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Analytical Tool for Measuring Emission Impact of Acceleration and Deceleration Lanes

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16. Abstract
In this study, nonlinear regression models were developed to take into account factors of acceleration or deceleration. To fully capture the dynamics of specific accelerations or decelerations, not only is the acceleration or deceleration of the current time period included in the models as independent variables, but those of previous time periods are also included. In addition, the durations that acceleration or deceleration has been exercised are also included as independent variables. The factor of road grade is considered in the models by adjusting the values of acceleration or deceleration according to the grade. Besides these independent variables, variables representing tractive power are also introduced into the models because they directly determine the amount of emissions that are produced by a vehicle. With this modeling approach, the validation results show that the emission model developed in this study can produce a close match to raw emissions data on both microscopic and macroscopic levels.

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SUMMARY

Air quality is one of the important factors that need to be considered in making transportation improvement decisions. Thus, computer analysis tools are expected to be developed that can help in making these decisions. On the other hand, the MOBILE5 model, which has been widely used in evaluating air quality improvement, is helpless when the transportation improvements are sensitive to factors such as acceleration/deceleration, grade, etc. which are not modeled in the MOBILE5 model. For example, improvements can be made to reduce the grade of a ramp, which can then reduce acceleration and deceleration. Intuitively, the more acceleration there is, the more emissions would be produced. Since the MOBILE5 model cannot model the impact of acceleration or deceleration on emissions, it cannot help the relevant decision-makings. Therefore, the objective of this study is to develop emissions models which can incorporate acceleration or deceleration.

In this study, nonlinear regression models were developed to take into account factors of acceleration or deceleration. To fully capture the dynamics of specific accelerations or decelerations, not only is the acceleration or deceleration of the current time period included in the models as independent variables, but those of previous time periods are also included. In addition, the durations that acceleration or deceleration has been exercised are also included as independent variables. The factor of road grade is considered in the models by adjusting the values of acceleration or deceleration according to the grade. Besides these independent variables, variables representing tractive power are also introduced into the models because they directly determine the amount of emissions that are produced by a vehicle. With this modeling approach, the validation results show that the emissions model developed in this study can produce a close match to raw emissions data on both microscopic and macroscopic levels.

INTRODUCTION

In air quality control and management, there are two types of pollutants considered: primary and secondary. The primary pollutants are those directly emitted to the atmosphere and include CO, SO_2, and lead. Ambient concentrations of such pollutants are directly related to their sources. Secondary pollutants are those formed by atmospheric processes, including chemical reactions and condensation. Ozone is a secondary pollutant, formed by the action of sunlight and a chemical reaction involving volatile organic compounds (VOCs, including HC) and nitrogen oxides (NOx). Airborne PM and air toxics are combinations of primary and secondary pollutants. In urban areas, motor vehicles generally are the dominant emissions sources of VOCs, NOx, and CO and their control is critical in reducing urban air-pollution problems caused by these emissions.

The Clean Air Act (CAA), which was last amended in 1990, requires the National Environmental Policy Act (NEPA) to set National Ambient Air Quality Standards (NAAQS) for these pollutants, which are viewed as harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. The criteria pollutants, for which standards have been set are: ozone, carbon monoxide (CO), nitrogen dioxide (NO_2), lead, sulfur dioxide (SO_2), and particulate matter (PM).

In addition, the NEPA requires documentation of the environmental impacts caused by major capital investments that use federal funds, such as the construction of major transit and highway projects. The NEPA requires that a project not result in a violation of air quality standards and that the project be included in a Transportation Improvement Program. NEPA also requires planners to provide a relative comparison of the air quality impacts of alternatives including the no-build alternative.

MOBILE was developed to estimate overall emissions levels, trends over time, and the effectiveness of mobile-source emission-control strategies. It deals with the on-road vehicle emissions of CO, HC, and NOx. There are other models in the MOBILE package such as NONROAD, PART5, and MOBTOX that estimate off-road emissions. The model has undergone significant evolution since its initial development. Current uses of the model include developing emissions inventories, demonstrating conformity of transportation and air-quality plans, and providing emissions estimates for dispersion and photochemical air-quality modeling.

It should be noted that MOBILE is not suitable for the evaluation of emissions impacts on projects such as ramp and intersection geometric design, traffic signal control, Intelligent Transportation Systems, etc. The problem with MOBILE is that it uses average speed as the only variable to represent driving dynamics. As a matter of fact, average speed cannot properly characterize driving dynamics (e.g., acceleration or deceleration). A large number of different driving patterns can have approximately the same average speed, but might demonstrate totally different driving dynamics and thus produce drastically different emissions. For example, traffic on a short and sharp grade ramp may travel at a similar speed on average as that on a long and smooth grade ramp. However, the emissions produced from the short and sharp ramp would be greater than those from the long and smooth one. Another example is that different signal timing plans may cause traffic to produce different variance of speed while keeping the average travel time the same. To take the change of speed (i.e., acceleration or deceleration) into account in the evaluation of projects such as ramp geometric design and signal timing, there is a strong need to develop an analytical tool that can be used for emission evaluation.

This study developed analytical emissions models that can be integrated with existing microscopic traffic models for project evaluation. Due to the difficulty in representing acceleration or deceleration in macroscale emissions models, microscale emissions models were developed that can estimate second-by-second emissions for given variables such as acceleration or deceleration and speed at the current and previous time periods. These variables were integrated into the microscopic traffic simulation model INTEGRATION, where speed profiles were produced from the microscopic traffic simulation and input into the developed microscale emissions models. The emissions models produce second-by-second emissions estimates which are then aggregated to produce an inventory of emissions for a study area.

In the following sections, a literature review is first introduced on the existing approaches to developing microscale emissions models. Based on this review, the methodology developed for this study is described. Following this, variables that have been included in some existing microscale models and the data that was collected in the studies of these models are described. After that, the calibration of the emissions models that were developed based on the collected emissions data is introduced with the presentation of calibration results. The validation of the microscale emissions models is then described. The interfaces that were developed for integrating microscale emissions models and microscopic traffic simulation models are described for training and implementation. Finally, the conclusions for this study are made and the identification of study needs for future are explored.

LITERATURE REVIEW

There are three approaches to developing microscale emissions models capable of taking acceleration or deceleration into account. Because the emissions data used for developing these models is measured in short time intervals (e.g., second-by-second), these emissions models are called instantaneous or continuous emissions models. They are also called modal emissions models because they include variables such as acceleration or deceleration that represent operational modes.

The most basic form of microscale emissions models is a multidimensional lookup table that simply stores the emissions values corresponding to a combination of speed and acceleration or deceleration. NETSIM is a microscopic traffic simulation model that uses this type of instantaneous emissions model. Obviously, this type of microscale emissions model is straightforward to implement, and the computational cost is very low. However, there are several potential problems with this approach. First, it cannot explicitly account for the time dependence in the emissions in response to the vehicle operations. Many vehicle types exist for which vehicle-operating history (e.g., the speed in the last several seconds of vehicle operations) can play a significant role in emissions measured at current time. Second, it is not convenient for these models to introduce other load-producing effects on emissions such as road grade or accessory use. Otherwise, numerous other lookup tables or perhaps a set of corrections need to be developed.

The second approach to developing microscale emissions models is to develop a neural network model that can learn and capture the correlation between emissions and acceleration or deceleration. This technique has thus far been successfully demonstrated on both light duty passenger vehicles and heavy-duty diesel vehicles. One of the problems with this approach is that the computational time for running a microscopic traffic simulation model with integrated neural network emissions models is substantial. Another problem is the difficulty for analysts in interpreting the influence of a variable on emissions.

The third approach is called analytical and physical modeling. In this approach, the entire emissions creation process is broken down into different components that correspond to physical phenomena associated with vehicle operations and emissions production. ([1]) Each component of the process is then modeled as an analytical representation consisting of various parameters that can characterize the process. These parameters typically vary with vehicle type, engine, and emissions technology. The majority of these parameters are specifications of the vehicle types, and are readily available (e.g., vehicle mass, engine size, and aerodynamic drag coefficient). Other key parameters relating to vehicle operations and emissions production can be deduced from actual second-by-second emissions data. The problem with this approach is the need to estimate a large number of parameters. Substantial estimation errors would be accumulated, and thus make the conceived advantage of emulating the mechanical emissions process difficult to fully achieve.

Given this introduction to these modeling approaches to microscale emissions modeling, nonlinear regression techniques were chosen in this study to relate factors such as acceleration or deceleration to second-by-second emissions. Even though a similar approach has been taken ([2]), more care was taken in this study to select the independent variables included in models. The variables that are not directly related to the emissions were not considered in the models. In addition, the models include a time series of acceleration or deceleration as independent variables which allow the time dependence of emissions on vehicle operations to be modeled.

METHODOLOGY

Based on the review of the existing microscale emissions models, a framework for deriving inventory emissions of a study area based on second-by-second emissions was developed. As presented in figure 1, the framework consists of three components: (1) an existing microscopic traffic simulation model, (2) microscale emissions models, and (3) an interface between these two types of models. This framework shows that the microscopic simulation model requires the inputs that describe transportation network and traffic and those that specify system improvement scenarios such as ramp geometric designs, traffic signal timing, and incident management strategies. The outputs from the traffic simulation model are vehicle speed profiles that are represented by second-by-second speed and acceleration or deceleration. The interface takes the inputs and outputs from the traffic simulation model and processes them to provide the format that is required for the microscale emissions model. The microscale emissions models then take the processed outputs from the interface to calculate the emissions. Again the interface aggregates the second-by-second emissions from the emissions models, formatting the results for easier analysis. This framework indicates that microscale emissions models which have the ability of representing acceleration or deceleration are the fundamental component for deriving inventory emissions for a study area.

In general, there are five steps to develop microscale emissions models:

1. Determine the modeling technique.
2. Determine the emissions influencing factors.
3. Identify the data sources.
4. Calibrate the microscale emissions models.
5. Validate the models.

In some cases, the technique that is chosen for modeling emissions determines the variables that can be considered in models. Thus, the modeling technique should be determined first. The second and third steps are interactive in nature. Before data collection, the number of variables that are expected to be included in emissions models may be greater than those that are obtainable in reality. After the identification of data sources and the type of data that is available, the initially identified variables may need to be adjusted appropriately. Provided with the data collected from one or more than one source, the next step is to calibrate emissions models. The last step of the model development is to validate the models. In this study, this five-step procedure was followed to develop a set of emissions models for CO, HC, and NOx emissions. The details of the development of our model are provided in the following sections.

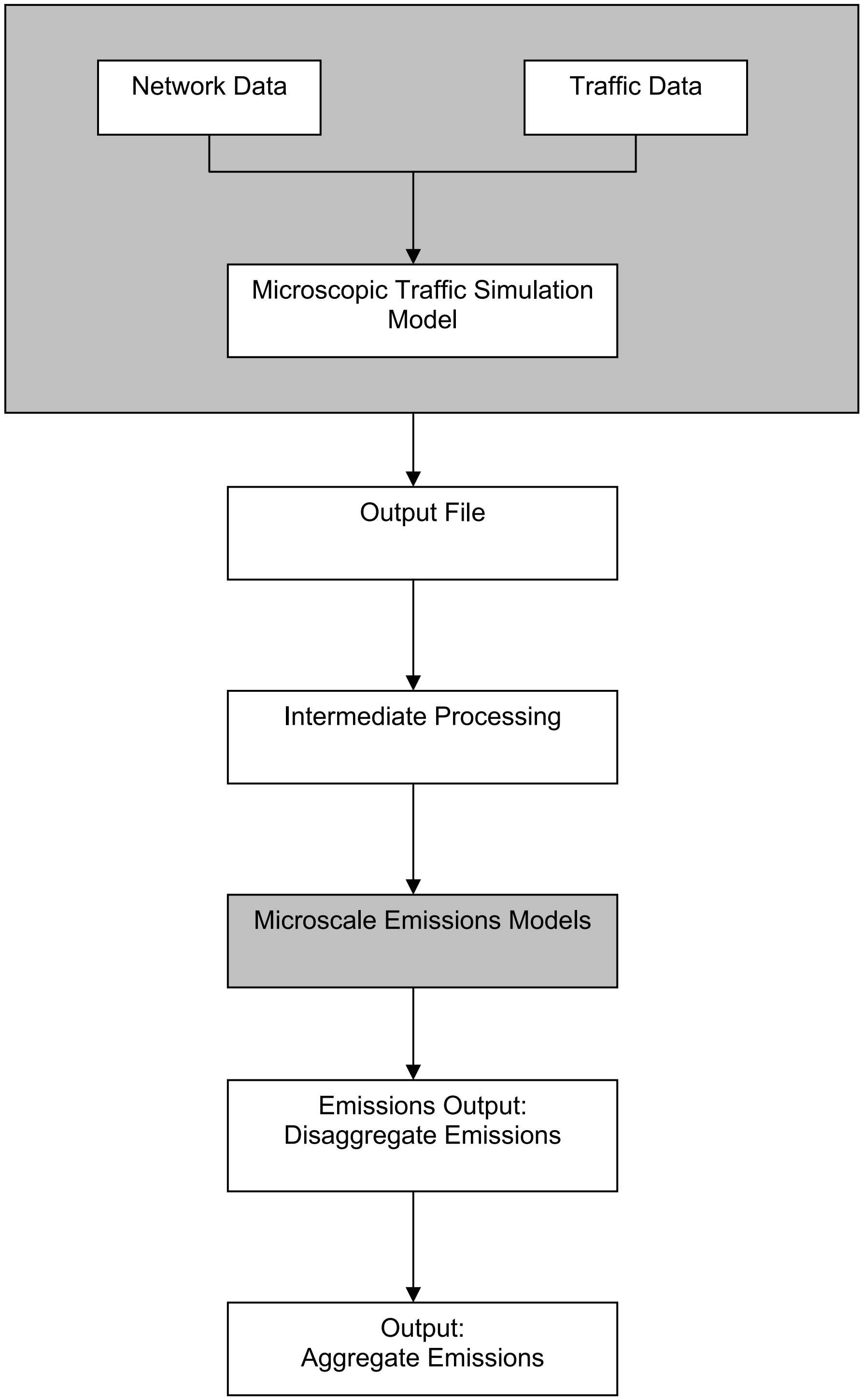

Figure 1. Framework for generating emissions inventory based on microscale emissions models.

IDENTIFICATION OF VARIABLES FOR DEVELOPING EMISSIONS MODELS

Three studies on developing microscale emissions models were reviewed in this study to identify the variables that were considered for their model developments. The first reviewed study was conducted by researchers in 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. ([1]) The microscale emissions model that was developed in the study is called the Comprehensive Modal Emissions Model (CMEM). The second reviewed study was undertaken by Texas Southern University. ([3]) In this study, on-road emissions data was collected by using a remote sensing technology. The third reviewed study was conducted at Virginia Tech where the INTEGRATION traffic simulation model was integrated with the developed microscale emissions models. ([2])

In the CMEM model ([1]) that was developed in the first study, emissions were modeled as products of mechanical processes. As indicated in figure 2, these mechanical processes are composed of six components: 1) engine power demand, 2) engine speed, 3) fuel/air ratio, 4) fuel-rate, 5) engine-out emissions, and 6) catalyst pass fraction. Represented as ovals in figure 2, four operating conditions were considered in the model: a) variable soak time start; b) stoichiometric operation; c) enrichment; and d) enleanment. Based on the comparison of vehicle power demand with power demand thresholds, the condition under which a vehicle is being operated at a given moment can be determined by using the model. Combining the outputs derived from preceding mechanical components with the determined operating conditions, a mechanical component with calibrated and readily available parameters can be used to calculate corresponding outputs, which can then be used as inputs for the following mechanical components. The final product from the CMEM is the second-by-second estimates of vehicle tailpipe emissions, which can be expressed as the product of three components: fuel rate (FR), engine-out emission indices ($g_{emission}$ /g_{fuel}), and time-dependent catalyst pass fraction (CPF):

$$e_{tailpipe} = FR \cdot \left(\frac{g_{emission}}{g_{feul}} \right) \cdot CRF,$$

where 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.

In summary, the model as a whole requires two groups of inputs, represented by rounded boxes in figure 2: A) operating variables; and B) model parameters. The output of the model is estimation of tailpipe emissions and fuel consumption. These inputs are also represented in table 1, with the operating variables in the shaded cells and the model parameters in the remaining cells.

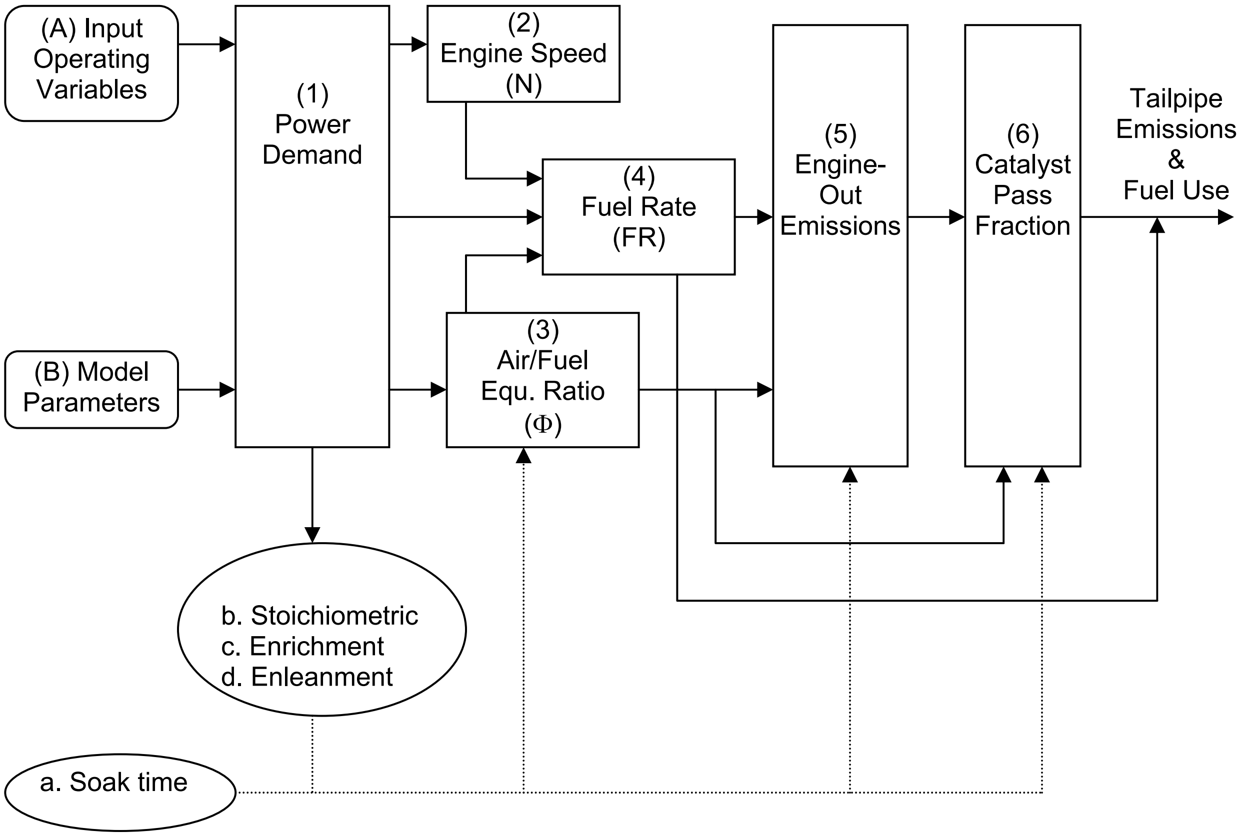

Figure 2. CMEM emissions model structure.

Table 1. Modal emissions model input parameters.

MODEL EMISSIONS MODEL PARAMETERS AND VARIABLES		
Readily-Available Parameters	**Calibrated Parameters**	
Specific Vehicle Parameters M – vehicle mass in lbs. V – engine displacement in liters Idle – idle speed of engine Trlhp – coastdown power in hp S - eng spd./veh spd. in rpm/mph Q_m - max torque in ft.lbs N_m - eng spd. in rpm @ Q_m P_{max} - max power in hp N_p - eng spd. in rpm @ P_{max} N_g - number of gears	***(Insensitive)*** ***Fuel Parameters*** K_0 - eng. fri. factor in kJ/(lit.rev) ε_1, ε_3 - drivetrain eff. Coefficients ***Engine-out Emission Parameters*** C_0 - CO enrich. coef. A_{CO} - EO CO index coef. A_{HC} - EO HC index coef. r_{HC} – EO HC residual value a_{1NOx} – NOx stoich index a_{2NOx} – NOx enrich index FR_{NO1}, FR_{NO2} - NOxFR threshold	(***Sensitive)*** ***Cold-Start Parameters*** β_{CO}, β_{HC}, β_{NOx} - cold start catalyst coefficients for CO, HC, and NOx respectively φ_{cold} - cold F/A equi. Ratio T_{cl} - surrogate temp reach stoich CS_{HC} - cold EO HC multiplier CS_{NO} - cold EO NO multiplier ***Hot Catalyst Parameters*** Γ_{CO}, Γ_{HC}, Γ_{NOx} - hot max CO, HC, and NOx catalyst efficiencies
Generic Vehicle Parameters η - indicated efficiency ε_1 - max. drivetrain eff. R(L) - gear ratio	***Enleanment Parameters*** Hc_{max} – max. HC_{lean} rate in g/s Hc_{trans} – trans. HC_{lean} rate in g/SP d SP_{th} – HC_{lean} threshold value r_R – HC_{lean} release rate in 1/s r_{O2} - ratio of O_2 and EHC φ_{min} – lean fuel/air equ. Ratio	b_{CO}, b_{HC}, b_{NO} - hot Cat CO, HC, and NOx coefficient c_{CO}, c_{HC}, c_{NO} - hot cat CO, HC and NOx coefficient id - NOx Cat tip-in coefficient
Operating Variables θ - road grade P_{acc} – accessory power in hp v - speed trace in mph T_{soak} – soak time (min) SH – specific humidity (grains H_2 0/lb.)	***Soak-time Parameters*** C_{soak_CO}, C_{soak_HC}, C_{soak_NO}– soak time engine coef. For CO, HC, NOx α_{soak_CO}, α_{soak_HC}, α_{soak_NO}– soak time Cat. coef. for CO, HC, NOx	***Enrichment Parameters*** φ_0 - max F/A equi. Ratio P_{scale} – SP threshold factor

In the study conducted by ([3]), ONROAD vehicle exhaust emissions models were developed to estimate CO and HC emissions. These models were developed based on the on-road emissions data collected at five highway locations in Houston, Texas, using remote emissions sensors. These ONROAD emissions estimation models identify the relationships between on-road vehicle exhaust emissions rates and vehicle instantaneous speed profiles. Since instantaneous speed profiles are a function of different traffic demands and control scenarios, these emissions models can be used to estimate the emissions implications of alternative traffic control and management strategies. Because the inputs and outputs of these ONROAD emissions models are second-by-second data, these models can be easily incorporated into microscopic traffic simulation or dynamic traffic assignment models where the instantaneous speed profiles can be tracked for vehicles consistently. Therefore, these emissions models are suitable for employment in traffic simulation and optimization analyses. The dependent variables in these emissions models are CO and HC emission rates for each vehicle type. The independent variables include instantaneous speed, acceleration or deceleration rate, ambient temperature, and humidity.

Nonlinear regression models and neural network models were employed in the study by ([2]). The dependent variables employed in these models are second-by-second emission rates for CO, HC, and NOx. Acceleration or deceleration and speed are used as the independent variables. For comparison, the dependent and independent variables used in these three reviewed studies are listed in table 2.

Table 2. List of dependent and independent variables employed in three emission studies.

	Independent Variables	**Dependent Variables**
CMEM	CO, HC, NOx	• Road grade. • Accessory power. • Speed. • Soak time. • Humidity.
ONROAD	CO, HC	• Speed. • Acceleration rate. • Ambient temperature. • Humidity.
INTEGRATION	CO, HC, NOx	• Acceleration. • Speed.

COLLECTIONS OF EMISSIONS DATA

Three sets of emissions data were obtained in this study from the University of California at Riverside, Texas Southern University, and Oak Ridge National Lab. The contents of these data sets are described in the following sections.

Data from the University of California at Riverside

In August 1995, the researchers at the University of California-Riverside, along with those 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 the 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.

In total, 357 vehicle tests were performed with 4 testing sequences consisting of different combinations of the following cycles:

- A complete 3-bag FTP test.
- A high speed cycle (US06).
- A modal emission cycle (MEC01) developed by the CE-CERT research team.

The newly constructed MEC01 cycle covers most speed, acceleration, and specific power ranges that span the performance envelope of most light-duty vehicles. This cycle is composed of a series of modal events such as various levels of accelerations, deceleration events, a set of constant cruise speeds, speed-fluctuation driving, and constant power driving. It consists of five different sections: stoichiometric cruise section, constant power section, constant acceleration section, air conditioning hill section, and repeat hill cruise section.

As shown in table 3, the following second-by-second measurements were obtained in the CE-CERT study:

- V_TARGET: targeted speed.
- V_ACTUAL: actual speed.
- ECO2: engine-out emission CO2.
- ECO: engine-out emission CO.
- EHC: engine-out emission HC.
- ENOx: engine-out emission NOx.
- TCO2: tailpipe emission CO2.
- TCO: tailpipe emission CO.
- THC: tailpipe emission HC.
- TNOx: tailpipe emission NOx.

The CMEM was developed based only on tailpipe emissions, not engine-out emissions. Instantaneous vehicle acceleration or deceleration is calculated according to the speeds at two consecutive time instants.

Table 3. Second-by-second data for FTP.

TIME	V_TARGET	V_ACTUAL	ECO2	ECO	EHC	ENOx	TCO2	TCO	THC	TNOx
1	0.000000	0.024400	0.007155	0.000572	0.002900	0.000016	0.018334	0.000061	0.000129	0.000000
2	0.000000	0.024400	0.010933	0.000444	0.001282	0.000007	0.015620	0.000240	0.000113	0.000006
3	0.000000	0.024400	0.048084	0.009574	0.002254	0.000048	0.051113	0.009558	0.001419	0.000033
4	0.000000	0.024400	0.411388	0.099721	0.027502	0.000633	0.341804	0.143582	0.016687	0.000235
5	0.000000	0.024400	0.824853	0.507996	0.052624	0.000810	0.893384	0.472066	0.058263	0.000551
6	0.000000	0.024400	1.052446	0.675589	0.102091	0.000943	1.159357	0.657589	0.084639	0.000785
...	...	...	...	...	...	...	...	...	...	...
2474	7.233200	5.772800	1.807608	0.173950	0.010662	0.001358	2.256501	0.007016	0.000402	0.000616
2475	4.024400	2.808300	1.804564	0.173657	0.011954	0.001614	2.257259	0.007019	0.000428	0.000908
2476	1.225800	0.610500	1.802823	0.173489	0.012709	0.001847	2.257694	0.007020	0.000459	0.001242
2477	0.063400	0.073200	1.801447	0.173357	0.013286	0.002041	2.258039	0.007021	0.000463	0.001414
2478	0.000000	0.024400	1.802041	0.173414	0.013024	0.002042	2.257890	0.007021	0.000448	0.001414

Data from Texas Southern University

Data Collection

Texas Southern University collected on-road emissions data using the remote emission sensor (RES), SMOG DOG, from five highway locations in Houston, Texas. SMOG DOG is an application of advanced technology developed for environmental monitoring from space adopted to accurate measurement of automotive emissions on earth. It was initially developed to provide a cost-effective tool for screening for high emitter vehicles and has been used in many successful applications in Arizona, California, North Carolina, Alaska, Georgia, and New Mexico. Some other states are also starting the use of RES to reduce automobile pollution. SMOG DOG can simultaneously measure emission concentrations of CO, HC, NOx, and CO_2 in the dispersing exhaust cloud of vehicles. A special feature of the SMOG DOG system is its enhancement of the capability to detect a vehicle's instantaneous speed and acceleration rate. The instantaneous speed and acceleration of a vehicle passing through the test site are monitored utilizing piezo strips and a computer. Speed and acceleration are then transferred to the main system computer and stored with the vehicle records.

In collecting emissions data, the following factors have been considered. First, emissions data should be collected for a wide range of speeds and acceleration rates in order to establish the relationship between an emission rate and a vehicle's instantaneous speed profile. Second, emissions data should be collected for diverse geometric conditions in order to determine how geometric conditions influence vehicle exhaust emissions. Third, the safety of the equipment operator of the SMOG DOG should be considered. With all of the above considerations in mind, many locations in the city of Houston were evaluated and five highway sites were earmarked for emissions data collection. Of the five locations, two are on-ramps, two are off-ramps and one is on a signalized street. For the on-ramp and off-ramp locations, one of each is on a slight uphill grade while the other two are on a slight downhill grade. While the vehicle emissions data for an idling mode should also be collected, the operation of SMOG DOG requires that the vehicle must be in motion. Hence, on-road emissions data for the idling mode was not collected in Texas study.

Considering the time required for setting up the SMOG DOG equipment and the need for collecting sufficient emissions data in each location, it is not practical to collect emissions for more than one site on each day. Therefore, emissions data at each site was collected for an entire day. The actual emissions data was collected during the period of April 29 to May 3, 1996. Table 4 illustrates a list of sites, which were selected for the data collection as well as the actual date when each site exercise was conducted.

Table 4. Emissions data collection sites in Texas's study.

#	Site	Characteristics	Collection Date
1	Holcombe & Yellowstone Blvd. Onto the I-288 Southbound	On-ramp with approximately 150 meters long and a 3-4 percent downhill grade	April 29, 1996
2	Reed Rd. Onto I-288 Northbound	On-ramp with approximately 250 meters long and a slight uphill grade	April 30, 1996
3	I-288 Southbound off to Reed Rd.	Off-ramp with approximately 250 meters long and a slight downhill grade	May 1, 1996
4	I-288 Northbound off to Yellowstone & Holcombe Blvd.	Off-ramp with approximately 150 meters long and a 3-4 percent uphill grade	May 2, 1996
5	Almeda Rd. Northbound between Holly Hall Rd. and El Paseo	Signal controlled surface street with a level grade	May 3, 1996

It should be noted that all the emissions data collection using the SMOG DOG did not consider the effect of cold start and hot start conditions of vehicles, although it is equally important to consider these factors in evaluating the existing emissions estimation capabilities. This is because all the emission factor models have considered these conditions as proportional contributors to the total emissions. The emissions data collected in the Texas's study represent only the emissions under hot stabilized condition of vehicles.

Data Format and Variables

The format of the data collected by TSU is represented in table 5 in which the columns' headings are explained below:

Vehicle no.	=	Sequence of vehicles that were collected for emissions data.
Date	=	Date when the vehicle's emissions were measured.
Time	=	Time when the vehicle's emissions were measured.
Sensor no.	=	Sequence of sensors that was used to measure the emissions.
License Plate No.	=	License plate number that was captured by camera of the SMOG DOG system.
CO%	=	Percentage of CO particles.
CO2%	=	Percentage of CO2 particles.
HC%	=	Percentage of HC particles.
Slope CO	=	Parameter needed in the SMOG DOG system.
Slope HC	=	Parameter needed in the SMOG DOG system.
Max CO2	=	Parameter needed in the SMOG DOG system.
Max CO	=	Parameter needed in the SMOG DOG system.
Max HC	=	Parameter needed in the SMOG DOG system.
Speed 1	=	Parameter needed in the SMOG DOG system.
Speed 2	=	Parameter needed in the SMOG DOG system.

Acceleration Rate	=	Acceleration.
NOx%	=	Percentage of NOx particle.
Slope NOx	=	Parameter needed in the SMOG DOG system.
Max NOx	=	Parameter needed in the SMOG DOG system.

In addition to these variables, ambient temperature and humidity were recorded for the sites when emissions were measured. Based on this data, only the following variables can be used for the analysis conducted in this study: HC, CO, NOx, Speed, and Acceleration (deceleration).

Table 5. Emissions data collected by TSU.

Veh. No.	Date	Time	Sensor No.	License Plate No.	CO%	CO2%	HC%	Slope CO	Slope HC	Max CO2	Max CO	Max HC	Speed 1	Speed 2	Accel. Rate	Nox%	Slope NOx	Max NOx
1	4/29/1996	11:19:32	10	NOPLATE	999	999	99999	0.9744	0.1323	7.4752	7.3174	0.997	99	99	999	99999	0	0
2	4/29/1996	11:20:37	10	DUF40P	0.02	15.03	0	0.0014	-0.002	0.4797	0.0292	0.0037	50.04	50.1	0.53	99999	0.005	0
3	4/29/1996	11:20:46	10	430YUV	0.29	14.85	141	0.0196	0.0009	0.3679	0.0625	0.0158	44.13	44.27	1.05	99999	-0.02	0
4	4/29/1996	11:20:51	10	GGX16F	999	999	99999	-0.0317	-0.0055	0.1364	0.0418	0.006	36.42	36.46	0.21	99999	0.026	0
5	4/29/1996	11:21:29	10	MLF01D	1.97	13.64	78	0.1446	0.0006	0.2197	0.0447	0.0039	43.84	43.72	-0.86	99999	0.044	0
6	4/29/1996	11:21:37	10	KA0991	999	999	99999	-5.4591	-0.0557	0.0189	0.1885	0.0042	30.67	30.5	-0.74	99999	9.99	0
7	4/29/1996	11:21:47	10	0334TD	999	999	99999	0.087	0.002	0.1772	0.0967	0.009	38.99	38.75	-1.37	99999	0.041	0
8	4/29/1996	11:22:17	10	HLM97L	4.74	11.65	0	0.4069	-0.001	0.3205	0.1521	0.0144	50.44	50.44	0	99999	0.026	0
9	4/29/1996	11:22:24	10	5902YY	999	999	99999	0.035	0.0017	0.7677	0.0729	0.0152	46.59	46.61	0.21	99999	0.005	0
10	4/29/1996	11:22:30	10	HRV32X	0.39	14.77	25	0.0264	0.0002	2.084	0.0714	0.008	36.25	36.52	1.7	300	0.002	0
11	4/29/1996	11:22:37	10	VJP73K	0.07	15	25	0.0047	0.0002	1.4358	0.0469	0.0052	36.12	36.41	1.7	395	0.002	0
12	4/29/1996	11:22:49	10	U	0.51	14.69	0	0.0345	-0.0002	2.8852	0.1361	0.0152	53.33	53.3	-0.29	92	0	0
13	4/29/1996	11:22:53	10	KVG58V	999	999	99999	-3.5648	0.0845	0.007	0.0595	0.012	55.96	56.03	0.79	99999	-0.299	0
14	4/29/1996	11:23:14	10	HKT51D	0.06	15.01	0	0.0039	-0.0009	0.9551	0.0768	0.0207	33.46	33.8	2.06	99999	0.006	0
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Data from Oak Ridge National Lab

The emissions data from the Oak Ridge National Laboratory was collected during a two-year time period starting from 1996 ([2]). In order to collect the emissions data, test vehicles were tested both on-road and on a chassis dynamometer. When the vehicles were tested on a chassis dynamometer, they were tested as functions of vehicle speed and acceleration by driving the cars through their entire operating envelope. The two data sets (one from on-road tests and one from chassis dynamometer tests) are merged numerically to generate look-up tables as functions of vehicle speed and acceleration. The emissions data is comprised of hydrocarbon (HC), oxides of nitrogen (NOx), and carbon monoxide (CO) emission rates. In total, eight vehicles were tested. The models of these vehicles are: Chevrolet Truck, Corsica, Oldsmobile, Geo Prizm, Jeep Grand Cherokee, Oldsmobile, Subaru, and Villager, which are viewed as representative of current Internal Combustion Engine (ICE) light-duty vehicles in the United States.

The raw data collected at the Oak Ridge National Lab (ORNL) contains 1,300-1,600 individual vehicle data points each collected every second during various driving cycles. Typically, vehicle acceleration values range from –1.5 to 3.7 m/s (at intervals of 0.3 m/s), and velocities vary from 0 to 33.5 m/s (0-121 km/h). A sample of the data set for a Corsica is shown in table 6.

Table 6. CO emission (mg/s) for Corsica.

		Acceleration (ft/s/s)												
		-5	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**…**	**9**	**10**	**11**	**12**
Speed (ft/s)	**0**	2.09	2.21	2.4	2.11	2.32	3.24	1.05	0.61	…	7.19	28.72	40.03	21.92
	1	2.37	2.58	2.97	2.42	2.66	3.66	1.13	0.6	…	7.33	29.52	38.61	21.68
	2	2.86	3.2	4	2.95	3.19	4.34	1.3	0.6	…	7.41	30.02	35.82	21.45
	3	3.46	3.88	5.28	3.55	3.71	5.04	1.58	0.62	…	7.18	28.9	31.98	21.8
	4	4.14	4.46	6.53	4.11	4.08	5.53	1.97	0.67	…	6.52	25.62	28.01	23.66
	5	4.96	4.87	7.46	4.56	4.24	5.69	2.44	0.75	…	5.53	20.82	25.16	28.25
	6	5.98	5.16	7.89	4.87	4.24	5.53	2.92	0.89	…	4.49	15.82	24.58	36.9
	…													
	…													
	…													
	107	9.19	8.3	8.8	8.92	19.01	30.58	170.61	861.54	…				
	108	8.57	8.34	8.91	8.81	19.77	35.76	181.86	951.07	…				
	109	8.45	8.49	8.98	8.79	20.48	40.05	192.6	1023.66	…				
	110	8.5	8.62	9.01	8.8	20.92	42.51	199.18	1064.72	…				

COMPARISON OF RESULTS FROM EXISTING EMISSIONS MODELS WITH FIELD DATA

Provided with the review of the microscale emissions models and the collection of emissions data from different sources, the difference between the emissions produced from the microscale models and those collected in labs or on roads was evaluated. Based on this evaluation, the need for developing better microscale emissions models to incorporate acceleration/deceleration was further enhanced.

To make the evaluation meaningful, the emissions data collected by Texas Southern University was chosen as the baseline condition because they was collected on-road and thus represent the real conditions. The data collected by UC at Riverside is in-lab measurements for recruited vehicles. Thus, they cannot reflect real conditions in the field. Only a part of the original ORNL data was collected on-road, and this part of on-road data cannot be distinguished from the data that was made available to this study. It is because the on-road data has been merged with the data collected in-lab which makes this part of data inseparable.

The microscale emissions models embedded in the microscopic traffic simulation model INTEGRATION were chosen for the comparison with on-road emissions data collected by TSU. As introduced above, these models are only incorporated with the acceleration or deceleration and speed for one period of time. The profile of these two variables in time, which influences the emissions substantially, is not included.

To have a reliable comparison between the emissions, INTEGRATION was calibrated for all the five locations where on-road emissions data was collected. In the calibration, the simulated traffic and physical conditions were made consistent with those when on-road data was collected. To do the calibration, the data for traffic and physical condition was obtained from Texas Southern University. The data includes grade, number of lanes, and length for each roadway segment and ramp as well as traffic demands with origin and destination specifications. In the calibration of the model, the mean and variance of speed on each roadway segment collected at the same time with the emissions data were compared with those output from simulation.

From figures 3 to 7 it can be observed that CO emission estimated by the emissions models in INTEGRATION does not change with speed when the grade on ramp is large. When the grades on ramps and intersection are small or flat, the variance of CO increases with speed. Similar pattern can be observed for HC emission. This indicates that the emissions models in INTEGRATION do have the capability of modeling the change of speed. However, this capability is vanished when the roadway geometrics have large grade. Second, the emissions estimated by emission models in INTEGRATION do not match very well to those of on-road data. This discrepancy for CO is more significant than for HC. Also, the match is better when a roadway is not on a large grade. Except for the location that does not have a grade, the on-road emissions data is always larger than the emissions from the emissions models in INTEGRATION.

This observation implies that the emissions models in INTEGRATION underestimate emissions in some cases.

Based on these observations, it can be concluded that there is a need to develop emissions models that can fully take into account the change of speed, i.e., acceleration or deceleration. Grade is a factor that should be incorporated into emissions models because the emissions models in INTEGRATION are not sensitive to grade.

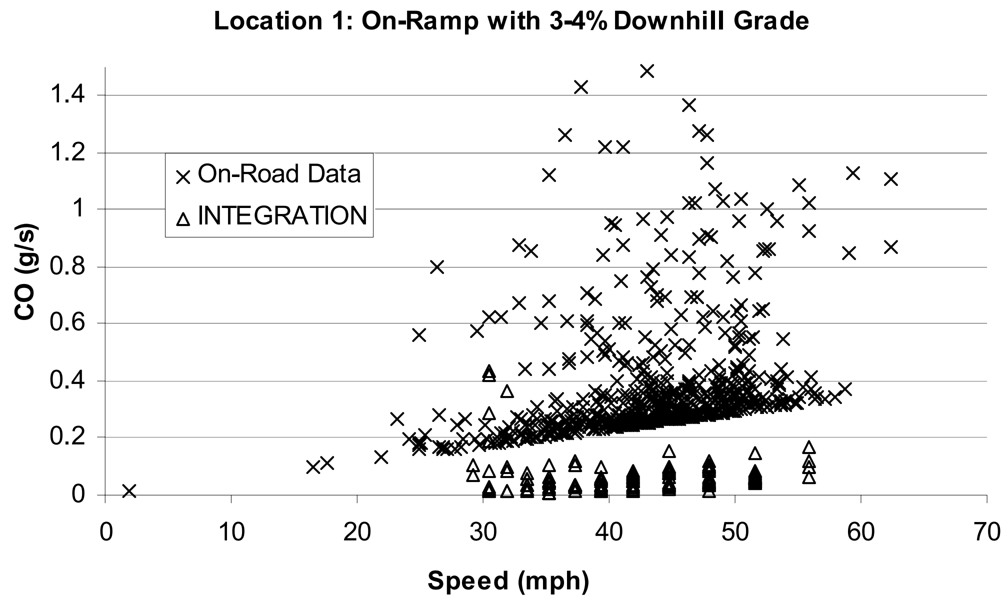

Figure 3. Comparison of CO emission at Location 1.

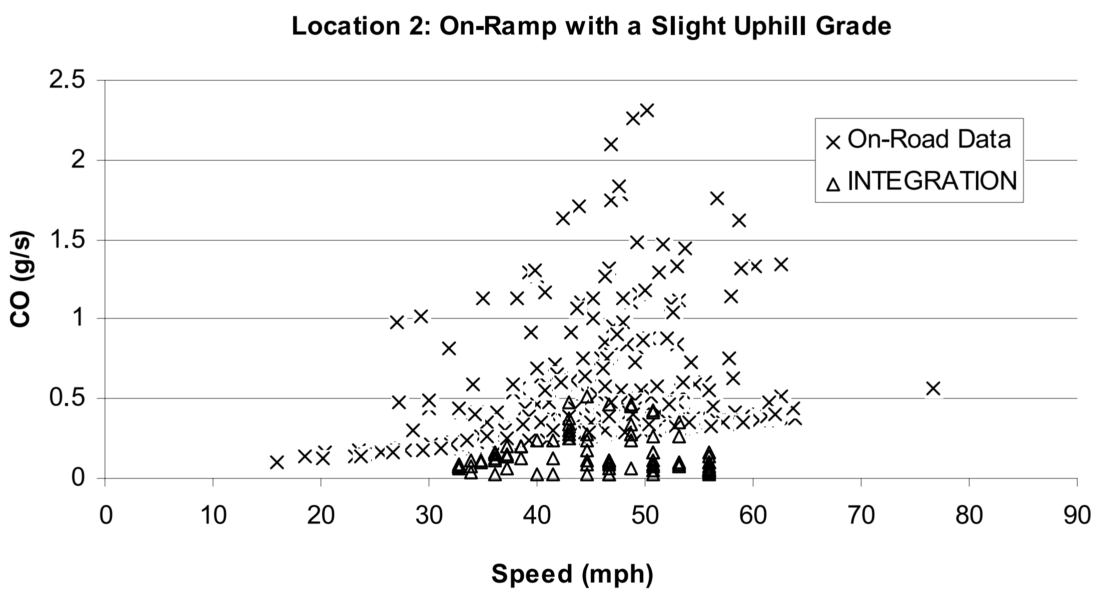

Figure 4. Comparison of CO emission at Location 2.

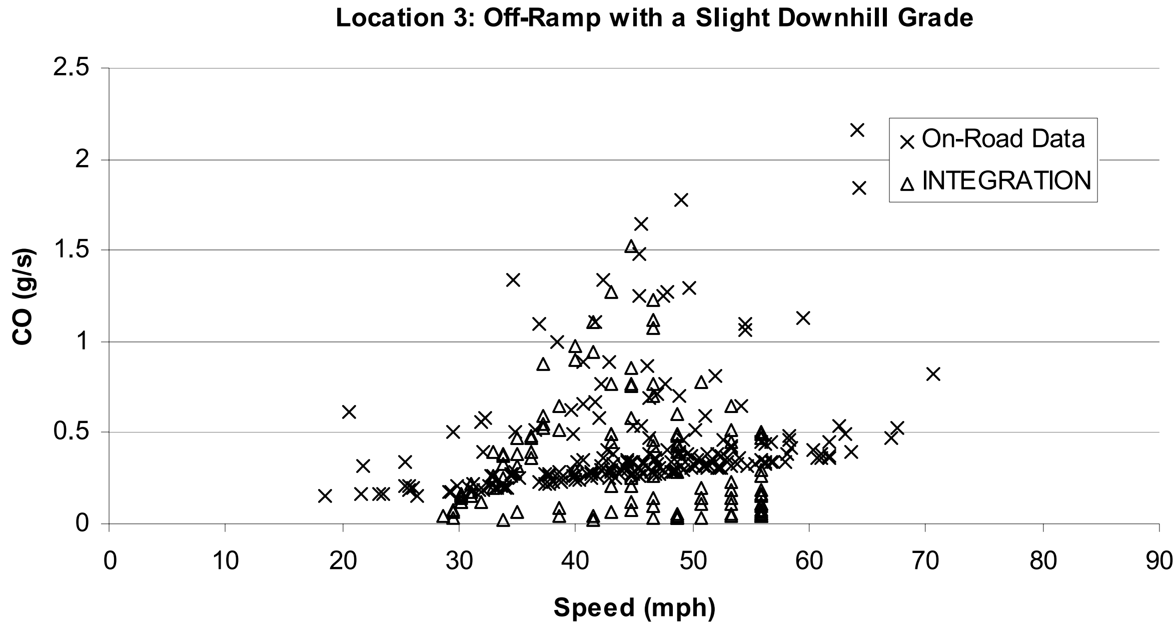

Figure 5. Comparison of CO emission at Location 3.

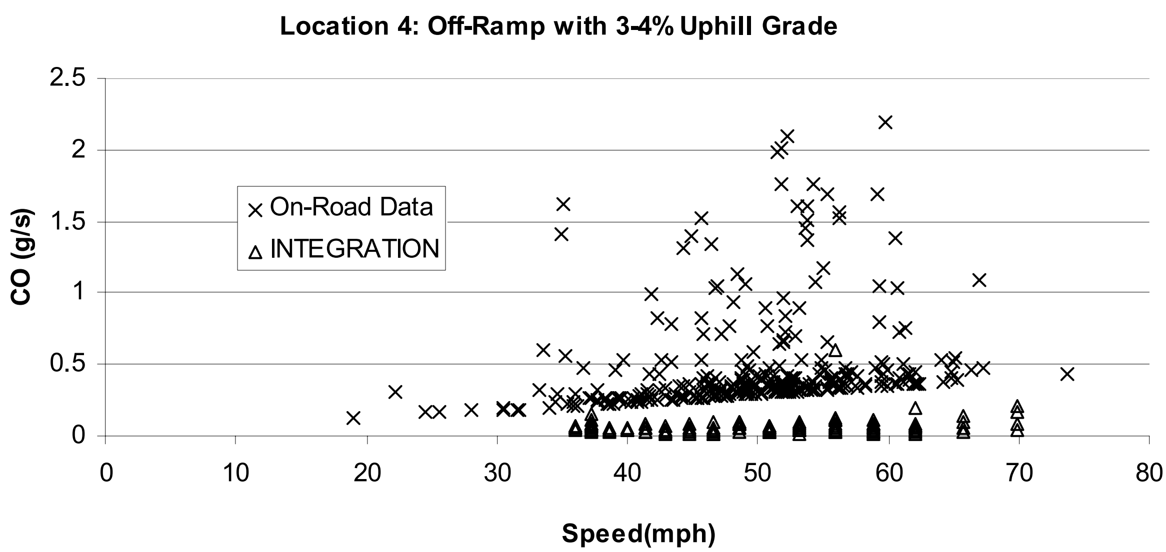

Figure 6. Comparison of CO emission at Location 4.

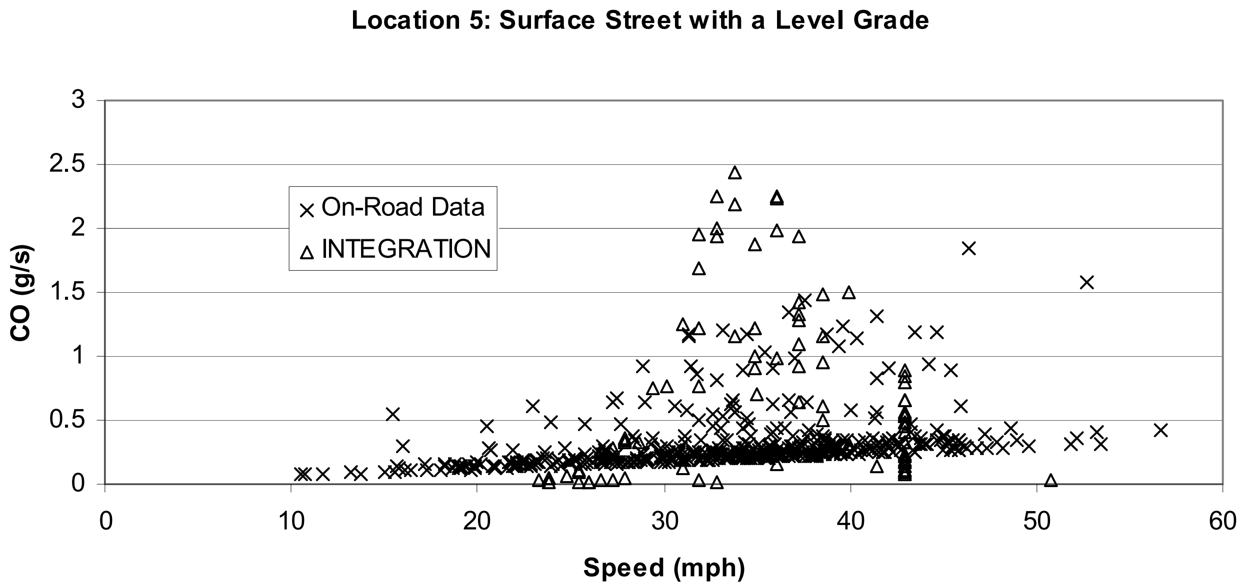

Figure 7. Comparison of CO emission at Location 5.

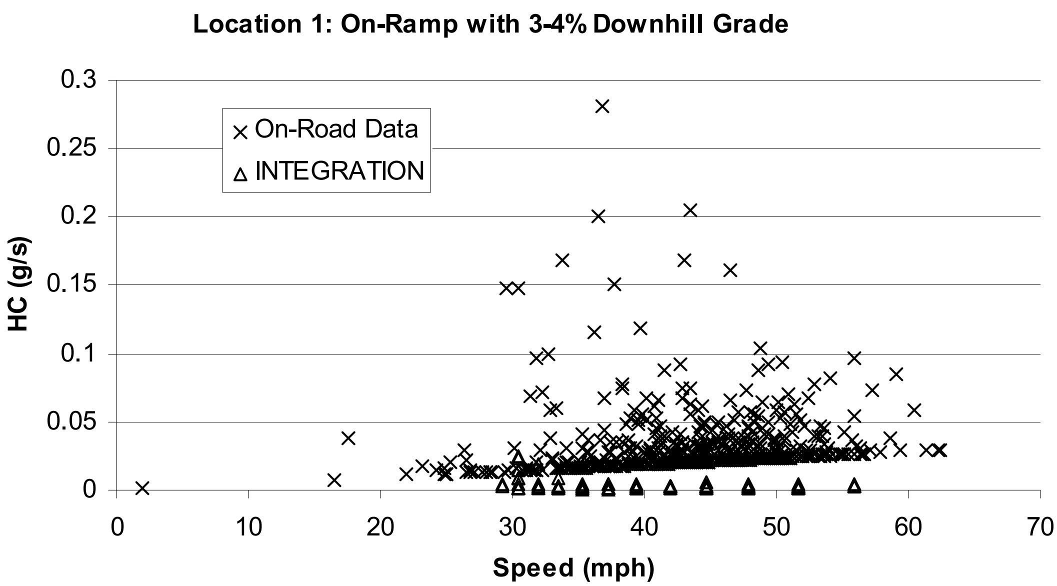

Figure 8. Comparison of HC emission at Location 1.

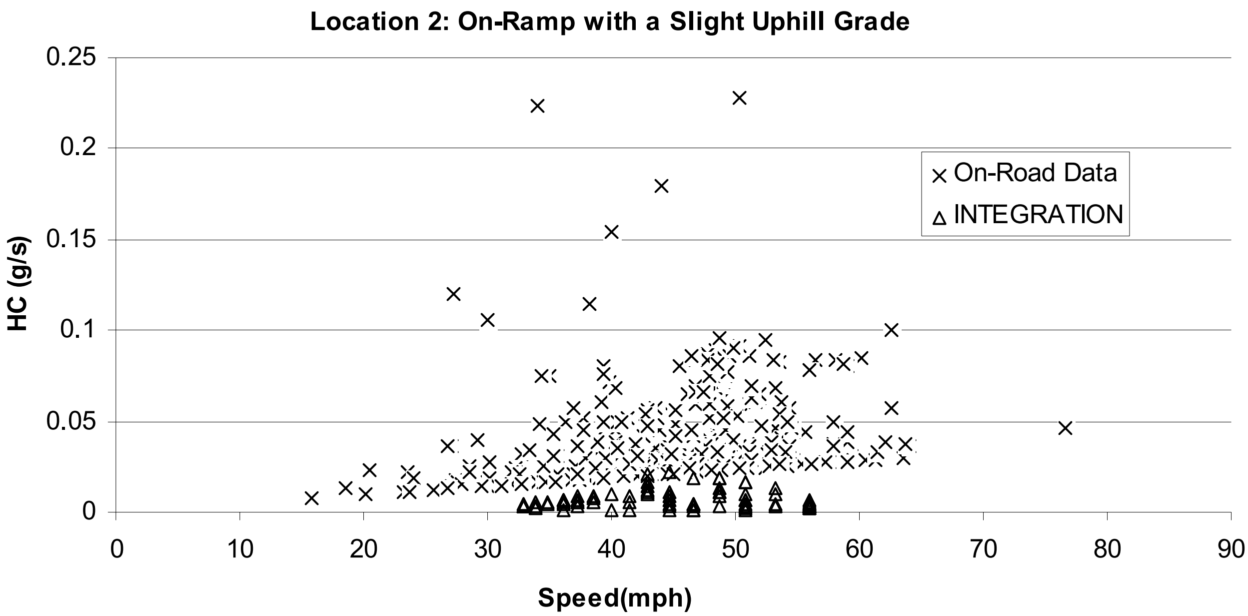

Figure 9. Comparison of HC emission at Location 2.

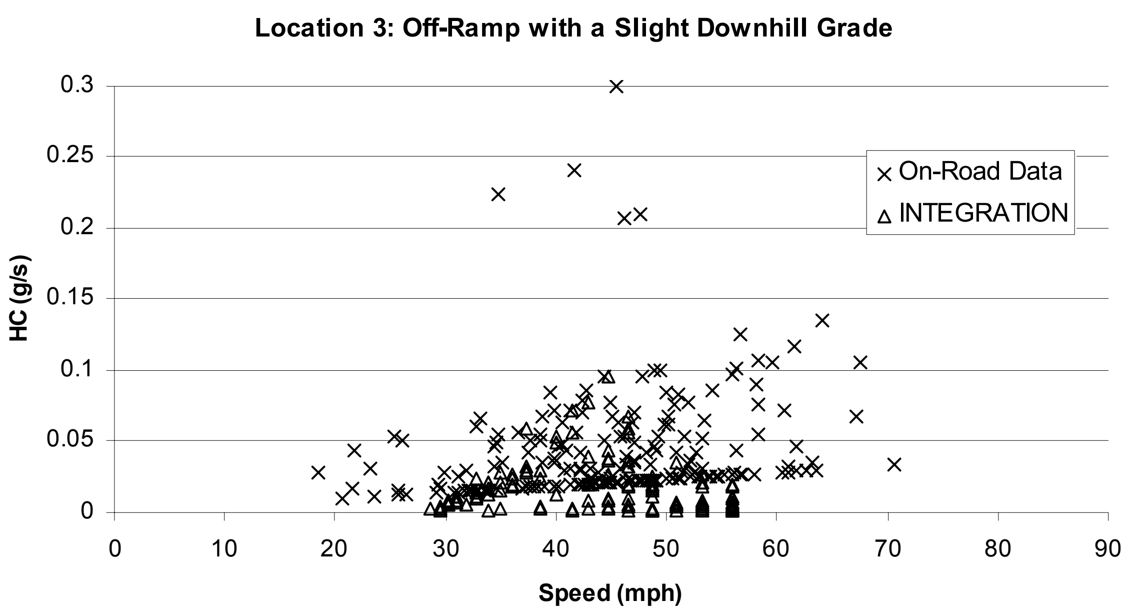

Figure 10. Comparison of HC emission at Location 3.

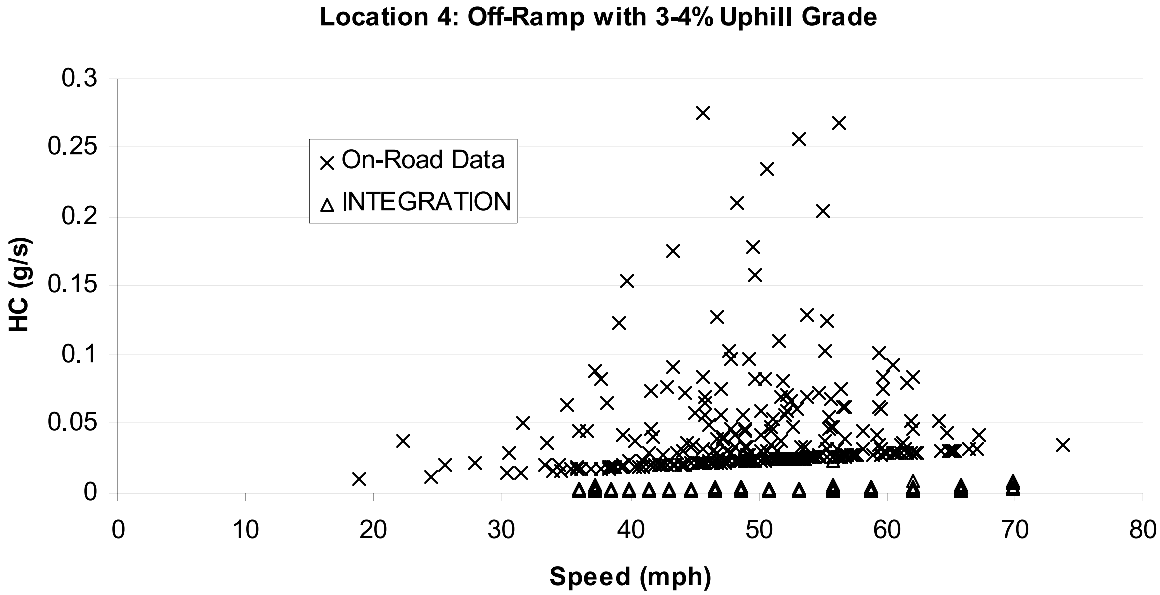

Figure 11. Comparison of HC emission at Location 4.

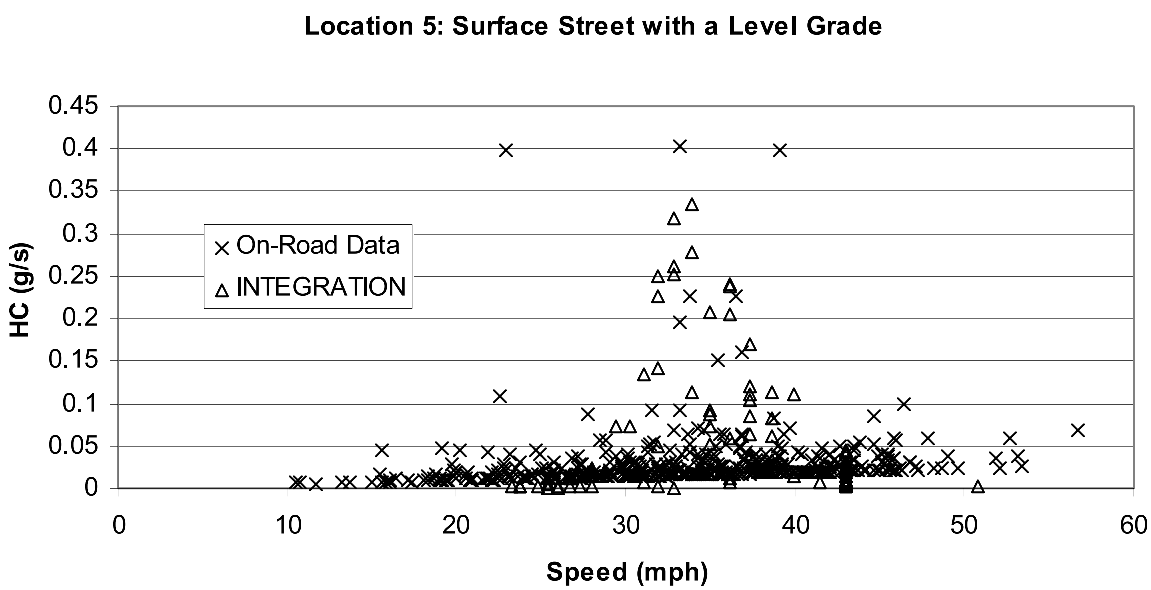

Figure 12. Comparison of HC emission at Location 5.

CALIBRATION OF EMISSIONS MODELS

The first step in calibrating an emissions model is to classify vehicles into groups. The reason to classify vehicles is that distinguishable characteristics exist between different types of vehicles and these characteristics cannot be identified without the classification of vehicles. In addition, it is impossible to develop a single emissions model suitable for different types of vehicles with different characteristics such as manufacturer, model year, etc. The second step in model calibration is to develop emissions models for each class of vehicle. The following sections describe these two steps individually.

Vehicle Classification

Vehicle Class

Based on the vehicle classifications adopted in the CE-CERT study and MOBILE5, the vehicles in this study, as shown in table 7, were classified with respect to vehicle weight, model year, and emitter type. The vehicle weight was classified as: LDGV, LDGT1, and LDGT2. The specifications for each vehicle weight class are defined as:

- LDGV: light-duty gasoline vehicles, i.e., passenger cars.
- LDGT1: light-duty gasoline trucks under 6000 lbs. gross vehicle weight.
- LDGT2: light-duty gasoline trucks with 6000 lbs. to 8500 lbs. gross vehicle weight.

As shown in table 7, there are four high emitter (HE) types. As defined in the CE-CERT study, 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 of 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. 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 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, and moderate to low NOx relative to properly-functioning vehicles. The fourth type of high emitter 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.

Table 7 shows that vehicles with different model year have different emissions characteristics, reflected in their classification in different emitter categories. For LDGVs with model year before 1975, all the vehicles were viewed as one category in terms of emissions performance, which was same as the model year group of 1976-1980. For LDGVs with model year groups 1981-1986, 1987-1990, and 1991-1993, however, four high emitter categories plus one normal category were created. For LDGVs with model year group 1994-1997, only two high emitter categories plus one normal category were provided. For LDGT1 with model year group before 1981, all the vehicles were viewed as one class. For LDGT1 with model years groups 1981-1986 and 1987-1990, four high emitter categories and one normal category were created. No high emitter type 2 was classified for model year group 1991-1993. For model year group 1994-1997, there were no categories of high emitter types 2 and 4. For LDGT2 with model year before 1993, all classified in the same category. For model year group 1994-1997, two categories were created, which are normal and high emitter type 1. The reason for not classifying a model year group into a certain emitter type is that the percentage of the corresponding vehicles is very low in the whole vehicle population.

Table 7. Vehicle classification.

	Model Year Group	**Emitter Type**
i	j	k
LDGV	**Before 1975**	One category
	(1975-1980)	One category
	(1981-1986)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(1987-1990)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(1991-1993)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(1994-1997)	Normal, HE Type 1, HE Type 2
LDGT1	**Before 1981**	One category
	(1981-1986)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(1987-1990)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(1991-1993)	Normal, HE Type 1, HE Type 3, HE Type 4
	(1994-1997)	Normal, HE Type 1, HE Type 3
LDGT2	**Before 1994**	One category
	(1994-1997)	Normal, HE Type 1

Percentages of Vehicle Classes

The proportion of each vehicle class in the vehicle population was calculated based on the vehicle model year distributions and the emitter type distributions. These proportions are presented in table 8. The vehicle model year percentages as shown in table 9 were obtained from MOBILE5, and the emitter type distribution listed in table 10 was obtained from the study by the CE-CERT. The derivation of the class proportion followed three steps.

Step 1: The model year percentages in table 9 were added up for the model year contained in a corresponding model year group.

Step 2: The derived percentages in Step 1 were multiplied by the emitter type percentages provided in table10.

Step 3: For some types of high emitter vehicles within a certain range of model years whose testing data are not available in the CE-CERT data set, the proportion of these types of vehicles was derived by distributing the corresponding percentages derived in Step 2 evenly over the other high emitter types in the same model year group. Note that the fractions of these types of vehicles are very small.

Table 8. Percentages of vehicle classification.

	Model Year Group	**Emitter Type**				
i	j	k				
LDGV	**Before 1975**	0.013013				
	(1976-1980)	0.049049				
	(1981-1986)	0.064414	0.014835	0.014835	0.055435	0.039820
	(1987-1990)	0.134685	0.013054	0.013054	0.027144	0.018027
	(1991-1993)	0.220440	0.005572	0.005572	0.006783	0.004118
	(1994-1997)	0.287427	0.003226	0.003226	0	0
LDGT1	**Before 1981**	0.107677				
	(1981-1986)	0.074686	0.023764	0.017200	0.064275	0.046169
	(1987-1990)	0.091376	0.009559	0.008716	0.018416	0.012230
	(1991-1993)	0.192343	0.006341	0	0.007398	0.005073
	(1994-1997)	0.307777	0.003141	0	0.003141	0
LDGT2	**Before 1993**	0.731343				
	(1994-1997)	0.264627	0.00403	0	0	

Table 9. Vehicle percentage provided in MOBILE5.

Model Year	LDGV	LDGT1	LDGT2
1997	0.049049	0.062812	0.053731
1996	0.079079	0.083749	0.071641
1995	0.083083	0.083749	0.071641
1994	0.082082	0.083749	0.071641
1993	0.084084	0.083749	0.071641
1992	0.081081	0.068794	0.051741
1991	0.077077	0.058824	0.049751
1990	0.056056	0.043868	0.033830
1989	0.050050	0.035892	0.053731
1988	0.051051	0.030907	0.030845
1987	0.050050	0.029910	0.027860
1986	0.054054	0.052841	0.079602
1985	0.047047	0.046859	0.083582
1984	0.037037	0.045862	0.048756
1983	0.024024	0.035892	0.038806
1982	0.019019	0.027916	0.029850
1981	0.014014	0.016949	0.017910
1980	0.015015	0.021934	0.022885
1979	0.011011	0.016949	0.017910
1978	0.008008	0.013958	0.014925
1977	0.006006	0.008973	0.008955
1976	0.005005	0.007976	0.007960
1975	0.004004	0.007976	0.008955
1974	0.003003	0.004985	0.005970
1973	0.010010	0.024925	0.025870

Table 10. Emitter type distribution listed in CE-CERT.

Model Year Group	Normal	HE Type 1	HE Type 2	HE Type 3	HE Type 4
(1981-1986)	0.33	0.106	0.076	0.284	0.204
(1987-1986)	0.65	0.069	0.063	0.131	0.087
(1991-1993)	0.91	0.022	0.023	0.028	0.017
(1994-1997)	0.98	0.006	0.008	0.004	0.002

Model Calibration

For each vehicle class, a nonlinear regression model was developed for each type of emissions (i.e., CO, HC, and NOx). The dependent variables include speed, the time duration the acceleration/deceleration has been sustained, acceleration/deceleration at current time and in the past nine time periods, and specific power for engine. Such regressions can be expressed as follows:

$$e_{i,j,k,m}(t) = \left[\beta_0 + \beta_V V(t) + \beta_{V^2} V^2(t) + \beta_{V^3} V^3(t) + \beta_{T'} T'(t) + \beta_{T''} T''(t) \right. \quad (1)$$

$$\left. + \beta_{A_1} A(t) + \cdots + \beta_{A_{t-9}} A(t-9) + \beta_W W(t) \right]_{i,j,k,m}$$

where:

i	=	1, 2, or 3 for vehicle type of LDGV, LDGT1, or LDGT2, respectively.
j	=	Vehicle model year category for vehicle type i, as shown in table 7, the number of which is different for vehicle type.
k	=	Vehicle high emitter category for model year category i and j. Table 7 shows that this category is also different for different vehicle model year categories.
m	=	Emission type 1, 2, or 3 for CO, HC, NOx, respectively.
$e_{i,j,k_i,m}(t)$	=	Type m emission for vehicle type i, model year category j, and high emitter category k.
β_0	=	Constant.
β_x	=	Coefficient for variable x.
$V(t)$	=	Speed (mph) at time t.
$T'(t)$	=	Continuing acceleration time (second) up to time t.
$T''(t)$	=	Continuing deceleration time (second) up to time t.
$A(t)$	=	Acceleration/deceleration at current time t.
$A(t-1)$	=	Acceleration/deceleration at time t-1.
$A(t-2)$	=	Acceleration/deceleration at time t-2.
$A(t-3)$	=	Acceleration/deceleration at time t-3.
$A(t-4)$	=	Acceleration/deceleration at time t-4.
$A(t-5)$	=	Acceleration/deceleration at time t-5.
$A(t-6)$	=	Acceleration/deceleration at time t-6.
$A(t-7)$	=	Acceleration/deceleration at time t-7.
$A(t-8)$	=	Acceleration/deceleration at time t-8.
$A(t-9)$	=	Acceleration/deceleration at time t-9.
$W(t)$	=	Specific power at time t, which equal to the product of V(t) and A(t).

$V(t)$, $V^2(t)$, and $V^3(t)$ are the determinants of emissions because they are factors that influence the total tractive power ([4]) as presented below:

$$P_{tract} = A \cdot V(t) + B \cdot V^2(t) + C \cdot V^3(t) + M \cdot a(t) + M \cdot g \cdot V(t) \cdot \sin\theta \quad (2)$$

where:

M	=	Vehicle mass with appropriate inertial correction for rotating and reciprocating parts (kg).
g	=	Gravitational constant (9.81 $m/m/s^2$).
θ	=	Road grade angle.

Note that acceleration or deceleration in Equation (1) is a converted value where the grade of road is taken into account by the following equation:

$$A(t) = a(t) + 9.81\left(\frac{g(t)}{\sqrt{1+g(t)^2}}\right).$$

In the equation, a(t) denotes the acceleration or deceleration at current time t, and g(t) represents the grade of the roadway segment where vehicles are running on at current time t.

It is an accepted fact that 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). This interdependence was investigated in this study, some results of which are shown in figures 13, 14, and 15. The results shown in these figures were obtained based on LDGVs whose model year group is 1981-1986 and are the first high emitter type. From the figures, it can be seen that it is the acceleration or deceleration in previous time periods, not the acceleration or deceleration at the current time, that has the most obvious impact on the current emissions. In addition, the patterns of the impacts are not the same for different emission types. To take this impact into account, variables of accelerations or decelerations in the current and the immediate past time periods are used in the modeling and denoted as $A(t), \ldots, A(t-9)$. In addition, variables that represent the extent or the duration that an acceleration or deceleration has been continuously executed since its inception were introduced in the models and they are denoted as $T'(t)$ and $T''(t)$, respectively.

The last variable included in the emission function is related to Specific Power (SP), which is approximated as two times the product of velocity *(*V) and acceleration *(*A) ([1]):

$$SP(t) = 2\ V(t)\ A(t) = 2\ W(t) \tag{3}$$

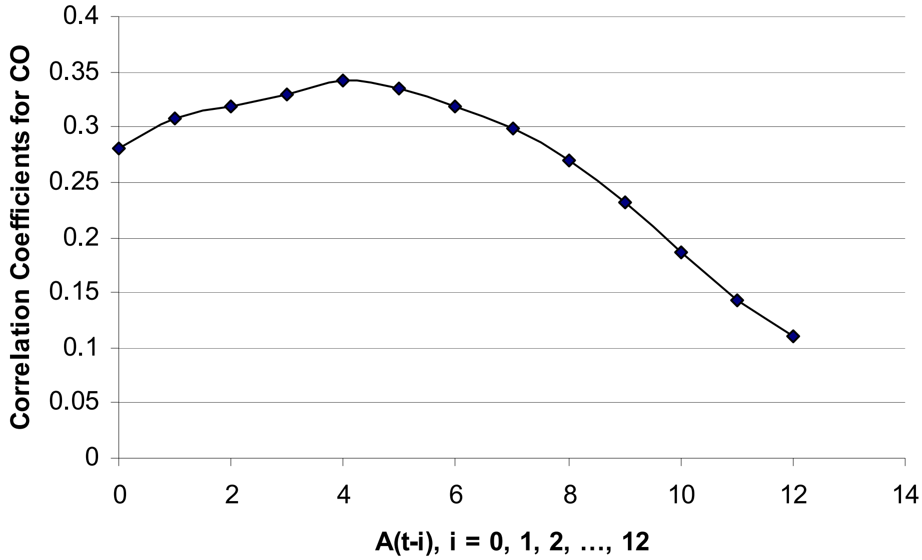

Figure 13. Correlation between CO emission and accelerations or decelerations in previous time periods.

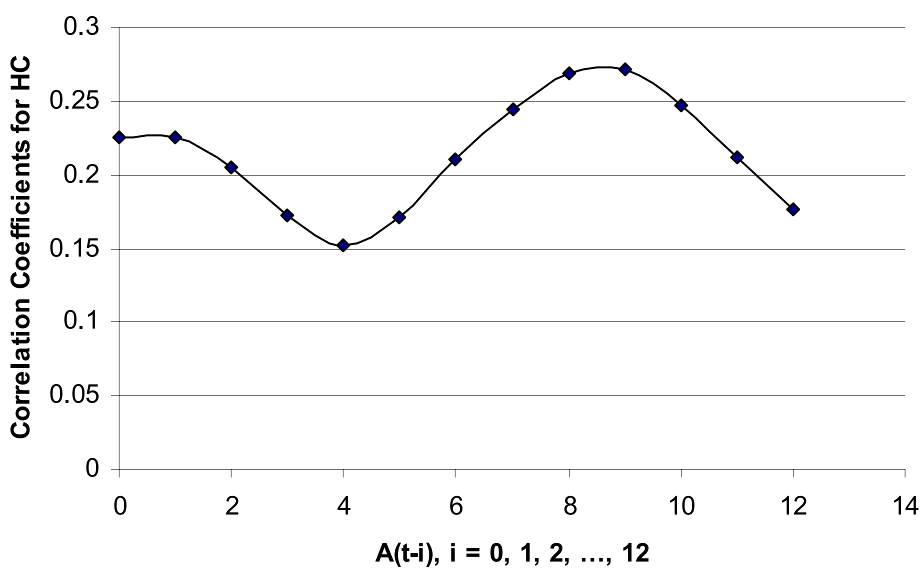

Figure 14. Correlation between HC emission and accelerations or decelerations in previous time periods.

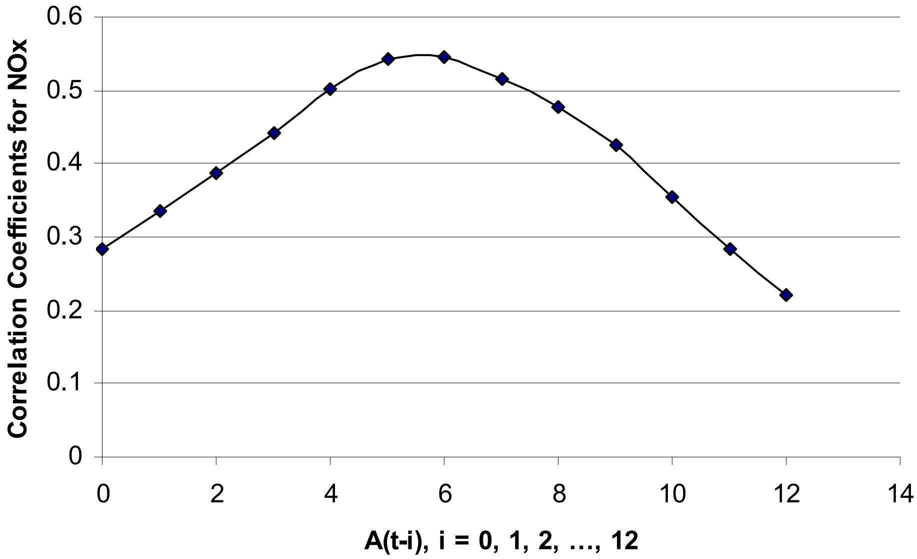

Figure 15 Correlation between NOx emission and accelerations or decelerations in previous time periods

Since SP multiplied by the vehicle mass is the kinetic power, it actually measures kinetic energy used during a driving episode. For easily tabulating the calibration results in the following sections, each emission function is symbolized in table 11, where *m* in Equation (1) for emission type is ignored.

Table 11. Emission function symbolization.

	Model Year Group	**Emitter Type**
i	j	k
LDGV	**Before 1975**	$e_{1,1,1}$
	(1976-1980)	$e_{1,2,1}$
	(1981-1986)	$e_{1,3,1}$, $e_{1,3,2}$, $e_{1,3,3}$, $e_{1,3,4}$, $e_{1,3,5}$
	(1987-1990)	$e_{1,4,1}$, $e_{1,4,2}$, $e_{1,4,3}$, $e_{1,4,4}$, $e_{1,4,5}$
	(1991-1993)	$e_{1,5,1}$, $e_{1,5,2}$, $e_{1,5,3}$, $e_{1,5,4}$, $e_{1,5,5}$
	(1994-1997)	$e_{1,6,1}$, $e_{1,6,2}$, $e_{1,6,3}$
LDGT1	**Before 1981**	$e_{2,1,1}$
	(1981-1986)	$e_{2,2,1}$, $e_{2,2,2}$, $e_{2,3,3}$, $e_{2,2,4}$, $e_{2,2,5}$
	(1987-1990)	$e_{2,3,1}$, $e_{2,3,2}$ $e_{2,3,3}$, $e_{2,3,4}$, $e_{2,3,5}$
	(1991-1993)	$e_{2,4,1}$, $e_{2,4,2}$, $e_{2,4,3}$, $e_{2,4,4}$
	(1994-1997)	$e_{2,5,1}$, $e_{2,5,2}$, $e_{2,5,3}$
LDGT2	**Before 1993**	$e_{3,1,1}$
	(1994-1997)	$e_{3,2,1}$, $e_{3,2,2}$

Providing with the symbolization of the emission functions, the calibration results of the coefficients and t-test values are listed in tables 12 to 14.

Table 12. Calibration results for CO.

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{1,1,1}$	Coefficient	0.2980304	0.01193152	-0.000448	0.0000859	0	0	0.005384	-0.0182	0.043315
	t-Statistic	17.2006169	3.60230134	-2.77803	4.2530750			4.170078	-1.52614	4.588715
$e_{1,2,1}$	Coefficient	0.1216879	0.00407979	0	-0.0000084	-0.00614	-0.00118	0	0	0
	t-Statistic	16.9118144	9.35776907		-5.91778	-7.83182	-2.18611			
$e_{1,3,1}$	Coefficient	0.0223428	0.00402513	-0.000112	0.0000876	-0.0009	-0.00094	-0.00678	0.004441	0.002519
	t-Statistic	8.8940010	8.21274989	-4.673776	2.922288	-3.38012	-4.66944	-5.51134	5.700104	3.089531
$e_{1,3,2}$	Coefficient	0.0610774	0	-1.69E-05	0.0000717	-0.00088	0	0	0	-0.01061
	t-Statistic	14.1985906		-1.136803	2.645068	-1.41918				-2.36912
$e_{1,3,3}$	Coefficient	0.1373427	0.00655559	-0.000165	0.0005150	0.007228	0.0015	-0.09525	0	0
	t-Statistic	13.0793421	3.30131083	-1.712614	4.302227	7.047505	1.859118	-14.8016		
$e_{1,3,4}$	Coefficient	0.0569122	0	1.54E-05	0	0	0	-0.0106	0	0.010079
	t-Statistic	12.3494832		3.564334				-1.89459		2.289398
$e_{1,3,5}$	Coefficient	0.0475474	0.00276434	0	0	-0.00369	0	-0.03615	0	0.012632
	t-Statistic	9.9720300	15.7176553			-5.58961		-8.27916		3.967394
$e_{1,4,1}$	Coefficient	0.0203414	0.00238739	-8.54E-05	0.0000841	-0.00098	0.00037	-0.00909	0.003789	0.002382
	t-Statistic	15.6366138	9.69342377	-7.142439	5.644604	-7.35311	3.634463	-7.91435	2.497342	2.019036
$e_{1,4,2}$	Coefficient	0.0128974	0.00383532	-0.000102	0.0000672	-0.0014	-0.00115	0.002908	-0.00574	0
	t-Statistic	5.4834335	8.56413672	-4.684803	2.481408	-5.71662	-6.48894	1.275489	-2.29923	
$e_{1,4,3}$	Coefficient	0.3863774	0.01530426	-0.000809	1.2E-05	-0.01366	-0.00713	-0.0473	0	0
	t-Statistic	20.5390117	4.215064	-4.558556	5.421129	-6.86609	-4.39477	-4.08833		
$e_{1,4,4}$	Coefficient	0.0216383	0	0.000102	-1.6E-06	-0.00165	-0.00056	-0.01142	0	0
	t-Statistic	4.9372231		6.729587	-5.76373	-2.73868	-1.63177	-3.39115		
$e_{1,4,5}$	Coefficient	0.0358796	0.00433266	-0.000134	1.58E-06	0	0	0	0.005073	0
	t-Statistic	10.0588261	6.22909693	-3.878269	3.640207				2.063345	
$e_{1,5,1}$	Coefficient	0.0171027	0.00189813	-7.25E-05	6.75E-07	-0.00105	0.00013	-0.00598	0.002489	0.004295
	t-Statistic	12.57	7.38	-5.756988	4.27E+00	-7.24	1.120073	-4.88673	1.55103	3.67491
$e_{1,5,2}$	Coefficient	0.0129144	0.00783401	-0.000273	2.52E-06	-0.00256	-0.00085	-0.01864	0.013141	0
	t-Statistic	0.0049864	0.00099494	4.86E-05	6.05E-07	0.000504	0.000434	0.005008	0.005417	
$e_{1,5,3}$	Coefficient	0.1062082	0.01528613	-0.000457	3.3E-06	-0.01085	-0.00374	0	-0.024	0
	t-Statistic	11.3980020	8.62203558	-5.319054	3.089999	-11.3489	-4.4905		-4.60939	

Table 12. Calibration results for CO (continued 1).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{1,1,1}$	Coefficient	0	0	0	0	0	0	0.025696	0.006919	**0.354151**
	t-Statistic							*4.17785*	*13.32786*	
$e_{1,2,1}$	Coefficient	0	-0.01994	0	0.009976	0	0	0.016362	0.00264	**0.174617**
	t-Statistic		*-4.62702*		*2.132274*			*4.963874*	*16.22315*	
$e_{1,3,1}$	Coefficient	0	0	0.001454	0.00198	0.001683	0	0	0.000734	**0.180677**
	t-Statistic			*1.797482*	*2.562065*	*2.1668*			*11.86984*	
$e_{1,3,2}$	Coefficient	0.006163	0.010129	0	0	0.007088	0	0.004637	0.001262	**0.456171**
	t-Statistic	*1.485761*	*3.934296*			*2.455203*		*1.855691*	*7.541934*	
$e_{1,3,3}$	Coefficient	0.036972	0	0.051103	0	0	0	0.0162	0.009847	**0.513426**
	t-Statistic	*5.923414*		*8.875214*				*3.995296*	*29.93497*	
$e_{1,3,4}$	Coefficient	0	0	0	0	0.008611	0	0.013251	0.001858	**0.379441**
	t-Statistic					*1.949453*		*3.223302*	*7.216586*	
$e_{1,3,5}$	Coefficient	0	0	0	0	0	0	0.010937	0.003706	**0.381573**
	t-Statistic							*5.180368*	*17.90755*	
$e_{1,4,1}$	Coefficient	0	0.001681	0.003228	0.002488	0	0	0.00139	0.001139	**0.267298**
	t-Statistic		*1.42862*	*2.128507*	*2.294411*			*2.566501*	*28.04654*	
$e_{1,4,2}$	Coefficient	-0.01215	0.008222	0.002926	0	0	0	0.002105	0.000483	**0.351036**
	t-Statistic	*-4.44558*	*2.262062*	*1.248111*				*2.247217*	*6.315118*	
$e_{1,4,3}$	Coefficient	0	0.028973	0	0	0	0	0.017607	0.001362	**0.255732**
	t-Statistic		*3.52236*					*2.473921*	*2.218213*	
$e_{1,4,4}$	Coefficient	-0.01169	0	0.006712	0.007589	0	0	0.00556	0.001752	**0.419039**
	t-Statistic	*-3.59875*		*1.395389*	*1.690155*			*2.413604*	*9.983132*	
$e_{1,4,5}$	Coefficient	-0.00653	0	0	0.005207	0	0	0	0.000938	**0.522788**
	t-Statistic	*-2.8511*			*3.254691*				*9.660416*	
$e_{1,5,1}$	Coefficient			0.001013		0.000915		0.002953	0.000809	**0.229719**
	t-Statistic			*1.3*		*1.073*		*4.449*	*18.79726*	
$e_{1,5,2}$	Coefficient	0.010159	0	0	0	0	-0.00423	0	0.001035	**0.28284**
	t-Statistic	*0.002913*					*0.001927*		*0.000166*	
$e_{1,5,3}$	Coefficient	0	0.024114	0	0.015811	0	0	0.00884	-0.00118	**0.425336**
	t-Statistic		*4.609489*		*3.052972*			*2.264018*	*-4.79664*	

Table 12. Calibration results for CO (continued 2).

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{1,5,4}$	Coefficient	0.031669395	-0.009473796	0.00062957	-7.74E-06	-0.0020837	0.0018496	-0.026265	0	0
	t-Statistic	*3.66998004*	*-5.4777202*	*7.513602*	*-7.48251*	*-2.29317*	*2.331097*	*-5.09347*		
$e_{1,5,5}$	Coefficient	0.178886378	0	-0.000163	2.45E-06	-0.0022389	0	0.0231705	-0.0131958	-0.0114077
	t-Statistic	*37.1757472*		*-9.781483*	*8.073866*	*-3.90764*		*5.249488*	*-1.98669*	*-2.47712*
$e_{1,6,1}$	Coefficient	0.010108793	0.001284055	-6.647E-05	7.711E-07	-0.0003712	0	0	0.0010663	0.0017688
	t-Statistic	*17.5663073*	*11.96768*	*-12.61557*	*11.67541*	*-6.02401*			*2.810131*	*3.446431*
$e_{1,6,2}$	Coefficient	0.017280353	0.005756696	-0.0002612	3.114E-06	0	0	-0.0094509	0.0145789	0
	t-Statistic	*3.5055969*	*5.81198149*	*-5.32147*	*5.084455*			*-2.87886*	*6.240748*	
$e_{1,6,3}$	Coefficient	0.056907167	-0.005484061	0.000455	-5.533E-06	0	-0.0011576	-0.0427707	0	0
	t-Statistic	*5.86304676*	*-2.8851382*	*4.93052*	*-4.83074*		*-1.38887*	*-7.33985*		
$e_{2,1,1}$	Coefficient	0.248751558	0.020454176	-0.0009727	1.25E-05	-0.0022608	0.0049049	0	0	0.0326703
	t-Statistic	*20.9064119*	*8.65081382*	*-8.459057*	*8.763398*	*-1.82962*	*4.330829*			*5.537609*
$e_{2,2,1}$	Coefficient	0.084052651	0.001743161	0	0	-0.0014265	0.0015889	-0.0376768	0	0.0159114
	t-Statistic	*22.5748417*	*13.2933349*			*-2.93559*	*4.309996*	*-11.6819*		*5.033386*
$e_{2,2,2}$	Coefficient	0.01741967	0	3.1731E-05	-3.689E-07	-0.001881	0.0005043	-0.0171933	0	0
	t-Statistic	*6.68105052*		*3.553075*	*-2.27891*	*-5.94135*	*1.971622*	*-8.88946*		
$e_{2,2,3}$	Coefficient	0.176391715	0.033714775	-0.001109	1.708E-05	0.0173922	0	-0.0845911	0	0.0698413
	t-Statistic	*11.1013603*	*10.8828216*	*-7.323925*	*9.076075*	*8.995292*		*-8.28204*		*7.544412*
$e_{2,2,4}$	Coefficient	0.081549407	0.010318741	-0.0004059	5.064E-06	-0.0069932	0	0	0	0
	t-Statistic	*3.95246521*	*2.44511869*	*-1.91666*	*1.891937*	*-2.50422*				
$e_{2,2,5}$	Coefficient	0.183115189	0.00546582	-3.326E-05	0	-0.0065814	-0.0015933	-0.0177995	0	0
	t-Statistic	*16.1771028*	*5.5014337*	*-1.88618*		*-5.14194*	*-1.86108*	*-2.45339*		
$e_{2,3,1}$	Coefficient	0.021097148	0.004014004	-0.0001561	1.761E-06	-0.0009129	-0.0003067	-0.0087985	0.0042905	0
	t-Statistic	*12.4630891*	*12.4830301*	*-10.03793*	*9.111934*	*-5.16382*	*-2.23317*	*-5.7633*	*2.690873*	
$e_{2,3,2}$	Coefficient	0.017650729	0.003183286	-0.0001411	1.884E-06	0.0002941	0	-0.0037029	0	0.0033307
	t-Statistic	*8.81126318*	*8.54247995*	*-7.808911*	*8.384412*	*1.478575*		*-2.75733*		*2.545476*
$e_{2,3,3}$	Coefficient	0.040388873	0.004991903	-6.074E-05	7.048E-07	0	0.0017403	-0.0347002	0	0
	t-Statistic	*5.71290634*	*3.62687438*	*-0.901951*	*0.840988*		*2.992304*	*-7.7434*		
$e_{2,3,4}$	Coefficient	0.041043347	-0.001808744	8.7695E-05	-2.621E-07	0	0	-0.0302232	0	0
	t-Statistic	*5.52856687*	*-1.2619203*	*1.252258*	*-0.3017*			*-6.94737*		

Table 12. Calibration results for CO (continued 3).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{1,5,4}$	Coefficient	0	0	0	0	0	0.0110093	0	0.0030739	**0.430911**
	t-Statistic						*3.454738*		*10.77184*	
$e_{1,5,5}$	Coefficient	0	0	0	0	0.0071362	0	0	0	**0.235998**
	t-Statistic					*3.224073*				
$e_{1,6,1}$	Coefficient	0.0006383	0	0	0.0008603	0	0	0.0015061	0.0001518	**0.156558**
	t-Statistic	*1.339617*			*2.970149*			*6.304019*	*8.302033*	
$e_{1,6,2}$	Coefficient	0	0	0	0	0	0	0	0.0013767	**0.428197**
	t-Statistic								*8.730923*	
$e_{1,6,3}$	Coefficient	0	0.010257	0	0	0	0	-0.0104036	0.0036841	**0.333988**
	t-Statistic		*2.571667*					*-2.97404*	*12.63997*	
$e_{2,1,1}$	Coefficient	0	0	0	-0.0099781	0	0	0	0.0037846	**0.241475**
	t-Statistic				*-2.04046*				*13.04042*	
$e_{2,2,1}$	Coefficient	0	0.0108628	0	0.0168585	0	0	0.0066618	0.0042121	**0.299396**
	t-Statistic		*3.467801*		*6.06835*			*3.378093*	*27.87292*	
$e_{2,2,2}$	Coefficient	0	0.0058913	0	0.0063065	0	0.006002	-0.0043924	0.0017057	**0.393173**
	t-Statistic		*3.296559*		*3.003628*		*2.050868*	*-1.78145*	*16.88334*	
$e_{2,2,3}$	Coefficient	0	0.0515074	0	0.0236709	0	0	0	0.0112767	**0.891931**
	t-Statistic		*5.571712*		*3.143024*				*22.55994*	
$e_{2,2,4}$	Coefficient	0	0	0	0	0	0	0.0186791	0.0037178	**0.241815**
	t-Statistic							*2.436162*	*7.831014*	
$e_{2,2,5}$	Coefficient	0.0107299	0	0	-0.0070798	0	0	0.0086226	0.0047314	**0.251918**
	t-Statistic	*1.700928*			*-1.15413*			*1.70132*	*12.61259*	
$e_{2,3,1}$	Coefficient	0.0021276	0.0032911	0	0.0032405	0	0	-0.0008535	0.0010624	**0.273521**
	t-Statistic	*1.329589*	*2.071967*		*3.245957*			*-1.20202*	*19.89763*	
$e_{2,3,2}$	Coefficient	0	0.0025357	0	0.0025202	0	0.0025533	-0.0051506	0.0006791	**0.33761**
	t-Statistic		*1.946952*		*1.92564*		*1.418108*	*-3.4108*	*10.82049*	
$e_{2,3,3}$	Coefficient	0.0103121	0	0.0138878	0.0142833	0	0	0	0.0048976	**0.4748**
	t-Statistic	*2.400524*		*2.186106*	*2.629829*				*23.08251*	
$e_{2,3,4}$	Coefficient	0	0.0171893	0	0.0139702	0	0	0	0.002615	**0.493537**
	t-Statistic		*4.046165*		*3.63798*				*11.76925*	

Table 12. Calibration results for CO (Continued 4).

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{2,3,5}$	Coefficient	0.071908501	0.002745217	-0.0001233	1.554E-06	-0.0008784	0.0018128	-0.0098949	0.008161	0
	t-Statistic	*14.0885279*	*2.86453736*	*-2.65907*	*2.696725*	*-1.6238*	*4.748814*	*-2.36094*	*2.096921*	
$e_{2,4,1}$	Coefficient	0.020126388	0.004399175	-0.0001614	1.567E-06	-0.0021515	-0.0002471	-0.0085799	0.0029326	0.0022014
	t-Statistic	*11.1175116*	*12.7157216*	*-9.642571*	*7.526365*	*-12.3328*	*-1.69766*	*-5.30469*	*1.400077*	*1.34041*
$e_{2,4,2}$	Coefficient	0.039762422	0.000324732	0	1.441E-07	0	0.0016752	-0.0165561	0.0086047	0.0132482
	t-Statistic	*6.84616098*	*0.89665826*		*1.202279*		*3.067994*	*-2.96729*	*1.202948*	*1.846975*
$e_{2,4,3}$	Coefficient	0.021204349	0.000744939	0	0	0	0	-0.0151667	0	0.004647
	t-Statistic	*7.8126562*	*7.15101789*					*-6.25173*		*2.194196*
$e_{2,4,4}$	Coefficient	0.025407409	0.006084001	-0.0002312	2.975E-06	-0.0012204	0.0014206	-0.0223579	0.0075228	0.0106191
	t-Statistic	*5.33819527*	*6.78955944*	*-5.339781*	*5.523829*	*-2.37118*	*3.99874*	*-5.68983*	*1.544327*	*2.741303*
$e_{2,5,1}$	Coefficient	0.011844376	0.002265837	-0.0001069	1.18E-06	-0.0003132	0	0	0	0.0018125
	t-Statistic	*6.70631255*	*6.90247567*	*-6.641027*	*5.845373*	*-1.8319*				*1.10161*
$e_{2,5,2}$	Coefficient	0.010282144	0.00193322	-6.147E-05	5.015E-07	-0.0012834	-0.0007848	0	0	0
	t-Statistic	*3.5540444*	*3.5546229*	*-2.318995*	*1.51637*	*-4.24317*	*-3.97709*			
$e_{2,5,3}$	Coefficient	0.049732183	0.005005379	-0.0002227	2.811E-06	-0.0015872	0	0	0.0074081	0
	t-Statistic	*10.2091197*	*5.43443215*	*-4.949801*	*5.009608*	*-3.46259*			*2.33978*	
$e_{3,1,1}$	Coefficient	0.041664159	0.006548834	-0.0003094	5.318E-06	-0.0010688		-0.0417713		0.0162794
	t-Statistic	*3.26093132*	*3.31742748*	*-3.52223*	*5.037733*	*-1.17432*		*-7.14414*		*2.951013*
$e_{3,2,1}$	Coefficient	0.018241589	0.002517968	-0.0001068	1.14E-06	-0.0011376	-0.0002694	-0.0025857	0	0.0038382
	t-Statistic	*15.2437557*	*12.8660241*	*-11.2413*	*9.671424*	*-10.6839*	*-2.19731*	*-2.67879*		*4.433146*
$e_{3,2,2}$	Coefficient	0.001001062	-0.001938273	0	0	-0.0193378	0	0.0066841	0	-0.0035521
	t-Statistic	*7.52602814*	*-4.3978992*			*-5.11443*		*2.11463*		*-1.10223*

Table 12. Calibration results for CO (continued 5).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{2,3,5}$	Coefficient	0	0.0186732	0	0.0071047	0	0	0.0116039	0.001991	**0.438875**
	t-Statistic		*6.719505*		*2.566437*			*5.526777*	*12.5579*	
$e_{2,4,1}$	Coefficient	0	0.003495	0	0	0	0	0.0021401	0.0013357	**0.24485**
	t-Statistic		*3.695385*					*3.254349*	*23.33613*	
$e_{2,4,2}$	Coefficient	-0.0206318	0	0.0140649	0.0070076	0	0.0069995	0	0.0022077	**0.478306**
	t-Statistic	*-3.68858*		*2.571049*	*1.284675*		*2.208637*		*11.8528*	
$e_{2,4,3}$	Coefficient	0	0.0065074	0	0.0046584	0	0	-0.007513	0.0014909	**0.474893**
	t-Statistic		*3.083392*		*2.351098*			*-5.03033*	*13.3058*	
$e_{2,4,4}$	Coefficient	0	-0.0106998	0.0089238	0.0080699	0.0058766	0	-0.0053238	0.0029281	**0.549551**
	t-Statistic		*-2.76102*	*1.793735*	*1.620847*	*1.520984*		*-2.36298*	*19.15672*	
$e_{2,5,1}$	Coefficient	0.0030846	-0.0023008	0	0	0	0	0.0037932	0.0003275	**0.173749**
	t-Statistic	*1.28878*	*-1.46124*					*5.862716*	*7.722577*	
$e_{2,5,2}$	Coefficient	-0.0017752	0	0	0	0	0	0.001087	0.0002726	**0.141371**
	t-Statistic	*-1.4877*						*1.065811*	*4.281824*	
$e_{2,5,3}$	Coefficient	0.0088673	0	0	0	0	0	0.0062441	0.0005035	**0.302262**
	t-Statistic	*3.437562*						*3.649016*	*3.631382*	
$e_{3,1,1}$	Coefficient			0.0077026			0.0070983		0.0040311	**0.275513**
	t-Statistic			*1.634265*			*1.806439*		*14.99086*	
$e_{3,2,1}$	Coefficient	0	0.0021558	0	0	0	-0.0012317	0.0019951	0.0005843	**0.175547**
	t-Statistic		*3.082665*				*-1.45409*	*3.166778*	*16.91839*	
$e_{3,2,2}$	Coefficient	0	0	0	0	0	0.0077221	-0.0074678	0.0020736	**0.402037**
	t-Statistic						*1.433954*	*-1.71078*	*12.71852*	

Table 13. Calibration results for HC.

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{1,1,1}$	Coefficient	0.048133	0.001847	-9E-05	1.15E-06	0.001337	-0.00106	0	0	0.010613
	t-Statistic	*31.4934*	*6.40939*	*-6.4425*	*6.60623*	*11.918*	*-7.5656*			*10.4746*
$e_{1,2,1}$	Coefficient	0.009766	0.000853	-2.8E-05	2.48E-07	-0.00021	-0.00053	0	0	0.00104
	t-Statistic	*12.354*	*5.81334*	*-3.8669*	*2.79191*	*-3.7669*	*-6.7246*			*2.54988*
$e_{1,3,1}$	Coefficient	0.003262	0.000475	-1.7E-05	1.68E-07	-9.1E-05	0	-6.2E-05	0.000392	0
	t-Statistic	*14.6347*	*11.1576*	*-8.3907*	*6.4921*	*-3.9715*		*-3.652*	*5.73845*	
$e_{1,3,2}$	Coefficient	0.00296	0.000628	-2.5E-05	2.68E-07	-9.2E-05	0	-0.00067	0	0
	t-Statistic	*8.29119*	*9.08951*	*-7.2964*	*6.33035*	*-2.8663*		*-3.1871*		
$e_{1,3,3}$	Coefficient	0.012271	0.001175	-5.5E-05	6.95E-07	0	0	0	0.000762	0
	t-Statistic	*10.1167*	*5.02392*	*-4.7521*	*4.83603*				*1.30114*	
$e_{1,3,4}$	Coefficient	0.003635	0.000625	-2.2E-05	2.34E-07	8.48E-05	0.000197	0	0	0.000896
	t-Statistic	*5.24248*	*4.75007*	*-3.442*	*2.91049*	*1.9561*	*2.59834*			*2.372*
$e_{1,3,5}$	Coefficient	0.004497	0.000596	-1.5E-05	1.35E-07	-0.00017	-0.00029	-0.00242	0	0.000659
	t-Statistic	*12.0359*	*8.38178*	*-4.3791*	*3.1357*	*-5.5048*	*-7.659*	*-9.4738*		*3.16616*
$e_{1,4,1}$	Coefficient	0.001675	0.000379	-1.5E-05	1.53E-07	-2.8E-05	-0.00015	-0.00051	0.000323	0.000297
	t-Statistic	*12.0471*	*14.4125*	*-11.776*	*9.60825*	*-2.61*	*-10.444*	*-4.1195*	*1.99474*	*2.3731*
$e_{1,4,2}$	Coefficient	0.001486	0.000302	-1.1E-05	9.62E-08	-6.7E-05	-0.00014	0.000176	0	0
	t-Statistic	*5.83518*	*6.19956*	*-4.4954*	*3.25348*	*-3.4884*	*-5.266*	*1.0925*		
$e_{1,4,3}$	Coefficient	0.015493	-0.0012	0.000111	-1.5E-06	0.000532	-0.00103	0.007517	0.002789	0
	t-Statistic	*7.98361*	*-3.219*	*6.07382*	*-6.604*	*3.16111*	*-5.0506*	*3.90683*	*1.33026*	
$e_{1,4,4}$	Coefficient	0.003081	0.000293	0	-2.8E-06	0	-0.00014	-0.00175	0	0
	t-Statistic	*4.03265*	*4.40248*		*-2.3257*		*-1.5493*	*-3.8381*		
$e_{1,4,5}$	Coefficient	0.007473	0.000234	0	0	0.000283	0.000361	0	0.001559	0
	t-Statistic	*12.9988*	*11.9804*			*4.58528*	*4.79406*		*3.74214*	
$e_{1,5,1}$	Coefficient	0.001667	9.19E-05	-2.1E-06	0	-2.5E-05	-7.5E-05	-7.1E-05	0	0.000257
	t-Statistic	*15.7168*	*10.0672*	*-12.779*		*-2.6473*	*-6.3146*	*-0.9687*		*4.4118*
$e_{1,5,2}$	Coefficient	0.002593	0.000505	-1.7E-05	1.72E-07	-0.00011	-0.00027	-0.0014	0	0.00088
	t-Statistic	*8.00108*	*7.52352*	*-5.2035*	*4.15738*	*-3.6411*	*-7.8286*	*-5.7643*		*3.5503*
$e_{1,5,3}$	Coefficient	0.007118	0.000764	0	-2.5E-07	0	-0.00064	0.003401	-0.00259	0
	t-Statistic	*7.97387*	*13.6035*		*-13.512*		*-5.9372*	*3.82435*	*-3.1432*	

Table 13. Calibration results for HC (continued 1).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{1,1,1}$	Coefficient	0.005978	0	0	-0.00957	0	0	0.003055	0.000196	**0.282379552**
	t-Statistic	*6.29943*			*-11.842*			*4.6019*	*4.67002*	
$e_{1,2,1}$	Coefficient	0	0	-0.00248	0	0	0	0.001912	0.000216	**0.155871237**
	t-Statistic			*-6.6234*				*6.27663*	*11.7607*	
$e_{1,3,1}$	Coefficient	-0.00031	-0.00027	0	0.000154	0.000262	0.000262	0.000216	3.96E-05	**0.157262355**
	t-Statistic	*-4.4865*	*-3.8607*		*2.14151*	*3.75312*	*3.85217*	*3.20969*	*11.7728*	
$e_{1,3,2}$	Coefficient	0	-0.00111	0	0	0	0.000537	0.000463	0.000132	**0.497067581**
	t-Statistic		*-7.12*				*2.00454*	*1.82412*	*12.551*	
$e_{1,3,3}$	Coefficient	0	0	0	0	0.002417	0	0	0.000259	**0.147443075**
	t-Statistic					*5.58564*			*8.20755*	
$e_{1,3,4}$	Coefficient	0	-0.00237	0	0	0	0	0.001855	0.000128	**0.392781483**
	t-Statistic		*-6.7501*					*7.32005*	*7.60253*	
$e_{1,3,5}$	Coefficient	0	0	0	-0.00072	0	0	0.00118	0.000283	**0.486144861**
	t-Statistic				*-4.1208*			*7.53843*	*23.6341*	
$e_{1,4,1}$	Coefficient	0	-0.00015	0	-7.7E-05	0	0	0.000296	9.21E-05	**0.199488967**
	t-Statistic		*-1.7073*		*-0.9982*			*5.13775*	*21.2198*	
$e_{1,4,2}$	Coefficient	-0.00024	0	0	0	0	-0.00044	0.000475	6.34E-05	**0.280311303**
	t-Statistic	*-1.925*					*-1.9882*	*2.24294*	*7.5934*	
$e_{1,4,3}$	Coefficient	0.003735	0	0	0	0	0	0.000885	-0.00094	**0.398534498**
	t-Statistic	*3.33491*						*1.22479*	*-14.952*	
$e_{1,4,4}$	Coefficient	0	0	-0.00105	0.001336	0	0	0.000664	0.000303	**0.426771411**
	t-Statistic			*-1.6431*	*1.98876*			*1.94586*	*11.499*	
$e_{1,4,5}$	Coefficient	0	0.001071	0	0	0	0	-0.0004	0.000106	**0.521788464**
	t-Statistic		*3.16049*					*-1.5365*	*5.34284*	
$e_{1,5,1}$	Coefficient	0	0	0	0	0	0	0.000241	4.62E-05	**0.197513315**
	t-Statistic							*6.08899*	*13.037*	
$e_{1,5,2}$	Coefficient	0	0.000353	0	0	0	0	0	0.000142	**0.368425893**
	t-Statistic		*1.88066*						*12.467*	
$e_{1,5,3}$	Coefficient	0	0.002831	0	0	0	0	0	-0.0003	**0.364552071**
	t-Statistic		*6.28863*						*-8.809*	

Table 13. Calibration results for HC (continued 2).

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{1,5,4}$	Coefficient	0.009784	-0.00398	0.000212	-2.6E-06	0.00089	0	-0.01338	0.003369	0
	t-Statistic	3.89729	-7.9583	8.80242	-8.6069	3.78347		-5.6784	1.51398	
$e_{1,5,5}$	Coefficient	0.012919	0.000568	-3.2E-05	3.9E-07	0	-0.00024	0.000947	0	-0.00151
	t-Statistic	14.16974	3.327842	-3.81421	3.74648		-2.65909	1.643185		-3.32428
$e_{1,6,1}$	Coefficient	0.00085	0.000215	-1.1E-05	1.28E-07	-1.6E-05	-1.7E-05	0.000254	0	0.000128
	t-Statistic	14.078	18.7194	-19.667	18.2526	-3.2257	-2.667	6.32772		4.07209
$e_{1,6,2}$	Coefficient	0.00128	0.000332	-1.4E-05	1.59E-07	0	-6.2E-05	-0.00105	0.00085	0
	t-Statistic	3.93799	5.15517	-4.5497	4.03565		-1.7818	-2.9386	2.37488	
$e_{1,6,3}$	Coefficient	0.004861	-0.0002	1.15E-05	-1.3E-07	0	-0.0001	-0.00128	0.000647	0
	t-Statistic	18.7536	-3.7904	4.43695	-3.9132		-3.3098	-4.7842	2.29106	
$e_{2,1,1}$	Coefficient	0.017833	0.001329	-4.4E-05	4.04E-07	0.000305	-0.00053	0	0.00149	0.001241
	t-Statistic	22.4844	8.68015	-5.9202	4.42055	4.09705	-6.6174		1.96433	1.80678
$e_{2,2,1}$	Coefficient	0.007101	0.000211	-8.5E-06	9.7E-08	0.000102	-0.00018	0	0	0.001452
	t-Statistic	13.8626	2.17436	-1.8059	1.65676	2.59996	-3.4774			3.41312
$e_{2,2,2}$	Coefficient	0.003995	0	3.82E-06	-5.3E-08	0	-0.00014	-0.00106	0.000545	0
	t-Statistic	16.9591		4.6881	-3.5495		-4.6667	-3.942	1.99234	
$e_{2,2,3}$	Coefficient	0.041265	0.000233	0	1.52E-07	0.000662	-0.00081	0	0.003883	0
	t-Statistic	19.1181	1.70112		3.46491	2.97513	-2.9658		2.90296	
$e_{2,2,4}$	Coefficient	0.013042	0.000523	0	9.13E-08	0	-0.00063	-0.00731	0	0.002997
	t-Statistic	3.73777	2.38276		1.25742		-1.2628	-2.7213		1.44009
$e_{2,2,5}$	Coefficient	0.008096	0.001095	-3.8E-05	3.72E-07	0	-0.00011	-0.00144	0.001253	0
	t-Statistic	14.3371	10.47	-7.412	5.84449		-1.8441	-2.9475	2.69448	
$e_{2,3,1}$	Coefficient	0.003156	0.000389	-1.6E-05	1.78E-07	-4.4E-05	-0.00012	-0.00102	0.000589	0.000348
	t-Statistic	18.4686	11.977	-10.005	9.14173	-3.155	-6.9605	-6.4645	2.74456	2.0957
$e_{2,3,2}$	Coefficient	0.004836	0.000513	-2.4E-05	2.97E-07	0	-0.00016	-0.00133	0.000798	0.000499
	t-Statistic	14.4381	7.95419	-7.5152	7.57868		-4.8021	-4.1934	1.84178	1.1482
$e_{2,3,3}$	Coefficient	0.003177	0	6.81E-06	-9.6E-08	6.23E-05	0	-0.00125	0.000451	0
	t-Statistic	11.8759		7.37391	-5.6899	2.30856		-4.2001	1.50037	
$e_{2,3,4}$	Coefficient	0.010398	-0.00155	7.9E-05	-9E-07	0.000138	0.000123	-0.00245	0	0
	t-Statistic	8.29297	-6.4317	6.85751	-6.3514	1.41508	1.08978	-3.0993		

Table 13. Calibration results for HC (continued 3).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{1,5,4}$	Coefficient	0	0	0.002379	0	0	0.00152	0	0.00111	**0.437368139**
	t-Statistic			*1.97211*			*1.4189*		*14.7612*	
$e_{1,5,5}$	Coefficient	0	0	0	0	0.00067	0	0.001014	0.00013	**0.141456497**
	t-Statistic					1.503212		2.404575	4.591051	
$e_{1,6,1}$	Coefficient	0	0	0	0	0	0	0.000164	5.26E-06	**0.153520171**
	t-Statistic							*7.61118*	*2.72718*	
$e_{1,6,2}$	Coefficient	0	0.000247	0	0	0	0	0	8.04E-05	**0.333080003**
	t-Statistic		*1.54273*						*7.29636*	
$e_{1,6,3}$	Coefficient	0.000341	0	0	0	0	0	0	7E-05	**0.238969934**
	t-Statistic	*2.29573*							*7.63526*	
$e_{2,1,1}$	Coefficient	0	0	0	-0.00228	0	-0.00086	0.000812	0.000124	**0.179040369**
	t-Statistic				*-5.0055*		*-1.1225*	*1.27615*	*5.64189*	
$e_{2,2,1}$	Coefficient	-0.00106	0	0	0	0.000808	0	0.001068	0.000159	**0.135377981**
	t-Statistic	*-2.5598*				*2.92499*		*4.23761*	*13.2286*	
$e_{2,2,2}$	Coefficient	-0.00054	0	0.000841	0	0	0.000755	0	0.000147	**0.452617686**
	t-Statistic	*-2.7708*		*4.86088*			*6.04971*		*15.6657*	
$e_{2,2,3}$	Coefficient	0.003381	0	-0.00301	0	0	0	0.006006	0.000713	**0.545213296**
	t-Statistic	*2.56272*		*-2.604*				*7.00458*	*12.1955*	
$e_{2,2,4}$	Coefficient	0	0	0	0	0	0	0.002296	0.000958	**0.315181607**
	t-Statistic							*1.70406*	*7.26701*	
$e_{2,2,5}$	Coefficient	0	-0.00072	-0.00191	-0.0008	0	0.001008	0.001265	0.000313	**0.335245642**
	t-Statistic		*-1.5256*	*-2.9645*	*-1.5718*		*2.04819*	*3.03625*	*17.6513*	
$e_{2,3,1}$	Coefficient	0	0.000157	0	0.000173	0	0	0.000183	0.000116	**0.279607224**
	t-Statistic		*1.37302*		*1.72956*			*2.55077*	*21.5912*	
$e_{2,3,2}$	Coefficient	0.00051	0	0	0.000445	0	0	0	0.000154	**0.328811212**
	t-Statistic	*1.67931*			*3.02196*				*14.0661*	
$e_{2,3,3}$	Coefficient	-0.00076	0	0.001019	0	0.001039	0	0	0.000166	**0.375159318**
	t-Statistic	*-3.4435*		*4.64697*		*6.14623*			*16.6531*	
$e_{2,3,4}$	Coefficient	0.00219	0	-0.00375	0	0.004204	0.002843	0.001218	0.000291	**0.49847262**
	t-Statistic	*2.9672*		*-4.718*		*4.01105*	*2.21138*	*1.35656*	*7.5224*	

Table 13. Calibration results for HC (continued 4).

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{2,3,5}$	Coefficient	0.017225	0.002171	-9.1E-05	9.85E-07	0	-0.00052	0	-0.00109	0
	t-Statistic	*13.0713*	*8.88984*	*-7.6838*	*6.63852*		*-3.7286*		*-1.4361*	
$e_{2,4,1}$	Coefficient	0.002056	0.000224	-7.8E-06	7.37E-08	-2.5E-05	-0.00016	-0.00095	0.000357	0.000277
	t-Statistic	*13.27*	*7.55709*	*-5.4425*	*4.14023*	*-2.0166*	*-10.425*	*-6.8635*	*1.99203*	*1.97481*
$e_{2,4,2}$	Coefficient	0.005443	0.000181	0	0	0.000186	0	-0.0036	0	0.003089
	t-Statistic	*5.9824*	*5.46542*			*1.79569*		*-4.437*		*2.89986*
$e_{2,4,3}$	Coefficient	0.005554	-0.00015	1.32E-05	-1.8E-07	0.000115	0	-0.00169	0.001408	0
	t-Statistic	*9.16754*	*-1.2449*	*2.35684*	*-2.6215*	*2.20975*		*-3.5112*	*3.13213*	
$e_{2,4,4}$	Coefficient	0.001887	0	1.42E-05	-2.1E-07	0.000139	-0.00028	-0.00519	0.001758	0
	t-Statistic	*2.95074*		*6.48094*	*-5.3386*	*2.34776*	*-3.2439*	*-7.8808*	*2.73214*	
$e_{2,5,1}$	Coefficient	0.000956	0.000301	-1.3E-05	1.44E-07	-3.1E-05	-4.4E-05	0	0	0.000284
	t-Statistic	*6.30943*	*10.5625*	*-9.654*	*8.23809*	*-2.8158*	*-3.0199*			*4.05775*
$e_{2,5,2}$	Coefficient	0.000849	0.000324	-1.4E-05	1.53E-07	-4E-05	-7.8E-05	0.000178	0	0
	t-Statistic	*3.1023*	*6.16666*	*-5.499*	*4.7395*	*-2.1183*	*-2.6733*	*1.14123*		
$e_{2,5,3}$	Coefficient	0.013531	0.00051	-5.5E-06	0	0	-0.00055	-0.00392	0.005809	0
	t-Statistic	*5.9106*	*2.54092*	*-1.5422*			*-2.4231*	*-1.7221*	*2.36388*	
$e_{3,1,1}$	Coefficient	0.001943	0.001289	-4.9E-05	5.37E-07	4.26E-05	0	-0.00064	0	0.00095
	t-Statistic	*2.96644*	*12.7345*	*-10.922*	*9.9535*	*1.04966*		*-2.1091*		*3.01585*
$e_{3,2,1}$	Coefficient	0.001553	0.000305	-1.4E-05	1.55E-07	-3.4E-05	-7.9E-05	0	0.000123	0.000171
	t-Statistic	*17.9785*	*18.436*	*-17.837*	*15.8841*	*-3.7091*	*-9.9896*		*1.49413*	*2.48246*
$e_{3,2,2}$	Coefficient	0.004157	7.57E-05	0	0	-0.00011	-0.00024	-0.00227	0	0.000904
	t-Statistic	*10.3996*	*5.64962*			*-2.8017*	*-5.5534*	*-5.7344*		*3.10442*

Table 13. Calibration results for HC (continued 5).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{2,3,5}$	Coefficient	0.000957	0	-0.00198	-0.00275	0	0.001616	0.002072	0.00052	**0.298556638**
	t-Statistic	*1.21331*		*-1.8741*	*-2.602*		*1.53779*	*2.28309*	*15.0722*	
$e_{2,4,1}$	Coefficient	0	-0.00021	0	0	0.000237	0	0.000457	0.000109	**0.214380676**
	t-Statistic		*-2.3714*			*2.67657*		*6.01101*	*22.2389*	
$e_{2,4,2}$	Coefficient	-0.00191	-0.00334	0	0.002926	0	0.003453	0	0.000456	**0.482036426**
	t-Statistic	*-1.4193*	*-3.1564*		*3.78862*		*5.83544*		*12.8251*	
$e_{2,4,3}$	Coefficient	-0.00341	0	0.002055	0.001219	0.000754	0.001349	-0.00055	0.000261	**0.588077161**
	t-Statistic	*-10.105*		*4.47069*	*2.03214*	*1.23359*	*2.2429*	*-1.3535*	*14.7003*	
$e_{2,4,4}$	Coefficient	0.001064	0	-0.00178	0	0.00162	0	0	0.000472	**0.397455911**
	t-Statistic	*2.21595*		*-3.7445*		*4.24047*			*18.2308*	
$e_{2,5,1}$	Coefficient	0	0	0	0	0	-0.00013	0.000175	2.82E-05	**0.194230377**
	t-Statistic						*-1.0991*	*1.45752*	*7.81007*	
$e_{2,5,2}$	Coefficient	0	0	0	0	0	0	0.000147	2.76E-05	**0.184736878**
	t-Statistic							*1.45622*	*3.1023*	
$e_{2,5,3}$	Coefficient	0.003271	0	0	0	0.004998	-0.00569	0.005167	-9.1E-05	**0.205702939**
	t-Statistic	*2.29876*				*2.1417*	*-1.6349*	*2.39003*	*-1.1733*	
$e_{3,1,1}$	Coefficient	0	-0.00091	0	-0.00047			0.000509	0.00012	**0.194058271**
	t-Statistic		*-2.8962*		*-1.6818*			*2.5405*	*9.47271*	
$e_{3,2,1}$	Coefficient	0.000128	0	0	0	0	-0.00017	0.000189	3.45E-05	**0.189630563**
	t-Statistic	*1.87176*					*-2.401*	*3.93088*	*14.744*	
$e_{3,2,2}$	Coefficient	0	0	0	0	0	0	0	0.000204	**0.384517612**
	t-Statistic								*11.9006*	

Table 14. Calibration results for NOx.

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{1,1,1}$	Coefficient	0.0045	0.0003	-2E-05	4E-07	0.0002	8E-05	-0.003	0	0.0004
	t-Statistic	12.022	4.7579	-5.421	9.572	6.5747	2.2844	-11.48		1.5826
$e_{1,2,1}$	Coefficient	0.0041	-6E-05	0	2E-07	0.0002	0.0005	-0.005	0	0.0004
	t-Statistic	14.752	-3.43		34.443	7.7623	16.058	-23.98		1.7256
$e_{1,3,1}$	Coefficient	0.0022	0.0002	-4E-06	1E-07	0.0001	0.0004	-0.002	0.0007	0.0009
	t-Statistic	11.37	4.1361	-2.369	4.8925	6.9115	17.904	-21.14	11.574	14.076
$e_{1,3,2}$	Coefficient	0.0029	-0.0005	2E-05	-2E-07	0.0002	0.0004	-0.003	0	0
	t-Statistic	9.6928	-8.267	8.5784	-5.938	6.2091	11.196	-14.45		
$e_{1,3,3}$	Coefficient	0.002	0.0002	-6E-06	1E-07	9E-05	0.0002	-0.003	0	0.0005
	t-Statistic	6.6875	4.0533	-2.033	2.9752	3.8473	6.3067	-14.13		1.8693
$e_{1,3,4}$	Coefficient	0.0017	0.0001	-8E-06	2E-07		0.0002	-0.002	0	0
	t-Statistic	6.09704	2.04381	-3.0903	7.08886		7.00104	-12.722		
$e_{1,3,5}$	Coefficient	0.0041	-0.0003	2E-05	0	0.0002	0.0013	-0.007	0	0.0012
	t-Statistic	7.8715	-6.105	20.348		4.9604	22.256	-19.49		3.3501
$e_{1,4,1}$	Coefficient	0.0012	0.0002	-5E-06	6E-08	3E-05	-3E-05	-0.002	0.0002	0
	t-Statistic	12.104	10.289	-5.354	5.4045	4.5227	-2.669	-20.82	2.1956	
$e_{1,4,2}$	Coefficient	0.0023	0.0001	4E-06	2E-08	0	0.0002	-0.005	0	0.0012
	t-Statistic	4.4197	1.3626	0.7921	0.3224		3.2549	-14.77		2.1447
$e_{1,4,3}$	Coefficient	0.0004	0	9E-06	-1E-07	5E-05	-1E-04	-0.002	0	0
	t-Statistic	1.8487		11.913	-9.551	2.3661	-3.824	-12.94		
$e_{1,4,4}$	Coefficient	0.0015	0	1E-05	-2E-07	0	0	-0.004	0	0
	t-Statistic	3.4986		7.5086	-5.151			-12.59		
$e_{1,4,5}$	Coefficient	0.0073	-0.0008	5E-05	-3E-07	0.0008	0.0013	-0.01	0	0
	t-Statistic	9.4213	-5.423	6.9466	-3.055	11.93	15.562	-20.34		
$e_{1,5,1}$	Coefficient	0.00089	5.4E-05	9.7E-07	-2E-08	3.44E-05	0	-0.0012	0	0.00022
	t-Statistic	10.543	3.2953	1.2071	-1.986	4.6651		-20.78		2.7121
$e_{1,5,2}$	Coefficient	0.002	0.0011	-4E-05	7E-07	0	9E-05	-0.005	0.001	0.0014
	t-Statistic	4.6503	13.108	-10.61	13.435		2.1001	-10.51	1.5061	3.3506
$e_{1,5,3}$	Coefficient	0.0013	0	8E-06	0	0.0003	0.0002	-0.007	0.0023	0
	t-Statistic	3.3175		26.318		5.0334	2.791	-13.06	4.9171	

Table 14. Calibration results for NOx (continued 1).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	R
$e_{1,1,1}$	Coefficient	0	0	0.0017	0.0008	0	0	0	0.0005	**0.6344812**
	t-Statistic			4.7982	2.4896				37.433	
$e_{1,2,1}$	Coefficient	0	0.0015	0.0017	0.0014	0.0007	0	-6E-04	0.0004	**0.6704179**
	t-Statistic		4.7694	3.9685	3.3309	2.1979		-3.988	40.824	
$e_{1,3,1}$	Coefficient	0.0008	0.0005	0.0003	0.0001	0	-1E-04	-1E-04	0.0002	**0.4970521**
	t-Statistic	12.48	8.5847	4.6165	2.0699		-2.081	-2.347	32.957	
$e_{1,3,2}$	Coefficient	0	0.0003	0.0013	0.0008	0	0.0006	0	0.0002	**0.8305298**
	t-Statistic		1.3142	3.7907	3.2325		3.8385		21.596	
$e_{1,3,3}$	Coefficient	0.0007	0.0009	0.0007	0	0	0	-7E-04	0.0003	**0.4185763**
	t-Statistic	1.7195	2.254	2.5966				-6.133	27.284	
$e_{1,3,4}$	Coefficient	-5E-04	0	0.0009	0.0014	0.0004	0	-5E-04	0.0002	**0.8377703**
	t-Statistic	-3.0482		3.70134	4.30909	1.77992		-3.6132	18.5543	
$e_{1,3,5}$	Coefficient	0	0.0009	0.0023	0.0016	0.0014	0	-0.001	0.0005	**0.7616189**
	t-Statistic		1.831	3.5407	2.3869	2.88		-4.158	26.665	
$e_{1,4,1}$	Coefficient	0.0003	0.0006	0.0006	0.0001	0	-2E-04	-3E-04	0.0002	**0.4520746**
	t-Statistic	3.4792	4.8436	5.052	1.582		-1.955	-3.672	53.906	
$e_{1,4,2}$	Coefficient	0.0023	0	0	0.0004	0	0	-0.002	0.0004	**0.6486878**
	t-Statistic	4.6482			1.4798			-6.799	23.9	
$e_{1,4,3}$	Coefficient	0.0008	0	0	0.0005	0	0	-7E-04	0.0002	**0.5522178**
	t-Statistic	5.0407			3.4962			-6.234	26.09	
$e_{1,4,4}$	Coefficient	0	0.0029	0	0	0	0	-8E-04	0.0003	**0.6151108**
	t-Statistic		12.25					-3.81	19.28	
$e_{1,4,5}$	Coefficient	-0.002	0.0039	0.0059	0.0032	0	0	-5E-04	0.0009	**0.9244889**
	t-Statistic	-2.085	3.1043	4.7159	3.9951			-1.613	35.727	
$e_{1,5,1}$	Coefficient	0.00031	0.00038	0.00027	0	0	0.00011	-0.0003	0.0001	**0.4034008**
	t-Statistic	2.9036	3.4897	3.5953			1.5056	-4.827	40.648	
$e_{1,5,2}$	Coefficient	0	0	0	0	0	0	-2E-04	0.0006	**0.8502543**
	t-Statistic							-1.519	44.414	
$e_{1,5,3}$	Coefficient	0	0	0.0013	0.0011	0	0	-8E-04	0.0006	**0.6735003**
	t-Statistic			2.9071	2.247			-3.244	30.199	

Table 14. Calibration results for NOx (continued 2).

		β_0	$V(t)$	$V^2(t)$	$V^3(t)$	T'	T''	$A(t)$	$A(t-1)$	$A(t-2)$
$e_{1,5,4}$	Coefficient	0.0015	0.0007	-3E-05	3E-07	0.0002	-2E-04	-0.003	0	0.0022
	t-Statistic	*1.9086*	*4.4821*	*-3.508*	*3.0953*	*2.5005*	*-2.588*	*-6.11*		*4.5546*
$e_{1,5,5}$	Coefficient	0.0021	0.0002	0.0005	1E-07	7E-05	0.0002	-0.006	0.001	0
	t-Statistic	*5.2223*	*8.2656*	*36.514*	*14.655*	*1.861*	*4.7551*	*-16.57*	*2.789*	
$e_{1,6,1}$	Coefficient	0.0005	0.0002	-6E-06	7E-08	1E-05	-2E-05	-5E-04	0	0.0001
	t-Statistic	9.98128	18.7963	-15.0935	13.5412	2.574905	-3.9947	-16.587		3.05544
$e_{1,6,2}$	Coefficient	0.0011	0.0005	-1E-05	1E-07	0.0001	0.0003	-0.005	0.0023	0.0009
	t-Statistic	*2.856*	*7.4617*	*-3.155*	*3.2301*	*4.2614*	*8.9965*	*-13.26*	*3.5649*	*1.3865*
$e_{1,6,3}$	Coefficient	0.0011	0.0004	-4E-06	0	0.0003	0.0003	-0.003	0.0013	0.0013
	t-Statistic	*1.6686*	*6.7097*	*-3.633*		*4.436*	*3.5847*	*-4.634*	*1.3293*	*1.7074*
$e_{2,1,1}$	Coefficient	0.0063	-0.0006	3E-05	0	0.0002	0.0005	-0.006	0	0
	t-Statistic	*13*	*-14.21*	*35*		*3.5783*	*9.7714*	*-20.17*		
$e_{2,2,1}$	Coefficient	0.0021	0.0002	-7E-06	1E-07	6E-05	0.0002	-0.002	0	0.0004
	t-Statistic	*13.334*	*7.7717*	*-4.84*	*8.1839*	*5.1493*	*10.193*	*-22.74*		*2.6505*
$e_{2,2,2}$	Coefficient	0.0059	-0.0002	2E-05	-2E-07	0.0002	0.0002	-0.006	0	0
	t-Statistic	*9.3549*	*-1.418*	*3.4053*	*-3.081*	*3.9925*	*3.6872*	*-15.52*		
$e_{2,2,3}$	Coefficient	0.0013	-7E-05	5E-06	-5E-08	3E-05	5E-05	-8E-04	0	0
	t-Statistic	*13.951*	*-3.708*	*5.8906*	*-3.998*	*3.138*	*4.1261*	*-14.11*		
$e_{2,2,4}$	Coefficient	0.0016	-0.0003	1E-05	0	5E-05	0.0007	-0.003	0	0
	t-Statistic	*3.6593*	*-7.544*	*15.049*		*1.1935*	*11.458*	*-9.066*		
$e_{2,2,5}$	Coefficient	0.0063	-0.0003	0	4E-07	0.0002	0.0012	-0.007	0	0.0013
	t-Statistic	*12.296*	*-8.1*		*36.74*	*5.0322*	*19.748*	*-19.21*		*3.3605*
$e_{2,3,1}$	Coefficient	0.0041	3E-05	0	7E-08	1E-04	0.0002	-0.004	0	0.0006
	t-Statistic	*20.375*	*2.2541*		*16.632*	*5.6576*	*7.5671*	*-25.07*		*2.7027*
$e_{2,3,2}$	Coefficient	0.0091	0.0002	-1E-05	3E-07	0.0003	0.0004	-0.007	0	0.0013
	t-Statistic	*18.531*	*2.2588*	*-3.031*	*5.3451*	*5.9522*	*7.5845*	*-19.85*		*2.8799*
$e_{2,3,3}$	Coefficient	0.0008	0.0003	-1E-05	1E-07	3E-05	-4E-05	-0.001	0	0.0004
	t-Statistic	*3.374*	*7.2474*	*-5.309*	*5.0849*	*1.3167*	*-1.571*	*-9.229*		*1.939*
$e_{2,3,4}$	Coefficient	0.0022	-0.0002	1E-05	-7E-08	4E-05	0.0002	-0.002	0	-3E-04
	t-Statistic	*6.0138*	*-3.211*	*3.4647*	*-1.692*	*1.4997*	*4.8539*	*-8.645*		*-1.367*

Table 14. Calibration results for NOx (continued 3).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{1,5,4}$	Coefficient	0	0	0.0019	0	0	-0.001	0	0.0004	**0.5289883**
	t-Statistic			*4.6373*			*-3.593*		*14.671*	
$e_{1,5,5}$	Coefficient	0.0009	0.0009	0.0013	0	0	0	0	-6E-04	**0.7323798**
	t-Statistic	*2.4663*	*1.9524*	*3.8879*					*-3.429*	
$e_{1,6,1}$	Coefficient	0.0001	0.0002	0.0002	5E-05	0	-8E-05	-2E-04	5E-05	**0.289934**
	t-Statistic	2.32319	3.44399	3.32252	1.28941		-1.9946	-4.7663	34.6766	
$e_{1,6,2}$	Coefficient	0.0007	0	0	0	0	0	-5E-04	0.0005	**0.9016604**
	t-Statistic	*1.7316*						*-3.519*	*41.905*	
$e_{1,6,3}$	Coefficient	0	0.0005	0	0	0	0	-4E-04	0.0004	**0.5646461**
	t-Statistic		*1.313*					*-1.596*	*18.716*	
$e_{2,1,1}$	Coefficient	0	0.001	0.0018	0.0013	0.0011	0	0.0007	0.0005	**0.674183**
	t-Statistic		*2.2412*	*2.5094*	*1.7713*	*2.1309*		*2.5366*	*30.489*	
$e_{2,2,1}$	Coefficient	0.0007	0.0009	0.0004	0	0	0	-3E-04	0.0002	**0.562595**
	t-Statistic	*3.2622*	*4.3533*	*2.8383*				*-4.541*	*47.777*	
$e_{2,2,2}$	Coefficient	0.0025	0.0015	0.0019	0	0	0	-6E-04	0.0005	**0.6611489**
	t-Statistic	*4.4669*	*1.9185*	*3.4998*				*-2.307*	*25.586*	
$e_{2,2,3}$	Coefficient	-1E-04	0.0003	0.0005	0.0003	0	0	0	8E-05	**0.8465959**
	t-Statistic	*-1.977*	*2.7653*	*5*	*3.7833*				*26.848*	
$e_{2,2,4}$	Coefficient	0.0006	0.0006	0	0	0	0.0003	0	0.0002	**0.679677**
	t-Statistic	*1.3208*	*1.4671*				*1.4661*		*10.905*	
$e_{2,2,5}$	Coefficient	0	0.0008	0.0025	0.0019	0.0008	0	0	0.0005	**0.7155961**
	t-Statistic		*1.6282*	*3.6847*	*2.774*	*1.7322*			*28.553*	
$e_{2,3,1}$	Coefficient	0.0004	0.0009	0.0007	0.0004	0	0	-4E-04	0.0003	**0.4575853**
	t-Statistic	*1.5006*	*2.909*	*2.408*	*1.8066*			*-4.487*	*41.927*	
$e_{2,3,2}$	Coefficient	0.0012	0.0013	0.0013	0	0	0	-6E-04	0.0005	**0.5480464**
	t-Statistic	*1.9742*	*2.0696*	*3.1595*				*-3.136*	*31.56*	
$e_{2,3,3}$	Coefficient	0.0003	0.0007	0.0002	0	-4E-04	0	-4E-04	0.0002	**0.4175386**
	t-Statistic	*1.2142*	*2.4946*	*1.1619*		*-2.348*		*-3.593*	*19.795*	
$e_{2,3,4}$	Coefficient	0	0.0007	0.0009	0	0	0	0.0003	0.0002	**0.6707267**
	t-Statistic		*2.3989*	*3.1977*				*2.2063*	*15.714*	

Table 14. Calibration results for NOx (continued 4).

		β_0	V(t)	$V^2(t)$	$V^3(t)$	T'	T''	A(t)	A(t – 1)	A(t – 2)
$e_{2,3,5}$	Coefficient	0.0055	0.0003	0	3E-07	0	0.0005	-0.009	0.0021	0
	t-Statistic	*7.6059*	*6.2342*		*20.475*		*6.431*	*-14.39*	*3.5254*	
$e_{2,4,1}$	Coefficient	0.0014	0.0002	-3E-06	5E-08	3E-05	-4E-05	-0.002	0	0.0003
	t-Statistic	*9.8286*	*5.98*	*-2.409*	*3.0012*	*2.4189*	*-3.003*	*-19.25*		*2.4507*
$e_{2,4,2}$	Coefficient	0.0038	-0.0001	0	3E-07	0.0004	0.0004	-0.007	0	-7E-04
	t-Statistic	6.10409	-3.16203		23.8675	6.311285	5.76499	-16.21		-1.2235
$e_{2,4,3}$	Coefficient	0.0008	0.0001	0	3E-08	0	8E-05	-0.002	-4E-04	0.0005
	t-Statistic	*2.9862*	*6.5969*		*6.4185*		*2.3242*	*-7.491*	*-1.381*	*1.6683*
$e_{2,4,4}$	Coefficient	0.0021	0.0002	0	1E-07	0.0001	0.0001	-0.004	0.0009	0
	t-Statistic	*5.1571*	*9.6992*		*13.241*	*3.3072*	*2.7524*	*-11.12*	*2.5031*	
$e_{2,5,1}$	Coefficient	0.0005	5E-05	1E-06	-3E-08	3E-05	-2E-05	-0.001	0.0002	0.0002
	t-Statistic	*3.9166*	*2.2161*	*1.2062*	*-2.307*	*3.2474*	*-1.251*	*-9.577*	*1.1608*	*1.4743*
$e_{2,5,2}$	Coefficient	0.0047	-0.0003	3E-05	-3E-07	0.0003	0.0007	-0.005	0	0.0013
	t-Statistic	*5.3654*	*-1.933*	*3.5133*	*-3.042*	*4.7593*	*7.5806*	*-7.707*		*2.2029*
$e_{2,5,3}$	Coefficient	0.0002	0.0002	-2.1E-06	0	-3E-05	-7E-05	-6E-04	0	0.0002
	t-Statistic	*1.0227*	*7.8054*	*-6.019*		*-1.5929*	*-3.15*	*-3.84*		*1.2438*
$e_{3,1,1}$	Coefficient	0.00296	0.00143	-6.1E-05	8.7E-07	0.000218	6E-05	-0.003	-0.0007	0.00177
	t-Statistic	*3.7132*	*11.801*	*-11.39*	*13.446*	*4.5002*	*1.0841*	*-5.97*	*-1.038*	*2.5369*
$e_{3,2,1}$	Coefficient	0.00085	0.00038	-1.6E-05	2.1E-07	0	-2E-05	-0.0014	0	0.0005
	t-Statistic	4.3294	12.9081	-12.345	13.6576		-1.5173	-15.45		3.5794
$e_{3,2,2}$	Coefficient	0.02619	-0.00054	2.4E-05	-2.7E-07	-0.00036	-0.0001	-0.0114	0.00358	0
	t-Statistic	*0.0246*	*-3E-04*	*2E-05*	*-2E-07*	*-0.0003*	*-1E-04*	*-0.011*	*0.0034*	

Table 14. Calibration results for NOx (continued 5).

		A(t – 3)	A(t – 4)	A(t – 5)	A(t – 6)	A(t – 7)	A(t – 8)	A(t – 9)	W(t)	**R**
$e_{2,3,5}$	Coefficient	0	0	0.0037	0.002	0	0	-9E-04	0.0007	**0.7400243**
	t-Statistic			*6.4485*	*3.4537*			*-2.693*	*29.228*	
$e_{2,4,1}$	Coefficient	0.0002	0.0005	0.0004	0.0002	0	0	-4E-04	0.0002	**0.4029031**
	t-Statistic	*1.2517*	*2.7953*	*2.286*	*1.9867*			*-6.723*	*40.648*	
$e_{2,4,2}$	Coefficient	0.0015	0.0038	0	0	0.002	0	-5E-04	0.0006	**0.857926**
	t-Statistic	2.12704	7.17517			5.23194		-1.5903	29.1395	
$e_{2,4,3}$	Coefficient	0.0004	0.0003	0.0003	0	0	0	-3E-04	0.0002	**0.7138117**
	t-Statistic	*1.3568*	*1.1175*	*1.4582*				*-2.436*	*18.521*	
$e_{2,4,4}$	Coefficient	0	0.0022	0	0	0	0	-4E-04	0.0005	**0.787933**
	t-Statistic		*10.881*					*-2.633*	*32.989*	
$e_{2,5,1}$	Coefficient	0	0.0002	0.0006	0	0	0	-3E-04	1E-04	**0.3669849**
	t-Statistic		*1.7679*	*5.2454*				*-5.976*	*23.504*	
$e_{2,5,2}$	Coefficient	0	0	0.0018	0.0033	0	0	0	0.0005	**0.5978196**
	t-Statistic			*2.0454*	*4.3047*				*16.005*	
$e_{2,5,3}$	Coefficient	0	0	0	0.0001	0	0	-2E-04	8E-05	**0.3153436**
	t-Statistic				*1.2305*			*-2.17*	*11.453*	
$e_{3,1,1}$	Coefficient	0.00082	0.00143	0	0	-0.0006	0	-0.0007	0.00058	**0.5777322**
	t-Statistic	*1.2044*	*2.9191*			*-1.703*		*-2.397*	*35.581*	
$e_{3,2,1}$	Coefficient	0.00021	0.00051	0	0	0	0	-0.0002	0.00014	**0.3360494**
	t-Statistic	1.1777	4.3538					-4.3173	36.1405	
$e_{3,2,2}$	Coefficient	0.00324	0	0.00136	0	0	-0.0017	0.00095	0.00055	**0.4670917**
	t-Statistic	*0.0033*		*0.0013*			*-0.002*	*0.0015*	*0.0006*	

VALIDATION OF EMISSIONS MODEL

The calibrated emissions models were validated on microscopic and macroscopic levels in this study, where the emissions estimated from the emissions models were compared with raw emissions data that were not used for calibration. In the microscopic evaluation, the emissions derived from emissions models for a speed profile were compared with the corresponding in-lab emissions data. The speed profile utilized in microscopic evaluation was used in the CE-CERT study to test a given vehicle with known vehicle type, model year, and higher emitter type. In the macroscopic evaluation, it was the emissions derived from the simulation models that were compared with on-road emissions data. The second-by-second emissions from the simulation models take vehicle proportions into account because the simulation cannot be as specific as in the CE-CERT tests where vehicles are known to be of a certain type, model year, and higher emitter type. The objective of the macroscopic evaluation is not to see a one-to-one match between the estimated and measured emissions because there is no one-to-one correspondence between them. The focus of the evaluation, however, is to observe the trends and the ranges in estimated emissions data to see whether they can match those presented in the on-road data. As a bottom line, the accuracy of emissions estimates for each individual vehicle class defined in this study can be examined by conducting a microscopic evaluation. The macroscopic evaluation is secondary in nature, and investigates the accuracy of the emissions estimates from an overall perspective.

Microscopic Evaluation

Specifically, emissions were estimated with inputs of a speed profile for a specific vehicle class in the microscopic evaluation. They were compared with the raw emissions data that was collected in the CE-CERT study for the same vehicle with the same speed profile. In the validation, the criterion of the Rooted Mean Squared Errors (RMSE) was employed, which can be expressed as:

$$RMSE_{i,j,k,m} = \sqrt{\frac{\sum_t \left[\hat{e}(t)_{i,j,km} - e_{i,j,k,m}(t)\right]^2}{T}} \qquad (4)$$

where T denotes the total number of time intervals included in the evaluation time period, and i, j, k, and m represent the type of emissions for the vehicle class specified by i, j, and k.

Two classes of vehicles, listed in table 14, were chosen for microscopic validation. Because the vehicle classification adopted in this study was different from that in the CE-CERT study, the vehicles classified in one class in this study may not be included in the same class in the CE-CERT study. To have a consistent evaluation, the two classes were chosen because they are identical with two classes from the CE-CERT study. As the emissions models developed in this study were based on data from the FTP cycle which was also the basis for the tests for all the vehicles in the CE-CERT study, we utilized emissions data from the MEC or US06 cycles in the microscopic validation. (See table 14.) Note that the CE-CERT study tested all the vehicles based on the FTP cycle and thus has data for all the vehicles. For the MEC and US06 cycles, however, some of the vehicles were not tested, and thus emissions data is not available for them and they cannot be used for emissions model validation in this study. As indicated in table 15, RMSE values for Poly's model are all in the range of satisfactory approximation to raw data and thus indicate a good validation of the model.

Table 15. Evaluation results based on RMSE.

Vehicle	Classification	Cycle	CO		HC		NOx	
			Poly's Model	CMEM Model	Poly's Model	CMEM Model	Poly's Model	CMEM Model
69th	LDGV before 1975	MEC	0.8390	1.5103	0.0485	0.0520	0.0383	0.0537
86th		MEC	0.8390	1.5220	0.0493	0.0533	0.0381	0.0528
154th		MEC	1.5044	1.4463	0.0707	0.0805	0.0333	0.0650
314th		MEC	1.2151	1.3132	0.0600	0.0789	0.0314	0.0637
314th		US06	1.2581	2.2039	0.0689	0.1128	0.0719	0.0907
198th	LDGT1 before 1981	MEC	1.3710	1.4613	0.0283	0.0419	0.0383	0.0568
204th		MEC	1.1874	1.1846	0.0244	0.0323	0.0300	0.0498
210th		MEC	0.6997	1.2148	0.0935	0.0972	0.0775	0.0793
222th		MEC	1.2265	1.5173	0.0245	0.0298	0.0601	0.0653
228th		MEC	1.3824	1.5146	0.0273	0.0308	0.0685	0.0753

In addition to validation through comparison of the estimated results with the raw emissions data, the performance of Poly's models was compared with that of the CMEM model developed in the CE-CERT study, and that of the INTEGRATION emissions model.

According to ([2]), the emissions models adopted in INTEGRATION take a form as follows:

$$\log(e_i(t)) = a + bA(t) + cA^2(t) + dA^3(t) + eV(t) + fV^2(t) + hA(t)V(t) + iA(t)V^2(t) + jA(t)V^3(t) + kA(t)^2V(t) + lA^2(t)V^2(t) + mA^2(t)V^3(t) + nA^3(t)V(t) + oA^3(t)V^2(t) + pA^3(t)V^3(t) \quad (5)$$

where:

$e_i(t)$ = Emission rates (mg/s) at time t.
a = Intercept.
b, c, …, p = Coefficients.
A(t) = Accelerations (m/s^2) at time t.
V(t) = Speed (m/s) at time t.

The parameters in Equation (5) have been provided in ([2]), and are listed in table 16.

Table 16. Model parameters for the emissions models embedded in INTEGRATION.

	CO	HC	NOx
a	0.887447	-0.72804	-1.06768
b	0.148841	0	0.254363
c	0.03055	0.023371	0.008866
d	-0.00135	-9.3E-05	-0.00095
e	0.070994	0.02495	0.046423
f	-0.00079	-0.00021	-0.00017
g	4.62E-06	1.95E-06	5.69E-07
h	0.00387	0.010145	0.015482
i	9.32E-05	-0.0001	-0.00013
j	-7.1E-07	6.18E-07	3.28E-07
k	-0.00093	-0.00055	0.002876
l	4.92E-05	3.76E-05	-5.9E-05
m	-3.1E-07	-2.1E-07	2.4E-07
n	0	-0.00011	-0.00032
o	-1.4E-06	3.31E-06	1.94E-06
p	0	-1.7E-08	-1.3E-08

This study found that the INTEGRATION emissions models sometimes produce unrealistically large emissions values. This is because the emissions in Equation (5) must go through a logarithmic transformation to make sure that the estimated emissions are positive. As it turns out, however, this transformation may produce vary large emissions values when acceleration become large. For this reason, the emissions results are distorted. Thus, the results from comparison with the INTEGRATION emissions model were not presented in this study.

Table 15 shows that most of the RMSE values derived for Poly's model are smaller than those for the CMEM model. This implies that Poly's model performs better than the CMEM model.

Macroscopic Level Evaluation

To make it possible to use the emissions models developed in this study in a transportation evaluation project, they were incorporated into the framework of the simulation model INTEGRATION. For this incorporation, an interface program was developed which can transform outputs from INTEGRATION into inputs for the emissions models, calculate the emissions based on the emissions models developed in this study, and present the emissions to users in an appropriate format.

Given the development of model integration, emissions can be derived for vehicles passing a point in a study area. By calibrating the INTEGRATION simulation model for the on-road emissions data collection locations specified by TSU, it is possible to compare the emissions derived from the simulation model to those collected on-road by TSU. In this study, the evaluation based on this comparison was referred to as macroscopic evaluation. Basically, the evaluation was based on the trends and ranges that are presented in the estimated and collected emissions. A consistency that can be observed between the trends and ranges indicates a validation of the estimation against the raw data.

Specifically, the emissions calculated from the emissions model are displayed in a chart. By clustering the data points on the chart, the trend and range of the emissions versus speed were observed. A visual judgement was made to see whether this trend and range were consistent with those reflected by the on-road data. A good match between them indicates a good validation of the model to the raw data.

There are several reasons for not having a direct one-to-one comparison (as in the microscopic evaluation) between simulated emissions and on-road collected emissions data in macroscopic validation. First, the vehicles measured on-road cannot be identified for details such as emitter types. One the other hand, emitter type is a vehicle classification level adopted in the emissions model calibration in this study. Thus, a one-to-one relationship cannot be established for vehicles between those simulated and measured on-road. Second, traffic simulation models cannot specify vehicle class in as much detail as was categorized in emissions model development.

Basically, the emissions derived from the simulation model are actually an average value where the composite of vehicle classification is taken into account. Specifically, the operation of averaging is based on the following equation:

$$e_{i,m}(t) = \sum_j \sum_k e_{i,j,k,m}(t) \cdot P_{i,j,k} \; , \quad (6)$$

where i denotes vehicle type of LDGV, LDGT1, and LDGT2, respectively. $P_{i,j,k}$ denotes the percentage of vehicles with model year group j and high emitter type k within vehicle type i, and m = 1, 2, and 3 for CO, HC, and NOx, respectively. It can be seen from the equation that, for a given vehicle of type i, the type m emission at time t is an average value that incorporate vehicle categorization of j and k within class i utilizing the proportion $P_{i,j,k}$ for each type of vehicle. Note that the vehicle proportions represented as $P_{i,j,k}$ should be chosen appropriately to reflect the vehicle population in the study area. This study took the values as given in table 7, which are synthesized based on national average values.

In addition to the validation of the model developed in this study, the CMEM model and the INTEGRATION emissions model were compared with Poly’s model. Since the results for the INTEGRATION emissions model do not match the on-road data very well, they were not presented in this section.

The emissions results for the Poly's and CMEM models and the on-road data collected in Texas are provided in figures 16 to 25. From these figures, it can be observed that the CO emission estimated by Poly's model increases with the speed for all the five locations. The same is true for HC emission. Also, the data points of Poly's model are a good match for those of on-road data in each location. These two observations indicate that Poly's model can produce well validated results.

The validation of Poly's model can also be supported by the following observations. Compared to the emissions results from CMEM model, the CO and HC emissions estimated by Poly's models are a closer match for the on-road data. Actually, the CMEM model always produces some irregular emission estimates that are far beyond the range of emissions laid out by the on-road data. These irregular emissions estimates significantly impact the overall estimated emissions level in a study area because some of these irregularities are substantially large.

Furthermore, the results of the better match represented by Poly's model implies that the vehicle proportions, which were based on national averages, reflected the conditions of the locations where the emissions were collected on-road. This implication suggests that NJDOT could also adopt these values, which have been provided as defaults in the interface designed in this study for calculating emissions.

In summary, Poly's model has been tested for validation on both the microscopic and macroscopic levels. On the microscopic level, Poly's model can produce emissions estimates with discrepancies from raw data that are within a satisfactory range. On the macroscopic level, Poly's model is a good match for the on-road data. Thus, it can be concluded that Poly's model has been well validated.

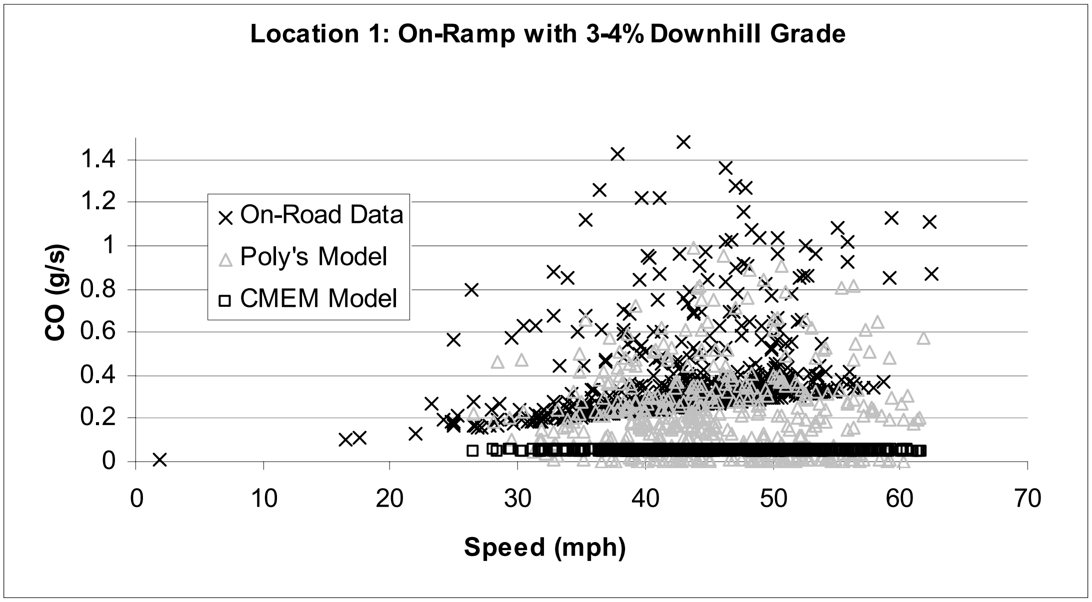

Figure 16. CO emission vs. speed at Location 1.

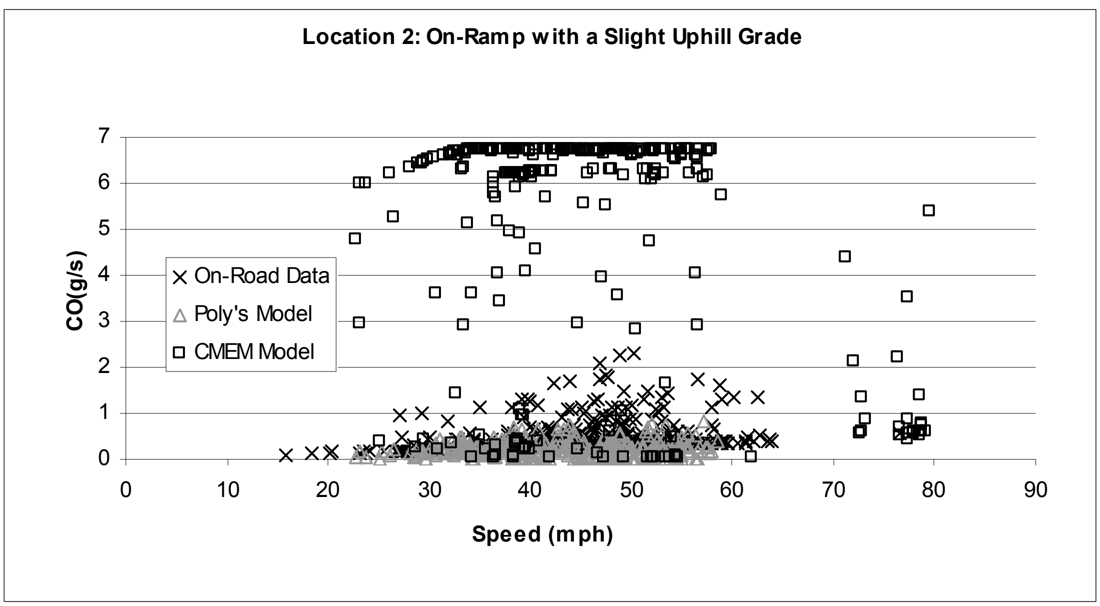

Figure 17. CO emission vs. speed at Location 2.

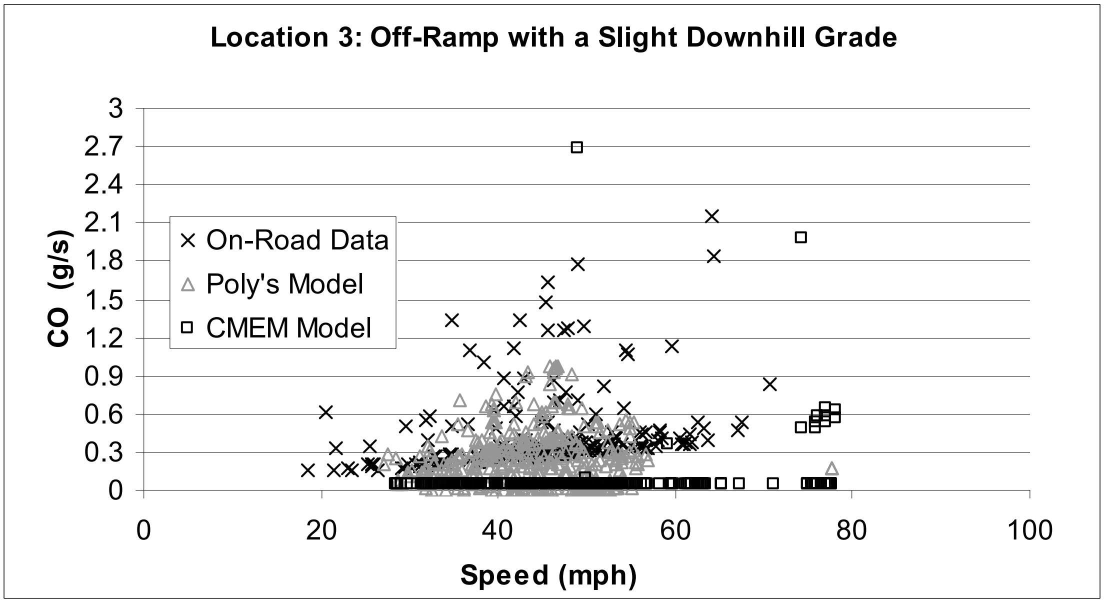

Figure 18. CO emission vs. speed at Location 3.

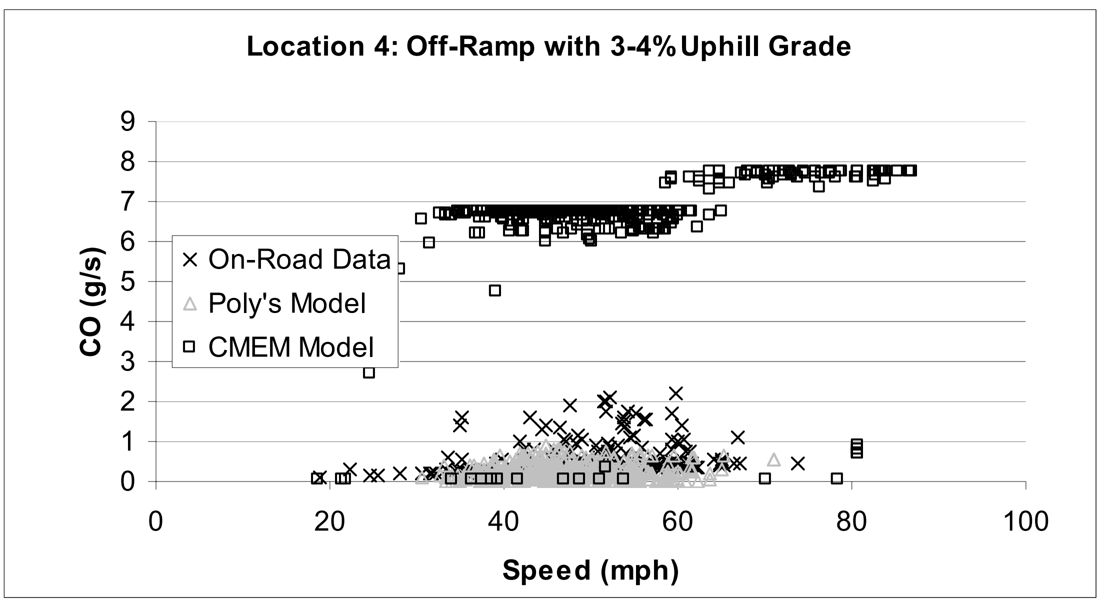

Figure 19. CO emission vs. speed at Location 4.

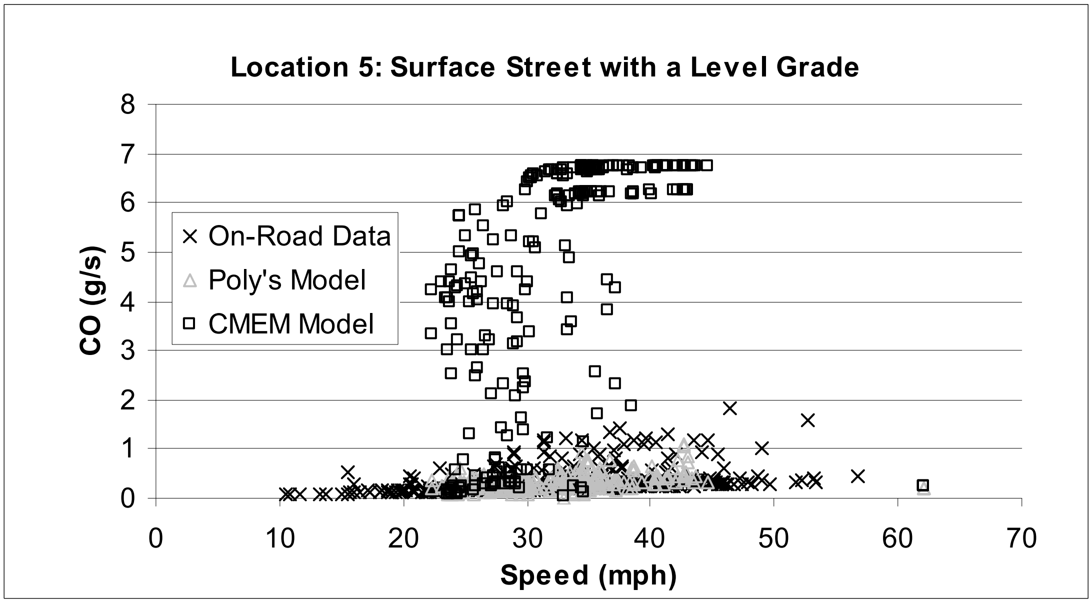

Figure 20. CO emission vs. speed at Location 5.

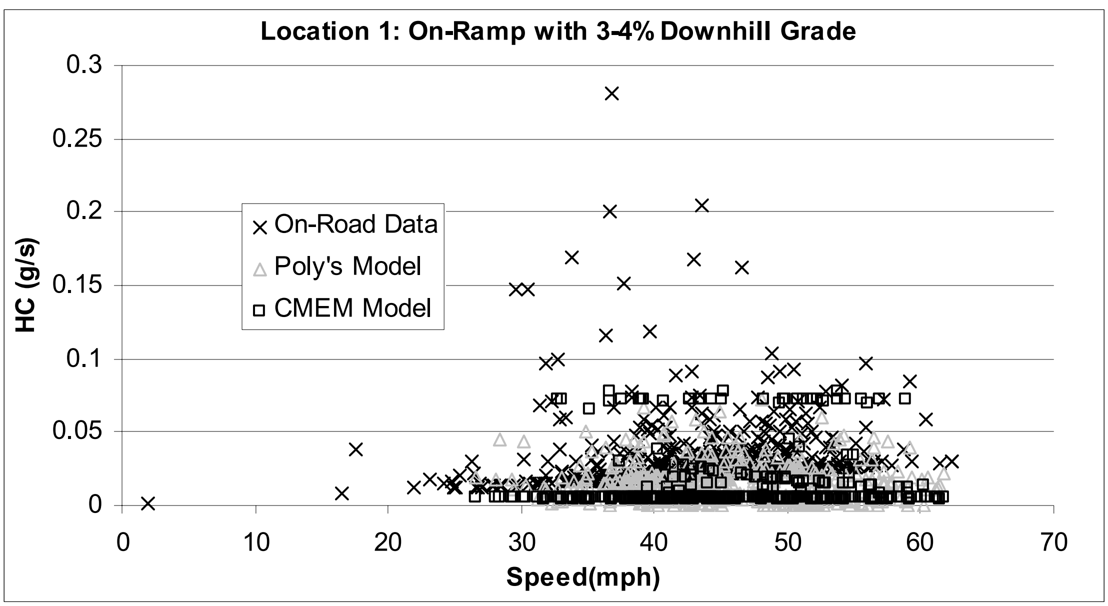

Figure 21. HC emission vs. speed at Location 1.

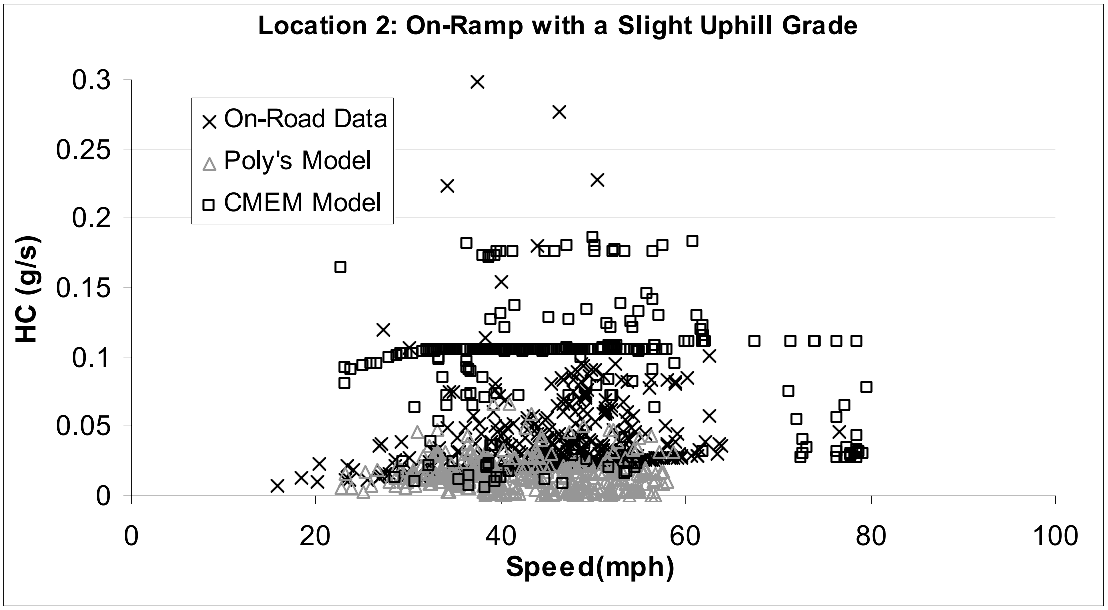

Figure 22. HC emission vs. speed at Location 2.

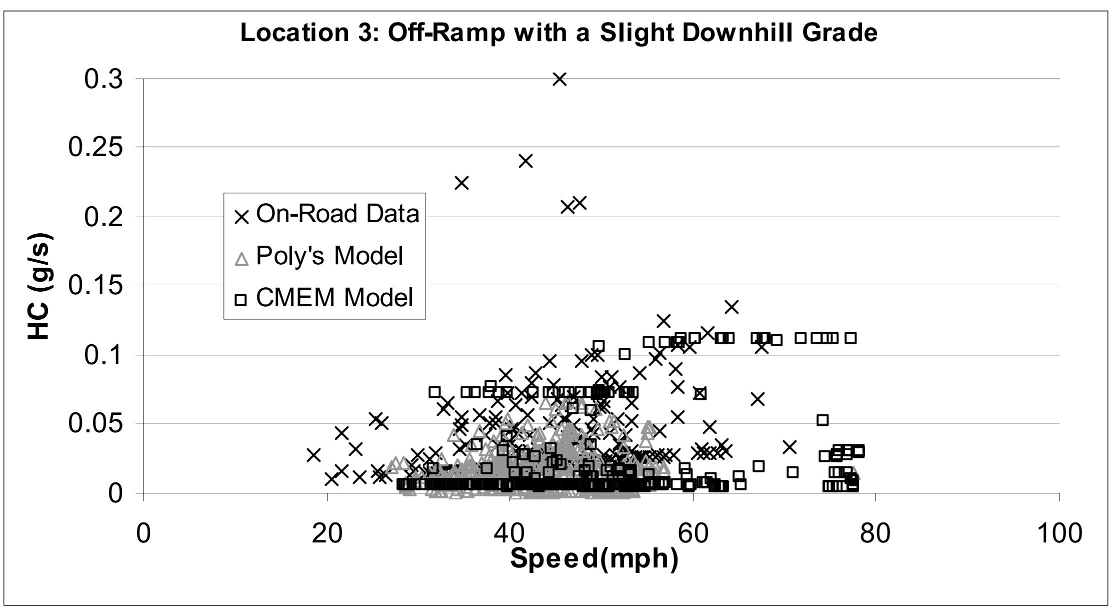

Figure 23. HC emission vs. speed at Location 3.

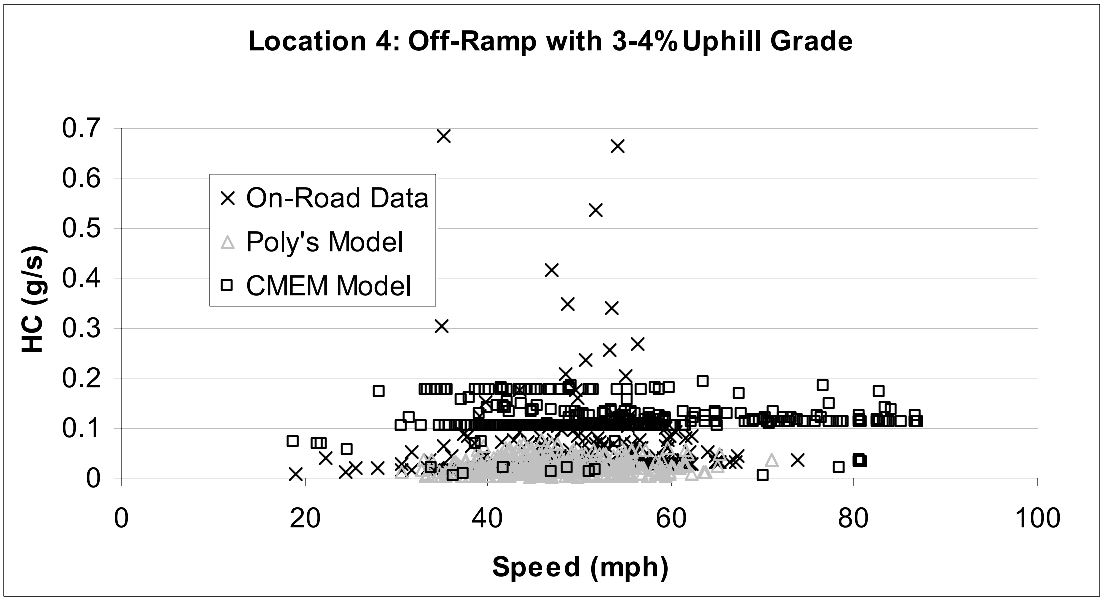

Figure 24. HC emission vs. speed at Location 4.

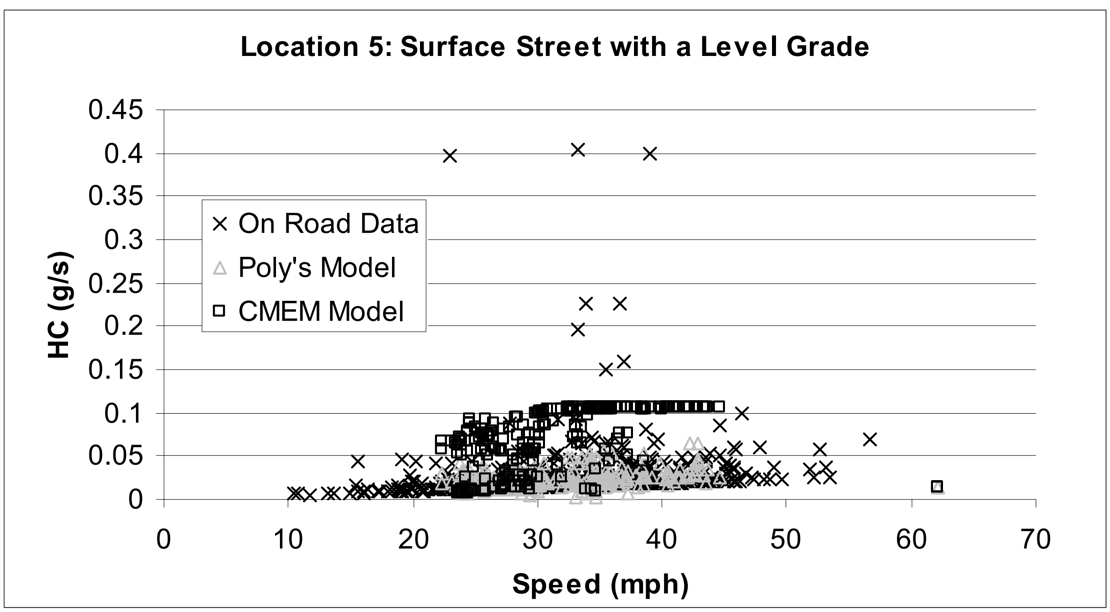

Figure 25. HC emission vs. speed at Location 5.

TRAINING AND IMPLEMENTATION

Interface Manual

As a product of the project, interfaces were designed to read outputs from INTEGRATION, calculate emissions based on the models developed in this study, and output the emissions results. To use these interfaces to calculate emissions, the following steps need to be followed:

1. Preparing to run INTERGRATION

   INTEGRATION is a microscopic traffic simulation model which was developed to analyze a number of specialized problems related to the operation and optimization of integrated freeway/arterial traffic networks, of real-time controls and of route guidance systems.

   To run INTERGRATION, you need to code your transportation network, which may be as simple as a ramp or an intersection. You also need to code traffic controls such as ramp metering and signal timing. In addition, you need to specify demand with origin and destination. For illustration, an example of using INTEGRATION is provided with this manual. For detailed information about INTERGRATION, you need to refer to the manual for INTERGRATION, which is also provided with this package.

2. Specifying vehicle percentage

   In Poly's emissions model, three types of vehicles were classified in terms of vehicle weight: Light Duty Gasoline vehicle (LDGV), Light Duty Gasoline Truck (LDGT1), and Light Duty Gasoline Truck (LDGV2). These three vehicle classes are further broken down in terms of the model year of the vehicles. As seen in figure 26, you need to specify the percentage for each class of vehicle. Otherwise, the interface will use the default values presented in figure 26.

   As shown in figure 26, you need to click on the menu "Vehicle Age." A dialogue box like the one shown in the lower part of figure 26 will be prompted up. To make sure that your inputs are accepted by the software, click on any of other cells after you key in each of your inputs.

3. Mapping Vehicle Types

   It should be noted that the vehicle classification specified for the purpose of emissions modeling is different from those adopted in INTEGRATION. Thus, you need to specify which class in INTEGRATION a class in emissions models corresponds to. Figure 27 shows an interface for keying in the correspondence. To make sure that your inputs are accepted by the software, click on any of other cells after you key in each of your inputs.

4. Running INTERGRATION

   Given the preparation of INTEGRATION model in step 1 and the specifications in step 2 and 3, you can run INTEGRATION by clicking on START INTEGRATION on the menu bar. Figure 28 demonstrates the running of INTEGRATION.

5. Reading INTERGRATION Output

   Before you calculate emissions, you need to retrieve outputs such as speed profile, grade, etc. from INTEGRATION. By clicking on "Read INTEGRATION Results" on the menu bar, as shown in figure 29, you will be shown how long it is going to take to finish reading the outputs.

6. Calculating Emissions

   After you obtain the data from INTEGRATION, you can calculate the emissions based on the emissions model developed in this study. The calculation can be done by clicking on "Calculate Emissions" on the menu bar, as shown in figure 30.

7. Displaying (second-by-second) Individual Emissions Results

   The emissions results can be displayed by clicking "Show Results" on the menu bar. The emissions shown in figure 31 are actually vehicle-by-vehicle in nature. If you key in –1 in the "link No." field or "vehicle ID" field, you will be shown emissions for all the links or all the vehicles. Otherwise, the system can show you emissions for a particular link or vehicle which you specify.

8. Displaying Link Emissions Results

   The interface showing the link-by-link emissions in figure 32 indicates that you can also manipulate the emissions for mean or variance considering link length etc.

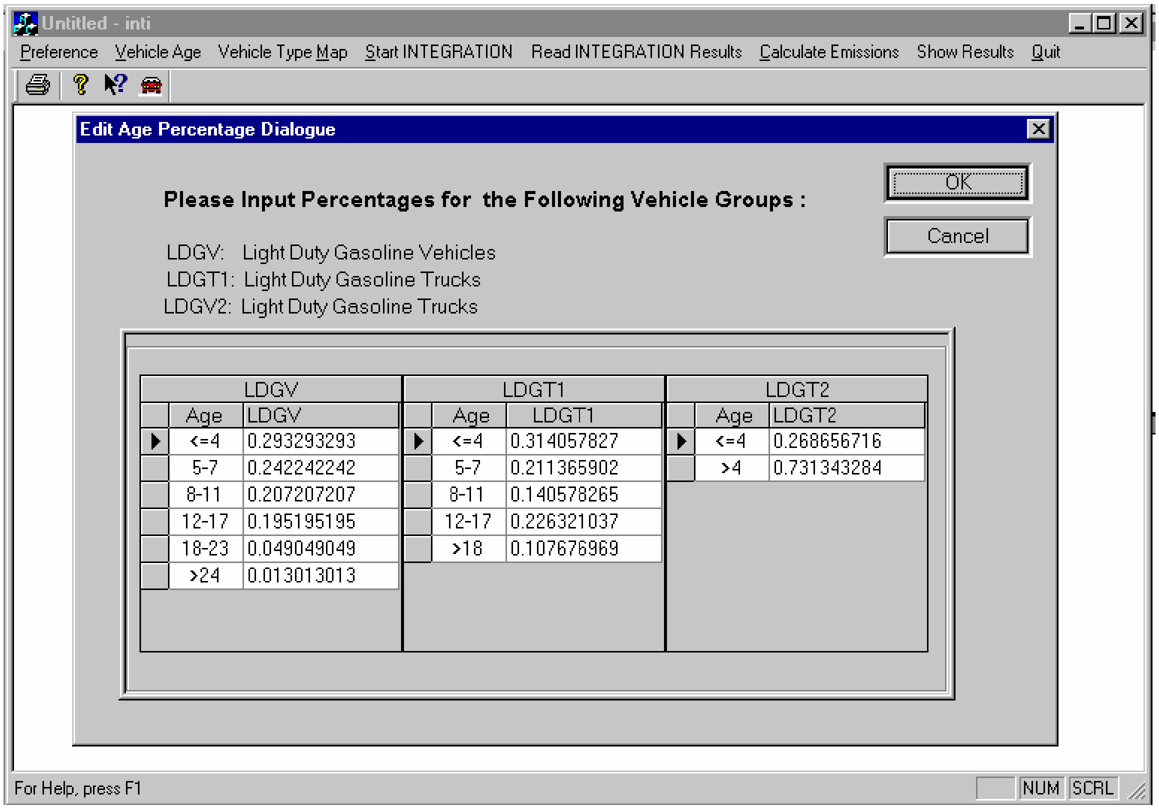

Figure 26. Interface for inputting vehicle type proportions.

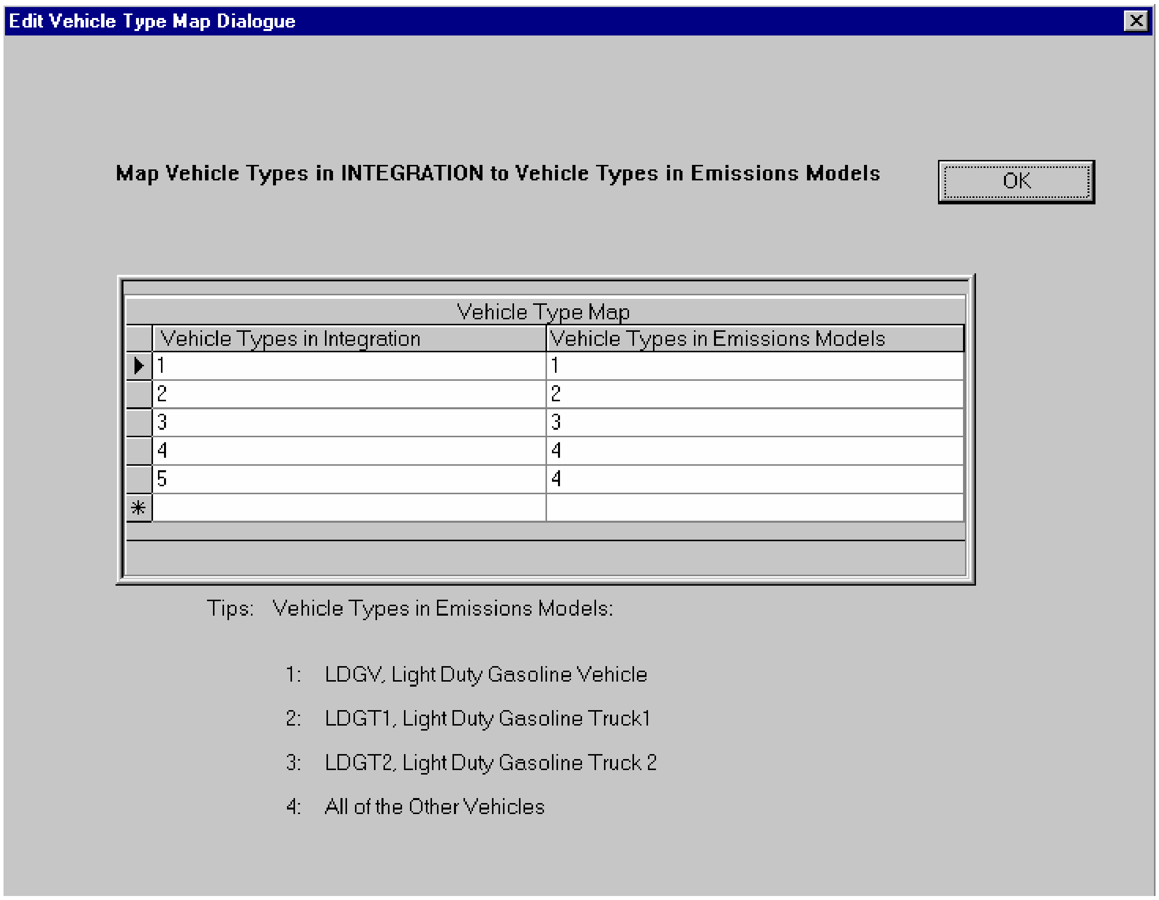

Figure 27. Interface for mapping vehicle types in INTEGRATION to vehicle classes specified in Poly's emissions model.

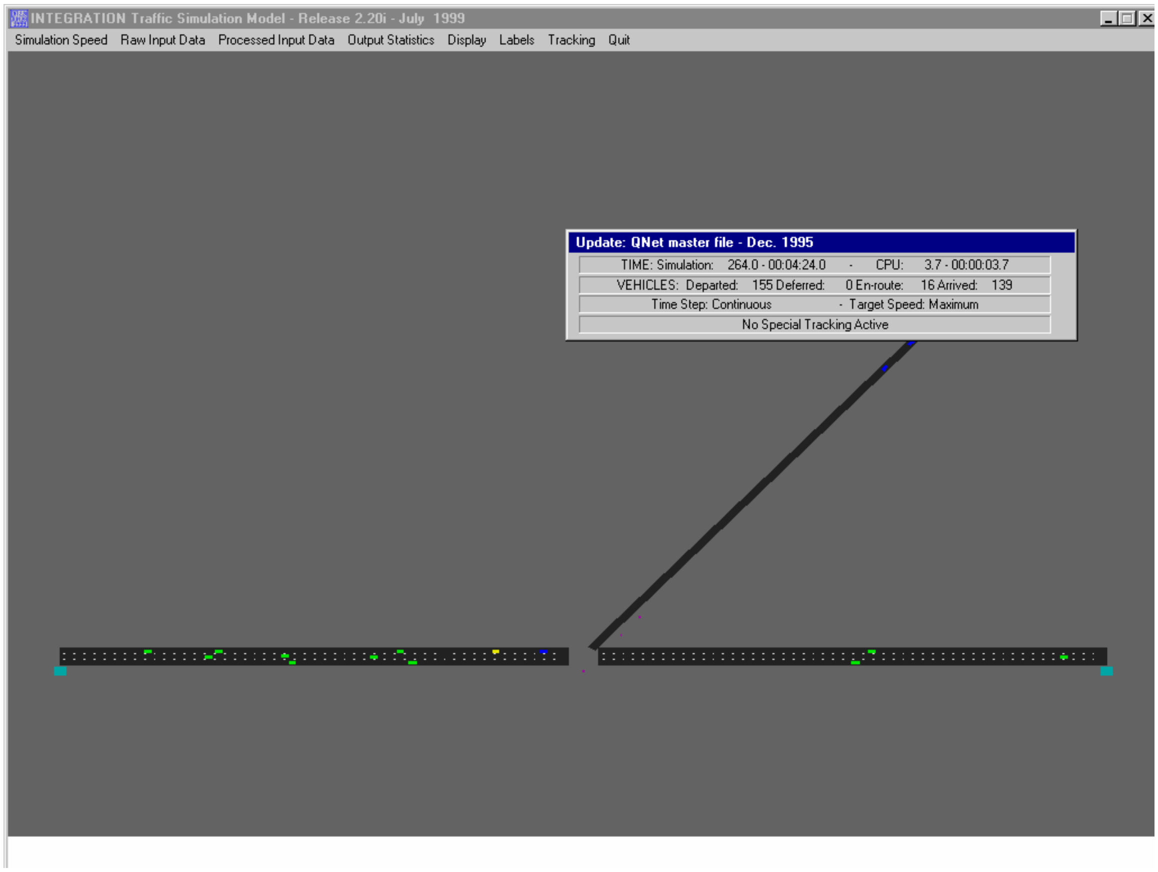

Figure 28. Interface showing the running of INTEGRATION.

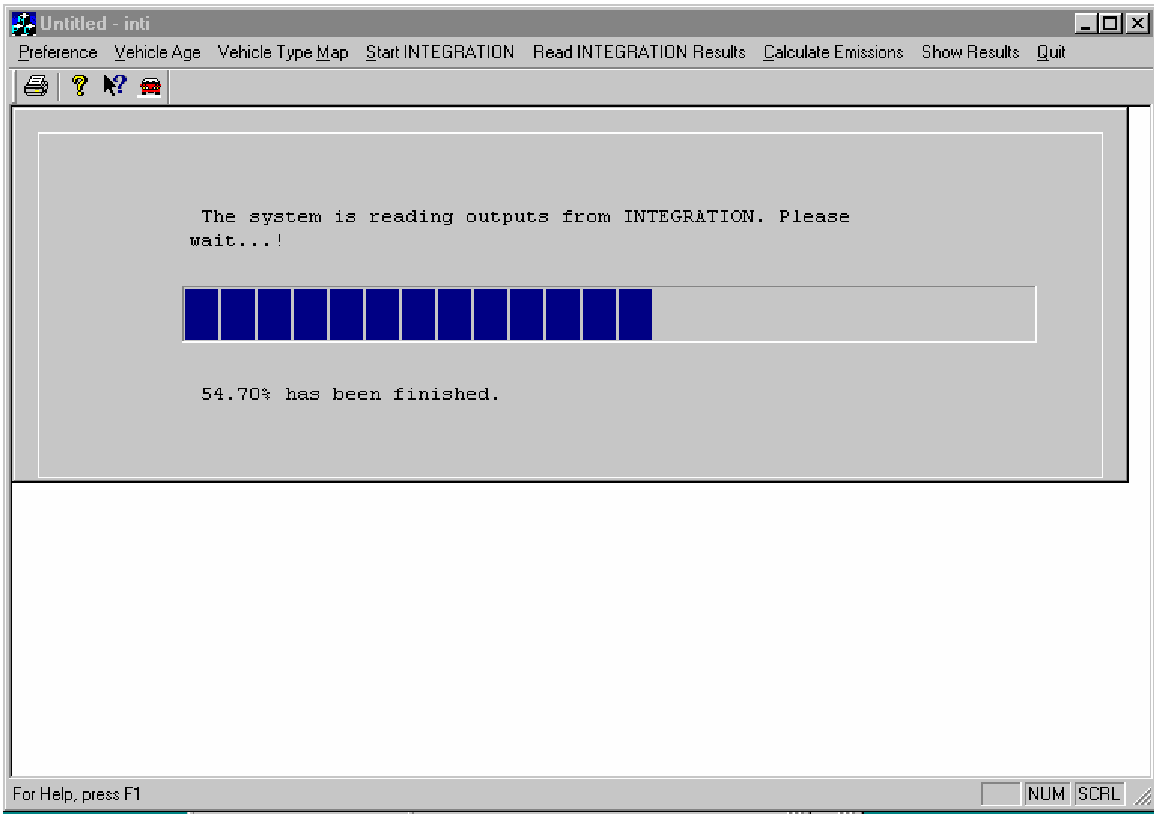

Figure 29. Interface showing reading outputs from INTEGRATION.

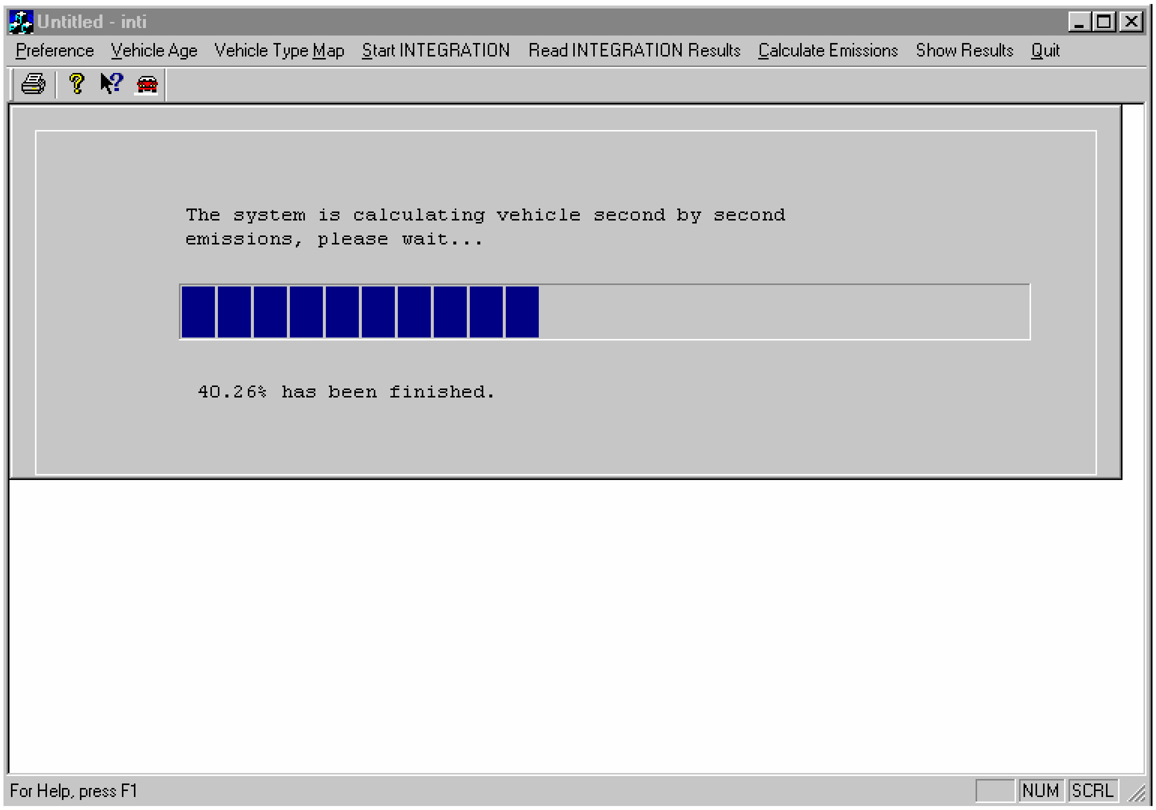

Figure 30. Interface showing converting outputs from INTEGRATION to Ploy's emissions models and doing the calculation.

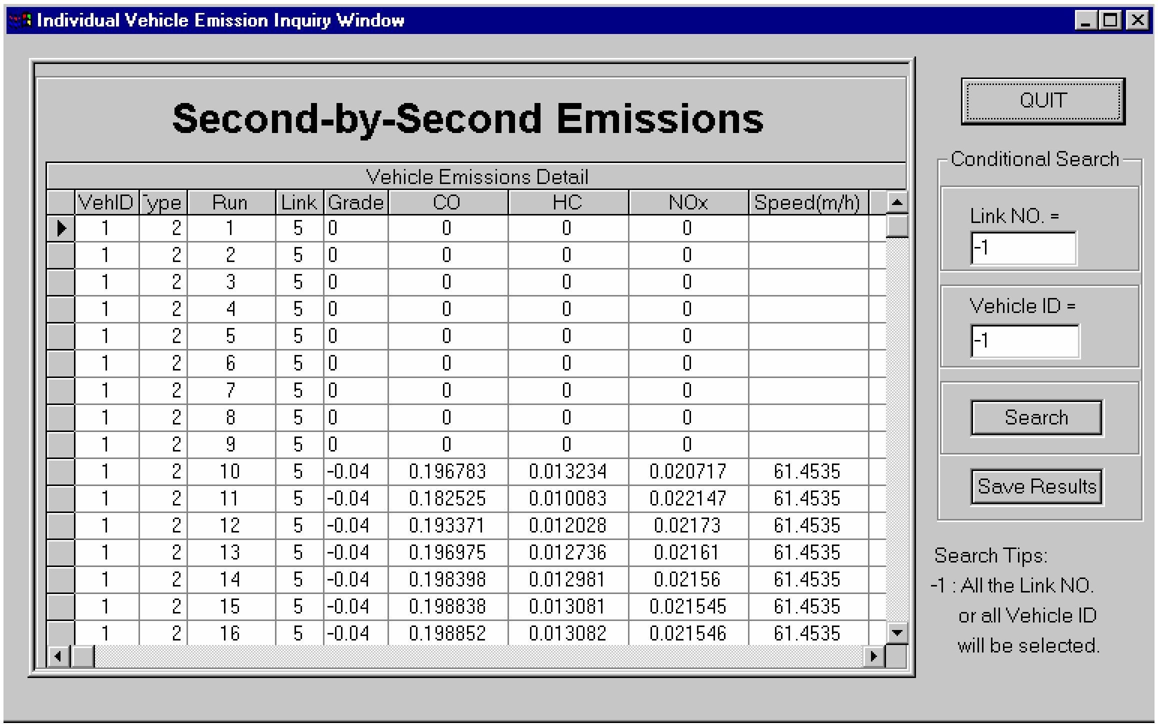

Figure 31. Interface showing the emissions of each individual vehicle.

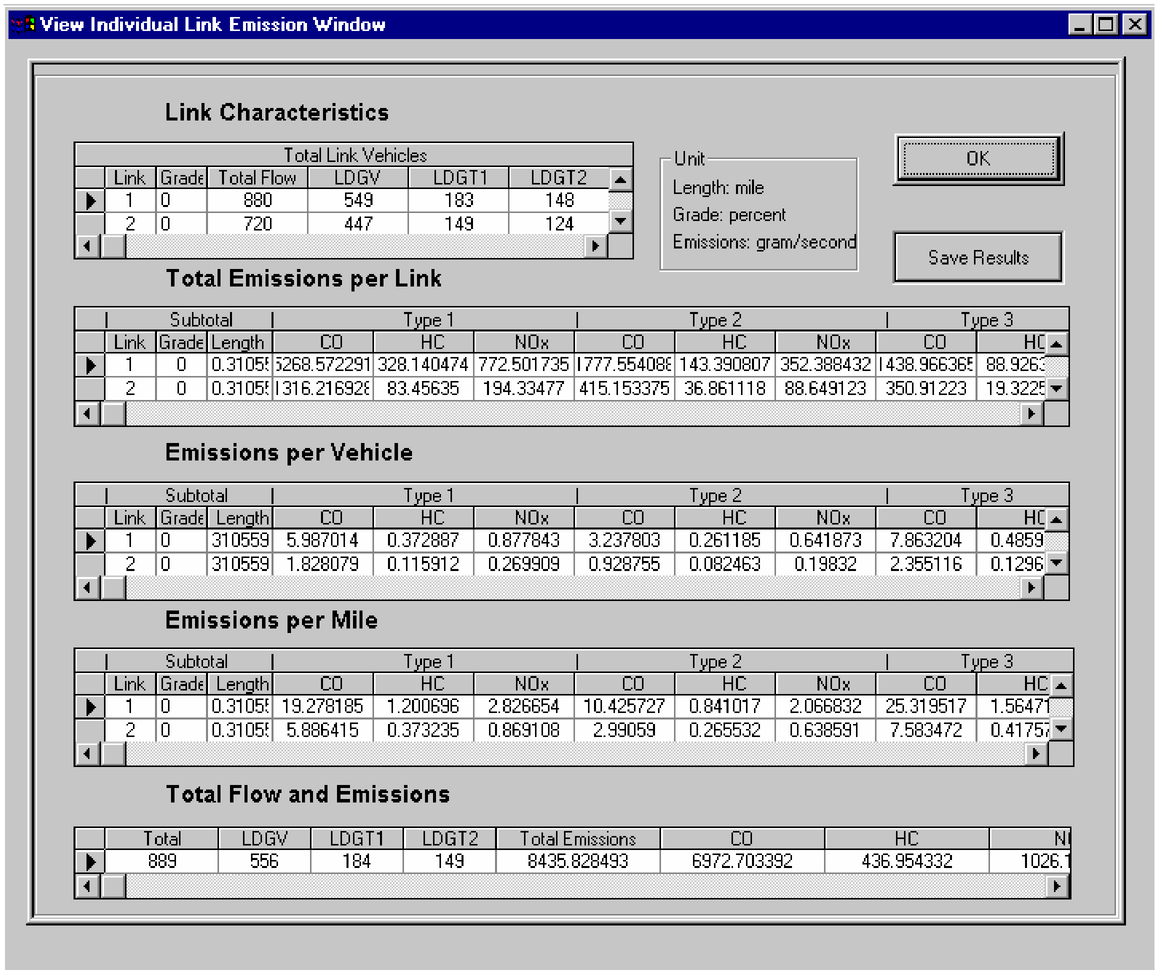

Figure 32. Interface showing emissions for each link of network.

An Application of INTEGRATION

In the application of INTEGRATION presented below, the location to be simulated primarily consists of an on-ramp with approximately 150 meters long and a 3-4 percent downhill grade. This location is actually Location 1 for which on-road emissions data were collected by the Texas Southern University. After keying in inputs into INTEGRATION, this intersection looks like that presented in figure 33. The inputs for this small network are provided in figure 34.

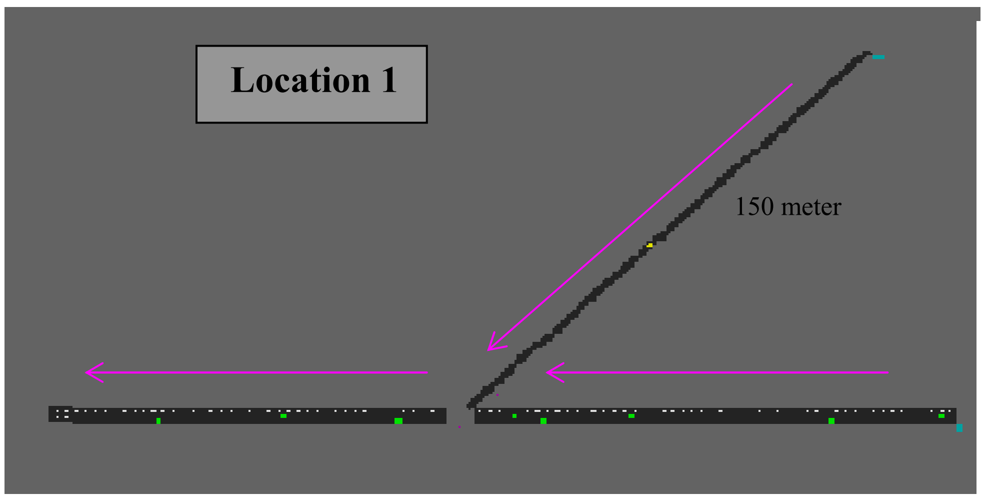

Figure 33. On-ramp at Location 1.

Node Coordinate File

```
6    1.0      1.0
1    0.5      1.0      2  -1   0
2    1.0      1.0      4   0   0
3    1.5      1.0      3   0   0
4    1.036  1.048   4  0   0
5    1.054  1.072   4  0   0
6    1.414  1.552   3  0   0
```

Link Characteristic File

```
5   1.0  1.0  1.0  1.0  1.0
1   2  1    0.5  130   2200   3     0      100    120    0 0 0  0   0       0  0  0  00000 11111
2   3  2    0.5   130  2200   3     0      100    120    0 0 0  0   0       0  0  0  00000 11111
3   4  2    0.06 110  1800   1    0.4      78    100    0 0 0  0   0       0  0  0  00000 11111
4   5  4    0.03 110  1800   1    0.4      78    100    0 0 0  0   0       0  0  0  00000 11111
5   6  5    0.6   110  1800   1    0.4      78    100    0 0 0  0   0       0  0  0  00000 11111
```

Signal File

```
0    0  1200
```

QNET Traffic Demand

```
8   0   0   1.0
1   3  1    900    1.0    0  1800    1    0.0 0.0 0.0 0.0  100  1.0
2   3  1    300    1.0    0  1800    0.0 1    0.0 0.0 0.0  100  1.25
3   3  1    250    1.0    0  1800    0.0 0.0 1    0.0 0.0  100  1.5
4   3  1    50      1.0    0  1800    0.0 0.0 0.0 1    0.0  100  2.5
5   6  1    220    1.0    0  1800    1    0.0 0.0 0.0 0.0  100  1.0
6   6  1    70      1.0    0  1800    0.0 1    0.0 0.0 0.0  100  1.25
7   6  1    50      1.0    0  1800    0.0 0.0 1    0.0 0.0  100  1.5
8   6  1    20      1.0    0  1800    0.0 0.0 0.0 1    0.0  100  2.5
```

Link Grade File

```
1  0
2  0
3 -0.04
4 -0.04
5 -0.04
```

Maximum acceleration file

```
4
1 1642    2.8 0.85 0.6 128 0.88 0.4   2.5  1  0.033  4.575
2  2222   5.8 0.6   0.6 142 0.81 0.7   6.8  1  0.033  4.575
3  3726   6.8 0.7   0.6 159 0.82 0.7   7     1  0.033  4.575
4  18870  8   0.4   0.6 155 0.76 0.86 9.48 1  0.05    4.575
```

Figure 34. Inputs for INTEGRATION.

CONCLUSIONS

In this study, nonlinear regression models were developed to take into account factors of acceleration or deceleration and grade, which are not considered in the MOBILE5 model and not well modeled by other existing microscale emissions models. The dependent variables in the nonlinear regression models are CO, HC, and NOx. To model the dynamics of acceleration or deceleration, not only is the acceleration or deceleration of the current time period included in the independent variables, but those of previous time periods are also included. In addition, the duration since acceleration or deceleration has been exercised is also included as independent variable. The factor of grade is considered by using the grade to adjust the values of acceleration or deceleration. Besides these independent variables, variables representing tractive power are also introduced into the models because they directly determine the amount of emissions to be produced by a vehicle. The representative variables of this kind are speed, the second and third power of speed, and a specific power factor that is a product of speed and acceleration or deceleration. With this modeling approach, the validation results show that the emissions model developed in this study can produce a close match for the raw data on both microscopic and macroscopic levels.

RECOMMENDATIONS

As can be observed from figures16 to 25, there are always some data points of on-road emissions located at the top of the charts which cannot be reached by Poly's model. Actually, the results of Poly's model are average values as shown in Equation (6), which may reduce the variance caused by high emitters. In addition, Poly's model was calibrated based only on the FTP data that was used in MOBILE5 but not updated to reflect the aggressive driving patterns of the current time. By including some emissions data for other deriving cycles tested in the CE-CERT study, the performance of Poly's model could be improved in this regard.

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