric, natural gas, diesel, and propane;

Vehicle Identification Number (VIN)—a vehicle registration database almost always contains the Vehicle Identification Number (VIN) for each vehicle. This VIN is a unique alphanumeric character set for each vehicle. Encoded in the VIN is a wealth of information such as make, model, vehicle creation date, manufacturing plant, engine and emission control equipment specifications, etc. It is a difficult task to decode VINs, since vehicle manufacturers use different formats. Commercial VIN decoders exist, however they are often incomplete and expensive. If it were possible to decode each vehicle's VIN, then the categorization process could be done nearly deterministically (rather than stochastically, as described below). Due to its complexity, we did not attempt to perform VIN decoding in our categorization program;

Cubic Inch Displacement (CID)—the vehicle's engine size is given as CID, and this is usually included in the VIN information. In California's vehicle registration database, CID is given as a separate field in the registration data;

Vehicle Weight—similar to CID, the vehicle weight is another key field in the database. Weight is particularly important in the truck classifications. Also, both CID (which can be related to horsepower) and weight are used to calculate the power-to-weight ratio of each vehicle. This is important in the CMEM automobile classification system;

Odometer—in most vehicle registration databases, there is a field for the odometer. The odometer information of most vehicle databases is only updated when a vehicle is sold or transferred. Recently, there have been efforts made to update the odometer information on a yearly basis using updated registration documents or by cross referencing to yearly smog check data or mileage surveys. However, the odometer data in California's current database is highly suspect and unreliable. For this reason, we use estimated mileage accrual rates (indexed by year) to determine the average mileage of a vehicle. In the categorization program, we assume a normal distribution around this average mileage, and use a stochastic random variable to estimate each vehicle's mileage.

5.3.2 Categorization Program*

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* Please note that this categorization program serves only as an *example* and was developed for the original 23 CMEM categories and is currently not implemented for all categories.

The categorization program is essentially a decision tree, illustrated in Figure 5.5a and 5.5b. The fields of the vehicle registration database that are used include vehicle type (car or truck), fuel type, model year, vehicle weight, and vehicle CID. The fuel type field is used to differentiate between gasoline and diesel powered vehicles. The first decision point in the program is determining whether the vehicle is a car or a truck. The car decision tree flow diagram is shown in Figure 5.5a, the truck decision tree flow diagram is shown in Figure 5.5b.

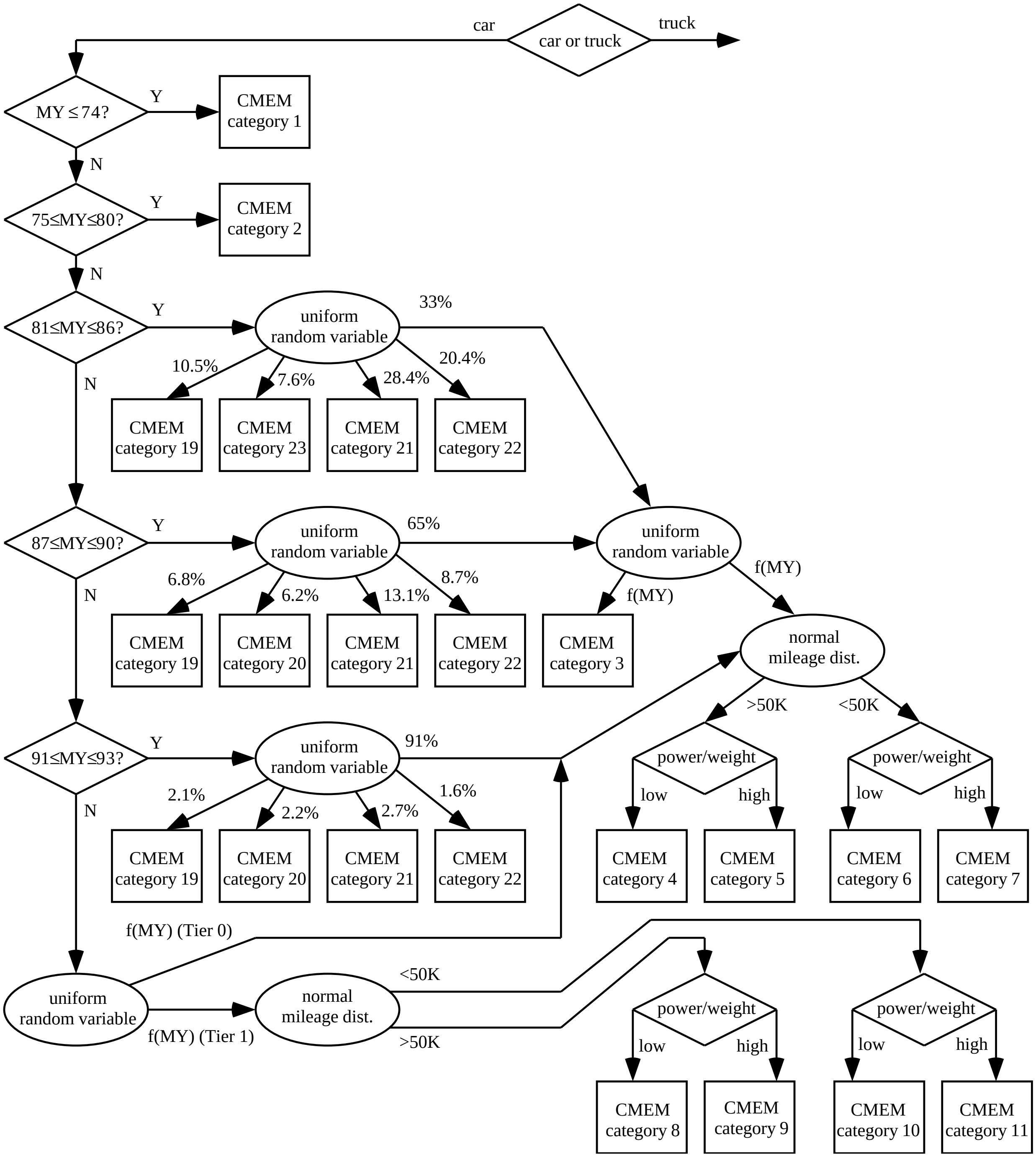

Figure 5.5a. Categorization decision tree for light-duty automobiles.

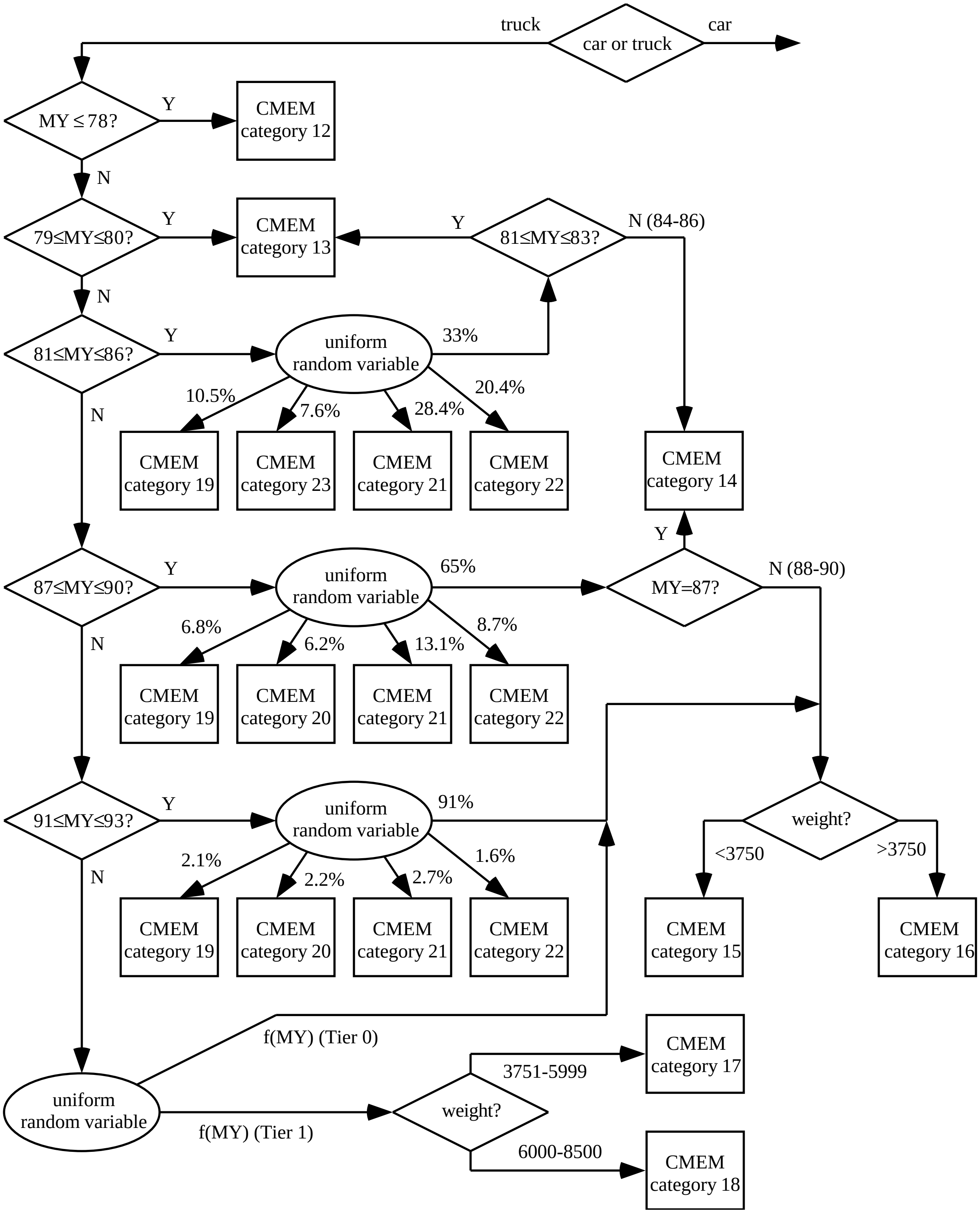

Figure 5.5b. Categorization decision tree for light-duty trucks.

Car Categorization

In this program, we consider a total of eleven separate car categories, and five shared high-emitter categories. Model year information is used throughout the decision tree as a proxy for vehicle technology (e.g., emission certification standard, emission control system, fuel system, etc.). If the year is 1974 or older, then these vehicles are classified into CMEM category 1 (non-catalyst cars). If the model-year is in the range of 1975-1980, then the vehicle is classified into CMEM category 2 (2-way catalyst cars).

After 1980, the vehicles can potentially fall into a high emitter category[*]. As specified in Chapter 3, an approximate high-emitter distribution was developed based on the Arizona I/M program dataset. This distribution will likely be different for different parts of the country. This example distribution is shown in Table 5.3.

MY Group	Normal Emitter	HE Type 1: runs lean (19)	HE Type 2 or 5: runs rich (20,23)	HE Type 3: misfire (21)	HE Type 4: bad catalyst (22)
MY 81-86	33%	10.5%	7.6%	28.4%	20.4%
MY 87-90	65%	6.8%	6.2%	13.1%	8.7%
MY 91-93	91%	2.1%	2.2%	2.7%	1.6%
MY 94-97[**]	98%	0.6%	0.8%	0.5%	0.3%

Table 5.3. Estimated high emitter proportion in fleet.

Since it is impossible to determine whether a vehicle is a high emitter (let alone what type of high emitter) directly from the vehicle database fields, the categorization is handled stochastically. A uniform random variable is generated, and the category decision is based on the high emitter distributions. If the vehicle is categorized to be a normal emitter, further processing is done on the vehicle information. Note that the percentages in Table 5.3 is only a "snapshot" in time, based on 1998 data. A methodology for calculating these percentages in future years is given in [Barth et al., 1999].

Beginning in 1981, fuel-injection technology started penetrating the vehicle fleet. In the CMEM categorization, a distinction is made between carbureted vehicles versus fuel injected vehicles. From 1981 (all vehicles have 3-way catalytic converters) the percent of the fleet with carburetors slowly decreases over the years. The approximate 3-way catalyst, carbureted vehicle distribution is shown in Table 5.4.

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
% carbureted veh.	91%	83%	73%	61%	49%	32%	26%	10%	13%	2%	0%

Table 5.4. Distribution of carbureted vehicles by model year.

Given this distribution of carbureted vehicles, again a uniform random variable is used to properly allocated vehicles to CMEM category 3. Vehicles that are not categorized as carbureted vehicles for model year time frame 1981-1986 go on for further processing into other CMEM categories.

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[*] Please note that vehicles older than 1980 can be high emitters, however their emission characteristics do not differ substantially from a normal emitting 1980 and older vehicle and are therefore not distinguished.

[**] Our analysis of high emitters was limited to MY97 and older vehicles; further research is necessary to estimate the distribution of high emitters among newer vehicles in the fleet (although preliminary evidence has shown that MY97 and newer vehicles have a very small high emitter fraction).

Accumulated Mileage

The next decision for the vehicles is based on accumulated mileage. Remember that in some cases the CMEM categorization differentiates between whether a vehicle has fewer than or greater than 50,000 accumulated miles. As discussed above, odometer information that may appear as a variable field in a vehicle registration database is often unreliable. The odometer information in these databases is not updated frequently enough, and also suffers from mis-readings of odometers that have rolled over. For these reasons, we determine accumulated mileage stochastically. Mileage accumulation rates by year have been compiled by both CARB and the US EPA based on various sources (e.g., odometer surveys, R.L. Polk & Company, etc. [US EPA, 1998]). For our Riverside California example case, we used the same mileage accumulation rates that CARB's MVEI modeling suite uses [CARB, 1996].

By summing the mileage accumulation rate for each year, it is possible to determine the average mileage for each vehicle year. For example, to determine a 1981's average mileage, we simply sum the mileage accumulation rates for 1997, 1996, 1995, …, and 1981. The average mileage for each vehicle year (determined for the base year 1998) is given in Table 5.5.

Year			**1997**	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**
Average mileage			14169	27732	40688	53037	64779	75914	86442	96363
Year	**1989**	**1988**	**1987**	**1986**	**1985**	**1984**	**1983**	**1982**	**1981**	**1980**
Average mileage	105677	114384	122485	130082	137246	144034	150491	156705	162776	168716
Year	**1979**	**1978**	**1977**	**1976**	**1975**	**1974**	**1973**	**1972**		
Average mileage	174535	180242	185845	191350	196764	202092	207339	212509		

Table 5.5. Average accumulated mileage by model year (relative to base year 1998).

We make an important assumption in mileage accumulation, i.e., that the mileage for a given model year is normally distributed around the average accumulated mileage. This says that given all the vehicles for a specific model year, the average accumulated mileage will be the center of the normal distribution, which tails off symmetrically in both directions (i.e., some vehicles will have higher mileage, others will have lower mileage). Further, we assume that the standard deviation of this normal distribution is approximately one third of the average accumulated mileage (if it is found that these assumptions are not true, substitute distributions can be used). The categorization program then uses a cumulative density function that predicts the probability a vehicle will have mileage greater than or less than the specified 50,000 mile cutpoint. The probability that these vehicles have less than 50,000 miles is given based on the area under the curves up to the cutpoint with respect to the total area. The cumulative density functions have been calculated for each model year, giving the above 50K/below 50K probabilities as illustrated in Table 5.6. Please note that these calculations depend on the base year of the inventory.

Year			**1997**	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**
prob(x<50K)			100%	99.25%	75.60%	43.11%	24.47%	15.05%	10.07%	7.24%
Year	**1989**	**1988**	**1987**	**1986**	**1985**	**1984**	**1983**	**1982**	**1981**	**1980**
prob(x<50K)	5.52%	4.40%	3.65%	3.11%	2.70%	2.39%	2.15%	1.95%	1.79%	1.65%
Year	**1979**	**1978**	**1977**	**1976**	**1975**	**1974**	**1973**	**1972**		
prob(x<50K)	1.53%	1.43%	1.34%	1.26%	1.19%	1.13%	1.07%	1.02%		

Table 5.6. Probability of mileage less than 50,000 miles by model year (relative to base year 1998).

In the categorization program, the normal distributions are set up for each vehicle year, and a random sample is taken from the distribution. The random sample value is then used to calculate the mileage which is then simply compared to the 50,000 mile cutpoint to determine which branch of the decision tree it falls in.

Power/Weight Ratio

After the mileage determination in the decision tree, the power/weight ratio is used next as a decision split. In the categorization program, the power/weight ratio can usually be calculated deterministically. The fields *CID* and *weight* are both used from the vehicle registration database. In order to calculate approximate horsepower of the engine, we rely on an empirical relationship between CID (cubic inch displacement) and horsepower, indexed by model year. Thus given CID from the database, HP can be calculated. Power to weight ratio is then simply calculated as HP/weight, where weight is determined directly from the vehicle registration database.

Once power/weight is calculated, it is compared to the cutpoints determined previously. For Tier 0 vehicles, the cutpoint is approximately 0.039. For Tier 1 vehicles, the cutpoint is approximately 0.415 (the average power/weight of new vehicles has gradually increased over the years). Once the power/weight decision is made, the vehicles fall into their final categorization, as seen in Figure 5.5a.

Further down in the decision tree, different high emitter distributions are used depending on the model year grouping. At the bottom of the tree, the remaining vehicles are Tier 1 vehicles, which are then divided into their appropriate categories depending again on mileage and power/weight. For the Tier 1 vehicles, a uniform random variable is used to approximate the penetration by model year. For 1994 vehicles, 40% of the cars are Tier 1 certified. For 1995, approximately 80% are Tier 1 certified. For 1996 and beyond, all cars are Tier 1 certified.

Truck Categorization

The categorization for trucks is similar to that of cars, although somewhat less complicated. Referring to Figure 5.5b, the model year of the vehicle is used to determine the path in the decision tree. If the model year is less than or equal to 1978, the truck is classified as CMEM category 12. If the truck model year ranges from 1979 to 1980, the truck is classified as CMEM category 13. From 1981 on, high-emitter probability distributions again come into play. Similar to the car decision tree, a uniform random variable is used to predict whether a truck is normal emitting, or a specific type of high emitter. If it is normal emitting and is in the model year range 1981-1983, then it is classified as CMEM category 13. If it is in the model year range 1984-1986, then it is classified as CMEM category 14.

For the model year grouping 1987-1990, a different high emitter distribution is used. If the vehicle is predicted to be normal emitting and model year 1987, it is classified as CMEM category 14. The remaining model years (1988-1990) are further differentiated by vehicle weight. If the weight (given directly by the vehicle registration database weight field) is less than 3750 lbs, then it is classified as CMEM category 15. If it is greater than 3750 lbs, it is a CMEM category 16.

For the model year grouping 1991 – 1993, again a different high emitter distribution is used. As before, if the vehicle is determined to be normal emitting, then it is further differentiated by weight. Similar to the car decision tree, a uniform random variable is used to determine if a truck is a Tier 1 vehicle in the later model years. In 1994, 10% of the trucks are Tier 1 certified. In 1995, 21% are Tier 1 certified. In 1996, 45% are Tier 1 certified. In subsequent years, all trucks are Tier 1 certified. The Tier 1 trucks are then differentiated by weight in the CMEM categorization.

5.3.3 Program Application

As an example, the categorization program was applied to the Riverside, California area. California's Department of Motor Vehicle's 1996 vehicle registration database was first pre-filtered to all of the zip-codes within Riverside's city limits. This subset contained approximately 179,000 vehicles. A second area was also defined to contain the zip-codes within Riverside's city limits as well as other outlying areas. This particular subset contained approximately 301,000 vehicles. When these subset databases were created, a large number of the irrelevant fields were eliminated to reduce the size of the data files. An example of the database input is shown in Figure 5.6.

```
,VIN,,,MKNAME,,MY,,YFSA,,,MODEL,,,FUEL,,CID,CLASS,WEIGHT
,2G37T3Z110630,,,PONTIAC,,73,,CA,,,LEMANS,,,G,,400,0,3799
,WBABF4323REK13579,,,BMW,,94,,CA,,,325IS,,,G,,152,0,3164
,1G4NV5537RC255985,,,BUICK,,94,,CA,,,SKYLARK,,,G,,138,0,2791
,4S2CG58V6S4333292,,,ISUZU,,95,,CA,,,RODEO,,,G,,195,0,3755
,JN6FD06S0EW001142,,,NISSAN,,84,,OS,,,720,,,G,,120,1,2836
,1P4GH44R2PX756692,,,PLYMOUTH,,93,,CA,,,VOYAGER,,,G,,201,0,3476
,1G2NE12T8TM508920,,,PONTIAC,,96,,CA,,,GRAND AM,,,G,,146,0,2662
,JB7FP5475DY800133,,,DODGE,,83,,CA,,,D50,,,G,,155,1,2630
,3GCCW80HXHS914471,,,CHEVROLET,,87,,CA,,,ELCAMINO,,,G,,305,0,3106
,JT5RN75TXJ0021701,,,TOYOTA,,88,,CA,,,CAB/CHASSIS,,,G,,144,1,2796
,2GCEC19H9R1196498,,,CHEVROLET,,94,,CA,,,GMT-400,,,G,,305,2,4210
,1FTCR14X7LPA49501,,,FORD,,90,,CA,,,RANGER,,,G,,245,1,3085
,YV1AX8854J1786521,,,VOLVO,,88,,CA,,,245,,,G,,141,0,3034
,1GNGR26K9HF129704,,,CHEVROLET,,87,,OS,,,R20 CONV,,,G,,350,2,5058
,JHMSM3421BC120156,,,HONDA,,81,,CA,,,ACCORD,,,G,,107,0,2249
,JHMAD5433FC029833,,,HONDA,,85,,CA,,,ACCORD,,,G,,112,0,2277
,1FMEU15G6CLA00315,,,FORD,,82,,CA,,,BRONCO,,,G,,351,0,4079
,1FALP62W2RH216207,,,FORD,,94,,CA,,,THUNDERBIRD,,,G,,281,0,3570
,1FMDU34X6RUB35970,,,FORD,,94,,CA,,,EXPLORER,,,G,,245,0,4053
,2MEBM79F4JX618498,,,MERCURY,,88,,CA,,,MARQUIS,,,G,,302,0,4025
```

Figure 5.6. Example database input into the categorization program. The fields are comma delimited, with a number of fields eliminated to save space.

The categorization program was applied to both of these database subsets. The results are shown in Table 5.6. It can be seen that as of 1998, the majority of the vehicles in the local Riverside registered fleet are Tier 0 certified vehicles, with mileage greater than 50,000 miles. It can be seen that adding vehicles in the outlying area results in a slightly newer vehicle fleet.

5.4 CATEGORIZATION FROM MOBILE/EMFAC MAPPINGS

As an alternative to characterizing the vehicle fleet through a registration database, it is possible to use the fleet characteristics many states have already calculated for their region using the conventional regional emission inventory models MOBILE (US EPA, for the 49 states) and EMFAC (CARB, for California). In order to calculate these emission inventory estimates, vehicle fleet percentages and/or vehicle populations have to be determined for the region in question. These vehicle fleet percentages and/or vehicle populations have been calculated for the gross vehicle categories of the regional models. For MOBILE, these categories consist of light duty gas vehicle (LDGV), light duty diesel vehicle (LDDV), light-duty gasoline trucks (LDGT), light-duty diesel trucks (LDDT), and a variety of different heavy-duty truck categories.

Since the current version of CMEM only addresses light-duty vehicles, we are only concerned at this point with LDGVs, LDGTs, and LDDTs. For each of these categories, MOBILE also specifies the vehicle fleet fraction by model year.

For CARB's MVEI model suite (i.e., EMFAC), the categories are very similar, with a bit more disaggregation for the light duty vehicle technologies. The categories include light duty automobiles (LDA) which are split into gasoline fueled with no catalytic converter (LDA-NOCAT), those with catalytic converter (LDA-CAT), and those that are diesel fueled (LDA-diesel). Similarly with light duty trucks (LDT), there are LDT-NOCAT, LDT-CAT, and LDT-diesel. CARB also has a wide range of medium- and heavy-duty truck categories, which are currently outside the scope of this project. Similar to MOBILE, CARB's MVEI model also specifies the vehicle fleet fraction by model year.

#	Vehicle Technology Category	Categorization Results	
	Normal Emitting Cars	**Riverside proper**	**Riverside region**
1	**No Catalyst**	10.22%	9.21%
2	**2-way Catalyst**	8.57%	8.28%
3	3-way Catalyst, Carbureted	9.16%	9.31%
4	3-way Catalyst, FI, >50K miles, low power/weight	12.11%	12.69%
5	3-way Catalyst, FI, >50K miles, high power/weight	15.39%	15.47%
6	3-way Catalyst, FI, <50K miles, low power/weight	1.07%	1.17%
7	3-way Catalyst, FI, <50K miles, high power/weight	1.62%	1.60%
8	Tier 1, >50K miles, low power/weight	1.37%	1.52%
9	Tier 1, >50K miles, high power/weight	2.49%	2.54%
10	Tier 1, <50K miles, low power/weight	1.30%	1.41%
11	Tier 1, <50K miles, high power/weight	2.55%	2.62%
	Normal Emitting Trucks		
12	Pre-1979 (<=8500 GVW)	4.62%	4.43%
13	1979 to 1983 (<=8500 GVW)	2.52%	2.50%
14	1984 to 1987 (<=8500 GVW)	4.26%	4.24%
15	1988 to 1993, <=3750 LVW	3.70%	3.86%
16	1988 to 1993, >3750 LVW	4.84%	4.82%
17	Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)	0.51%	0.52%
18	Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)	0.46%	0.44%
	High Emitting Vehicles		
19	Runs lean	2.25%	2.25%
20	Runs rich	3.17%	3.19%
21	Misfire	4.45%	4.48%
22	Bad catalyst	1.52%	1.57%
23	Runs very rich	1.84%	1.88%

Table 5.6. Vehicle/Technology categorization results for the Riverside area.

Vehicle fleet percentages and vehicle populations have already been determined for many regions, therefore it makes sense to take advantage of this information in determining vehicle fleet percentages and/or populations for the CMEM vehicle categories. For this reason, *mappings* can been created between CARB's and EPA's vehicle category types and CMEM's vehicle categories. Using these mappings, states can take existing vehicle distributions based on the current CARB/EPA models and translate them for input into CMEM. This mapping procedure is illustrated in Figure 5.7.

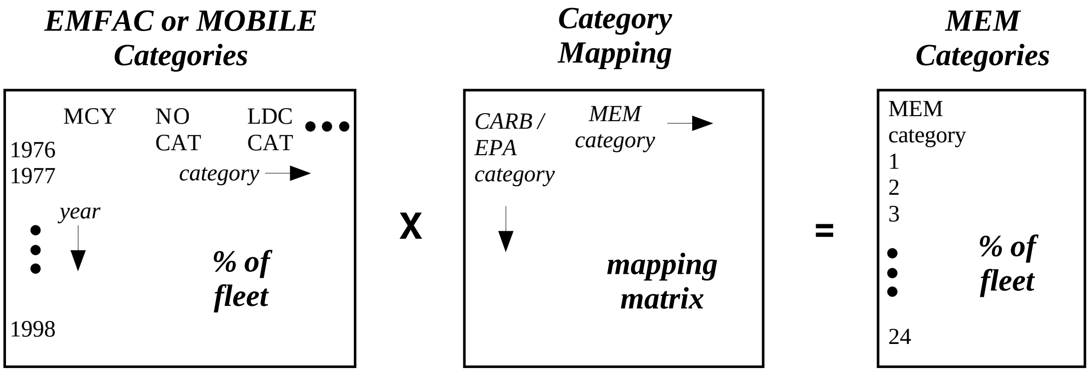


Figure 5.7. EMFAC/MOBILE to MEM category mapping procedure.

In this illustration, the gross vehicle categories of MOBILE or MVEI are given across the top of a matrix, while the model year index runs along the side. The category mapping simply gives the percentage distribution for each category/year bin that corresponds to the appropriate CMEM category. These mappings can be created using knowledge of what vehicle model years correspond to the different CMEM categories. For example, model year 1974 and older automobiles do not have catalytic converters, therefore all of these vehicles can be categorized into CMEM category 1 (CMEM category 12 for LDTs). Information that was used in creating the decision trees of the previous section is also used here in determining the weights of the mappings.

As an example of a mapping for a 1998 base year, we have taken the CMEM categories (categories 1-23 before Phase 4) and produced mappings for LDGVs, as shown in Table 5.7. Because this mapping was created for light duty automobiles only, all of the truck categories have zero weights. An example mapping for LDGTs is given in Table 5.8. Similarly, since this mapping applies to trucks only, the automobile categories have zero weights.

LDGV									CMEM CATEGORY														
MY	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**sum**
1972	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1973	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1974	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1975	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1976	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1977	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1978	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1979	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1980	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1981	0.0%	0.0%	66.4%	3.4%	3.4%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1982	0.0%	0.0%	60.6%	5.9%	5.9%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1983	0.0%	0.0%	53.3%	9.8%	9.8%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1984	0.0%	0.0%	44.5%	13.7%	13.7%	0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1985	0.0%	0.0%	35.8%	18.0%	18.0%	0.5%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1986	0.0%	0.0%	23.4%	24.2%	24.2%	0.8%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1987	0.0%	0.0%	20.5%	27.9%	27.9%	1.1%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1988	0.0%	0.0%	7.9%	33.9%	33.9%	1.6%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1989	0.0%	0.0%	10.3%	32.6%	32.6%	1.9%	1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1990	0.0%	0.0%	1.6%	35.7%	35.7%	2.8%	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1991	0.0%	0.0%	0.0%	39.6%	39.6%	4.4%	4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	7.1%	2.3%	1.1%	0.0%	100%
1992	0.0%	0.0%	0.0%	37.4%	37.4%	6.6%	6.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	7.1%	2.3%	1.1%	0.0%	100%
1993	0.0%	0.0%	0.0%	33.2%	33.2%	10.8%	10.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%	7.1%	2.3%	1.1%	0.0%	100%
1994	0.0%	0.0%	0.0%	17.1%	17.1%	12.9%	12.9%	11.4%	11.4%	8.6%	8.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1995	0.0%	0.0%	0.0%	2.4%	2.4%	7.6%	7.6%	9.8%	9.8%	30.2%	30.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1996	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%	49.6%	49.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1997	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%

Table 5.7. Example LDGV -> CMEM category (categories 1-23 prior to Phase 4) mapping for base year 1998.

LDGT										CMEM CATEGORY													
MY	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**sum**
1972	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1973	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1974	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1975	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1976	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1977	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1978	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1979	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1980	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1981	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1982	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1983	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1984	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1985	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1986	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	73.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.0%	12.2%	3.5%	7.8%	100%
1987	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	79.0%	0.0%	0.0%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1988	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	36.3%	42.7%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1989	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	32.4%	46.6%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1990	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.3%	53.7%	0.0%	0.0%	3.9%	8.7%	6.1%	2.3%	0.0%	100%
1991	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	29.0%	59.0%	0.0%	0.0%	1.5%	7.1%	2.3%	1.1%	0.0%	100%
1992	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	23.8%	64.2%	0.0%	0.0%	1.5%	7.1%	2.3%	1.1%	0.0%	100%
1993	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.6%	63.4%	0.0%	0.0%	1.5%	7.1%	2.3%	1.1%	0.0%	100%
1994	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	65.0%	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1995	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	22.0%	57.0%	21.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1996	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.2%	32.9%	31.7%	23.2%	0.0%	0.0%	0.0%	0.0%	0.0%	100%
1997	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	41.3%	58.7%	0.0%	0.0%	0.0%	0.0%	0.0%	100%

Table 5.8. Example LDGT -> CMEM category (categories 1-23 prior to Phase 4) mapping for base year 1998.

5.5 PARAMICS CMEM PLUG-IN

The Paramics CMEM plugin provides an interface between CMEM and Paramics, an application developed by Quadstone Limited for microscopic traffic simulation. Paramics consists of a suite of high performance software tools, where individual vehicles are modeled in fine detail for the duration of their entire trip, providing very accurate traffic flow, transit time and congestion information, as well as enabling the modeling of the interface between drivers and intelligent transportation system technology. The Paramics software is portable and scalable, allowing a unified approach to traffic modeling across the whole spectrum of network sizes, from single junctions up to national networks. Key features of the Paramics model includes direct interfaces to macroscopic data formats, sophisticated microscopic car-following and lane-change algorithms, integrated routing functionality, direct interfaces to point-count traffic data, batch model operation for statistical studies, a comprehensive visualization environment, and integrated simulation of ITS elements [Paramics, 1998].

One of the key attributes of the PARAMICS model is its open architectures enabling the integration of plug-in modules for carrying out specific functions. This is performed through "Application Programming Interfaces" or APIs. Integrating CMEM within PARAMICS was accomplished by creating an API through the use of the Paramics Programmer utility. The PARAMICS Programmer utility is a framework that allows the user to access many of PARAMICS features and variables as the simulation takes place.

The CMEM/Paramics API was written in C and is primarily based on two elements: 1) control functions and 2) callback functions. Control functions are functions that Paramics uses as part of its standard simulation. These control functions allow the user to override or add additional code to the simulation run. Callback functions allow the user to retrieve specific information from the simulation such as vehicle and network attributes. On UNIX systems, the plug-in is compiled as a shared object file (.so) and a path directing the Paramics simulation to the .so file is specified in the .plugin file. This allows Paramics to find and load the plug-in on opening.

The CMEM/Paramics API calls the CMEM function during the Paramics simulation in order to obtain calculated emission values for each vehicle at every second. This is done through the overloading of control functions, most notably the *vehicle_link_action*, which is where the CMEM function call is located. This control function is called for every vehicle on every link at each time-step. During this function call, the current vehicle type, speed, acceleration and previous vehicle history are identified using callback functions and from previously stored values. This information is passed to the CMEM function which calculates emissions for that vehicle type at that second and with that history. Updated vehicle history values are then stored for future events. Emission values are also stored at this point and are cumulated and summarized at given intervals during the simulation.

5.5.1 Running with the CMEM Plug-in

Currently, the CMEM plugin has been compiled for Linux and Windows machines. On UNIX based machines, Paramics Programmer uses a shared object (.so) file to link with API code. The shared object file for the CMEM plugin is named *cmemPlugin.so*. For the Windows operating system, the CMEM plug-in is in the form of a dynamic link library file (.dll) named *cmemPlugin.dll,* The link between Paramics and the plug-in must be established before the Paramics application is initiated. Once the Paramics application is initiated and Paramics has linked with the appropriate plug-ins, Paramics will process any specified user interface parameter files.

Linking the CMEM Plug-in with a Paramics Run

In order for Paramics to run a plugin file, the plugin file must be properly located or referenced. In Paramics V5, plug-ins can be network specific so there are several options for including them in Paramics runs. The primary path for Paramics to find plug-ins is the default plugin directory. Plug-ins in this directory will always be loaded and are not network specific. The default plug-in directory is <PARAMICSHOME<\plugins\<PLATFORM>. The typical path for this directory on a Windows machine would be

```
C:\Program Files\Paramics\plugins\windows
```

For more information on the various ways plug-ins can be included in Paramics simulation runs please refer to the Paramic's *Programmer User Guide* sections on *Loading Plugins*.

Specifying the User Interface Parameter

The Paramics *configuration* file, among other things, can direct Paramics to parse parameter files for plug-ins. These parameter files enable the definition of user interface elements associated with the plug-ins. The CMEM plug-in uses such a parameter file (*cmemParameters*) to define the variable "Reporting Interval (min)", which lets Paramics know to create the Graphical User Interface (GUI) or sliding bar control for that variable (Figure 5.10).

The *configuration* file is usually located in the directory of the network being loaded. In order to enable the sliding bar control for the "Reporting Interval (min)" variable, it is necessary to add the line in Figure 5.8, directing Paramics to parse the *cmemParameters* file, to the *configuration* file for the appropriate network.

```
read parameters file "cmemParameters"
```

Figure 5.8. Line specifying user interface parameter in the ***configuration*** file.

The *cmemParameters* file contains information used by Paramics to determine the initial value, range and precision of the sliding bar control. The example file in Figure 5.8 indicates to Paramics that the CMEM plug-in uses a variable labeled "Reporting Interval (min)", that this variable has an initial value of 2 whose range is between 1 and 1440 and whose precision is 0, meaning it requires integer values only. In order to adjust the reporting interval, the *cmemParameters* file must be present since the CMEM plugin only looks for parameter values from variables defined in this file. If the *cmemParameters* file is not present or Paramics is not properly directed to read the *cmemParameters* file in the Paramics *configuration* file, then the reporting interval will be set to the default value of ten minutes and the sliding bar control will not be available.

```
api coefficients 1
2 "Reporting Interval (min)" range 1 to 1440 precision 0
```

Figure 5.8. Sample Paramics user interface parameter file.

Reporting Interval

The reporting interval variable is used to define the length or the time gap between summarized outputs . This time interval is initially set in the *cmemParameters* file (see previous subsection) and can be adjusted once the Paramics application has been started via the sliding control shown below in Figure 5.10. This sliding control can be found under the Paramics pull down menu Tools→API Tool. The upper and lower range values for the reporting interval sliding control as well as the sliding control precision are also set in the *cmemParameters* file (see previous subsection). Note that the sliding control value can quickly be moved by dragging the slider and letting go, but also by using the keyboard arrow keys. The arrow keys make it easy to manipulate the sliding control value by one minute increments. It is possible to change the reporting time interval value during a run. The reporting time interval will be based on the simulation time at that time as shown by the Paramics simulation clock in the upper left had of the Modeller application and will not be based on previous output times.

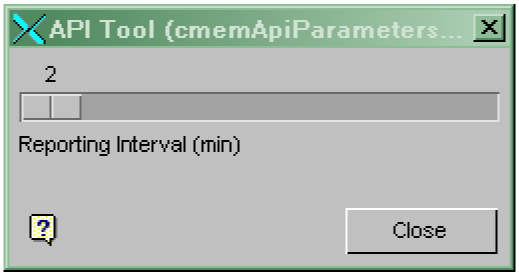


Figure 5.10 Reporting Interval (min) slider.

Vehicle Categorization

One of the key challenges for microscopic models in general is matching the different vehicle types represented in the traffic simulation component with the vehicle types represented within the emissions component. Traffic simulation models typically have different vehicle types that are based on how they operate within a roadway network. In addition to the obvious divisions of vehicle types (i.e., motorcycles, passenger cars, buses, heavy-duty trucks), categories are often made based on vehicle performance (e.g., high-performance cars, low-performance cars) that can be closely related to traffic simulation parameters. For heavy-duty trucks, transportation models/datasets typically categorize their vehicles based on their configuration and number of axles. In all cases, a straightforward approach to handling the vehicle matching is to create an appropriate *mapping* between the vehicle types defined in the traffic simulation model, and the vehicle types defined in the emission model.

Category mapping between the CMEM plug-in and Paramics is defined by the user in the file *cmemModelParameters.txt* located in the network directory. An example of this file is shown in Figure 5.9 The format of the *cmemModelParameters.txt* file is important. The CMEM API will look for five fields delimited by at least one space. Multiple spaces are interpreted as one. The descriptions of the fields are as follows. The first field is more for the users understanding and is not actually interpreted by the API. The second field is the Paramics vehicle type as defined in the Paramics network. In the third field, the CMEM API looks for an "=" sign. The fourth field indicates which CMEM model the category refers to and must be either exactly *ldvCat* or *hddvCat*. In this case *ldvCat* stands for the CMEM Light

Duty Vehicle model and *hddvCat* stands for the CMEM Heavy Duty Diesel Vehicle model. The fifth field is the CMEM category number that the Paramics vehicle type maps to. A list of the possible category numbers, by model type are presented in Table 5.10.

```
vehType 1 = ldvCat 1
vehType 2 = ldvCat 1
vehType 3 = ldvCat 1
vehType 4 = ldvCat 7
vehType 5 = ldvCat 13
vehType 6 = ldvCat 22
vehType 7 = ldvCat 1
vehType 8 = hddvCat 5
vehType 9 = hddvCat 6
vehType 10 = hddvCat 7
```

Table 5.9 Example of *cmemModelParameters.txt* File.

LDV Categories	Description
1	No Catalyst
2	2-way Catalyst
3	3-way Catalyst, Carbureted
4	3-way Catalyst, FI, >50K miles, low power/weight
5	3-way Catalyst, FI, >50K miles, high power/weight
6	3-way Catalyst, FI, <50K miles, low power/weight
7	3-way Catalyst, FI, <50K miles, high power/weight
8	Tier 1, >50K miles, low power/weight
9	Tier 1, >50K miles, high power/weight
10	Tier 1, <50K miles, low power/weight
11	Tier 1, <50K miles, high power/weight
12	Pre-1979 (<=8500 GVW)
13	1979 to 1983 (<=8500 GVW)
14	1984 to 1987 (<=8500 GVW)
15	1988 to 1993, <=3750 LVW
16	1988 to 1993, >3750 LVW
17	Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)
18	Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)
19	Runs lean
20	Runs rich
21	Misfire
22	Bad catalyst
23	Runs very rich
24	Tier 1, >100K miles
25	Truck, Gasoline-powered, LDT (> 8500 GVW)
26	Ultra-Low Emission Vehicle (ULEV)
27	Super Ultra-Low Emission Vehicle (SULEV)
40	Truck, Diesel-powered, LDT (> 8500 GVW)
HDDV Categories	**Description**
5	HDD 1994-1997, 4 stroke, Electric, FI Normal Emitting
6	HDD 1998, 4 Stroke, Electric, FI Normal Emitting
7	HDD 1992-2000, 4 Stroke, Electric, FI Normal Emitting

Table 5.10 Available CMEM categories

5.5.2 CMEM Plug-in Output

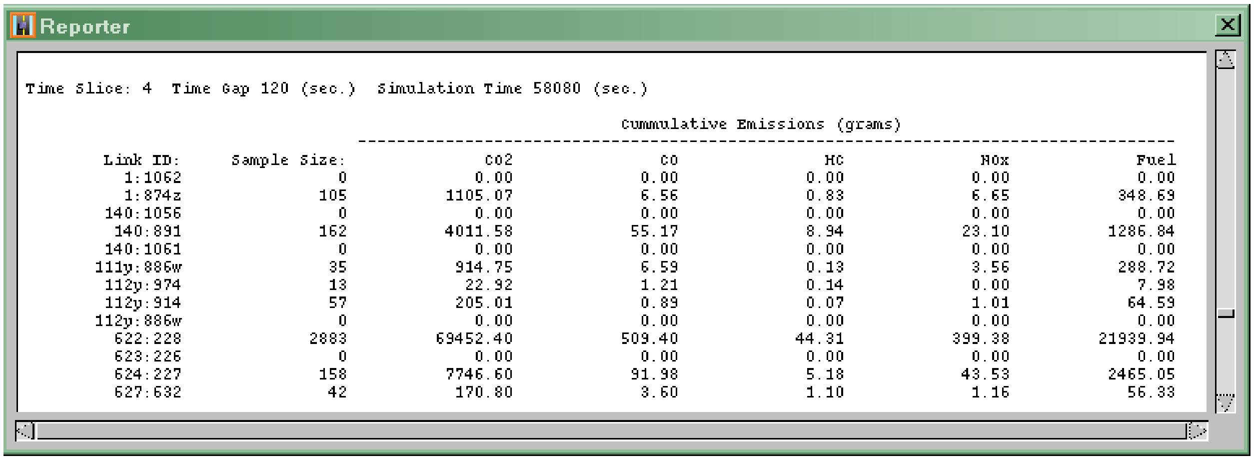
CMEM plug-in output data is currently being presented through the Paramics Reporter tool (Figure 5.11) which displays data during the Paramics run and in two text files labeled *cmemEmissionsSummary.dat* and *cmemActivitySummary.dat* (Figures 5.12 and 5.13). The CMEM plug-in output files are recorded to the current network directory. Common output between all three data formats includes the values for Time Slice, Time Gap, Simulation Time, Link ID, and Sample Size which are explained below.

Time Slice:	Time Slice refers to the time period being summarized. The first time period is Time Slice 1, the second is Time Slice 2, etc .... The same Time Slices are consistent with each other for all three output formats, but different Time Slices may summarize time periods of different lengths. Time Slice 1 may include 60 seconds of summarized data, Time Slice 2 may include 5 minutes of summarized data, and so on, depending on the value of the reporting interval (Time Gap).
Time Gap:	The length of the Time Slice's presented in the output data are defined by the reporting interval and are presented as the variable Time Gap. See section 5.5.1 Reporting Interval for information on modifying the reporting interval. If the reporting interval is not modified during a run, then the time periods being summarized will remain consistent as well. The default value is ten minutes.
Simulation Time :	The value for Simulation Time is the simulation time at the point of summary and will always be an integer value. Paramics does process vehicle activity at a rate greater than one second, but the CMEM plugin calculates vehicle emission on a second-by-second basis and for this reason only whole seconds are considered.
Link ID:	Link ID consists of two node names separated by a colon and specifies the specific link and link direction. The first node in Link ID is the starting node and the second node is the ending node with traffic moving in the direction from start to end.
Sample Size:	The value Sample Size is a report of the number of seconds all vehicles exist on a given link for a given Time Slice. This is to say that if a vehicle exists on a link for 30 seconds during a given Time Slice, it is counted 30 times and the Sample Size is incremented by 30. This method of cumulating values is consistent with the method for cumulating emission values.

The Reporter tool and the *cmemEmissionSummary.dat* file both display the total CO2, CO, HC, NOx and fuel use values in grams. The *cmemActivitySummary.dat* file provides some vehicle and link information.

Paramics Reporter Tool

The Paramics reporter tool can be found under the Paramics pull down menu Tools→Reporter. Emission values are presented here in real simulation time (Figure 5.11) according to the reporting interval (Section 5.1.1 *Reporting Interval*). The emission summary output is also recorded to the *cmemEmissionSummary.dat* file.



```
Time Slice: 4  Time Gap 120 (sec.)  Simulation Time 58080 (sec.)

                                                Cummulative Emissions (grams)
                                   ---------------------------------------------------------------------------------
       Link ID:    Sample Size:              CO2              CO              HC             NOx             Fuel
         1:1062               0             0.00            0.00            0.00            0.00             0.00
         1:874z             105          1105.07            6.56            0.83            6.65           348.69
       140:1056               0             0.00            0.00            0.00            0.00             0.00
        140:891             162          4011.58           55.17            8.94           23.10          1286.84
       140:1061               0             0.00            0.00            0.00            0.00             0.00
      111y:886w              35           914.75            6.59            0.13            3.56           288.72
       112y:974              13            22.92            1.21            0.14            0.00             7.98
       112y:914              57           205.01            0.89            0.07            1.01            64.59
      112y:886w               0             0.00            0.00            0.00            0.00             0.00
        622:228            2883         69452.40          509.40           44.31          399.38         21939.94
        623:226               0             0.00            0.00            0.00            0.00             0.00
        624:227             158          7746.60           91.98            5.18           43.53          2465.05
        627:632              42           170.80            3.60            1.10            1.16            56.33
```

Figure 5.11 Reporter window output.

CMEM Plugin Emission Summary File (cmemEmissionSummary.dat)

The *cmemEmissionSummary.dat* file reports total emission data for the pollutants CO2, CO, HC, and NOx in grams and fuel use in grams for each link during each Time Slice (Figure 5.14). The CMEM Plug-in calculates emission and fuel use values for each vehicle at each second and stores them in lookup tables using the functions provided by Paramics for creating and manipulating lookup tables. The CMEM plug-in then uses these lookup tables to summarize data for each link at specified time intervals (section 5.5.1 *Reporting Interval*). Cumulating data follows the same method used to cumulate the value Sample Size (section 5.5.2). That is that the one second emission value for each vehicle is cumulated for each second that that vehicle exists on a given link. Using the Sample Size, the average one second emission for a vehicle on a given link can be calculated.

```
Time Slice: 1  Time Gap 300 (sec.)  Simulation Time 57900 (sec.)

                                     Cummulative Emissions (grams)
                          ----------------------------------------------------------------------
Link ID:     Sample Size:      CO2         CO              HC              NOx              Fuel
 1:1062           0           0.00        0.00            0.00            0.00              0.00
 1:874z         161        1549.45       11.95            2.90            9.99            492.06
 140:1056         0           0.00        0.00            0.00            0.00              0.00
 140:891        223        4627.69       38.40            5.67           26.19           1466.67
 140:1061         0           0.00        0.00            0.00            0.00              0.00
 111y:886w      123        1061.26       54.92            1.05            2.97            360.84
 112y:974       103         153.79        2.04            0.22            0.01             49.73
 112y:914       195         413.67        3.22            0.32            1.08            131.78
 112y:886w        0           0.00        0.00            0.00            0.00              0.00
 622:228       6503      157899.02     1289.44          104.89          895.39          49951.58
 623:226          0           0.00        0.00            0.00            0.00              0.00
 624:227        263       21049.31      127.13            6.70          115.29           6626.06
 627:632         86         640.20        6.16            1.36            4.42            204.11
                                        •
                                        •
                                        •
```

Figure 5.12 Example Paramics emission summary file.

CMEM Plugin Activity Summary File (cmemActivitySummary.dat)

The cmemActivitySummary.dat file presents average velocities in mph and average negative and positive accelerations in mph/s and average grade in degrees as well as link length in miles and vehicle distance traveled in miles (Figure 5.15).

Velocity(mph):	The average velocity across all vehicles and every second during a given Time Slice.
Accel (mph):	The average positive or negative acceleration across all vehicles and every second during a given Time Slice.
Grade (deg):	The average slope or grade of the link traveled by all vehicles at every second during a given Time Slice.
Link (miles):	Link length is the reported link length from Paramics and is a physical characteristic of the network which will remain constant for each link.
Dis (miles):	The vehicle distance traveled refers to the total distance traveled on a given link by all the vehicles during a particular Time Slice. Total vehicle distance traveled will depend on the number of vehicles on the link during the time slice and the length of the link traveled by vehicles still on the link at the time of summary.

```
Time Slice: 1  Time Gap 300 (sec.) Simulation Time 57900 (sec.)

Average
--------------------------------------------
Link ID:  Sample Size:  Velocity(mph)  Accel(mph/s) Grade(deg) Link(miles)  Dis(miles)

1:1062         0           0.00           0.00         0.00      0.0340         0.00
1:874z       161          26.21          -0.16         0.00      0.0315         1.17
140:1056       0           0.00           0.00         0.00      0.0281         0.00
140:891      223          20.27          -0.90         0.00      0.0758         1.26
140:1061       0           0.00           0.00         0.00      0.0292         0.00
111y:886w    123          10.54           3.19         0.00      0.0270         0.36
112y:974     103          26.82          -0.00         0.05      0.1115         0.77
112y:914     195          27.24          -0.02         0.00      0.0579         1.48
112y:886w      0           0.00           0.00         0.00      0.0280         0.00
622:228     6503          26.32           0.45         0.00      0.3358        47.54
623:226        0           0.00           0.00         0.00      0.0286         0.00
624:227      263          24.83           1.67         0.00      0.1169         1.81
627:632       86          27.12          -0.36         0.00      0.0367         0.65
627:227        0           0.00           0.00         0.00      0.0554         0.00
628:865z       0           0.00           0.00         0.00      0.0498         0.00
628:226       42          27.77          -0.09         0.00      0.0528         0.32
30:865z     2522          14.64          -0.57         0.00      0.0516        10.26
630:228      382          27.05          -0.02         0.00      0.0546         2.87
632:887z    1399           6.45          -0.36         0.00      0.0759         2.51
632:232        0           0.00           0.00         0.00      0.0684         0.00
                                     •
                                     •
                                     •
```

Figure 5.13 Example *cmemActivitySummary.dat* file.

6 Future Work

In developing this comprehensive modal emission model, many modeling issues were considered, such as different vehicle/technology categories, variable soak time starts, enrichment and enleanment behavior, and high-emitter characteristics. When developing the model, we attempted to capture many of the important aspects of vehicle operation and its effect on tailpipe emissions. However, because the production of vehicle emissions is a complex process and dependent on may variables, it was impossible to model every aspect at a high level of detail. In addition, CMEM is a “living” model: it needs to be updated periodically to properly represent the current vehicles in any given fleet. Future vehicle fleets will surely include new technologies that are not represented in this first version of the model. The following future work is recommended:

Incorporation of New Vehicle/Technology Categories—In order to better estimate emission inventories into future years (e.g., 2010, 2020), additional vehicle/technology categories must be incorporated into the model.

Variable Soak Time Starts—The variable soak time starts are based on several curves that represent emission-control behavior and catalyst cooling. However, this part of the model is based on only three emission “starts”: a hot start (FTP Bag 2 or MEC01 or US06), a 10-minute soak warm start (FTP Bag 3), and a 24-hour soak cold start (FTP Bag 1). The equations that predict variable soak time start emissions can be vastly improved with additional start emissions data. A test program should be developed to measure emissions from a wide range of soak-times. Further, the cycles should be varied after these soak times since the catalyst light-off times depend on the aggressiveness of the testing cycle.

Secondary Load Power Estimation—The default air conditioning power estimation in the model is based on a single temperature/humidity combination. Under in-use conditions, the load from AC operation varies widely, based upon temperature, humidity, and sun load. Users should be aware of this factor and attempt to provide appropriate AC load factors for their specific operating conditions.

Ambient Temperature—The model is calibrated for an ambient temperature of 75 degrees F. While hot, stabilized emissions are not greatly affected by ambient temperature, cold start emissions are. Therefore, the model is not well suited for ambient temperatures below 50 degrees without modification to account for longer cold start periods.

High Emitting Vehicles—In this NCHRP project, an initial characterization of high emitters has been made, and high emitting vehicle models have been developed. In order to improve high emitting vehicle modeling, many more high emitting vehicles need to be tested, and the cause of their high emissions needs to be better investigated. In addition, data sets from many more inspection/maintenance programs need to be analyzed to determine the vehicle activity component of high emitters (e.g., vehicle fleet distribution). In the model development to date, high emitting vehicles have been characterized through 1997. Recent evidence has shown that the more modern vehicles have very low probabilities of being high emitters, however additional activity and emission data need to be collected to improve this part of the model.

Future Vehicle Model Prediction—As described previously, CMEM has been developed using a physical, power-demand approach based on a parameterized analytical representation of emissions production. Each component is modeled as an analytical representation consisting of various parameters that are characteristic of the process. These parameters vary according to the vehicle type, engine, emission technology, and level of deterioration. One distinct advantage of this physical approach is that it is possible to adjust many of these physical parameters in order to predict emissions of future vehicle models. Although it is difficult to predict with any degree of certainty what the technology mix of vehicles will be in the future, some projections of future emission control systems and engine technology can be made. As an example, it is likely that the enrichment "power-threshold" for many vehicles will tend to increase as the emission control systems become more robust, and more vigorous certification testing (e.g., SFTP) takes place. The emission effects of other changes can be predicted, such as engines with lighter materials, breathing enhancements, variable displacement, variable compression ratios, pre-heated catalyst systems, lean-burn NOx catalysts, etc. It is recommended that a study be performed with CMEM to predict the emission characteristics of future vehicle/technology categories. This can be accomplished by adjusting many of the parameters of the physical component modules in a way that makes sense based on technology trends. Simple examples of this are to look at increasing enrichment thresholds of more recent model vehicles, shorter catalyst light off times, etc. The resulting emission factors of future vehicle/technology categories can then be used in estimating inventories well into the next millennium.

***CMEM Integration into Transportation Frameworks*—**In Phase 3 of this project, much effort was spent in identifying how CMEM can be integrated into various transportation modeling environments. The core and batch executable models have been developed in a flexible fashion so that they can easily be incorporated into various frameworks. In addition, velocity/acceleration-index emission/fuel lookup tables were created, which can be integrated into many existing microscopic transportation simulation models (e.g., CORSIM, NETSIM, etc.). This integration work should continue with other types of transportation data and/or models, getting the maximum utility out of CMEM.

7 References

An, F. and M. Ross. 1993a. A Model of Fuel Economy and Driving Patterns. *SAE Technical Paper number 930328*.

An, F. and M. Ross. 1993b. A Model of Fuel Economy with Applications to Driving Cycles and Traffic Management. *Transportation Research Record 1416*.

An, F., M. Barth, M. Ross and J. Norbeck. 1997. The Development of a Comprehensive Modal Emissions Model: Operating Under Hot-Stabilized Conditions. Transportation Research Board Record Series 1587: 52-62, Washington DC, 1997.

Barth, M., T. Younglove, T. Wenzel, G. Scora, F. An, M. Ross, and J. Norbeck, "Analysis of Modal Emissions from a Diverse In Use Vehicle Fleet," *Transportation Research Record 1587*, TRB, National Research Council, Washington, D. C., 1997, pp. 73-84.

Barth, M., F. An, T. Younglove, C. Levine, G. Scora, M. Ross, and T. Wenzel. "The development of a comprehensive modal emissions model. (Draft) Final report to the National Cooperative Highway Research Program, November, 1999, 255 p.

CARB. 1994. *On-Road Remote Sensing of CO and HC Emissions in California*. California Air Resources Board, prepared by Donald Stedman, Gary Bishop, Stuart Beaton, James Peterson, Paul Guenther, Ian McVey, and Yi Zhang, Denver Research Institute., Contract No. A032-093.

California Air Resources Board, 1996. *Comparison of the IM240 and ASM Tests in CARB's I&M Pilot Program*, CARB Mobile Source Division, June 1996.

CARB. 1996. *Methodology for Estimating Emissions from On-Road Motor Vehicles*. Technical Support Division, CARB.

Code of Federal Regulations: *Protection of the Environment,* 40 CFR 86.

Cocker, D., Johnson, K., Miller, J.W. Norbeck, J.N., Development and Application of a Mobile Laboratory for Measuring Emissions From Diesel Engines I. Regulated Gaseous Emissions, *Environmental Science & Technology*, 38(7) pp 2182 – 2189.

Coordinating Research Council, Project E-55: Heavy-Duty Vehicle Chassis Dynamometer Testing For Emissions Inventory, see http://www.crcao.com/annualreport/emission/e55.htm, accessed November 15, 2003.

Draper, N. and Harry Smith. "Applied Regression Analysis." John Wiley and Sons, Inc. New York, New York.1966, 64-65.

Efron, B. and R. Tibshirani. "Bootstrap Methods for Standard Errors, Confidence Intervals, and Other Measures of Statistical Accuracy." Statistical Science. 1986, Vol. 1, Number 1, 54-77.

FHWA, "TSIS: Traffic Software Integrated System User's Manual", Office of Traffic Operations, 1999.

Lawson, D. R., P. Groblicki, D.H. Stedman, G.A. Bishop, and P.L. Guenther, "Emissions of In-Use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program," *J. Air & Waste Manage. Assoc.*, **40**, 1096-1105, 1990.

Maldonado, H.; Agrawal, A.; Carlock, M.; (2002) *Development of Heavy-Duty Vehicle Chassis Dynamometer Driving Cycles.* 12th CRC On-Road Vehicle Emissions Workshop Conference Proceedings, San Diego, CA.

Manos, M. J., J. W. Bozek, and T.A. Huls, "Effect of Laboratory Conditions on Exhaust Emissions", SAE Technical Paper 720124 (1972). See also: www.epa.gov/orcdizux/labmthod.html.

Mathworks, Inc., 1999, MATLAB Analysis Software, 3 Apple Hill Drive, Natick, MA 01760. www.mathworks.com.

McAlinden, K. 1994. Michigan Roadside Study: Analysis of Repairs on High Emission Vehicles. Fourth CRC On-Road Vehicle Emission Workshop. San Diego, CA.

Murrell, J.D., K.H. Hellman, and R.M. Heavenrich. Light Duty Automotive Technology and Fuel Economy Trends Through 1993. USEPA Technical Report EPA/AA/TDG/93-01, USEPA, Ann Arbor, MI.

Prague, C. N., and M. R. Irwin, *Access 97 Bible*, IDG Books Worldwide, Inc, Chicago, IL, 1997.

Schulz, D., T. Younglove, and M. Barth,. Statistical analysis and model validation of automobile emissions, Proceedings of the 1999 Joint Statistical Meetings, Baltimore, MD, August, 1999.

Sierra Research, "Development of Speed Correction Cycles", US EPA Document Number M6.SPD.001, June, 1997.

Soliman, A. and Georgio Rizzoni, "The Effects of Various Engine Control System Malfunctions on Exhaust Emissions Levels During the EPA I/M 240 Cycle," Society of Automotive Engineers, Warrendale PA, 940448, 1994.

Stedman, D. "Automobile Carbon Monoxide Emission," *Envir. Science Technol.* 1989, **23**, 147.

Stedman, D. Gary A. Bishop, Philip Aldrete, and Robert S.Slott, "On-Road Evaluation of an Automobile Emission Test Program," *Envir. Science Technol.* 1997, **31**, 927-931.

Stephens, R., J. Allen, et al. 1994. Real-World Emissions Variability as Measured by Remote Sensors. *Society of Automotive Engineers, Technical Paper #940582*.

Truex, T., J. Collins, J. Jetter, B. Knight, T. Hayashi, N. Kishi, and N. Suzuki (2000) "Measurement of Ambient Roadway and Vehicle Exhaust Emissions-An Assessment of Instrument Capability and Initial On-Road Test Results with an Advanced Low Emission Vehicle", Society of Automotive Engineers, Technical Paper #SAE 2000-01-1142.

US EPA, "Fleet Characterization Data for Use in MOBILE6 Final Report", 1998. US EPA, Office of Mobile Sources Technical Report #EPA420-P-98-016.

Wenzel, T. "Analysis of Emissions Deterioration of In-Use Vehicles, Using Arizona IM240 Data," presented at the Society of Automotive Engineers Government/Industry Meeting, Washington DC, May 1997.

Appendix A: Vehicle Testing Summary Sheet

This vehicle testing summary sheet lists all of the vehicles that were tested in the NCHRP 25-11 project. The columns are as follows:

num is vehicle test number (note bad tests were deleted);

Veh. Name is the vehicle name;

MY is model year;

date is date tested;

testn1 is the first VERL test number;

testn2 is the second VERL test number;

Cat is the vehicle/technology category (based on recruitment bins);

Emitter is the emitter level classification;

FTP, US06, MEC: **E** engine-out data, **T** tailpipe data;

AC - air conditioning hill performed; **E** engine-out data, **T** tailpipe data;

RPT - repeat hill performed; **E** engine-out data, **T** tailpipe data;

veh par - detailed vehicle parameters measured;

Mass – weight of vehicle (lbs.);

Tier is the emission certification category;

Veh Type is the type of vehicle;

State is the origin state of the vehicle;

Odom – odometer reading on test date;

Z/weight is power to weight ratio;

THCgm is grams per mile total HC over the FTP;

TCOgm is grams per mile total CO over the FTP, and

TNOxgm is grams per mile total NO_x over the FTP.

num	Veh. Name	MY	date	test n1	test n2	Cat	Emitter	FTP	US06	MEC	AC	RPT	veh par	Mass	Tier	Veh Type	State	Odom	Z/weight	THCgm	TCOgm	TNOxgm
9	**Ford_E_150_83**	83	6/3/96	h9606004	h9606005	13	high	ET	ET	ET	ET	ET	yes	4250	0	truck	CA	38812	0.041	2.21	79.57	0.39
13	**Toyota_Celica_8**	81	6/16/96	h9606028	h9606044		high	ET	ET	ET	ET	ET	yes	3000	0	car	CA	24601	0.035	4.41	21.13	2.08
14	**Ford_Bronco_82**	82	6/18/96	h9606038	h9606039	13	high	ET	ET	ET	ET	ET	yes	4500	0	truck	CA	61706	0.039	2.03	9.05	1.75
15	**Honda_Civic_76**	76	6/20/96	h9606042	h9606043	1	normal	ET	ET	ET	ET	ET	yes	2000	0	car	CA	88705	0.034	0.91	3.99	0.91
16	**Honda_Civic_91**	91	6/21/96	h9606047	h9606048	4	normal	ET	ET	ET	ET	ET	yes	2500	0	car	CA	73546	0.037	0.16	3.57	0.36
17	**Toyota_Tercel_9**	95	6/25/96	h9606054	h9606055	10	normal	ET	ET	ET	ET	ET	yes	2250	1	car	CA	23249	0.041	0.09	1.20	0.06
18	**Toyota_PU_90**	90	6/25/96	h9606056	h9605058	15	normal	ET	ET	ET	ET	ET	yes	2750	0	truck	CA	91080	0.042	0.24	2.64	0.17
19	**Honda_Prelude_8**	82	6/26/96	h9606059	none	2	high	ET	none	none	none	none	yes	2500	0	car	CA	191203	0.040	5.80	11.73	4.01
20	**Buick_Century_8**	86	6/27/96	h9606062	h9606063	4	normal	ET	ET	ET	ET	ET	yes	3500	0	car	CA	74009	0.032	0.48	4.90	0.49
21	**Datsun_240Z_73**	73	6/27/96	h9606064	none	1	high	E	none	none	none	none	yes	3000	0	car	CA	42843	0.039	7.87	43.50	3.36
22	**Chevy_Suburban_**	87	6/28/96	h9606066	h9606067	14	normal	ET	ET	ET	ET	ET	yes	6000	0	truck	CA	96394	0.041	0.65	5.89	0.59
23	**Cadillac_84**	84	7/2/96	h9607007	h9607008	20	high	ET	ET	ET	ET	ET	yes	3500	0	car	CA	14955	0.039	1.13	15.93	4.55
24	**Dodge_Spirit_91**	91	7/3/96	h9607010	h9607011	6	normal	ET	ET	ET	ET	ET	yes	2750	0	car	CA	13718	0.036	0.15	1.96	0.22
25	**Oldsmobile_98_7**	79	7/9/96	h9607018	h9607019	2	high	ET	ET	ET	ET	ET	yes	4000	0	car	CA	36425	0.041	3.68	72.08	1.82
26	**Oldsmobile_89**	89	6/13/96	h9606026	h9606027	5	normal	ET	ET	ET	ET	ET	yes	3250	0	car	CA	112614	0.049	0.43	4.19	1.55
27	**Honda_Accord_85**	85	7/10/96	h9607022	h9607023	3	normal	ET	ET	ET	ET	ET	yes	2500	0	car	CA	222517	0.039	0.35	5.69	0.76
28	**Plymouth_MV_88**	88	7/11/96	h9607025	h9607026	19	high	ET	ET	ET	ET	ET	yes	3500	0	truck	CA	169982	0.029	1.14	7.48	2.12
29	**Chevy_Suburban_**	94	7/11/96	h9607027	h9607028	16	normal	ET	ET	ET	ET	ET	yes	6000	0	truck	CA	38629	0.033	0.38	7.80	0.66
30	**GMC_Safari_96**	96	7/12/96	h9607029	h9607030	17	normal	ET	ET	ET	ET	ET	yes	5500	1	truck	CA	8125	0.035	0.15	1.28	0.23
31	**Ford_Aerostar_8**	86	7/12/96	h9607031	h9607032	14	normal	ET	ET	ET	ET	ET	yes	3500	0	truck	CA	14926	0.041	0.40	8.07	0.84
32	**Cadillac_NS_96**	96	7/16/96	h9607037	h9607038	11	normal	ET	ET	ET	ET	ET	yes	4000	1	car	CA	13287	0.069	0.05	0.54	0.15

33	**Buick_Lesabr_96**	96	7/23/96	h9607045	h9607046	11	normal	ET	ET	ET	ET	ET	yes	3500	1	car	CA	22607	0.059	0.07	0.55	0.10
34	**Buick_Lesabr_BO**	96	7/24/96	h9607049	h9607050		high	ET	ET	ET	ET	ET	no	3500	1	car	CA	22651	0.059	0.27	3.55	1.69
35	**Jeep_Cherokee_9**	95	7/26/96	h9607055	h9607056	9	normal	ET	ET	ET	ET	ET	yes	3750	1	car	CA	50541	0.051	0.16	1.43	0.45
36	**Dodge_MiniVan_9**	95	8/2/96	h9608005	h9608006	19	high	ET	ET	ET	ET	ET	yes	4125	1	truck	CA	23392	0.039	0.22	3.41	1.16
37	**Honda_Civic_95**	95	8/6/96	h9608008	h9608009	11	normal	ET	ET	ET	ET	ET	yes	2250	1	car	CA	49814	0.045	0.13	0.93	0.19
38	**Ford_Van_95**	95	8/7/96	h9608011	none	18	normal	ET	none	none	none	none	yes	8000	1	truck	CA	46266	0.026	0.15	3.59	0.30
39	**GMC_S15_Truck_8**	85	8/27/96	h9608057	h9608058	22	high	ET	ET	ET	ET	ET	no	3500	0	truck	CA	27754	0.039	2.66	49.70	5.89
40	**Nissan_Truck_84**	84	8/28/96	h9608061	h9608062	22	high	ET	ET	ET	ET	ET	no	3000	0	truck	49	131983	0.035	2.98	27.42	2.19
41	**Chevy_Cavalier_**	90	8/30/96	h9608069	h9608070		high	ET	ET	ET	ET	ET	no	3250	0	car	49	112434	0.029	0.38	8.74	0.36
42	**Pontiac_90**	90	9/4/96	h9609003	h9609004	22	high	ET	ET	ET	ET	ET	no	3125	0	car	CA	103649	0.051	2.53	13.24	4.73
43	**Dodge_Truck_91**	91	9/5/96	h9609007	h9609008	22	high	ET	ET	ET	ET	ET	yes	3500	0	truck	CA	140298	0.033	0.86	11.90	2.00
44	**Honda_Accord_90**	90	9/6/96	h9609009	h9609010	5	normal	ET	ET	ET	ET	ET	no	3000	0	car	CA	77229	0.042	0.15	2.41	0.78
45	**Honda_Civic_95**	95	9/10/96	h9609017	h9609018	10	normal	T	T	T	T	T	no	2250	1	car	CA	43708	0.031	0.12	0.80	0.23
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
47	**Honda_Civic_89**	89	9/12/96	h9609026	h9609027	19	high	ET	ET	ET	ET	ET	no	2250	0	car	CA	59360	0.041	0.23	6.16	1.81
48	**Infinity_G20_95**	95	9/13/96	h9609031	h9609032	11	normal	ET	ET	ET	ET	ET	no	3000	1	car	CA	21468	0.047	0.15	1.40	0.22
49	**Ford_Mini_93**	93	9/20/96	h9609055	h9609056	15	normal	ET	ET	ET	ET	ET	yes	3750	0	truck	49	76489	0.039	0.22	2.72	0.15
50	**Honda_Civic_96**	96	9/24/96	h9609061	h9609062	11	normal	T	T	T	T	T	no	2625	1	car	CA	20975	0.048	0.06	1.33	0.03
51	**Ford_F150_75**	75	9/25/96	h9609065	none	12	high	T	none	none	none	none	no	3500	0	truck	CA	16464	0.042	1.29	20.31	1.41
52	**Toyota_Camry_92**	92	10/3/96	h9610007	h9610008	5	normal	ET	ET	ET	ET	ET	yes	3250	0	car	49	77272	0.042	0.20	1.65	0.52
53	**Plymth_Breeze_9**	96	10/3/96	h9610009	h9610011	11	normal	ET	ET	ET	ET	ET	no	3000	1	car	CA	15096	0.044	0.12	1.58	0.20
54	**Chevy_Capri_94**	94	10/4/96	h9610012	h9610013	11	normal	ET	ET	ET	ET	ET	no	4250	1	car	CA	43625	0.047	0.24	3.57	0.35

55	**Chevy_Van_86**	86	10/8/96	h9610018	h9610019	21	high	ET		ET	ET	ET	no	4000	0	truck	CA	62890	0.041	3.02	17.85	0.86
56	**Mazda_Protege_9**	90	10/8/96	h9610020	h9610021	6	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	46261	0.035	0.28	3.59	0.46
57	**Cad_Eldorado_82**	82	10/9/96	h9610022	h9610023	22	high	ET	ET	ET	ET	ET	yes	4000	0	car	CA	51233	0.041	1.24	12.15	2.73
58	**Ford_Ranger**	92	10/9/96	h9610024	h9610025	0	normal	ET	ET	ET	ET	ET	no	3500	0	car	CA	52009	0.041	0.24	4.54	0.50
59	**GM_Reagal_86**	86	10/11/96	h9610030	h9610031	6	normal	ET	ET	ET	ET	ET	yes	3500	0	car	CA	26103	0.031	0.26	0.71	0.92
60	**Ford_Aerostar_9**	94	10/16/96	h9610042	h9610043	15	normal	ET	none	ET	ET	ET	yes	3750	0	truck	CA	51061	0.039	0.21	1.97	0.62
61	**Toyota_Corolla_**	94	10/1796	h9610045	h9610046		high	T	T	T	T	T	no	2750	1	car	CA	27339	0.042	0.47	4.34	0.20
62	**Honda_Accord_85**	85	10/18/96	h9610049	h9610050	23	high	ET	ET	ET	ET	ET	no	2625	0	car	49	189506	0.033	2.94	88.49	0.37
63	**Honda_Passport_**	94	10/29/96	h9610064	h9610061	17	normal	ET	ET	ET	ET	ET	no	5500	1	truck	CA	30475	0.032	0.26	2.22	0.34
64	**Ford_F150_86**	86	10/30/96	h9610062	h9610063	14	normal	ET	none	ET	none	ET	no	3500	0	truck	CA	20930	0.042	0.66	2.08	0.85
65	**Toyota_Tercel_9**	93	10/31/96	h9610066	h9610067	6	normal	ET	ET	ET	ET	ET	no	2250	0	car	CA	25384	0.036	0.32	2.69	0.15
66	**Chevy_PU_88**	88	11/1/96	h9611001	h9611002	16	normal	ET	ET	ET	ET	ET	no	4000	0	truck	CA	26201	0.041	0.65	3.96	0.43
67	**Ford_T-Bird_96**	96	11/1/96	h9611003	h9611004	11	normal	ET	ET	ET	ET	ET	no	4000	1	car	CA	16390	0.051	0.15	1.77	0.06
68	**Ford_F150_84**	84	11/6/96	h9611011	none		high	T	none	none	none	none	no	3500	0	truck	CA	62689	0.042	1.11	5.66	1.57
69	**Oldsmobile_71**	71	11/5/96	h9611017	h9611018	1	high	ET	none	ET	none	ET	no	3500	0	car	CA	95629	0.042	10.01	41.69	2.13
71	**Toyota_CLA_92**	92	11/12/96	h9611027	h9611028	22	high	ET	ET	ET	ET	ET	no	2500	0	car	CA	101019	0.041	1.89	10.83	1.83
72	**Ford_Festiva_88**	88	11/13/96	h9611030	h9611031	3	normal	ET	ET	ET	none	ET	no	2000	0	car	CA	155944	0.029	0.40	5.32	1.13
73	**Chevy_Camaro_88**	88	11/14/96	h9611034	h9611035	4	normal	ET	none	ET	none	ET	no	3500	0	car	CA	93424	0.039	0.57	6.36	0.47
74	**Dodge_Neon_96**	96	11/15/96	h9611038	h9611039	11	normal	ET	ET	ET	ET	ET	no	2500	1	car	CA	5312	0.053	0.08	0.94	0.13
75	**Ford_Mustange_9**	95	11/19/96	h9611044	h9611045	10	normal	ET	none	ET	ET	ET	yes	3500	1	car	CA	28905	0.041	0.11	1.51	0.12
76	**Mazda_626_93**	93	11/20/96	h9611048	h9611049	5	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	54244	0.043	0.21	2.97	0.30
77	**Toyota_Tercel_9**	92	11/21/96	h9611052	h9611053	20	high	ET	ET	ET	ET	ET	no	2250	0	car	49	64393	0.036	0.99	7.86	1.21

78	**Honda_Prelude_8**	85	11/22/96	h9611054	h9611055	19	high	ET	ET	ET	ET	ET	no	2750	0	car	49	204385	0.036	1.02	10.19	1.03
79	**Toyota_Celica_8**	83	11/22/96	h9611056	h9611057		high	ET	none	ET	ET	ET	no	2750	0	car	CA	158954	0.038	0.50	4.32	1.67
80	**Ford_Taurus_97**	97	11/26/96	h9611063	h9611064	10	normal	ET	ET	ET	ET	ET	no	3625	1	car	CA	3415	0.039	0.02	0.80	0.34
82	**Toyota_Camry_89**	89	11/25/96	h9611066	h9611067	4	normal	ET	ET	ET	ET	ET	no	3000	0	car	CA	117470	0.038	0.30	4.06	0.66

num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
83	**Mazda_B300_94**	94	11/27/96	h9611068	h9611069	17	normal	ET	none	ET	ET	ET	yes	4000	1	truck	CA	44873	0.035	0.29	3.03	0.22
84	**Jeep_Wrangler_9**	95	12/2/96	h9612003	h9612004	17	normal	ET	none	ET	none	ET	no	4000	1	truck	CA	39029	0.045	0.27	2.95	0.12
85	**Ford_Taurus_85**	85	12/2/96	h9612005	h9612006	5	normal	ET	ET	ET	ET	ET	yes	3500	0	car	CA	56471	0.040	0.28	4.52	0.26
86	**Ford_Mustang_67**	67	12/13/96	h9612008	h9612009	1	high	ET	none	ET	none	ET	no	3000	0	car	CA	92374	0.039	3.48	83.86	0.95
87	**Toyota_Tercel_8**	81	12/13/96	h9612022	h9612023	21	high	ET	none	ET	ET	ET	no	2250	0	car	CA	105699	0.028	1.39	10.32	0.88
88	**Dodge_88**	88	12/5/96	h9612017	h9612018	15	normal	ET	ET	ET	none	ET	no	3625	0	truck	CA	85372	0.063	0.45	8.85	0.74
90	**Ford_Aerostar_9**	94	12/11/96	h9612024	h9612026	15	normal	ET	none	ET	ET	ET	yes	3750	0	truck	CA	71207	0.036	0.29	3.16	0.38
91	**Ford_Tempo_90**	90	12/11/96	h9612027	h9612028	4	normal	ET	none	none	none	none	no	3000	0	car	CA	71696	0.033	0.18	4.36	0.31
92	**Saturn_96**	96	12/12/96	h9612032	h9612033	10	normal	ET	ET	ET	ET	ET	no	2625	1	car	CA	18000	0.038	0.09	0.63	0.20
93	**Datsun_81**	81	12/16/96	h9612035	h9612036	2	high	ET	none	none	none	none	no	2375	0	car	49	118577	0.034	0.41	7.13	0.99
95	**Olds_Regency_90**	90	12/17/96	h9612040	h9612041	4	normal	ET	ET	ET	ET	ET	no	3625	0	car	CA	146761	0.039	0.17	1.70	0.21
96	**Cadillac_BHM_96**	96	12/18/96	h9612044	h9612045		high	ET	none	ET	ET	ET	no	4500	0	car	49	73865	0.039	0.30	1.10	0.95
97	**Oldsmobile_98_8**	83	12/19/96	h9612048	h9612049	23	high	ET	none	ET	none	ET	no	4250	0	car	49	16347	0.041	7.80	162.88	0.24
98	**Toyota_PU_85**	85	12/19/96	h9612050	h9612051	14	normal	ET	none	ET	none	ET	no	2750	0	truck	CA	126328	0.035	0.37	5.84	1.21
99	**Pont_Firebird_8**	89	12/20/96	h9612053	h9612054	5	normal	ET	none	ET	ET	ET	no	3375	0	car	CA	104631	0.064	0.78	4.95	0.98
100	**Ford_Thunbird_8**	80	12/20/96	h9612056	h9612057	2	high	ET	none	ET	none	ET	no	3500	0	car	CA	76087	0.040	3.14	30.31	1.28
101	**Chevy_K1500_95**	95	12/23/96	h9612057	h9612058	18	normal	ET	none	ET	none	ET	no	6500	1	truck	CA	20085	0.031	0.20	2.31	0.55

102	**Dodge_Spirit_94**	94	1/3/96	h9701003	h9701004	11	normal	ET	ET	ET	ET	ET	yes	3000	1	car	CA	49492	0.047	0.13	1.08	0.23
103	**Ply_Sundance_93**	93	1/4/97	h9701005	h9701006	4	normal	ET	ET	ET	ET	ET	yes	2875	0	car	CA	76590	0.032	0.21	3.56	0.92
104	**Nissan_Sentra_9**	95	1/6/97	h9701007	h9701008	11	normal	ET	ET	ET	ET	ET	no	2750	1	car	CA	35291	0.042	0.11	1.47	0.12
105	**Saturn_96**	96	1/7/97	h9701009	h9701010	10	normal	ET	ET	ET	ET	ET	no	2625	1	car	CA	7107	0.038	0.11	0.76	0.12
106	**Saturn_93**	93	1/7/97	h9701011	h9701012	6	normal	ET	ET	ET	ET	ET	no	2625	0	car	CA	30232	0.038	0.16	1.29	0.33
107	**Nissan_PU_92**	92	1/8/97	h9701013	h9701014	15	normal	ET	none	ET	ET	ET	no	3125	0	truck	CA	57196	0.043	0.27	6.86	0.19
108	**Toyota_Camry_94**	94	1/8/97	h9701015	h9701016	11	normal	ET	ET	ET	ET	ET	yes	3625	1	car	CA	22258	0.052	0.13	2.08	0.12
109	**Chevy_Chevel_72**	72	1/9/97	h9701017	h9701018	1	high	ET	none	ET	E	ET	no	3500	0	car	49	15639	0.042	21.79	302.77	0.66
110	**Cadillac_CDV_84**	84	1/9/97	h9701019	h9701020	22	high	ET	none	ET	ET	ET	yes	3625	0	car	CA	94221	0.037	1.19	15.07	3.89
111	**Ford_T_Bird_93**	93	1/10/97	h9701021	h9701022	6	normal	ET	none	ET	ET	ET	yes	4250	0	car	CA	26347	0.033	0.27	4.33	0.32
112	**Mazda_Protege_9**	92	1/10/97	h9701023	h9701024	5	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	75174	0.045	0.31	3.41	0.23
113	**Nissan_Sentra_9**	90	1/14/97	h970127	h970128	4	normal	ET	ET	ET	ET	ET	no	2625	0	car	CA	141134	0.034	0.43	10.69	0.22
114	**Dodge_Ram_MV_88**	88	1/14/97	h970129	h970130	15	normal	ET	ET	ET	ET	ET	yes	3500	0	truck	49	139526	0.039	0.80	4.03	0.81
115	**Ford_Aerostar_9**	92	1/15/97	h970131	h970132	15	normal	ET	none	ET	ET	ET	yes	3750	0	truck	CA	67620	0.039	0.19	2.68	0.45
116	**Chevy_Cavalr_96**	96	1/15/97	h970133	h970134	11	normal	ET	ET	ET	ET	ET	no	2875	1	car	CA	5690	0.042	0.06	1.04	0.47
117	**Honda_Accord_92**	92	1/16/97	h970135	h970136	4	normal	ET	ET	ET	ET	ET	no	3250	0	car	CA	80394	0.038	0.14	1.37	0.18
118	**Chevy_AstroV_88**	88	1/16/97	h970137	h970138	22	high	ET	none	ET	E	ET	no	3750	0	truck	CA	27257	0.036	1.46	8.85	2.01
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
119	**Toyota_Camry_95**	95	1/17/97	h970139	h970140	10	normal	ET	ET	ET	ET	ET	yes	3500	1	car	CA	29209	0.036	0.10	0.62	0.34
120	**Chevy_Camaro_96**	96	1/17/97	h970141	h970142	11	normal	ET	none	ET	E	ET	no	3625	1	car	CA	25877	0.055	0.10	1.39	0.17
121	**Toyota_4Runn_95**	95	1/21/97	h970143	h970144	17	normal	ET	none	ET	E	ET	yes	5400	1	truck	CA	40243	0.028	0.23	3.17	0.62
122	**Toyota_Tercel_9**	91	1/22/97	h9701047	h9701048	4	normal	ET	ET	ET	ET	ET	no	2250	0	car	CA	104710	0.036	0.51	3.44	0.35
123	**Chry_Lebaron_95**	95	1/22/97	h9701049	h9701050	11	normal	ET	ET	ET	ET	ET	yes	3375	1	car	CA	22197	0.042	0.16	1.19	0.28
125	**Dodge_Spirit_90**	90	1/24/97	h9701053	h9701054	20	normal	ET	ET	ET	ET	ET	yes	3125	0	car	CA	183392	0.048	0.51	13.14	0.51
126	**Suzuki_Swift_92**	92	1/24/97	h971015	h9701056	7	normal	ET	ET	ET	ET	ET	no	2125	0	car	CA	48461	0.047	0.25	2.44	0.20

				5																		
127	**GMC_Sonom_PU_92**	92	1/24/97	h9701057	h9701058	16	normal	ET	none	ET	E	ET	no	4250	0	truck	CA	63684	0.038	0.37	5.05	1.07
128	**Ford_T_Bird_78**	78	1/28/97	h9701063	h9701064	2	high	ET	none	ET	E	ET	no	4500	0	car	CA	1255	0.041	2.06	46.77	3.37
129	**Honda_Accord_95**	95	1/28/97	h9701065	h9701066	10	normal	ET	ET	ET	ET	ET	no	3250	1	car	CA	37194	0.040	0.07	0.94	0.19
130	**Subaru_Gl_86**	86	1/29/97	h9701067	h9701068	20	high	ET	ET	ET	ET	ET	no	2500	0	car	CA	96949	0.044	1.13	24.72	0.34
131	**Toyota_PU_85**	85	1/30/97	h9701070	h9701071	14	normal	ET	none	ET	E	ET	no	2750	0	truck	CA	162398	0.035	0.27	6.40	0.57
132	**Honda_Civic_79**	79	1/30/97	h9701072	h9701073	1	high	ET	ET	ET	none	E	no	2000	0	car	CA	48372	0.034	2.85	17.94	0.95
133	**Honda_Civic_95**	95	1/31/97	h9701074	h9701075	8	normal	ET	ET	ET	ET	ET	no	2375	1	car	CA	52111	0.029	0.13	1.72	0.16
134	**Saturn_SL_92**	92	1/31/97	h9701076	h9701077	4	normal	ET	ET	ET	ET	ET	no	2625	0	car	CA	94427	0.032	0.19	2.64	0.58
135	**Nissan_Sentra_9**	91	2/3/97	h9702004	h9702005	5	normal	ET	ET	ET	ET	ET	no	2625	0	car	CA	75800	0.042	0.31	4.60	0.28
136	**Nissan_240SX_93**	93	2/3/97	h9702006	h9702007	7	normal	ET	ET	ET	ET	ET	no	3125	0	car	CA	43009	0.050	0.26	6.58	0.32
137	**BMW_325i_89**	89	2/4/97	h9702008	h9702009	5	normal	ET	ET	ET	ET	ET	no	3750	0	car	CA	101470	0.045	0.56	5.67	0.28
138	**Pontiac_Bonn_88**	88	2/4/97	h9702010	h9702011	5	normal	ET	ET	ET	ET	ET	yes	3750	0	car	CA	79114	0.040	0.14	1.75	0.29
139	**Toyota_PU_95**	95	2/5/97	h9702012	h9702013	17	normal	ET	none	T	E	T	no	4400	1	truck	CA	52322	0.026	0.18	0.88	0.49
140	**Dodge_Dakota_96**	96	2/5/97	h9702014	h9702015	17	normal	ET	none	T	E	T	no	4390	1	truck	CA	3722	0.027	0.09	0.73	0.11
141	**Ford_Escort_96**	96	2/6/97	h9702016	h9702017	10	normal	ET	ET	ET	ET	ET	no	2875	1	car	CA	13719	0.031	0.06	0.74	0.07
142	**Honda_Accord_83**	83	2/6/97	h9702018	h9702019	2	normal	ET	ET	ET	E	ET	no	2500	0	car	CA	181208	0.030	0.55	7.58	0.45
143	**Chevy_C10_81**	81	2/26/97	h9702030	h9702024	13	high	ET	none	T	E	T	no	3875	0	truck	CA	41332	0.039	3.57	24.95	1.46
144	**Ford_Ranger_95**	95	2/26/97	h9702025	h9702026	17	normal	ET	none	ET	E	E	yes	4220	1	truck	CA	43551	0.027	0.12	1.27	0.33
145	**Toyota_PU_88**	88	2/27/97	h9702029	h9702028	20	high	ET	none	T	E	T	no	2750	0	truck	CA	194042	0.042	1.46	27.70	0.21
146	**Chevy_G10_81**	81	2/27/97	h9702031	h9702032	13	high	ET	none	ET	ET	ET	no	4250	0	truck	49	206341	0.041	3.45	61.37	0.62
147	**Mazda_Protege_9**	94	2/28/97	h9702034	h9702035	7	normal	ET	ET	ET	ET	ET	no	2875	0	car	CA	40201	0.042	0.25	3.02	0.42

148	**Jeep_CJ5_83**	83	2/28/97	h9702036	h9702037	13	high	ET	none	T	E	T	no	2875	0	truck	CA	51544	0.039	0.91	23.48	0.71
149	**Ford_Tbird_89**	89	3/3/97	h9703003	h9703004	6	normal	ET	ET	ET	ET	ET	no	3875	0	car	CA	30800	0.036	0.23	1.70	0.54
150	**Dodge_Dakota_92**	92	3/4/97	h9703005	h9703006	19	high	ET	none	ET	ET	ET	no	4000	0	truck	CA	76384	0.045	1.57	8.70	1.93
151	**Toyota_PU_91**	91	3/5/97	h9703007	h9703008	15	normal	ET	none	ET	ET	ET	no	3000	0	truck	CA	30440	0.039	0.13	0.99	0.30
152	**Dodge_Dakota_95**	95	3/5/97	h9703009	h9703010	17	normal	ET	none	ET	ET	ET	no	5630	1	truck	CA	44432	0.039	0.39	5.15	0.80
153	**Hyundai_Excel_8**	89	3/6/97	h9703011	h9703012	21	high	ET	ET	ET	E	ET	no	2500	0	car	CA	61058	0.027	1.03	6.33	0.87
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
154	**Ford_Mustang_65**	65	3/6/97	h9703013	h9703014	1	high	ET	none	ET	none	ET	no	3000	0	car	CA	25426	0.039	5.34	24.23	1.51
155	**GMC_1500_92**	92	3/7/97	h9703015	h9703016	16	normal	ET	none	ET	ET	ET	yes	4250	0	truck	CA	66270	0.049	0.73	8.72	1.15
156	**Nissan_Altima_9**	96	3/7/97	h9703017	h9703018	11	normal	T	T	T	T	T	no	3250	1	car	CA	14212	0.046	0.15	3.56	0.34
157	**BMW_735i_85**	85	3/11/97	h9703023	h9703024		high	ET	none	ET	none	ET	no	4000	0	car	49	141715	0.052	1.50	9.02	4.30
158	**Ford_F_150_86**	86	3/11/97	h9703025	h9703026	19	high	ET	none	ET	ET	ET	no	3750	0	truck	CA	22001	0.039	0.75	2.33	2.55
159	**Toyota_PU_88**	88	3/12/97	h9703028	h9703029	15	normal	ET	none	ET	ET	ET	no	2750	0	truck	49	162245	0.042	0.56	2.38	1.17
160	**Nissan_PU_90**	90	3/12/97	h9703030	h9703031	20	normal	ET	none	ET	ET	ET	no	3125	0	truck	CA	114720	0.043	0.48	13.90	0.84
161	**Buick_Regal_84**	84	3/13/97	h9703034	h9703035	20	high	ET	none	ET	ET	ET	no	3500	0	car	CA	46057	0.031	2.04	14.55	0.25
162	**Mazda_MX6_88**	88	3/13/97	h9730336	h9703037	4	normal	ET	ET	ET	ET	ET	no	3000	0	car	CA	151512	0.037	0.38	5.77	0.48
163	**Honda_Civic_94**	94	3/14/97	h9703038	h9703039	8	normal	ET	ET	ET	ET	ET	no	2625	1	car	CA	78056	0.039	0.10	0.99	0.22
164	**Nissan_280zx_79**	79	3/25/97	h9703053	h9703054	2	normal	T	none	T	T	T	no	3000	0	car	49	35355	0.048	1.00	11.61	2.69
165	**Acura_Integra_9**	96	3/25/97	h9703055	h9703056	11	normal	T	T	T	T	T	no	2875	1	car	CA	4280	0.049	0.12	0.50	0.25
166	**Dodge_Ram_1500_**	96	3/26/97	h9703057	h9703028	18	normal	ET	none	ET	none	ET	no	6400	1	truck	CA	24104	0.034	0.27	1.63	0.71
167	**Ford_Explorer_9**	92	3/27/97	h9703060	h9703061	16	normal	ET	none	ET	ET	ET	yes	4250	0	truck	CA	92324	0.036	0.23	4.19	0.71
168	**Toyota_Pickup_8**	84	3/28/97	h9703062	h9703063	19	normal	ET	none	ET	ET	ET	no	2750	0	truck	49	138310	0.035	0.80	4.24	1.49

169	**Mercury_Tracer_**	81	3/28/97	h9703064	h9703065	7	normal	ET	ET	ET	ET	ET	no	2500	0	car	49	6025	0.051	0.52	2.71	0.98
170	**Chevy_Corsica_8**	88	3/28/97	h9703066	h9703067	19	normal	ET	ET	ET	ET	ET	yes	3125	0	car	CA	124806	0.029	0.45	4.46	1.24
171	**Dodge_Ram_Picku**	85	3/31/97	h9703068	h9703069	22	high	ET	none	ET	ET	ET	no	2750	0	truck	CA	93385	0.035	1.04	23.68	1.82
172	**Toyota_Pickup_9**	91	4/2/97	h9704005	none	15	normal	ET	none	none	none	none	no	3000	0	truck	CA	93178	0.039	0.21	2.31	0.25
173	**Ford_Ranger_92**	92	4/2/97	h9704006	h9704007	15	normal	ET	none	ET	none	ET	yes	3375	0	truck	CA	61976	0.030	0.41	2.26	0.37
175	**Dodge_Caravan_8**	88	4/3/97	h9704010	h9704011	19	high	ET	ET	ET	ET	ET	yes	3625	0	truck	CA	101045	0.039	1.26	7.64	1.17
176	**GMC_Sierra_89**	89	4/4/97	h9704016	h9704015	16	normal	ET	none	ET	ET	ET	yes	3875	0	truck	CA	100890	0.054	0.87	6.67	1.04
177	**Dodge_250_Van_9**	90	4/4/97	h9704017	h9704018	16	normal	ET	none	ET	ET	ET	no	3875	0	truck	CA	60753	0.049	0.36	6.61	0.66
178	**Chevy_S_10_Pick**	92	4/7/97	h9704022	h9704023	21	high	ET	none	ET	ET	ET	no	2750	0	truck	CA	82519	0.038	1.20	5.25	0.69
179	**Chevy_Silverado**	84	4/8/97	h9704024	h9704025	14	normal	ET	none	ET	ET	ET	no	4000	0	truck	CA	39533	0.041	0.42	4.51	1.46
180	**Nissan_Pickup_9**	90	4/8/97	h9704026	h9704027	15	normal	ET	none	ET	none	ET	no	3125	0	truck	CA	130600	0.043	0.46	5.71	0.25
181	**Chevy_SUV_94**	94	4/9/97	h9704028	h9704029	16	normal	ET	none	ET	ET	ET	yes	4750	0	truck	CA	36449	0.044	0.41	4.63	0.49
182	**Dodge_Caravan_8**	89	4/9/97	h9704030	h9704031	19	normal	ET	ET	ET	ET	ET	yes	3750	0	truck	CA	83057	0.038	0.73	4.77	1.20
183	**Chevy_Spirit_85**	85	4/10/97	h9704032	h9704033	20	high	ET	T	ET	none	ET	no	1750	0	car	CA	55719	0.027	5.34	30.80	1.49
184	**Honda_Accord_Ex**	90	4/10/97	h9704034	h9704035	5	normal	ET	ET	ET	ET	ET	no	3125	0	car	49	109713	0.040	0.17	1.69	0.31
185	**Ford_Escort_94**	94	4/11/97	h9704036	h9704037	6	normal	T	T	T	T	T	yes	2625	0	car	CA	31924	0.034	0.12	0.48	0.23
186	**Pontiac_Transpo**	91	4/11/97	h9704038	h9704039	16	normal	ET	ET	ET	ET	ET	yes	4000	0	truck	CA	123618	0.030	0.28	4.11	0.83
187	**Toyota_Paseo_95**	95	4/15/97	h9704043	h9704044	9	normal	ET	ET	ET	ET	ET	yes	2375	1	car	CA	56213	0.042	0.19	1.62	0.13
188	**Toyota_Camry_94**	94	4/15/97	h9704045	h9704046	8	normal	T	T	T	T	T	no	3500	1	car	CA	56197	0.036	0.25	0.66	0.41
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
189	**Alfa_Romeo_Spid**	86	4/16/97	h9704047	h9704048	22	high	ET	ET	ET	ET	ET	no	2750	0	car	CA	46495	0.042	1.85	15.19	1.25
190	**Toyota_X_cab_92**	92	4/16/97	h9704049	h9704050	15	normal	ET	none	ET	ET	ET	no	2750	0	truck	CA	58773	0.042	0.18	1.39	0.24

191	**Saturn_SL2_93**	93	4/17/97	h9704051	h9704052	9	normal	ET	ET	ET	ET	ET	yes	2625	1	car	CA	63125	0.047	0.22	1.57	0.35
192	**Honda_Civic_DX_**	94	4/17/97	h9704053	h9704054	9	normal	ET	ET	ET	ET	ET	no	2375	1	car	CA	57742	0.043	0.16	2.22	0.31
193	**Nissan_Pickup_8**	86	4/18/97	h9704057	h9704058	14	normal	ET	none	ET	none	ET	no	2750	0	truck	CA	221760	0.035	0.32	5.52	0.49
194	**Chrysler_5th_Av**	86	4/18/97	h9704059	h9704060	4	normal	T	none	T	none	T	no	4000	0	car	CA	87798	0.035	0.60	11.17	1.19
195	**Ford_Ranger_96**	96	4/21/97	h9704064	h9704065	17	normal	ET	none	ET	ET	ET	no	4740	1	truck	CA	32612	0.024	0.13	0.90	0.46
196	**Ford_Bronco_II_**	86	4/22/97	h9704066	h9704067	22	high	ET	none	ET	ET	ET	no	3375	0	truck	49	45327	0.039	2.27	13.01	1.72
197	**Dodge_Intrepid_**	95	4/22/97	h9704068	h9704069	9	normal	T	T	T	T	T	no	3625	1	car	CA	62007	0.044	0.26	1.14	0.15
198	**Chevy_C_20_78**	78	4/23/97	h9704071	h9704072	12	high	ET	none	ET	none	ET	no	4250	0	truck	CA	974	0.041	1.83	7.25	2.44
199	**Dodge_Spirit_94**	94	4/24/97	h9704077	h9704078	9	normal	ET	ET	ET	ET	ET	yes	3000	1	car	CA	57407	0.047	0.16	1.03	0.25
200	**Ford_Mustang_79**	79	4/25/97	h9704085	h9704086	23	high	ET	none	ET	none	ET	no	3000	0	car	CA	18631	0.029	4.00	106.32	0.42
201	**Dodge_Spirit_94**	94	4/25/97	h9704091	h9704087	9	normal	ET	ET	ET	ET	ET	no	3000	1	car	CA	56338	0.047	0.14	0.83	0.28
202	**Ford_Windstar_9**	97	4/29/97	h9704094	h9704095	19	high	ET	ET	ET	ET	ET	no	4250	1	truck	CA	19743	0.036	0.06	5.70	4.62
203	**Ford_Explorer_9**	97	4/29/97	h9704096	h9704097	17	normal	ET	ET	ET	ET	ET	no	4700	1	truck	CA	15164	0.034	0.11	0.58	0.12
204	**Ford_Ranger_73**	73	4/30/97	h9704098	h9704099	12	normal	ET	none	ET	ET	ET	no	3750	0	truck	CA	18037	0.042	2.56	40.96	1.47
205	**Dodge_Caravan_8**	85	4/30/97	h9704100	h9704101	23	high	ET	T	ET	none	ET	no	2750	0	truck	49	55665	0.035	8.62	98.58	0.50
206	**Datsun_200sx_77**	77	4/30/97	h9705004	h9705005	3	normal	ET	none	ET	ET	ET	no	2750	0	car	49	30224	0.035	0.41	5.47	1.12
207	**Toyota_Pickup_8**	88	5/1/97	h9705006	h9705007	15	normal	ET	none	ET	none	ET	no	2875	0	truck	CA	86911	0.040	0.33	3.82	0.56
208	**Jeep_Wrangler_8**	89	5/6/97	h9705014	h9705015	22	high	ET	none	ET	none	ET	yes	3625	0	truck	49	111622	0.031	3.68	7.27	4.03
209	**Dodge_Caravan_9**	94	5/6/97	h9705016	h9705017	21	high	ET	E	ET	ET	ET	yes	3875	1	truck	CA	77603	0.037	3.19	13.17	0.09
210	**Chevrolet_Custo**	72	5/7/97	h9705018	h9705019	12	high	ET	none	ET	none	ET	no	4000	0	truck	49	51170	0.041	9.20	27.44	6.30
211	**Ford_Festva_93**	93	5/7/97	h9705020	h9705021	6	normal	ET	ET	ET	none	ET	no	2000	0	car	CA	16938	0.032	0.15	1.33	0.11
212	**Mazda_B2000_SE_**	86	5/8/97	h9705023	h9705024	14	normal	ET	none	ET	none	ET	no	3000	0	truck	CA	166511	0.035	0.61	8.52	0.77

213	**Ford_TBird_94**	94	5/8/97	h9705025	h9705026	8	normal	ET	ET	ET	ET	ET	yes	3875	1	car	CA	72691	0.036	0.12	0.72	0.34
214	**Chevrolet_C1500**	88	5/9/97	h9705027	h9705028	21	high	ET	none	ET	ET	ET	no	3625	0	truck	CA	208028	0.039	1.51	8.10	0.87
215	**Ford_SuperWagon**	80	5/9/97	h9705029	h9705030	13	high	ET	none	ET	none	ET	no	5250	0	truck	CA	75463	0.041	2.66	18.73	2.94
216	**Toyota_Pickup_9**	92	5/13/97	h9705036	h9705037	15	normal	ET	none	ET	none	ET	no	2875	0	truck	CA	58159	0.040	0.15	1.78	0.27
217	**Chevrolet_Capri**	85	5/13/97	h9705038	h9705039	2	normal	ET	none	ET	ET	ET	yes	4250	0	car	CA	93486	0.040	0.55	6.20	1.39
218	**Ford_Mustang_LX**	90	5/14/97	h9705041	h9705042	7	normal	T	none	T	T	T	no	3000	0	car	CA	11302	0.075	0.18	0.44	1.06
219	**Hyundai_Elantra**	92	5/14/97	h9705043	h9705044		high	ET	ET	ET	none	ET	yes	2875	0	car	CA	50107	0.035	1.21	7.96	0.69
220	**Nissan_Sentra_G**	96	5/15/97	h9705046	h9705047	10	normal	T	T	T	T	T	no	2750	1	car	CA	13845	0.035	0.09	0.60	0.19
221	**Honda_Prelude_9**	92	5/15/97	h9705048	h9705049	5	normal	ET	ET	ET	ET	ET	no	3250	0	car	CA	90621	0.049	0.19	1.24	0.36
222	**Ford_F250_72**	72	5/16/97	h9705051	h9705052	12	normal	ET	none	ET	none	ET	no	4000	0	truck	CA	15731	0.041	4.06	59.28	3.92
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
223	**Toyota_Tercel_9**	93	5/16/97	h9705053	h9705054	4	normal	ET	ET	ET	ET	ET	no	2250	0	car	CA	52789	0.036	0.38	2.39	0.33
224	**Jeep_Wrangler_9**	92	5/19/97	h9705059	h9705060	15	normal	ET	none	ET	none	ET	no	3375	0	truck	CA	71210	0.036	0.27	4.25	0.16
225	**Dodge_Ram_84**	84	5/20/97	h9705061	h9705062	22	high	ET	none	ET	ET	ET	no	4250	0	truck	CA	14672	0.041	3.43	65.65	2.35
226	**Honda_Accord_LX**	94	5/20/97	h9705063	h9705064	8	normal	ET	ET	ET	ET	ET	no	3250	1	car	CA	57192	0.040	0.12	1.81	0.17
228	**Chevrolet_Camin**	78	5/22/97	h9705068	h9705069	12	high	ET	none	ET	none	ET	no	4000	0	truck	49	67974	0.041	8.97	173.77	0.70
229	**Honda_Civic_LX_**	93	5/22/97	h9705070	h9705071	9	normal	ET	ET	ET	ET	ET	no	2625	1	car	CA	61032	0.048	0.11	1.01	0.31
230	**Toyota_Celica_G**	85	5/23/97	h9705073	h9705074	4	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	52520	0.038	0.36	2.79	0.82
231	**Jeep_Wrangler_9**	90	5/23/97	h9705075	h9705078	20	high	ET	none	ET	none	ET	yes	3375	0	truck	CA	73234	0.035	0.71	21.45	0.36
232	**Mitsubishi_Ecli**	93	5/27/97	h9705079	h9705080	6	normal	ET	ET	ET	ET	ET	yes	3000	0	car	CA	40526	0.031	0.20	0.87	0.57
233	**Isuzu_Rodeo_95**	95	5/28/97	h9705082	h9705083	17	normal	ET	none	ET	none	ET	no	4450	1	truck	CA	14067	0.027	0.20	3.02	0.24
234	**Ford_F150_97**	97	5/29/97	h9705087	h9705088	18	normal	T	none	T	T	T	no	6550	1	truck	CA	13599	0.025	0.16	1.36	0.13

235	**Ford_Ranger_93**	93	6/3/97	h9706009	h9706007	15	normal	ET	none	ET	none	ET	yes	3625	0	truck	CA	74660	0.044	0.13	0.78	0.23
236	**Dodge_Neon_97**	97	6/1/97	h9706012	h9706010	10	normal	ET	ET	ET	ET	ET	no	2750	1	car	CA	370	0.035	0.36	4.74	0.28
237	**Ford_F150_96**	96	6/4/97	h9706013	h9706014	18	normal	ET	none	ET	none	ET	yes	6250	1	truck	49	24595	0.028	0.11	0.97	0.16
238	**Chevy_Astrovan_**	95	6/10/97	h9706025	h9706026	17	normal	ET	none	ET	none	ET	yes	5950	1	truck	CA	18885	0.032	0.46	4.13	0.60
239	**Buick_Park_Ave_**	88	6/10/97	h9706027	h9706028	4	normal	ET	ET	ET	ET	ET	no	3500	0	car	49	116544	0.039	0.21	1.56	0.20
240	**Nissan_Sentra_8**	84	6/11/97	h9706037	h9706038	20	high	ET	none	ET	none	ET	no	2375	0	car	CA	163270	0.029	1.23	21.01	1.20
241	**Geo_Tracker_93**	93	6/11/97	h9706043	h9706044	15	normal	ET	none	ET	none	ET	yes	2750	0	truck	CA	69008	0.029	0.70	10.03	0.48
242	**Saturn_SL2_94**	94	6/12/97	h9706041	h9706042	9	normal	ET	ET	ET	ET	ET	yes	2625	1	car	CA	64967	0.047	0.16	1.34	0.23
243	**Mitsubishi_PU_8**	85	6/16/97	h9706050	h9706051	14	normal	ET	none	ET	none	ET	no	2750	0	truck	CA	52296	0.035	0.46	10.74	0.55
244	**Crown_Victoria_**	94	6/17/97	h9706054	h9706055		high	ET	ET	ET	ET	ET	yes	4000	1	car	CA	58923	0.041	0.36	6.06	0.43
245	**Chevy_1500_96**	96	6/19/97	h9706056	h9706057	18	normal	ET	ET	ET	ET	ET	yes	6200	1	truck	CA	29697	0.028	0.18	1.39	0.30
246	**Nissan_Sentra_8**	85	6/23/97	h9706079	h9706080	23	high	ET	ET	ET	ET	ET	no	2375	0	car	CA	99665	0.034	1.88	69.05	0.33
247	**Chevy_Tahoe_95**	95	6/23/97	h9706077	h9706078	18	normal	ET	ET	ET	ET	ET	yes	6800	1	truck	CA	31734	0.027	0.29	3.16	0.79
248	**Saturn_SL2_93**	93	6/11/97	h9706032	h9706033	7	normal	ET	ET	ET	ET	ET	yes	2500	0	car	49	42264	0.050	0.16	2.08	0.18
249	**Toyota_Camry_91**	91	6/19/97	h9706058	h9706059	6	normal	ET	ET	ET	ET	ET	no	3500	0	car	CA	30781	0.033	0.24	4.52	0.12
250	**Olds_98_94**	94	6/24/97	h9706081	h9706082	8	normal	ET	ET	ET	ET	ET	yes	3875	1	car	CA	54825	0.039	0.17	0.92	0.24
251	**Chevy_1500_94**	94	6/24/97	h9706083	h9706084	18	normal	ET	none	ET	none	ET	yes	6100	1	truck	CA	57840	0.027	0.34	5.37	0.52
252	**Ford_F_150_95**	95	6/25/97	h9706087	h9706088		high	ET	none	ET	none	ET	yes	4250	1	truck	CA	77505	0.039	0.59	2.68	0.88
253	**Toyota_Corolla_**	96	6/25/97	h9706089	h9706090	10	normal	ET	ET	ET	ET	ET	no	2875	1	car	CA	29480	0.035	0.17	1.80	0.25
254	**Hyundai_92**	92	6/26/97	h9706095	h9706096	22	high	ET	ET	ET	none	ET	no	2625	0	car	49	131834	0.034	1.40	5.29	2.96
256	**Toyota_Corolla_**	78	6/10/97	h9706030	h9706031	2	high	ET	none	ET	none	ET	no	2500	0	car	CA	14836	0.028	2.55	9.10	1.63
257	**Nissan_Altima_9**	93	6/12/97	h9706035	h9706036	7	normal	ET	ET	ET	ET	ET	no	3250	0	car	CA	32058	0.046	0.20	1.90	0.47

258	**Chevy_Beretta_9**	91	6/20/97	h9706065	h9706066	5	normal	ET	ET	ET	ET	ET	no	3000	0	car	49	82723	0.047	0.28	6.55	0.88

num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
259	**Honda_Accord_LX**	95	6/20/97	h9706067	h9706068	7	normal	ET	ET	ET	ET	ET	no	3000	0	car	CA	49764	0.042	0.13	1.89	0.40
260	**Toyota_Camry_LE**	95	7/1/97	h9707002	h9707003	9	normal	ET	ET	ET	ET	ET	no	4000	1	car	CA	51286	0.047	0.18	1.63	0.18
261	**Pontiac_Lemans_**	78	7/1/97	h9707004	h9707005	2	high	ET	ET	ET	E	ET	no	4000	0	car	CA	50041	0.041	1.48	19.18	2.79
262	**Pontiac_Lemans_**	90	7/2/97	h9707007	h9707008	4	normal	ET	ET	ET	E	ET	no	2500	0	car	CA	85012	0.030	0.47	2.12	0.45
263	**Honda_Civic_EX_**	95	7/2/97	h9707009	h9707010	8	normal	ET	ET	ET	ET	ET	no	2750	1	car	CA	54843	0.037	0.16	1.69	0.15
264	**Geo_Storm_90**	90	7/3/97	h9707013	h9707014	5	normal	ET	ET	ET	ET	ET	no	2625	0	car	49	109951	0.050	0.47	6.44	0.67
265	**Toyota_Camry_DX**	91	7/8/97	h9707023	h9707024	6	normal	ET	ET	ET	ET	ET	no	3500	0	car	CA	36061	0.033	0.14	3.11	0.15
266	**Plymouth_Acclai**	94	7/8/97	h9707025	h9707026	8	normal	ET	ET	ET	ET	ET	no	3125	1	car	CA	56936	0.035	0.13	2.91	0.10
267	**Buick_Roadmaste**	91	7/9/97	h9707028	h9707029		high	ET	ET	ET	ET	ET	no	4250	0	car	CA	56407	0.041	0.23	1.27	1.72
268	**Ford_Escort_91**	91	7/8/97	h9707030	h9707031	6	normal	T	T	T	T	T	no	2625	0	car	49	48075	0.034	0.16	1.71	0.18
269	**Honda_Accord_LX**	93	7/10/97	h9707034	h9707035	4	normal	ET	ET	ET	ET	ET	no	3250	0	car	CA	52557	0.038	0.10	1.31	0.32
270	**Mercury_Tracer_**	91	7/10/97	h9707036	h9707037	6	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	41866	0.032	0.09	0.60	0.23
271	**Datsun_510_81**	81	7/11/97	h9707039	h9707040	2	high	ET	ET	ET	E	ET	no	2625	0	car	CA	124170	0.034	0.72	13.67	2.20
272	**Dodge_Ram_1500_**	96	7/10/97	h9707041	h9704042	18	normal	ET	ET	ET	ET	ET	no	6400	1	truck	CA	21501	0.027	0.17	2.48	0.17
273	**Chevy_Corsica_9**	92	7/14/97	h9707051	h9707052	21	high	ET	ET	ET	ET	ET	no	3000	0	car	CA	134585	0.037	1.26	9.00	0.85
274	**Nissan_Sentra_8**	86	7/14/97	h9707053	h9707054	3	normal	ET	ET	ET	ET	ET	no	2375	0	car	CA	228988	0.029	0.43	7.54	0.69
275	**Ford_F_150_Van_**	83	7/15/97	h9707056	h9707057	13	normal	ET	ET	ET	E	ET	no	4000	0	truck	49	8255	0.039	0.89	3.76	1.12
276	**Mazda_626_83**	83	7/15/97	h9707058	h9707059	23	high	ET	ET	ET	E	ET	no	2750	0	car	49	166743	0.030	2.45	78.33	0.15
277	**Volkswagen_Fox_**	92	7/16/97	h9707062	h9707063	22	high	ET	ET	ET	ET	ET	no	2500	0	car	49	78738	0.032	2.82	38.87	1.24
278	**Honda_Accord_LX**	84	7/16/97	h9707064	h9707065	3	normal	ET	ET	ET	ET	ET	no	2625	0	car	CA	122391	0.033	0.38	5.50	0.96

279	**Honda_Civic_LX_**	93	7/22/97	h9707072	h9707073	6	normal	ET	ET	ET	ET	ET	no	2375	0	car	CA	44972	0.029	0.11	0.77	0.34
280	**Saturn_SL2_93**	93	7/23/97	h9707076	h9707077		high	ET	ET	ET	ET	ET	no	2625	1	car	CA	150139	0.047	0.38	4.58	0.33
281	**Honda_Accord_EX**	93	7/24/97	h9707079	h970780	9	normal	ET	ET	ET	ET	ET	no	3250	1	car	CA	72804	0.043	0.20	1.27	0.34
282	**Geo_Metro_96**	96	7/28/97	h9707091	h9707092	10	normal	ET	ET	ET	ET	ET	no	2000	1	car	CA	32034	0.030	0.07	0.54	0.17
283	**Monte_Carlo_81**	81	7/29/97	h9707094	h9707095	23	high	ET	ET	ET	none	ET	no	3500	0	car	CA	43254	0.039	2.20	53.31	1.29
284	**Honda_Accord_LX**	93	7/31/97	h9707101	h9707102	8	normal	ET	ET	ET	ET	ET	no	3500	1	car	CA	97869	0.040	0.22	2.22	0.46
285	**Chevy_1500_Pick**	90	7/31/97	h9707104	h9707105		high	ET	ET	ET	ET	ET	no	3625	0	truck	CA	162673	0.042	0.83	7.05	1.10
286	**Honda_Accord_LX**	95	8/1/97	h9708001	h9708002	11	normal	ET	ET	ET	ET	ET	no	3000	1	car	CA	20606	0.043	0.10	0.92	0.15
287	**Acura_Vigor_94**	94	8/1/97	h9708003	h9708004	8	normal	ET	ET	ET	ET	ET	no	3500	1	car	CA	61040	0.037	0.23	2.17	0.30
288	**Plymouth_Duster**	94	8/4/97	h9708009	h9708010		high	ET	ET	ET	ET	ET	yes	2875	1	car	CA	72483	0.035	0.14	1.52	0.64
289	**Ford_F_150_92**	92	8/5/97	h9708012	h9708011	18	normal	ET	ET	ET	ET	ET	no	6100	1	truck	CA	54962	0.024	0.16	1.63	0.07
290	**Toyota_Tercel_9**	93	8/6/97	h9708014	h9708015	4	normal	ET	ET	ET	ET	ET	no	2250	0	car	CA	111977	0.036	0.47	5.40	0.58
291	**Dodge_Ram_97**	97	8/6/97	h9708016	h9708017	18	normal	ET	ET	ET	ET	ET	no	6727	1	truck	CA	96	0.024	0.37	1.78	0.26
292	**GMC_Jimmy_90**	90	8/7/97	h9708021	h9708022	20	normal	ET	ET	ET	ET	ET	no	3500	0	truck	CA	109657	0.039	0.71	11.88	0.78
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
293	**Plymouth_Voyage**	94	8/8/97	h9708023	h9708024	17	normal	ET	ET	ET	ET	ET	yes	5200	1	truck	CA	80722	0.030	0.25	2.05	0.71
294	**Nissan_PU_88**	88	8/11/97	h9708029	h9708030	22	high	ET	ET	ET	ET	ET	no	3125	0	truck	CA	102556	0.035	3.34	18.19	2.86
295	**Chevy_AstroVan_**	90	8/12/97	h9708032	h9708033	19	high	ET	ET	ET	ET	ET	no	3000	0	truck	CA	127580	0.058	1.21	6.64	1.42
296	**Toyota_PU_94**	94	8/14/97	h9708039	h9708040	15	normal	ET	ET	ET	ET	ET	yes	3500	0	truck	CA	45964	0.039	0.15	2.10	0.20
297	**Chevy_Caprice_9**	94	8/14/97	h9708041	h9708042	19	high	ET	ET	ET	ET	ET	no	4500	1	car	CA	78060	0.044	0.36	5.59	2.16
298	**Chevy_AstroVan_**	90	8/21/97	h9708062	h9708059	19	high	ET	ET	ET	ET	ET	yes	3000	0	truck	CA	145799	0.058	0.84	1.78	7.41
299	**Honda_Civic_84**	84	8/26/97	h9708071	h9708072	20	high	ET	ET	ET	none	ET	no	2250	0	car	CA	173388	0.034	0.86	16.84	1.96

300	**Chevy_Celebrity**	90	8/28/97	h9708079	h9708080	23	high	ET	ET	ET	ET	ET	yes	3000	0	car	CA	133333	0.035	8.46	115.46	0.60
301	**Chevy_Corsica_9**	91	8/29/97	h9708082	h9708083	20	high	ET	ET	ET	ET	ET	yes	3000	0	car	CA	136424	0.032	3.96	42.18	1.71
302	**Ford_Taurus_Wg_**	95	8/29/97	h9708084	h9708085	8	normal	ET	ET	ET	ET	ET	yes	3625	1	car	CA	63558	0.039	0.10	0.84	0.33
303	**Geo_Metro_91**	91	9/3/97	h9709008	h9709009	19	normal	ET	ET	ET	ET	ET	yes	1875	0	car	49	11317	0.029	0.66	6.23	2.71
304	**Oldsmobile_Cutl**	94	9/4/97	h9709013	h9709014	20	high	ET	ET	ET	ET	ET	yes	3250	1	car	CA	80877	0.049	0.91	7.84	2.92
305	**Toyota_Pickup_8**	84	9/5/97	h9709016	h9709017	22	high	ET	ET	ET	none	ET	no	2750	0	truck	CA	174279	0.035	34.92	163.79	1.25
306	**Geo_Metro_91**	91	9/9/97	h9709027	h9709028	19	high	ET	ET	ET	ET	ET	yes	1875	0	car	CA	11441	0.029	0.69	4.67	2.36
307	**Toyota_Corolla_**	93	9/10/97	h9709018	h9709019	9	normal	ET	ET	ET	ET	ET	no	2750	1	car	CA	102240	0.042	0.25	2.56	0.44
308	**GMC_1500_95**	95	9/10/97	h9709037	h9709038	18	normal	ET	ET	ET	ET	ET	no	6100	1	truck	CA	83911	0.030	0.38	4.39	0.92
309	**Toyota_Pickup_8**	81	9/11/97	h9709042	h9709043	13	high	ET	ET	ET	none	ET	no	2875	0	truck	CA	64403	0.035	3.07	50.46	3.67
310	**Dodge_Caravan_9**	89	9/12/97	h9709050	h9709051	15	normal	ET	ET	ET	ET	ET	yes	3750	0	truck	CA	129418	0.027	0.54	11.97	0.77
311	**Chevy_Astrovan_**	92	9/16/97	h9709057	h9709058	19	high	ET	ET	ET	ET	ET	yes	4500	0	truck	CA	113522	0.033	0.63	3.07	4.49
313	**Honda_Civic_94**	94	9/17/97	h9709061	h9709062	8	normal	ET	ET	ET	ET	ET	no	2625	1	car	CA	91045	0.039	0.11	0.69	0.34
314	**Ford_Mustang_65**	65	9/17/97	h9709063	h9709064	1	high	ET	ET	ET	none	ET	no	3000	0	car	CA	26735	0.042	11.07	10.47	2.47
315	**Dodge_Dakota_91**	91	9/18/97	h9709065	h9709066	22	high	ET	ET	ET	none	ET	yes	3500	0	truck	CA	159209	0.036	0.95	11.73	2.06
316	**GMC_Sonoma_97**	97	9/19/97	h9709070	h9709071	17	normal	ET	ET	ET	ET	ET	no	4200	1	truck	CA	1240	0.033	0.10	0.59	0.19
317	**Toyota_Corolla_**	94	9/19/97	h9709072	none	11	normal	ET	none	none	none	none	no	2750	1	car	CA	28630	0.042	0.25	2.25	0.39
318	**GMC_1500_PU_95**	95	9/23/97	h9709080	h9709081	18	normal	ET	ET	ET	ET	ET	no	6200	1	truck	CA	48686	0.028	0.28	2.88	0.45
319	**Honda_Civic_DX_**	97	9/23/97	h9709082	h9709083	10	normal	ET	ET	ET	ET	ET	no	2625	1	car	CA	6172	0.034	0.04	1.13	0.02
320	**GMC_Sonoma_91**	91	9/24/97	h9709084	h9709085	16	normal	ET	ET	ET	ET	ET	no	4000	0	truck	CA	74322	0.039	0.45	4.61	1.81
321	**Dodge_Dakota_91**	91	9/30/97	h9710006	h9709117		high	ET	ET	ET	none	ET	yes	3500	0	truck	CA	159482	0.036	1.16	11.49	1.85
322	**Chevy_Astrovan_**	94	9/30/97	h9790989	h9709090	16	normal	ET	ET	ET	ET	ET	no	4625	0	truck	CA	102737	0.039	0.17	2.33	0.73

324	**Chevy_Malibu_97**	97	10/14/97	h9710026	h9710027	10	normal	ET	ET	ET	ET	ET	no	3375	1	car	CA	3015	0.039	0.13	1.32	0.18
326	**Acura_Integra_R**	89	10/16/97	h9710036	h9710037	5	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	138747	0.043	0.41	5.06	0.27
327	**Ford_Windstar_9**	97	10/17/97	h9710040	h9710041	17	normal	ET	ET	ET	ET	ET	no	5120	1	truck	CA	19386	0.032	0.11	0.44	0.09
328	**Dodge_Shadow_94**	94	10/21/97	h9710054	h9710055	4	normal	ET	ET	ET	ET	ET	no	2875	0	car	CA	78611	0.035	0.33	5.25	1.17
329	**Plymouth_Breeze**	97	10/32/97	h9710062	h9710063	10	normal	ET	ET	ET	ET	ET	no	3250	1	car	CA	23099	0.035	0.11	0.70	0.25
num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
330	**Chevy_Suburban_**	97	10/32/97	h9710069	h9710064	18	normal	ET	ET	ET	ET	ET	no	6800	1	truck	CA	3327	0.041	0.19	1.43	0.29
332	**Chrysler_Town_8**	89	10/28/97	h9710077	h9710078	6	normal	ET	ET	ET	ET	ET	no	3250	0	car	CA	34193	0.035	0.29	5.46	0.34
333	**Plymouth_Carave**	87	10/28/97	h9710079	h9710078	4	normal	ET	ET	ET	ET	ET	no	2875	0	car	CA	53938	0.034	0.56	12.00	0.66
334	**Mercury_Cougar_**	92	10/29/97	h9710082	h9710083	4	normal	ET	ET	ET	ET	ET	no	3875	0	car	CA	55397	0.036	0.17	1.72	0.11
335	**Plymouth_Voyage**	91	10/29/97	h9710084	h9710085	15	normal	ET	ET	ET	ET	ET	no	3750	0	truck	CA	107944	0.027	0.25	7.93	1.16
336	**Acura_Integra_8**	88	10/30/97	h9710087	h9710085	5	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	158879	0.043	0.74	7.00	0.80
337	**Pontiac_Grand_A**	86	10/31/97	h9710092	h9710093	6	normal	ET	ET	ET	ET	ET	no	2750	0	car	CA	29025	0.035	0.23	1.11	0.91
338	**Ford_Bronco_86**	86	10/31/97	h9710094	h9710095	14	normal	ET	ET	ET	ET	ET	no	3750	0	truck	CA	16489	0.039	0.29	3.15	0.73
339	**Oldsmobile_Cutl**	83	11/4/97	h9711009	h9711010	2	high	ET	ET	ET	none	ET	no	3000	0	car	CA	99899	0.037	0.85	4.83	2.49
340	**Ford_Festiva_88**	88	11/6/97	h9711016	h9711017	2	normal	ET	ET	ET	none	ET	no	2000	0	car	49	68287	0.029	0.46	4.19	0.74
400	**Ford_F_350_95**	95	12/18/98	h9812047	h9812048	40	normal	T	T*	T	no	T	no	7000	1	truck	CA	37503	0.030	0.9653	2.03	7.0451
401	**Ford_F_250_87**	87	12/22/98	h9812055	h9812056	40	normal	T	T*	T	no	T	no	6600	0	truck	CA	81909	0.027	0.523	1.37	6.5021
402	**Dodge_250_90**	90	12/22/98	h9812057	h9812058	40	normal	T	T*	T	no	T	no	6900	0	truck	CA	118568	0.023	1.1765	1.8	0.5315
403	**Dodge_250_92**	92	12/23/98	h9812059	h9812060	40	normal	T	T*	T	no	T	no	6100	0	truck	CA	55745	0.026	0.718	1.25	3.3425
404	**Dodge_250_95**	95	12/24/98	h9812061	h9812062	40	normal	T	T*	T	no	T	no	6100	0	truck	CA	36615	0.026	0.514	1.41	8.2507
405	**Ford_F_250_86**	86	1/5/99	h9901006	h9901007	40	normal	T	T*	T	no	T	no	6600	0	truck	CA	61294	0.027	0.6449	1.72	4.2106

406	**Dodge_250_97**	97	1/5/99	h9901008	h9901009	40	normal	T	T*	T	no	T	no	6100	1	truck	CA	29862	0.035	0.5286	1.38	6.4494
407	**Ford_F_350_96**	96	1/6/99	h9901010	h9901011	40	normal	T	T*	T	no	T	no	7600	1	truck	CA	39855	0.028	0.552	1.28	4.593
408	**Ford_F_350_86**	86	1/6/99	h9901012	h9901013	40	normal	T	T*	T	T	T	no	7500	0	truck	CA	72695	0.024	0.6595	1.07	7.2564
409	**Ford_F_350_83**	83	1/7/99	h9901014	h9901015	40	normal	T	T*	T	no	T	no	6600	0	truck	CA	72461	0.027	0.957	2.42	6.6522
410	**Ford_F_350_96**	96	1/8/99	h9901016	h9901017	25	normal	ET	ET*	ET	ET	ET	no	6300	1	truck	CA	31380	0.039	0.153	1.2	0.1876
411	**Dodge_Ram_97**	97	1/9/99	h9901018	h9901030	25	normal	ET	ET*	ET	ET	ET	yes	5800	1	truck	CA	20048	0.041	0.1525	2.13	0.9028
412	**GMC_Sierra_89**	89	1/12/99	h9901031	h9901032	25	normal	ET	ET*	ET	ET	ET	yes	6300	0	truck	CA	91351	0.037	0.667	9.53	2.923
413	**Ford_F_350_92**	92	1/13/99	h9901033	h9901034	25	normal	ET	ET*	ET	ET	ET	no	5800	0	truck	CA	58665	0.040	1.039	11.97	5.0786
414	**Ford_F_350_87**	87	1/14/99	h9901035	h9901036	25	high	ET	ET*	ET	ET	ET	no	5800	0	truck	CA	14866	0.040	3.6349	49.36	5.3546
415	**Ford_F_350_96**	96	1/14/99	h9901037	h9901038	25	normal	ET	ET*	ET	ET	ET	no	6300	1	truck	CA	20224	0.039	0.2049	1.52	0.1114
416	**GMC_3500_88**	88	1/15/99	h9901040	h9901041	25	normal	ET	ET*	ET	ET	ET	no	5200	0	truck	CA	14408	0.045	1.048	6.16	2.0504
417	**Chevy_95_C3500**	95	1/20/99	h9901046	h9901047	25	normal	ET	ET*	ET	ET	ET	no	5800	0	truck	CA	53535	0.050	0.6111	9.76	3.1674
418	**GMC_3500_88**	88	1/26/99	h9910169	h9910172	25	normal	ET	ET*	ET	ET	ET	no	5200	0	truck	CA	103022	0.045	0.7801	8.04	0.5392
419	**95_GMC Jimmy**	95	1/27/99	h9901073	h9901074	21	high	ET	ET*	ET	ET	ET	no	3625	1	truck	CA	97202	0.054	2.74	8.33	0.4058
420	**95_Ford_Escort**	95	1/26/99	h9901070	h9901071	24	normal	ET	ET*	ET	no	ET	yes	2625	1	car	CA	104890	0.034	0.1166	2.15	0.265
421	**96_Ford_Escort**	96	1/29/99	h9901080	h9901081	24	normal	ET	ET*	ET	no	ET	no	2625	1	car	CA	111203	0.034	0.1556	3.37	0.1147
422	**95_Ford_Windstar**	95	2/24/99	h9903007	h9902054	20	high	ET	ET*	ET	ET	ET	yes	3875	0	car	CA	104760	0.040	0.6158	24.11	0.287

num	**Veh. Name**	**MY**	**date**	**test n1**	**test n2**	**Cat**	**Emitter**	**FTP**	**US06**	**MEC**	**AC**	**RPT**	**veh par**	**Mass**	**Tier**	**Veh Type**	**State**	**Odom**	**Z/weight**	**THCgm**	**TCOgm**	**TNOxgm**
423	**96_VW_GTI**	96	2/26/99	h9902058	H9902061	24	normal	ET	ET*	ET	ET	ET	no	3250	1	car	CA	105430	0.035	0.1687	3.27	0.1127
424	**99 Buick_Century**	99	6/16/99	h9906051	h9906052		high	ET	ET*	ET	ET	ET	no	3625	1	car	CA	14510	0.044	0.1594	0.42	0.1095
426	**98_Pontiac_Sunfire**	98	6/23/99	h9906074	h9906075		high	ET	ET*	ET	ET	ET	yes	3000	1	car	CA	28278	0.038	0.1226	3.47	0.0608
427	**95_Jeep_Cherokee**	95	6/29/99	h9906093	h9906094	24	normal	ET	ET*	ET	ET	ET	no	3750	1	truck	CA	151740	0.051	0.2258	1.23	0.3877

428	**94_Mercury_Villager**	94	7/8/99	h9907015	h9907016	24	normal	ET	ET*	ET	ET	ET	-	4000	1	car	CA	100160	0.038	0.2878	2.11	0.5266
429	**98_Toyota_Camry**	98	7/16/99	h9907031	h9907034	20	high	ET	ET*	ET	ET	ET	no	3375	1	car	CA	13247	0.037	1.0337	37.47	0.0584
430	**95_Chevy_S10**	95	9/10/99	h9909032	h9909033	24	normal	ET	ET*	ET	ET	ET	no	2875	1	car	CA	100250	0.037	0.4818	4.81	0.2713

Appendix B: Composite Vehicle Default Parameters

On the follow pages, the default parameters of the composite vehicles are given. For a listing of the vehicle/technology types, refer to Table 3.1. For a listing of the parameters, refer to Table 3.2 and Table 4.2.

	Unit	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
V	Liter	4.75	3.20	1.68	2.51	2.45	2.21	2.35	2.37	2.04	2.14	2.76	6.10
M	lb.	3000	3031	2438	3066	3158	3031	2922	3170	2913	2955	3288	4000
Trlhp	hp	13.3	12.8	11.3	11.9	12.4	12.1	12.3	11.4	11.4	11.5	12.8	18.3
S (rpm/mph)		25.39	25.4	35.4	44.6	39.3	40.9	39.6	40.0	36.2	39.6	38.2	36.8
N_m	rpm	1766	2856	3323	3307	4027	3215	4288	3619	4150	3218	3908	1286
Q_m	lb.ft	250.4	168.0	95.2	143.3	151.3	126.1	148.4	139.0	128.3	125.4	170.1	319.6
P_{max}	hp	119.6	120.0	77.1	110.8	140.1	100.5	141.0	119.6	130.0	108.2	153.5	165.6
Np	rpm	3259	4560	5261	4908	5520	4754	5650	5127	5650	5011	5404	2783
Idle	rpm	967	900	950	871	880	825	900	855	900	871	846	1000
N_g	d.l.	4	4	4	4	4	4	5	4	5	4	4	3
k_0 - kJ(/rev.liter)		0.316	0.316	0.240	0.247	0.206	0.233	0.222	0.188	0.210	0.206	0.236	0.206
ε_1	d.l.	0.698	0.782	0.860	0.900	0.912	0.889	0.917	0.866	0.907	0.918	0.913	0.550
ε_3	d.l.	0.150	0.100	0.100	0.100	0.094	0.100	0.090	0.096	0.099	0.100	0.100	0.190
C_0	d.l.	3.440	3.219	3.325	3.669	3.821	3.519	3.775	3.592	3.894	3.693	3.781	3.292
a_{CO}	d.l.	0.375	0.157	0.158	0.121	0.133	0.097	0.090	0.090	0.086	0.091	0.080	0.275
a_{HC}	d.l.	0.018	0.014	0.017	0.015	0.025	0.011	0.016	0.011	0.013	0.009	0.009	0.009
r_{HC}	g/s	0.021	-0.005	0.002	0.001	0.008	0.004	0.001	0.002	0.001	0.003	0.004	0.014
a_{1NO}	d.l.	0.015	0.029	0.033	0.029	0.029	0.036	0.036	0.036	0.036	0.036	0.033	0.026
a_{2NO}	d.l.	0.033	0.022	0.014	0.038	0.035	0.035	0.035	0.040	0.034	0.033	0.037	0.040
FR_{NO1}	g/s	-0.745	-0.439	-0.215	-0.287	-0.316	-0.291	-0.277	-0.249	-0.255	-0.306	-0.272	-0.789
FR_{NO2}	g/s	0.015	0.110	0.005	0.259	0.372	0.199	0.147	0.746	0.198	0.185	0.379	0.895
hc_{max}	g/s	0.215	0.150	0.080	0.065	0.106	0.067	0.075	0.054	0.065	0.063	0.046	0.171
hc_{trans}	g.s/mph^2	2.999	1.433	0.649	0.354	4.993	4.804	0.250	0.456	0.271	4.804	4.967	4.993
r_R	1/s	0.320	0.167	0.581	0.370	0.034	0.228	0.392	0.401	0.316	0.301	0.082	0.106
ϕ_{min}	d.l.	0.891	0.691	0.402	0.314	0.232	0.373	0.175	0.320	0.161	0.123	0.288	0.969
δSP_{th}	mph^2/s	18.30	0.00	12.13	0.00	88.20	103.32	0.00	5.01	0.00	106.39	110.75	88.20
r_{O2}	d.l.	7.76	8.27	13.67	35.85	42.92	40.54	36.85	67.19	45.30	50.45	63.91	2.16
C_{soak_co}	hour	400.00	73.44	68.56	247.18	38.74	100.18	49.51	127.58	217.18	280.68	166.43	377.86
C_{soak_hc}	hour	0.38	97.21	32.81	19.26	34.66	20.65	22.68	11.30	0.38	15.12	32.22	0.01
C_{soak_no}	hour	400.00	57.50	11.75	295.09	400.00	400.00	400.00	43.34	400.00	400.00	400.00	0.38
α_{CO}	1/hr	238.66	24.00	240.00	17.06	11.91	45.14	240.00	240.00	18.52	224.87	240.00	24.00
α_{HC}	1/hr	0.64	11.00	240.00	12.96	38.61	114.86	240.00	240.00	240.00	240.00	40.48	24.00
α_{NO}	1/hr	66.34	6.30	240.00	0.53	20.10	3.61	240.00	9.35	6.62	0.26	3.70	0.01
β_{CO}	g	499.99	0.03	24.10	18.56	18.99	24.09	23.52	34.42	39.04	9.33	16.86	0.05
β_{HC}	g	499.94	57.31	29.29	15.03	17.72	18.91	31.87	16.57	16.39	10.41	12.76	0.05
β_{NO}	g	288.20	53.60	22.02	19.34	18.26	4.83	27.69	10.43	14.21	6.21	4.47	500.00
T_{cl}	g	165.63	586.67	128.51	143.29	107.68	88.68	89.69	69.65	75.51	50.23	85.58	251.47
ϕ_{cold}	d.l.	1.26	1.21	1.21	1.18	1.21	1.17	1.19	1.11	1.14	1.15	1.19	1.25
CS_{HC}	d.l.	3.98	3.18	3.11	4.74	2.51	4.21	3.19	3.49	4.64	4.55	4.72	1.92
CS_{NO}	d.l.	1.68	1.40	0.20	2.96	3.65	4.90	1.94	3.21	1.81	4.84	4.14	0.61
Γ_{CO}	%	0.00	85.55	100.00	99.86	99.76	99.73	99.78	99.84	99.98	99.98	99.96	0.00
Γ_{HC}	%	0.00	84.25	99.67	99.91	99.78	99.88	99.90	99.86	99.93	99.83	99.95	0.00
Γ_{NO}	%	0.00	29.23	64.86	95.02	95.88	91.07	99.13	100.00	99.78	99.85	99.65	0.00
b_{CO}	1/(g/s)	0.00	0.02	0.33	0.30	0.23	0.15	0.08	0.11	0.07	0.10	0.04	0.00
c_{CO}	1/(g/s)	0.00	19.99	19.99	0.31	0.12	1.70	1.05	1.20	0.72	0.96	1.48	0.00
b_{HC}	1/(g/s)	0.00	0.00	0.08	0.09	0.04	0.04	0.05	0.02	0.02	0.02	0.01	0.00
c_{HC}	1/(g/s)	0.00	4.87	2.38	0.00	0.09	0.55	0.05	0.48	0.26	0.36	0.59	0.00
b_{NO}	1/(g/s)	0.00	4.73	2.78	1.76	1.06	1.01	1.44	0.43	0.82	0.87	0.41	0.00
c_{NO}	1/(g/s)	0.00	0.52	5.00	2.73	1.71	2.21	3.37	0.00	3.57	1.48	1.32	0.00
Id	d.l.	0.00	0.13	0.37	0.34	0.18	0.19	0.36	0.00	0.15	0.07	0.04	0.00
ϕ_0	d.l.	1.26	1.25	1.21	1.23	1.24	1.25	1.24	1.24	1.26	1.24	1.24	1.27
P_{scale}	d.l.	1.198	1.028	1.12	1.313	1.149	1.116	1.128	1.289	1.689	1.312	1.283	1.663

Composite vehicle model input parameters (categories 1-12), * d.l. stands for dimensionless. See Table 3.1 for a description of the category types.

	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**40**
V	4.62	2.94	2.77	4.87	3.42	5.14	3.16	2.23	2.50	2.88	2.67	2.55	6.99	6.66
M	3900	3153	3351	4300	3938	4375	3643	2833	3021	3298	3054	3229	5929	6778
Trlhp	17.6	14.6	15.2	19.8	18.0	21.0	15.2	12.8	13.4	15.3	12.8	14.3	21.3	20.7
S	25.9	40.5	39.0	30.1	33.6	23.0	34.4	41.7	42.1	37.8	40.1	38.2	30.6	30.2
N_m	1959	2689	3029	2432	2953	2121	2888	3143	2867	2858	2696	3733	2543	1633
Q_m	238.2	162.8	157.8	257.6	193.8	276.3	172.0	133.6	137.6	156.8	153.7	145.3	377.9	385.6
P_{max}	143.2	118.5	128.7	175.5	150.0	182.6	130.5	107.9	104.5	122.3	106.1	122.8	244.3	186.1
Np	3607	4615	4847	3972	4603	3763	4817	5016	4854	4740	4763	4758	3914	2978
Idle	920	867	895	800	850	817	886	900	967	923	914	833	829	867
N_g	3	4	4	4	4	4	4	4	4	4	4	4	4	4
k_0	0.233	0.218	0.213	0.206	0.215	0.188	0.243	0.229	0.234	0.249	0.274	0.206	0.191	0.135
ε_1	0.695	0.858	0.855	0.864	0.888	0.762	0.903	0.854	0.956	0.863	0.930	0.919	0.735	0.960
ε_3	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.000	0.100	0.000	0.100	0.100	0.200
C_0	3.735	3.548	3.718	3.911	3.765	3.857	3.751	3.402	3.713	3.607	3.401	3.899	3.580	0.002
a_{CO}	0.201	0.105	0.106	0.085	0.086	0.081	0.079	0.239	0.134	0.157	0.289	0.102	0.097	0.007
a_{HC}	0.009	0.011	0.012	0.009	0.010	0.009	0.014	0.019	0.061	0.019	0.023	0.012	0.007	0.003
r_{HC}	0.008	0.003	-0.003	-0.002	0.004	0.003	0.001	0.003	-0.005	-0.010	0.000	-0.001	0.001	0.002
a_{1NO}	0.026	0.026	0.033	0.029	0.029	0.026	0.036	0.033	0.022	0.029	0.002	0.034	0.030	0.032
a_{2NO}	0.009	0.031	0.033	0.025	0.040	0.038	0.020	0.030	0.019	0.036	0.006	0.040	0.040	0.000
FR_{NO1}	-0.672	-0.448	-0.342	-0.525	-0.407	-0.528	-0.278	-0.355	-0.306	-0.328	-0.872	-0.258	-0.805	0.002
FR_{NO2}	0.005	0.298	0.218	0.005	0.742	0.226	0.127	0.199	0.015	0.431	0.005	0.895	0.895	0.000
hc_{max}	0.119	0.088	0.082	0.066	0.069	0.048	0.063	0.138	0.178	0.128	0.156	0.087	0.152	0.008
hc_{trans}	0.395	1.095	2.075	1.746	0.654	0.045	0.516	4.993	4.993	3.293	0.989	0.955	0.382	0.010
r_R	0.685	0.339	0.114	0.123	0.542	0.621	0.245	0.157	0.010	0.126	0.446	0.142	0.215	0.233
ϕ_{min}	0.798	0.556	0.392	0.712	0.237	0.662	0.431	0.456	0.136	0.462	0.596	0.153	0.446	0.000
δSP_{th}	0.00	14.59	5.42	4.51	14.41	0.00	0.45	110.92	111.80	4.08	10.32	0.00	15.69	0.00
r_{O2}	7.14	19.08	22.82	12.23	41.60	19.66	29.85	16.31	12.53	25.87	9.75	73.65	31.22	42.28
C_{soak_co}	269.73	194.95	73.47	68.84	176.78	112.58	194.96	42.95	217.18	400.00	21.84	264.49	119.93	400.0
C_{soak_hc}	17.41	9.71	16.72	400.00	0.01	41.65	47.05	27.42	400.00	0.38	62.59	12.43	112.88	0.01
C_{soak_no}	400.00	400.00	400.00	400.00	400.00	134.87	0.01	400.00	400.00	5.78	3.06	400.00	0.38	3.30
α_{CO}	0.64	14.75	12.63	35.92	30.67	18.65	0.64	240.00	0.64	0.64	24.26	0.64	240.00	0.00
α_{HC}	0.01	11.23	240.00	240.00	240.00	22.26	0.64	240.00	239.97	0.01	13.87	239.97	240.00	0.00
α_{NO}	24.00	14.20	13.16	240.00	7.15	5.01	239.89	83.48	0.64	0.69	4.46	240.00	240.00	0.00
β_{CO}	500.00	27.43	31.58	57.11	28.27	27.91	108.65	94.98	500.00	500.00	370.30	500.00	500.00	0.00
β_{HC}	102.49	38.38	48.83	500.00	18.88	24.47	500.00	60.98	499.99	500.00	119.59	499.99	500.00	0.00
β_{NO}	0.00	36.22	20.11	111.31	15.11	30.09	500.00	48.04	500.00	63.69	45.38	16.56	500.00	0.00
T_{cl}	261.16	332.42	143.78	202.44	100.18	151.30	109.28	167.63	77.43	248.61	853.65	50.79	250.45	191.3
ϕ_{cold}	1.29	1.12	1.14	1.12	1.11	1.11	1.12	1.31	1.17	1.23	1.37	1.17	1.14	1.00
CS_{HC}	3.71	1.90	1.94	1.69	3.98	4.12	2.68	2.85	0.00	1.24	2.90	3.86	4.63	0.98
CS_{NO}	0.00	2.01	2.44	2.39	3.99	2.54	0.39	1.17	4.70	1.73	10.50	3.57	0.92	3.53
Γ_{CO}	46.44	99.77	99.76	99.86	99.98	99.86	97.69	92.48	97.85	86.75	79.06	100.00	99.98	0.00
Γ_{HC}	53.29	98.47	99.77	99.60	99.94	99.81	96.61	92.09	97.13	87.01	74.62	99.96	99.53	0.00
Γ_{NO}	0.00	71.52	94.75	94.55	99.84	99.81	55.58	69.01	80.61	41.24	28.28	100.00	76.80	0.00
b_{CO}	0.18	0.24	0.30	0.14	0.06	0.06	0.39	0.50	0.50	0.50	0.50	0.17	0.04	0.00
c_{CO}	19.99	2.11	0.46	0.99	1.24	0.77	0.35	0.08	19.99	19.99	3.37	3.22	0.03	0.00
b_{HC}	0.08	0.08	0.10	0.07	0.02	0.02	0.15	0.39	0.19	0.51	0.98	0.05	0.02	0.00
c_{HC}	49.99	1.59	0.01	0.02	0.30	0.34	0.00	0.00	1.02	0.00	0.00	0.14	0.00	0.00
b_{NO}	10.74	2.54	1.71	2.01	0.55	0.61	5.55	4.20	5.76	5.88	20.00	0.90	1.10	0.00
c_{NO}	4.69	2.77	1.51	2.59	2.30	2.99	2.12	2.91	0.00	4.10	0.20	0.00	5.00	0.00
Id	1.00	0.60	0.16	0.26	0.12	0.17	0.37	0.81	0.00	1.00	0.10	0.00	0.63	0.00
ϕ_0	1.24	1.19	1.24	1.24	1.22	1.23	1.25	1.31	1.16	1.24	1.39	1.26	1.18	1.00
P_{scale}	1.313	1.019	1.162	1.329	1.269	1.53	1.272	1.196	0.716	1.152	0.128	1.431	1.689	-

Composite vehicle model input parameters (categories 13-40). See Table 3.1 for a description of the category types.