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Analytical Tool for Measuring Emission Impact of Acceleration and Deceleration Lanes

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Hualiang (Harry) Teng, Ph.D.
Assistant Professor
Polytechnic University

Lei Yu, Ph.D.
Associate Professor
Texas Southern University

and

Yi (GRACE) Qi
Research Fellow
Polytechnic University

In cooperation with

University Transportation Research Center, Region 2
City College of New York

New Jersey Department of Transportation
and
U.S. Department of Transportation

MARSHAK HALL J910
THE CITY COLLEGE OF NEW YORK, NEW YORK 10031 212-650-8050 FAX 212-650-8374
WWW.UTRC2.ORG

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16. Abstract

Air quality has become one of the important factors to be considered in making transportation improvement decisions. Thus, tools are expected to help such decision-makings. On the other hand, MOBILE5 model, which has been widely used in evaluating air quality improvement, become helpless when the transportation improvements are sensitive to factors such as acceleration/deceleration, grade, etc. which are not modeled in MOBILE5 model. For example, improvements can be made to reduce the grade of a ramp, thus reduce high acceleration and deceleration. Intuitively, high acceleration would induce high emissions. MOBILE5 model, however, doesn't model the impact of acceleration/deceleration on emissions, thus cannot help the relevant decision-makings. Therefore, the objective of this study is to develop emission models to incorporate into acceleration/deceleration.

In this study, nonlinear regression models were developed to take into account factors of acceleration or deceleration, which are not considered in MOBILE5 model. To fully capture the dynamics of acceleration/deceleration, not only the acceleration or deceleration of the current time period is included in the independent variables, but also those of previous time periods. In addition, the duration that acceleration or deceleration has been exercised is also included as independent variables. The factor of grade is considered in the models by using the grade to adjust the values of acceleration or deceleration. Besides these independent variables, variables representing traction power are also introduced into the models because they directly determine the amount of emissions to be 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 the raw emissions data in both microscopic and macroscopic levels.

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Air quality has become one of the important factors to be considered in making transportation improvement decisions. Thus, tools are expected to help such decision-makings. On the other hand, MOBILE5 model, which has been widely used in evaluating air quality improvement, become helpless when the transportation improvements are sensitive to factors such as acceleration/deceleration, grade, etc. which are not modeled in MOBILE5 model. For example, improvements can be made to reduce the grade of a ramp, thus reduce high acceleration and deceleration. Intuitively, high acceleration would induce high emissions. MOBILE5 model, however, doesn't model the impact of acceleration/deceleration on emissions, thus cannot help the relevant decision-makings. Therefore, the objective of this study is to develop emission models to incorporate into acceleration/deceleration.

In this study, nonlinear regression models were developed to take into account factors of acceleration or deceleration, which are not considered in MOBILE5 model. To fully capture the dynamics of acceleration/deceleration, not only the acceleration or deceleration of the current time period is included in the independent variables, but also those of previous time periods. In addition, the duration that acceleration or deceleration has been exercised is also included as independent variables. The factor of grade is considered in the models 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. With this modeling approach, the validation results show that the emission model developed in this study can produce a close match to the raw emissions data in 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 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, 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 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. NEPA requires that a project will 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 only 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 estimates off-road emissions, for PM, and for air toxics, respectively. 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 to evaluate emissions impacts for 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. Vehicle emissions are strongly coupled with driving dynamics, and average speed often does not properly characterize these dynamics. A large number of different driving patterns can have approximately the same average speed, but might have totally different driving dynamics and thus drastically different emissions responses. For example, a short and large grade ramp may result in similar average speed as a long and small grade ramp. However, the emissions produced from the first ramp would be larger than the second one. Another example for traffic signal is that a signal timing plan may cause traffic with bigger speed variance than the other one while keep the average travel time same. To take the change of speed, i.e., acceleration/deceleration, into account in evaluating a project such as ramp geometric design, signal timing, etc., there is a strong need to develop an analytic emission tool for emission evaluation.

This study developed analytical emissions models that can be coupled with existing transportation models for project evaluation. Due to the difficulty of representing acceleration/deceleration in a macroscle emission model, we chose to develop microscale emission models that can estimate second-by-second emissions given variables such as acceleration or deceleration and speed at the current and previous time periods. For such microscale emission models, they can be integrated into a microscopic traffic simulation model. They can take speed profiles produced from the simulation as input to the developed microscale emission models. The second-by-second emission estimates from the developed emission models can then be aggregated to produce an inventory of emissions for an area under study.

In the following sections, a literature review is first introduced on the existing approaches to developing microscale emission models. Based on this review, a methodology developed for this study is described followed by a description of variables that have been included in some existing microscale models and the data collected in other studies and to be used in this study. The calibration of the emission models developed based on the collected emission data is introduced with presentation of calibration results. The validation of the microscale emission models is described followed by conclusions of the study and identification of future study needs.

LITERATURE REVIEW

To capture the emissions effects of acceleration or deceleration, three approaches have been taken in developing microscale emissions models. Because the emissions data that were based upon for developing these models are second-by-second, or in short intervals, these emissions models are called instantaneous or continuous emission model. They are also called modal emission models because they include variables that represent operational mode such as acceleration or deceleration.

The most basic form of microscale emissions models is a multidimensional lookup table that simply stores the corresponding emissions values corresponding to a combination of speed and acceleration/deceleration. NETSIM is an example of using this type of instantaneous emissions model. Obviously, this type of microscale emissions models is straightforward to implement, and the computational cost is very low. However, there are several potential problems with it. First, it cannot explicitly account for the time dependence in the emissions in response to the vehicle operation. Many vehicle types exist for which vehicle-operating history (e.g., the speed in the last several seconds of vehicle operation) 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.

Another approach of developing microscale emission models is to develop neural network model that can learn and capture the correlation between emissions and acceleration/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 traffic simulation model would be substantial if the neural network emission models are integrated. Another problem is the difficulty in interpreting the influence of a certain variable on emissions.

Another approach to modeling microscale emissions is called analytical and physical modeling approach. In this type of approach, the entire emission creation process is broken down into different components that correspond to physical phenomena associated with vehicle operation and emissions production (Barth et al. 1996). 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 according to the vehicle type, engine, and emissions technology. The majority of these parameters are stated as specifications by the vehicle manufacturers, and are readily available (e.g., vehicle mass, engine size, and aerodynamic drag coefficient). Other key parameters relating to vehicle operation and emissions production can be deduced from actual second-by-second emission data. Due to a large number of parameters to be estimated, their accumulated errors would be substantial, thus the conceived advantage of emulating the mechanical emission process can not be fully achieved.

Given the introduction to these modeling approaches, this study chose the nonlinear regression techniques. Different from the nonlinear models developed in studies such as Ahn et al. (1999), the models developed in this study incorporate variables that directly related to emissions.

METHODOLOGY

Based on the review of the existing microscale emission models, a framework was developed to illustrate the role that a microscale emission model plays in the whole model system. As presented in Figure 1, the framework consists of three components: (1) an existing microscopic traffic simulation model, (2) a microscale emission model, and (3) an interface between them. This framework shows that, with the inputs of the network and traffic data, and the specification of system improvement scenarios such as ramp geometric designs, traffic signal timing, incident management strategies, etc., the traffic simulation model provides outputs such as second-by-second speed, acceleration or deceleration, etc. The interface takes the inputs and outputs from the traffic simulation model and process them to a format that is needed for the microscale emission model. The microscale emission models then take the processed outputs from the simulation model to calculate the emissions. The interface aggregate the microscale outputs from the emission models and format them to forms that can be convenient for the users to do their analysis.

This framework indicates that the core of this study is to develop microscale emission models. In general, the procedure to develop these emission models consists of the following steps:

(a) Determine the modeling approach to be taken.
(b) Determine the emission influencing factors to be considered.
(c) Identify the data sources.
(d) Calibrate the microscale emission models.
(e) Validate the models.

The second and third steps are interactive in nature. For a given modeling approach, such as the nonlinear modeling approach employed in this study, the expected variables to be included may be more than those obtainable. Based on identified data sources, the initially identified influencing factors to be modeled have to be adjusted appropriately.

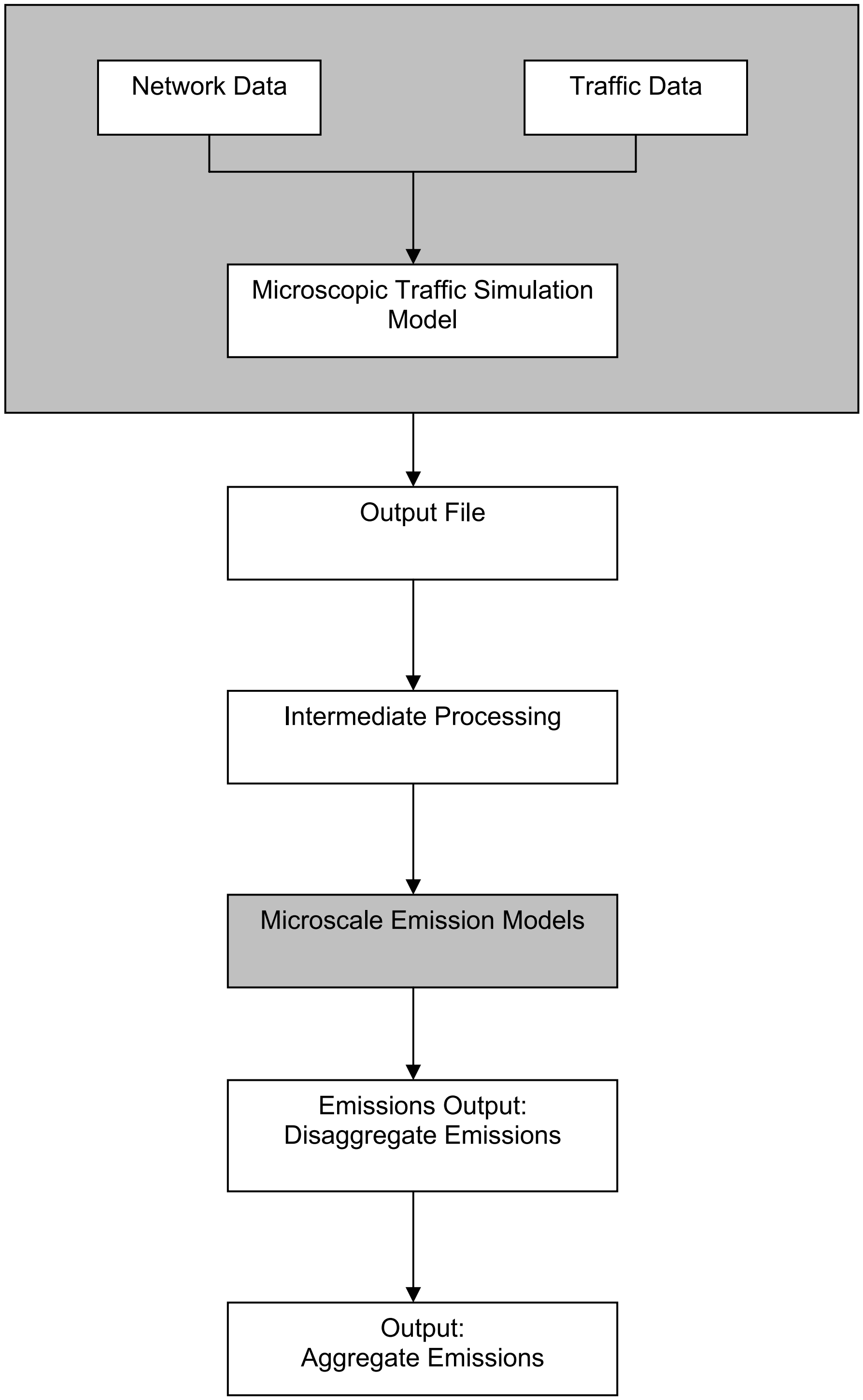

Figure 1 Framework for Generating Emission Inventory Based on Microscale Emission Models

IDENTIFICATION OF VARIABLES FOR DEVELOPING EMISSION MODELS

In this study, three studies that are related to developing microscale emission models were emphasized to identify the variables they considered. The first study is that 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 (Barth et al. 2000). In this study, the Comprehensive Modal Emission Model (CMEM) was developed. The second study is that undertaken by Texas Southern University (Yu 1997) where on-road emission data were collected using a remoter sensing technology. The last study is that finished at Virginia Tech where INTEGRATION traffic simulation model was used as a model system component to interact to the developed emission models (Ahn et al. 1999).

In the CMEM model (Barth et al. 2000), the emissions was modeled as a product of mechanical process, which is composed of six components, as indicated in Figure 2: 1) engine power demand, 2) engine speed, 3) fuel/air ratio, 4) fuel-rate, 5) engine-out emissions, and 6) catalyst pass fraction. As represented as ovals in Figure 2, there are four operating conditions in the model: a) variable soak time start; b) stoichiometric operation; c) enrichment; and d) enleanment. The model first determines in which condition the vehicle is operating at a given moment by comparing the vehicle power demand with power demand thresholds. Combining the outputs from the previous mechanical components with the determined operating conditions, a mechanical component calculate its output based on calibrated and readily available parameters. The final product from the CMEM is the second-by-second 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):

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

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

In summary, the model, as a whole, requires two groups of inputs (rounded boxes in Figure 2: A) input operating variables; and B) model parameters. The output of the model is tailpipe emissions and fuel consumption. In Table 1, the shaded cell contains operating variables and the remaining cells include model parameters.

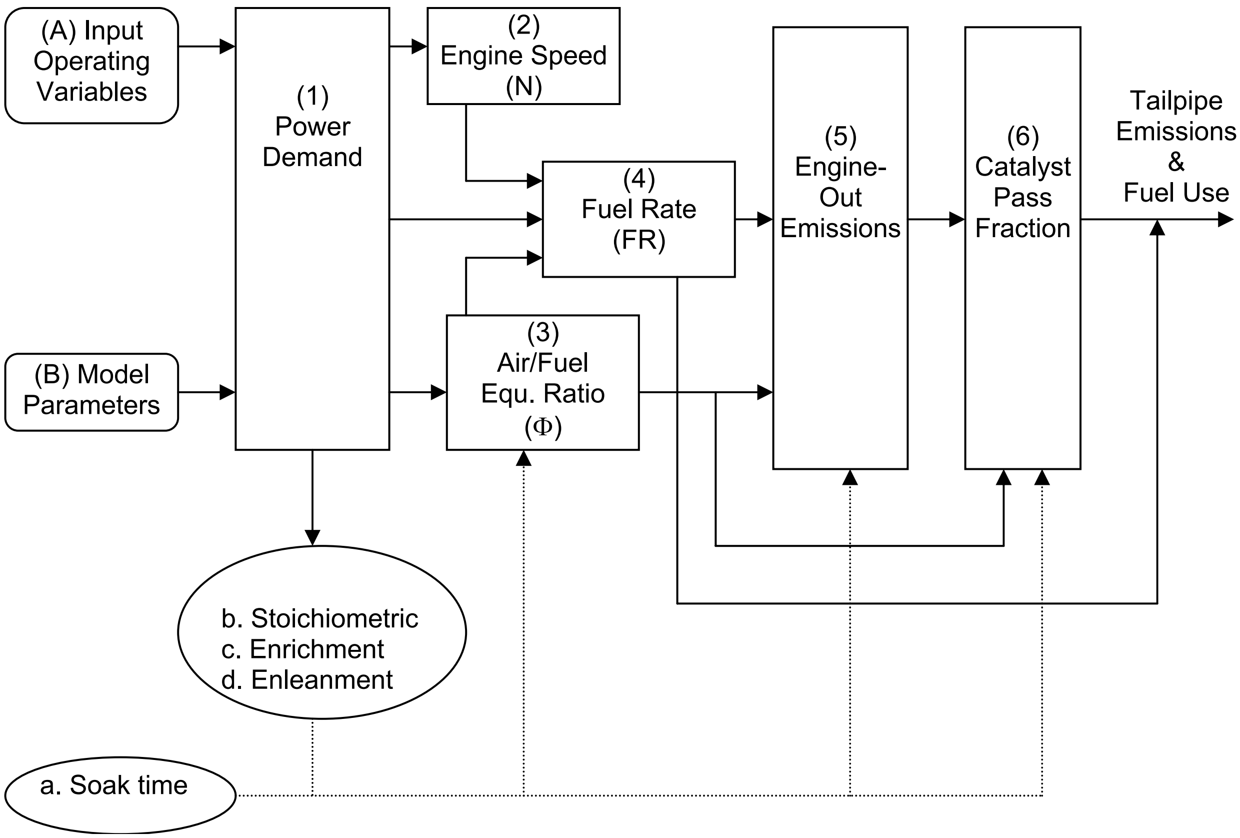

Figure 2 CMEM Emission Model Structure

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 ***Generic Vehicle Parameters*** η - indicated efficiency ε_1 - max. drivetrain eff. R(L) - gear ratio ***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.)	***(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 ***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 ***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	***(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 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 ***Enrichment Parameters*** φ_0 - max F/A equi. Ratio P_{scale} – SP threshold factor

The study conducted by Yu (1997) developed the ONROAD vehicle exhaust emission model for estimating CO and HC emissions. This model was developed based on the on-road emission data collected from five highway locations in Houston area using a remote emission sensor. The ONROAD emission estimation model establishes relationships between the on-road vehicle exhaust emission rates and a vehicle's instantaneous speed profile. Since a vehicle's instantaneous speed profile is a function of different traffic demand and control scenarios, this emission model can be used to estimate the emission implications of alternative traffic control and management strategies. Because of the aggregate nature of the ONROAD emission model, it can be easily incorporated into a traffic simulation or dynamic traffic assignment model where a vehicle's instantaneous speed profile can be tracked consistently. Hence, this emission model is ideal for traffic simulation and optimization analyses.

The dependent variables in the regression analysis are the CO and HC emission rates for each vehicle type. The independent variables are instantaneous speed, acceleration or deceleration rate, ambient temperature, and humidity.

In the study by Ahn et al. (1999), nonlinear regression model and neural network model were developed. The dependent variables are emission rates for CO, HC, and NOx, while the independent variables only contain acceleration or deceleration and speed.

For comparison, the dependent and independent variables of these three studies were 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 EMISSION DATA

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

Data from 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 three 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; and be composed of a series modal events such as various levels of accelerations, deceleration events, a set of constant cruise speeds, speed-fluctuation driving, and constant power driving. It consists of five different sections: *stoichiometric cruise sectio*n, *constant power sectio*n, *constant acceleration sectio*n, *air conditioning hill sectio*n, and *repeat hill cruise sectio*n.

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.

In this study, we only use the tailpipe emissions, not the engine-out emissions. Instantaneous vehicle acceleration can be calculated based on the speeds of two consecutive time periods.

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 emission data using the remote emission sensor (RES), SMOG DOG, from five highway locations in Houston area. SMOG DOG is an application of advanced technology developed for environmental monitoring from space to accurate measurement of automotive emissions on earth. It was initially developed for providing a cost-effective tool for screening for high emitter vehicles and has experienced 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. The 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 in detecting a vehicle's instantaneous speed and acceleration rate. The instantaneous speed value and acceleration rate of a vehicle passing through the test site are monitored utilizing piezo strips and a computer. Speed and acceleration data are then transferred to the main system computer and stored with the vehicle records.

In collecting the emissions data, the following factors have been considered. First, emission 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, emission data should be collected for diverse geometric conditions in order to determine how geometric conditions influence the 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 the emission 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 another one of each is on a slight downhill grade. While the vehicle emission data for an idling mode should also be collected, the operation of SMOG DOG requires that the vehicle must be in motion. Hence, the on-road emission data for the idling mode are not collected in Texas's study.

Considering the time for setting up the SMOG DOG equipment and the need for collecting sufficient emission data for each location, it is not practical to collect emissions for more than one site on each day. Therefore, emission data at each site were collected for an entire day. The actual emission data were 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.

It should be noted that all the emission 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 emission estimation capabilities. This is because all the emission factor models have considered these conditions as proportional contributors to the total emissions. The emission data collected in the Texas's research represent only the emissions under hot stabilized condition of vehicles.

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

Data format and variables

The raw data collected by TSU was represented in Table 5 in which the columns' headings are explained below.

Vehicle no.	=	sequence of vehicles that were collected for emission 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	=	a parameter needed in the SMOG DOG system,
Slope HC	=	a parameter needed in the SMOG DOG system,
Max CO2	=	a parameter needed in the SMOG DOG system,
Max CO	=	a parameter needed in the SMOG DOG system,
Max HC	=	a parameter needed in the SMOG DOG system,
Speed 1	=	a parameter needed in the SMOG DOG system,
Speed 2	=	a parameter needed in the SMOG DOG system,
Acceleration Rate	=	acceleration,
NOx%	=	percentage of NOx particle,
Slope NOx	=	a parameter needed in the SMOG DOG system, and
Max NOx	=	a parameter needed in the SMOG DOG system.

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

Table 5 Emission 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 emission data from the Oak Ridge National Laboratory were collected during a two-year time period starting from 1996 (Ahn et al. 1999). In order to collect the emission data, test vehicles are tested on-road and on a chassis dynamometer as functions of vehicle speed and acceleration while driving the cars through their entire operating envelope. The two data sets 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. Data were gathered for a total of eight light-duty vehicles (Chevrolet Truck, Corsica, Oldsmobile, Geo Prizm, Jeep Grand Cherokee, Oldsmobile 88, Subaru, Villager), which are 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) contain 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 data set for a Corsica is shown in Figure 6.

Table 6 Emission CO (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 EMISSION MODELS WITH FIELD DATA

Given the identification of the microscale emission models and emission data sources, it is necessary to evaluate the difference between the emissions produced from the microscale models and those collected in labs or on roads. Based on this evaluation, the need for developing better models to incorporate acceleration/deceleration can be further enhanced.

To make the evaluation meaningful, the emission data collected by the Texas Southern University were chosen as the baseline because they were collected on-road and thus can represent the real conditions to some extents. The data from UC at Riverside were collected in lab. Thus they cannot reflect real conditions particular in terms of mix of vehicles. The original ORNL data set is only partially collected on-road. However, the part of on-road data cannot be distinguished from the data available to this study because they have been merged with those collected in-lab and are not distinguishable from the existing data format.

The microscale emission models embedded in the microscopic traffic simulation model INTEGRATION were chosen for comparing with real emission data. In these models, only acceleration/deceleration and speed of one time period are incorporated. The profile of these two variables, which influences the emissions substantially, is not included.

To have a reliable comparison of the emissions, the INTEGRATION simulation model was calibrated for all the five locations where the on-road emission data were collected. This calibration can make sure that the traffic and physical conditions simulated be consistent with those when on-road data were collected. To do the calibration, the data of traffic and physical condition were obtained from Texas Southern University. The data include grades, number of lanes, and length of each roadway segment, and ramp and traffic demands with origin and destination specification. In calibrating the model, the mean and variance of speed on each roadway segment collected with the emissions data were compared with those from simulation.

From Figure 3 to 7 it can be observed that the emission CO estimated by the emission models of INTERGRATION does not change with speed when the grade of ramp is large. When the grades of the ramps and the intersection is small or flat, the variance of CO increases with speed. Similar pattern can be observed for HC. This indicates that the INTERGRATION emission model do have the capability of modeling the change of speed. However, this capability is vanished when the geometrics of roadway have large grade. Second, the emissions estimated by INTERGRATION emission models 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 the roadway is not on a large grade. Except for the location without grade, the on-road emission data are always larger than the emissions from INTERGRATION emission model. This observation implies that the INTERGRATION emission model may underestimate emissions in some cases.

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

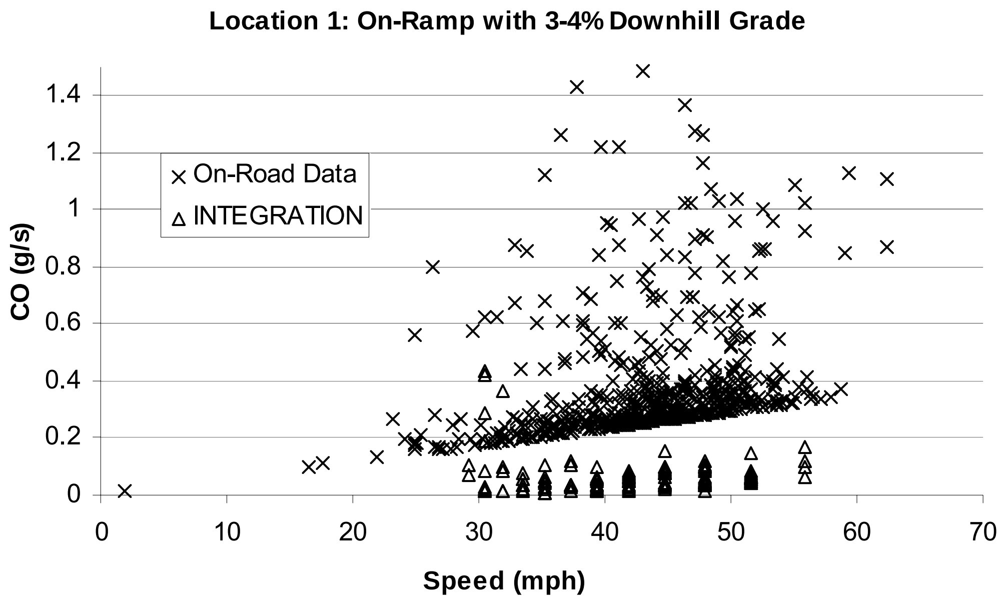

Figure 3 Comparison of Emission CO at Location 1

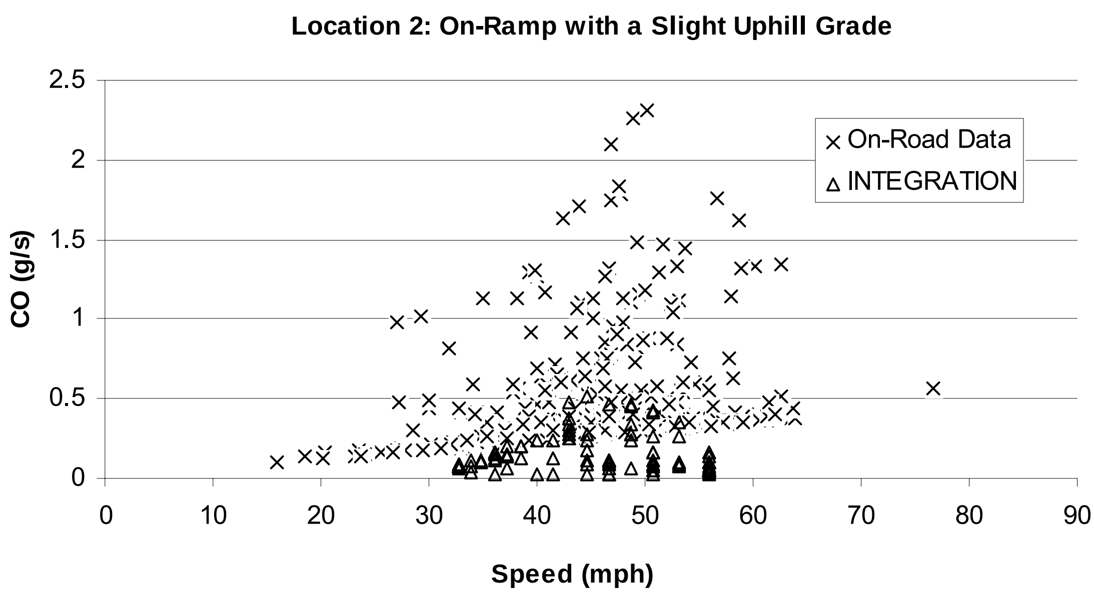

Figure 4 Comparison of Emission CO at Location 2

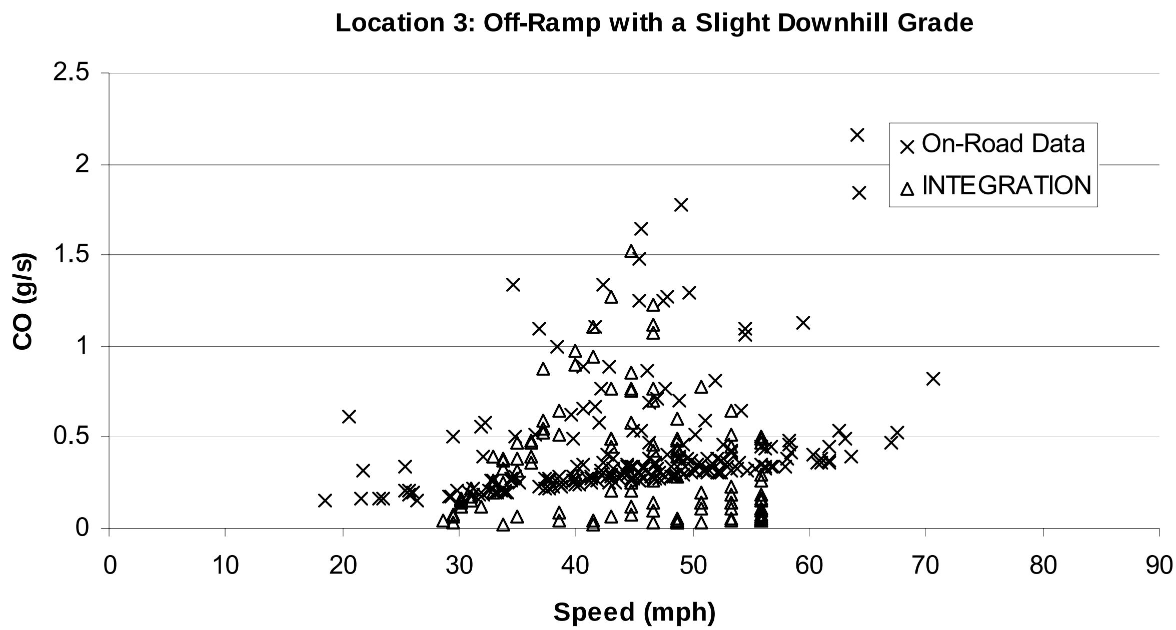

Figure 5 Comparison of Emission CO at Location 3

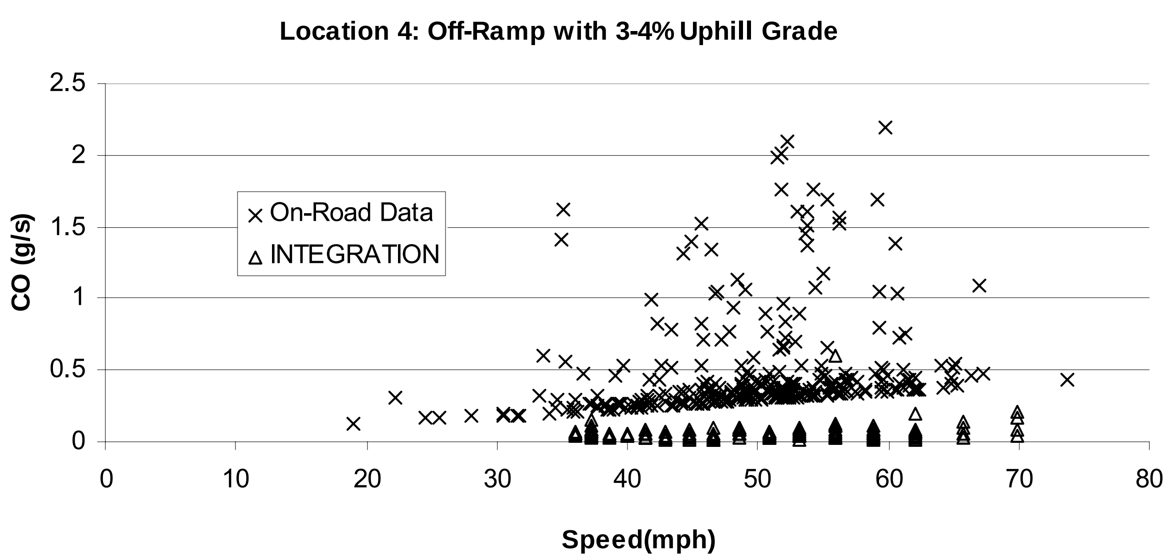

Figure 6 Comparison of Emission CO at Location 5

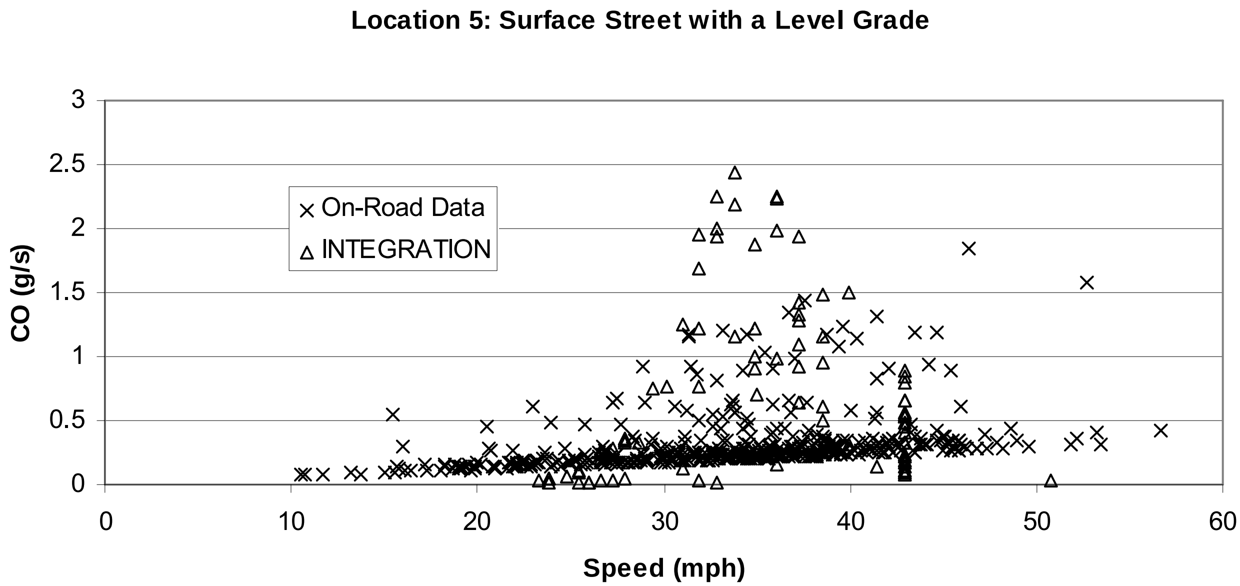

Figure 7 Comparison of Emission CO at Location 5

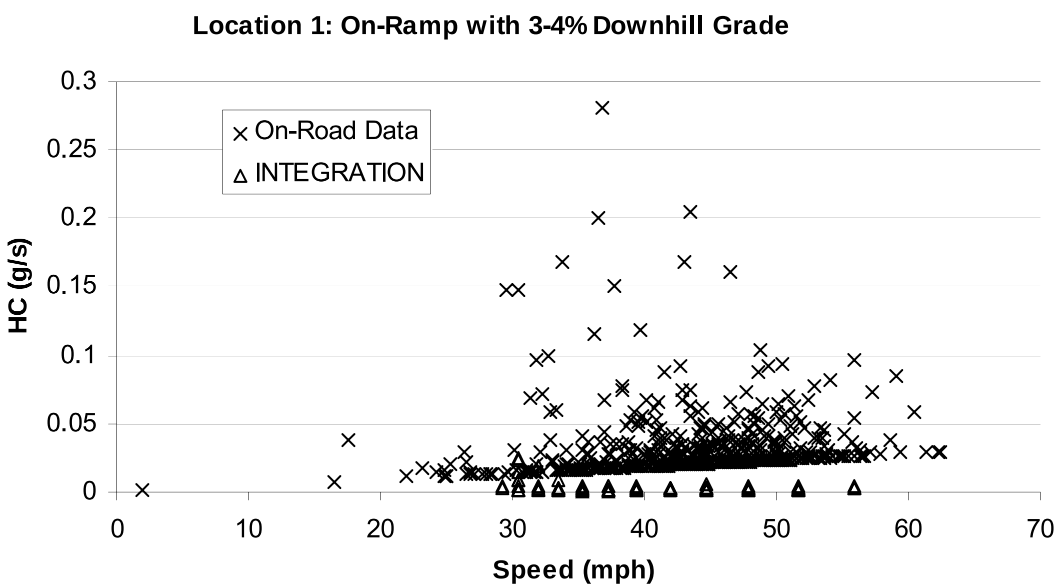

Figure 8 Comparison of Emission HC at Location 1

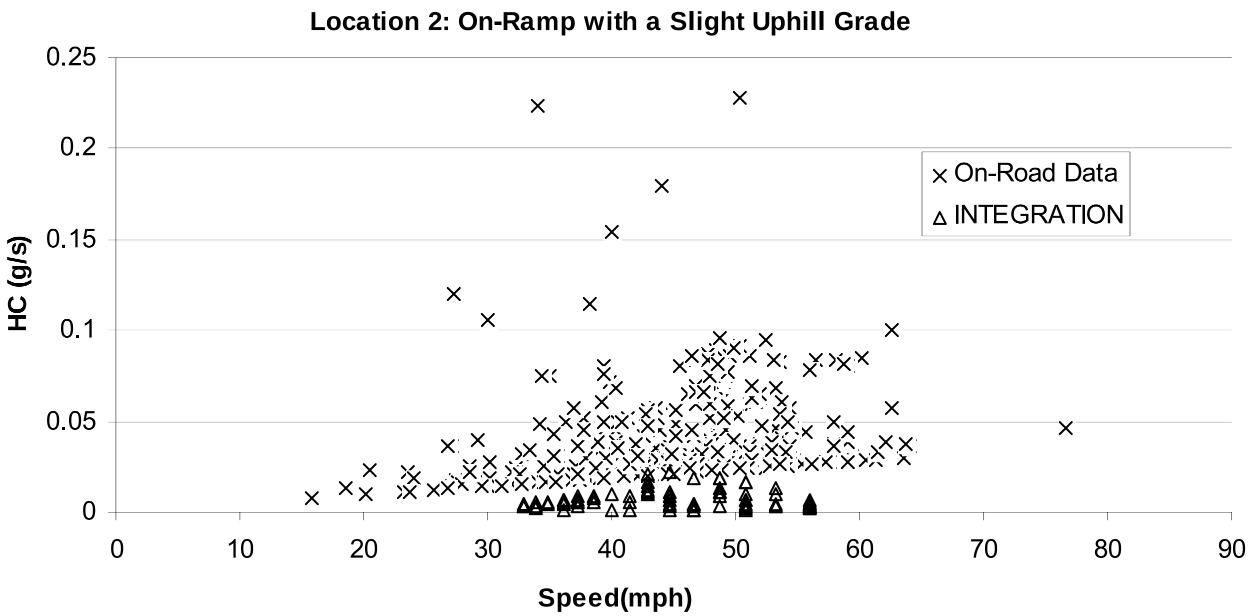

Figure 9 Comparison of Emission HC at Location 2

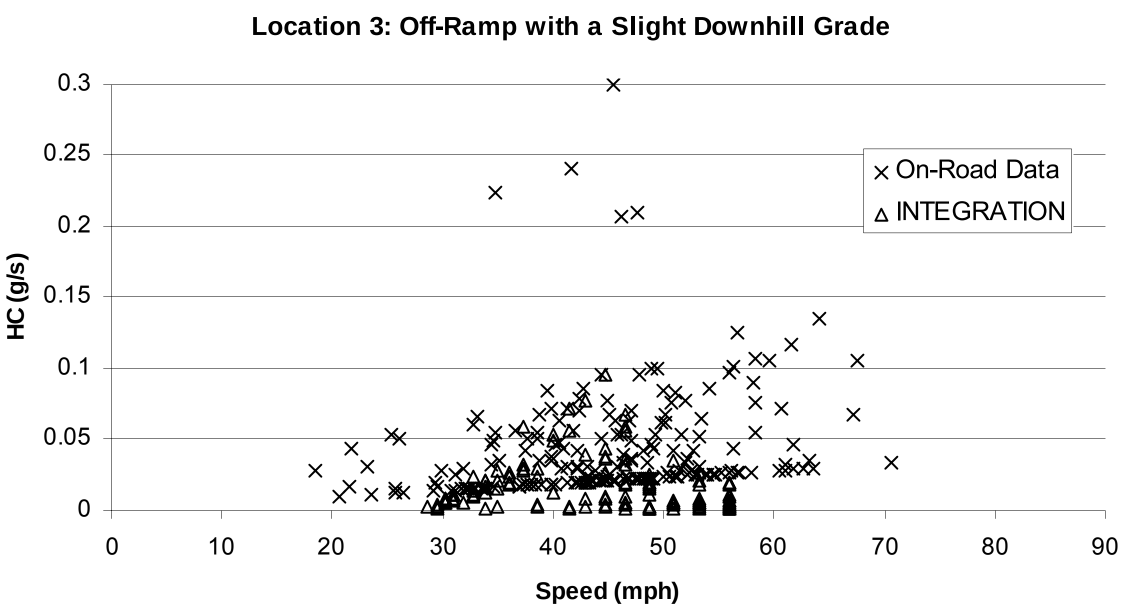

Figure 10 Comparison of Emission HC at Location 3

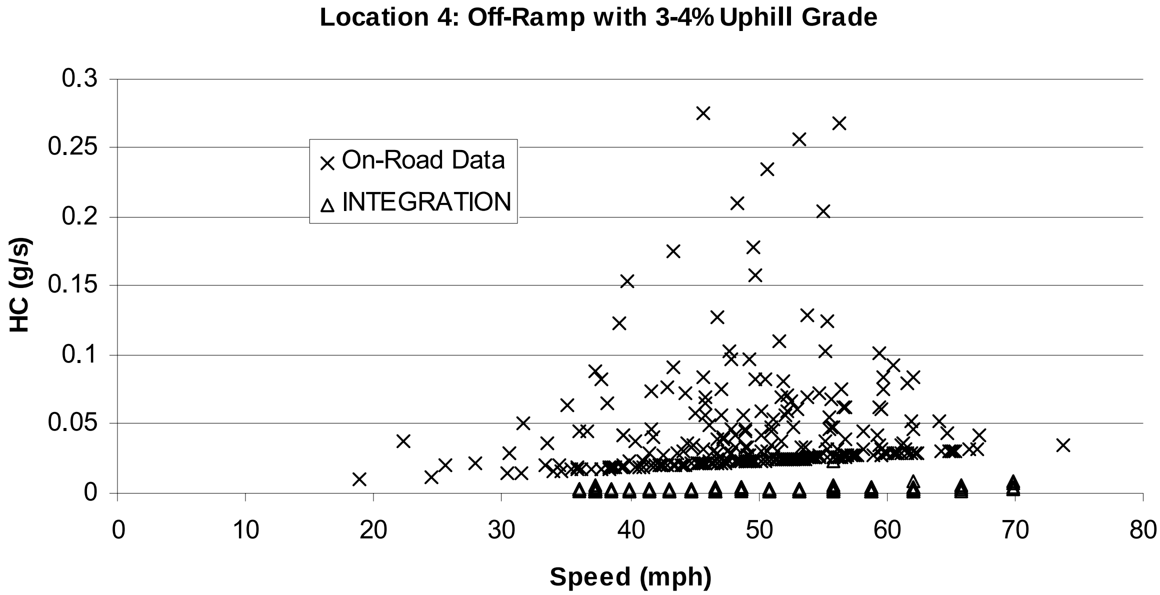

Figure 11 Comparison of Emission HC at Location 4

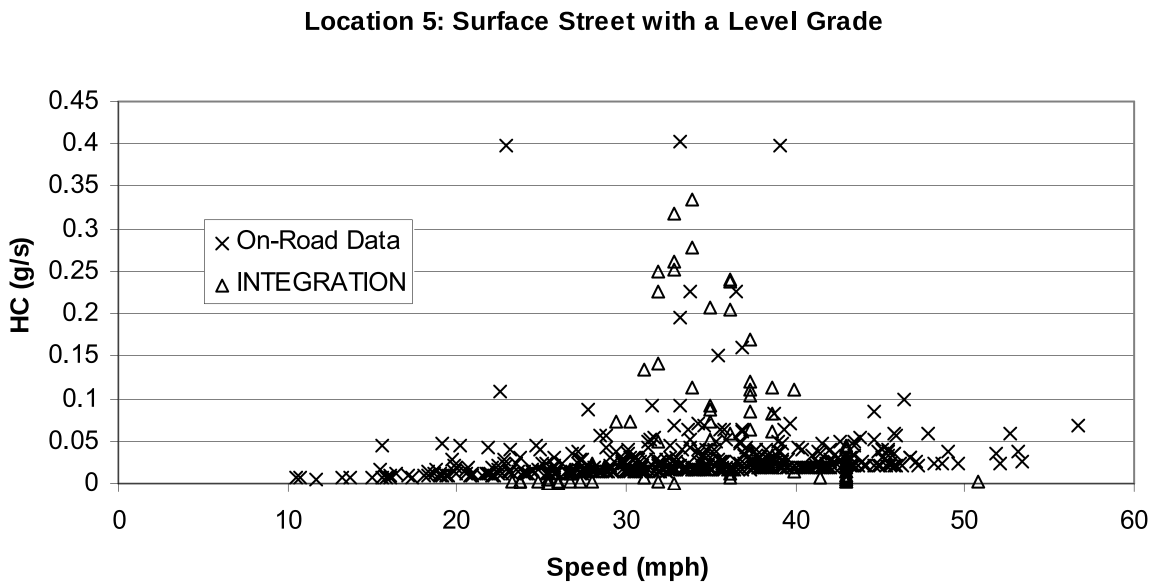

Figure 12 Comparison of Emission HC at Location 5

CALIBRATION OF EMISSION MODELS

The first step of calibrating emissions model is to classify vehicles into groups for each of which a unique set of models can be developed. The reason to classify vehicles is that distinguishable characteristics exist between different types of vehicles and these characteristics cannot be identified without classification of vehicles. In addition, it is impossible to develop an emission model for each type of vehicles existing for each manufacturer, made year, etc. Given a classification of vehicles, the second step is to develop emission models for each class of vehicles. The following sections describe these two steps one by one.

Vehicle Classification

Vehicle class

Obviously, it is difficulty to develop an emission model to each type of vehicles, which are characterized by different manufacturing and operational features. Based on the vehicle classifications adopted in the CE-CERT study and MOBILE5, the vehicles in this study were classified based on vehicle weight, made year, and emitter type, which has been shown in Table 7. With regard to vehicle weight, the vehicles can be classified into LDGV, LDGT1, and LDGT2 with specifications as follows:

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

As shown in Table 7, vehicles are classified into four groups in terms of high emitter (HE) types. As defined in the study of CE-CERT*, the first type of high emitter*, the fuel-air ratio is chronically lean or goes lean in transient operation calling for moderate-power. An average 2% or more lean is likely to saturate the catalyst with oxygen. For this type of high emitter, CO and HC emissions are typically low, but the NOx emissions are high, relative to emissions of clean vehicles. *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 emitters* 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 made year have different emission characteristics, reflected as having different number of emitter categories. For LDGV with made year less than 75, all the vehicles can be viewed as one category in terms of emissions performance, which is same as the made year group of (76-80). For LDGV with made year groups (81-86), (87-90), and (91-93), however, four high emitter categories plus one normal category can be classified. For LDGV with made year group (94-97), only two high emitter categories plus one normal category are provided. For LDGT1 with made year group less than 81, all the vehicles can be viewed as one class. For LDGT1 with made years groups (81-86) and (87-90), four high emitter categories are classified with one normal category. For made year group (91-93), there is no category for high emitter type 2. For made year group (94-97), there are no categories of high emitter type 2 and type 4. For LDGT2 with made year group of less than 93, there is only category. For made year group (94-97), two categories are classified, which are normal and high emitter type 1. The reason for not classifying a made year group into a certain emitter type is that the percentage of the corresponding vehicles is very low in the whole vehicle population.

Percentages of Vehicle Classes

Given the vehicle classification presented in Table 7, the proportion of each class, as presented in Table 8, was calculated based on the vehicle made year distributions and the emitter type distributions. The vehicle made year percentages was provided in MOBILE5, as shown in Table 9, and the emitter type distribution was provided in CE-CERT, as listed in Table 10. Specifically, the derivation of the class proportion follows three steps. First, the percentages in Table 9 were added up for the made year contained in a corresponding made year group. Second, the derived percentages derived in Step 1 are multiplied by the emitter type percentages provided in Table10. Third, there are some types of high emitter vehicles within a certain range of made year whose testing data are not available in the CE-CERT data set. The fractions of these types of vehicles are very small. In calculating the proportion for these types of vehicles, we distributed the corresponding percentages derived in Step 2 evenly over the other high emitter types in the same made year group.

Table 7 Vehicle Classification

	Made Year Group	***Emitter Type***
i	j	k
LDGV	**Less than 75**	One category
	(75-80)	One category
	(81-86)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(87-90)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(91-93)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(94-97)	Normal, HE Type 1, HE Type 2
LDGT1	**Less than 81**	One category
	(81-86)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(87-90)	Normal, HE Type 1, HE Type 2, HE Type 3, HE Type 4
	(91-93)	Normal, HE Type 1, HE Type 3, HE Type 4
	(94-97)	Normal, HE Type 1, HE Type 3
LDGT2	**Less than 94**	One category
	(94-97)	Normal, HE Type 1

Table 8 Percentages of Vehicle Classification

	Made Year Group	*Emitter Type*				
i	j	k				
LDGV	**Less than 75**	0.013013				
	(76-80)	0.049049				
	(81-86)	0.064414	0.014835	0.014835	0.055435	0.039820
	(87-90)	0.134685	0.013054	0.013054	0.027144	0.018027
	(91-93)	0.220440	0.005572	0.005572	0.006783	0.004118
	(94-97)	0.287427	0.003226	0.003226	0	0
LDGT1	**Less than 81**	0.107677				
	(81-86)	0.074686	0.023764	0.017200	0.064275	0.046169
	(87-90)	0.091376	0.009559	0.008716	0.018416	0.012230
	(91-93)	0.192343	0.006341	0	0.007398	0.005073
	(94-97)	0.307777	0.003141	0	0.003141	0
LDGT2	**Less than 93**	0.731343				
	(94-97)	0.264627	0.00403	0	0	

Table 9 Vehicle Percentage Provided in MOBILE5

Made Year	LDGV	LDGT1	*LDGT2*
97	0.049049	0.062812	0.053731
96	0.079079	0.083749	0.071641
95	0.083083	0.083749	0.071641
94	0.082082	0.083749	0.071641
93	0.084084	0.083749	0.071641
92	0.081081	0.068794	0.051741
91	0.077077	0.058824	0.049751
90	0.056056	0.043868	0.033830
89	0.050050	0.035892	0.053731
88	0.051051	0.030907	0.030845
87	0.050050	0.029910	0.027860
86	0.054054	0.052841	0.079602
85	0.047047	0.046859	0.083582
84	0.037037	0.045862	0.048756
83	0.024024	0.035892	0.038806
82	0.019019	0.027916	0.029850
81	0.014014	0.016949	0.017910
80	0.015015	0.021934	0.022885
79	0.011011	0.016949	0.017910
78	0.008008	0.013958	0.014925
77	0.006006	0.008973	0.008955
76	0.005005	0.007976	0.007960
75	0.004004	0.007976	0.008955
74	0.003003	0.004985	0.005970
73	0.010010	0.024925	0.025870

Table 10 Emitter Type Distribution Listed in CE-CERT

Made Year Group	Normal	HE Type 1	HE Type 2	HE Type 3	HE Type 4
(81-86)	0.33	0.106	0.076	0.284	0.204
(87-86)	0.65	0.069	0.063	0.131	0.087
(91-93)	0.91	0.022	0.023	0.028	0.017
(94-97)	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 special power for engine. Such regressions can be expressed as follows:

$$e_{i,j,k,m}(t) = \Big[\beta_0 + \beta_V V(t) + \beta_{V^2} V^2(t) + \beta_{V^3} V^3(t) + \beta_{T'} T'(t) + \beta_{T''} T''(t) + \beta_{A_1} A(t) + \Lambda + \beta_{A_{t-9}} A(t-9) + \beta_W W(t)\Big]_{i,j,k,m} \quad (1)$$

where:

i	=	1, 2, and 3 for vehicle type of LDGV, LDGT1, and LDGT2 respectively,
j	=	vehicle made 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 made year category i and j. Table 7 shows that this category is also different for different vehicle made year category.
m	=	emission type 1, 2, and 3 for CO, HC, NOx respectively.
$e_{i,j,k_i,m}(t)$	=	type m emission for vehicle type i, made 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 (An et al. 1997) as presented below:

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

where:

M	=	the vehicle mass with appropriate inertial correction for rotating and reciprocating parts (kg),
g	=	the gravitational constant (9.81 $m/m/s^2$), and
θ	=	the road grade angle.

Note that acceleration or deceleration in the Equation (1) has been converted, where the grade has been taken account by the following equation:

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

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

It has been realized 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 and shown in Figure 13, 14, and 15. Here, the results shown on these figures were obtained based on the LDGV whose made year group is (81-86) and is the first high emitter type. From the figures, it can be seen that it is the acceleration or deceleration of some time periods ago, not the acceleration/deceleration at current time, that has the most obvious impact on the current emissions. In addition, the patterns of the impact are not 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 and denoted as $A(t), \ldots, A(t-9)$. In addition, variables are introduced to represent the extent, or the duration, that an acceleration/ deceleration has been continuously executed since they are exercised 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) (Barth, et al. 2000):

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

Since Specific Power multiplied by the vehicle mass is the kinetic power, Specific Power actually measures kinetic energy used during a driving episode.

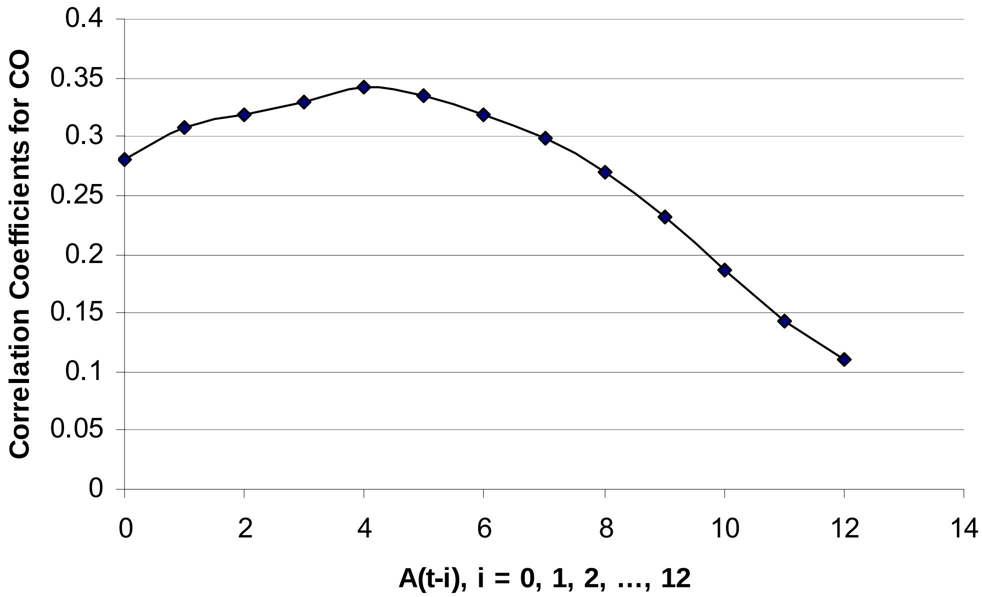

Figure 13 Correlation between Emission CO and Accelerations or Decelerations in Previous Time Periods

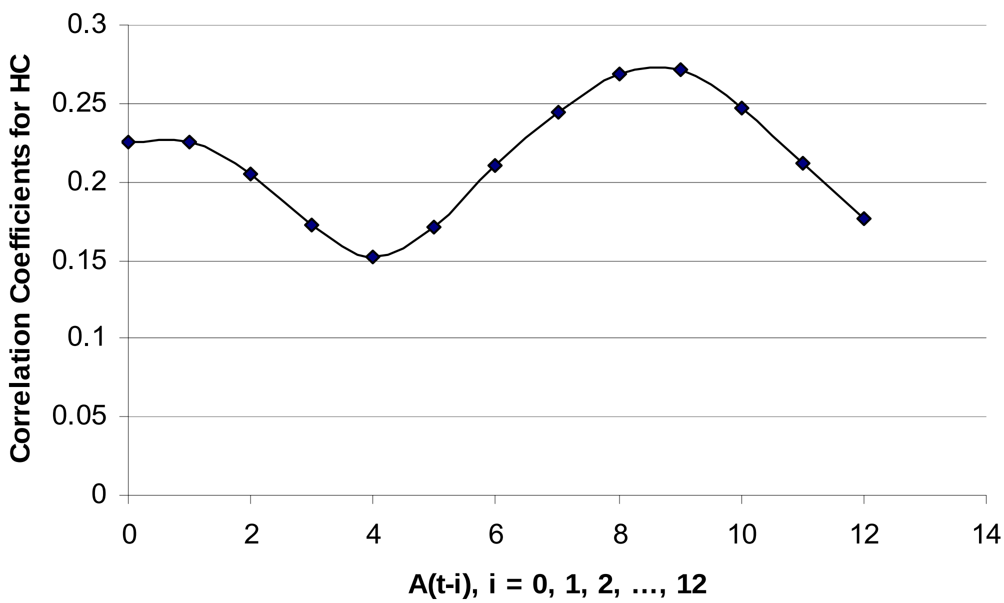

Figure 14 Correlation between Emission HC and Accelerations or Decelerations in Previous Time Periods

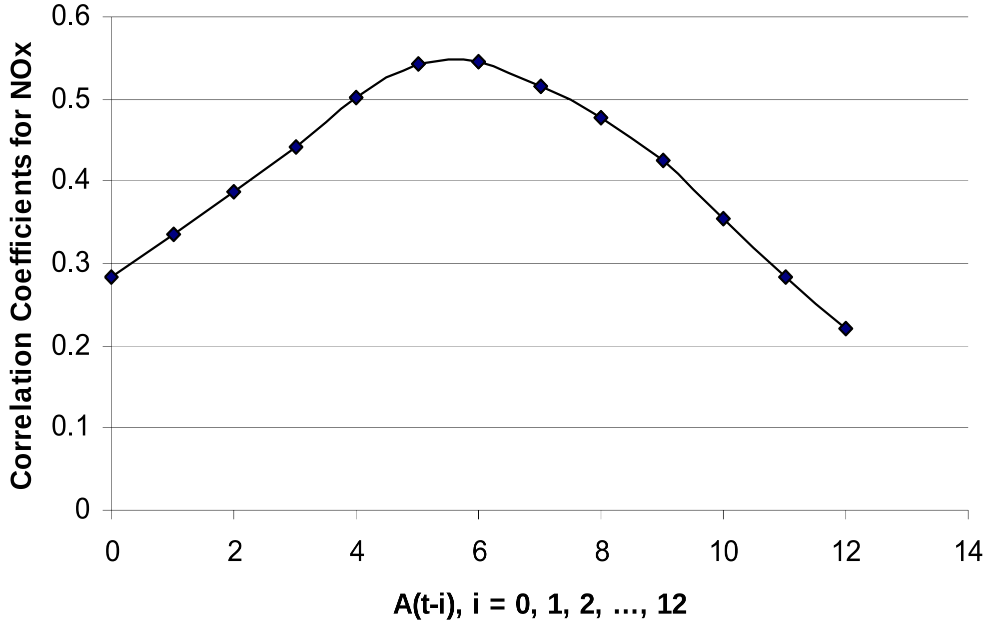

Figure 15 Correlation between Emission NOx and Accelerations or Decelerations in Previous Time Periods

For easily tabulating the calibration results in the following sections, each emission function was symbolized in Table 11, where m in Equation (1) for emission type is ignored.

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

Table 11 Emission Function Symbolization

	Made Year Group	***Emitter (HE) Type***
i	j	k
LDGV	**Less than 75**	$e_{1,1,1}$
	(76-80)	$e_{1,2,1}$
	(81-86)	$e_{1,3,1}$, $e_{1,3,2}$, $e_{1,3,3}$, $e_{1,3,4}$, $e_{1,3,5}$
	(87-90)	$e_{1,4,1}$, $e_{1,4,2}$, $e_{1,4,3}$, $e_{1,4,4}$, $e_{1,4,5}$
	(91-93)	$e_{1,5,1}$, $e_{1,5,2}$, $e_{1,5,3}$, $e_{1,5,4}$, $e_{1,5,5}$
	(94-97)	$e_{1,6,1}$, $e_{1,6,2}$, $e_{1,6,3}$
LDGT1	**Less than 81**	$e_{2,1,1}$
	(81-86)	$e_{2,2,1}$, $e_{2,2,2}$, $e_{2,3,3}$, $e_{2,2,4}$, $e_{2,2,5}$
	(87-90)	$e_{2,3,1}$, $e_{2,3,2}$ $e_{2,3,3}$, $e_{2,3,4}$, $e_{2,3,5}$
	(91-93)	$e_{2,4,1}$, $e_{2,4,2}$, $e_{2,4,3}$, $e_{2,4,4}$
	(94-97)	$e_{2,5,1}$, $e_{2,5,2}$, $e_{2,5,3}$
LDGT2	**Less than 93**	$e_{3,1,1}$
	(94-97)	$e_{3,2,1}$, $e_{3,2,2}$

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 EMISSION MODEL

The calibrated emission models were validated in microscopic and macroscopic levels in this study. For validation, the emissions estimated from the emission models were compared with raw data that were not used for calibration. In this study, both microscopic and macroscopic evaluations were based on second-by-second emissions. In the microscopic evaluation, the emissions derived from emission models for a speed profile that was used to test for a given vehicle with known vehicle type, made year, and higher emitter type are compared with in-lab emissions data. In the macroscopic evaluation, however, the emissions derived from the simulation models incorporated with developed emission models were compared with on-road emission data. The objective of the macroscopic evaluation is not to see a one-to-one close 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 of estimated emission data to see whether they can match those presented in the on-road data. By conducting the microscopic evaluation, the accuracy of emission estimates for each individual vehicle class defined in this study can be examined. After the macroscopic evaluation, the accuracy of the emission estimates can be investigated from an overall perspective.

Microscopic Evaluation

Specifically, in the microscopic evaluation, the emissions were estimated with inputs of a speed profile for a specific vehicle class. They were compared with the raw data collected in the CE-CERT study. The validation employed the criterion of the Rooted Mean Squared Errors (RMSE), 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 represents the type of emissions for vehicle class specified by i, j, and k.

Two classes of vehicles, as listed in Table 14, were chosen in the microscopic validation. As described in previous chapters, the vehicle classification adopted in this study is different from that in the CE-CERT study. As a result, the vehicles classified in one class in this study may not be included in a same class in the CE-CERT study. Therefore, for sake of consistency, this study only chose two classes of vehicles from the CE-CERT where the included vehicles are also included in a same class in this study. In addition, it should be known that the emission models developed in this study were based on data set of FTP cycle because all of the vehicles have been tested based on this cycle in the CE-CERT study. To conduct the validation, as shown in Table 14, we utilized emission data from the MEC or US06 cycles. Note that the CE-CERT study tested all the vehicles based on 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 emission data are not available for them and they cannot be used for emission model validation in this study. As a result, we chose the emission data for the 314th vehicle tested based on the US06 cycle and that for the vehicles tested based on the MEC cycle in the CE-CERT study. As indicated in Table 15, RMSE values of Poly's model are all in the range of satisfactory approximation to raw data and thus indicate a good validation of the model.

In addition to the validation by comparing the estimated results with the raw emission data, the performance of the Poly's models were compared with that of the CMEM model developed in the CE-CERT study, and that of the INTEGRATION emission model.

According to Ahn et al. (1997), the emission models adopted in INTEGRATION take a form as follows:

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

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, and
V(t)	=	speed (m/s) at time t.

The parameters in Equation (5) have been provided in Ahn et al. (1997), and are listed in Table 16.

This study found that the INTEGRATION emission models sometimes produce unrealistic large emissions values. It is because the emissions in Equation (5) have been taken logarithmic transformation to make sure the estimated emissions are positive. As it turns out, however, this transformation may produce vary large emission values when acceleration become large such that the emission results are distorted. Thus, the results from comparing with the INTEGRATION emission model were not presented in this study.

Table 15 shows that most of the RMSE values derived for Poly's model are smaller than that for the CMEM model. This implies that Poly's model performs better than the CMEM 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 Less than 75	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 Less than 81	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

Table 16 Model Parameters for the Emission 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

Macroscopic Level Evaluation

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

Given this development of model integration, emissions can be derived for vehicles passing a point in a study area. By calibrating the INTEGRATION simulation model based on the 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 is referred to as macroscopic evaluation. In this evaluation, the comparison is not based on a one-to-one relationship between the emissions. Rather, the evaluation is based on the trends and ranges presented in the estimated and collected emissions. A consistency observed between the trends and ranges indicates a validation of the estimation against the raw data.

There are several reasons for not taking a one-to-one comparison approach for simulated and on-collected emission data in macroscopic validation. First, the vehicles measured on-road for emissions cannot be identified for details such as emitter types. One the other hand, emitter type is a vehicle classification level adopted in the emission 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 such a detail as categorized in emission model development. To conquer this limitation of simulation model, the emission derived from the simulation model is designed as an average value where the composite of vehicles within the top level of vehicle classification is taken into account. Specifically, the operation of averaging is based on the following equation:

$$e_{i,m}(t) = \sum_{j}\sum_{k} e_{i,j,k,m}(t) \cdot P_{i,j,k} \ , \qquad (6)$$

where i denotes vehicle type of LDGV, LDGT1, and LDGT2, respectively. $P_{i,j,k}$ denotes percentage of vehicle with made 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 of each types of vehicles.

Here, to have a consistent comparison, 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 is synthesized based on national average values.

Different from the microscopic evaluation where an evaluation criterion is employed, the microscopic validation was only based on visual observation of the data displayed in charts. To do the validation, the emissions calculated from the emission model are displayed in a chart versus the speed at current time interval. By clustering the data points on the chart, the trend and range of the emissions versus speed can be observed. A visual judgement can be made to see whether this trend and range are consistent to those reflected by the on-road data. A good match between them indicates a good validation of the model to the raw data.

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

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

The validation of Poly's model can also be supported by the following observations. Comparing to the emission results from CMEM model, the emissions CO and HC estimated by Poly's models have a close match to the on-road data. Actually, the CMEM model always has some irregular emission estimates that are far beyond the range of emissions laid out by the on-road data. These irregular emissions estimates would 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 taken based on national level reflected the conditions of the locations where the emissions were collected on-road. This implication suggest 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 in both the microscopic and macroscopic levels. In the microscopic level, Poly's model can produce emissions with discrepancies from raw data in a satisfactory range. In the macroscopic level, Poly's model has a good match to the on-road data. Thus, it can be concluded that Poly's model was well validated.

CONCLUSIONS AND FUTURE STUDY NEEDS

In this study, nonlinear regression models were developed to take into account factors of acceleration or deceleration and grade, which are not considered in MOBILE5 model and not well modeled by some existing microscale emission models. The dependent variables in the nonlinear regression models are CO, HC, and NOx. To fully capture the dynamics of acceleration/deceleration, not only the acceleration or deceleration of the current time period is included in the independent variables, but also those of previous time periods. In addition, the duration since acceleration or deceleration has been exercised is also included as independent variables. The factor of grade was considered in the models by using the grade to adjust the values of acceleration or deceleration. Besides these independent variables, variables representing tractive power were 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 special factor that is a product of speed and acceleration or deceleration. With this modeling approach, the validation results show that the emission model developed in this study can produce a close match to the raw data in both microscopic and macroscopic levels.

It can be observed from Figures16 to 25, there are always some data points of on-road emissions that are laid on top of the charts and 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 only based on the data of FTP that was used in MOBILE5 but not updated to reflect the aggressive driving patterns in the current times. By including some emission data of other deriving cycles tested in the CE-CERT study, the performance of the Poly's model could be improved in this regard.

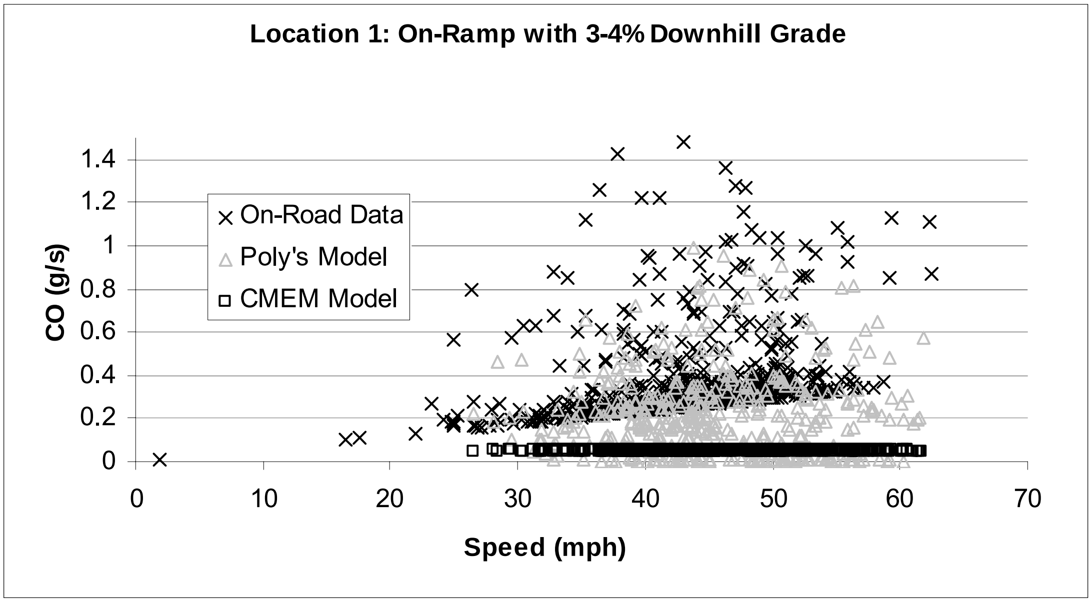

Figure 16 Emission CO vs. Speed at Location 1

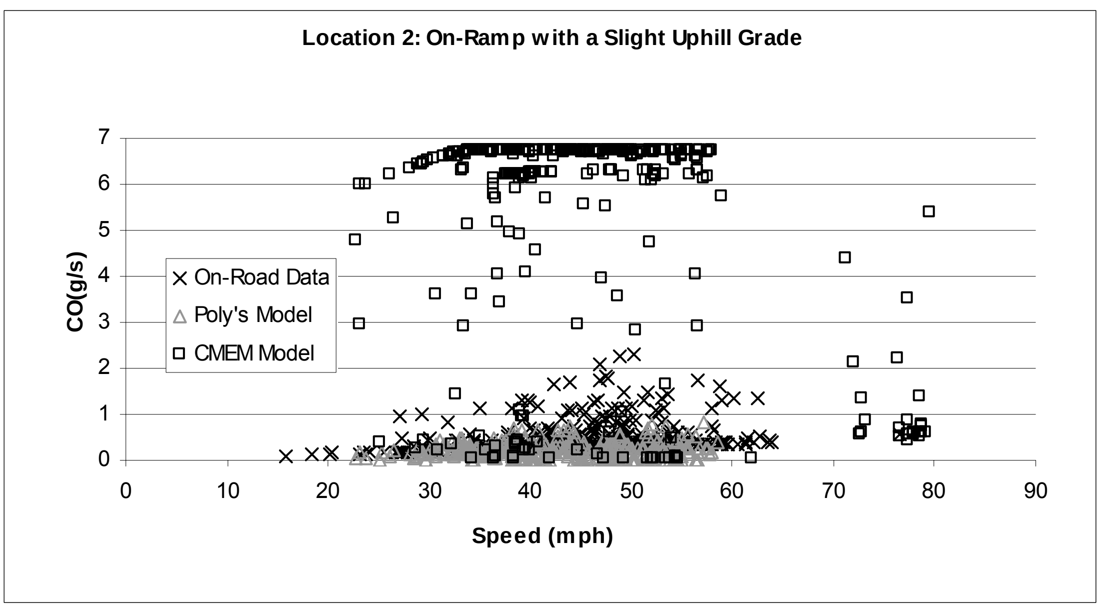

Figure 17 Emission CO vs. Speed at Location 2

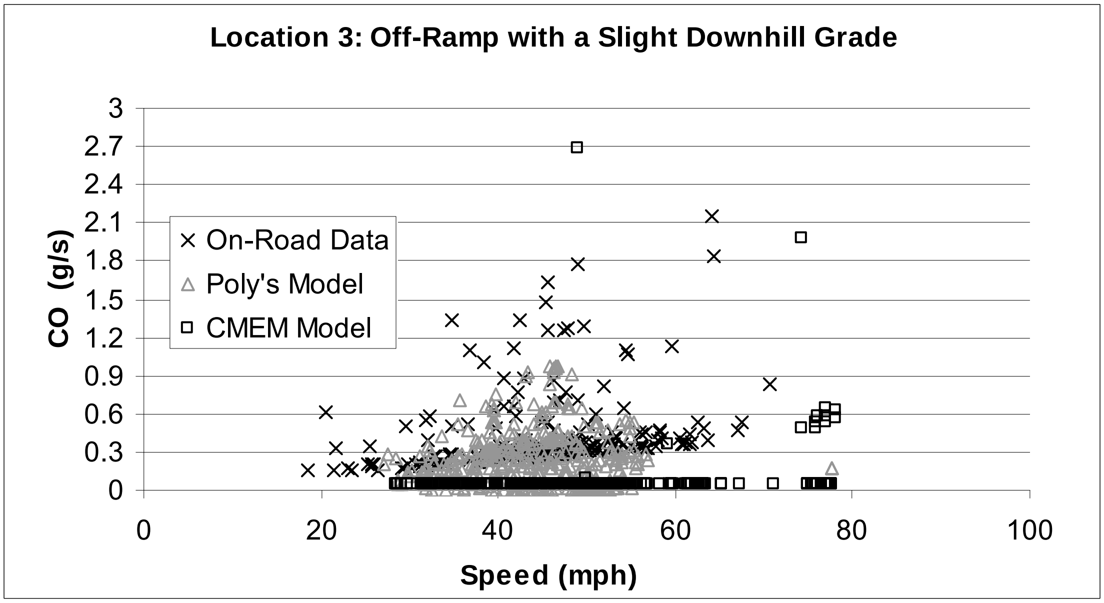

Figure 18 Emission CO vs. Speed at Location 3

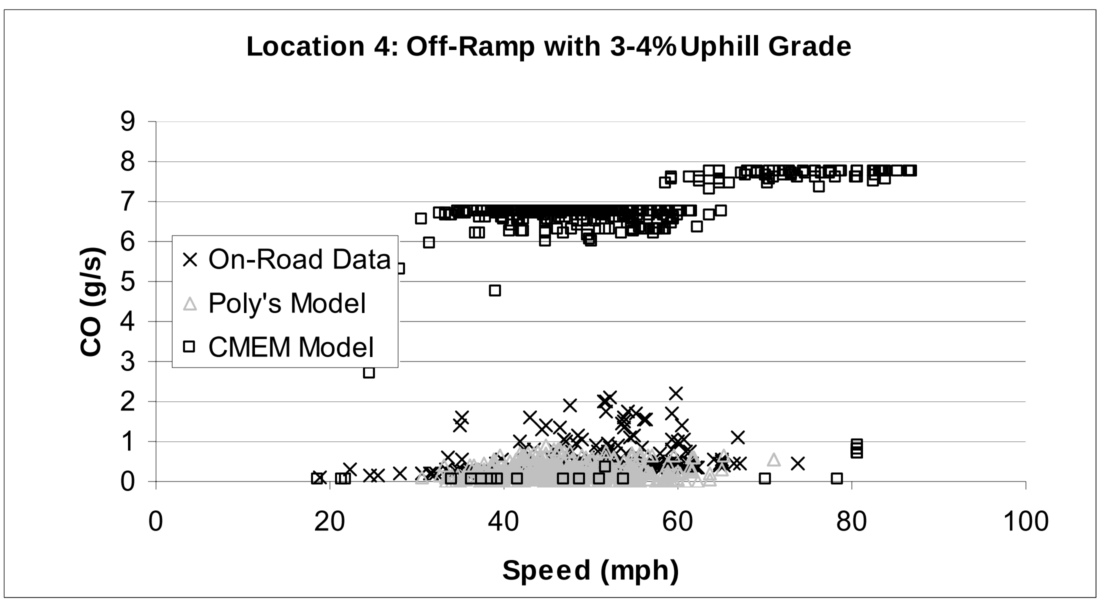

Figure 19 Emission CO vs. Speed at Location 4

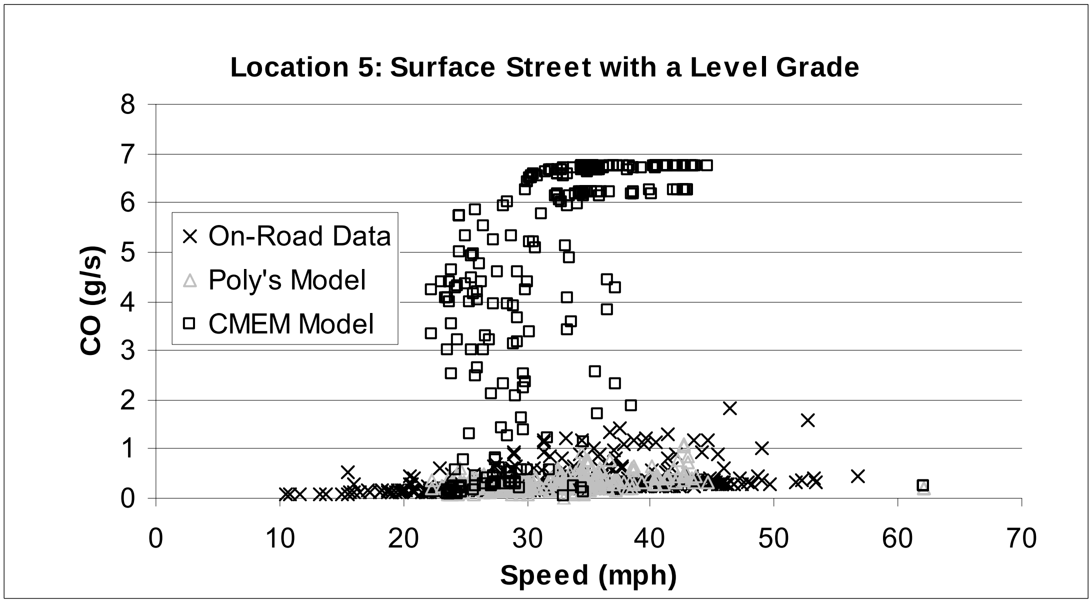

Figure 20 Emission CO vs. Speed at Location 5

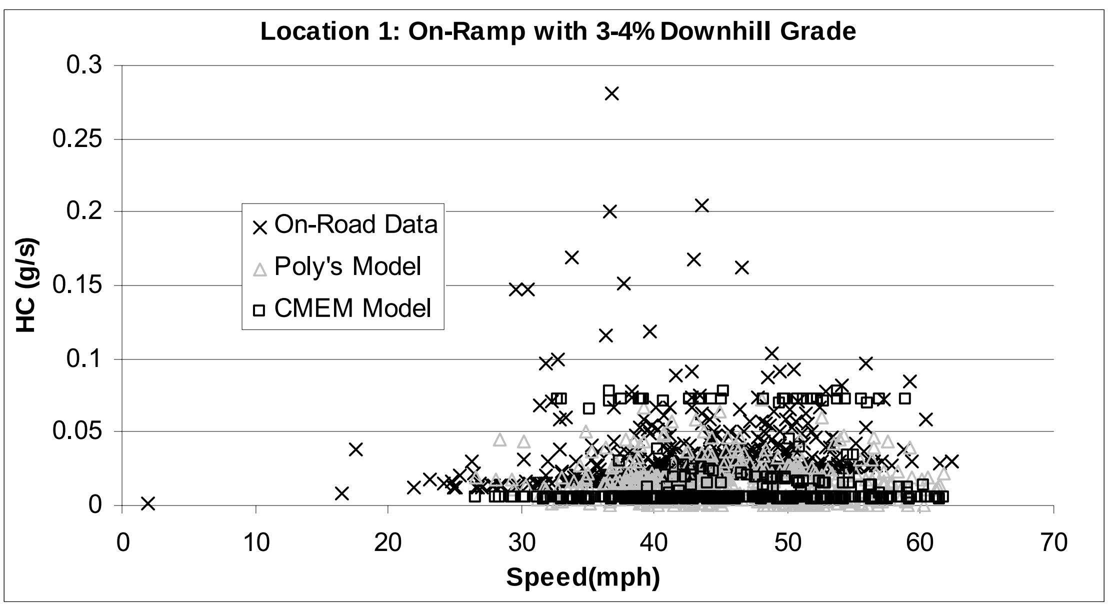

Figure 21 Emission HC vs. Speed at Location 1

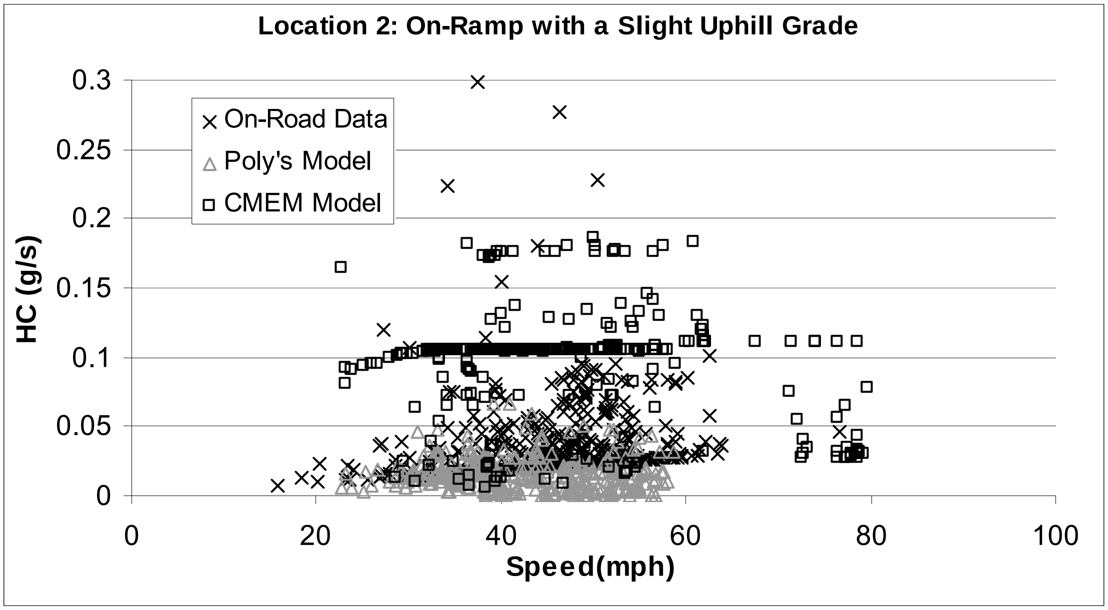

Figure 22 Emission HC vs. Speed at Location 2

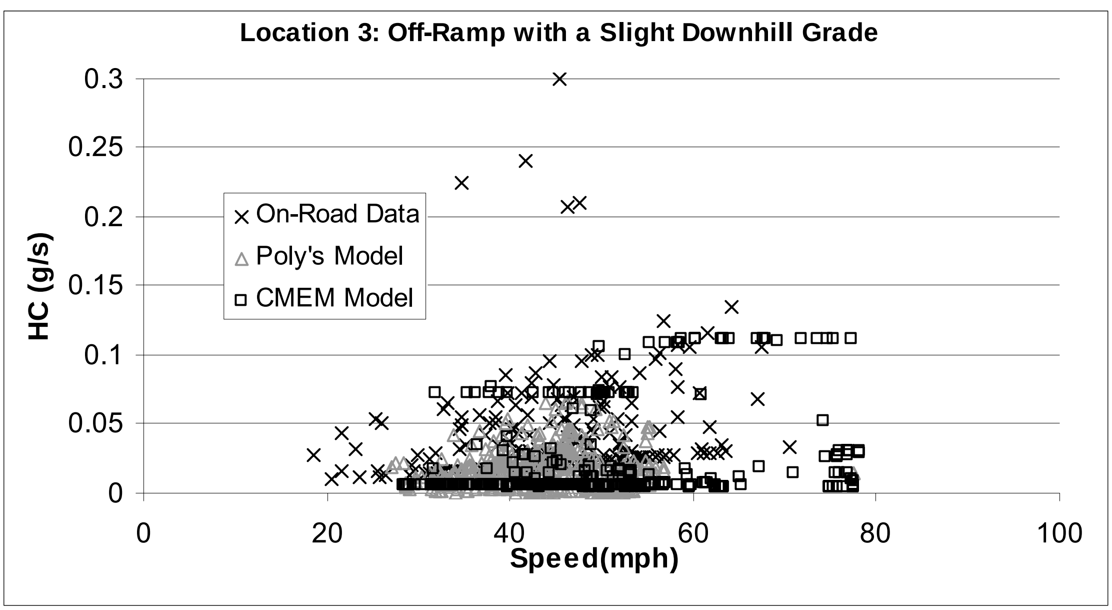

Figure 23 Emission HC vs. Speed at Location 3

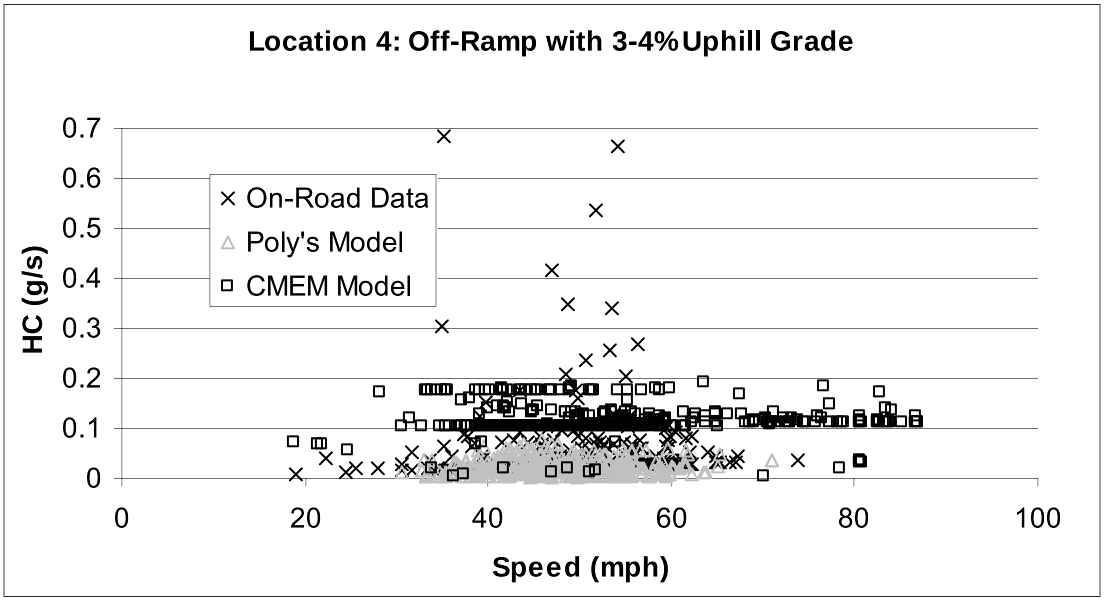

Figure 24 Emission HC vs. Speed at Location 4

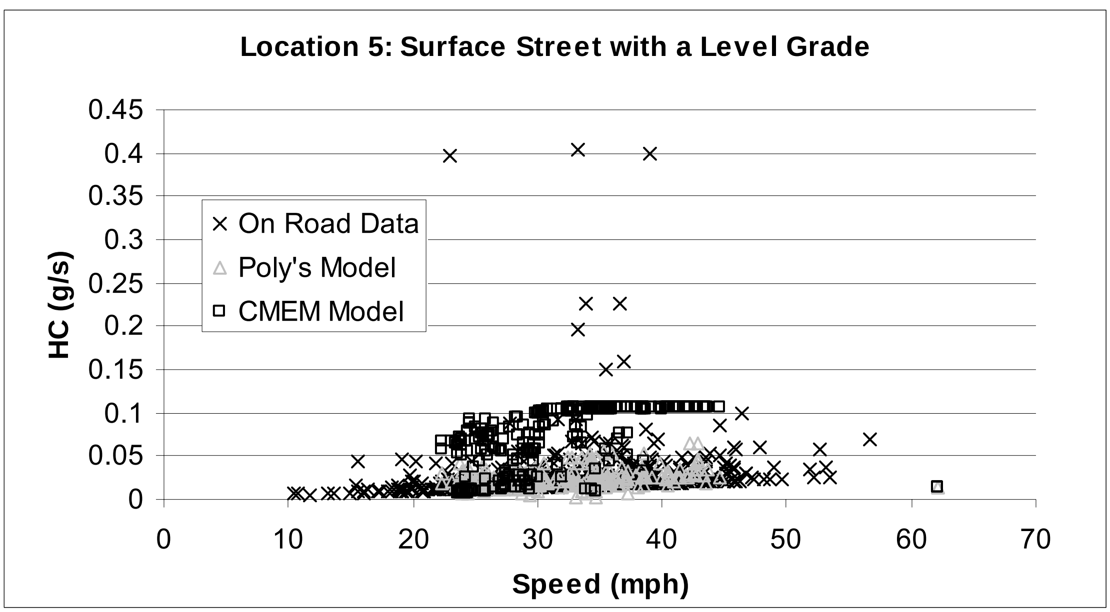

Figure 25 Emission HC vs. Speed at Location 5

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APPENDIX 1: INTERFACE MANUAL

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

1. Prepare running INTERGRATION

The 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 was provided with this manual. For detailed information about INTERGRATION, you need to refer to the manual of INTERGRATION, which is also provided with the product.

2. Specify vehicle percentage

In Poly's emission model, three types of vehicles were classified in terms of vehicle weight: Light Duty Gasoline vehicle (LDGV), Light Duty Gasoline Trucks (LDGT1), and Light Duty Gasoline Trucks (LDGV2). These three vehicle classes are further broken down in terms of made-year of the vehicles. According to Figure 26, you need to specify the percentage for each class of vehicles. Otherwise, the Interface will assume you take the default values as presented in Figure 26.

As shown in Figure 26, you need to click on menu "vehicle Age." A screen as the one shown in the lower part of Figure 26 will prompt up.

3. Map Vehicle Types

   It should be noted that the vehicle classification specified for the purpose of emission modeling is different from those adopted in INTEGRATION. Thus, you need to specify which class in INTEGRATION corresponds to a class in emission models. Figure 27 shows an interface for keying the correspondence.

4. Run 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 the menu of INTEGRATION. Figure 28 demonstrates the running of INTEGRATION.

5. Read INTERGRATION Output

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

6. Compute Emissions

   After you obtain the needed data from INTEGRATION, you can calculate the emissions based on the emission models developed in this study. The calculation can be done by clicking on the "Compute Emission", as shown in Figure 30.

7. Display Emissions Results

   The emission results can be displayed to the users by clicking "Show Result". The emissions shown in Figure 31 are actually vehicle by vehicle. If you key in –1 for “link no” or “vehicle ID”, 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 as you specified.

8. Inquire 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.

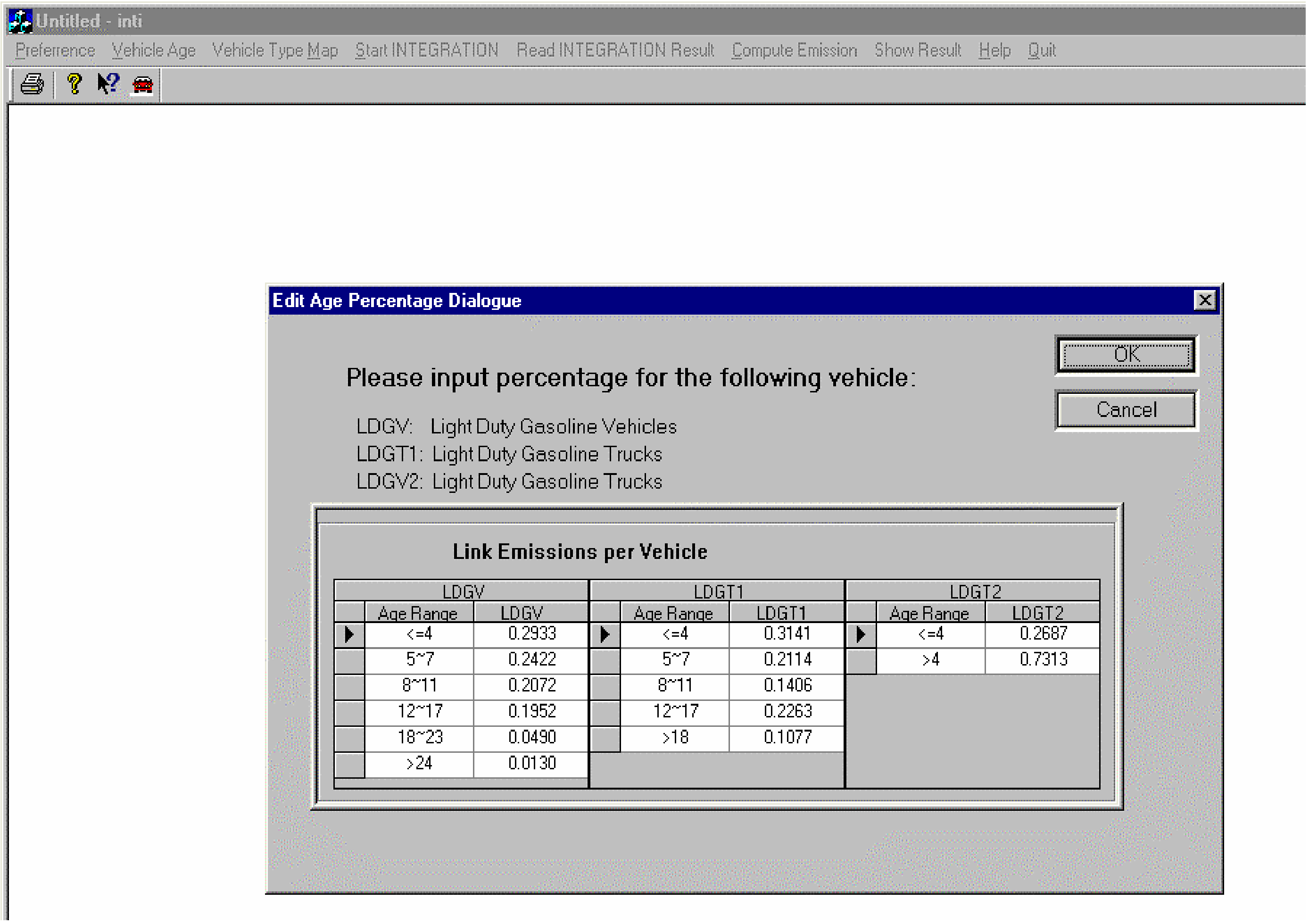


Figure 26 Interface for Inputting Vehicle Proportions

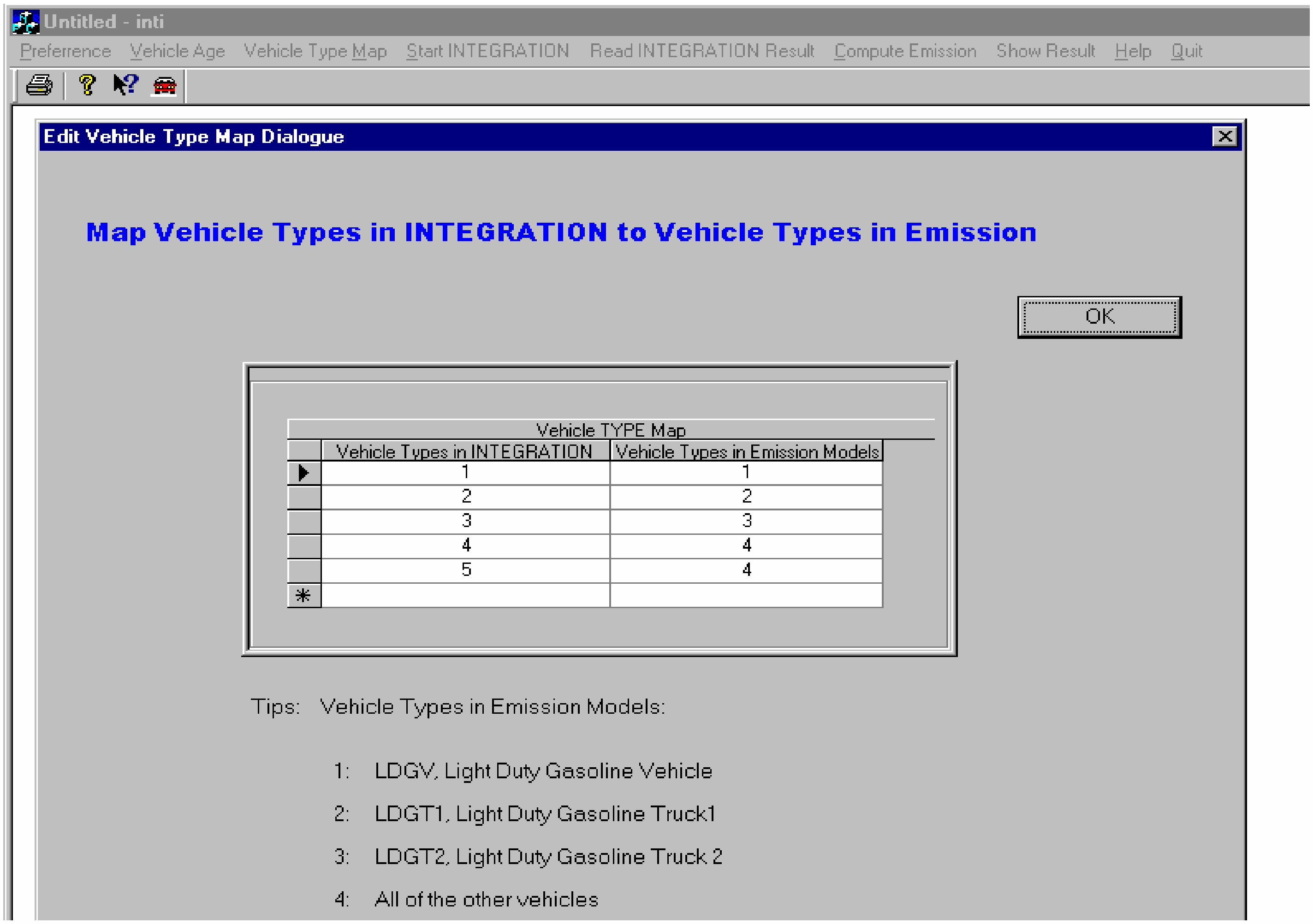


Figure 27 Interface for Mapping Vehicle Types in INTEGRATION to Vehicle Classes Specified in Poly's Emission Model

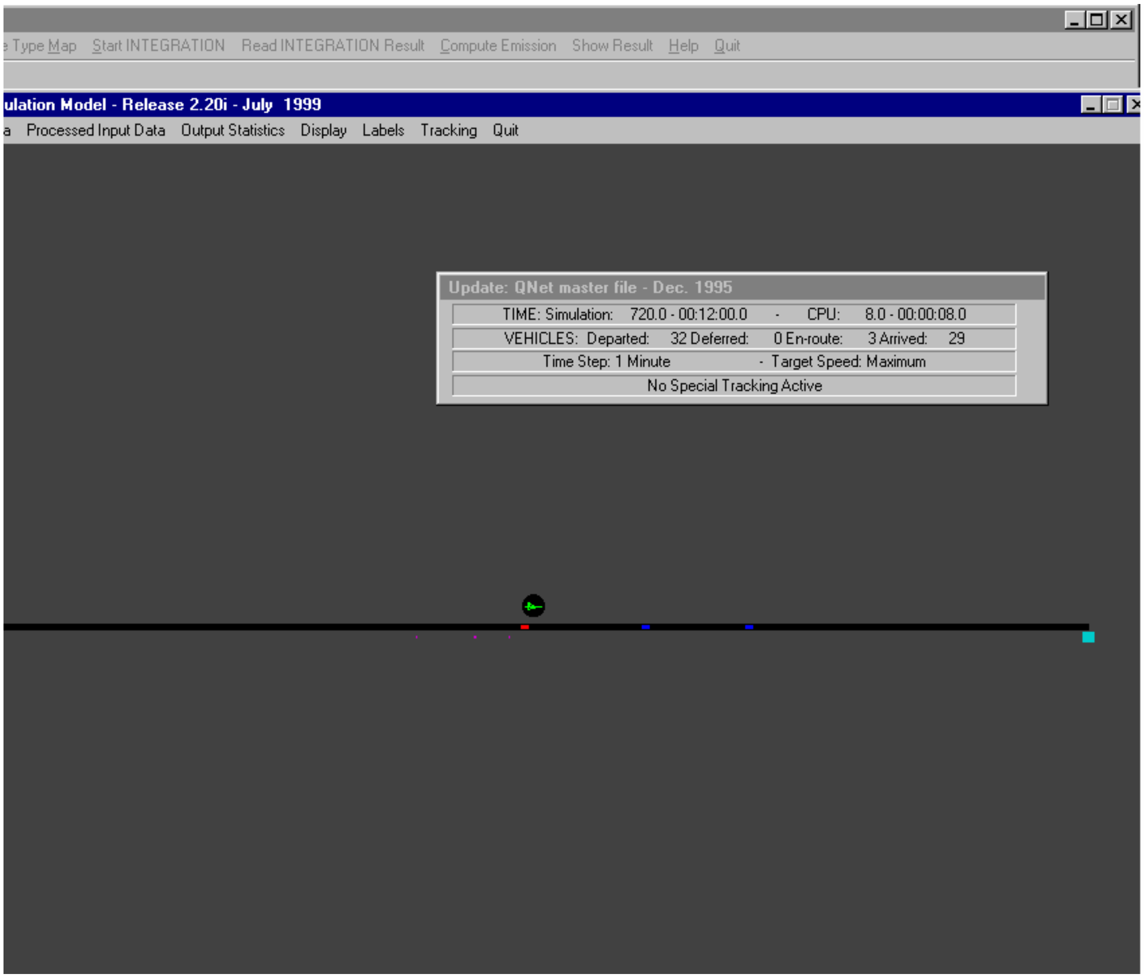


Figure 28 Interface Showing the Running of INTEGRATION

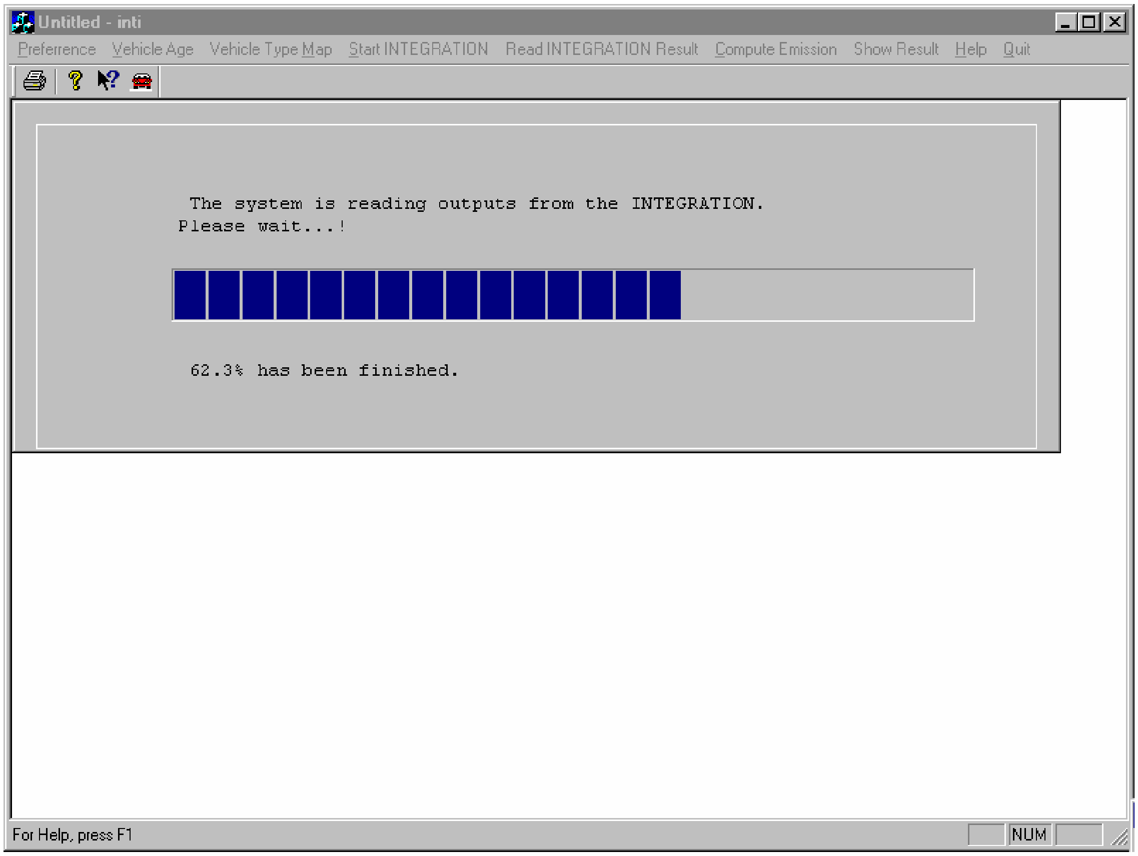


Figure 29 Interface Showing Reading Output from INTEGRATION

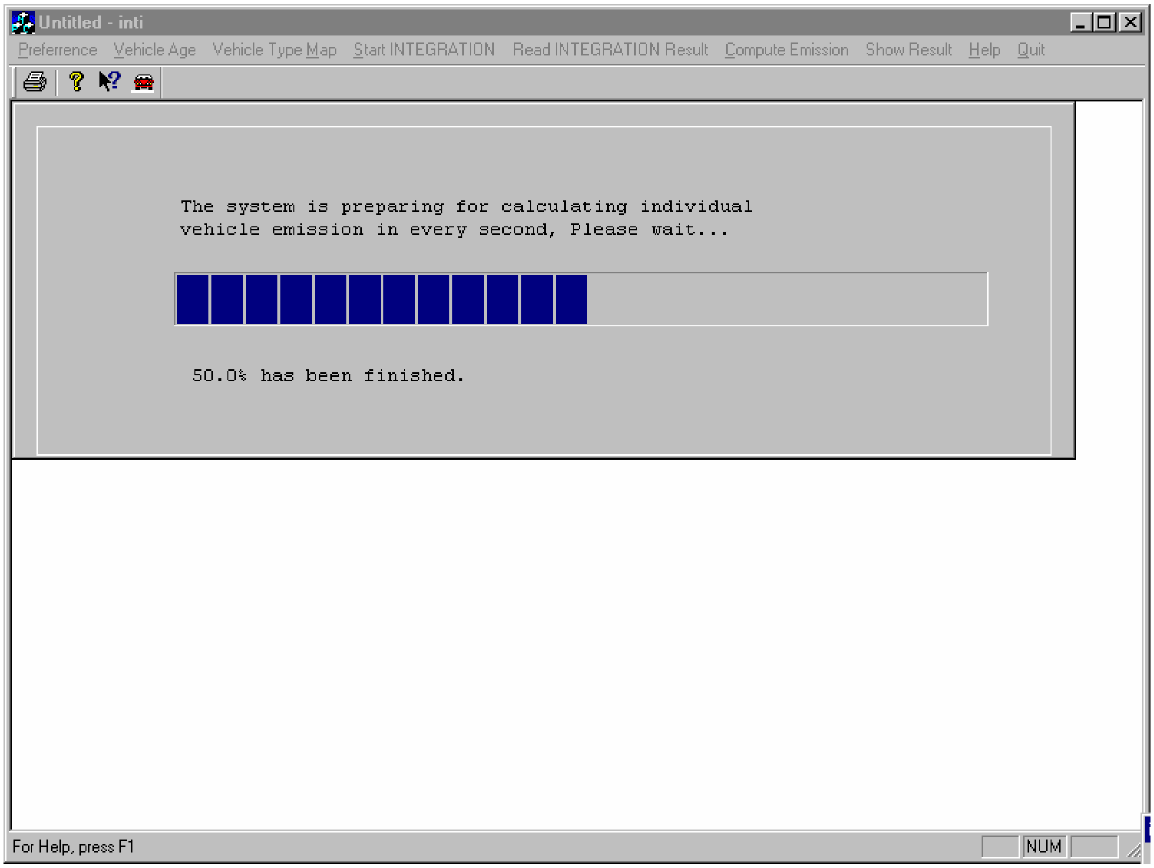


Figure 30 Interface Showing Converting Output from INTEGRATION to Ploy's Emission Models and Doing the Calculation

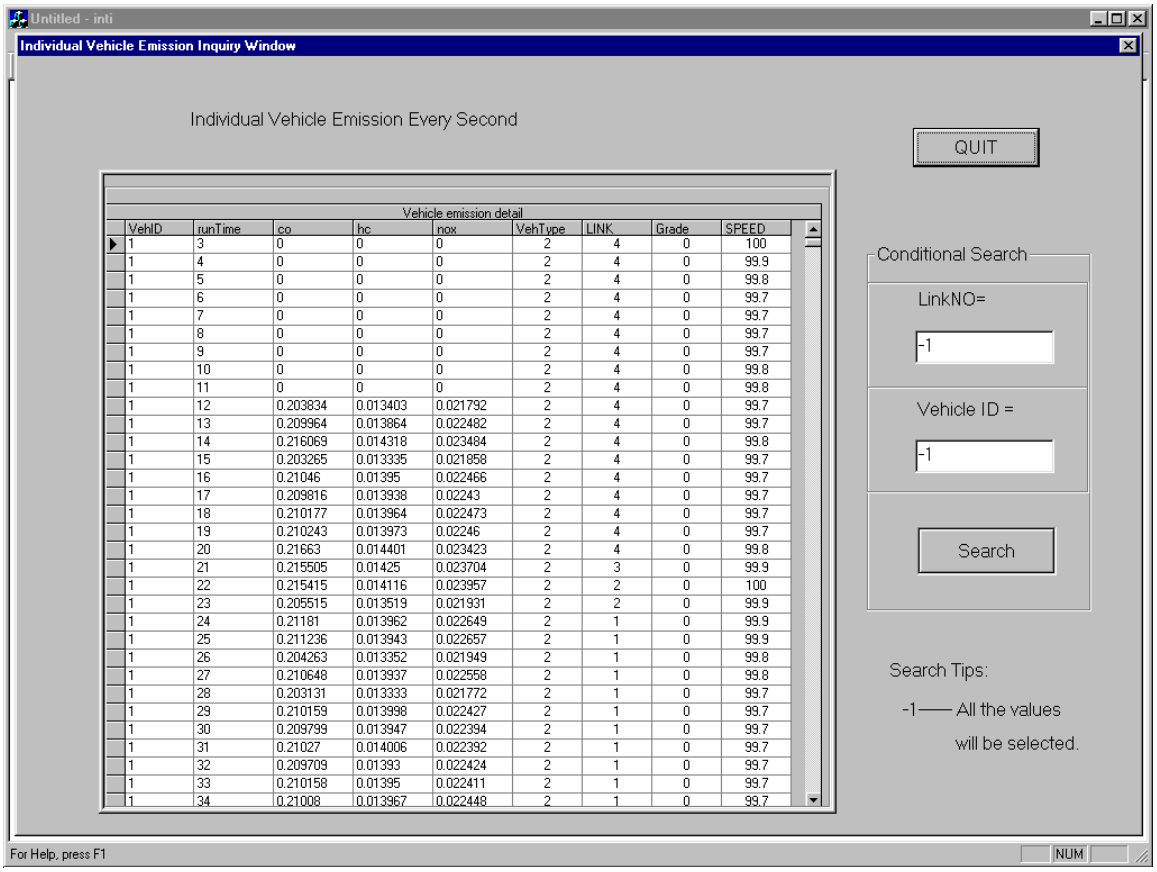
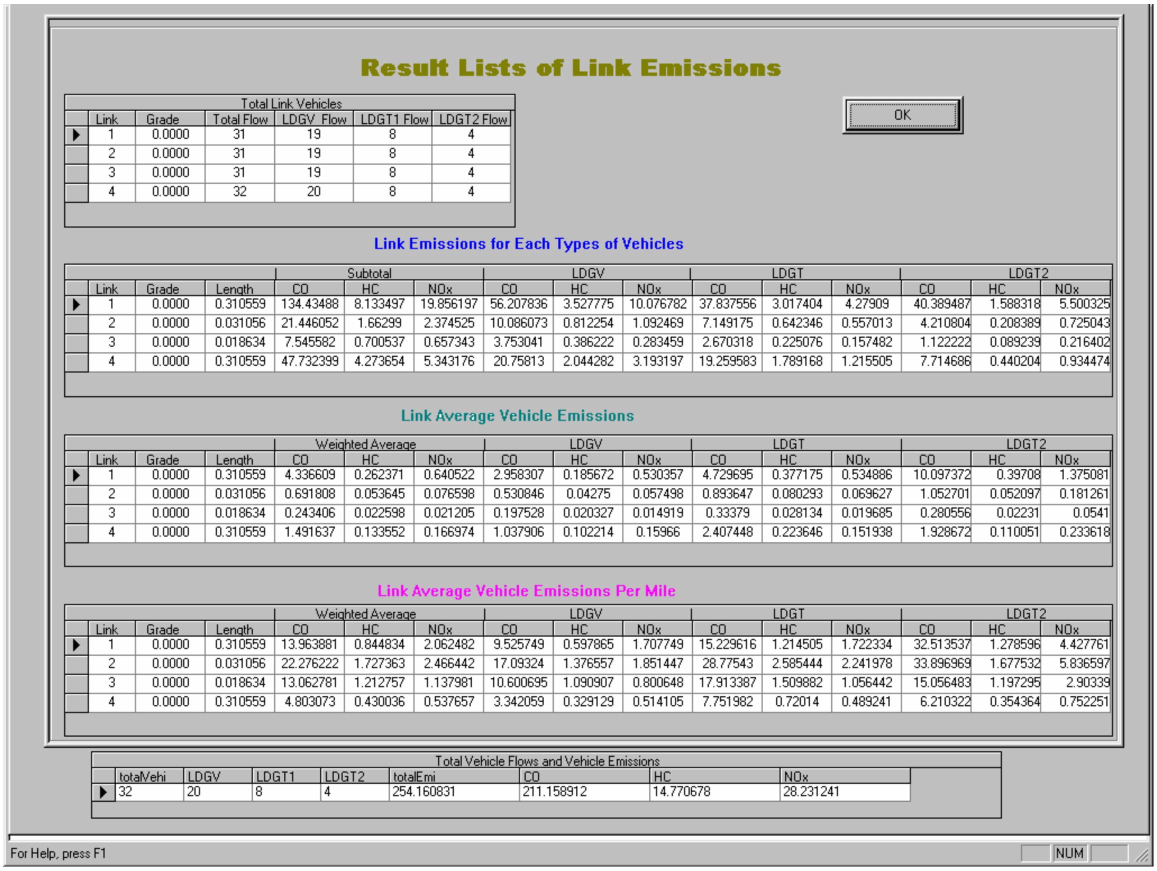


Figure 31 Interface Showing the Emissions of Each Individual Vehicles



Result Lists of Link Emissions

OK

Total Link Vehicles					
Link	Grade	Total Flow	LDGV Flow	LDGT1 Flow	LDGT2 Flow
1	0.0000	31	19	8	4
2	0.0000	31	19	8	4
3	0.0000	31	19	8	4
4	0.0000	32	20	8	4

Link Emissions for Each Types of Vehicles

			Subtotal			LDGV			LDGT			LDGT2		
Link	Grade	Length	CO	HC	NOx	CO	HC	NOx	CO	HC	NOx	CO	HC	NOx
1	0.0000	0.310559	134.43488	8.133497	19.856197	56.207836	3.527775	10.076782	37.837556	3.017404	4.27909	40.389487	1.588318	5.500325
2	0.0000	0.031056	21.446052	1.66299	2.374525	10.086073	0.812254	1.092469	7.149175	0.642346	0.557013	4.210804	0.208389	0.725043
3	0.0000	0.018634	7.545582	0.700537	0.657343	3.753041	0.386222	0.283459	2.670318	0.225076	0.157482	1.122222	0.089239	0.216402
4	0.0000	0.310559	47.732399	4.273654	5.343176	20.75813	2.044282	3.193197	19.259583	1.789168	1.215505	7.714686	0.440204	0.934474

Link Average Vehicle Emissions

			Weighted Average			LDGV			LDGT			LDGT2		
Link	Grade	Length	CO	HC	NOx	CO	HC	NOx	CO	HC	NOx	CO	HC	NOx
1	0.0000	0.310559	4.336609	0.262371	0.640522	2.958307	0.185672	0.530357	4.729695	0.377175	0.534886	10.097372	0.39708	1.375081
2	0.0000	0.031056	0.691808	0.053645	0.076598	0.530846	0.04275	0.057498	0.893647	0.080293	0.069627	1.052701	0.052097	0.181261
3	0.0000	0.018634	0.243406	0.022598	0.021205	0.197528	0.020327	0.014919	0.33379	0.028134	0.019685	0.280556	0.02231	0.0541
4	0.0000	0.310559	1.491637	0.133552	0.166974	1.037906	0.102214	0.15966	2.407448	0.223646	0.151938	1.928672	0.110051	0.233618

Link Average Vehicle Emissions Per Mile

			Weighted Average			LDGV			LDGT			LDGT2		
Link	Grade	Length	CO	HC	NOx	CO	HC	NOx	CO	HC	NOx	CO	HC	NOx
1	0.0000	0.310559	13.963881	0.844834	2.062482	9.525749	0.597865	1.707749	15.229616	1.214505	1.722334	32.513537	1.278596	4.427761
2	0.0000	0.031056	22.276222	1.727363	2.466442	17.09324	1.376557	1.851447	28.77543	2.585444	2.241978	33.896969	1.677532	5.836597
3	0.0000	0.018634	13.062781	1.212757	1.137981	10.600695	1.090907	0.800648	17.913387	1.509882	1.056442	15.056483	1.197295	2.90339
4	0.0000	0.310559	4.803073	0.430036	0.537657	3.342059	0.329129	0.514105	7.751982	0.72014	0.489241	6.210322	0.354364	0.752251

Total Vehicle Flows and Vehicle Emissions							
totalVehi	LDGV	LDGT1	LDGT2	totalEmi	CO	HC	NOx
32	20	8	4	254.160831	211.158912	14.770678	28.231241

For Help, press F1 NUM

Figure 32 Interface Showing Emissions for Each Links of Network

APPENDIX 2: AN APPLICATION OF INTEGRATION

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

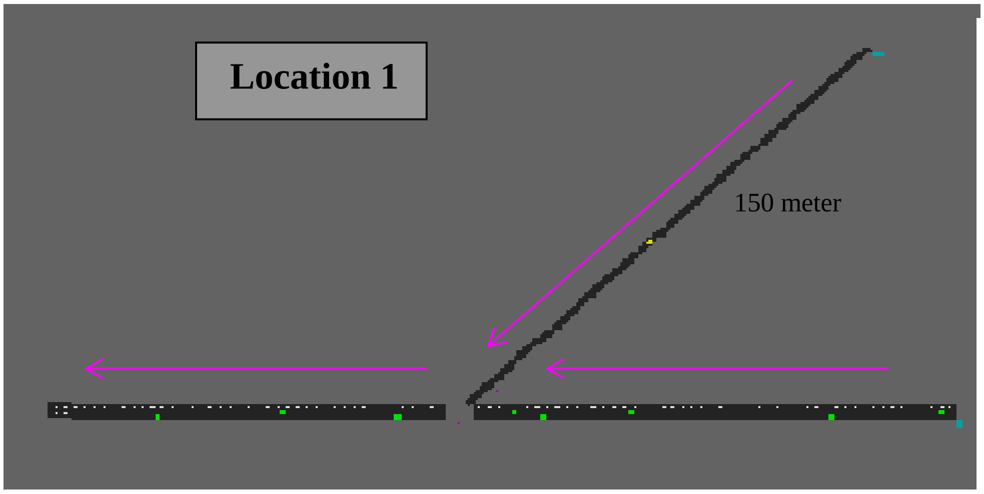


Figure 33 On-Ramp at Location 1

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