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16. Abstract

The development of advanced infrared remote emission sensing technology brings us a cost-effective and convenient instrument for collecting on-road vehicle exhaust emissions. A research project sponsored by Texas Department of Transportation (TxDOT 0-1485) collected 5000+ on-road emission and modal traffic data using a Remote Emission Sensor (RES) in Houston, and established a series of modal emission models for estimating on-road vehicle emissions. One of the major findings in the TxDOT 0-1485 project was that High Emitter Vehicles (HEV) were included in the collected on-road emission data, which were not significant in quantity, but might pose considerable effects on the quality of the emission models. This research intends to examine the effects of high emitter vehicles on the emission modeling. The research attempts to establish a series of emission regression equations based on different cutting percentages of HEV data. This emission modeling process is based on the notion that the resulting emission models will eventually be modified by incorporating a correction factor to represent the real-world on-road vehicle emissions. The developed emission regression equations are evaluated to determine how the cutting percentages affect the quality of emission models. They are also compared with MOBILE and EMFAC to find out if the emission factor models have effectively captured the effects of high emitter vehicles.

It is found that high emitter vehicles do have significant effects on the emission models. Removing the small portion of HEV data will considerably improve the quality of the emission models. Further, it is found that both MOBILE and EMFAC considerably underestimate the on-road emissions, and therefore these models have not adequately considered the effects of high emitter vehicles in the emission estimation.

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EFFECTS OF HIGH EMITTER VEHICLES ON THE ON-ROAD VEHICLE EMISSION MODELING

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ABSTRACT

The development of advanced infrared remote emission sensing technology brings us a cost-effective and convenient instrument for collecting on-road vehicle exhaust emissions. A research project sponsored by Texas Department of Transportation (TxDOT 0-1485) collected 5000+ on-road emission and modal traffic data using a Remote Emission Sensor (RES) in Houston, and established a series of modal emission models for estimating on-road vehicle emissions. One of the major findings in the TxDOT 0-1485 project was that High Emitter Vehicles (HEV) were included in the collected on-road emission data, which were not significant in quantity, but might pose considerable effects on the quality of the emission models. This research intends to examine the effects of high emitter vehicles on the emission modeling. The research attempts to establish a series of emission regression equations based on different cutting percentages of HEV data. This emission modeling process is based on the notion that the resulting emission models will eventually be modified by incorporating a correction factor to represent the real-world on-road vehicle emissions. The developed emission regression equations are evaluated to determine how the cutting percentages affect the quality of emission models. They are also compared with MOBILE and EMFAC to find out if the emission factor models have effectively captured the effects of high emitter vehicles.

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EXECUTIVE SUMMARY

The rapid development and deployment of various Intelligent Transportation Systems (ITS) technologies nationwide represent an unprecedented opportunity to reduce congestion and mobile source emissions, and thus help in meeting the federal conformity requirements, especially for non-attainment areas. One of the key factors to the successful application of ITS technologies to improving air quality lies in the accurate estimation of emission reductions that would be achieved through various advanced traffic control and management strategies. To this end, a modal emission model that can well-reflect the effects of a vehicle's modal events, such as acceleration, deceleration, cruise speed, and idling, on vehicle emissions is needed. Such an emission model should be designed in such a way that it can be readily incorporated into a dynamic traffic simulation or a general traffic modeling framework. In other words, the emission model should be designed for traffic engineering purposes.

There are three major vehicle exhaust emission species that directly contribute to air pollution: Carbon Monoxide (CO), HydroCarbon (HC), and Oxides of Nitrogen (NOx). For some time, the estimation of these emissions has relied heavily on the Environmental Protection Agency (EPA) approved mobile source emission factor models MOBILE (US EPA, 1991) and EMFAC (CARB, 1996). EMFAC is used in California only because the state has stricter environmental standards than other states. MOBILE and EMFAC emission factor models are widely used to evaluate numerous air quality planning functions, but require the average speed as the sole descriptor of a vehicle's modal events and driving conditions. This input requirement of average speed corresponds to a specific series of defined driving cycles, such as the Federal Test Procedure (FTP) urban driving cycle and highway economy driving cycle. An emission factor model is used to produce the emission factors (in grams per mile) of CO, HC, and NOx for various vehicle classifications based on more specific inputs of ambient temperature, model and calendar year, fuel volatility and operating mode.

MOBILE and EMFAC emission factor models are essentially insensitive to a vehicle's modal events, such as acceleration/deceleration, cruise and idling. Thus, they cannot be used to effectively evaluate the traffic control and management strategies that are aimed at reducing vehicle emissions. These models offer little help for evaluating operational improvements that smooth traffic flow through better ramp metering, signal coordination, incident management, High Occupancy Vehicle (HOV) lane operation, and various Intelligent Transportation Systems (ITS) applications. In addition, the emission factors in MOBILE and EMFAC are derived from the FTP driving cycles of in-laboratory emission testing, which are found by many recent researchers to be significantly different from many of today's urban situations (Yu, 1998). Especially, these models' capabilities in representing on-road driving conditions for networks equipped with advanced technologies such as ITS were not extensively investigated.

The development of advanced infrared remote emission sensing technology brings us a cost-effective and convenient instrument for collecting on-road vehicle exhaust emissions. Although initially the Remote Emission Sensor (RES) was proven to be useful in screening for the High Emitter Vehicles (HEV) on the road, there are many advantages to use RES in emission model evaluation and emission model development. This is because the emission data collected by RES will naturally reflect the on-road vehicle fleet combinations and current vehicular technologies. RES is also inexpensive and easy to use compared with the in-laboratory emission testing.

In a research project for the Texas Department of Transportation (TxDOT 0-1485), Yu collected 5000+ vehicle emission records from five locations in Houston using the advanced RES (Yu, 1998a). The data were then used to develop a series of mathematical relationships between emission rates and vehicles' instantaneous speed and acceleration rate (Yu, 1998b). What was found in the development of the on-road emission model was the fact that the on-road emission data have included many high emitter vehicles, which are not significant in quantity but may pose considerable effects on the emission model accuracy and quality. Therefore, there is a need to examine the effects of HEV data on the emission modeling in order to take full advantage of the on-road source of vehicle emission data.

The primary objective of this research is to examine the effects of high emitter vehicles on the emission modeling. The on-road emission data that were collected using the remote emission sensor in Houston are used to establish a series of regression emission equations based on different cutting percentages of HEV data (0%, 10%, 20%, and 30%). The emission rates and emission factors that are generated from the established emission models including the extrapolated idling emission rates are evaluated to determine how the high emitter vehicles affect the emission modeling. Further, the emission models are compared with the emission factors generated by the widely used emission factor models MOBILE and EMFAC.

It is found that high emitter vehicles have significant effects on the emission models. Removing the small portion of the HEV data will considerably improve the quality of the emission models. This is also evidenced by the fact that cutting 20% and 30% of HEV data will not significantly improve the emission models over cutting 10% of HEV data. Further, it is found that both MOBILE and EMFAC considerably underestimate the on-road emissions. Cutting 30% of on-road HEV data still produces much higher emission estimations than MOBILE and EMFAC.

It is noted that if HEV data are removed from the database in developing emission models, there should be a complementary means to include a factor to correct the final emission estimations to reflect the effects of high emitter vehicles. Otherwise, there will be a systematic error in the emission estimations that will have excluded the consideration of HEV data. Therefore, it is recommended that further research be conducted regarding how to incorporate the error correction factor into the emission modeling process.

It is also noted that the emission modeling process in this research has used a very rough vehicle type classification method. However, this should not affect the conclusions regarding how the HEV data will impact the vehicle emission modeling. In any emission modeling effort for real-world applications, vehicle types should be classified either in a similar way to MOBILE, or in other ways that consider more detailed classes of vehicle weight, type, and technologies.

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CHAPTER 1

INTRODUCTION

1-1. Background of Research

The rapid development and deployment of various Intelligent Transportation Systems (ITS) technologies nationwide represent an unprecedented opportunity to reduce congestion and mobile source emissions and thus help in meeting the federal conformity requirements, especially for non-attainment areas. One of the key factors to the successful application of ITS technologies to improving air quality lies in the accurate estimation of emission reductions that would be achieved through various advanced traffic control and management strategies. To this end, a modal emission model that could well-reflect the effects of a vehicle's modal events, such as acceleration, deceleration, cruise speed, and idling, on vehicle emissions is needed. Such an emission model should be designed in a fashion such that it can be readily incorporated into a dynamic traffic simulation or a general traffic modeling framework. In other words, the emission model should be designed for the purpose of traffic engineering studies.

There are three major vehicle exhaust emission species that directly contribute to the air pollutants: Carbon Monoxide (CO), HydroCarbon (HC), and Oxides of Nitrogen (NOx). For some time, the estimation of these emissions has relied heavily on the Environmental Protection Agency (EPA) approved mobile source emission factor models MOBILE (US EPA, 1991) and EMFAC (CARB, 1996). EMFAC is used in California only because the state has stricter environmental standards than other states. MOBILE and EMFAC emission factor models are widely used to evaluate numerous air quality planning functions but require the average speed as the sole descriptor of a vehicle's modal events and driving conditions. This input requirement of average speed corresponds to a specific series of defined driving cycles, such as the Federal Test Procedure (FTP) urban driving cycle and highway economy driving cycle. An emission factor model is used to produce the emission factors (in grams per mile) of CO, HC, and

NOx for various vehicle classifications based on more specific inputs of ambient temperature, model and calendar year, fuel volatility and operating mode.

MOBILE and EMFAC emission factor models are essentially insensitive to a vehicle's modal events, such as acceleration/deceleration, cruise and idling. Thus, they cannot be used to effectively evaluate the traffic control and management strategies that are aimed at reducing vehicle emissions. These models offer little help for evaluating operational improvements that smooth traffic flow through better ramp metering, signal coordination, incident management, High Occupancy Vehicle (HOV) lane operation, and various Intelligent Transportation Systems (ITS) applications. In addition, the emission factors in MOBILE and EMFAC are derived from the FTP driving cycles of in-laboratory emission testing, which are found by many recent studies to deviate significantly from many of today's urban situations. Especially, their capabilities in representing on-road driving conditions for networks equipped with advanced technologies such as ITS were not extensively investigated.

There have been extensive research efforts in the past five years in the area of vehicle emission modeling. The most notable one is the development of a new generation of vehicle emission model by University of California at Riverside (An et. al., 1997, 1998, 1999; Barth, et. al., 1999, 2000). This model is designed to reflect sensitivity to vehicles' modal activities. However, the development of this model has followed a traditional method in the emission data collection: using the in-laboratory emission testing data. Without doubt, the in-laboratory emission testing can provide a pool of accurate and reliable source of emission data. However, there is a major drawback in merely relying on in-laboratory emission testing: testing vehicles are very selective and too limited. It is almost impossible to test all types of vehicles, technologies, ages, etc. at an acceptable level of cost and within a certain time frame. In addition, the model developed by the UC Riverside is still at the test stage and it is still unknown how effectively this model can be used by traffic engineers for performing the microscopic level of emission analysis for advanced traffic control and management strategies.

There are numerous other emission models developed by researchers in the past years including emission estimation in the traffic simulation and optimization models, such as TRANSYT-7F (Penic and Upchurch, 1992), INTEGRATION (Van Aerde, 1999), FREQ (Imada and May, 1985), NETSIM (Rathi and Santiago, 1989), and INTRAS (Wicks and Liebermann, 1980). These traffic simulation/optimization models have incorporated their own emission estimation methods, but none of these methods were tested or validated for the on-road driving vehicles and conditions.

The development of advanced infrared remote emission sensing technology brings us a cost-effective and convenient instrument for collecting on-road vehicle exhaust emissions. Although initially the Remote Emission Sensor (RES) was proven to be useful in screening for the High Emitter Vehicles (HEV) on the road (Bishop et al, 1994; Sorbe, 1995; and Jack et al, 1995), there are many advantages using RES in emission model evaluation and emission model development. This is because the emission data collected by RES will naturally reflect the on-road vehicle fleet combinations and current vehicular technologies. It is also inexpensive and easy to use compared with the in-laboratory emission testing.

In a research project for the Texas Department of Transportation, Yu collected 5000+ vehicle emission data from five highway locations in Houston using the advanced RES (Yu, 1998a). The data were then used to develop a series of mathematical relationships (called ONROAD emission model) between emission rates and vehicles' instantaneous speed and acceleration rate (Yu, 1998b). What was found in the development of the ONROAD emission model was the fact that the on-road emission data included high emitter vehicles, which are not significant in quantity but may pose considerable effects on the model accuracy and quality. Therefore, there is a need to examine the effects of HEV data on the emission modeling in order to take full advantage of the on-road source of vehicle emissions. Such an examination will also benefit other emission modeling efforts by assisting researchers to better understand the role of HEV data in the emission models.

1-2. Objective of Research

The primary objective of this research is to examine the effects of high emitter vehicles on the emission modeling. The emission data to be used in this research were collected from the remote emission sensor for the TxDOT research project (Yu, 1998a). The research will strive to model on-road vehicle emissions based on the data that are derived by cutting different percentages of HEV data from the original emission data sets. Cutting different percentages of the original HEV data results in different levels of quality in the regression models. These models are evaluated as well as compared with MOBILE and EMFAC to determine the effects of HEVs on the emission models.

CHAPTER 2

LITERATURE REVIEW

This chapter will review the state-of-the-art in the vehicle emission modeling. In the past decades, especially in the past five years, numerous emission models have been developed by researchers and various public agencies. The review in this chapter will emphasize the most widely used emission factor models and other emission models, which represent a wide range of efforts in this fast-evolving research area.

2-1. Emission Factor Models

Emission factor models are used to generate emission factors for each emission species, which will be interfaced with travel demand models to calculate the mobile source emissions estimates. Specifically, an emission factor model calculates the emissions of HC, CO and NOx in grams per mile, a travel demand model supplies an estimate of Vehicle Miles of Travel (VMT), and then the total grams of pollutants emitted by vehicles can be calculated by multiplying the emission factors by the VMT. At present, there are two EPA approved emission factor models, MOBILE that is required by EPA to be used by all states but California, and EMFAC, which is used in California only.

MOBILE Emission Factor Model

MOBILE was developed to estimate HC, CO and NOx emission factors for gasoline-fueled and diesel highway motor vehicles. While the version of MOBILE5a has been widely used, the newest version is MOBILE6.

MOBILE calculates emission factors for eight individual vehicle types in two regions (low and high altitude) of the country. Its emission factor estimates depend on various conditions such as ambient temperatures, average travel speed, operating modes, fuel volatility, and mileage accrual rates. MOBILE will estimate emission factors for any calendar year between 1960 and 2020, inclusive. The 25 most recent model years are considered to be in operation in each calendar year.

The eight vehicle types used in MOBILE include light-duty gasoline vehicles (LDGV), light-duty gasoline truck 1 (LDGT1), light-duty gasoline truck 2 (LDGT2), heavy-duty gasoline vehicles (HDGV), light-duty diesel vehicles (LDDV), light-duty diesel trucks (LDDT), heavy-duty diesel vehicles (HDDV), and motorcycles (MC). The MOBILE derives its emission factors by multiplying the Basic Emission Rate (BER) by a series of correction factors that account for various variables. All of the BER equations for light duty vehicles describing emissions as a function of accumulated mileage are based on the 19.6 mph (31.5 km/hr) average trip speed, which corresponds to the FTP urban driving cycle for light-duty vehicles (Code of Federal Regulation 40 Part 86).

The speed correction factors are derived from analysis of emission data taken from tests over driving cycles of different average speeds. The range of average speeds for which MOBILE contains speed correction factors is 2.5 to 65 mph (4.0 to 105 km/hr). The speed correction factors are divided into ranges of average speeds: low speeds, consisting of speeds from 2.5 mph to 19.6 mph; mid-range speeds, from 19.6 mph to 48 mph (77km/hr); and high speeds, from 48 mph to 65 mph. The general shape of the curves describing HC and CO emission as functions of average speed exhibits high g/mi emissions at very low speeds, with emission factors dropping rapidly as average speed increases up to 19.6 mph, then emissions dropping more slowly as average trip speed increases from 19.6 to 48 mph, no change in emissions in the rage 48 to 55 mph (88 km/hr), and finally emissions rising again as average speed increases.

MOBILE utilizes an input file that provides program control information and the data describing the scenarios for which emission factors are to be estimated. The input information consists of three distinct sections: the Control section, the One-time Data section, and the Scenario section. The Control section is the portion of the input file that controls the input, output, and execution of the program. For example, the Control section indicates whether MOBILE will require the user to supply additional input data, or analyze a scenario that includes an inspection and maintenance program, or output the emission factors in a format suitable for visual inspection or in a format suitable as input to another program.

Some parameters used in the emission factor calculations have internal values built into MOBILE. The One-time Data section is the portion of the input that allows the user to define parameter values different from those internal to MOBILE, which will be used in the calculations for all of the scenarios within a given run. For example, in the One-time Data section the user can specify alternate annual mileage accumulation rates or registration distributions by age for each vehicle type. In addition, the One-time Data section allows the user to specify further control program parameters, such as descriptions of inspection and maintenance programs.

The Scenario section is the portion of the MOBILE input that details the individual scenarios for which emission factors are to be calculated. For example, in the Scenario section the user specifies the calendar year of evaluation and the average speed(s) to be assumed. Each MOBILE run can include many scenarios, and each scenario can have different scenario parameters.

MOBILE generates four outputs, the interactive user dialog, which includes all input format specifications, prompting messages, diagnostic messages (errors and warnings), and formatted emission factor report. The formatted emission factor report includes the emission factor information for all the scenarios that were provided in the input file. The resulting emission factors include total HC, exhaust HC, evaporative HC, refueling HC, running HC, resting HC, exhaust CO and exhaust NOx, for each of eight vehicle types as described earlier. These resulting emission factors can be combined with the total vehicle miles of travel, which can be derived from a travel demand model, to produce the final emission estimate for a target traffic network.

EMFAC Emission Factor Model

EMFAC emission factor model was developed by the California Air Resources Board (CARB) and the California Department of Transportation (CALDOT). California is allowed to use EMFAC instead of MOBILE because it has stricter environmental standards than the national standards and EMFAC produces slightly different results. It can generate exhaust and evaporative emission factors of HC, CO, and NOx. It can also estimate emissions for particulate matter from tire wear to exhaust. Its emission factors can be input into the BURDEN model to produce emission inventories.

Two companion models CALIMFAC and WEIGHT provide input to EMFAC in order to generate emission factors. CALIMFAC model produces base emission rates for each model year when a vehicle is new and as it accumulates mileage and the emission controls deteriorate. The WEIGHT model calculates the relative weighting each model year should be given in the total inventory, and each model year's accumulated mileage. The EMFAC uses these pieces of information, along with correction factors and other data, to produce fleet composite emissions factors.

The emission testing procedure for EMFAC emission factors is similar to that for MOBILE emission factors except that emission characteristics of California were considered and incorporated. The EMFAC uses a series of correction factors to simulate non-standard conditions of in-laboratory emission testing. The correction factors that are used to adjust the basic emission rates in EMFAC include fuel correction factors, speed correction factors, cycle correction factors, high emitter correction factors, bag correction factors, and composite emission factors.

The major difference between EMFAC and MOBILE is that EMFAC employs 13 combinations of vehicle classes and technology groups as opposed to only eight vehicle types in MOBILE. The 13 combinations of vehicle classes and technology groups include non-catalyst light-duty autos, catalyst light-duty autos, diesel light-duty autos, non-catalyst light-duty trucks, catalyst light-duty trucks, diesel light-duty trucks, non-catalyst medium-duty trucks, catalyst medium-duty trucks, non-catalyst heavy-duty trucks, catalyst heavy-duty trucks, diesel heavy trucks, diesel urban buses, and motorcycles.

The input data to EMFAC include the calendar year (any year between 1970 and 2020), model year, model year groups, either summer or winter inventory, speed range (3-65 mph), temperature range (30 - 110 F), I/M program on or off and type of output.

The results of the EMFAC calculation can be formulated into one of the two types of output files. The report output file summarizes the data in a tabular format and the impact rates file summarizes the data for each possible combination of inputted parameters.

2-2. Other Emission Models

As indicated previously, MOBILE and EMFAC predict vehicle emissions based in part on average trip speeds and were built upon regression analysis based on FTP defined driving cycles. Since these models are intended to predict emission inventories for large regional areas, they offer little help for evaluating operational improvements that are more microscopic in nature, such as ramp metering, signal coordination, and many ITS applications. What is needed is an emissions model that considers at a more fundamental level, the modal operation of a vehicle such as idle, cruise, and various levels of acceleration/deceleration rates. Numerous research attempts have been made in the past decade to develop such an emission model. This section will review some of selected models in this category.

UC Riverside Modal Emission Model

UC Riverside has developed a comprehensive modal emissions model under sponsorship of the National Cooperative Highway Research Program (NCHRP Project 25-11) (An et al, 1997, 1998, 1999; Barth et al, 1997, 1999, 2000). The overall objective of this project is to develop and verify a comprehensive modal emission model that accurately reflects the impacts of a vehicle's operating mode. The model is comprehensive in the sense that it will be able to predict emissions for a wide variety of Light Duty Vehicles (LDV) in various states of conditions (properly functioning, deteriorated, and malfunctioning).

The UC Riverside emission model is being designed so that it can interface with a wide variety of transportation models and transportation data sets. As part of the modal emission model development, 28 different vehicle/technology categories have been identified and are being implemented in the model. These vehicle/technology categories have been chosen based on vehicle class (car or truck), emission control technology (non-catalyst, 3-way catalyst, etc.), emission standard levels, power-to-weight ratio, and emitter level categories (normal emitter, high emitter).

The conventional emission factor models are based on bag emissions data of FTP driving cycles collected from certification tests of new cars, surveillance programs, and inspection/maintenance programs. These large sets of emissions data provide the basis for the conventional emission inventory models and are indexed primarily by model year. The emission data for the UC Riverside emission model were collected second-by-second from a sample of vehicles to build emissions for the national fleet. The choice of vehicles for this sample is crucial, since only a small sample (300+ vehicles) will be the basis for the model.

The input operating variables in the model include second-by-second speed (from which acceleration can be derived), grade, and accessory use (such as air conditioning). In many cases, grade and accessory use may be specified as static inputs or parameters. In addition, the vehicle soak time and special loads are specified as static input variables.

GIT Emission Model

There is an on-going research effort at Georgia Tech University in conjunction with the EPA to develop a next generation modal emissions model within a Geographic Information System (GIS) framework (Fomunung et. al., 2000; Bachman, 1999; Bachman et. al., 1997, 1998). Georgia Tech's modal emissions model is designed to improve emission estimates by considering a variety of vehicle activities, environmental factors, vehicle and driver characteristics, and the spatial and temporal distributions of these characteristics. The framework for this model is a modal basis, where emissions rates are employed for specific modes of vehicle operation. Important vehicle operating modes include engine starts, idle, hot stabilized operation, enrichment conditions (influenced by high acceleration and power demand), hot soak evaporation, etc.

The technology group definitions and corresponding emission rates for the model were developed through regression analyses of vehicle emissions test data (more than 700 vehicles and 4000 vehicles' test). The emission data were derived based on real-world driving with real-world fleets experiencing real-world driving environments. This means a research program based on remote sensing, on-road studies, instrumented vehicles, rather than simply supplements laboratory analysis.

The model employs on-network and off-network components. On-network estimates include activities, which are attributed to a transportation system on a link-by-link basis. On-network data used in emissions modeling may include temporally modeled and/or monitored traffic volumes, speeds, and fleet characteristics. Local roads, however, are included in an off-network database by aggregating their characteristics into mini-transportation analysis zones (analogous to the methods typically employed in travel demand forecasting models). Other off-network activity is handled on a zonal basis derived from socioeconomic and environmental data.

The activities for various vehicle technology groups are tracked within the model so that separate base emissions rates can be employed. Emission rate algorithms are based upon statistical analysis of emissions data and designed to reflect state of the practical emissions modeling. Emission rates will be determined for all the modes, which are modeled.

The Georgia Tech GIS-based emission model does not generate aggregate emission rates or emission factors like emission factor models. Instead, it predicts spatial and temporal allocation of motor vehicle emissions in an urban area. It requires the development and integration of new data and requires a large amount of time and effort to produce the data required. Costs associated with developing GIS-based emissions models are likely to be large primarily associated with model development, standardization, and integration of new data sources.

Emission Estimation in Traffic Simulation Models

Traffic simulation models are the most widely used tools by traffic engineers to evaluate traffic control and management strategies of a complicated urban network. In order to enhance their capabilities in performing vehicle emission analysis of various traffic network scenarios and controls, many of existing traffic simulation models have incorporated their own emission estimation equations. Different from the MOBILE and EMFAC, which require supplemental travel demand models for generating the final emission estimates, a traffic simulation model can produce a complete emission estimation of traffic networks with a single modeling package.

The examples of traffic simulation models with the emission estimation capabilities include the TRANSYT-7F, INTEGRATION, FREQ, NETSIM, and INTRAS. The current version of TRANSYT-7F model (Courage and Wallace, 1991) does not have the emission estimation capabilities. Enhancements to the existing model have been suggested by Penic and Upchurch (1992), which would estimate emissions based on microscopic measures, mainly the four modes of a vehicle's motion: acceleration, deceleration, cruise and idle. The emission estimation in INTEGRATION (Van Aerde, 1999) was based on a series of emission equations, which were developed based on the emission data from the Oak Ridge National Lab. The FREQ model (May, 1990) predicts vehicle emissions during a given time slice for a given subsection of the network based on results from the EMFAC emission factor model. The microscopic simulation model NETSIM (Rathi and Santiago, 1989) computes emissions on a link level based on a table of emission rates. INTRAS (Wicks and Liebermann, 1980), a microscopic model for freeway corridors, is also capable of providing link-specific values of vehicle emissions.

The following descriptions about emission estimation in traffic simulation models will focus on TRANSYT-7F and INTEGRATION as representations to illustrate the difference between the emission factor models and the emission estimation in traffic simulation models.

TRANSYT-7F is a traffic signal simulation and optimization computer program, which uses a macroscopic deterministic platoon dispersion model to simulate the flow of traffic through a street network. It is used extensively through the United States to optimize the performance of urban signal systems with respect to delays and number of intersection stops. As indicated previously, the current version of TRANSYT-7F does not have the emission estimation capabilities. Penic and Upchurch suggested an enhancement to TRANSYT-7F for estimating emissions, which would involve modifying the TRANSYT-7F input routines to accept new data cards and adding pollution equations as subroutines.

The suggested TRANSYT-7F emission equations were developed based on the emissions data summarized by McGill (1985). The test procedure used combined laboratory and on-road tests using six vehicles. Data were collected in tabular form as a function of both acceleration and velocity. These six vehicles were tested for emissions of CO, HC and NOx. Upon completion of the tests, the consumption and emission values from all of the vehicles tested were averaged in proportion to each vehicle's contribution to the January 1986, U.S. vehicle fleet.

For each emission species of CO, HC and NOx, the emission estimation is performed for four distinguished modes of travel, namely delay emissions, acceleration speed change emissions, deceleration speed change emissions, and constant speed emissions. The delay emission is a fixed value in the unit of grams per second, which is considered to represent the idling emission rate. The acceleration and deceleration emissions were made functions of initial and final speed values and the road grades. The constant speed emissions were made functions of a vehicle's instantaneous speed value and the road grades, which are considered to represent the emission rates for cruising.

The TRANSYT-7F emission estimation equations are virtually a modal emission model that captures each vehicle's modal activities, such that the emission effects of a traffic signal timing plan can be effectively evaluated. It should be noted that the sample size of test vehicles for TRANSYT-7F emission equations is very small and is not approved by EPA for use to provide the accurate estimation of emissions for attainment or non-attainment areas. However, these equations are still useful for evaluating how the vehicle emissions are affected by different traffic signal control plans.

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. Its emission estimation capabilities were enhanced by incorporating the emission estimation model. This emission model estimates the emissions of a specific vehicle as it experiences travel along a specified route, influenced by the traffic flow characteristics and the countless traffic management strategies associated with the driven network.

The emission estimation model in INTEGRATION was designed as polynomial functions of the independent variables such as the instantaneous speed value and the ambient temperature. It can predict emissions for three vehicle classes, light-duty gasoline vehicles, light-duty gasoline trucks 1 and light-duty gasoline trucks 2. It can also predict the idling emission rate and cold start impact on emissions.

2-3. Summary of Literature Review

As shown earlier, the available emission estimation models include emission factor models and many other types of emission models. Emission factor models MOBILE and EMFAC use the average speed as the sole indicator of a vehicle's modal activities, and thus they cannot be used to evaluate the emission implications of operational improvements of traffic control and management strategies. While emission estimations in traffic simulation models are designed more sensitive to vehicles' modal events, their emission databases are very limited and they were not extensively tested and validated for their accuracy in representing the on-road vehicle emissions. The new generation of modal emission models has been developed at UC Riverside and Georgia Tech. The UC Riverside model relies more on the conventional in-laboratory testing of sample vehicles, while the Georgia Tech emission model is GIS based and is developed based more on remote sensing programs.

What is lacking in all of existing emission modeling is the examination of effects of high emitter vehicles on the quality of emission models. Yu (1998b) developed a series of modal emission estimation equations based on the on-road emission and modal traffic data, and indicated that there exist high emitter vehicles in the real-word, which are not significant in quantity, but may pose considerable effects on the final emission modeling. Therefore, there is a need to examine how the different levels of high emitter vehicles will affect the accuracy and quality of the emission models.

CHAPTER 3

DESIGN OF STUDY

This chapter will present the source of the emission data to be used in this research, vehicle type classification for emission modeling, and methodology to be used for examining effects of high emitter vehicles on the emission modeling.

3-1. Source of Emission Data

The source of the emission data to be used in this research is the emission data collected in a TxDOT project (Yu, 1998a). In the TxDOT project, the remote emission sensor SMOG DOG (SBRC, 1995 and Jack, et. al., 1995) was used to collect 5000+ on-road emissions of CO, HC and NOx. 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 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, which consists of a sensor head, source, video camera, and state-of-the-art electronics for capture, display, and storage of both image data (automobile license plates) and vehicle emission data, uses a remote sensing technique that has been used for many years for satellite monitoring of ecological and environmental points of interest like earth's atmosphere and forest. In its vehicle emission sensing, infrared "light" is passed through a vehicle's exhaust plume and is absorbed by the different gases in the plume. The sensor determines changes in the selective absorption of infrared radiation by molecular vibrational modes at wavelengths specific to the pollutant; i.e., HC, CO, NOx, and CO_2. Changes are measured using chemically specific detectors, which sense radiation only at these wavelengths. The motion of a vehicle through the beam triggers the simultaneous measurement of CO, HC, NOx, and CO_2 in the dispersing exhaust cloud for a user-selectable period (typically one-second). The data from all four pollutants are analyzed on a real time basis and the results, expressed as a percentage of the exhaust, are stored on a computer disk. The image data are stored on a VCR tape, which can be read by an operator and the license plate information is entered into the same file as the emission data.

A special feature of the SMOG DOG system is its enhancement of the capability in detecting a vehicle's 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. The simultaneous measurements of emissions, speed and acceleration rate provide an opportunity to establish a relationship between the emissions and a vehicle's instantaneous speed profile.

The on-road emission data were collected from the five highway locations in Houston. The final products of this emission collection efforts include standard ASCII files which include emission concentration percentages and speed and acceleration data, hourly updates on ambient temperature and humidity, license plate TIF files, and video tapes of the rear of vehicles with emission data superimposed. In the end, about 5,000+ emission data were collected. A sample of the collected emission data from the remote emission sensor is shown in Appendix A.

As indicated earlier, the collected on-road emission data for CO, HC, and NOx are concentrations in the unit of percentage or parts per million (ppm). This type of emission data is not very useful for the emission modeling purpose, and cannot be compared with the emission factors or emission rates that are generated by the existing emission models. Usually, emission factors and emission rates in the units of grams per mile and grams per second are more useful units in practice. Therefore, the first step in processing the collected emission data will be to convert these data from the unit of concentration to the unit of emission factors or emission rates. While the author did not find, in the literature, any differences in using the terms of an emission factor and an emission rate, the following definitions of emission factors and emission rates will be used in the rest of this report in order to clarify which unit, grams per mile or grams per second, is referred when it is mentioned: an emission factor represents the emissions in grams per mile while an emission rate represents emissions in grams per second. The lack of the capability for directly collecting emission factor/rate is a shortcoming of the remote emission sensor.

Conversion of emission concentrations to emission rates is a very difficult task. While most of the emission concentrations can be related to emission rates, in some cases emission concentration is not related to the emission rate completely. In a research report prepared by the South Coast Air Quality Management District (SCAQMD), the linear correlation relationships were developed between the emission concentrations from the smog check data to IM240 emissions in grams per mile readings (Huges, 1995). While this conversion method is not perfect, it is the only one that exists in literature.

The smog check test and IM240 test are two tests that are implemented in California to enhance the Inspection and Maintenance (I/M) program. The smog test detects the emission concentrations of the exhaust of vehicles at idle and at a fast idle speed of approximately 2500 RPM. If the emission concentrations exceed the emission thresholds which are specific for each vehicle type and model year, the vehicle will be sent to conduct the IM240 test which can identify the emissions in grams per mile to confirm if the vehicle is a High Emitter Vehicle. The IM240 test lasts for 240 seconds, which was developed as a time efficient substitute for the more involved Federal Test Procedure (FTP) test.

Recognizing the problem that the Smog Check Test cannot provide the mass emission data needed to quantify emissions, the SCAQMD developed correlations between smog check data and IM240 mass emissions readings. These correlations were based on data from AQMD’s Orange County remote sensing program, the City of Los Angeles Remote Sensor Program, and Hughes remote emission sensing data. The equations based on these data were developed so that CO and HC values in grams per mile based on measured Smog Check Test concentration data for these pollutants could be estimated.

For more details about converting the emission concentrations to emission factors and emission rates for the remotely collected emission data, please refer the report by Yu (1998a).

3-2. Vehicle Classification

After all the emission data are converted from the original concentrations to the grams per mile and the grams per second, any invalid data are deleted from the database. The invalid data represent the instances when SMOG DOG was unable to detect or identify certain types of emissions. In these circumstances, the data were recorded as 99999. Thus, the initial data reduction process screened for the valid data for CO and HC emissions and resulted in two groups of a database. One group contains the valid CO emission data and the other one lists the valid HC emission data.

Recalling that MOBILE and EMFAC emission factor models can produce emission factors or emission rates for more detailed classified vehicle types as indicated in Chapter 2, the collected emission data should also be classified into different vehicle types. Since the scope of this research does not generate detailed information about each vehicle that was detected in terms of what vehicle type it belongs to, MOBILE or EMFAC like classifications of vehicle types are impossible. It is noted that the emission data collected using SMOG DOG has generated videotapes, which recorded the image of each detected vehicle. Using these videotapes, the vehicles can be visually classified into different types. Due to the limitation of the video, it is not possible to classify vehicles into the detailed categories as in MOBILE and EMFAC. However, three vehicle types are classified in this research as follows:

- Vehicle Type 1 (VT-1): passenger cars,
- Vehicle Type 2 (VT-2): van and pick-up trucks,
- Vehicle Type 3 (VT-3): other trucks, and
- Aggregate (VT): all vehicles.

After the conversion and reduction of the collected on-road emission data as described above, the CO emissions and HC emissions are organized into the following data groups, namely the VT emission group, VT-1 emission group, VT-2 emission group and VT-3 emissions group. The resulting emissions are illustrated in Appendix B by showing emission rates versus vehicles' instantaneous speed. Figure B-1 illustrates the scattered CO emission data for the aggregate emissions for the instantaneous speed versus CO emission rate. It can be noted from this graph that the data are heavily concentrated around the lower portion of the scattered points, while some emission data are spread over the higher portion of the data area. The emission data falling into the higher portion of the data area can be considered as a representation of the high emitter vehicles. The tidy curve at the bottom of the congested emission data points can be considered to represent the emission rates of brand new vehicles. It can be seen from this graph that no vehicles will emit emissions that fall below this tidy bottom curve. Figures B-2 to B-4 represent similar graphs for CO emissions for VT-1, VT-2, and VT-3, while Figures B-5 through B-8 represent similar graphs for HC emissions for VT, VT-1, VT-2 and VT-3.

3-3. Modeling Methodology

Figures B-1 through B-8 in Appendix B have shown two unique features that make the emission data different from other types of randomly collected data. First, there is a tidy curve (may not be a straight line) at the bottom of the scattered data. In any other types of randomly collected data, it is hard to find a similar tidy curve in the scattered data. Second, if the tidy curve is considered as the trend of the regression analysis, all the scattered data fall into the area above the tidy curve at the bottom. This is very unusual for randomly collected data, as in most of cases, the scattered data should fall around both sides of the general trend of the regression analysis.

If a curve could be identified that perfectly replicates the bottom tidy curve of the emission data, the correlation coefficient of the regression analysis would be very high. With the increased inclusion of the emission data above the bottom tidy curve, the quality of the regression should decrease. If the emission data that stand on the bottom tidy curve are considered as those that are collected from brand new vehicles, the data that fall into the area above the bottom tidy curve will clearly represent the data that are collected from used vehicles with different ages and conditions. A regression curve based on all emission data will then be a representation of a weighted combination of emission rates from vehicles with different ages and conditions including technologies. This is similar to the concept in developing emission models based on in-laboratory testing. The only difference is that the in-laboratory emission testing-based models rely artificially on a combination of selected testing vehicles, while the on-road emission data are the actual combination of vehicle types, ages, and other conditions.

Cutting certain amounts of high emission data will obviously improve the quality of emission models that are developed based on the on-road collected emission data. The compromise is that the resulting models will unavoidably miss the representation of those high emitter vehicles. A potential solution to this compromise is that the emission models be corrected by some type of correction factor to reflect the effects of high emitter vehicles. However, this problem is beyond the scope of this research. This report will focus on the examination of how the cutting of HEV data will affect the actual emission modeling.

Simply cutting a given percentage (e.g. 10%) of HEV data across the entire speed range is not an acceptable way to screen the emission data. Use Figure B-1 in Appendix B as an example. If the top 10% HEV data is to be cut, most of the data that are cut will likely be those at higher speeds. Thus, this cutting will miss the HEV data at lower speeds. It is noted that emissions are sensitive differently at different speeds. In other words, the HEV data are relative to the speeds of vehicles. Thus, cutting any HEV data has to be done with a consideration of actual speeds. For example, if 10% of HEV data are to be cut, the 10% should be referenced to the 10% of HEV data at each speed point. In this context, the following method of cutting HEV data is used in this research.

The entire speed range from 0 to 80 mph is broken down to 16 increments of 5 mph. These increments include 0~5, 5~10, 10~15, 15~20, 20~25, 25~30, 30~35, 35~40, 40~45, 45~50, 50~55, 55~60, 60~65, 65~70, 70~75, and 75~80 mph. For each increment range, the probability distribution histogram of the emission data is plotted, in which the cutting point of emission can be easily determined based on the percentage of accumulative distribution. Figure 1 is an example of the distribution histogram of the aggregate CO emission data for the speed range of 35~40 mph.

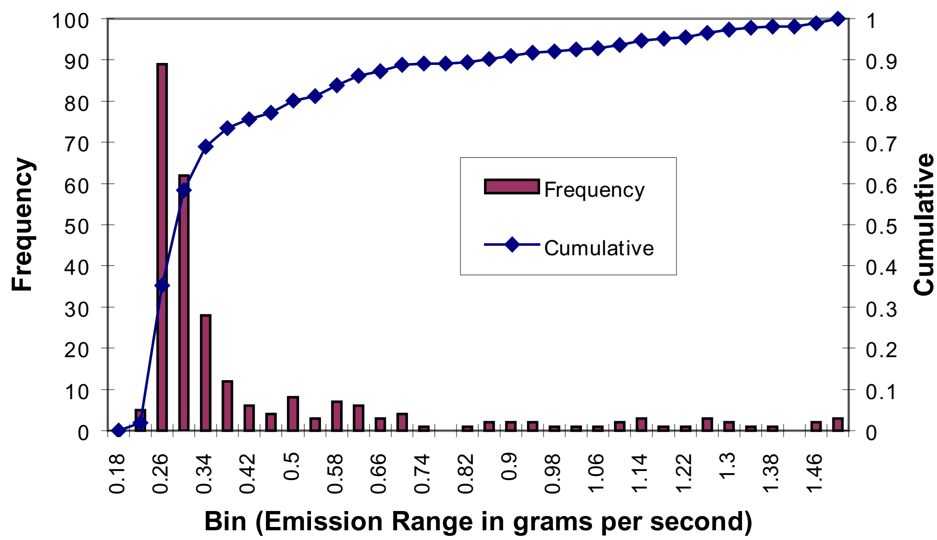

Figure 1: Distribution Histogram for the Aggregate CO Emission Rates at the Speed Range of 35~40 mph

From Figure 1, if 10% of HEV data are to be cut (90% of cumulative emission data are retained) for the emission modeling purpose, the aggregate CO emission cutting point should be at around 0.85 grams per second. In other words, the CO emission data that are above 0.85 are deleted. On the other hand, if 20% or 30% of HEV data are to be cut, the cutting point will be at around 0.485 or 0.34. Clearly, the HEV data are not significant in quantity, but have big effects on the cutting points of emissions.

Figure 2 is another example for the aggregate HC emissions at the speed range of 30~35 mph. From Figure 2, if 10%, 20%, and 30% of emission data are to be cut respectively (90%, 80% and 70% emission data are retained), the cutting points of the aggregate HC emission will be at around 0.106, 0.065, and 0.048 grams per second. In other words, the aggregate HC emission data above one of these cutting points should be deleted.

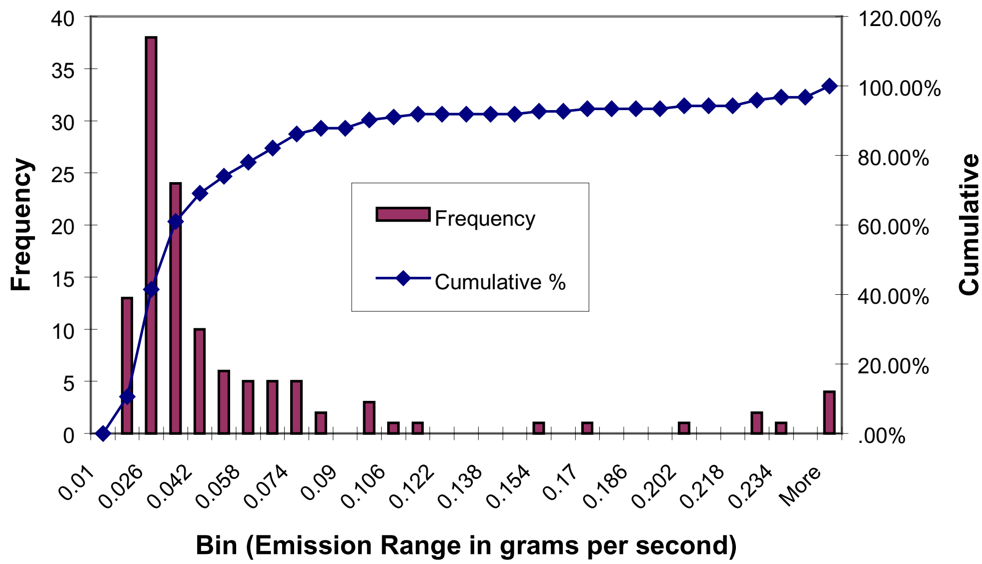

Figure 2: Distribution Histogram for the Aggregate HC Emission Rates at the Speed Range of 30~35 mph

In this research, CO and HC emission data for all vehicle types that were defined in Section 3-2 are processed based on the above methodology for three different levels of HEV data cutting: 10%, 20%, and 30%. Then, the remaining emission data are used to establish emission models using a regular regression analysis tool. The results of regression analysis are evaluated as well as compared with MOBILE and EMFAC emission factors to determine the effects of high emitter vehicles on the emission modeling.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter will first present a summary of the regression analyses, which are performed based on the emission data that were described in Chapter 3. Then, the effects of higher emitter vehicles on the emission modeling are discussed. Finally, a comparison of the emission modeling with different levels of HEV data with MOBILE and EMFAC emission factors is provided.

4-1. Summary of Regression Analysis

The raw emission data described in Section 3-1 were processed using the methodology presented in Sections 3-2 and 3-3, which resulted in emission databases that include emission rates, instantaneous speed value, acceleration/deceleration rates, ambient temperature, and humidity. While the geometric grades are very important information that affect the emissions, the on-road emission data collection could only be conducted at five locations with two of them in uphill grades, two of them in downhill grades, and one of them in at-grade. These data are not sufficient to satisfactorily incorporate the grade data into the development of the emission model. Therefore, this study will not consider the geometric grade data.

Definition of Variables

The dependent variables in the regression analysis are the emission rates of CO and HC for each vehicle type at different cutting percentages of HEV data. Potential independent variables are the instantaneous speed, acceleration rate, ambient temperature, and humidity. These variables are expressed by the following notations:

$EMIs_x$ =	Emission rate in grams per second for emission species *EMI* and vehicle type *x*,
EMI =	Emission species CO or HC,
X =	Vehicle type, VT, V-1, VT-2, or VT-3,
u =	A vehicle's instantaneous speed in miles per hour (mph),
a =	A vehicle's acceleration rate in mph per second,

t =	Ambient temperature in Fahrenheit degree,
h =	Ambient humidity in percentage (%), and
$c_0, c_1, \ldots$ =	Constant values (regression model coefficients).

Regression Analysis Design

The first step in any regression analysis will be the selection of mathematical equations that may best fit the field-collected data. The research by Penic and Upchurch (1992) has indicated that the exponential equations would result in the best goodness-of-fit between field emission data and the regression curves. However, Baker (1994) used multiple variable polynomial equations in a similar modeling effort. Further statistical test and examination of the emission data collected for this research have found that the exponential equations are more suitable than other forms of mathematical equations for establishing relationships between emission rates and various independent variables.

Having decided to use the exponential equations in formulating the emission model, we should then determine how many independent variable terms should be included in each emission equation. Considering all of the possible independent variable terms, the following six are selected for the regression analysis: speed, speed square, acceleration, acceleration square, ambient temperature, and humidity. Technically, there exist unlimited potential combinations of various independent variable terms that can be tested. However, testing all of them is not feasible. In addition, most of them are not statistically appropriate as which can also be easily judged from the regression analysis results. The format of the exponential emission equation is illustrated by the following equation:

$$LN(EMIs_x) = c_0 + c_1u + c_2u^2 + c_3a + c_4a^2 + c_5t + c_6h \quad (1)$$

Selecting six independent variable terms as the initial inputs for the regression analysis does not secure the inclusion of any of these variable terms in the final regression formula, as they may not satisfy the statistical requirements for the regression analysis. In other words, any of the six independent variable terms can be deleted from further consideration so long as they are not statistically satisfactory. The statistical examination about the quality of the regression equation will primarily go through the following steps:

Step 1: Check the coefficient of correlation or the *R*-square of the regression analysis. This will indicate the amount of the total variability in the values of the response variable that is accounted for by the fitted regression model. The closer the correlation coefficient is to either 1 or –1 the stronger is the linear association between the dependent and independent variables. However, one should be cautious if the correlation coefficient is closer to 1 for the very large sample size, as indicated by Hayter (1996).

Step 2: The *F-test* is used to determine the general acceptance of the regression model. A large *p-value* in the *F-test* indicates that there is no evidence that any of the input variables affects the distribution of the response variable. A small *p-value*, on the other hand, indicates that the response variable is related to at least one of the independent variables.

Step 3: The *t-test* is used to determine the acceptance of each individual independent variable. Hayter (1996) suggests that *p-values* larger than 10% in a *t-test* indicate that the corresponding input independent variable can be dropped from the model, while *p-values* smaller than 1% indicate that the corresponding independent variable should be kept in the model. However, a *p-value* between 1% and 10% does not provide a clear indication, and how the corresponding independent variables are dealt with is left to the experimenter's judgment.

The above steps will serve as the main guideline in the selection of independent variable terms in the regression analysis.

Regression Analysis

Following the steps described above, the regression analysis is conducted. Tables in Appendix C present the details in deleting variable terms that are found not appropriate statistically for inclusion in the regression equation. Take Table C-1 as an example. In the Step 1 of Table C-1, the regression analysis that involves all of the six independent variable terms results in a correlation coefficient of 0.5209. While this value is not very high, it is a realistic number considering the quantity of the emission data set. The *p-value* in the *F-test* is 0, which indicates that at least one of the selected six independent variable terms is statistically related to the dependent variable CO emission rate. The *p-values* of *t-test* for six independent variable terms indicate that the variable a^2 (acceleration square) should be removed from the regression equations as its *p-value* 0.9567 is the highest and higher than 10% (0.01) threshold value as described previously. In the Step 2, the regression analysis is re-conducted by excluding the variable a^2. Similar analysis requires that the variable t, which is the ambient temperature, should be removed from the inclusion. Then Step 3 removes the variable h, which is the humidity. In the Step 4, the *p-values* for *F-test* and for all independent variables in *t-test* fall into the acceptable range and thus all of the rest variables are kept in the regression equation. In Step 5, the Speed Square is removed and the speed is retained as the former results in lower correlation coefficient than the latter one. Therefore, eventually the emission equation for the aggregate CO emissions include speed and acceleration rate.

In Table C-1, although six independent variable terms are initially considered in the regression analysis, the ambient temperature and the humidity have to be deleted from the inclusion considering the statistical requirement. This means that either these two variables are not related to the aggregate CO emission rates or the collected emission data are not sufficient for establishing reliable statistical relationships between the CO emissions and the temperature and humidity. Tables C-2 through C-32 illustrate the process in performing the regression analysis for the other cutting percentages of HEV data, emission species, and vehicle types.

The results of all regression analyses for different cutting levels of HEV data can be summarized into the following mathematical equations in Tables 1-4, which can be used to calculate the emission rates of CO and HC for each vehicle type at each instantaneous speed value and acceleration rate.

TABLE 1 Summary of Regression for 100% Emission Data

CO Aggregate Emission Rate:

$$LN(CO) = -2.2182+0.0300u-0.0184a$$

CO Emission Rate for Vehicle Type 1:

$$LN(CO1) = -2.2493+0.0312u-0.0270a$$

CO Emission Rate for Vehicle Type 2:

$$LN(CO2) = -2.1076+0.0270u$$

CO Emission Rate for Vehicle Type 3:

$$LN(CO3) =-1.9798+0.0005u^2$$

HC Aggregate Emission Rate:

$$LN(HC) = -4.9619+0.0288u-0.0445a+0.0075t$$

HC Emission Rate for Vehicle Type 1:

$$LN(HC1) = -4.4435+0.0303u-0.0430a$$

HC Emission Rate for Vehicle Type 2:

$$LN(HC2) = -5.1106+0.0250u+0.0111t$$

HC Emission Rate for Vehicle Type 3:

$$LN(HC3) = -3.8593+0.0004u^2$$

TABLE 2 Summary of Regression for 90% Emission Data

CO Aggregate Emission Rate:

$$LN(CO) = -2.9791+0.0629u-0.0004a$$

CO Emission Rate for Vehicle Type 1:

$$LN(CO1) = -3.0092+0.0640u-0.0004a$$

CO Emission Rate for Vehicle Type 2:

$$LN(CO2) = -3.0141+0.0683u-0.0005u^2$$

CO Emission Rate for Vehicle Type 3:

$$LN(CO3) = -2.3493+0.0259u$$

HC Aggregate Emission Rate:

$$LN(HC) = -6.0851+0.0848u-0.0007u^2 -0.0302a+0.0062t$$

HC Emission Rate for Vehicle Type 1:

$$LN(HC1) = -505072+0.0924u-0.0008u^2$$

HC Emission Rate for Vehicle Type 2:

$$LN(HC2) = -5.9533+0.0728u-0.0006u^2 -0.0402a+0.0074t$$

HC Emission Rate for Vehicle Type 3:

$$LN(HC3) = -4.5973+0.0280u$$

TABLE 3 Summary of Regression for 80% Emission Data

CO Aggregate Emission Rate:

$$LN(CO) = -2.9519+0.0588u -0.0004u^2 –0.0075a$$

CO Emission Rate for Vehicle Type 1:

$$LN(CO1) = -2.9817+0.0593u-0.0004u^2$$

CO Emission Rate for Vehicle Type 2:

$$LN(CO2) = -3.0274+0.0657u-0.0005u^2$$

CO Emission Rate for Vehicle Type 3:

$$LN(CO3) = -2.3623+0.0258u$$

HC Aggregate Emission Rate:

$$LN(HC) = -6.2271+0.0867u-0.0007u^2-0.0201a+0.0063t$$

HC Emission Rate for Vehicle Type 1:

$$LN(HC1) = -6.3927+0.0974u-0.0008u^2+0.0058t$$

HC Emission Rate for Vehicle Type 2:

$$LN(HC2) = -5.5958+0.0579u-0.0004u^2-0.0210a+0.0009t$$

HC Emission Rate for Vehicle Type 3:

$$LN(HC3) = -4.0771+0.0003u^2$$

TABLE 4 Summary of Regression for 70% Emission Data

CO Aggregate Emission Rate:
$LN(CO) = -2.3954+0.0275u-0.0056a$
CO Emission Rate for Vehicle Type 1:
$LN(CO1) = -2.9464+0.0553u-0.0003u^2$
CO Emission Rate for Vehicle Type 2:
$LN(CO2) = -2.98713959505341+0.059988u-0.000413626939548069u^2$
CO Emission Rate for Vehicle Type 3:
$LN(CO3) = -2.3824+0.0258u$
HC Aggregate Emission Rate:
$LN(HC) = -6.194+0.0857u-0.0007u^2-0.0150a+0.0052t$
HC Emission Rate for Vehicle Type 1:
$LN(HC1) = -6.4733+0.0979u-0.0008u^2+0.0056t$
HC Emission Rate for Vehicle Type 2:
$LN(HC2) = -5.4127+0.0517u-0.0003u^2 +0.0036t$
HC Emission Rate for Vehicle Type 3:
$LN(HC3) = -401297+0.0003u^2$

It should be noted that the emission rate was defined as the emissions in the unit of grams per second. If the derivation of an emission factor, which represents the emissions in grams per mile, is required, the following equation should be used, where the *EMImx* represents the emission factor in grams per mile for the emission species *EMI* and vehicle type *x*.

$$EMIm_x = \frac{EMIs_x}{u} \qquad (2)$$

4-2. HEV Effects on Emission Modeling

Section 4-1 established emission models based on cutting different percentages of higher emitter vehicles. Those emission models can generate instantaneous emission rates or emission factors. This section will use figures to illustrate how the cutting of higher emitter vehicles will affect the final emission models.

Figures 3 through 6 illustrate the comparisons of aggregate CO emission factors and CO emission factors for vehicle types 1-3 for different cutting percentages of HEV data. In Figure 3, CO-100 represents that none of HEV data is cut, while CO-90, CO-80, and CO-70 represent that 10%, 20%, and 30% of HEV data are cut respectively. It is shown from these figures that while cutting 10% of HEV data brings considerable decreases in CO emission factors, further cutting of HEV data does not result in more significant decreases in CO emission factors. This is especially true for the vehicle type 3 (large trucks). This means that the small portion of high emitter vehicles has more significant effects on the emission modeling results than the moderately high emitter vehicles. Therefore, merely removing the small number of HEV data may significantly improve the quality of the emission models. It should be noted that if the HEV data are removed from the emission modeling process, there should incorporate some error correction factor in the final emission model in order to accurately represent the on-road emission situations. However, the relevant work, is beyond the scope of this report.

Figures 7 through 10 illustrate the comparisons of aggregate CO emission rates and CO emission rates for vehicle types 1-3 for cutting different percentages of HEV data. It is shown that the decreases of CO emission rates at higher speeds are notable when the HEV data are removed at any level. This is especially obvious for vehicle type 3. It should be noted that although the emission rate is a very important factor in evaluating total emissions, it is the emission factor that determines the total emissions for a particular trip. In other words, grams-per-mile emissions are more important than grams-per-second in determining the total emissions for the regional wide network.

Figures 11 through 14 illustrate the comparisons of aggregate HC emission factors and HC emission factors for vehicle types 1-3 and Figures 15 through 18 illustrate the comparisons of aggregate HC emission rates and HC emission rates for vehicle types 1-3 for cutting different percentages of HEV data. All figures can be interpreted in a similar way as figures for CO emissions in Figures 3-10 except Figures 12 and 16. Figures 12 and 16 illustrate that vehicle type 2 (passenger cars) is not very sensitive to the cutting of HEV data. The most possible reason for this is that there are no passenger vehicles that emit unusually high HC emissions in the emission data.

In the emission models, if the curves in Figures 7~10 and 15~18 are extrapolated to the left side, their intercepts with the y-axis can be interpreted as the emission rates at speed zero (0) mph, or idling emission rates. Based on this method, the CO and HC idling emission rates are derived and illustrated by Figures 19 and 20. It is shown that while both CO and HC idling emission rates are higher when no HEV data are cut, the idling emission rates are relatively stable for cutting either 10%, 20%, or 30% of HEV data. In other words, the higher emitter vehicles have more effects on the modeled idling emission rates than the moderately high emitter vehicles.

The improvement of the quality of the emission models by cutting the HEV data can also be examined by showing the relationships of regression correlation coefficients versus the cutting percentage of HEV data. Figures 21 and 22 are created for this purpose. It is shown from these figures that correlation coefficients continue to increase with the increase of cutting percentage of HEV data. While this may not be a surprising outcome from a common sense perspective, it must be noted that for other randomly collected statistical data sets, cutting data from one side of the trend may not necessarily improve the regression results. The emission data collected from on-road are different from other statistical data sets in that the HEV data are spread over one side of the tidy curves. Another point that can be drawn from Figures 21 and 22 is that the increase of the correlation coefficient from 0% to 10% cutting is sharper than others. This again demonstrates that the first 10% high emitter vehicles impose more effects on emission modeling than the next range of moderately high emitter vehicles.

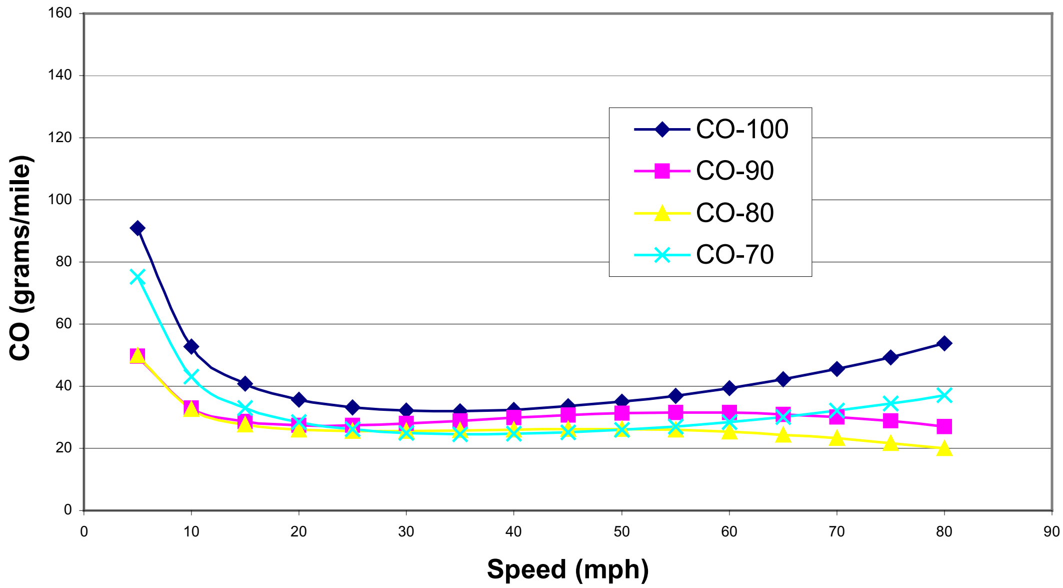

Figure 3: Comparison of Aggregate CO Emission Factors for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

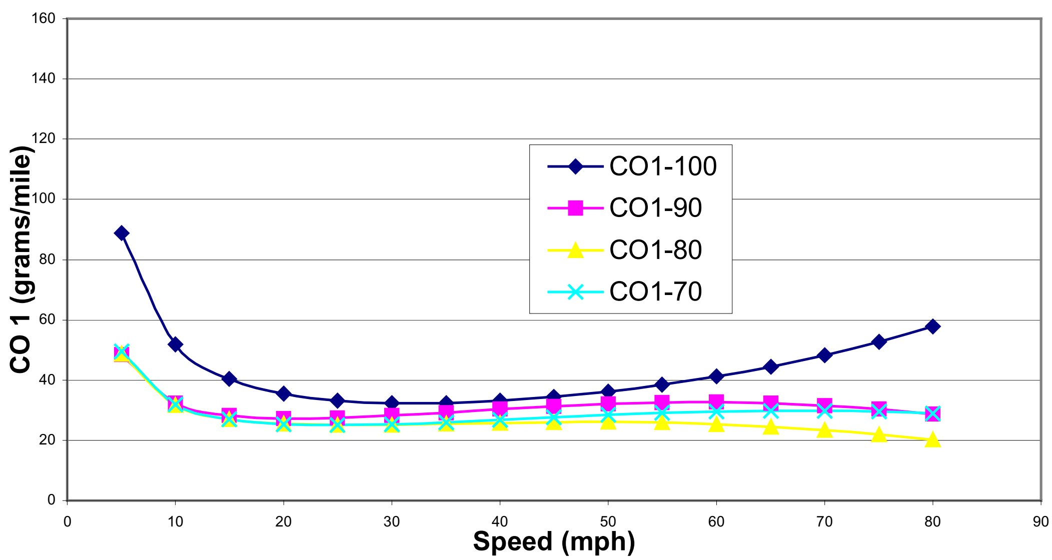

Figure 4: Comparison of CO Emission Factors for Vehicle Type 1 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

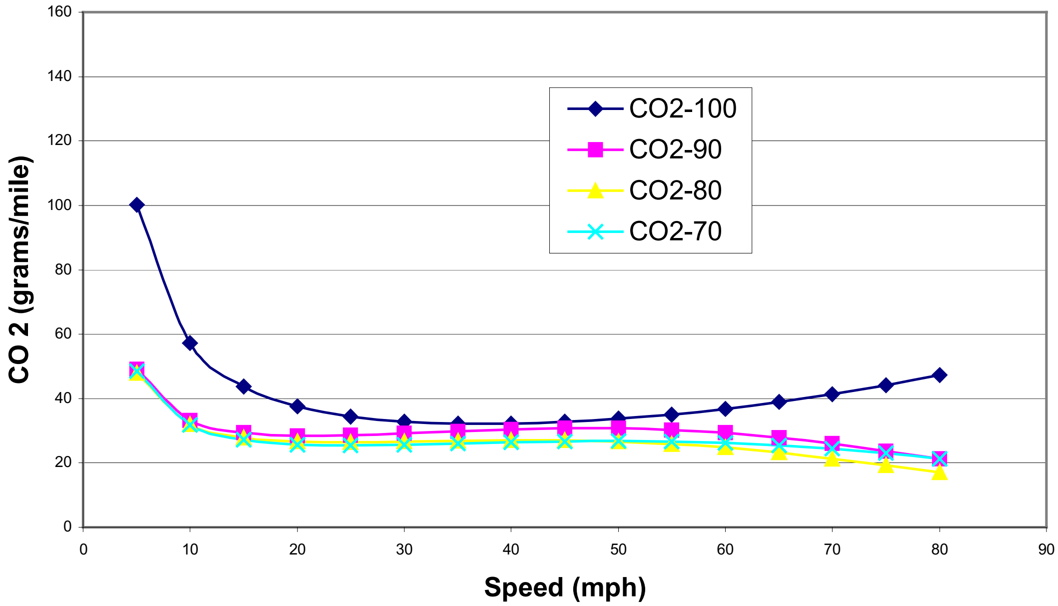

Figure 5: Comparison of CO Emission Factors for Vehicle Type 2 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

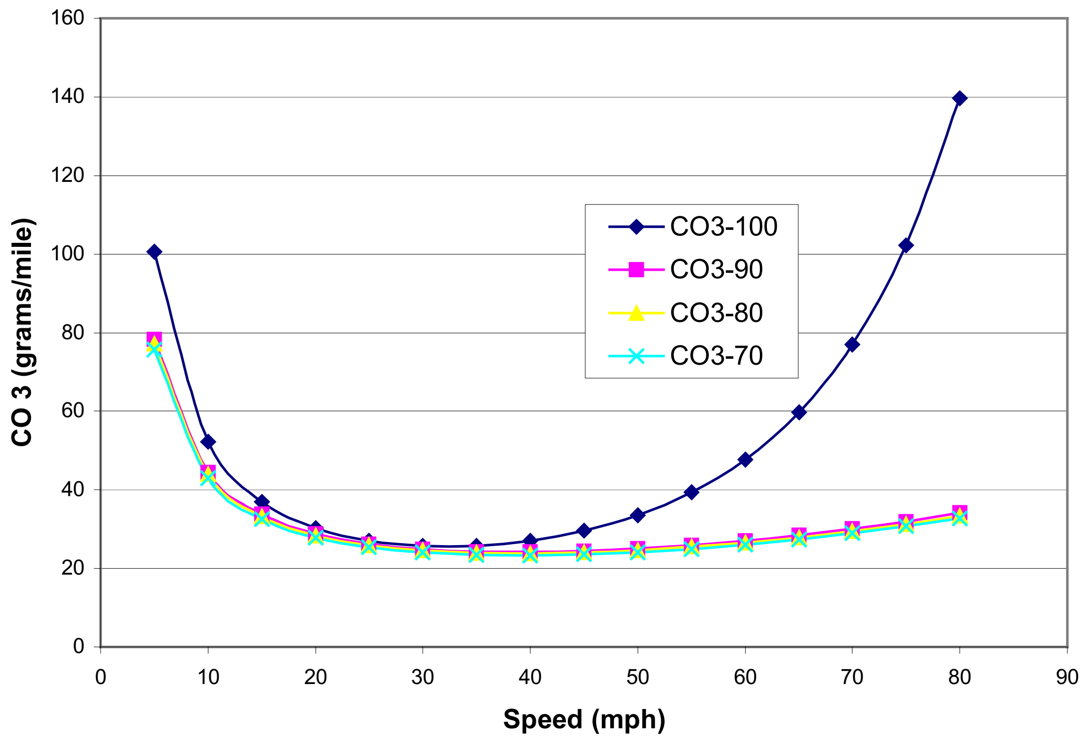

Figure 6: Comparison of CO Emission Factors for Vehicle Type 3 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

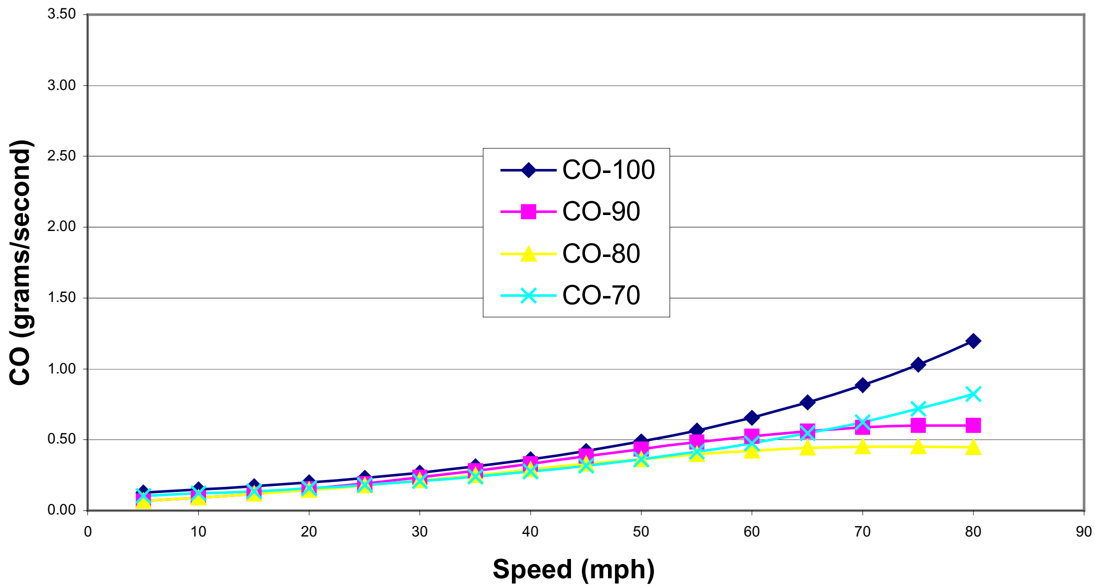

Figure 7: Comparison of Aggregate CO Emission Rates for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

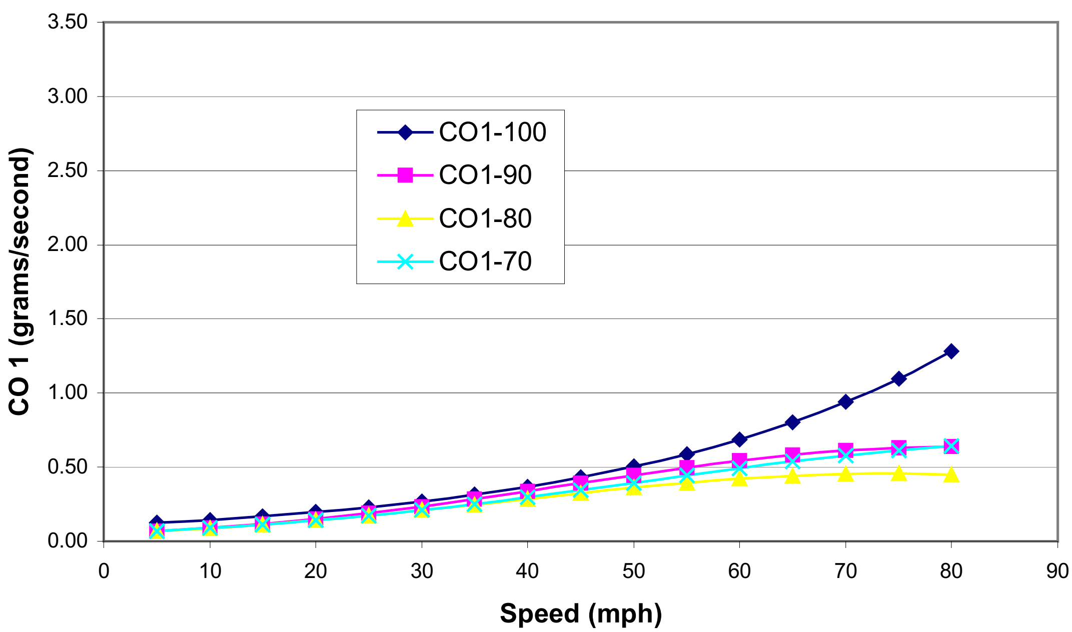

Figure 8: Comparison of CO Emission Rates for Vehicle Type 1 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

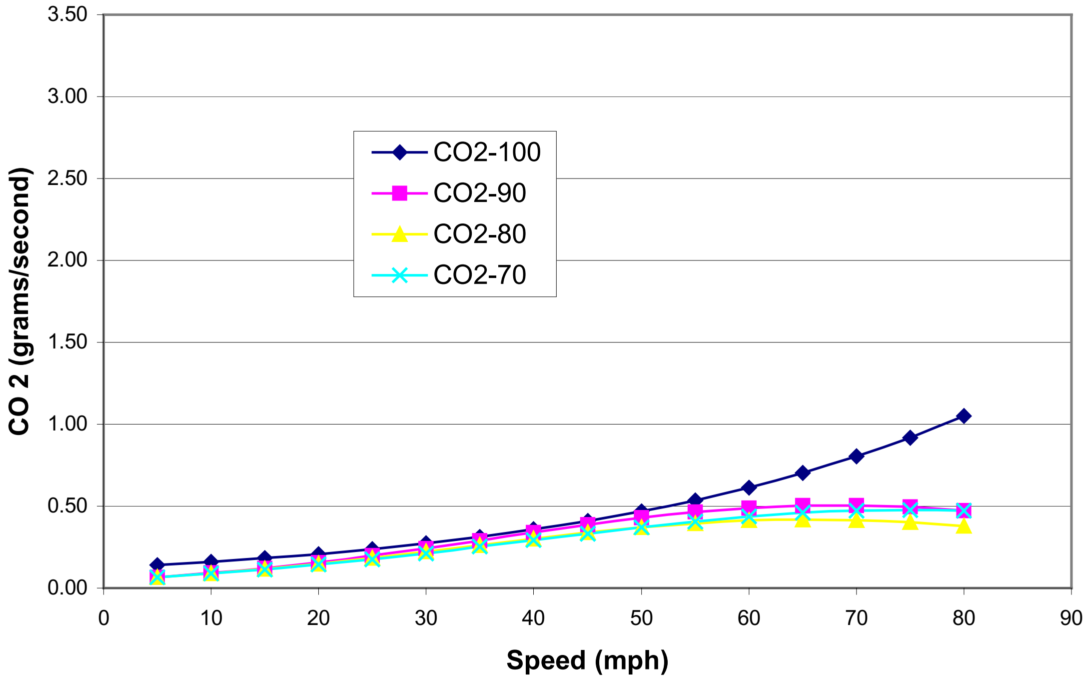

Figure 9: Comparison of CO Emission Rates for Vehicle Type 2 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

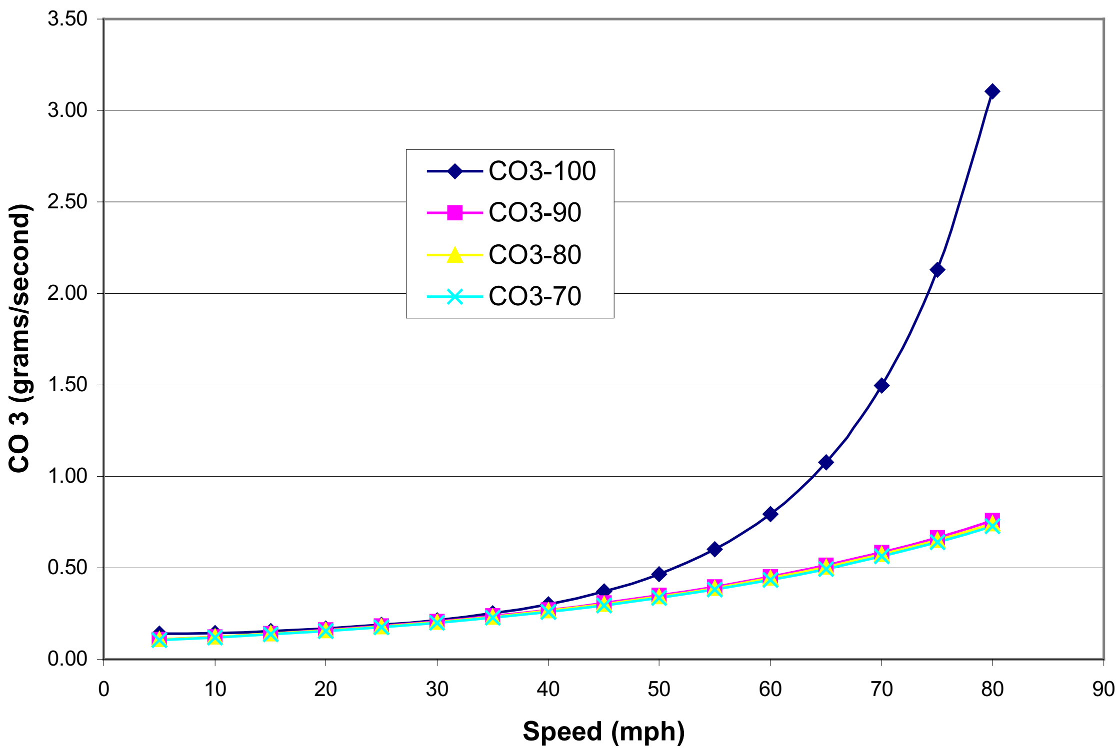

Figure 10: Comparison of CO Emission Rates for Vehicle Type 3 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

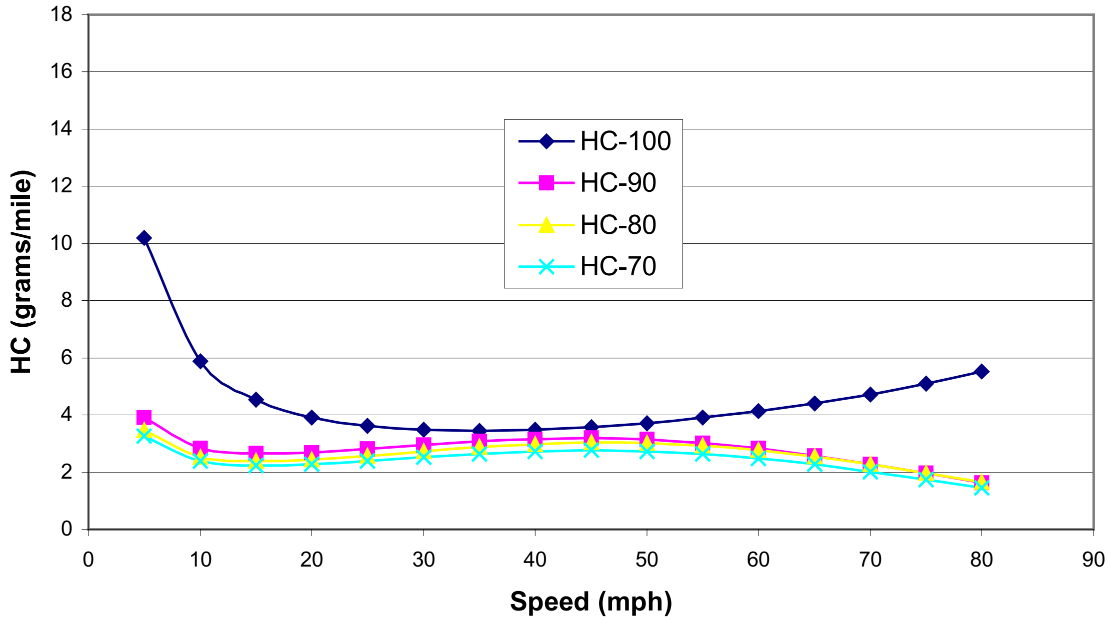

Figure 11: Comparison of Aggregate HC Emission Factors for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

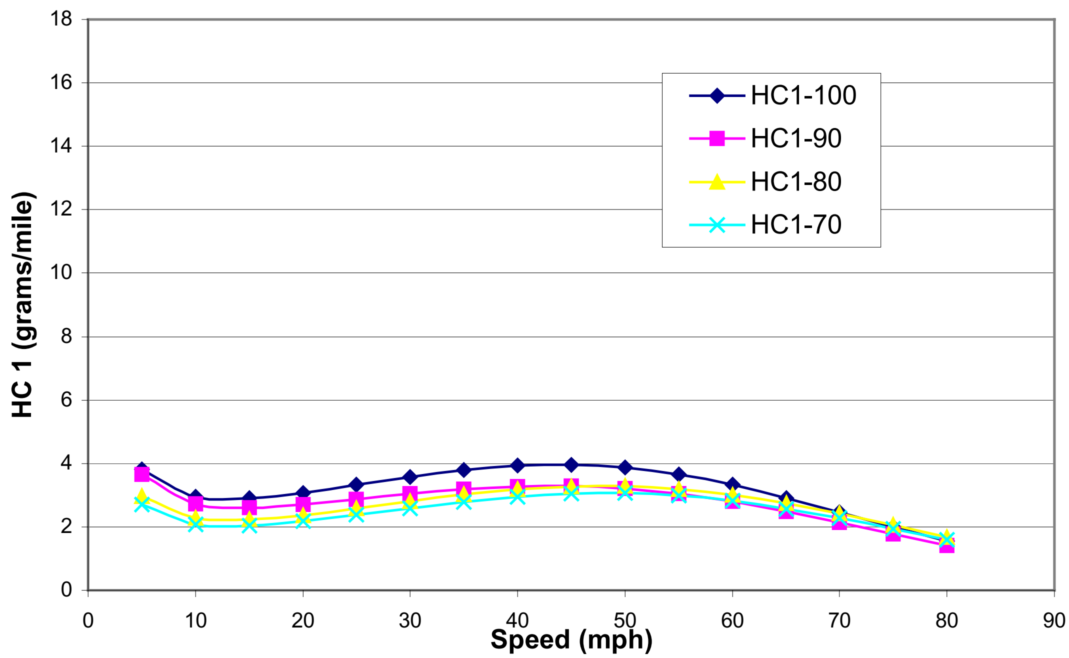

Figure 12: Comparison of HC Emission Factors for Vehicle Type 1 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

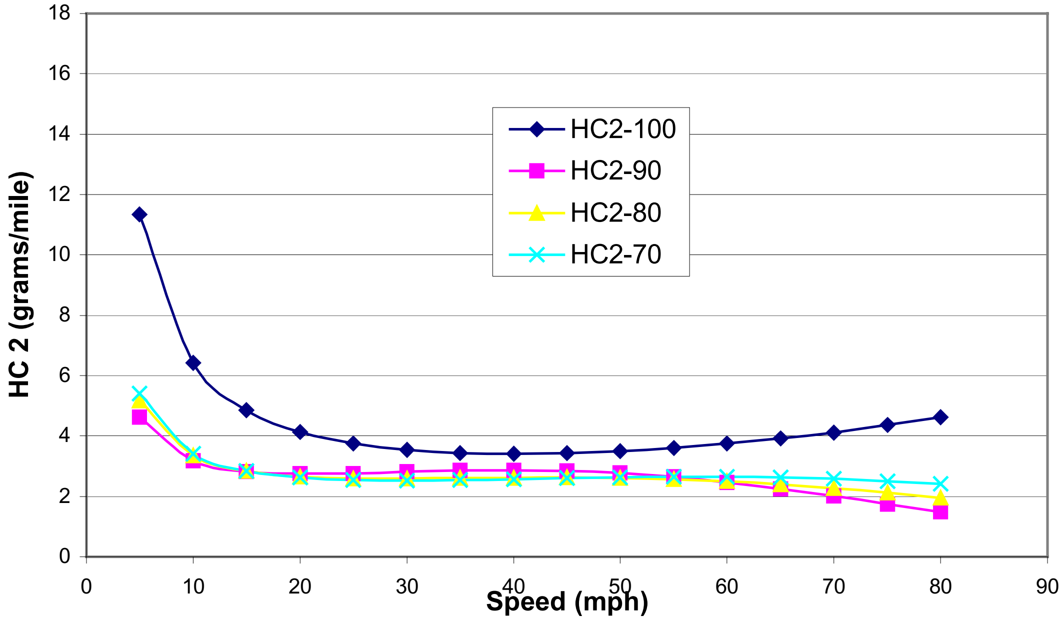

Figure 13: Comparison of HC Emission Factors for Vehicle Type 2 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

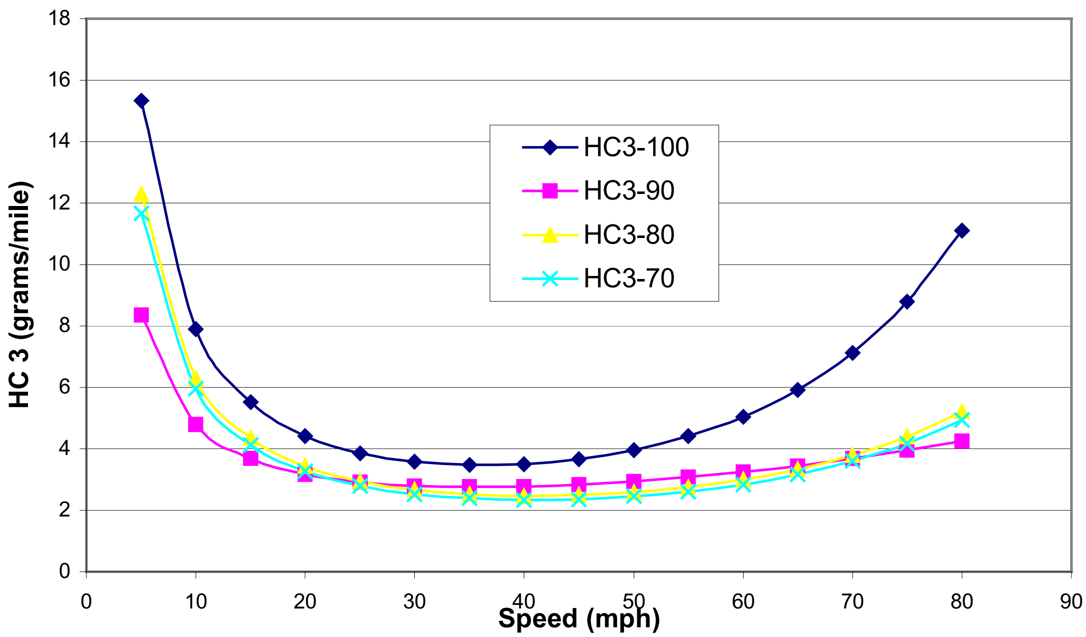

Figure 14: Comparison of HC Emission Factors for Vehicle Type 3 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

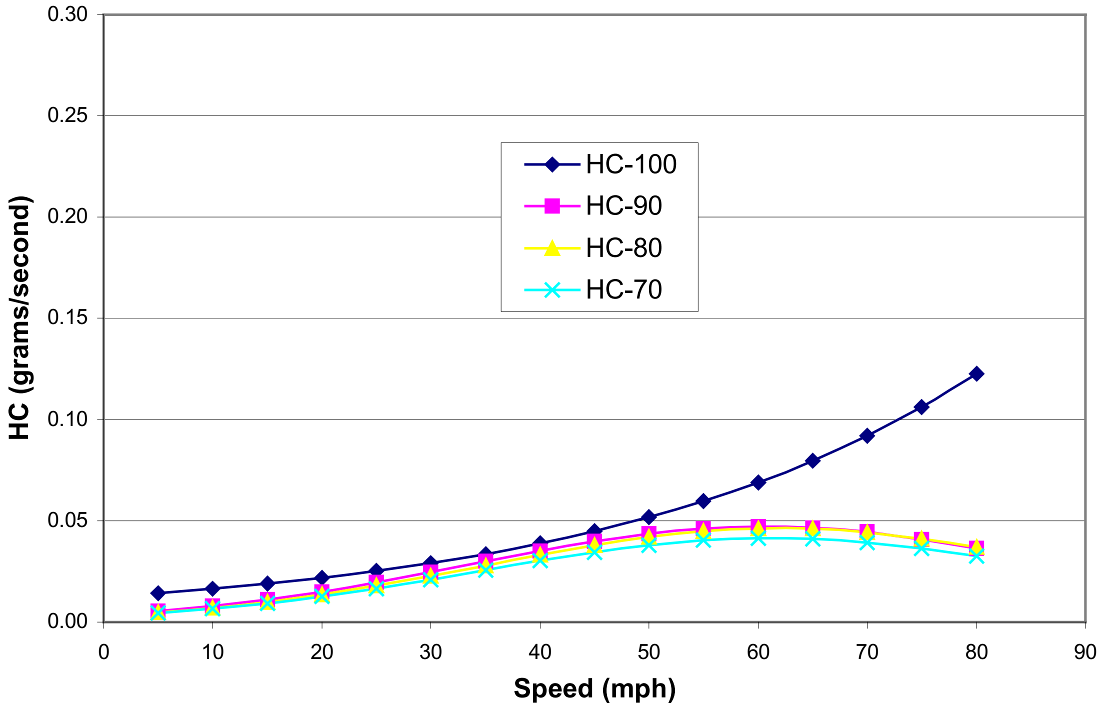

Figure 15: Comparison of Aggregate HC Emission Rates for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

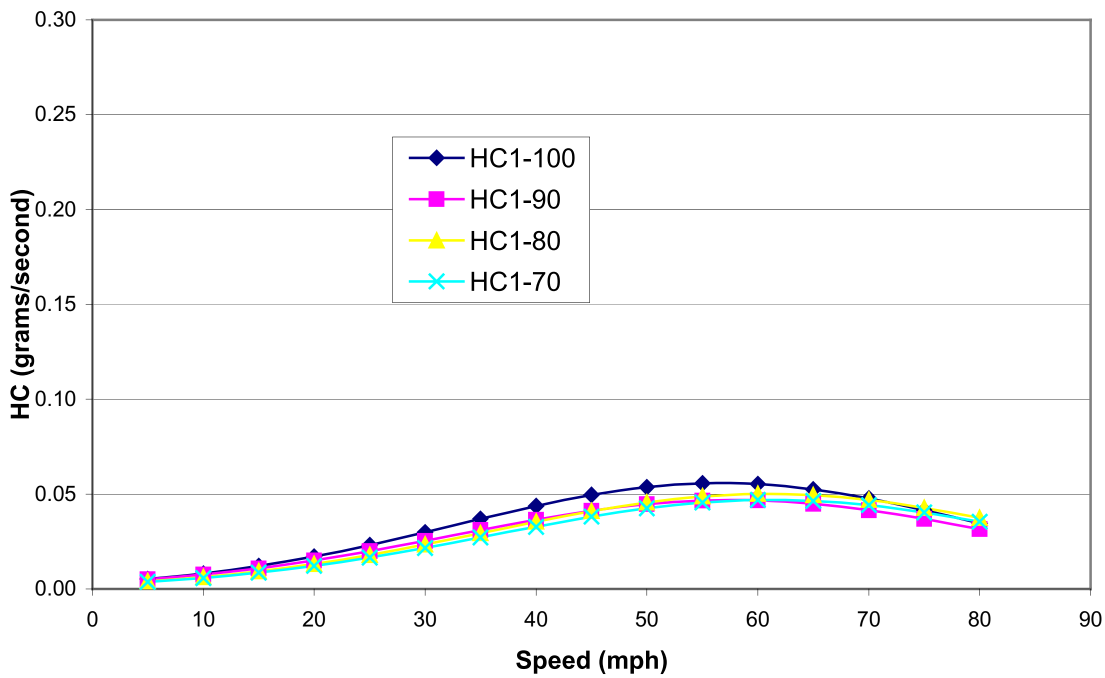

Figure 16: Comparison of HC Emission Rates for Vehicle Type 1 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

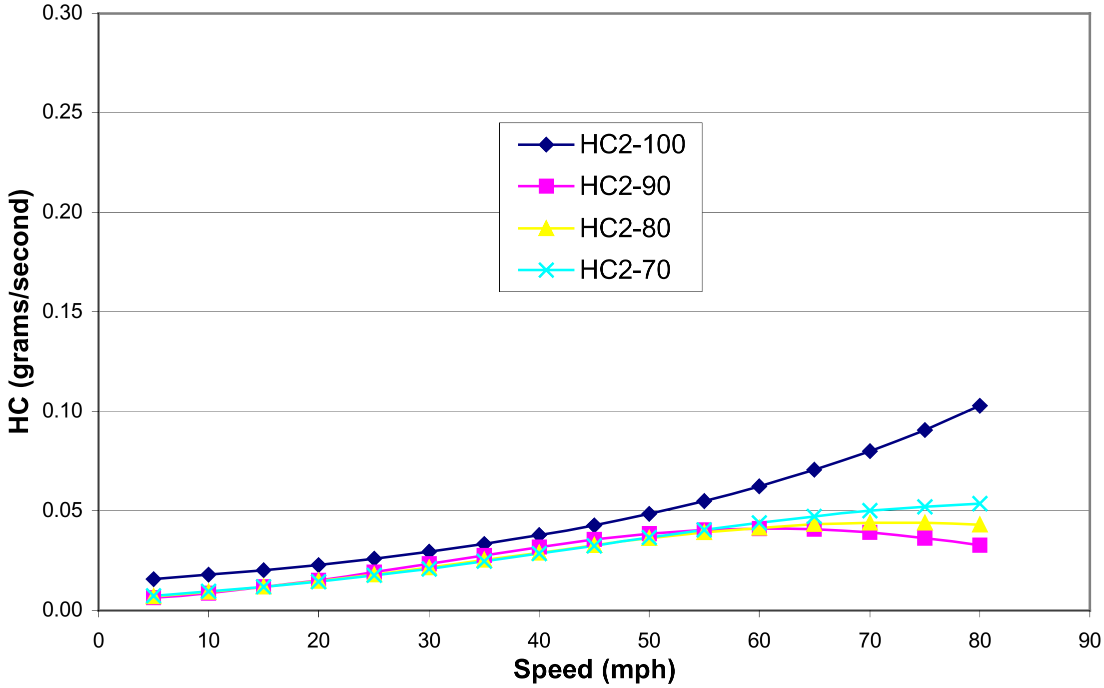

Figure 17: Comparison of HC Emission Rates for Vehicle Type 2 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

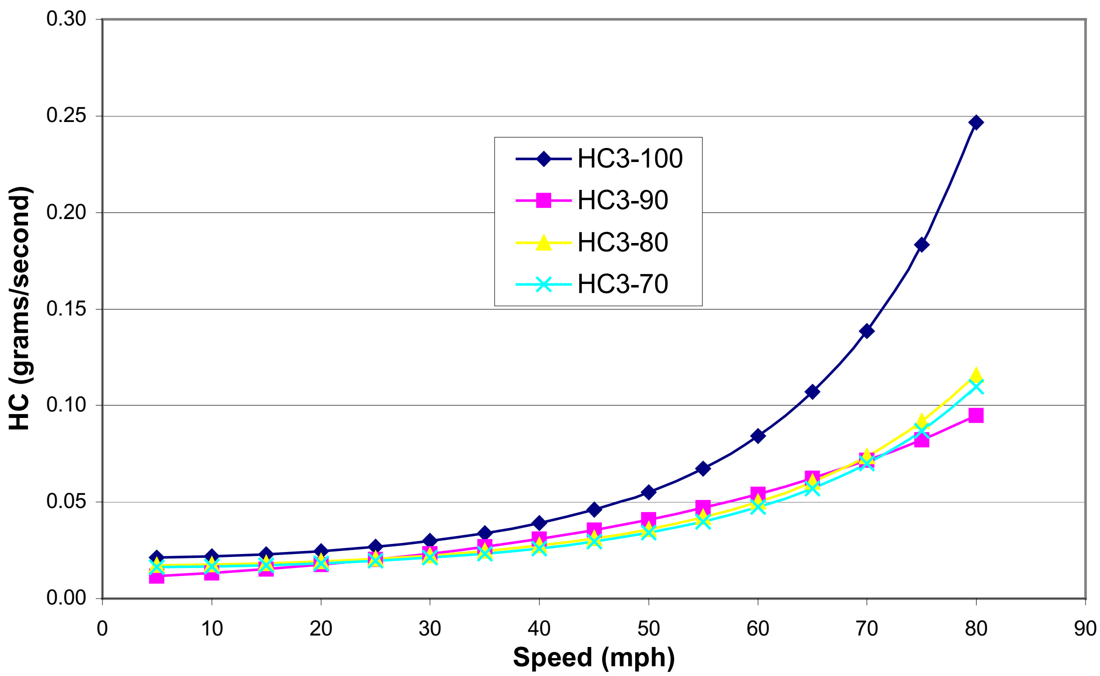

Figure 18: Comparison of HC Emission Rates for Vehicle Type 3 for Different Percentages of Retained Emission Data (or Different Percentages of HEV Data Cutting)

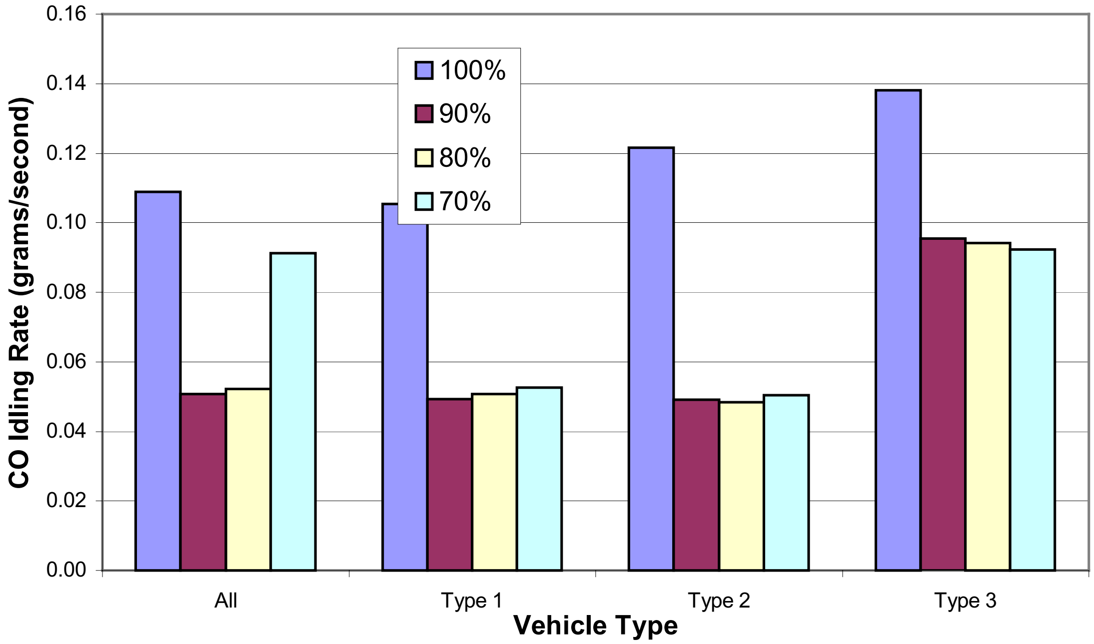

Figure 19: Comparison of Idling CO Emission Rates Generated from Emission Models based on Different Percentages of Cutting HEV Data

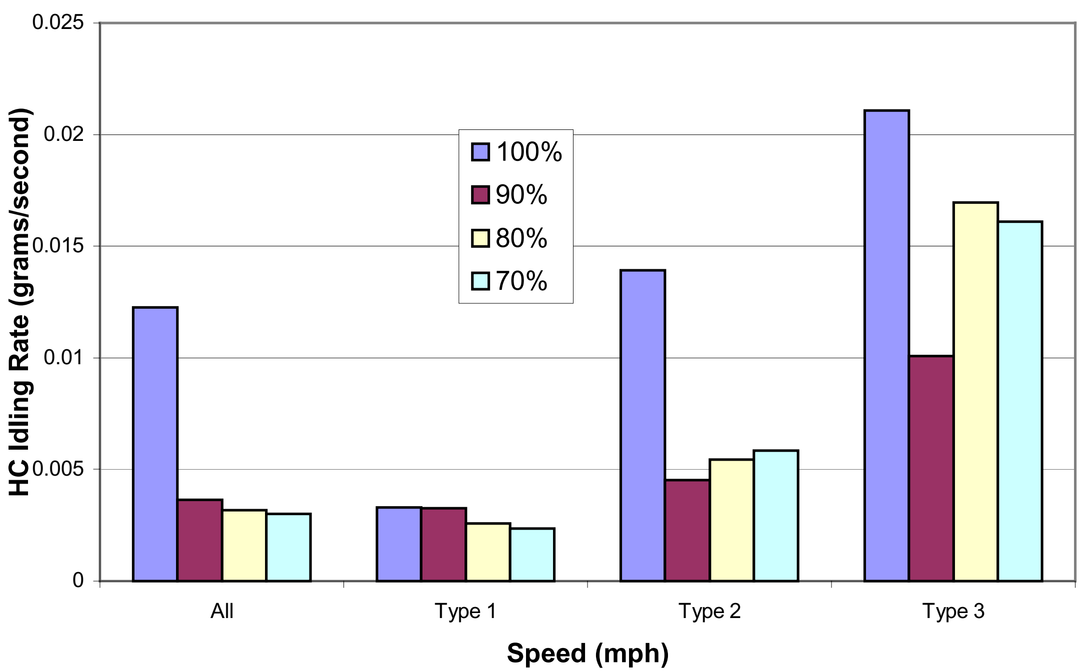

Figure 20: Comparison of Idling HC Emission Rates Generated from Emission Models based on Different Percentages of Cutting HEV Data

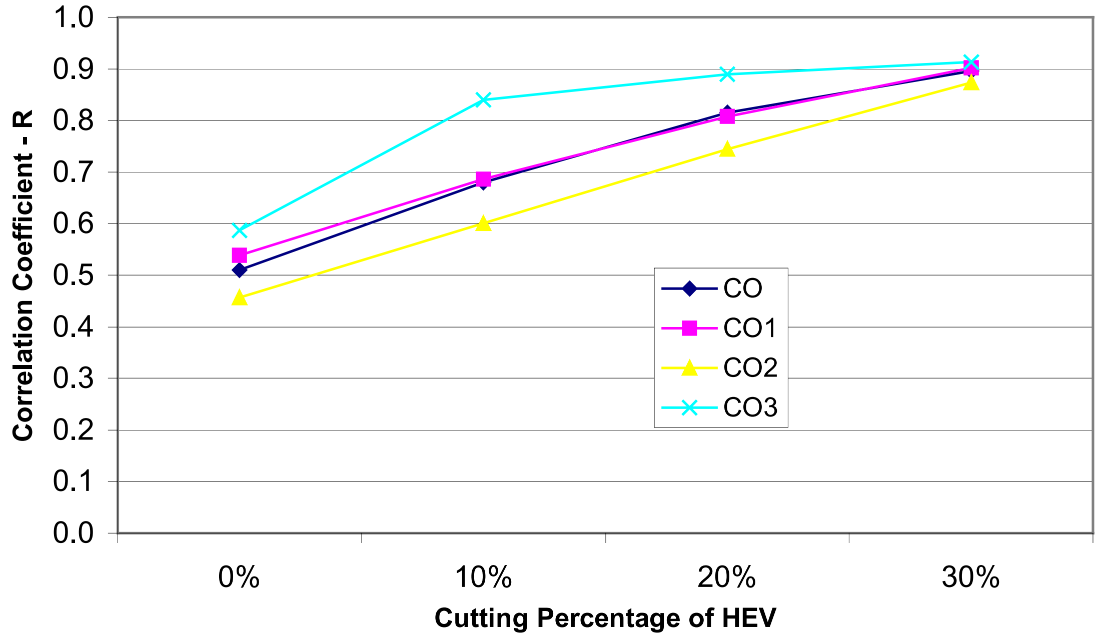

Figure 21: Correlation Coefficients versus Cutting Percentage of HEV Data for CO Emissions

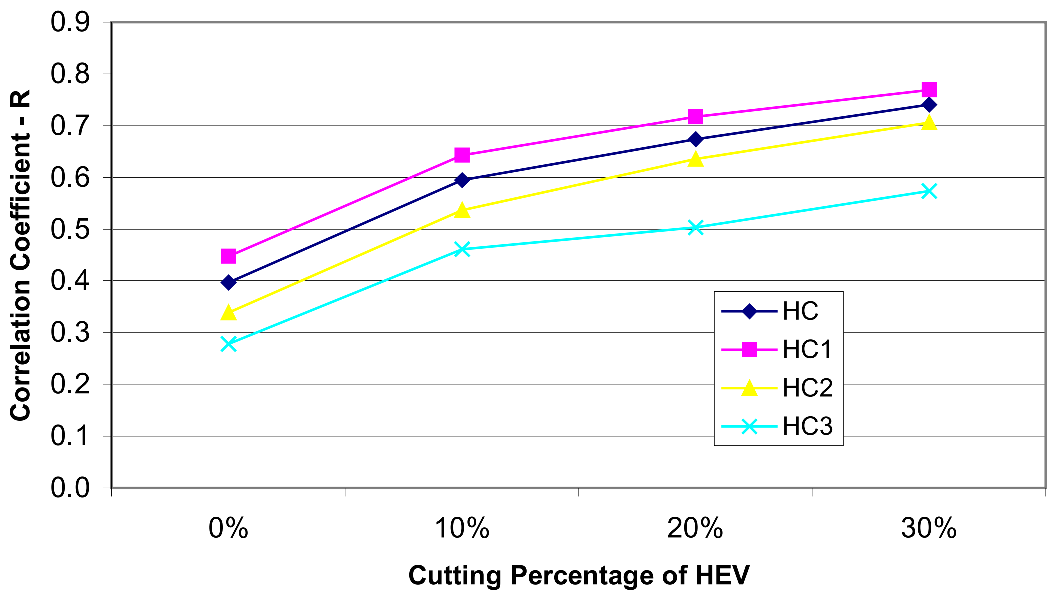

Figure 22: Correlation Coefficients versus Cutting Percentage of HEV Data for CO Emissions

4-3. Comparison with Emission Factor Models

As shown in the preceding section, the high emitter vehicles do have considerable effects on the emission modeling. This section will demonstrate how the higher emitter vehicles will affect the emission factors in comparison with emission factors generated from MOBILE and EMFAC.

As indicated earlier, both MOBILE and EMFAC use the average speed as the sole descriptor of a vehicle's modal activities, and all the effects of acceleration, deceleration, idling and cruise are aggregated into a single emission factor, which represents the emissions for a complete trip of a vehicle. In order to more clearly demonstrate how the MOBILE emission factors are derived in association with the instantaneous modal activities, three standard FTP driving cycles are presented by Figure 23 through Figure 25. Figures 23 through 25 illustrates the FTP urban driving cycle for light-duty vehicles, FTP highway fuel economy driving cycle, and FTP driving cycle for heavy-duty vehicles. Consider Figure 23 as an example to show how the emission factors are derived. The vertical axis represents the instantaneous speed and the horizontal axis represents the time. The dots show the acceleration/deceleration rates.

The FTP urban driving cycle for light-duty vehicles consists of a cold start segment, a hot stabilized segment, and a hot start segment. Initially, the vehicle is stored for a minimum of 12 hours before testing to simulate a 12-hour overnight soak period. The vehicle is then driven over the start segment, which lasts 505 seconds, and the emissions collected are defined as Bag 1, cold start emissions. Once the vehicle is in a hot stabilized mode (engine and catalyst at normal operating temperature), Bag 2 emissions are collected over the remaining 867 seconds of driving. After a ten-minute soak, the 505 seconds of the start segment is repeated and the emissions collected are defined as Bag 3, hot start emissions. The final emission factor is derived based on the weighted sum of the emissions from three bags divided by the total miles traveled.

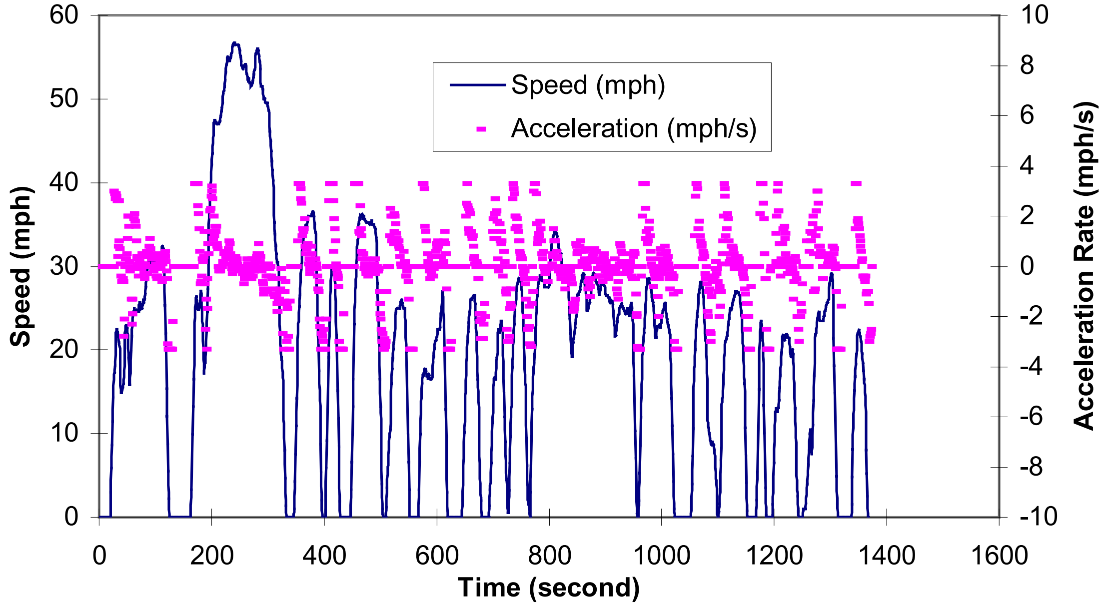

Figure 23: Time Versus Instantaneous Speed and Acceleration Rate for FTP Urban Driving Cycle for Light-Duty Vehicles

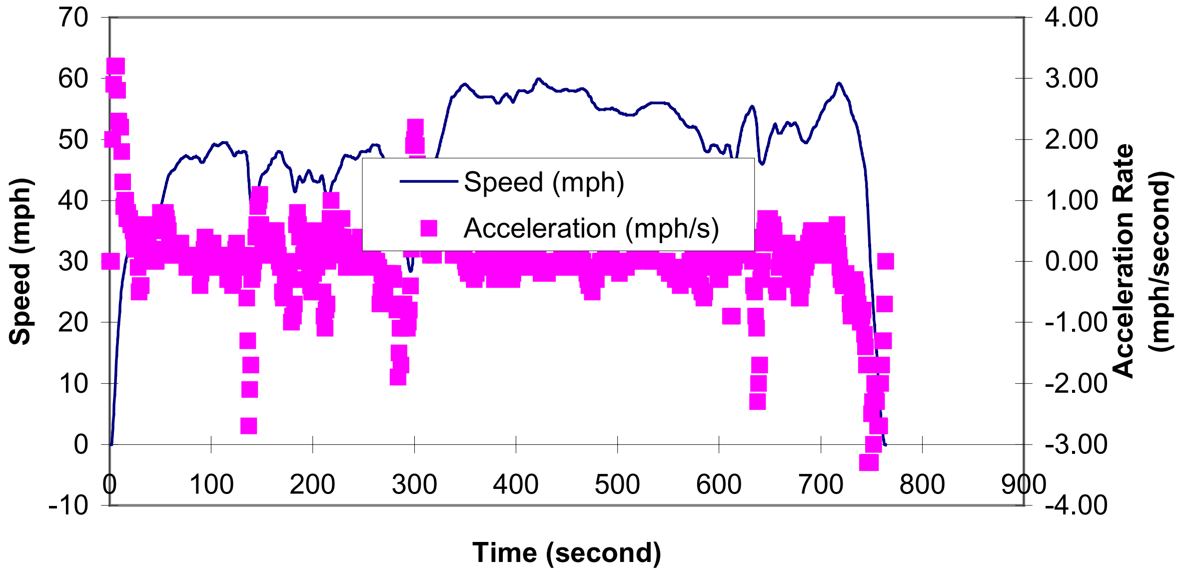

Figure 24: Time Versus Instantaneous Speed and Acceleration Rate for FTP Highway Fuel Economy Driving Cycle

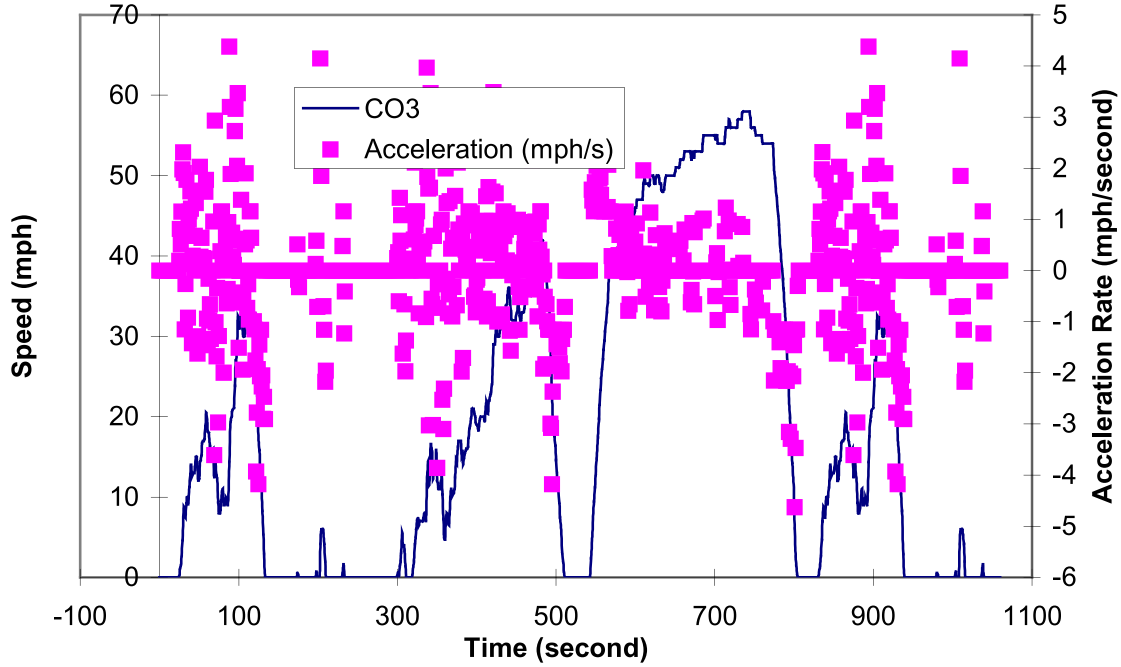

Figure 25: Time Versus Instantaneous Speed and Acceleration Rate for FTP Driving Cycle for Heavy-Duty Vehicles

In generating emission factors, the MOBILE emission factor model is implemented by inputting an average speed of 19.6 mph for the light duty vehicles and light duty trucks, and an average speed of 18.8 mph for the heavy-duty vehicles. The ambient temperature was fixed to 75°F (24°C), as which was also used in emulation of driving cycles using the emission equations developed in Section 4-1. Most of the other required parameters in MOBILE are set to the model default values, which generally represent the national average conditions. For the implementation of EMFAC, the 19.6-mph of speed is an invalid input to the model, as an integer value of speed is required. Thus, 20 mph of speed is used as an approximation to the standard FTP average speed for light duty vehicles and trucks.

The major problem proceeding the emission factor comparison effort is the inconsistency of definitions of vehicle types between the on-road-based emission regression equations, and MOBILE and EMFAC. The on-road emission equations classify all vehicles into only three types, while MOBILE incorporates eight vehicle types, and EMFAC uses 13 vehicle types. Therefore, there should be a way to convert all the emission factors for various vehicle types into a consistent vehicle type scheme, so that the emission factors derived from three different models can be appropriately compared.

It is assumed that the definition of vehicle types based on the on-road emission data is used for the emission factor comparison purpose. In other words, three vehicle types are used, which are named passenger cars, van and pick-up trucks, and other trucks. The emission factors from MOBILE and EMFAC will be combined into the same three vehicle types. For this purpose, the Houston Galveston Area Council (HGAC) 1993 vehicle's registration report is used as a reference for vehicle type information. Although this report is three years old and may not exactly represent the on-road vehicle information for our emission data collections, it is felt that actual vehicle types should not deviate too much from this report. The actual conversion of emission factors for MOBILE and EMFAC is described as follows.

For MOBILE, the LDGV will match the VT-1 and LDDV is not considered when calculating the emission factor. A combination of 75% of LDGT1 and 25% of LDDT will match the VT-2. A combination of 54% of LDT2 which includes 70% LDGT2 and 30% LDDT, and 46% of HDV which includes 60% HDGV and 40% HDDV will match VT-3. The aggregate emission factor will exclude the effect of motorcycles since no motorcycle emission data were collected during the data collection.

For the EMFAC, the emission factor that matches VT-1 is considered a combination of 50% catalyst and 50% non-catalyst gasoline vehicles without the effect of diesel vehicles. For VT-2, a combination of 50% catalyst and 50% non-catalyst, and 75% gasoline and 25% diesel vehicles are considered. For VT-3, again, catalyst and non-catalyst trucks are each counted 50%, gasoline trucks account 60% and diesel trucks account 40%, and MDTs account 54% and HDTs account 46%.

Based on what has been described above, the emission factors are derived for VT, VT-1, VT-2 and VT-3 from MOBILE and EMFAC, which are comparable to emission factors, which are derived from the on-road emission equations by emulating the various

FTP driving cycles. The emission information that can be derived from the on-road emission equations is the instantaneous emission factors or rates. If the emission rate at each of the FTP driving cycle incremental steps is calculated based on the instantaneous speed value and acceleration rate, then the full FTP driving cycles can be emulated. While the original description of the FTP driving cycles in the Code of Federal Regulation (1986) does not include the acceleration rate, it can be easily derived by figuring the differential speed for any two consecutive seconds.

Figures 26 through 29 are the resulting comparisons of CO and HC emission factors for the on-road emission equations with different cutting percentages of HEV data, EMFAC and MOBILE. Obviously, without cutting HEV data, the estimation of emission factors for on-road emission equations is much higher than MOBILE and EMFAC emission factors. In other words, both MOBILE EMFAC underestimate on-road emissions. When HEV data are removed from the database, the estimation of the on-road emission factors is much closer to MOBILE and EMFAC emission factors, especially for the urban driving cycles. For the highway economy driving cycle, it seems that both MOBILE and EMFAC emission factors are too low, much lower than even cutting 30% of HEV data. Different cutting percentages of HEV data are found to not generate significantly different emission factors. Therefore, as long as 10% HEV data are removed, the emission models will become relatively stable.

It is noted that the FTP driving cycles for the emission testing take into account the various operating conditions of vehicles such as cold start, hot start and hot stabilized. However, the on-road emission data collected for this research are considered to only represent the hot stabilized mode of vehicles. As such, the emission factors derived from the on-road emission data should be lower in theory than the emission factors from emission factor models, as the hot stabilized condition is considered the most emission efficient mode. Nonetheless, the emission factors from the on-road emission equations are virtually higher, especially for the highway fuel economy driving cycle. This further confirmed the fact that both MOBILE and EMFAC underestimate on-road emissions.

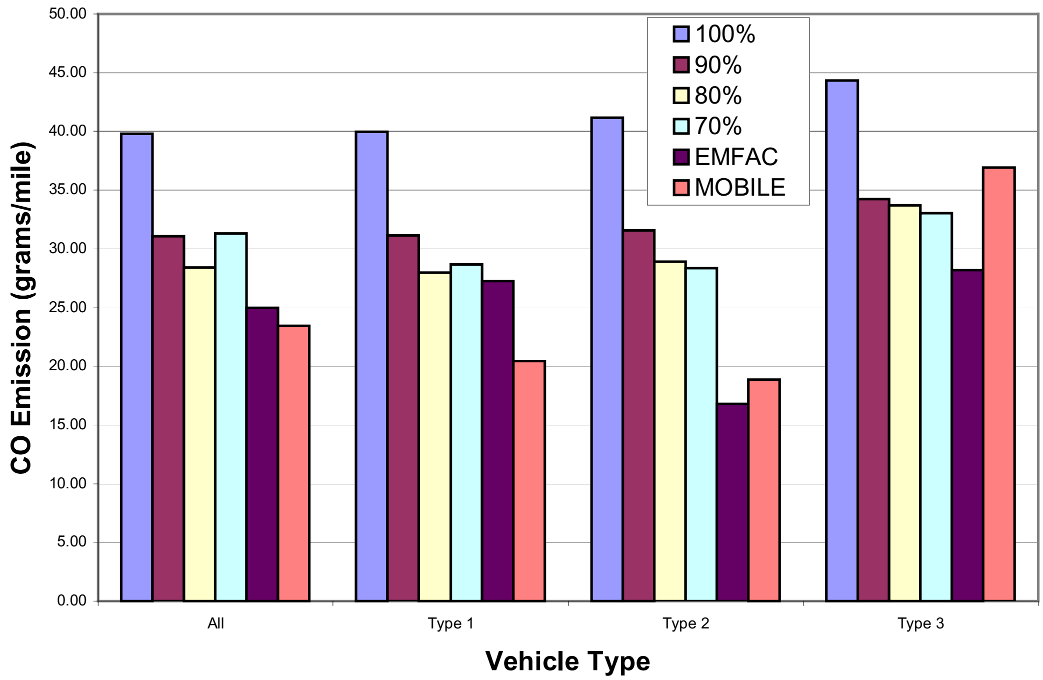

Figure 26: Comparison of CO Emission Factors for FTP Urban Driving Cycle

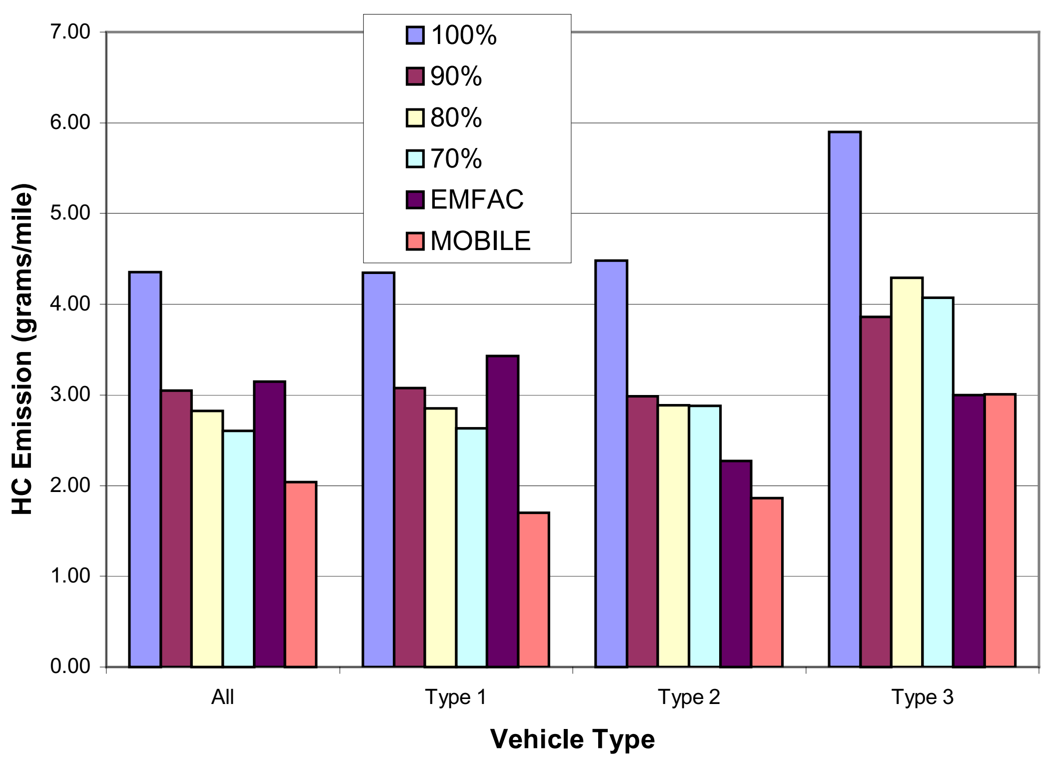

Figure 27: Comparison of HC Emission Factors for FTP Urban Driving Cycle

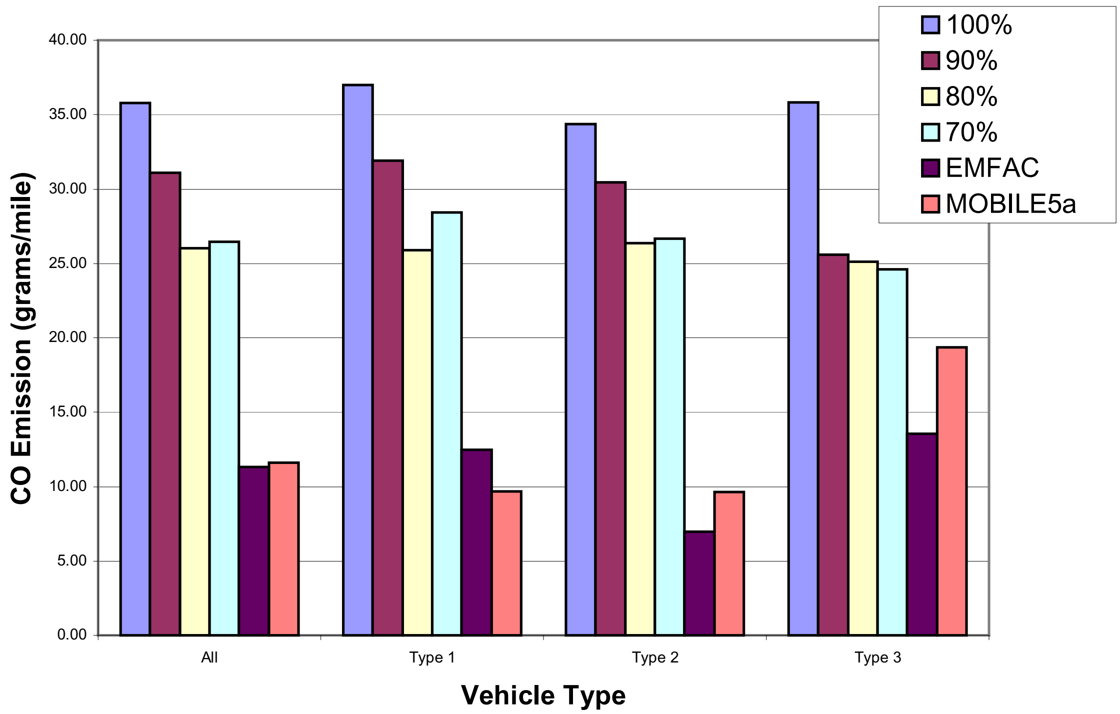

Figure 28: Comparison of CO Emission Factors for FTP Highway Fuel Economy Driving Cycle

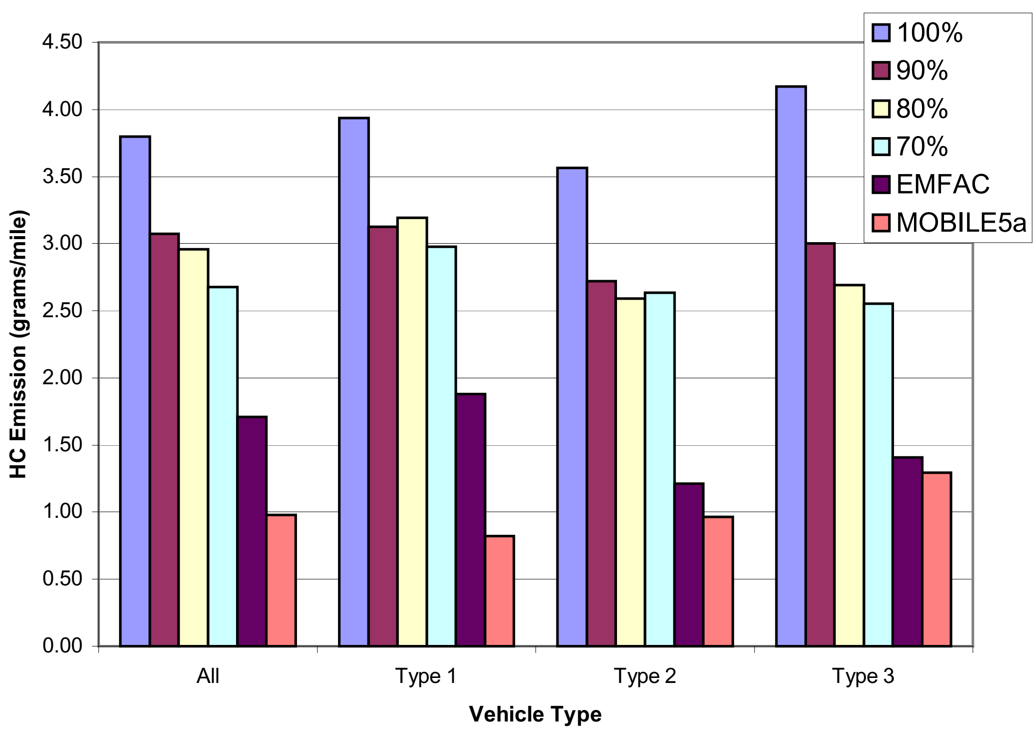

Figure 29: Comparison of HC Emission Factors for FTP Highway Fuel Economy Driving Cycle

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This research has evaluated the effects of higher emitter vehicles on the emission modeling. The on-road emission data that were collected using the remote emission sensor in Houston are used to establish a series of regression emission equations based on cutting different percentages of HEV data (0%, 10%, 20%, and 30%). The emission rates and emission factors that are generated from the established emission models are evaluated including the extrapolated idling emission rates. The on-road emission models are also compared with the widely used emission factor models MOBILE and EMFAC.

It is found that high emitter vehicles have significant effects on the emission models. Removing the small portion of the HEV data will considerably improve the quality of the emission models. This is also evidenced by the fact that cutting 20% and 30% of HEV data will not significantly improve the emission models over cutting 10% of HEV data. Further, it is found that both MOBILE and EMFAC considerably underestimate the on-road emissions. On-road emission models based on cutting 30% of HEV data still produce much higher emission estimations than MOBILE and EMFAC.

It is noted that if HEV data are removed in developing emission models, there should be an effective means to include an error factor to correct the final emission estimations in order to reflect the effects of high emitter vehicles. Otherwise, there could be a systematic error in the emission estimations that will have excluded the consideration of HEV data. Therefore, it is recommended that further research be conducted in regards to how to incorporate the error correction factor in the emission modeling process.

It should also be noted that the emission modeling process in this research has used a very rough vehicle type classification scheme. It is considered, however, that this vehicle type classification method should not affect the conclusions regarding how the HEV data will impact the vehicle emission modeling. In any emission modeling effort for practical applications, vehicle types should be classified either in a similar way to MOBILE, or in other ways that consider more detailed classes of vehicle weight, type, and technologies.

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APPENDIX A: A SAMPLE OF REMOTE EMISSION SENSING DATA

Column* 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	04-29-1996	11:19:32	10	NOPLATE	999.00	999.00	99999	0.9744	0.1323	7.4752	7.3174	0.9970	99.00	99.00	999.00	99999	0.0000	0.0000
2	04-29-1996	11:20:37	10	DUF40P	0.02	15.03	0	0.0014	-0.0020	0.4797	0.0292	0.0037	50.04	50.10	0.53	99999	0.0050	0.0000
3	04-29-1996	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	-0.0200	0.0000
4	04-29-1996	11:20:51	10	GGX16F	999.00	999.00	99999	-0.0317	-0.0055	0.1364	0.0418	0.0060	36.42	36.46	0.21	99999	0.0260	0.0000
5	04-29-1996	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	0.0440	0.0000
6	04-29-1996	11:21:37	10	KA0991	999.00	999.00	99999	-5.4591	-0.0557	0.0189	0.1885	0.0042	30.67	30.50	-0.74	99999	9.9900	0.0000
7	04-29-1996	11:21:47	10	0334TD	999.00	999.00	99999	0.0870	0.0020	0.1772	0.0967	0.0090	38.99	38.75	-1.37	99999	0.0410	0.0000
8	04-29-1996	11:22:17	10	HLM97L	4.74	11.65	0	0.4069	-0.0010	0.3205	0.1521	0.0144	50.44	50.44	0.00	99999	0.0260	0.0000
9	04-29-1996	11:22:24	10	5902YY	999.00	999.00	99999	0.0350	0.0017	0.7677	0.0729	0.0152	46.59	46.61	0.21	99999	0.0050	0.0000
10	04-29-1996	11:22:30	10	HRV32X	0.39	14.77	25	0.0264	0.0002	2.0840	0.0714	0.0080	36.25	36.52	1.70	300	0.0020	0.0000
11	04-29-1996	11:22:37	10	VJP73K	0.07	15.00	25	0.0047	0.0002	1.4358	0.0469	0.0052	36.12	36.41	1.70	395	0.0020	0.0000
12	04-29-1996	11:22:49	10	U	0.51	14.69	0	0.0345	-0.0002	2.8852	0.1361	0.0152	53.33	53.30	-0.29	92	0.0000	0.0000
13	04-29-1996	11:22:53	10	KVG58V	999.00	999.00	99999	-3.5648	0.0845	0.0070	0.0595	0.0120	55.96	56.03	0.79	99999	-0.2990	0.0000
14	04-29-1996	11:23:14	10	HKT51D	0.06	15.01	0	0.0039	-0.0009	0.9551	0.0768	0.0207	33.46	33.80	2.06	99999	0.0060	0.0000
15	04-29-1996	11:23:30	10	UU2222	0.00	15.10	0	-0.0041	-0.0002	1.0740	0.0745	0.0128	57.69	57.90	1.73	0	-0.0030	0.0000
16	04-29-1996	11:23:38	10	KFJ52Z	0.01	15.05	195	0.0009	0.0013	1.2474	0.0714	0.0199	42.17	42.32	1.03	0	-0.0110	0.0000
17	04-29-1996	11:23:41	10	900XYU	999.00	999.00	99999	0.0926	-0.0022	0.2791	0.0423	0.0038	36.93	36.82	-0.74	99999	0.0390	0.0000
18	04-29-1996	11:23:44	10	STZ33P	0.00	15.12	8	-0.0064	0.0001	3.2768	0.0743	0.0054	36.29	36.47	1.11	263	0.0010	0.0000
19	04-29-1996	11:23:56	10	NV9431	0.34	14.81	0	0.0230	-0.0014	0.4427	0.1209	0.0180	50.41	50.56	1.37	99999	-0.0170	0.0000
20	04-29-1996	11:24:09	10	GH2027	9.30	8.39	205	1.1084	0.0024	0.1788	0.1878	0.0125	42.76	42.94	1.28	99999	0.0000	0.0000
21	04-29-1996	11:24:12	10	DCM73U	0.28	14.84	0	0.0187	-0.0057	0.3666	0.0465	0.0076	42.32	42.34	0.16	99999	0.0190	0.0000
22	04-29-1996	11:24:15	10	WJB47Z	999.00	999.00	99999	0.0848	-0.0102	0.1694	0.0849	0.0176	43.61	43.47	-0.95	99999	0.0920	0.0000
23	04-29-1996	11:24:21	10	NOPLATE	999.00	999.00	99999	-0.0681	-0.0156	0.1491	0.0578	0.0145	43.03	42.99	-0.34	99999	0.0320	0.0000
24	04-29-1996	11:24:25	10	P	999.00	999.00	99999	0.3852	0.0037	0.0311	0.0765	0.0202	57.73	57.41	-3.11	99999	-0.2920	0.0000
25	04-29-1996	11:24:38	10	NOPLATE	0.27	14.86	77	0.0182	0.0005	3.5995	0.0908	0.0062	38.84	39.18	0.98	1102	0.0070	0.0000
26	04-29-1996	11:24:41	10	CK7537	3.70	12.40	0	0.2982	-0.0006	1.0100	0.3359	0.0121	34.60	34.63	0.16	1143	0.0090	0.0000
27	04-29-1996	11:24:44	10	CLX90L	999.00	999.00	99999	0.3595	-0.0059	0.1754	0.0914	0.0109	46.88	46.77	-0.86	99999	-0.0390	0.0000
28	04-29-1996	11:24:50	10	GHF20N	1.04	14.31	460	0.0726	0.0032	0.5312	0.0463	0.0050	43.33	43.51	1.39	99999	-0.0130	0.0000
29	04-29-1996	11:24:54	10	VZJ84K	0.19	14.91	0	0.0126	-0.0022	0.8177	0.0867	0.0107	39.75	39.85	0.63	99999	-0.0060	0.0000
30	04-29-1996	11:24:57	10	ME2845	0.40	14.76	0	0.0270	-0.0027	0.5879	0.0397	0.0083	42.17	42.13	-0.25	99999	0.0070	0.0000
31	04-29-1996	11:25:00	10	DU3882	999.00	999.00	99999	0.0711	0.0055	0.4075	0.0474	0.0112	41.32	41.36	0.28	99999	-0.0100	0.0000
32	04-29-1996	11:25:04	10	U	999.00	999.00	99999	0.0738	-0.0030	1.1528	0.0970	0.0134	42.85	43.08	1.39	99999	0.0000	0.0000
33	04-29-1996	11:25:15	10	682OXC	999.00	999.00	99999	-0.0157	0.0138	0.2266	0.0772	0.0116	41.97	41.87	-0.60	99999	0.0130	0.0000
34	04-29-1996	11:25:25	10	EYO585	5.19	11.34	348	0.4578	0.0031	0.2463	0.1179	0.0111	47.02	46.77	-1.74	99999	0.0180	0.0000
35	04-29-1996	11:25:29	10	U	0.31	14.84	4	0.0206	0.0000	0.7373	0.0677	0.0114	46.38	46.48	0.79	99999	-0.0010	0.0000
36	04-29-1996	11:25:34	10	U	0.00	15.10	0	-0.0045	-0.0010	1.0436	0.0837	0.0179	41.51	41.74	1.29	976	0.0060	0.0000
37	04-29-1996	11:25:54	10	8451ZU	0.92	14.39	0	0.0637	-0.0015	1.0343	0.0867	0.0134	43.19	43.35	1.09	732	0.0050	0.0000
38	04-29-1996	11:26:29	10	BM2689	5.97	10.77	76	0.5546	0.0007	0.6970	0.3899	0.0160	47.43	47.73	1.99	99999	-0.0070	0.0000
39	04-29-1996	11:26:39	10	KHC35B	0.29	14.84	0	0.0196	-0.0007	0.5516	0.0948	0.0131	45.60	46.12	3.93	99999	0.0230	0.0000
40	04-29-1996	11:26:44	10	DT9877	999.00	999.00	99999	0.4755	-0.0026	0.2273	0.0973	0.0151	38.77	39.07	1.99	99999	-0.0680	0.0000
41	04-29-1996	11:26:48	10	U	999.00	999.00	99999	-0.0490	-0.0032	1.0800	0.1613	0.0183	45.50	45.73	1.41	99999	0.0070	0.0000
42	04-29-1996	11:26:55	10	MKG24R	999.00	999.00	99999	0.2212	-0.0018	0.1056	0.0786	0.0109	39.35	39.41	0.38	99999	0.0500	0.0000
43	04-29-1996	11:27:00	10	JXD24P	999.00	999.00	99999	0.1667	0.0084	0.1526	0.0519	0.0088	41.44	41.30	-1.07	99999	0.0200	0.0000
44	04-29-1996	11:27:08	10	MKH23T	0.17	14.93	0	0.0112	-0.0011	0.6605	0.0828	0.0144	43.28	43.65	2.77	99999	0.0010	0.0000
45	04-29-1996	11:27:13	10	1465WD	999.00	999.00	99999	0.0924	0.0006	0.7860	0.2283	0.0114	39.25	39.41	0.98	99999	-0.0070	0.0000
46	04-29-1996	11:27:26	10	SE3337	999.00	999.00	99999	0.0120	-0.0223	0.0360	0.0549	0.0146	44.83	44.73	-0.68	99999	-0.1590	0.0000
47	04-29-1996	11:27:31	10	U	999.00	999.00	99999	1.0265	0.1384	6.2229	6.4354	0.8638	45.42	45.99	1.91	99999	-0.0080	0.0000
48	04-29-1996	11:27:34	10	U	0.79	14.51	99999	0.0545	0.0098	0.6107	0.1051	0.0163	42.59	42.48	-0.68	99999	0.0170	0.0000
49	04-29-1996	11:27:38	10	PRY41M	0.29	14.84	0	0.0194	-0.0016	1.2714	0.0627	0.0078	39.09	39.33	1.66	1835	0.0120	0.0000
50	04-29-1996	11:27:48	10	U	3.47	12.60	2850	0.2754	0.0226	1.1360	0.3367	0.0286	36.28	36.59	1.62	174	0.0010	0.0000

*Explanation of Columns:

Column 1. Vehicle No.

Column 2. Date of Data Collection.

Column 3. Time of Data Collection.

Column 4. Sensor No.

Column 5. License Plate No. of the Vehicle Detected.

Column 6. CO%.

Column 7. CO_2%.

Column 8. HC%.

Column 9. Slope CO (used for calibration of the sensor).

Column 10. Slope HC (used for calibration of the sensor).

Column 11. Maximum CO_2.

Column 12. Maximum CO.

Column 13. Maximum HC.

Column 14. Speed 1 in miles per hour.

Column 15. Speed 2 in miles per hour.

Column 16. Acceleration Rate in mph/second.

Column 17. NOx%.

Column 18. Slope NOx (used for calibration of the sensor).

Column 19. Maximum NOx.

APPENDIX B: CHARTS OF COLLECTED EMISSION DATA

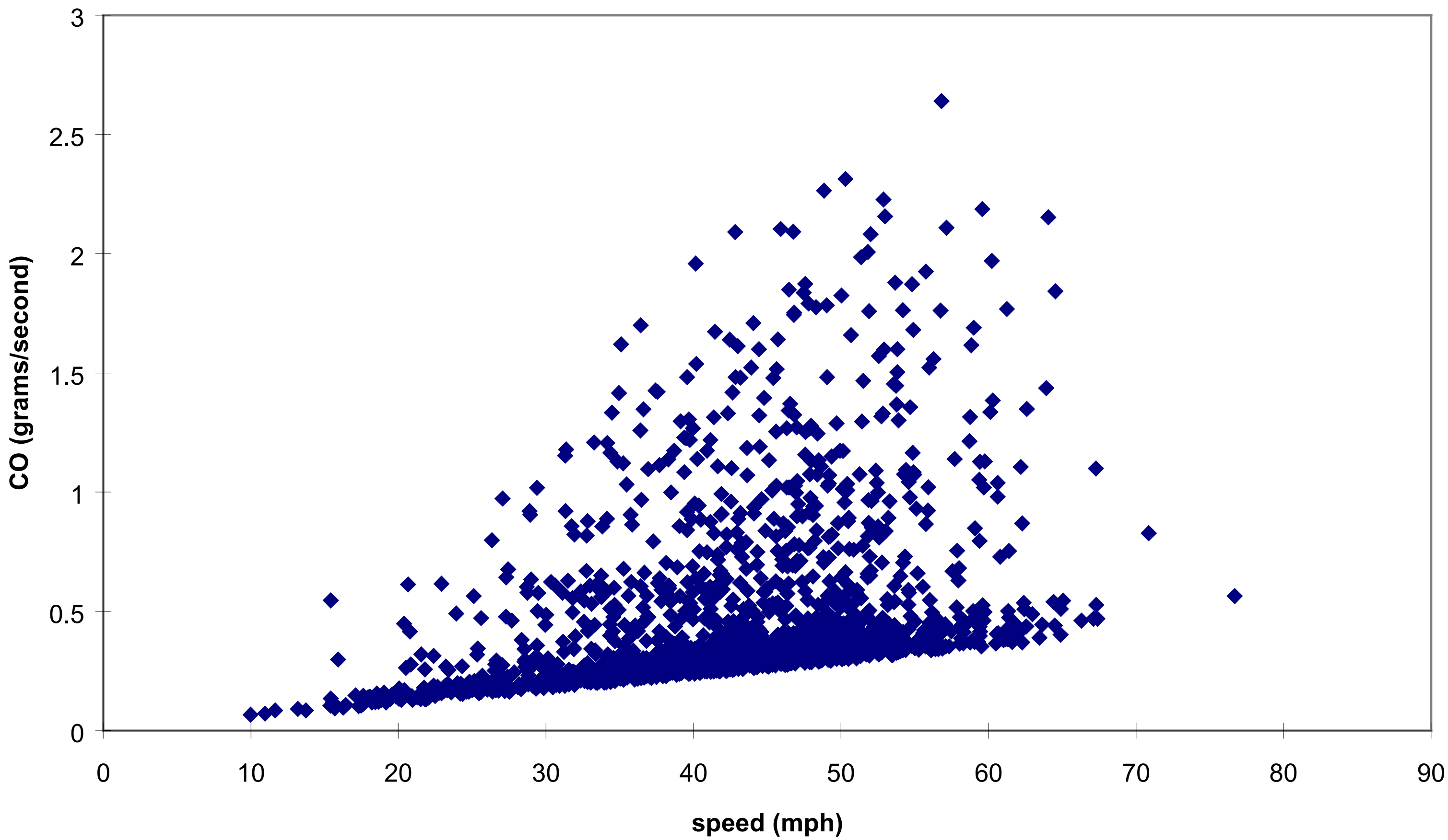

Figure B-1: Aggregate CO emission rates versus instantaneous speed values

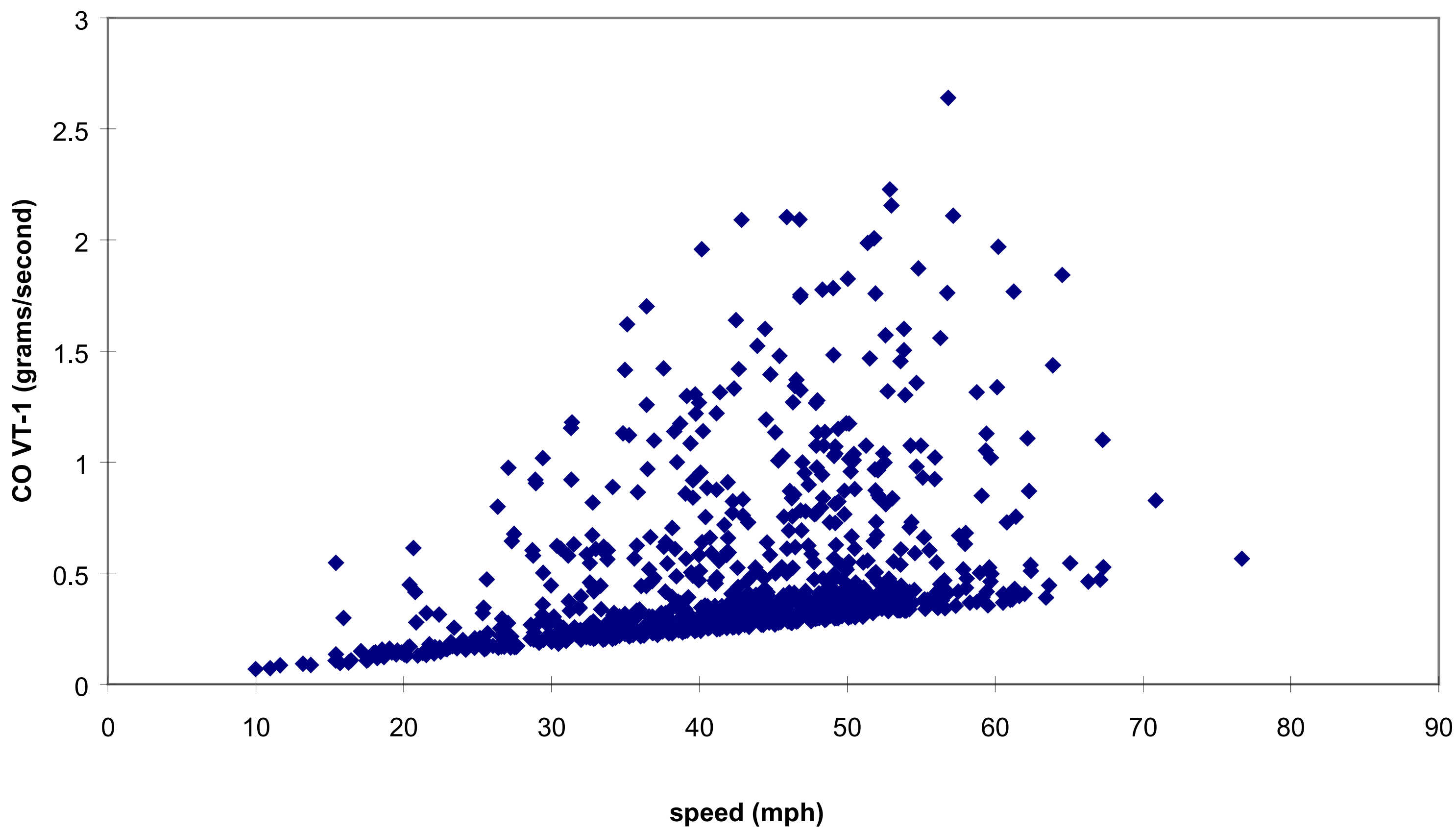

Figure B-2: CO emission rates versus instantaneous speed values for vehicle type 1

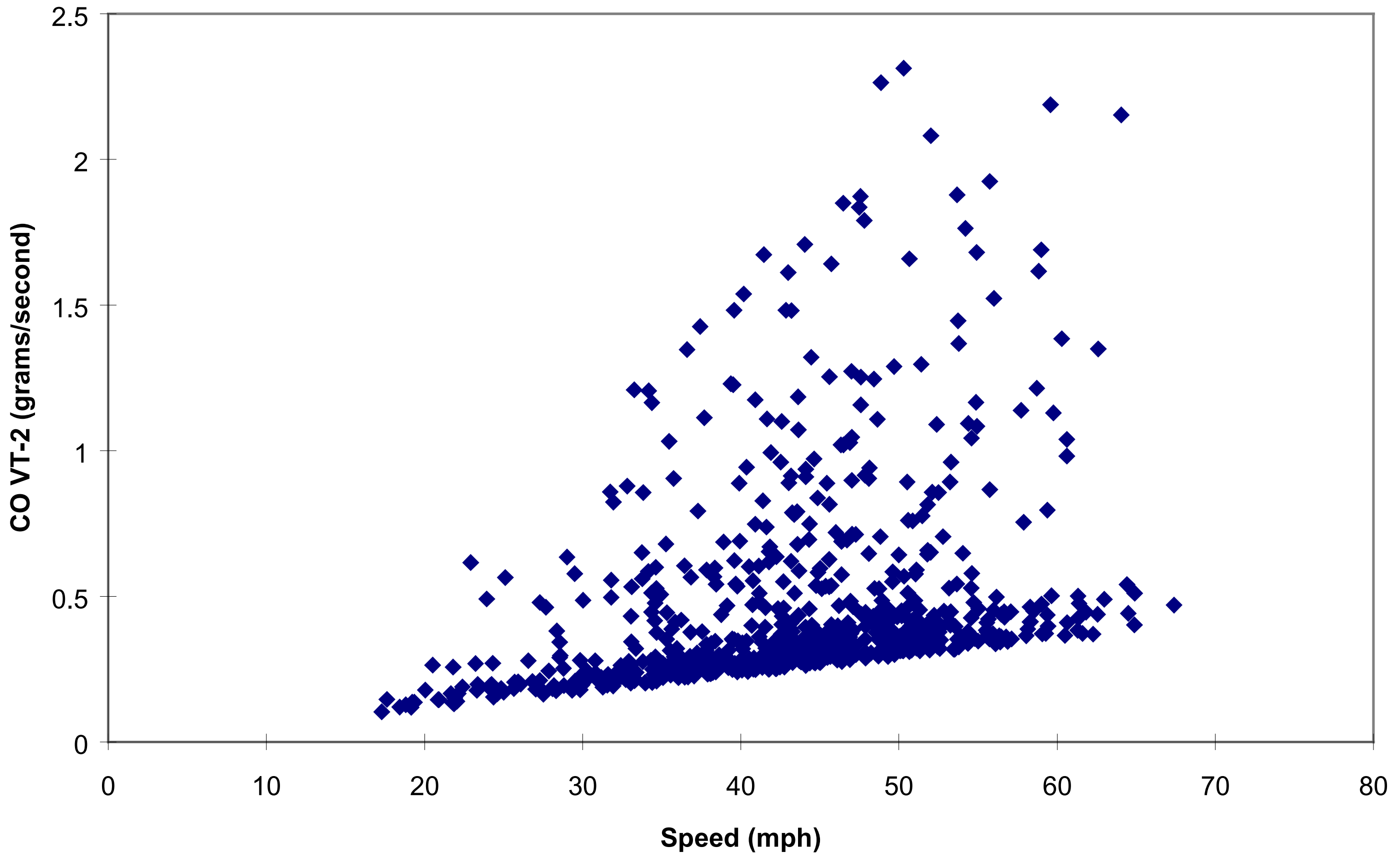

Figure B-3: CO emission rates versus instantaneous speed values for vehicle type 2

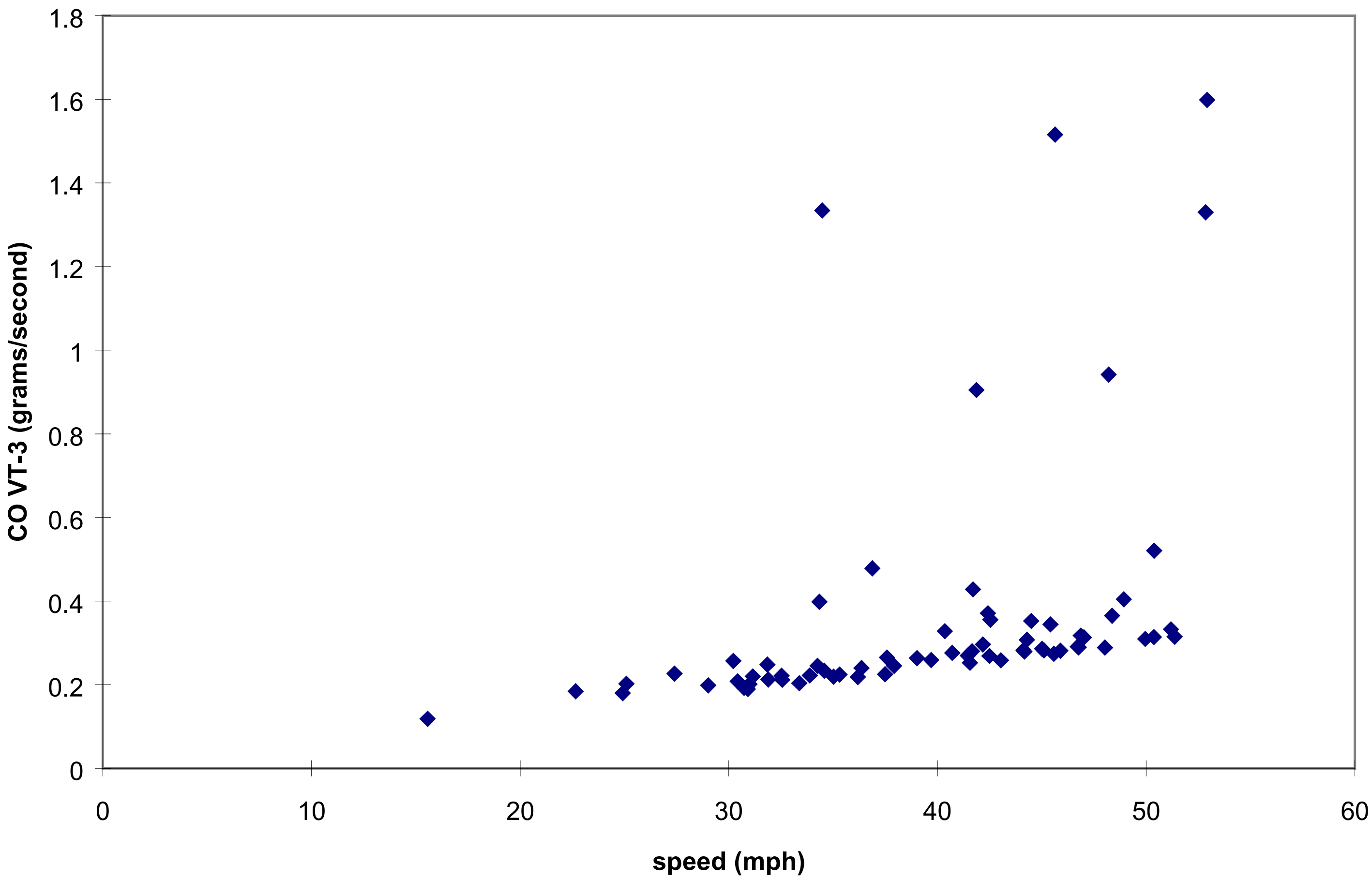

Figure B-4: CO emission rates versus instantaneous speed values for vehicle type 3

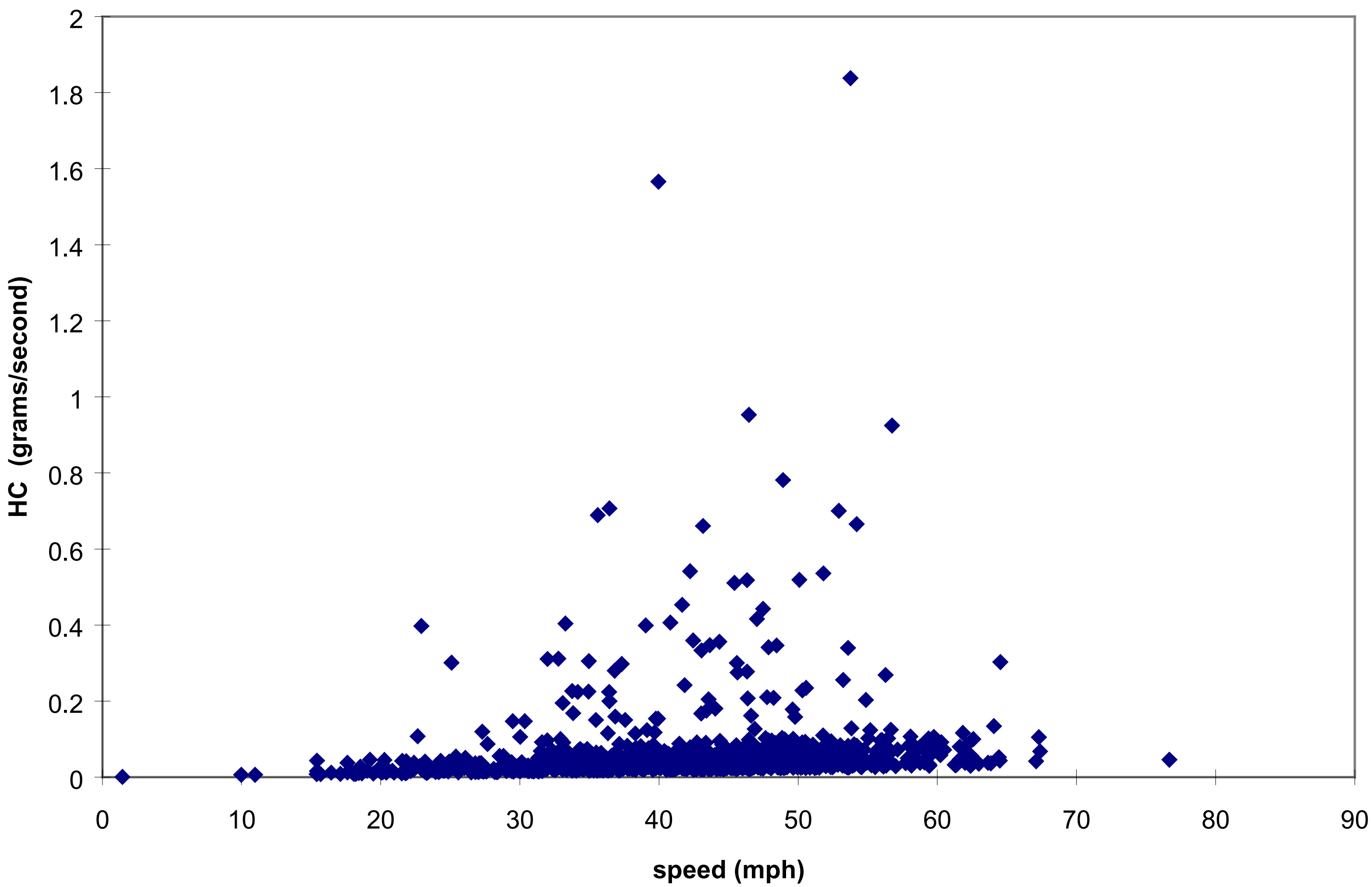

Figure B-5: Aggregate HC emission rates versus instantaneous speed values

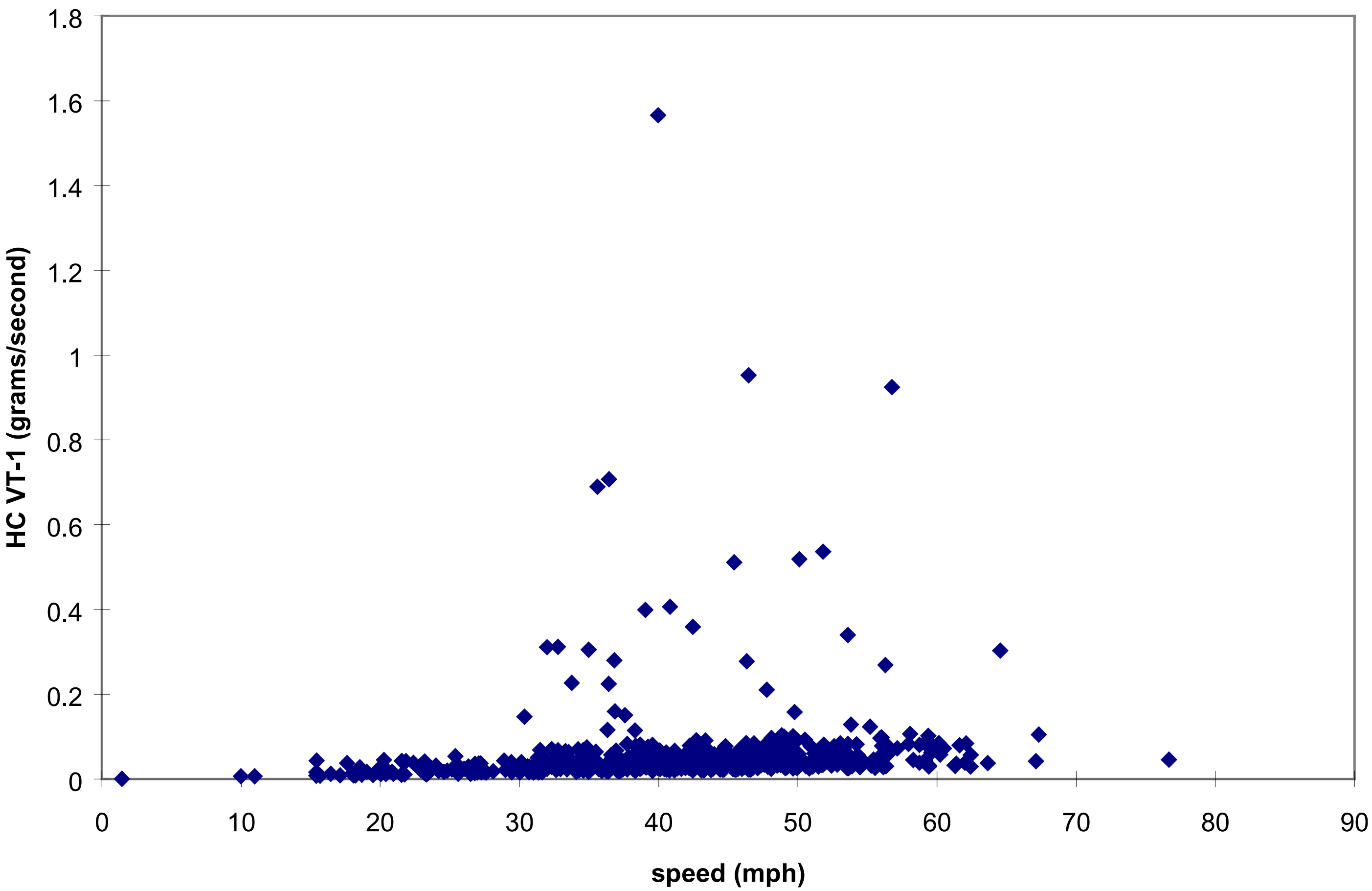

Figure B-6: HC emission rates versus instantaneous speed values for vehicle type 1

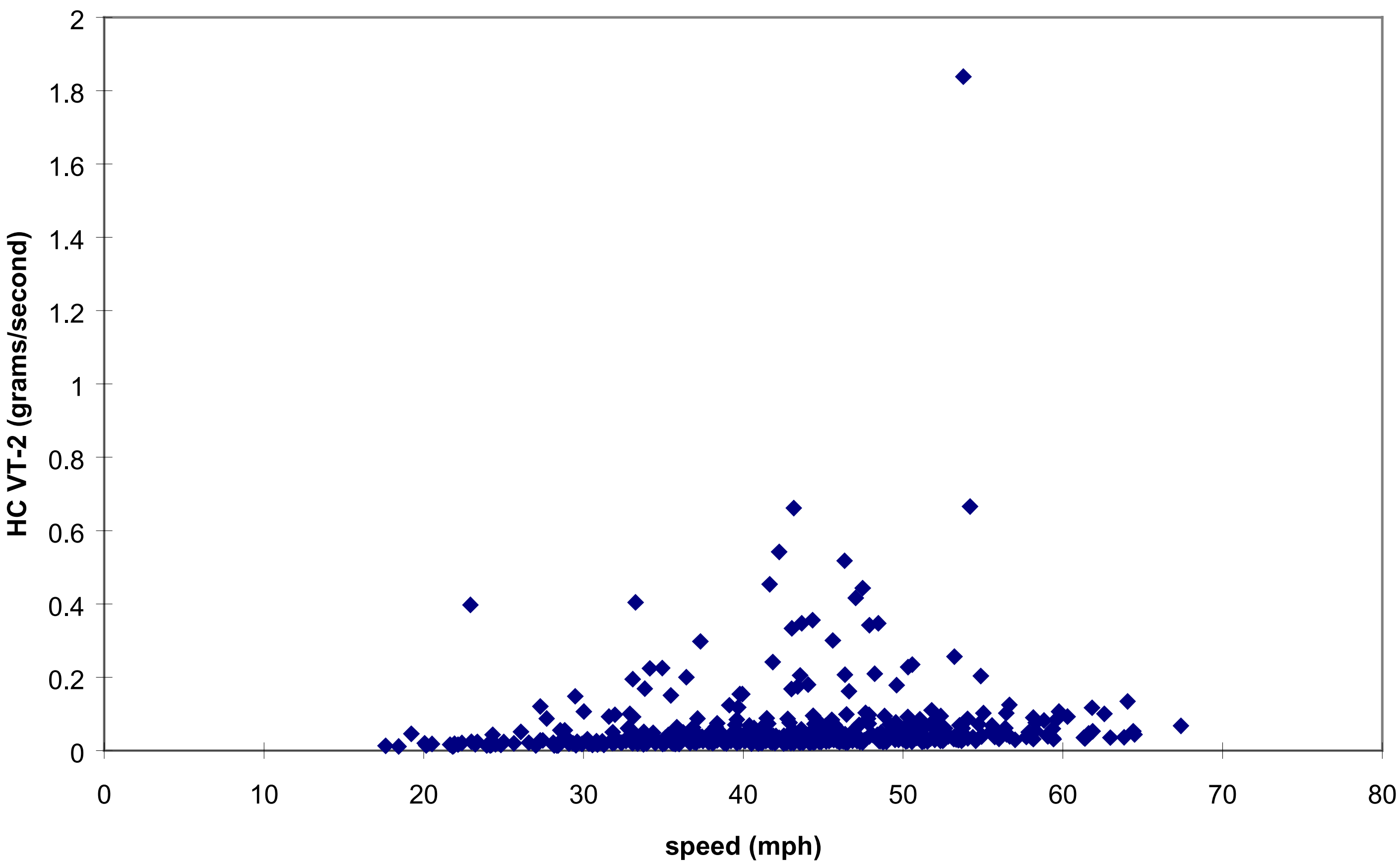

Figure B-7: HC emission rates versus instantaneous speed values for vehicle type 2

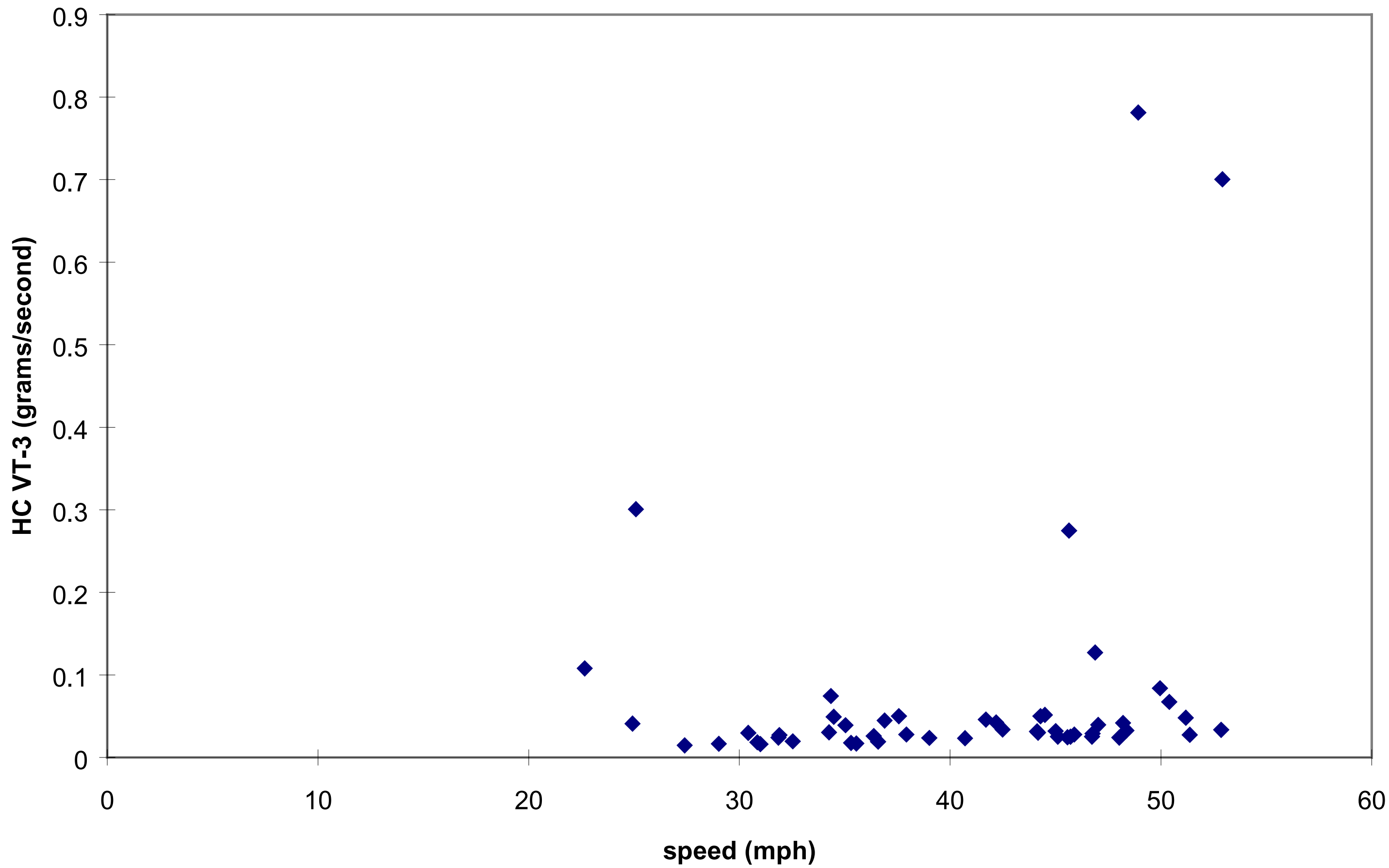

Figure B-8: HC emission rates versus instantaneous speed values for vehicle type 3

APPENDIX C: SUMMARY OF REGRESSION TABLES

TABLE C-1 Summary of Regression Analysis for CO with 100% of Data

LN (CO) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 1786
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-2.9099	0.0000	-2.9090	0.0000	-2.8346	0.0000	-2.904651	0.0000	-2.2182	0.0000
B	0.0664	0.0000	0.0664	0.0000	0.0656	0.0000	0.065628	0.0000	0.0300	0.0000
C	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.000436	0.0000		
D	-0.0178	0.0055	-0.0178	0.0055	-0.0177	0.0056	-0.018186	0.0044	-0.0184	0.0042
E	0.0001	**0.9567**								
F	0.0006	0.6704	0.0006	**0.6692**						
G	-0.1233	0.3020	-0.1228	0.3025	-0.1484	**0.1497**				
Coef. Corrl. R	0.5209		0.5209		0.5208		0.5200		0.5100	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-2 Summary of Regression Analysis for CO with 90% of Data

LN (CO) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 1593
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-2.8628	0.0000	-2.8651	0.0000	-2.9346	0.0000	-2.9747	0.0000	-2.9791	0.0000
B	0.0621	0.0000	0.0622	0.0000	0.0629	0.0000	0.0629	0.0000	0.0629	0.0000
C	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000
D	-0.0098	0.0246	-0.0098	0.0249	-0.0098	0.0244	-0.0101	**0.0203**		
E	-0.0002	**0.8293**								
F	-0.0006	0.5575	-0.0006	**0.5555**						
G	-0.1095	0.1747	-0.1107	0.1685	-0.0869	**0.2111**				
Coef. Corrl. R	0.6815		0.6815		0.6814		0.6810		0.6797	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-3 Summary of Regression Analysis for CO with 80% of Data

LN (CO) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 1419 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-3.0520	0.0000	-3.0493	0.0000	-3.0155	0.0000	-2.9519	0.0000		
B	0.0599	0.0000	0.0598	0.0000	0.0596	0.0000	0.0588	0.0000		
C	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000		
D	-0.0075	0.0097	-0.0076	0.0091	-0.0075	0.0098	-0.0075	0.0094		
E	0.0002	**0.7303**								
F	0.0008	0.2133	0.0008	0.2126	0.0006	**0.2704**				
G	0.0304	0.5772	0.0318	**0.5587**						
Coef. Corrl. R	0.8156		0.8156		0.8155		0.8153			
F-test	0.0000		0.0000		0.0000		0.0000			

TABLE C-4 Summary of Regression Analysis for CO with 70% of Data

LN (CO) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 1243 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-0.0156	0.5161	-0.0076	0.7059	0.0023	0.8802	-2.3961	0.0000	-2.3954	0.0000
B	0.0068	0.0000	0.0067	0.0000	0.0066	0.0000	0.0275	0.0000	0.0275	0.0000
C	0.0000	0.2887	0.0000	0.2724	0.0000	**0.2025**				
D	-0.0016	0.0170	-0.0015	0.0184	-0.0015	0.0184	-0.0056	0.0067	-0.0056	0.0065
E	0.0003	0.0337	0.0003	0.0301	0.0003	0.0315	0.0002	**0.5342**		
F	0.0001	0.3423	0.0001	**0.4567**						
G	0.0077	**0.5429**								
Coef. Corrl. R	0.8662		0.8662		0.8661		0.8959		0.8959	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-5 Summary of Regression Analysis for CO Type 1 with 100% of Data

LN (CO1) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 946 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test
A	-2.7415	0.0000	-2.7735	0.0000	-2.7673	0.0000	-2.893427	0.0000	-2.2493	0.0000
B	0.0653	0.0000	0.0656	0.0000	0.0653	0.0000	0.065474	0.0000	0.0312	0.0000
C	-0.0004	0.0002	-0.0004	0.0001	-0.0004	0.0001	-0.000425	0.0002		
D	-0.0271	0.0028	-0.0271	0.0028	-0.0271	0.0028	-0.027166	0.0027	-0.0270	0.0030
E	0.0005	0.7983	0.0005	**0.7996**						
F	-0.0003	**0.8938**								
G	-0.2782	0.0930	-0.2673	0.0636	-0.2658	**0.0648**				
Coef. Corrl. R	0.5510		0.5510		0.5510		0.5487		0.5388	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-6 Summary of Regression Analysis for CO Type 1 with 90% of Data

LN (CO1) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 856 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test
A	-2.9166	0.0000	-2.9400	0.0000	-2.9257	0.0000	-2.9968	0.0000	-3.0092	0.0000
B	0.0642	0.0000	0.0644	0.0000	0.0637	0.0000	0.0637	0.0000	0.0640	0.0000
C	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000
D	-0.0124	0.0617	-0.0124	0.0618	-0.0121	0.0686	-0.0121	**0.0671**		
E	0.0013	0.3446	0.0013	**0.3449**						
F	-0.0002	**0.8938**								
G	-0.1655	0.1711	-0.1575	0.1339	-0.1533	**0.1442**				
Coef. Corrl. R	0.6886		0.6886		0.6882		0.6872		0.6857	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-7 Summary of Regression Analysis for CO Type 1 with 80% of Data

LN (CO1) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 762
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-2.8490	0.0000	-2.8493	0.0000	-2.9343	0.0000	-2.9733	0.0000	-2.9817	0.0000
B	0.0584	0.0000	0.0584	0.0000	0.0592	0.0000	0.0591	0.0000	0.0593	0.0000
C	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000
D	-0.0082	0.0805	-0.0082	0.0802	-0.0082	0.0827	-0.0082	**0.0811**		
E	0.0000	**0.9825**								
F	-0.0007	0.4854	-0.0007	**0.4853**						
G	-0.1172	0.1665	-0.1173	0.1657	-0.0881	**0.2306**				
Coef. Corrl. R	0.8092		0.8092		0.8091		0.8087		0.8078	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-8 Summary of Regression Analysis for CO Type 1 with 70% of Data

LN (CO1) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 672
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-3.0642	0.0000	-3.0668	0.0000	-3.0471	0.0000	-2.9379	0.0000	-2.9464	0.0000
B	0.0570	0.0000	0.0570	0.0000	0.0563	0.0000	0.0551	0.0000	0.0553	0.0000
C	-0.0003	0.0000	-0.0003	0.0000	-0.0003	0.0000	-0.0003	0.0000	-0.0003	0.0000
D	-0.0071	0.0210	-0.0071	0.0209	-0.0071	0.0217	-0.0071	**0.0217**		
E	0.0011	0.0746	0.0011	**0.0744**						
F	0.0011	0.1038	0.0011	0.0596	0.0011	**0.0696**				
G	-0.0026	**0.9641**								
Coef. Corrl. R	0.9036		0.9036		0.9031		0.9026		0.9018	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-9 Regression Analysis for CO Type 2 with 100% of Data

LN (CO2) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 770 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-3.3608	0.0000	-3.3727	0.0000	-3.2219	0.0000	-3.2233	0.0000	-2.9814	0.0000	-2.1076	0.0000
B	0.0749	0.0000	0.0756	0.0000	0.0743	0.0000	0.0743	0.0000	0.0708	0.0000	0.0270	0.0000
C	-0.0006	0.0003	-0.0006	0.0002	-0.0006	0.0003	-0.0006	0.0003	-0.0005	0.0005		
D	-0.0082	0.3760	-0.0082	0.3793	-0.0073	**0.4266**						
E	-0.0006	**0.7381**										
F	0.0030	0.1481	0.0030	0.1519	0.0022	0.2184	0.0022	**0.2160**				
G	0.1369	0.4437	0.1306	**0.4622**								
Coef. Corrl. R	0.4726		0.4725		0.4719		0.4712		0.4696		0.4563	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-10 Regression Analysis for CO Type 2 with 90% of Data

LN (CO2) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 700 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-3.1508	0.0000	-3.1063	0.0000	-3.1219	0.0000	-3.0236	0.0000	-3.0141	0.0000
B	0.0700	0.0000	0.0696	0.0000	0.0703	0.0000	0.0688	0.0000	0.0683	0.0000
C	-0.0005	0.0000	-0.0005	0.0000	-0.0005	0.0000	-0.0005	0.0000	-0.0005	0.0000
D	-0.0090	0.1729	-0.0088	0.1818	-0.0085	0.1921	-0.0086	**0.1880**		
E	-0.0006	0.6567	-0.0005	**0.6807**						
F	0.0011	0.4528	0.0009	0.4902	0.0009	**0.4823**				
G	0.0395	**0.7547**								
Coef. Corrl. R	0.6030		0.6029		0.6028		0.6024		0.6011	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-11 Summary of Regression Analysis for CO Type 2 with 80% of Data

LN (CO2) = $A+Bs+Cs^2+Da+Ea^2+Ft+Gh$, Total Number of Data = 620

s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-3.0615	0.0000	-3.0572	0.0000	-2.9771	0.0000	-2.9648	0.0000	-3.0274	0.0000
B	0.0674	0.0000	0.0672	0.0000	0.0661	0.0000	0.0657	0.0000	0.0657	0.0000
C	-0.0005	0.0000	-0.0005	0.0000	-0.0005	0.0000	-0.0005	0.0000	-0.0005	0.0000
D	-0.0052	0.2484	-0.0054	0.2283	-0.0052	**0.2395**	-0.1279	**0.0726**		
E	0.0003	**0.7609**								
F	0.0006	0.5586	0.0006	**0.5496**						
G	-0.0958	0.2584	-0.0926	0.2706	-0.1189	0.0969				
Coef. Corrl. R	0.7471		0.7470		0.7468		0.7462		0.7446	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-12 Summary of Regression Analysis for CO Type 2 with 70% of Data

LN (CO2) = $A+Bs+Cs^2+Da+Ea^2+Ft+Gh$, Total Number of Data = 547

s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-3.0318	0.0000	-3.0557	0.0000	-3.0070	0.0000	-3.0050	0.0000	-2.987140	0.0000
B	0.0615	0.0000	0.0617	0.0000	0.0609	0.0000	0.0608	0.0000	0.059988	0.0000
C	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.0004	0.0000	-0.000414	0.0000
D	-0.0024	0.4232	-0.0025	0.3938	-0.0026	**0.3865**				
E	0.0005	0.3501	0.0005	0.3668	0.0005	0.3701	0.0005	**0.3521**		
F	0.0003	0.6591	0.0004	**0.4567**						
G	-0.0204	**0.7229**								
Coef. Corrl. R	0.8743		0.8742		0.8741		0.8739		0.8737	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-13 Summary of Regression Analysis for CO Type 3 with 100% of Data

LN (CO3) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 70 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-1.8908	0.1390	-1.8762	0.0507	-1.7902	0.0000	-1.7601	0.0000	-1.9736	0.0000	-1.9798	0.0000
B	0.0048	0.9216	0.0047	**0.9215**								
C	0.0004	0.4876	0.0004	0.4841	0.0005	0.0000	0.0005	0.0000	0.0005	0.0000	0.0005	0.0000
D	0.0204	0.6860	0.0204	0.6815	0.0204	**0.6797**						
E	-0.0315	0.3070	-0.0316	0.2997	-0.0315	0.2971	-0.0245	0.3239	-0.0254	**0.3038**		
F	0.0001	**0.9861**										
G	-0.3996	0.6063	-0.4062	0.5461	-0.4043	0.5447	-0.4362	**0.5080**				
Coef. Corrl. R	0.6004		0.6004		0.6003		0.5989		0.5953		0.5865	
F-test	0.0001		0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-14 Summary of Regression Analysis for CO Type 3 with 90% of Data

LN (CO3) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 61 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-2.4271	0.0000	-2.6043	0.0000	-2.7089	0.0000	-2.6871	0.0000	-2.3045	0.0000	-2.3493	0.0000
B	0.0484	0.0038	0.0492	0.0031	0.0488	0.0033	0.0468	0.0046	0.0250	0.0000	0.0259	0.0000
C	-0.0003	0.1149	-0.0004	0.1078	-0.0003	0.1201	-0.0003	**0.1702**	-0.0314	**0.0221**		
D	-0.0467	0.0092	-0.0481	0.0066	-0.0466	0.0081	-0.0339	0.0139				
E	0.0126	0.2181	0.0132	0.1900	0.0119	**0.2342**						
F	-0.0014	**0.5410**										
G	-0.3175	0.2395	-0.2297	**0.3103**								
Coef. Corrl. R	0.8682		0.8672		0.8645		0.8607		0.8556		0.8405	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-15 Summary of Regression Analysis for CO Type 3 with 80% of Data

LN (CO3) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 58 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-2.9642	0.0000	-2.6682	0.0000	-2.6001	0.0000	-2.5891	0.0000	-2.3353	0.0000	-2.3623	0.0000
B	0.0402	0.0034	0.0401	0.0035	0.0410	0.0027	0.0398	0.0036	0.0253	0.0000	0.0258	0.0000
C	-0.0002	0.2635	-0.0002	0.2441	-0.0002	0.2019	-0.0002	**0.2667**	-0.0220	**0.0550**		
D	-0.0378	0.0190	-0.0349	0.0276	-0.0365	0.0200	-0.0236	0.0416				
E	0.0118	0.1904	0.0100	0.2580	0.0109	**0.2139**						
F	0.0023	**0.2743**										
G	0.3626	0.1806	0.1713	**0.4046**								
Coef. Corrl. R	0.9063		0.9039		0.9026		0.8995		0.8970		0.8894	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-16 Summary of Regression Analysis for CO Type 3 with 70% of Data

LN (CO3) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 51 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-3.0055	0.0000	-2.9077	0.0000	-2.8280	0.0000	-2.4986	0.0000	-2.3682	0.0000	-2.3824	0.0000
B	0.0330	0.0077	0.0261	0.0000	0.0270	0.0000	0.0261	0.0000	0.0256	0.0000	0.0258	0.0000
C	-0.0001	**0.5592**										
D	-0.0361	0.0247	-0.0350	0.0269	-0.0161	0.1368	-0.0147	0.1740	-0.0155	**0.1542**		
E	0.0146	0.0931	0.0143	**0.0983**								
F	0.0034	0.1082	0.0035	0.0924	0.0025	**0.2153**						
G	0.4676	0.0609	0.4896	0.0458	0.4505	0.0691	0.2505	**0.1785**				
Coef. Corrl. R	0.9287		0.9281		0.9233		0.9206		0.9173		0.9135	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-17 Summary of Regression Analysis for HC with 100% of Data

LN (HC) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 1117 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-6.2404	0.0000	-6.2405	0.0000	-6.380152	0.0000	-4.9619	0.0000		
B	0.0945	0.0000	0.0945	0.0000	0.095265	0.0000	0.0288	0.0000		
C	-0.0008	0.0000	-0.0008	0.0000	-0.000820	0.0000				
D	-0.0418	0.0002	-0.0418	0.0002	-0.042268	0.0001	-0.0445	0.0001		
E	0.0000	**0.9949**								
F	0.0087	0.0003	0.0087	0.0003	0.009458	0.0000	0.0075	0.0004		
G	-0.1314	0.5108	-0.1316	**0.5083**						
Coef. Corrl. R	0.4258		0.4258		0.4254		0.3967			
F-test	0.0000		0.0000		0.0000		0.0000			

TABLE C-18 Summary of Regression Analysis for HC with 90% of Data

LN (HC) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 1025 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-5.9036	0.0000	-5.8986	0.0000	-6.0851	0.0000				
B	0.0842	0.0000	0.0838	0.0000	0.0848	0.0000				
C	-0.0007	0.0000	-0.0007	0.0000	-0.0007	0.0000				
D	-0.0287	0.0001	-0.0296	0.0000	-0.0302	0.0000				
E	0.0010	**0.4704**								
F	0.0051	0.0009	0.0051	0.0009	0.0062	0.0000				
G	-0.1841	0.1437	-0.1748	**0.1627**						
Coef. Corrl. R	0.5956		0.5954		0.5943					
F-test	0.0000		0.0000		0.0000					

TABLE C-19 Summary of Regression Analysis for HC with 80% of Data

LN (HC) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 918 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test
A	-6.0673	0.0000	-6.2621	0.0000	-6.2271	0.0000				
B	0.0869	0.0000	0.0877	0.0000	0.0867	0.0000				
C	-0.0007	0.0000	-0.0007	0.0000	-0.0007	0.0000				
D	-0.0173	0.0043	-0.0181	0.0027	-0.0201	0.0008				
E	0.0025	0.0307	0.0023	**0.0461**						
F	0.0052	0.0001	0.0064	0.0000	0.0063	0.0000				
G	-0.1871	**0.0831**								
Coef. Corrl. R	0.6774		0.6761		0.6743					
F-test	0.0000		0.0000		0.0000					

TABLE C-20 Summary of Regression Analysis for HC with 70% of Data

LN (HC) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 800 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test	Coefficients	t-test
A	-6.2231	0.0000	-6.2167	0.0000	-6.1946	0.0000				
B	0.0864	0.0000	0.0864	0.0000	0.0857	0.0000				
C	-0.0007	0.0000	-0.0007	0.0000	-0.0007	0.0000				
D	-0.0141	0.0112	-0.0141	0.0111	-0.0150	0.0061				
E	0.0013	0.2611	0.0013	**0.2558**						
F	0.0053	0.0000	0.0052	0.0000	0.0052	0.0000				
G	0.0062	**0.9490**								
Coef. Corrl. R	0.7404		0.7404		0.7399					
F-test	0.0000		0.0000		0.0000					

TABLE C-21 Summary of Regression Analysis for HC Type 1 with 100% of Data

LN (HC1) = $A+Bs+Cs^2+Da+Ea^2+Ft+Gh$, Total Number of Data = 554
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-6.1099	0.0000	-6.1109	0.0000	-6.3541	0.0000	-5.717824	0.0000	-4.4435	0.0000
B	0.1043	0.0000	0.1044	0.0000	0.1055	0.0000	0.099976	0.0000	0.0303	0.0000
C	-0.0009	0.0000	-0.0009	0.0000	-0.0009	0.0000	-0.000882	0.0000		
D	-0.0405	0.0091	-0.0404	0.0090	-0.0403	0.0093	-0.040554	0.0091	-0.0430	0.0069
E	-0.0002	**0.9477**								
F	0.0052	0.1070	0.0052	0.1068	0.0066	**0.0178**				
G	-0.2299	0.3911	-0.2306	**0.3888**						
Coef. Corrl. R	0.4965		0.4965		0.4954		0.4875		0.4470	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-22 Summary of Regression Analysis for HC Type 1 with 90% of Data

LN (HC1) = $A+Bs+Cs^2+Da+Ea^2+Ft+Gh$, Total Number of Data = 505
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		Step 2		Step 3		Step 4		Step 5	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-5.8147	0.0000	-5.8085	0.0000	-5.8176	0.0000	-5.5072	0.0000		
B	0.0945	0.0000	0.0942	0.0000	0.0945	0.0000	0.0924	0.0000		
C	-0.0008	0.0000	-0.0008	0.0000	-0.0008	0.0000	-0.0008	0.0000		
D	-0.0123	0.2391	-0.0124	**0.2348**						
E	0.0012	**0.5628**								
F	0.0027	0.2103	0.0027	0.2085	0.0027	**0.2163**				
G	-0.3380	0.0575	-0.3339	0.0602	-0.3309	0.0626	-0.4422	0.0040		
Coef. Corrl. R	0.6454		0.6450		0.6438		0.6424			
F-test	0.0000		0.0000		0.0000		0.0000			

TABLE C-23 Summary of Regression Analysis for HC Type 1 with 80% of Data

LN (HC1) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 444
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-6.2566	0.0000	-6.2627	0.0000	-6.4207	0.0000	-6.3927	0.0000		
B	0.0974	0.0000	0.0976	0.0000	0.0982	0.0000	0.0974	0.0000		
C	-0.0008	0.0000	-0.0008	0.0000	-0.0008	0.0000	-0.0008	0.0000		
D	-0.0057	**0.5345**								
E	0.0029	0.1086	0.0029	0.1029	0.0029	**0.1103**				
F	0.0050	0.0114	0.0049	0.0116	0.0059	0.0005	0.0058	0.0006		
G	-0.1531	0.3492	-0.1518	**0.3530**						
Coef. Corrl. R	0.7195		0.7192		0.7185		0.7166			
F-test	0.0000		0.0000		0.0000		0.0000			

TABLE C-24 Summary of Regression Analysis for HC Type 1 with 70% of Data

LN (HC1) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 399
s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants

	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-6.4113	0.0000	-6.4146	0.0000	-6.5026	0.0000	-6.4733	0.0000		
B	0.0984	0.0000	0.0985	0.0000	0.0988	0.0000	0.0979	0.0000		
C	-0.0008	0.0000	-0.0008	0.0000	-0.0008	0.0000	-0.0008	0.0000		
D	-0.0020	**0.8187**								
E	0.0024	0.1927	0.0024	0.1941	0.0023	**0.2007**				
F	0.0052	0.0044	0.0052	0.0044	0.0057	0.0003	0.0056	0.0003		
G	-0.0869	0.5693	-0.0859	**0.5734**						
Coef. Corrl. R	0.7707		0.7706		0.7704		0.7693			
F-test	0.0000		0.0000		0.0000		0.0000			

TABLE C-25 Summary of Regression Analysis for HC Type 2 with 100% of Data

LN (HC2) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 512 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-6.4256	0.0000	-6.4214	0.0000	-6.5449	0.0000	-6.593385	0.0000	-5.1106	0.0000
B	0.0893	0.0001	0.0890	0.0001	0.0899	0.0001	0.091394	0.0001	0.0250	0.0000
C	-0.0008	0.0055	-0.0008	0.0052	-0.0008	0.0045	-0.000793	0.0036		
D	-0.0388	0.0198	-0.0391	0.0155	-0.0400	**0.0123**				
E	0.0003	**0.9234**								
F	0.0124	0.0009	0.0124	0.0009	0.0131	0.0001	0.013294	0.0000	0.0111	0.0005
G	-0.1146	0.7062	-0.1097	**0.7140**						
Coef. Corrl. R	0.3745		0.3745		0.3742		0.3596		0.3386	
F-test	0.0000		0.0000		0.0000		0.0000		0.0000	

TABLE C-26 Summary of Regression Analysis for HC Type 2 with 90% of Data

LN (HC2) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 462 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-6.0869	0.0000	-6.0932	0.0000	-5.9533	0.0000				
B	0.0732	0.0000	0.0738	0.0000	0.0728	0.0000				
C	-0.0006	0.0011	-0.0006	0.0008	-0.0006	0.0010				
D	-0.0422	0.0001	-0.0412	0.0000	-0.0402	0.0001				
E	-0.0007	**0.7298**								
F	0.0082	0.0004	0.0081	0.0004	0.0074	0.0002				
G	0.1368	0.4692	0.1249	**0.5012**						
Coef. Corrl. R	0.5376		0.5374		0.5368					
F-test	0.0000		0.0000		0.0000					

TABLE C-27 Summary of Regression Analysis for HC Type 2 with 80% of Data

LN (HC2) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 414 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-5.5224	0.0000	-5.5096	0.0000	-5.5958	0.0000				
B	0.0583	0.0000	0.0573	0.0000	0.0579	0.0000				
C	-0.0004	0.0042	-0.0004	0.0050	-0.0004	0.0042				
D	-0.0193	0.0195	-0.0203	0.0125	-0.0210	0.0084				
E	0.0009	**0.5633**								
F	0.0046	0.0113	0.0046	0.0107	0.0051	0.0009				
G	-0.0905	0.5452	-0.0761	**0.6055**						
Coef. Corrl. R	0.6366		0.6362		0.6359					
F-test	0.0000		0.0000		0.0000					

TABLE C-28 Summary of Regression Analysis for HC Type 2 with 70% of Data

LN (HC2) = A+Bs+Cs^2+Da+Ea^2+Ft+Gh, Total Number of Data = 362 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants										
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**	
	Coefficients	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**	**Coefficients**	**t-test**
A	-5.3602	0.0000	-5.4232	0.0000	-5.4061	0.0000	-5.4127	0.0000		
B	0.0519	0.0000	0.0523	0.0000	0.0517	0.0000	0.0517	0.0000		
C	-0.0003	0.0038	-0.0003	0.0034	-0.0003	0.0037	-0.0003	0.0036		
D	-0.0158	0.0288	-0.0165	0.0192	-0.0174	**0.0102**				
E	0.0007	0.6196	0.0006	**0.6765**						
F	0.0032	0.0311	0.0036	0.0044	0.0036	0.0048	0.0036	0.0045		
G	-0.0576	**0.6465**								
Coef. Corrl. R	0.7122		0.7120		0.7118		0.7053			
F-test	0.0000		0.0000		0.0000		0.0000			

TABLE C-29 Summary of Regression Analysis for HC Type 3 with 100% of Data

LN (HC3) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 51 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	1.6412	0.6260	1.3565	0.6835	3.0987	0.2610	3.6304	0.1710	3.8704	0.1444	-3.8593	0.0000
B	-0.3864	0.0088	-0.3784	0.0096	-0.3924	0.0069	-0.3921	0.0067	-0.4103	0.0044		
C	0.0053	0.0052	0.0053	0.0053	0.0054	0.0041	0.0053	0.0042	0.0056	0.0025	0.0004	0.0483
D	-0.1277	0.2422	-0.0872	0.3525	-0.0918	0.3264	-0.1006	**0.2762**				
E	0.0456	**0.4563**										
F	0.0132	0.3701	0.0135	**0.3565**								
G	1.5471	0.3327	1.7013	0.2808	0.9984	**0.4672**						
Coef. Corrl. R	0.5231		0.5141		0.5001		0.4913		0.4709		0.2779	
F-test	0.0229		0.0141		0.0090		0.0044		0.0024		0.0483	

TABLE C-30 Summary of Regression Analysis for HC Type 3 with 90% of Data

LN (HC3) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 45 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-5.3624	0.0179	-5.3132	0.0133	-4.9584	0.0000	-5.0449	0.0000	-4.3968	0.0000	-4.5973	0.0000
B	0.0385	0.6945	0.0392	0.6833	0.0218	0.0187	0.0255	0.0036	0.0238	0.0055	0.0280	0.0015
C	-0.0002	0.8681	-0.0002	**0.8553**								
D	-0.1398	0.0311	-0.1409	0.0240	-0.1401	0.0227	-0.1013	0.0382	-0.1017	**0.0379**		
E	0.0349	0.3091	0.0353	0.2937	0.0356	**0.2822**						
F	0.0080	0.3105	0.0077	0.2518	0.0075	0.2511	0.0072	**0.2655**				
G	0.0683	**0.9380**										
Coef. Corrl. R	0.5760		0.5759		0.5754		0.5579		0.5384		0.4606	
F-test	0.0133		0.0061		0.0024		0.0015		0.0008		0.0015	

TABLE C-31 Summary of Regression Analysis for HC Type 3 with 80% of Data

LN (HC3) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 40 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-4.1500	0.0331	-4.0816	0.0286	-4.5385	0.0000	-4.5294	0.0000	-3.9618	0.0000	-4.0771	0.0000
B	-0.0240	0.7793	-0.0221	**0.7914**								
C	0.0005	0.6205	0.0005	0.6302	0.0002	0.0228	0.0003	0.0030	0.0003	0.0044	0.0003	0.0009
D	-0.1376	0.0314	-0.1400	0.0219	-0.1420	0.0177	-0.0961	0.0348	-0.0896	**0.0476**		
E	0.0354	0.2500	0.0362	0.2256	0.0361	**0.2213**						
F	0.0076	0.2734	0.0071	0.2387	0.0075	0.1915	0.0069	**0.2347**				
G	0.1137	**0.8796**										
Coef. Corrl. R	0.6201		0.6197		0.6187		0.5961		0.5738		0.5031	
F-test	0.0096		0.0042		0.0017		0.0011		0.0006		0.0009	

TABLE C-32 Summary of Regression Analysis for HC Type 3 with 70% of Data

LN (HC3) = A+Bs+Cs²+Da+Ea²+Ft+Gh, Total Number of Data = 36 s = Speed, a = Acceleration Rate, t = Temperature, h = Humidity, A,B,C,D,E,F,G = Constants												
	Step 1		**Step 2**		**Step 3**		**Step 4**		**Step 5**		**Step 6**	
	Coeff.	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**	**Coeff.**	**t-test**
A	-3.4022	0.0292	-3.2414	0.0308	-4.3915	0.0000	-3.9664	0.0000	-4.0241	0.0000	-4.1297	0.0000
B	-0.0610	0.3771	-0.0553	**0.4103**								
C	0.0010	0.2589	0.0009	0.2884	0.0002	0.0103	0.0002	0.0127	0.0003	0.0008	0.0003	0.0003
D	-0.1434	0.0054	-0.1495	0.0026	-0.1554	0.0015	-0.1465	0.0024	-0.0926	**0.0136**		
E	0.0431	0.0727	0.0453	0.0531	0.0452	0.0519	0.0428	**0.0652**				
F	0.0053	0.3329	0.0040	0.3969	0.0052	**0.2476**						
G	0.2892	**0.6196**										
Coef. Corrl. R	0.7328		0.7301		0.7226		0.7076		0.6662		0.5738	
F-test	0.0006		0.0002		0.0001		0.0001		0.0001		0.0003	

APPENDIX D: MODELED ON-ROAD EMISSION RATES

TABLE D-1 Modeled On-Road Emission Rates for Aggregate CO Emissions (grams/second)

Speed	CO-100	CO-90	CO-80	CO-70
5	0.12638	0.06893	0.06940	0.10457
10	0.14680	0.09162	0.09036	0.11998
15	0.17052	0.11936	0.11534	0.13767
20	0.19807	0.15242	0.14429	0.15796
25	0.23007	0.19079	0.17695	0.18125
30	0.26724	0.23408	0.21269	0.20796
35	0.31042	0.28151	0.25060	0.23862
40	0.36057	0.33184	0.28941	0.27379
45	0.41882	0.38343	0.32762	0.31415
50	0.48649	0.43427	0.36353	0.36045
55	0.56509	0.48210	0.39538	0.41358
60	0.65639	0.52461	0.42151	0.47454
65	0.76244	0.55956	0.44048	0.54449
70	0.88562	0.58503	0.45117	0.62475
75	1.02870	0.59954	0.45298	0.71684
80	1.19491	0.60224	0.44579	0.82251

TABLE D-2 Modeled On-Road Emission Rates for CO Emissions for Vehicle Type 1 (grams/second)

Speed	CO1-100	CO1-90	CO1-80	CO1-70
5	0.12330	0.06726	0.06753	0.06874
10	0.14414	0.08989	0.08815	0.08862
15	0.16851	0.11775	0.11279	0.11255
20	0.19699	0.15119	0.14147	0.14080
25	0.23029	0.19029	0.17391	0.17353
30	0.26922	0.23476	0.20957	0.21068
35	0.31473	0.28388	0.24754	0.25198
40	0.36794	0.33649	0.28659	0.29689
45	0.43013	0.39094	0.32524	0.34459
50	0.50285	0.44521	0.36179	0.39400
55	0.58785	0.49698	0.39447	0.44379
60	0.68722	0.54379	0.42160	0.49243
65	0.80339	0.58321	0.44167	0.53827
70	0.93920	0.61312	0.45353	0.57961
75	1.09797	0.63179	0.45648	0.61484
80	1.28357	0.63814	0.45036	0.64249

Note 1: Speed is in mph and emission rate is in grams per second
Note 2: CO and CO1 = Aggregate CO and CO for vehicle type 1
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

TABLE D-3 Modeled On-Road Emission Rates for CO Emissions for Vehicle Type 2 (grams/second)

Speed	CO2-100	CO2-90	CO2-80	CO2-70
5	0.13907	0.06821	0.06644	0.06740
10	0.15916	0.09245	0.08889	0.08829
15	0.18214	0.12220	0.11597	0.11337
20	0.20845	0.15754	0.14758	0.14269
25	0.23855	0.19808	0.18316	0.17603
30	0.27300	0.24290	0.22171	0.21286
35	0.31242	0.29052	0.26174	0.25231
40	0.35754	0.33888	0.30137	0.29314
45	0.40917	0.38554	0.33844	0.33384
50	0.46826	0.42780	0.37069	0.37266
55	0.53588	0.46297	0.39598	0.40775
60	0.61327	0.48865	0.41255	0.43732
65	0.70183	0.50303	0.41920	0.45974
70	0.80318	0.50505	0.41545	0.47374
75	0.91917	0.49455	0.40156	0.47850
80	1.05191	0.47232	0.37855	0.47374

TABLE D-4 Modeled On-Road Emission Rates for CO Emissions for Vehicle Type 3 (grams/second)

Speed	CO3-100	CO3-90	CO3-80	CO3-70
5	0.13979	0.10863	0.10714	0.10504
10	0.14498	0.12365	0.12189	0.11950
15	0.15407	0.14075	0.13868	0.13596
20	0.16776	0.16021	0.15777	0.15468
25	0.18715	0.18235	0.17950	0.17598
30	0.21393	0.20757	0.20421	0.20021
35	0.25056	0.23627	0.23233	0.22777
40	0.30068	0.26893	0.26432	0.25914
45	0.36971	0.30611	0.30071	0.29482
50	0.46578	0.34844	0.34212	0.33541
55	0.60125	0.39661	0.38922	0.38159
60	0.79523	0.45145	0.44282	0.43413
65	1.07768	0.51386	0.50379	0.49391
70	1.49639	0.58491	0.57315	0.56192
75	2.12892	0.66578	0.65207	0.63929
80	3.10338	0.75783	0.74186	0.72731

Note 1: Speed is in mph and emission rate is in grams per second
Note 2: CO2 and CO3 = CO for vehicle type 2 and vehicle type 3
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

TABLE D-5 Modeled On-Road Emission Rates for Aggregate HC Emissions (grams/second)

Speed	HC-100	HC-90	HC-80	HC-70
5	0.01415	0.00544	0.00480	0.00455
10	0.01634	0.00789	0.00703	0.00662
15	0.01887	0.01105	0.00994	0.00931
20	0.02179	0.01493	0.01356	0.01264
25	0.02517	0.01949	0.01787	0.01658
30	0.02907	0.02457	0.02274	0.02099
35	0.03357	0.02991	0.02794	0.02567
40	0.03876	0.03515	0.03315	0.03030
45	0.04476	0.03989	0.03798	0.03454
50	0.05170	0.04371	0.04202	0.03802
55	0.05970	0.04625	0.04489	0.04041
60	0.06894	0.04726	0.04630	0.04148
65	0.07962	0.04663	0.04612	0.04111
70	0.09194	0.04442	0.04435	0.03934
75	0.10618	0.04086	0.04119	0.03635
80	0.12262	0.03629	0.03693	0.03243

TABLE D-6 Modeled On-Road Emission Rates for HC Emissions for Vehicle Type 1 (grams/second)

Speed	HC1-100	HC1-90	HC1-80	HC1-70
5	0.00530	0.00506	0.00412	0.00376
10	0.00818	0.00756	0.00632	0.00577
15	0.01207	0.01086	0.00931	0.00852
20	0.01706	0.01499	0.01317	0.01209
25	0.02306	0.01987	0.01790	0.01648
30	0.02983	0.02532	0.02338	0.02157
35	0.03692	0.03098	0.02934	0.02714
40	0.04372	0.03643	0.03538	0.03280
45	0.04954	0.04116	0.04098	0.03809
50	0.05372	0.04468	0.04561	0.04250
55	0.05573	0.04659	0.04877	0.04556
60	0.05533	0.04669	0.05010	0.04692
65	0.05256	0.04495	0.04945	0.04643
70	0.04777	0.04157	0.04690	0.04414
75	0.04155	0.03695	0.04274	0.04032
80	0.03458	0.03155	0.03741	0.03539

Note 1: Speed is in mph and emission rate is in grams per second
Note 2: HC and HC1 = Aggregate HC and HC for vehicle type 1
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

TABLE D-7 Modeled On-Road Emission Rates for HC Emissions for Vehicle Type 2 (grams/second)

Speed	HC2-100	HC2-90	HC2-80	HC2-70
5	0.01576	0.00641	0.00720	0.00751
10	0.01786	0.00882	0.00933	0.00951
15	0.02024	0.01178	0.01186	0.01186
20	0.02294	0.01526	0.01477	0.01457
25	0.02599	0.01919	0.01803	0.01764
30	0.02946	0.02342	0.02157	0.02103
35	0.03338	0.02773	0.02530	0.02471
40	0.03783	0.03186	0.02909	0.02859
45	0.04287	0.03553	0.03278	0.03259
50	0.04859	0.03845	0.03621	0.03660
55	0.05506	0.04038	0.03921	0.04049
60	0.06240	0.04116	0.04161	0.04413
65	0.07072	0.04071	0.04329	0.04737
70	0.08014	0.03907	0.04414	0.05010
75	0.09082	0.03640	0.04412	0.05220
80	0.10292	0.03290	0.04323	0.05357

TABLE D-8 Modeled On-Road Emission Rates for HC Emissions for Vehicle Type 3 (grams/second)

Speed	HC3-100	HC3-90	HC3-80	HC3-70
5	0.02129	0.01159	0.01708	0.01621
10	0.02191	0.01334	0.01747	0.01658
15	0.02299	0.01534	0.01814	0.01721
20	0.02459	0.01765	0.01912	0.01814
25	0.02681	0.02030	0.02045	0.01941
30	0.02980	0.02335	0.02221	0.02107
35	0.03376	0.02686	0.02449	0.02323
40	0.03900	0.03089	0.02740	0.02600
45	0.04592	0.03553	0.03113	0.02953
50	0.05511	0.04087	0.03590	0.03406
55	0.06744	0.04701	0.04202	0.03987
60	0.08412	0.05408	0.04993	0.04737
65	0.10696	0.06221	0.06023	0.05714
70	0.13864	0.07155	0.07375	0.06997
75	0.18320	0.08231	0.09167	0.08697
80	0.24677	0.09468	0.11566	0.10973

Note 1: Speed is in mph and emission factor is in grams per mile
Note 2: HC2 and HC3 = HC for vehicle type 1 and vehicle type 2
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

APPENDIX E: MODELED ON-ROAD EMISSION FACTORS

TABLE E-1 Modeled On-Road Emission Factors for Aggregate CO Emissions (grams/mile)

Speed	CO-100	CO-90	CO-80	CO-70
5	91.00	49.63	49.97	75.29
10	52.85	32.98	32.53	43.19
15	40.92	28.65	27.68	33.04
20	35.65	27.44	25.97	28.43
25	33.13	27.47	25.48	26.10
30	32.07	28.09	25.52	24.96
35	31.93	28.95	25.78	24.54
40	32.45	29.87	26.05	24.64
45	33.51	30.67	26.21	25.13
50	35.03	31.27	26.17	25.95
55	36.99	31.56	25.88	27.07
60	39.38	31.48	25.29	28.47
65	42.23	30.99	24.40	30.16
70	45.55	30.09	23.20	32.13
75	49.38	28.78	21.74	34.41
80	53.77	27.10	20.06	37.01

TABLE E-2 Modeled On-Road Emission Factors for CO Emissions for Vehicle Type 1 (grams/mile)

Speed	CO1-100	CO1-90	CO1-80	CO1-70
5	88.78	48.43	48.62	49.49
10	51.89	32.36	31.73	31.90
15	40.44	28.26	27.07	27.01
20	35.46	27.21	25.46	25.34
25	33.16	27.40	25.04	24.99
30	32.31	28.17	25.15	25.28
35	32.37	29.20	25.46	25.92
40	33.11	30.28	25.79	26.72
45	34.41	31.28	26.02	27.57
50	36.20	32.06	26.05	28.37
55	38.48	32.53	25.82	29.05
60	41.23	32.63	25.30	29.55
65	44.50	32.30	24.46	29.81
70	48.30	31.53	23.32	29.81
75	52.70	30.33	21.91	29.51
80	57.76	28.72	20.27	28.91

Note 1: Speed is in mph and emission factor is in grams per mile
Note 2: CO and CO1 = Aggregate CO and CO for vehicle type 1
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

TABLE E-3 Modeled On-Road Emission Factors for CO Emissions for Vehicle Type 2 (grams/mile)

Speed	CO2-100	CO2-90	CO2-80	CO2-70
5	100.13	49.11	47.84	48.53
10	57.30	33.28	32.00	31.79
15	43.71	29.33	27.83	27.21
20	37.52	28.36	26.56	25.68
25	34.35	28.52	26.37	25.35
30	32.76	29.15	26.60	25.54
35	32.13	29.88	26.92	25.95
40	32.18	30.50	27.12	26.38
45	32.73	30.84	27.08	26.71
50	33.71	30.80	26.69	26.83
55	35.08	30.30	25.92	26.69
60	36.80	29.32	24.75	26.24
65	38.87	27.86	23.22	25.46
70	41.31	25.97	21.37	24.36
75	44.12	23.74	19.27	22.97
80	47.34	21.25	17.03	21.32

TABLE E-4 Modeled On-Road Emission Factors for CO Emissions for Vehicle Type 3 (grams/mile)

Speed	CO3-100	CO3-90	CO3-80	CO3-70
5	100.65	78.21	77.14	75.63
10	52.19	44.51	43.88	43.02
15	36.98	33.78	33.28	32.63
20	30.20	28.84	28.40	27.84
25	26.95	26.26	25.85	25.34
30	25.67	24.91	24.51	24.02
35	25.77	24.30	23.90	23.43
40	27.06	24.20	23.79	23.32
45	29.58	24.49	24.06	23.59
50	33.54	25.09	24.63	24.15
55	39.35	25.96	25.48	24.98
60	47.71	27.09	26.57	26.05
65	59.69	28.46	27.90	27.36
70	76.96	30.08	29.48	28.90
75	102.19	31.96	31.30	30.69
80	139.65	34.10	33.38	32.73

Note 1: Speed is in mph and emission factor is in grams per mile
Note 2: CO2 and CO3 = CO for vehicle type 2 and vehicle type 3
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

TABLE E-5 Modeled On-Road Emission Factors for Aggregate HC Emissions (grams/mile)

Speed	HC-100	HC-90	HC-80	HC-70
5	10.19	3.92	3.46	3.27
10	5.88	2.84	2.53	2.38
15	4.53	2.65	2.38	2.23
20	3.92	2.69	2.44	2.28
25	3.62	2.81	2.57	2.39
30	3.49	2.95	2.73	2.52
35	3.45	3.08	2.87	2.64
40	3.49	3.16	2.98	2.73
45	3.58	3.19	3.04	2.76
50	3.72	3.15	3.03	2.74
55	3.91	3.03	2.94	2.65
60	4.14	2.84	2.78	2.49
65	4.41	2.58	2.55	2.28
70	4.73	2.28	2.28	2.02
75	5.10	1.96	1.98	1.74
80	5.52	1.63	1.66	1.46

TABLE E-6 Modeled On-Road Emission Factors for HC Emissions for Vehicle Type 1 (grams/mile)

Speed	HC1-100	HC1-90	HC1-80	HC1-70
5	3.82	3.64	2.97	2.71
10	2.94	2.72	2.28	2.08
15	2.90	2.61	2.23	2.05
20	3.07	2.70	2.37	2.18
25	3.32	2.86	2.58	2.37
30	3.58	3.04	2.81	2.59
35	3.80	3.19	3.02	2.79
40	3.93	3.28	3.18	2.95
45	3.96	3.29	3.28	3.05
50	3.87	3.22	3.28	3.06
55	3.65	3.05	3.19	2.98
60	3.32	2.80	3.01	2.82
65	2.91	2.49	2.74	2.57
70	2.46	2.14	2.41	2.27
75	1.99	1.77	2.05	1.94
80	1.56	1.42	1.68	1.59

Note 1: Speed is in mph and emission factor is in grams per mile
Note 2: HC and HC1 = Aggregate HC and HC for vehicle type 1
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data

TABLE E-7 Modeled On-Road Emission Factors for HC Emissions for Vehicle Type 2 (grams/mile)

Speed	HC2-100	HC2-90	HC2-80	HC2-70
5	11.35	4.62	5.18	5.41
10	6.43	3.18	3.36	3.42
15	4.86	2.83	2.85	2.85
20	4.13	2.75	2.66	2.62
25	3.74	2.76	2.60	2.54
30	3.53	2.81	2.59	2.52
35	3.43	2.85	2.60	2.54
40	3.40	2.87	2.62	2.57
45	3.43	2.84	2.62	2.61
50	3.50	2.77	2.61	2.64
55	3.60	2.64	2.57	2.65
60	3.74	2.47	2.50	2.65
65	3.92	2.25	2.40	2.62
70	4.12	2.01	2.27	2.58
75	4.36	1.75	2.12	2.51
80	4.63	1.48	1.95	2.41

TABLE E-8 Modeled On-Road Emission Factors for HC Emissions for Vehicle Type 3 (grams/mile)

Speed	HC3-100	HC3-90	HC3-80	HC3-70
5	15.33	8.35	12.30	11.67
10	7.89	4.80	6.29	5.97
15	5.52	3.68	4.35	4.13
20	4.43	3.18	3.44	3.26
25	3.86	2.92	2.95	2.79
30	3.58	2.80	2.67	2.53
35	3.47	2.76	2.52	2.39
40	3.51	2.78	2.47	2.34
45	3.67	2.84	2.49	2.36
50	3.97	2.94	2.58	2.45
55	4.41	3.08	2.75	2.61
60	5.05	3.24	3.00	2.84
65	5.92	3.45	3.34	3.16
70	7.13	3.68	3.79	3.60
75	8.79	3.95	4.40	4.17
80	11.10	4.26	5.20	4.94

Note 1: Speed is in mph and emission factor is in grams per mile
Note 2: HC2 and HC3 = HC for vehicle type 1 and vehicle type 2
Note: 3: 100, 90, 80 and 70 = cutting 0%, 10%, 20% and 30% of HEV data