To the Graduate Council:

I am submitting herewith a dissertation written by Aladdin A. Barkawi entitled "An Evaluation of Modal and Average Speed Approaches for Mobile Source Emissions Estimation." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

Arun Chatterjee, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

AN EVALUATION OF MODAL AND AVERAGE SPEED APPROACHES FOR MOBILE SOURCE EMISSIONS ESTIMATION

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Aladdin Barkawi
May 1997

DEDICATION

To my beloved parents, Adnan and Naela;

To my wonderful wife, Rosana;

and my beautiful children, Lina and Omar

ACKNOWLEDGMENTS

Firstly and pre-eminently, I am deeply indebted to my major academic advisor, Dr. Arun Chatterjee for his continuous guidance and assistance during the course of this research and preparation of this dissertation. I also wish to thank the other members of my Ph.D. committee for their timely and invaluable guidance and support in the conduct of this research and preparation of this dissertation: Dr. Fred Wegmann, Dr. Terry Miller and Dr. Elden DePorter.

Sincere thanks to Dr. Wegmann for all his academic support from the very beginning of my graduate studies and throughout the completion of this research. Special appreciation to Dr. Miller for his valuable comments throughout the course of development of this research. Many thanks to Dr. DePorter for taking his valuable personal time to review this research.

I also wish to extend my sincere thanks to the Federal Highway Administration for providing me with opportunity to be part of the Academic Study Program. In particular, Special thanks to my Associate Administrator, Mr. Robert Betsold; Office Director, Mr. George Ostensen; and my Division Chief, Mr. John MacGowan.

I also wish to deeply thank all the member of my family for their continuous support. Especially my wife, Rosana, for her continuous encouragement and kindness while I worked on the Ph.D. program.

ABSTRACT

Following the passage of the Clean Air Act Amendment (CAAA) in 1990, there have been renewed efforts to accurately quantify the emission of pollutants from mobile sources.

There are two existing approaches to estimate exhaust emission from mobile sources: 1) MOBILE5a, which was the "Average Speed" approach and, 2) TRAF-NETSIM, which was the "Modal" approach. This study identified the strengths and limitations of these two approaches for vehicle exhaust emission estimation. To make a valid comparison between the two approaches, the hot- stabilized portion (Bag 2) of the FTP cycle was used as a common platform to calibrate the two independent approaches. Using the results of traffic simulation, the difference between these two approaches was quantified.

The base line comparison of average emission rates from a modal approach and an average speed approach produced interesting results. It was observed that the average emission rates for all three pollutants (HC, CO, NOx) reported by MOBILE5a were greater than the average emission rates obtained from TRAF-NETSIM embedded tables. Within the operating range of FTP hot stabilized portion, emission rates for HC, and CO obtained from MOBILE5a were three times higher than that obtained from modal approach. However, for NOx, MOBILE5a's rates were one and half times higher than those of TRAF-NETSIM.

This study developed modal adjustment factors (MAFs) for each pollutant, which was defined as the ratio of the actual emission rate embedded in NETSIM for a specified

combination of acceleration and speed to the average FTP emission rate of the pollutant. This study illustrates that MAFs vary widely — from 0.3 to more than 150 times — implying that the average FTP emission rates are not truly representative of modal rates within the considered ranges of speed and acceleration.

This study demonstrated the use of both "modal" and "average speed" approaches for the evaluation of the impact of a traffic improvement strategy on emissions from light duty gasoline vehicles. The traffic improvement strategy that was analyzed was the coordination of traffic signal operation along an arterial road. A simple case involving an arterial operation was selected to achieve this objective. The analysis was performed using TRAF-NETSIM for the modal approach and MOBILE5a was used for the average speed approach. The reduction in the cumulative hourly emission for all three pollutants (HC, CO, and NOx) due to the implementation of signal coordination using the modal approach was larger than those of the average speed approach. The average speed approach reported a negative benefit (an increase) for NOx due to signal coordination.

This study used a simulation-based procedure for quantifying the effect of driver behavior on mobile source emissions. Two mixes of driver populations were examined: uniform and aggressive. It was found that the quantity of emissions considerably increased with the increase in the aggressiveness of driver population. Based on this study, it was concluded that the base emission factors used in various analytical models may be corrected for aggressiveness of driver population.

This study was limited to nonfreeway arterial operations only. Because freeway operation is different with respect to acceleration and speed, a similar analysis should be performed to evaluate freeway operation to gain a more comprehensive understanding of the characteristics of modal emissions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

Background

Motor vehicles are direct contributors to carbon monoxide (CO), and particulate matters, and they also contribute to the production of ozone by emitting hydrocarbons (HC) and nitrogen oxides (NOx), which photochemically react to produce ozone. It has been estimated that highway transportation accounts for nearly 50 percent of the total emissions of air pollutants such as carbon monoxide, hydrocarbons, and nitrogen oxides.

A number of federal regulations, including the Clean Air Act Amendment of 1990 (CAAA) (Public Law 101-549, 42 U.S.C. 7401, et seq.) and complementary provisions of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (Public Law 102-240, 49 U.S.C. 101 note) stress the transportation sector's obligations to support environmental and energy security objectives. As a result traditional transportation projects, such as additions to highway capacity, have come under close scrutiny as potential contributors to air pollution.

Though CAAA emphasizes transportation control measures as proactive solutions, it also insists that transportation plans conform to the intent and objectives of the State Implementation Plans (SIPs) and not aggravate the frequency and severity of air quality violations. As a result, transportation planners and traffic engineers must prove that their proposed projects will, at minimum, "Do no harm."

There are two existing approaches to estimate exhaust emission from mobile sources. EPA's MOBILE model includes empirical relationships of emission rate with average travel speed, temperature, fleet characteristics, and several other variables. This approach is popularly known as "Average Speed" approach. TRAF-NETSIM simulates individual vehicles operating behavior on a highway and depends upon 'lookup' Vehicle Emission Tables (VETs) to estimate exhaust emissions. The VETs include emission rates for different combinations of speed and acceleration. This is known as the "Modal" approach. There are advantages and disadvantages associated with both approaches.

Study Objectives

The objective of this research study is to identify the strengths and limitations of the "average speed" and "modal" approaches for emission estimation. Using the results of traffic simulation the difference between these two approaches will be quantified. Specific objectives of the effort are presented below:

1. Perform a base line comparison of exhaust emission rates produced by average speed approach of "MOBILE", and modal approach of "TRAF-NETSIM". Suitable parameters will be identified to bring the two independent techniques on a common platform to make a valid comparison.
2. Using data collected for "TRAF-NETSIM", develop modal adjustment factors (MAF's) through the use of a "Pivot" point approach. The MAF's will be analyzed to identify the pattern of variation of emission rates with respect to speed and acceleration.
3. Evaluate the effect of traffic engineering strategies such as signal synchronization on exhaust emission level using "modal" and "average speed" approaches.
4. Evaluate the effect of different driving styles (aggressive versus passive) on exhaust emission level using the modal approach.

As a part of this effort, TRAF-NETSIM source code, wherever necessary, will be modified to accomplish the above objectives. A reasonable amount of data will be collected and reduced to conduct a sensitivity analysis.

Document Organization

The remainder of this document is organized as follows: The state-of-the-art of different emission modeling techniques currently being used to estimate exhaust emissions from vehicles operating on highways is reviewed in Chapter 2. In Chapter 3, the study methodology is described in detail. An analysis of the Bag 2 of the Federal Test Procedure (FTP) driving cycle, and a base line comparison between the two modeling approaches (average speed and modal) are presented in Chapter 4. In Chapter 5, Modal Adjustment Factors (MAF's) are developed and analyzed. An evaluation of the effect of selected traffic engineering strategies on emission levels using "modal" and "average speed" modeling approaches is presented in Chapter 6. In Chapter 7, an evaluation of the effect of driver type on emission level using the modal approach is presented. Conclusions and recommendations are presented in Chapter 8.

Chapter 2

State-of-the-Art Review

A few different emissions modeling techniques are currently being used to estimate exhaust emissions from vehicles operating on highways. A detailed investigation of the existing techniques and their applications has been conducted using the Transportation Research Information Service (TRIS), and the findings are presented in this Chapter.

State Implementation Plans

Under the CAAA, EPA sets nationwide standards for maximum permissible levels of air pollution, while States retain primary responsibility for monitoring air quality and implementing measures to comply with these standards. When an area is found to violate Federal air quality standards, the state in which it is located is required to develop and implement a plan (State Implementation Plan, or SIP) for eliminating the violation and then maintaining the standard [1]. Among the required elements of a SIP is a comprehensive inventory of current emissions from all sources in the area, and the projections showing what actions to be taken by the state will produce the emission reductions necessary for attaining the national ambient air quality standards.

The 1990 amendments to the Clean Air Act strengthened the requirement that local transportation plans and programs conform with the intent of an area's prevailing SIP to bring pollution levels into compliance with air quality standards. The strengthened conformity rule requires metropolitan planning organizations in nonattainment and maintenance areas to document that the regional emissions related consequences of implementing their transportation plans and programs are consistent with the emission reductions estimated in the adopted SIP.

Environmental Protection Agency (EPA)'s Approach

The Federal Test Procedure (FTP) cycle and the MOBILE model were developed by EPA. EPA utilizes the FTP cycle to measure the emission rates of automobiles. The analytical model MOBILE is used to make emission estimations. These are presented in the following sections.

Federal Test Procedure (FTP)

Emission factors are produced based on driving characteristics embodied in a pre-determined driving cycle, known as the Federal Test Procedure (FTP) [2]. This test cycle was originally developed in 1972 as a certification test for vehicle manufactures and has a specified driving trace of speed versus time, which is intended to reflect actual driving conditions on urban roads. Emissions of CO, NOx, and HC are collected for three sections of the cycle (called bags) and are used as base emission rates. Different driving cycles are used to test different vehicle types. For light duty cars and trucks, the FTP is a multimode driving cycle based on California data for a typical urban commute to work. Different portions of FTP drive cycle are presented in Table 2.1.

Table 2.1

Federal Test procedure (FTP)

Bag No.	Time (second)	Speed (mph)	Miles Traveled
1 (Cold Start)	505	25.6	3.59
2 (Hot Stabilized)	867	16.2	3.91
3 (Hot Start)	505	25.6	3.59

The FTP involves a dynamometer test of emissions over a 7.5 mile "driving cycle" lasting 22.9 minutes, with an average speed of 19.6 mph. Exhaust emissions during the first 505 seconds are captured in Bag 1 and represent "cold start" emissions. During this portion of the test, the vehicle travels 3.59 miles at an average speed of 25.6 mph. The remaining 867 seconds of the test are captured in Bag 2 representing "hot stabilized" emissions. During the hot stabilized portion of the test, the vehicle travels 3.91 miles at an average speed of 16.2 mph. After a 10 minute soak, the first 505 seconds of the test is repeated with the emissions captured in Bag 3, to represent the "hot start" emission mode. Each of these components of the emissions are weighted assuming 20.6 percent of the VMT is in cold start mode, 27.3 percent in the hot start mode, and 52.1 percent in the hot stabilized modes, to determine an average (grams per mile) emission rate for comparison to emission standards. The vehicle emissions test is performed at 75 degrees Fahrenheit, using a standard fuel. Appendix I includes EPA Urban Dynamometer driving schedule. As an example, a part of the driving schedule is presented in Table 2.2.

Table 2.2

A Part of FTP (Hot Stabilized) Driving Schedule

Time (sec)	Speed (MPH)	Acceleration MPH/Sec
505	0.0	
506	0.0	0.0
---	---	---
552	0.0	-3.3
---	---	---
678	3.5	-2.3
---	---	---

FTP is criticized for not truly representing the "real world" driving for a number of reasons. One of them is that the accelerations are not severe enough (limited to the maximum acceleration of 3.3 mph/sec and a maximum of speed of 57 mph) [3]. Based upon the data collected during a study, 8.5% of all speeds exceeded the FTP maximum rate and more than 88% of the trips contained an acceleration activity that exceeded 4 mph/sec. In fact, more than one third of the trips monitored included an acceleration rate at some point during the trip more than 7 mph/sec.

Based upon the vehicle activity data being collected and analyzed, the possible options being assessed by EPA include: 1) revising the FTP based upon driving behavior studies, 2) adding a Bag 4 emission testing cycle to the FTP, and 3) developing new emission testing cycles and requirements.

MOBILE Model

MOBILE5a model, the latest version of MOBILE, provides emission factors (grams per mile) for a vehicle fleet for any calendar year between 1960 and 2020. The model can evaluate impacts due to changes in average speed of travel as well as changes in a wide variety of external factors, such as temperature, altitude, fuel, and inspection/maintenance programs. MOBILE5a [4,5] is based on fixed driving cycles, most prominently the FTP. The estimation of emissions from mobile sources involves two major steps. The first step consists of determining a set of emission factors which specifies the rate at which emissions are generated, and the second step is to produce an estimate of vehicle activity measured in terms of vehicle miles of travel (VMT). The MOBILE model provides the emission factors. The model includes a set of basic emission rates, which are adjusted to fit specific situations. There are a series of correction factors including those for speed. These speed correction factors are derived from limited off-cycle testing speeds greater than 57 MPH, accelerations greater than 3.3 (MPH-S) performed on laboratory dynamometers.

Traffic activity data is measured in terms of vehicle miles travel (VMT). The VMT may be stratified according to the functional class of roads, and average travel speeds. The VMT is multiplied with an emissions factor, producing emissions estimate. Traffic activity data used for the emission inventory can come from a number of sources, although it is typically produced from a meso-scale, regional transportation model.

Many traffic professionals consider that MOBILE5A is an inadequate tool for the evaluation of traffic flow improvement strategies, and advanced traffic management techniques for the following reasons:

1) The principal limitation is that the changes in emissions due to vehicle speed are estimated by MOBILE5a based on "average route speed." For example, the same emissions are predicted by MOBILE5a when a vehicle travels at an average speed of 20 mph over a length of roadway even when the driving patterns are different. It does not consider whether a vehicle cruises at a steady speed or its travel is made up of a combination of idling and hard accelerations.

2) The emission data within MOBILE is based on FTP, which was established over two decades ago. FTP was intended to represent the operation of a typical in-use urban vehicle. However, it did not include "off-cycle" vehicle operation which consists of speeds in excess of 57 MPH and acceleration rates above 3.3 mi/h/s, which are common events in today's traffic operation. It has been shown in a number of studies that the FTP does not accurately characterize today's actual driving behavior [6,7]. Efforts are currently underway to revise the FTP.

3) The non-representative nature of the FTP driving cycle is exacerbated by the procedure used for collecting and analyzing emissions. The emissions from the three driving segments are used by the emission models to statistically construct the relationship between emission rates and average speeds. Thus, the models statistically smooth the effect of accelerations and decelerations. Two vehicle trips with the same average speed, can have different speed profiles consisting of drastically different modal characteristics (acceleration, deceleration, idle, etc.). The two trips will produce different amount of emissions. This is particularly true for the current closed-loop emission control systems where it has been shown that dynamic operations of the vehicle are an important variable in predicting vehicle emissions [4,8].

The speed correction factors built in MOBILE model are derived from transient tests (not steady-speed tests) including the light-duty vehicle FTP. The tests span a series of average speeds up to 65 MPH. EPA used a few other cycles to develop speed correction factors. However, running these other cycles and scaling them to construct the speed correction curves may not accurately mimic real-world driving conditions. Inherent in this derivation of the speed correction curves is the assumption that averages in the skewed distributions representing the range of emissions at measured speeds can be combined in a valid manner to yield emissions factors for other (non-measured) speeds. For cycles other than the FTP, emissions are less well known since far fewer vehicles are tested on these other cycles. Actual emissions at a given speed depend on engine load (acceleration); hence, for example, the fluctuations about a given average speed--their amplitudes, and frequency of occurrence, will greatly affect the emissions accompanying that average speed. Real-world conditions may, in some cases, exceed the valid range of the test cycles; for example, real-world speeds often exceed the test cycle maximum of 65 MPH, and real-world accelerations commonly exceed 3.3 MPH/S maximum in the FTP cycle.

The importance of accelerations/decelerations is also underestimated. Studies have shown that a single power acceleration can produce more CO than is emitted in the balance of a typical short (<5 MI) trip [9]. Other events leading to high engine load can also produce high emissions. For example, a vehicle traveling on a steep road grade can produce a very high level of emissions; however, because of the nature of the current model inputs, grades are not taken into account. This raises doubt over the validity of the FTP for use in assessing the true impact of accelerations/decelerations and grades on exhaust emissions.

Oak Ridge National Laboratory (ORNL) Study

In the early 1980s the Federal Highway Administration (FHWA), recognized the need for more realistic and representative data on post-1980 vehicles with regard to their fuel consumption and emissions performance. FHWA sponsored a "Vehicle Testing

Project" at the Oak Ridge National Laboratory (ORNL) in order to generate a new database for traffic models (i.e., TRAF-NETSIM) used by transportation engineers. One of the objectives of the project was to test six vehicles for hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NO_X) emissions and create a data base of those vehicles (i.e., computer models of the vehicle emissions characteristics of the six vehicles) from which the vehicle emissions tables required for the FHWA traffic simulation models could be generated. Additionally, correction factors for road grade effects that can be applied to the base vehicle emissions tables were to be determined. Also, for each of the six vehicles tested for emissions, the difference in emissions resulting from stopping and restarting the engine as opposed to letting it idle was measured [10].

The basic requirement of the FHWA models was that vehicle emissions had to be specified as a function of vehicle speed and acceleration. To relate vehicle emissions to vehicle speed and acceleration ORNL designed an experiment that included chassis dynamometer tests as well as on -road tests. The major criticism of the approach pursued in this experiment is that the measurement of vehicle emissions on the chassis dynamometer captures only the steady state values, ignoring transients conditions, since a condition must be held steady while measurements are made.

In 1992, FHWA and ORNL agreed that this effort was warranted again because of the significant differences between today's fleets of vehicles and those of the 1980s. The main objectives of this new and ongoing project is to update vehicle emissions and fuel consumption tables embedded in TRAF-NETSIM. This effort includes the collection of modal emissions and fuel consumption data of a number of vehicles operating under hot stabilized condition, and it will incorporate the effects of grade and ambient temperature also. In addition, ORNL team will identify vehicle and performance parameters that are useful to model vehicle emissions and fuel consumption of a large population of vehicles, and develop a model which will require a minimal number of measurements of other vehicles. The routine vehicle data acquisition will include practically all of the vehicle's operating range. It will cover the range of speed and acceleration achievable within safe limits on test facilities such as an airport runway. A combination of on-road and chassis dynamometer data will be collected. The results of this study are still being analyzed.

Overview of TRAF-NETSIM

This section presents the various features of the TRAF-NETSIM program. TRAF-NETSIM [11] is a microscopic and stochastic simulation model of traffic operations on urban street networks. The simulation model uses a fixed-time, discrete event approach to describe the dynamics of traffic operations. The program models the movement of each vehicle in a street network as it travels along the links and through intersections which are controlled by traffic signals and signs. The vehicles interact with one-another and respond to the traffic control devices.

TRAF-NETSIM simulates traffic flow on urban street networks by representing the movement of individual driver-vehicle combinations stochastically. For each vehicle entering the network, vehicle and driver characteristics are generated randomly. As vehicle moves from one link to the another, their turning movement on the new link is randomly assigned while satisfying the user-specified, link specific turn movement percentages. Random number generation in TRAF-NETSIM is based on a linear recursive procedure. Using a multplicative congruence technique, a sequence of random numbers are generated by always calculating the next random number from the last one obtained.

Operating as a one-second interval-scanning model, each vehicle in the network is processed once every second, as it moves through the system, with the time-space trajectory being recorded at 0.1 second resolution. Vehicle motion is governed by a series of car-following, queue discharge, and lane-changing algorithms, in response to traffic control devices.

The time-step record of each vehicle's performance, as it moves through the network, is updated in a detailed "vehicle array" and a "link array." The vehicle array contains recorded data, such as, cumulative travel time, distance, delay, number of stops, in addition to its present position and its projected action at the next node. The link array contains link statistics similar to the vehicle array, but also includes the cumulative number of vehicles and the turning movements processed, as well as, the link occupancy and the queue lengths.

The following sections briefly describe input to the program, and the output received at the end of execution (with a particular emphasis on vehicle emission computations).

Detailing of Highway Network

The physical street system is represented as a network comprised of one-way links with the intersections represented as nodes. It is possible to simulate any type of controls including yield signs, stop signs, fixed time signals, and signals with actuated controls. The user has to specify various attributes of the link including length of link, lengths of turning bays, and number of lanes along with widths over the entire link and in turning bays.

The length of each link is specified by the user. If the user requires graphical output, he should also specify the coordinates of each node. The program also facilitates the user to describe link curvature though optional input data. The user can specify turning movements along with volumes from a link in different directions on to adjacent links. The user also has an option to provide turn movement variations with in a time period. This comprehensive input about the geometry of the network and traffic volumes enables the user to realistically create the highway network for simulation.

Realistic Fleet and Driver Characteristics

In TRAF-NETSIM [12,13], sixteen different types of vehicles including trucks and buses can be modeled. Primarily, the fleet may be stratified as private automobiles, trucks, mass transit vehicles and carpool vehicles. The user can reserve lanes for buses and carpool, specify the percentage of trucks and carpool vehicles on each link. Such fine-grained representation allows the model to include enough variety to ensure that the actual composition of the nation's vehicle fleet is reflected. There are default maximum values of acceleration, speed, headway, length and occupancy of vehicle for various components of the fleet built into the program. The default maximum values of acceleration and speed for private automobile are 5.5 mph/sec and 75 mph respectively.

Parameters can be specified to represent different personality types for drivers, to represent different level of aggressiveness in traffic. The personality of the driver varies from passive to aggressive over a scale of 10. This enables to generate transient "enrichment" events, wherein a vehicle is accelerated rapidly, outside the limits of the federal test procedure for motor vehicles. Some recent experiments suggest that enrichment events may contribute substantially more pollution than the "normal" driving patterns.

Simulation of Traffic Control Devices

TRAF-NETSIM can simulate a network of intersections with any type of controls including yield signs, stop signs, fixed-time signals, actuated signals, and signals with different cycle lengths. For fixed-time signals, the user may specify any cycle length, number of phases, phase sequence, and phase split. For actuated signals, the program is capable to able to simulate the type 170 or NEMA controller logic up to eight-phase, fully actuated, dual ring controller, including volume-density and phase overlap. Because the program knows the position and time of each vehicle and the location of the detectors, it knows when and where a call is placed, and it changes signals accordingly. Pedestrian actuation is either by a user-specified frequency or stochastically determined by Poisson arrival based on user specified pedestrian volume.

Fuel Consumption and Emissions

The program has fuel consumption rates and pollutant emission rates embedded in the program. The model allows the user to modify any or all of the portions of the tabulated data that define fuel consumption rates and pollutant emission rates. The default table of emission rates is derived from measurements made at ORNL in the early eighties, and represents an aggregate of data for the six passenger cars that were examined in that study. As every vehicle tested had a different emission profile, statistical analysis would not produce reliable fits to the data, necessitating the production of (3-dimensional) tables as the basic model form. In these tables, emission rates were expressed as a function of acceleration (between -9 ft/sec^2 to 12 ft/sec^2) and speed (between 0 ft/Sec to 110 ft/Sec). The vehicle emissions tables embedded in TRAF-NETSIM for all three pollutant types (HC, CO, NOx) are included in Appendix II. No emission data were available from ORNL for trucks and buses.

TRAF-NETSIM facilitates to read in new data for emission rates for passenger vehicles, if one has available in a format similar to that used for the ORNL data. Given a vehicle type and speed, the rates for acceleration, or deceleration values can be specifies for that particular vehicle using record type 60 [11] .

It should be noted that with in the program, the speed and acceleration are corrected as integers before emission rates (in Grams/Second) are picked up from the tables. At the end of each second, emission rates for each of the three types of emissions (HC, CO, & NO_X) for every vehicle on a link is accumulated and converted into Kilograms/Mile-hour. Environmental Measures of Effectiveness (MOEs) are reported as output at intermediate intervals and also as cumulative values as specified by the user.

Relevant TRAF-NETSIM Inputs And Outputs

Control Parameters

The progress of the simulation performed by TRAF-NETSIM is controlled by a number of "cards," which are input records that are read before a simulation run begins. In particular, record 02 allows specification of details about how TRAF-NETSIM will compute fuel consumption and pollutant emissions [11].

Environmental MOEs

The environmental MOEs reported by NETSIM include fuel consumption and emissions (HC, CO, & NO_X) for every link (specified unidirectional roadway section). The fuel consumption is expressed in gallons for passenger cars, trucks and buses. The emissions (HC, CO, & NO_X) are reported as Kilograms/Mile-Hour for each link. These results can be obtained at specified intervals. Cumulative statistics for the duration of simulation are reported at the end of the output. Such environmental output is presented in Table 2.3.

Table 2.3

A Typical Environmental Output Reported by NETSIM

Link No.	Fuel Consumption						Emission Rates		
	Gallons			M.P.G.			(Kg/Mile-Hour)		
	Auto	Truck	Bus	Auto	Truck	Bus	HC	CO	NOx
(18, 4)	1.3	0.0	0.0	6.9	0.0	0.0	0.872	51.580	2.594
(4,18)	0.8	0.0	0.0	6.3	0.0	0.0	0.576	40.990	1.878
(19, 5)	1.2	0.0	0.0	0.3	0.0	0.0	0.925	11.171	1.044
(5,19)	0.2	0.0	0.0	3.7	0.0	0.0	0.336	22.071	1.190
(23,12)	2.7	0.0	0.0	1.3	0.0	0.0	1.338	21.061	2.729
(12,23)	0.6	0.0	0.0	7.6	0.0	0.0	0.554	37.004	1.820
(24,16)	0.2	0.0	0.0	7.3	0.0	0.0	0.353	27.053	0.965
(16,24)	0.3	0.0	0.0	6.6	0.0	0.0	0.422	29.529	1.389
(9,10)	0.6	0.0	0.0	3.6	0.0	0.0	0.239	7.680	0.686
(10,21)	1.1	0.0	0.0	1.9	0.0	0.0	0.448	13.817	1.168
(10, 9)	0.0	0.0	0.0	3.4	0.0	0.0	0.003	0.090	0.008
(22, 9)	0.3	0.0	0.0	3.1	0.0	0.0	0.269	9.072	0.641
(9,22)	0.0	0.0	0.0	3.7	0.0	0.0	0.073	5.045	0.246
(13,25)	0.2	0.0	0.0	3.5	0.0	0.0	0.270	19.148	0.881
Subnetwork	40.4	0.0	0.0	4.1	0.0	0.0	0.456	19.635	1.217

Limitation of TRAF-NETSIM in the Prediction of Exhaust Emissions

Though TRAF-NETSIM is unique from other models in considering the vehicle operating modes (cruising, deceleration, queuing and acceleration), in its current form has limitations as a tool to estimate pollution from motor vehicles. In particular, the model depends upon "look up" Vehicle Emission Tables (VETs) that were built on data obtained from 6 vehicles tested under steady state conditions. The tested vehicles do not represent the entire fleet currently operating on highways and considerable amount of emissions occur in real world under transient conditions. Also, the model assumes that engines of all vehicles operate under hot stabilized condition which is not true. Significant amount of emissions occur cold start condition of the engine.

TRAF-NETSIM has no provision for recognizing ambient temperature and grade of the highway, which can have a significant impact on vehicle emissions. Besides these traffic related parameters, the model also does not take into consideration a variety of vehicle related parameters including air conditioning on/off, coolant temperature, vehicle condition/age, fuel formulation and technology which are also very important in quantifying the emissions from vehicles operating on highways.

CARB's Approach

In California, mobile source emission inventory at the current time is developed by linking vehicle activity estimates to an emission rate model (EMFAC7F). The EMFAC model produces a computerized multi-dimensional matrix of activity-specific emission rates for specified environmental and operating conditions [14]. The existing emission rates used in EMFAC7F were derived through the testing of thousands of new and in-use light-duty vehicles. The testing is conducted on a laboratory dynamometer. The vehicle is run through a specific operating cycle (starts, stop, accelerations, and constant speed cruises) in a set pattern. The bag sample of emission collected (partially in the cold engine mode, and partially in the warm stabilized mode) are analyzed to determine the average emission effects for the vehicles operating under the test parameters. Similar to the EPA model (MOBILE), the EMFAC model uses average speed correction factors to compute emission rates.

This procedure also results in underestimation of motor vehicle emissions. This is because the empirical models used to develop the speed correction factors for motor vehicle emission rates do not account for modal operations such as acceleration and deceleration. In addition, a regression analysis on existing grams/mile data may tend to unrealistically force a statistical fit at high and low speeds [15]. To account this CARB to initiate a new modeling approach referred to as "The 25-BIN Modeling Approach" [3].

The 25-BIN Modeling Approach involves the development of 5 sets of 5 emission testing cycles. Each set of cycles would be designed to better reflect typical vehicle activity on five roadway classifications (freeways, expressway, arterial, connectors, and local roads) under five congestion levels. The congestion level will be defined in terms of level of service (LOS), where LOS is based upon traffic density for freeways and expressways and upon percentage of free flow speed on arterials [16]. Vehicles will be tested for each of the 25 testing cycles and baseline exhaust emission rates will be developed for each roadway classification and level of service. Thus, fleet average emission rates can be obtained from one of the 25" bins" and then applied to vehicle activity that occurred under the specified conditions. This is the major difference between this approach and the FTP approach which is based on developing a baseline exhaust emission factors under a single test cycle (FTP) and correcting these emission factors to estimate emissions at speeds other than the FTP average speed.

Although the proposed 25-bin approach currently is the only approach to address some of the deficiencies of EPA's emission model, this approach also employs aggregate data sets. Each typical cycle would contain a large amount of emission variations within the cycle. Vehicle activity data would also be aggregated into one of the five levels of service classifications. Though this approach is a significant improvement, it still may be inadequate for certain purposes and applications.

Summary of Literature Review

From the above literature review, there are several limitation with the existing modeling approaches. In the modal emission approach, the emission rates data were collected in mid-eighties. The emission rates embedded in NETSIM were obtained from 6 light duty passenger vehicles. These vehicles do not represent the current fleet operating on the highway networks. In the other hand the average speed model like MOBILE approximates vehicle operating modes (cruising, deceleration, queuing and acceleration) through empirical relations in estimating of exhaust emissions and these empirical relations were not verified to be valid. In addition, The database incorporated in MOBILE was based on FTP cycle. The FTP does not include speeds over 57 mph nor sharp accelerations (i.e. greater than 3.3 mph/sec), and some of the 'off-cycle' conditions are likely to result in enrichment, which yields high carbon monoxide and hydrocarbon emission rates. Linking such data with uncertain data about vehicle activity dose not lead to realistic estimation of the emission inventories.

Chapter 3
Methodology

From the literature review presented in the preceding chapter, it is clear that the current state-of-the-practice uses the average speed approach of "MOBILE " model to estimate exhaust emissions for inventory purposes as well as for assessing the impact of transportation control measures. Although the MOBILE model reflects changes in emission rates (grams/mile) for a vehicle fleet for any calendar year between 1960 and 2020 due to changes in average speed of travel, as well as in a wide variety of external factors, such as temperature, altitude, fuel type, and inspection/maintenance program, the model has limited capability to predict changes in emissions caused by changes in speed and acceleration at a detailed level and a localized scale. Recognizing the above limitation, several research studies were initiated recently to investigate the effects of speed and acceleration on emission level. This is known as the "modal approach". The modal approach was investigated on a limited basis by ORNL in the early eighties. These limitations were described in the previous section. Current modal emission studies did not utilize the results from the ORNL study. These current efforts are not expected to be completed for a few more years. The ORNL results, however, were incorporated in TRAF-NETSIM. In this study, the ORNL "modal approach" study results will be used to assess the usefulness of the modal approach. A comparison of the emission estimation results from the average speed approach and modal approach will be performed.

The vehicle emission rates built into TRAF-NETSIM and MOBILE were obtained under different testing conditions. The VETs incorporated in TRAF-NETSIM were developed under steady-state operating conditions for hot stabilized engines. These lookup tables include emission rates in grams/second per vehicle for different combinations of acceleration and speed. The emission factors built into MOBILE are based on average driving characteristics embodied in FTP. In order to make a reasonable comparison of the results obtained from MOBILE and TRAF-NETSIM, a **'Pivot Point"** approach will be utilized. This approach will involve the derivation of modal adjustment factors (MAF) for each cell in the VET's. This will be accomplished through the simulation of the hot stabilized portion of the FTP cycle. The proposed mechanism is presented in Figure 3.1. These MAF's will be analyzed in different ways to determine how much the "modal emission" approach based results differ from those of the "average speed" approach. The study approach consists of the following five stages:

- **Analysis of FTP's Hot Stabilized Driving Cycle Using Emission Rates from VETs in TRAF-NETSIM**

  For every second of the hot stabilized portion of the FTP drive cycle, the speed and acceleration are known [1]. FTP's hot stabilized driving cycle will be simulated using the emission rates from VETs in TRAF-NETSIM. For every second i of the hot stabilized cycle and for the specified acceleration (a_i) and speed (s_i) for that particular second, the vehicle emission rate (VE_{i-a-s}) from VETs will be collected. The average modal emission rate ($FTP_{AVG-VET}$) of each of the three pollutants CO, NO_x, and HC over 867 seconds of time will be computed using the following equation:

$$FTP_{AVG-VET} = \sum_{i=506}^{i=1372} VE_{i-a-s} \div 867 \qquad \textbf{3.1}$$

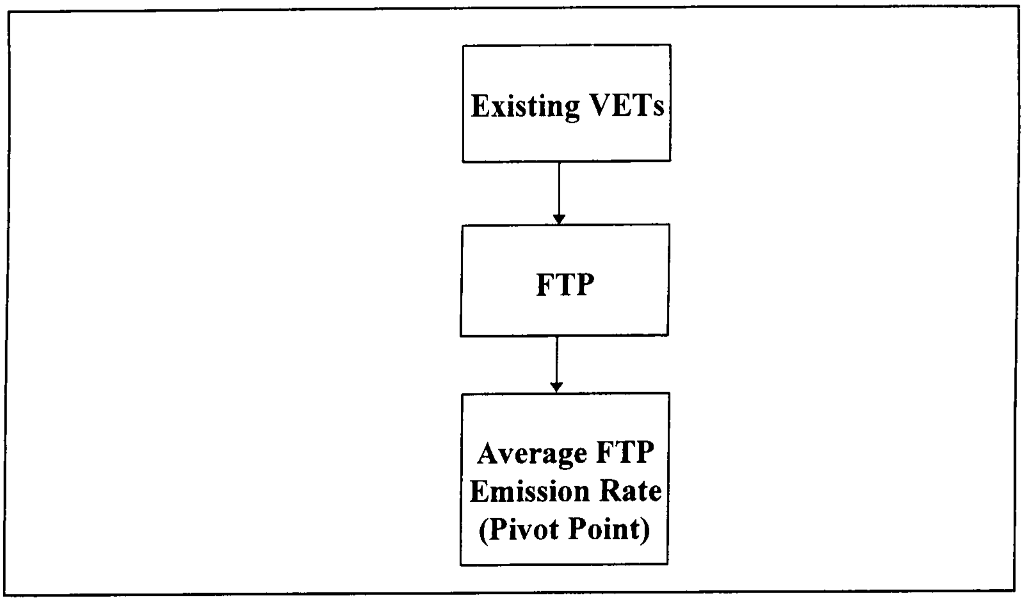

Figure 3.1

Computation of Average FTP Emission Rate

- **Base Line Comparison of Average Emission Rates from Modal Approach and Average Speed Approach**

  The MOBILE model will be executed for the vehicle mix, temperature, altitude, and other conditions similar to those for the ORNL emission rates. The average speed (16.2 mph) for the FTP's hot stabilized portion of the driving cycle will be used. The purpose of this task is to determine the emission rates for CO, HC, and NOx produced by the MOBILE model under conditions similar to those used by ORNL. These average emission rates will be compared with $FTP_{AVG\text{-}VET}$ rates described in task 1. This base line comparison is to determine how different the values from the two sources are under similar conditions.

- **Development and Analysis of Modal Adjustment Factors (MAF's).**

  The Modal Adjustment Factors (MAF) for every combination of speed and acceleration in VET will be calculated using the $FTP_{AVG\text{-}VET}$ rate as the pivot point. This calculation will be performed for all three pollutants. If $VE_{a\text{-}s}$ is the modal emission rate for a specified acceleration *a* and speed *s* in VET, the modal adjustment factor ($MAF_{VEa\text{-}s}$) for that emission rate will be obtained as follows:

$$MAF_{VEa-s} = VE_{a-s} \div FTP_{AVG-VET} \qquad \textbf{3.2}$$

The modal adjustment factors (MAF) will be analyzed to identify the pattern of variation with respect to speed and acceleration. The purpose of this sensitivity analysis is to address the following types of questions:

a) Which combinations of speed and acceleration produce high emission rates?

b) Which combinations of speed and acceleration produce low emission rates?

- **Evaluation of the Impact of a Traffic Engineering Strategy on Emissions Using Modal Approach (TRAF-NETSIM) and Average Speed Approach (MOBILE5a)**

There are certain traffic engineering strategies that influence driving pattern. One of the commonly used technique is signal progression (synchronization). Intuitively, we know that the average speed approach (MOBILE) is inappropriate to evaluate the air quality impact of such a strategy. This study will demonstrate if and by how much the results from the modal approach differ from those from the average speed approach. For this purpose, a case study analysis will be performed. Changes in emission level before and after implementing the above strategy will be analyzed using both approaches.

- **Evaluation of the Effect of Driver Type (Aggressive Vs Uniform) Distribution on Emission Level Using Modal Approach (TRAF-NETSIM)**

TRAF-NETSIM model has the built-in capability to reflect driver behavior. Utilizing this capability, this study will assess how driver behavior affects the level of exhaust emissions from automobiles. Using the same case study used in the previous evaluation, the driver type parameter will be varied, and the changes in results will be analyzed. Although it is questionable as to what actions can be taken to change driver behavior, the results of this analysis will provide an insight concerning the impact of driver behavior on vehicle exhaust emissions.

Chapter 4

Baseline Comparison of Average Emission Rates from Modal Approach and Average Speed Approach

The modal approach for estimating exhaust emissions was investigated on a limited basis by ORNL in the early eighties. The ORNL results were incorporated in TRAF-NETSIM. The results were based on the testing of six light duty gasoline vehicles. Both model year and make of these vehicles are presented in Table 4.1.

Table 4.1

Particulars of Vehicles Tested by ORNL for TRAF-NETSIM

Model Year	Vehicle Model Name
1981	Buick Century
1982	Chevrolet Wagon
1982	Datsun 210
1982	Ford Fairmont
1983	Pontiac Firebird
1984	Chevrolet S-1

The tested vehicles in this project were obtained from local rental agencies. The emission testing was conducted using a chassis dynamometer. Maps of steady-state emissions as a function of vehicle speed and acceleration were made. The data from the six vehicles were combined into one table using appropriate statistical techniques. The emission rates in grams/second were stored for a speed range of 0 to 110 ft/sec and an acceleration range of -9 to +12 ft/sec^2. Appendix II contains the emission tables for all three pollutants, specifically, Hydrocarbons (HC), Carbon Monoxide (CO), and Oxides of Nitrogen (NOx). These tables are embedded in TRAF-NETSIM.

As the data source and mechanics of computation are different for the modal approach (TRAF-NETSIM) and average speed approach (MOBILE5), the results from these two approaches are also different. No previous attempt has been made to compare the results of these two sources using a common computational scenario and thereby assess the differences in the rates embedded in the related techniques. A valid comparison of the results from these two techniques would enable us to export the results from one technique to another. Therefore, a baseline comparison was made to verify how different the average emission rates of ORNL study for the three pollutants are from those computed by MOBILE5a. As a first step, a common scenario was identified to run the analysis. Enough care was exercised to make a comparison under similar conditions.

Identification of a Common Scenario to Make Comparative Analysis

The emission rate tables developed as a part of the ORNL study were applicable to warmed up (hot stabilized) vehicles only. Also, the test was conducted under a specified set of conditions. It is very important that these conditions are met to make a reasonable comparison with EPA's MOBILE model. As FTP is a standardized procedure with a fixed drive cycle, the hot stabilized portion of the FTP drive cycle was selected as the common platform for a comparative analysis.

Analysis of the Hot Stabilized Portion (Bag 2) of FTP

The hot stabilized portion (Bag 2), of the Federal Test Procedure (FTP) driving cycle for light-duty vehicles is shown in Figure 4.1.

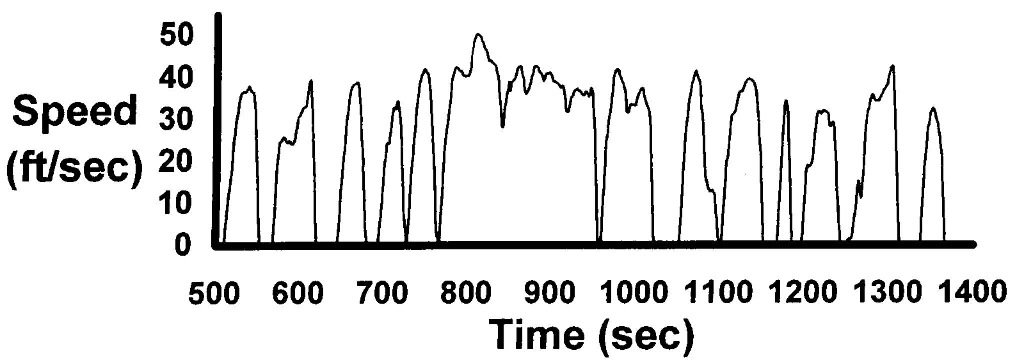

Figure 4.1

FTP Drive Cycle (Hot Stabilized Portion)

This driving cycle involves a dynamometer test of emissions over a 3.87 mile lasting 867 seconds, with an average speed of 16.2 mph. Exhaust emissions during this portion are captured in Bag 2. For every second of the hot stabilized cycle, acceleration and speed are examined to classify the driving mode. If the rate of change of speed is positive, the driving is classified as "acceleration", and if it is negative, it is treated as "deceleration." If the acceleration is zero and speed is greater than zero, the driving mode is considered as "cruise." If the acceleration is zero, and the speed also is zero, the driving mode is considered as "idle." For every second of the hot stabilized portion of the FTP cycle, and for the specified speed and acceleration, the vehicle exhaust emission rate is extracted from the vehicle emission tables embedded in TRAF-NETSIM for all three pollutants (Appendix II).

The emission rates for each particular driving mode are accumulated at the end of the cycle (867 second). In addition, for each driving mode, the cumulative emission rates, and the percentage of emissions for the three different pollutant (HC, CO, and NOx) are presented in Table 4.2. Depending on the pollutant type, the emission rate may be high when accelerating under high speeds. This gives us an idea about the effect of vehicle driving mode on emission rates.

Table 4.2

FTP Emissions According to Driving Mode

Driving Mode (Duration in Sec)	HC Emission (gm)	HC % of Emission	CO Emission (gm)	CO % of Emission	NOx Emission (gm)	NOx % of Emission
Acceleration (270)	0.3232	56.1	5.672	64.9	1.413	83.5
Deceleration (133)	0.0531	9.2	0.551	6.3	0.028	1.7
Cruise (303)	0.1512	26.2	2.024	23.1	0.2029	12.0
Idling (161)	0.0486	8.5	0.486	5.7	0.0486	2.8
Cumulative (867)	0.5761	100.0	8.733	100.0	1.6925	100.0

From Table 4.2, the driving mode "cruise" has the longest duration, followed by "acceleration", "idling", and "deceleration" respectively. During the cruise mode, the highest emitted pollutants are CO and NOx. During the acceleration mode, CO is the highest emitted pollutant by vehicles. This is followed by NOx, and HC respectively. Although idling mode is the third longest driving mode in duration, vehicles are emitting the least amount of HC and CO emissions during that mode. During the deceleration mode, NOx is the least emitted pollutant by vehicles among the three pollutants. The average modal emission rate ($FTP_{AVG\text{-}VET}$) of each of the three pollutants HC, CO, and NO_x, over 867 seconds of time is computed using the following equation:

$$FTP_{AVG-VET} = \sum_{i=506}^{i=1372} VE_{i-a-s} \div 867 \qquad \textbf{4.1}$$

The average emission rates in milligrams per second for all three pollutants are shown in Table 4.3.

Table 4.3

Average FTP Emission Rates For Various Pollutants

Pollutant	Average Emission Rate (Hot Stabilized Cycle) Milligrams/Second
HC	0.66
CO	10.07
NOx	1.95

The above average emission rates for the hot stabilized cycle based on ORNL rates, for all three pollutants, are compared with the emission rates obtained from the execution of the MOBILE model.

The average emission rate over FTP hot stabilized cycle for all vehicles utilized in the development of the emission rates embedded in TRAF-NETSIM were obtained by executing MOBILE5a. Considerable care was exercised in the specification of various parameters in Local Area Parameter (LAP) record. MOBILE5a was executed for 100 percent hot stabilized light duty passenger vehicles. The speed used to execute the model is 16.2 mph which represents FTP Bag 2 average speed. The model was executed for each of the six vehicles using 100 percent registration distribution by age for that particular vehicle model year. Actual mileage on the six vehicles were not available, therefore, MOBILE5a (national average) annual mileage accumulation rates were utilized. The minimum and maximum temperatures, and the base year and in-use Reid Vapor Pressure (RVP) for all six vehicles are presented in Table 4.4.

Table 4.4

Local Area Parameter Records To Execute MOBILE5a

Model Year and Type	Min. Temp ^0F	Max. Temp ^0F	Base RVP	In-use RVP	Calendar Year
'81 Buick Century	75	90	11.50	11.50	1984
'82 Chevrolet Wagon	75	93	11.50	11.50	1984
'82 Datsun 210	52	82	11.50	11.50	1984
'82 Ford Fairmont	59	77	11.50	11.50	1984
'83 Pontiac Firebird	31	33	11.50	11.50	1984
'84 Chevrolet S-1	68	86	11.50	11.50	1984

The MOBILE emission rates (ER) obtained were in grams/mile. These rates were multiplied by 3.87 miles and 1000 milligrams/grams. The obtained product was divided by 867 second. Thus, average emission rates in milligrams/second were obtained. The average emission rates obtained from MOBILE are presented in Table 4.5.

Table 4.5

MOBILE5a Emission Rates for Vehicles Tested by ORNL

Model Year and Type	HC	CO	NOx	HC	CO	NOx
	Grams/Mile			Milligrams/Second		
1981 Buick Century	0.69	9.51	0.82	3.08	42.45	3.66
1982 Chevrolet Wagon	0.55	8.39	0.70	2.46	37.45	3.12
1982 Datsun 210	0.54	7.60	0.72	2.41	33.92	3.21
1982 Ford Fairmont	0.54	7.60	0.72	2.41	33.92	3.21
1983 Pontiac Firebird	0.31	5.20	0.71	1.38	23.21	3.17
1984 Chevrolet S-1	0.18	3.71	0.38	0.80	16.56	1.70
Average Emission Rate	0.47	7.00	0.68	2.09	31.25	3.01

Discussion of Results

A summary of the average FTP emission rates for all the three pollutants obtained from the two models of data are presented in Table 4.6.

Table 4.6

Summary of the Emission Rates Derived from Two Sources

Source	HC (MG/Sec)	CO (MG/Sec)	NOx (MG/Sec)
MOBILE5a	2.09	31.25	3.01
TRAF-NETSIM	0.66	10.07	1.95
Ratio	3.20	3.10	1.54

The ratio between the average emission rates for the FTP hot stabilized cycle based on MOBILE5a, to TRAF-NETSIM for HC, CO, and NOx are 3.20, 3.10, and 1.54 respectively. This difference may be due to the fact that the actual mileage of vehicles used in ORNL testing was not available. The default values for the mileage accrual rate in MOBILE5a were used. Of note, actual mileage is a critical input for making corrections to the base emission rates of MOBILE. In addition, the base emission rates within MOBILE are obtained within a temperature window of 68°F to 86°F to ensure the consistency of the test results. When MOBILE5a is executed for other conditions, the correction factors are applied. When MOBILE5a was executed for each of the vehicles tested by ORNL, correction factors were applied, which might have contributed to the differences in the average emission rates. The emission rates for all three pollutants obtained from MOBILE5a for each of the six vehicles tested at ORNL, along with average emission rates for the six vehicles, and those obtained from TRAF-NETSIM are presented in Figures 4.2 through 4.4. The pattern is similar for all the pollutants. The average emission rates from MOBILE for all the vehicles are greater than those obtained from TRAF-NETSIM data.

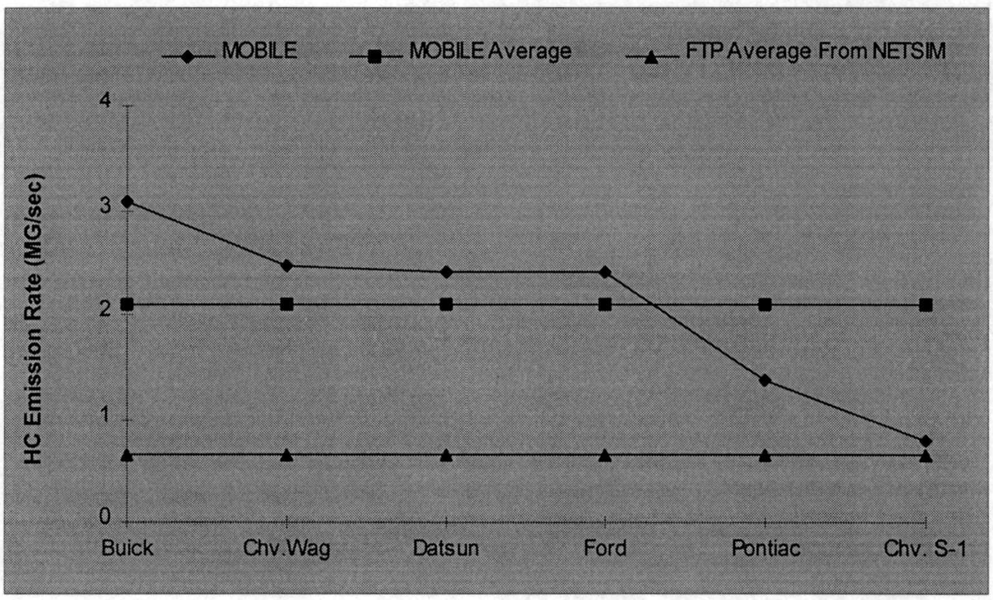

Figure 4.2

Emission Rates For HC

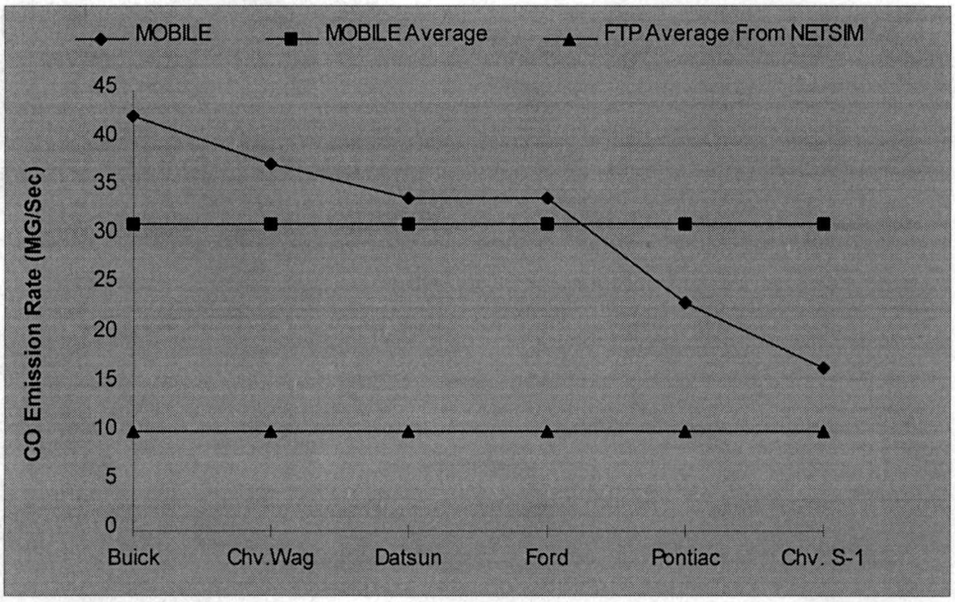

Figure 4.3

Emission Rates For CO

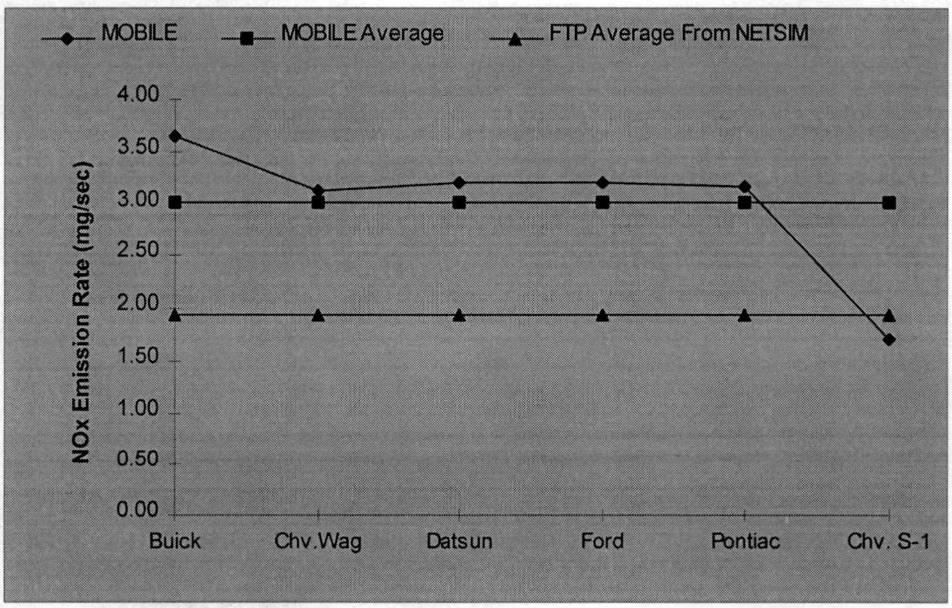

Figure 4.4

Emission Rates For NOx

Summary

For comparing the emission rates embedded in TRAF-NETSIM with those of MOBILE5a, the Federal Test Procedure (FTP) hot stabilized portion was identified as a common platform. A comparison of results was made after the analysis of Bag 2 of the FTP under similar operating conditions. It was observed that the average emission rates reported by MOBILE5a were greater than the average emission rates obtained from TRAF-NETSIM embedded tables. Within the operating range of FTP hot stabilized portion, emission rates for HC, and CO obtained from MOBILE5a were three times higher than those obtained from ORNL study. However, for NOx, MOBILE5a rates were one and half times higher.

Chapter 5

Development and Analysis of Modal Adjustment Factors (MAFs)

Modal Adjustment Factors (MAF) for every combination of speed and acceleration in VET are calculated using the $FTP_{AVG.-VET}$ rate, as determined in Chapter 4, as the pivot point. This calculation is performed for all three pollutants. If V_{a-s} is the modal emission rate for a specified acceleration a and speed s in VET, the modal adjustment factor (MAF_{a-s}) for that emission rate is obtained as follows:

$$MAF_{a-s} = V_{a-s} \div FTP_{AVG-VET} \qquad \textbf{5.1}$$

The adjustment factor of each pollutant is the ratio of the modal emission rate embedded in TRAF-NETSIM for a specified combination of acceleration and speed, and the average FTP emission rate for the pollutant. This gives us an idea about how much the rate varies from the average FTP rate. If the factor is greater than 1, this implies that the modal rate is higher than the average rate; hence, average FTP rate is underestimating emissions under such driving conditions. If the adjustment factor is less than 1, this implies that the modal rate is lower than the average FTP rate; therefore, the average FTP rate is overestimating the emission under those driving conditions. Appendix III contains MAFs for Hydrocarbon, Carbon Monoxide, and Nitrogen Oxide, respectively. A detailed analysis is presented for all three pollutants in the following sections.

Sensitivity Analysis Of Hydrocarbon Modal Adjustment Factors

The Hydrocarbon (HC) Modal Adjustment Factors (MAFs) for a wide range of speeds and acceleration varying from -9 ft/sec^2 to +12 ft/sec^2 are presented in Figures 5.1 through Figure 5.4.

In Figure 5.1, the MAFs for acceleration in a range from -9 ft/sec^2 to -4 ft/sec^2 over the entire speed range are presented. The MAFs varied from 0.46 to 2.4. For a speed of 20 ft/sec, the MAF for this range of acceleration is 1. This implies that at that speed and for this range of acceleration, the average FTP emission rate is the same as the emission rate embedded in TRAF-NETSIM. For speeds less than 20 ft/sec, the MAFs are less than 1. In this operational range, the average FTP emission rate is higher than the HC emission rate embedded in TRAF-NETSIM. The MAF increases uniformly with speed. At high speeds and hard deceleration, the average FTP emission rate is substantially less than those emission rates embedded in TRAF-NETSIM.

Figure 5.2 presents the variation of MAFs over FTP operating range. The speed varies from 0 to 50 ft/sec, and the acceleration varies from -3 to +3 ft/sec^2. It appears that the FTP average emission rate is a good representation for speeds less than 20 ft/sec. Above the speed of 20 ft/sec, irrespective of acceleration, the FTP average is underestimating the emission of HC. This is particularly true for accelerations more than 1 ft/sec^2.

Figure 5.3 presents the variation of MAFs over an acceleration range contained within the FTP range but for speeds outside the FTP range. The speed varies from 51 to 90 ft/sec. The acceleration varied from -3 to +3 ft/sec^2. Over an acceleration range of -3 ft/sec^2 to 1 ft/sec^2, the FTP average rate did not vary greatly with speed. However, for accelerations of 2 ft/sec^2 and 3 ft/sec^2 (for this higher speed range), the emission rates embedded in TRAF-NETSIM are up to 25 times higher than the FTP average emission rate. This implies that the FTP average emission rate is a poor representation of emission for that operating range, and it is underestimating the emission rate substantially.

Figure 5.4 presents the variation of MAFs over accelerations outside the FTP range. The acceleration varies from 4 to 12 ft/sec^2. The speed varies from 0 to 90 ft/sec.

From Figure 5.4, it is clear that the FTP average emission rate is not a good representation for this range of vehicle operation and is underestimating the emission rate substantially.

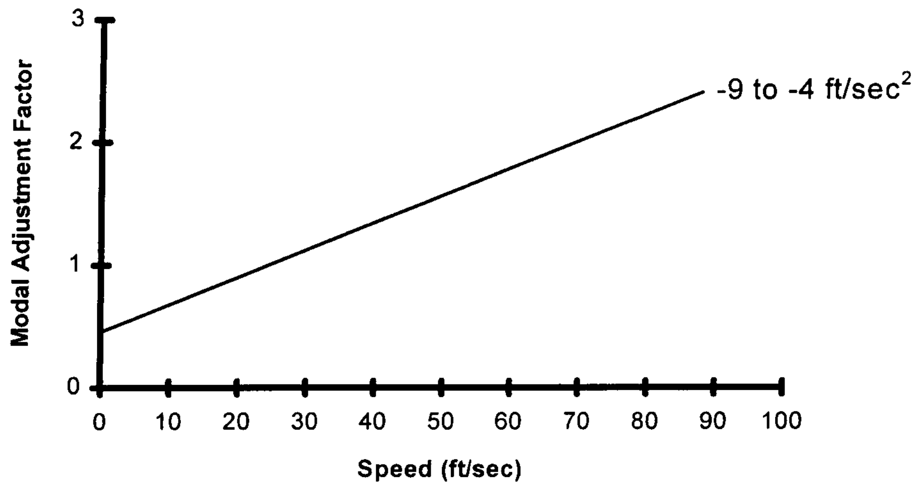

Figure 5.1

Variation Of MAF For HC Over Acceleration Range Of -9 to -4 ft/sec^2

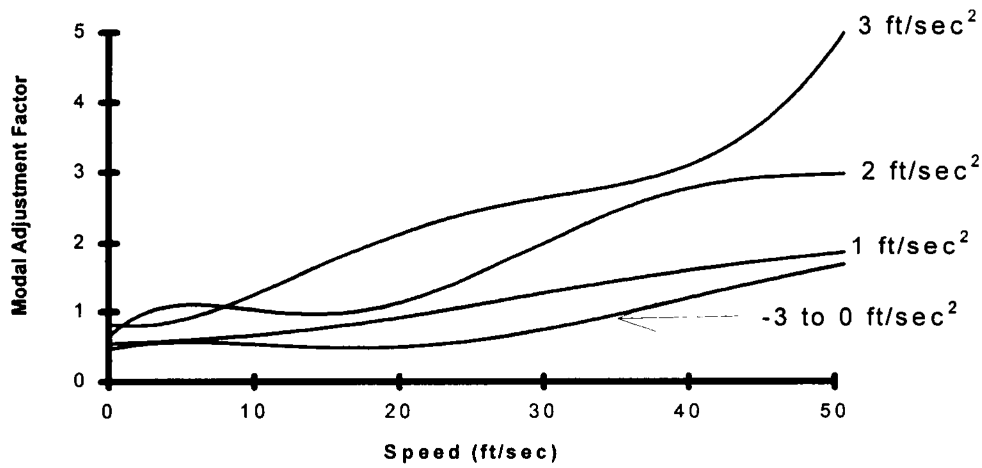

Figure 5.2

Variation Of MAF For HC Over FTP Operating Range

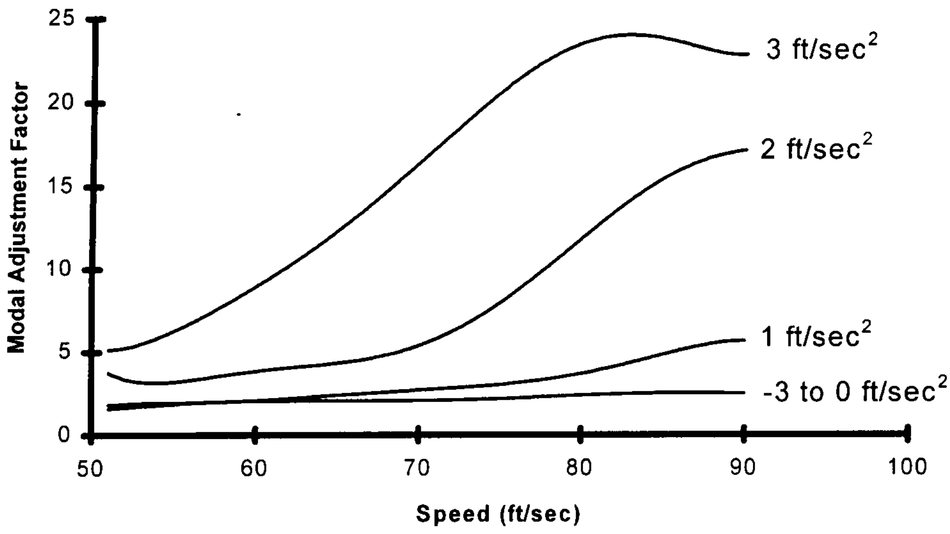

Figure 5.3

Variation Of MAF For HC Over FTP Acceleration Range But Outside FTP Speed

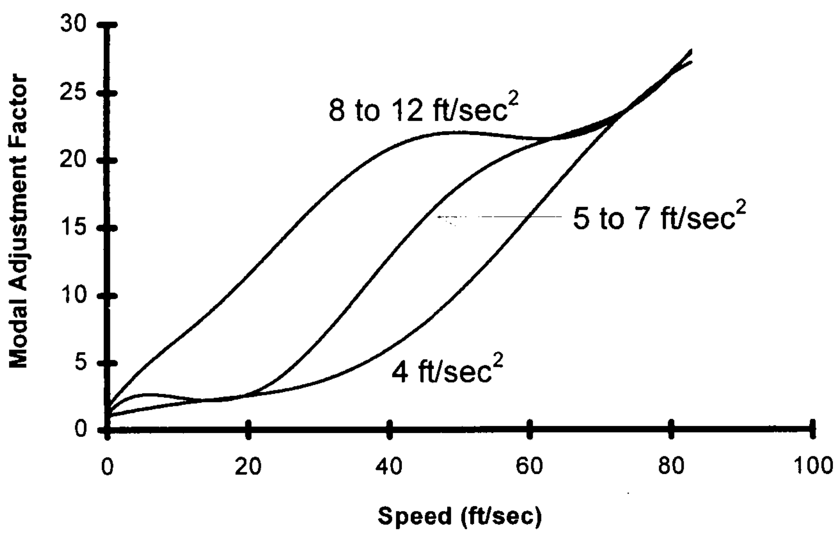

Figure 5.4

Variation Of MAF For HC Over Accelerations Outside FTP Range

Sensitivity Analysis Of Carbon Monoxide (CO) Modal Adjustment Factors

The CO MAFs with respect to speed over an acceleration range varying from -9 ft/sec^2 to +12 ft/sec^2 are presented in Figures 5.5 through 5.8. The CO MAFs vary over a wide range from 0.3 to nearly 180.

In Figure 5.5, the CO MAFs for deceleration in a range from -9 ft/sec^2 to -4 ft/sec^2 over the entire speed range are presented. The MAF increases with increase in speed and varies from 0.3 to 0.5. Irrespective of the speed, under the deceleration mode, the average FTP emission rate is higher than those emission rates embedded in TRAF-NETSIM.

Figure 5.6 presents the variation of MAFs over FTP operating range of speed and acceleration. The FTP average emission rate is a good representation for accelerations less than or equal to 1 ft/sec^2. Above that range, the FTP average is underestimating CO emission rate. This is particularly true for accelerations more than 1 ft/sec^2.

Figure 5.7 presents the variation of MAF over accelerations within the FTP range but for speeds outside FTP range. Over an acceleration range between -3 ft/sec^2 to 0 ft/sec^2, the FTP average rate is steady and always higher than the modal emission rate. For speeds outside those accelerations range, the FTP average emission rate is a poor representation of emission and underestimates emissions substantially.

Figure 5.8 presents the variation of MAFs over accelerations outside the FTP range. The acceleration varied from 4 to 12 ft/sec^2. The FTP average emission rate is a poor representation for this range of vehicle operation and it is always underestimating the emission rate.

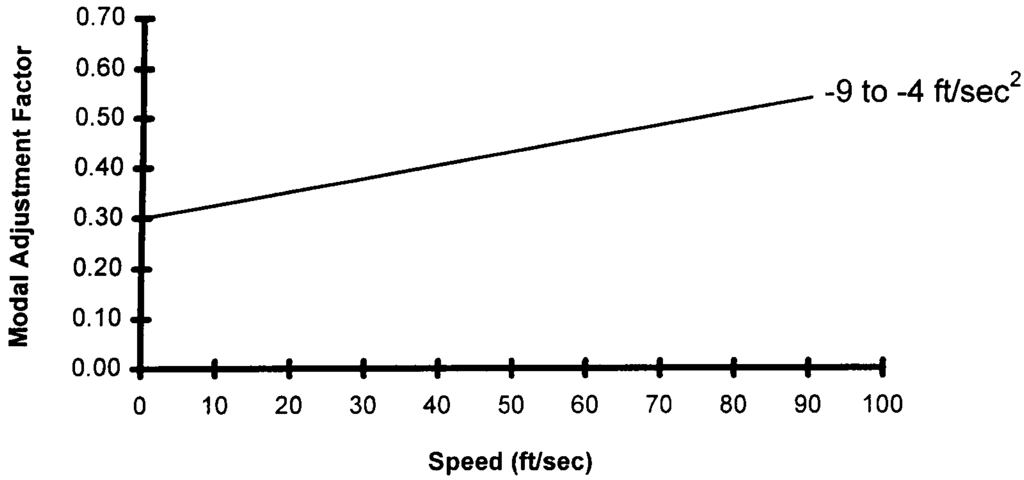

Figure 5.5

Variation Of MAF for CO Over Acceleration Range of -9 to -4 ft/sec^2

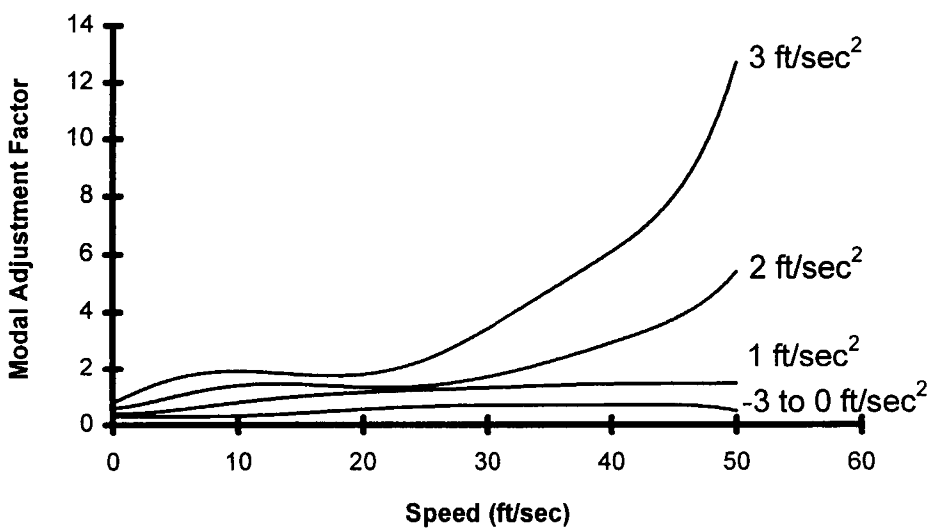

Figure 5.6

Variation Of MAF For CO Over FTP Operating Range

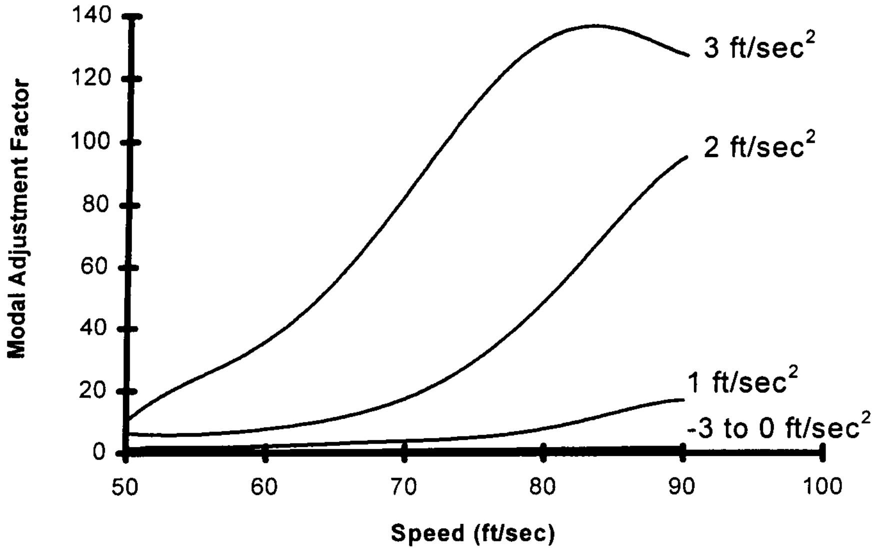

Figure 5.7

Variation Of MAF For CO Over FTP Acceleration Range But Outside FTP Speed

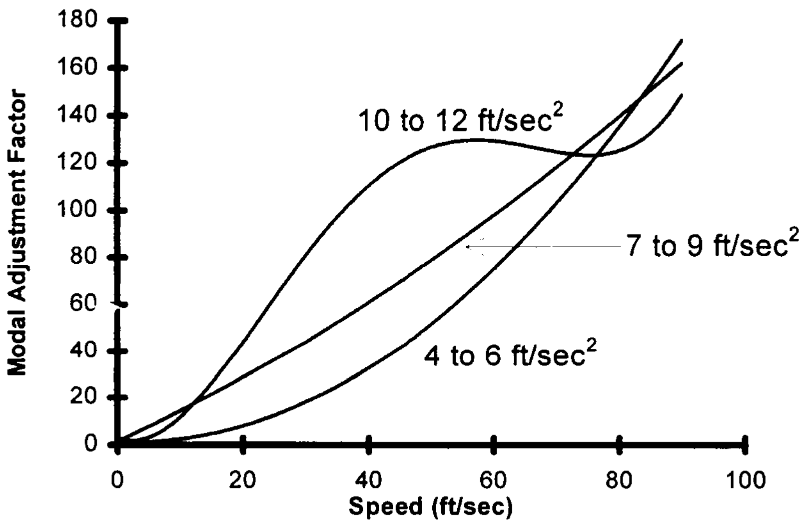

Figure 5.8

Variation Of MAF For CO Over Accelerations Outside FTP Range

Sensitivity Analysis Of Nitrogen Oxides (NOx) Modal Adjustment Factors

The NO_x MAFs with respect to speed and acceleration range of -9 ft/sec^2 to +12 ft/sec^2 are presented in Figures 5.9 through 5.12. The NOx MAFs vary over a wide range from 0.06 to nearly 26.

In Figure 5.9, the MAFs for acceleration in a range from -9 ft/sec^2 to -4 ft/sec^2 over the entire speed range are presented. The MAF decreases with increase in speed. The MAFs vary from 0.06 to 0.17. Figure 5.9 shows that, irrespective of speed, the average FTP emission rate is overestimating the NO_x emission rate.

Figure 5.10 presents the variation of MAFs over accelerations and speed within the FTP cycle's range. Over the range of acceleration between -3 ft/sec^2 to 0 ft/sec^2, the FTP average rate is steady and always more than the modal emission rate. Hence, in this range, FTP is overestimating the emissions rate. For higher acceleration rates, the FTP average emission rate is a poor representation and it is always underestimating the emission rate.

Figure 5.11 presents the variation of MAFs over accelerations within the FTP range but for speeds outside FTP range. The speed varies from 51 to 90 ft/sec. The acceleration varies from -3 to +3 ft/sec^2. Over an acceleration between -3 ft/sec^2 to 0 ft/sec^2, the FTP average emission rate did not vary greatly with speed. For accelerations of 1, 2 and 3 ft/sec^2 , the FTP average rate is a poor representation for this speed range and is always underestimating the emission rate.

Figure 5.12 presents the variation of MAFs over an acceleration range outside the FTP cycle's range. The acceleration range varies from 4 to 12 ft/sec^2. The FTP average emission found to be substantially lower than modal emission rates.

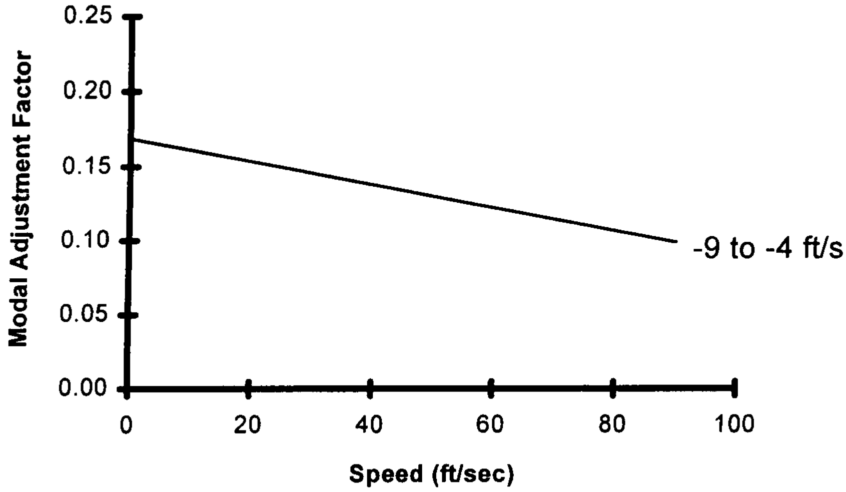

Figure 5.9

Variation Of MAF For NOx Over Acceleration Range Of -9 To -4 ft/sec^2

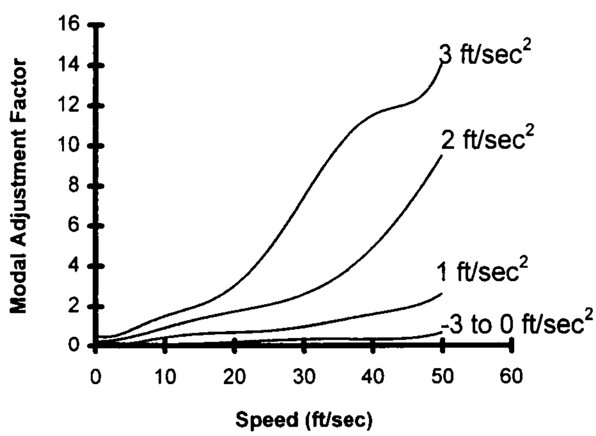

Figure 5.10

Variation Of MAF For NOx Over FTP Operating Range

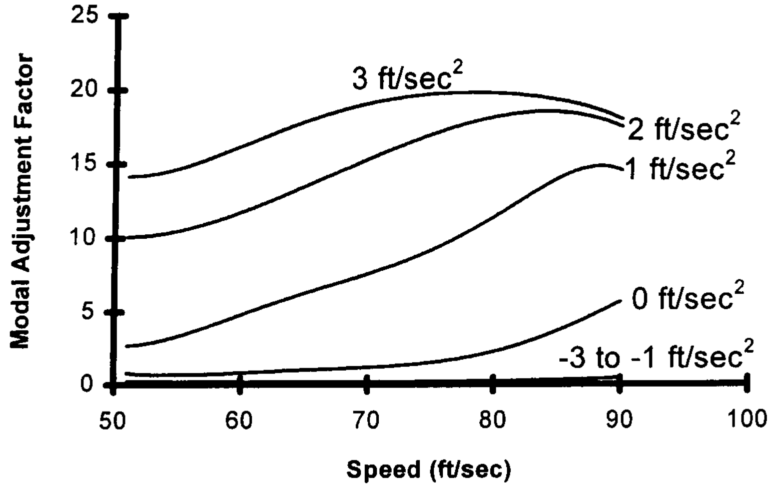

Figure 5.11

Variation Of MAF For NOx Over FTP Acceleration Range But Outside FTP Speed

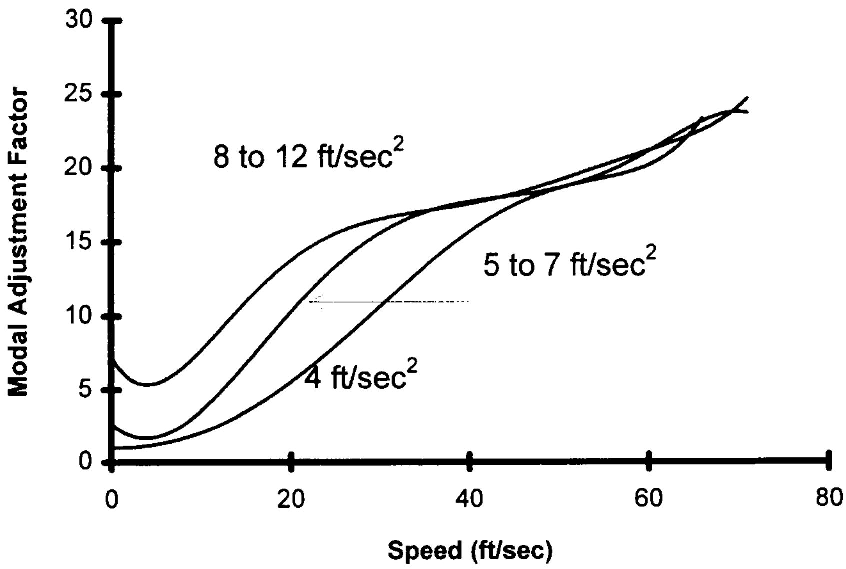

Figure 5.12

Variation Of MAF For NOx Over Accelerations Outside FTP Range

SUMMARY

The analysis documented in this chapter shows that the FTP average emission rate is not a good representation of modal emission rates. For various pollutants, under specific speed and acceleration, the modal emissions are found to be 25 times to 155 times greater than the average FTP emission rate. The FTP emission rates are higher for the deceleration mode. Although, the vehicle-seconds of operation in the acceleration mode is not the largest among all modes for FTP cycle, vehicles are emitting the most emission during that mode.

Chapter 6

Evaluation of the Impact of a Traffic Engineering Strategy on Emissions Using Modal Approach (TRAF-NETSIM) and Average Speed Approach (MOBILE5a)

Motor vehicles are direct contributors of carbon monoxide (CO), and particulate matters, and they also contribute to the production of ozone by emitting hydrocarbons (HC) and nitrogen oxides (NO_x), which photochemically react to produce ozone. In order to be eligible for funding under Congestion Mitigation and Air Quality (CMAQ) program, proposed transportation improvements must quantitatively demonstrate a reduction in emissions level.

Although the effect of the driving mode of vehicle operation on emission is recognized, limited attempt has been made to quantify the benefits due to traffic improvement strategies using the modal approach. This chapter of the report presents the details of an analysis that used both "modal" and "average speed" approaches for the evaluation of the impact of a traffic improvement strategy on emissions from light duty gasoline vehicles. The traffic improvement strategy to be analyzed is the coordination of signal operation along an arterial road. A simple case study involving an arterial operation is selected to achieve this objective. The analysis will be performed with TRAF-NETSIM, a widely used traffic simulation model.

A "before" and "after" study, was performed by synthesizing exhaust emissions based on the driving modes of operation. The mode of each vehicle for every second of operation (acceleration, deceleration, cruise and idling) is recorded and this information is used to quantity the emission associated with the respective mode of operation. Traffic Measures of Effectiveness (MOEs) for the "before" and "after" situations are compared. The increase in mobility due to the traffic improvement strategy is assessed, and the emissions rates are synthesized on the basis of various modes. The analysis identifies which mode is the major contributor of exhaust vehicle emission. The environmental MOEs are compared for each mode and also for the entire operation. This first set of "before" and "after" studies was followed with another using the average speed approach. Then a comparison was made of the findings based on the two different approaches.

Description of the Case Study

The highway network selected for this study is located in the city of Fargo, North Dakota. This is a four-lane arterial (13^{th} Avenue) running in east-west direction with a number of cross streets between 25^{th} Street and 45^{th} Street. The cross streets have one lane in each direction. Traffic moves in both directions. During the peak hour, the traffic volume at the signalized intersection is 2382 vph (13^{th} Avenue and 42^{nd} Street). The major street carries approximately 80% of the traffic volume, while the remaining 20% is carried by the minor street. The posted speed limit on the arterial is 35 mph. A schematic diagram is presented in Figure 6.1.

The traffic control system includes a variety of devices ranging from two-way stop signs on minor streets to traffic signals. Interstate 29 runs in north-south direction. There is substantial traffic interchange between the arterial and the freeway. Major cross streets are identified in the diagram. The geometry and traffic volumes of all the intersections are available. The network has links varying in length from 180 ft to 1500 ft. There are six signalized intersections on the arterial. The signals are assumed to be operating under a pre-timed mode. At unsignalized intersections, the side streets have stop sign control. The approaches to the signalized intersections have lengths varying between 1480 ft and 2700 ft. The lengths of side streets included in the network are approximately 500 ft.

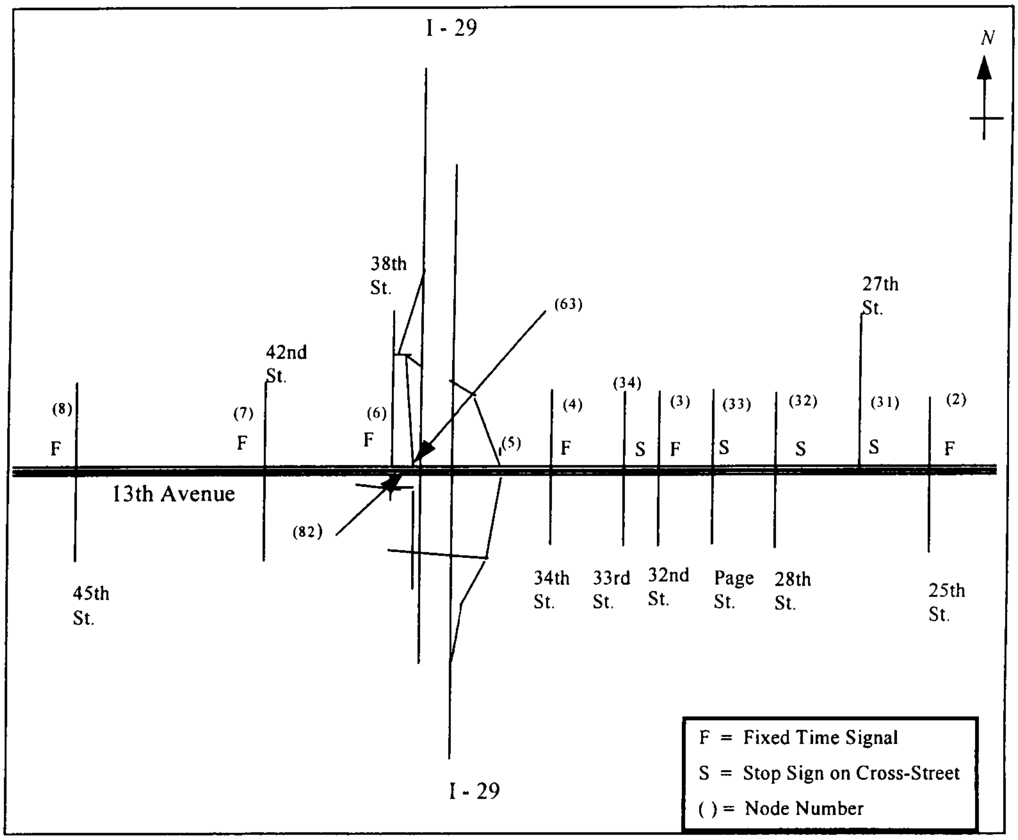

Figure 6.1

Highway Schematic Diagram

Evaluation Using Modal Approach

Currently TRAF-NETSIM is available as a component of CORSIM program. CORSIM is an integrated program to simulate a highway network consisting of both freeways and surface streets. The program reports the results of freeway segments and surface arterial segments separately. The network link-node diagram to prepare the input data to run simulation is presented in Figure 6.2.

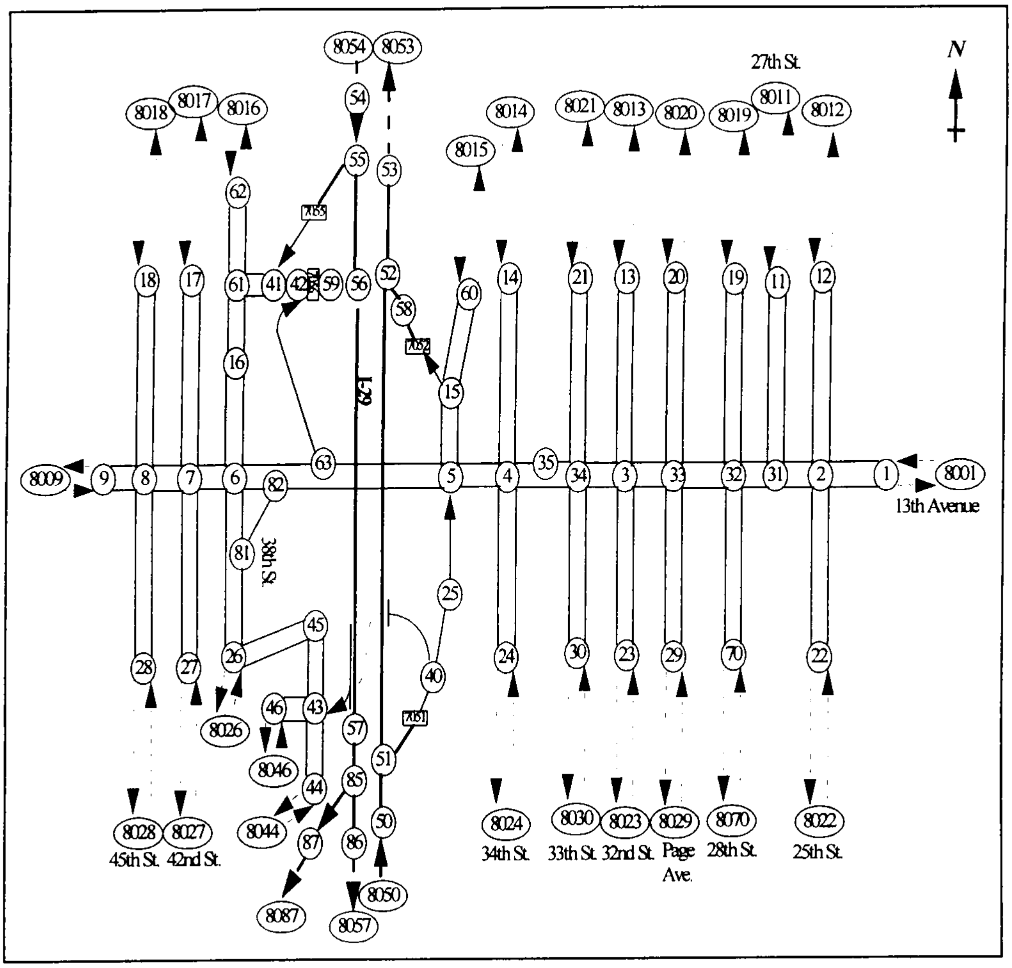

Figure 6.2

Link-Node Diagram of the Case Study

The traffic improvement strategy to be tested is to study the effect of the coordination of the signal system on traffic flow and emissions. Initially, the signal settings at each intersection are treated as isolated cases. These individual signal settings are optimized individually using the software PASSER. Simulation of the arterial operation under these conditions is referred to as "isolated operation" in this report. The same signal settings later are optimized by adjusting the offsets to create a pre-timed coordinated operation. This is referred to as "coordinated operation" in this report.

A summary of vehicle average speeds in both directions on the arterial and for the overall network is presented in Table 6.1.

Table 6.1

Summary of Average Speed for the Two Cases (MPH)

Traffic Direction	Isolated Operation	Coordinated Operation	% Improvement
Eastbound	16.1	17.2	6.8
Westbound	16.9	17.6	4.1
Side Streets	8.1	8.3	2.5
Network	11.4	11.8	3.5

From Table 6.1, the average speed for vehicles traveling in the eastbound direction on the arterial improved by 6.8%. Although the average speed on side streets improved slightly (2.5%), the average speed remained to be relatively low. As for the entire network, the average speed improved by only 3.5%, after signal coordination was implemented. This improvement is relatively small for such an effective traffic control strategy. This may be due to the fact that the original pre-timed settings of signals at the signalized intersections were effective for the overall network to start with.

The following is a comparison of the results of these two cases to determine the effect of the coordination of signal operation on emission level.

Isolated Operation Scenario

The duration and total emissions for each mode along with the cumulative emissions of all three pollutants (HC, CO, NOx) at the end of one hour of simulation period for isolated operation of signals are presented in Table 6.2 and Figure 6.3.

Table 6.2

Summary of Environmental MOEs of Arterial Under Isolated Operation

Mode of Operation	Vehicle Seconds of Operation	HC Emission Kilograms	CO Emission Kilograms	NOx Emission Kilograms
Deceleration	977748	0.44	3.82	0.23
Acceleration	1007868	4.04	231.12	15.58
Cruise	544092	0.26	3.42	0.38
Idling	1390992	0.42	4.17	0.42
Cumulative	3,920,700	5.16	242.53	16.61

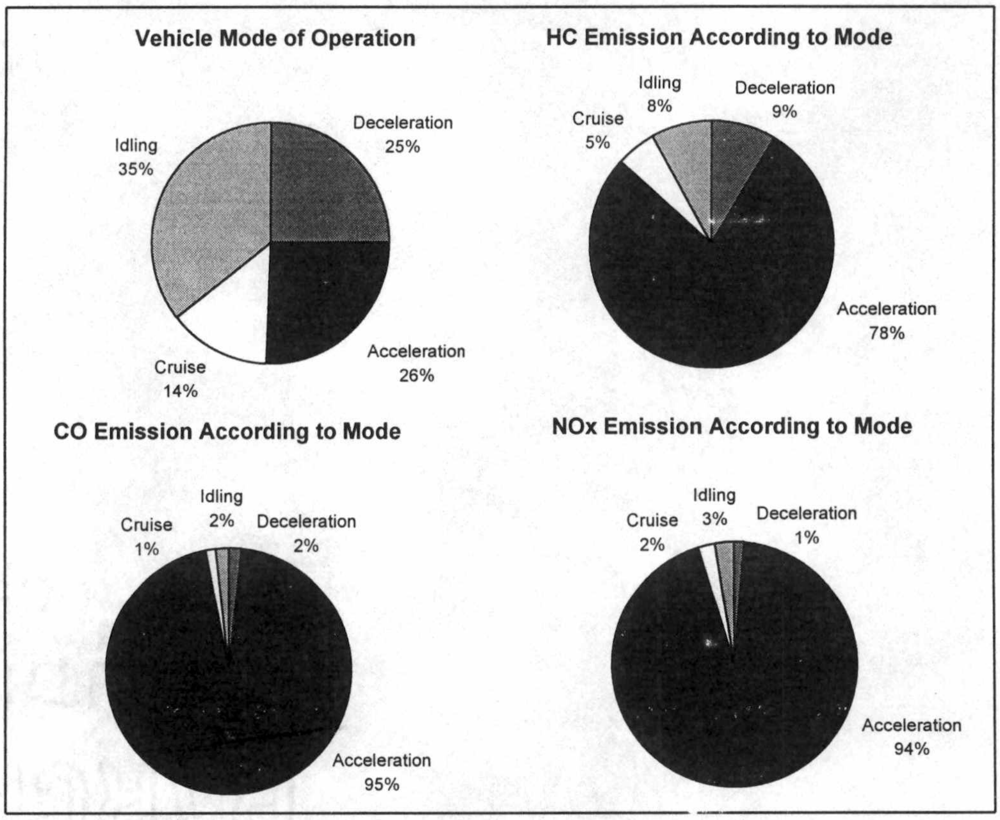

Figure 6.3

A Synthesis of Emissions Under Isolated Operation

From Table 6.2, the idling mode has the largest duration followed by the acceleration mode. The emission values for HC and CO emissions are lowest in cruise mode. However, NOx emission is lowest in deceleration mode. Emissions level during the acceleration mode is largest and considerably larger than the emissions during all other modes combined together. This is true for all the three pollutants. Based on the simulation results, CO is the largest contributor among all three pollutants. This is followed by NOx and HC, respectively. Figure 6.3 shows that 78% of HC and over 90% of CO and NOx are emitted during the acceleration mode.

Coordinated Operation Scenario

After signal coordination was implemented, the simulation was executed again for one hour, and the summary of results of environmental MOEs are presented in Table 6.3 and Figure 6.4.

Table 6.3

Summary of Environmental MOEs of Arterial Under Coordinated Operation

Mode of Operation	Vehicle Seconds of Operation	HC Emission Kilograms	CO Emission Kilograms	NOx Emission Kilograms
Deceleration	925926	0.42	3.62	0.22
Acceleration	968868	3.84	220.47	14.77
Cruise	577206	0.28	3.65	0.41
Idling	1340154	0.40	4.02	0.40
Cumulative	3,812,154	4.94	231.76	15.80

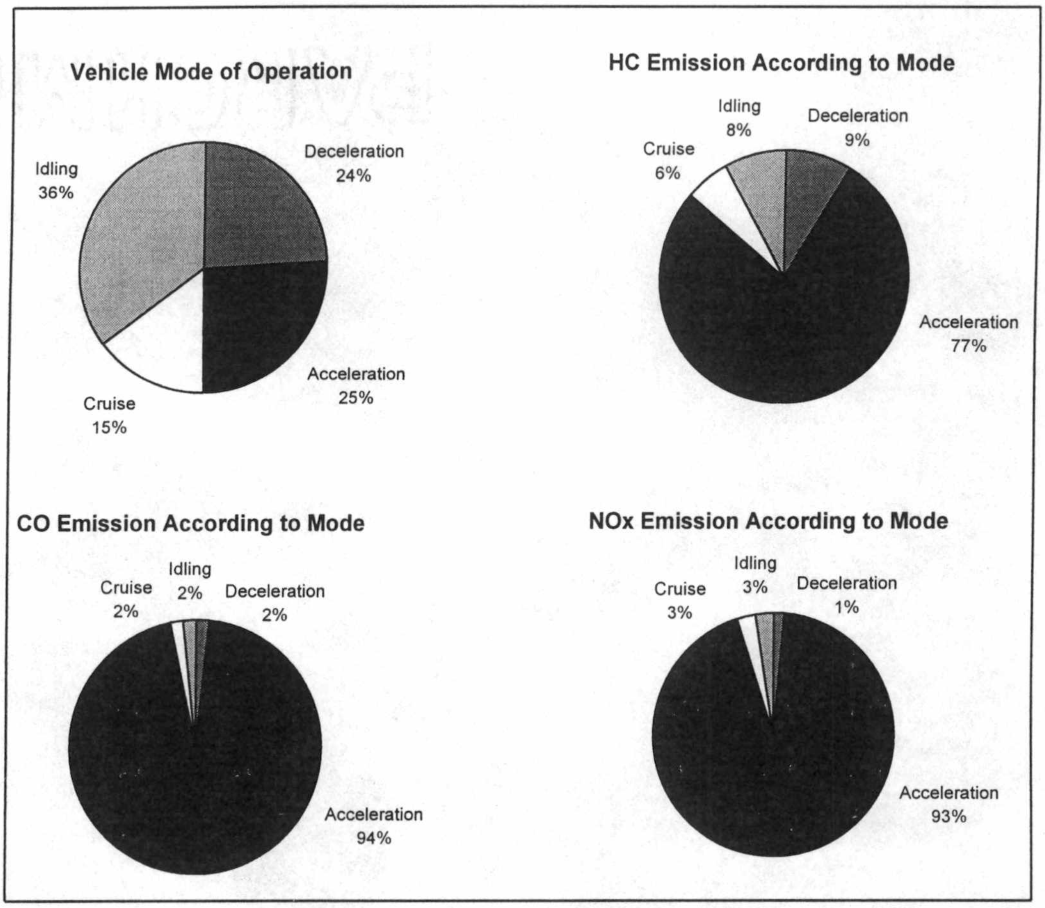

Figure 6.4

A Synthesis of Emissions Under Coordinated Operation

From Table 6.3, the vehicle seconds of operation under coordinated operation follows similar pattern as the isolated scenario. As for the three pollutants, with the exception of HC, the emission values for both CO, and NOx are lowest in the deceleration mode. HC emission level is lowest in cruise mode. Figure 6.4 shows that during the acceleration mode, over 90% of the CO and NOx is emitted. The acceleration mode accounts for 77% of HC.

Results of Modal Approach

A summary of the cumulative hourly emissions based on the modal approach for all three pollutants are presented in Table 6.4.

Table 6.4

Summary of Cumulative Hourly Emissions (Kilogram)

(Modal Approach)

Scenario Type	HC	CO	NO_x
Isolated Operation	5.16	242.53	16.61
Coordinated Operation	4.94	231.76	15.80
Cumulative Benefits	+0.22	+10.77	+0.81
% Reduction	4.26	4.44	4.88

+ Indicates a Reduction

From Table 6.4, HC was the least contributor among all three pollutants for both scenarios. This is followed by NOx and CO, respectively. There was a substantial reduction in the cumulative hourly emission for all three pollutants due the implementation of signal coordination. The percent reductions were 4.26%, 4.44%, and 4.88% for HC, CO, and NOx respectively. A comparison of the cumulative hourly emissions in grams for all three pollutants under the two different scenarios is illustrated in Figure 6.5.

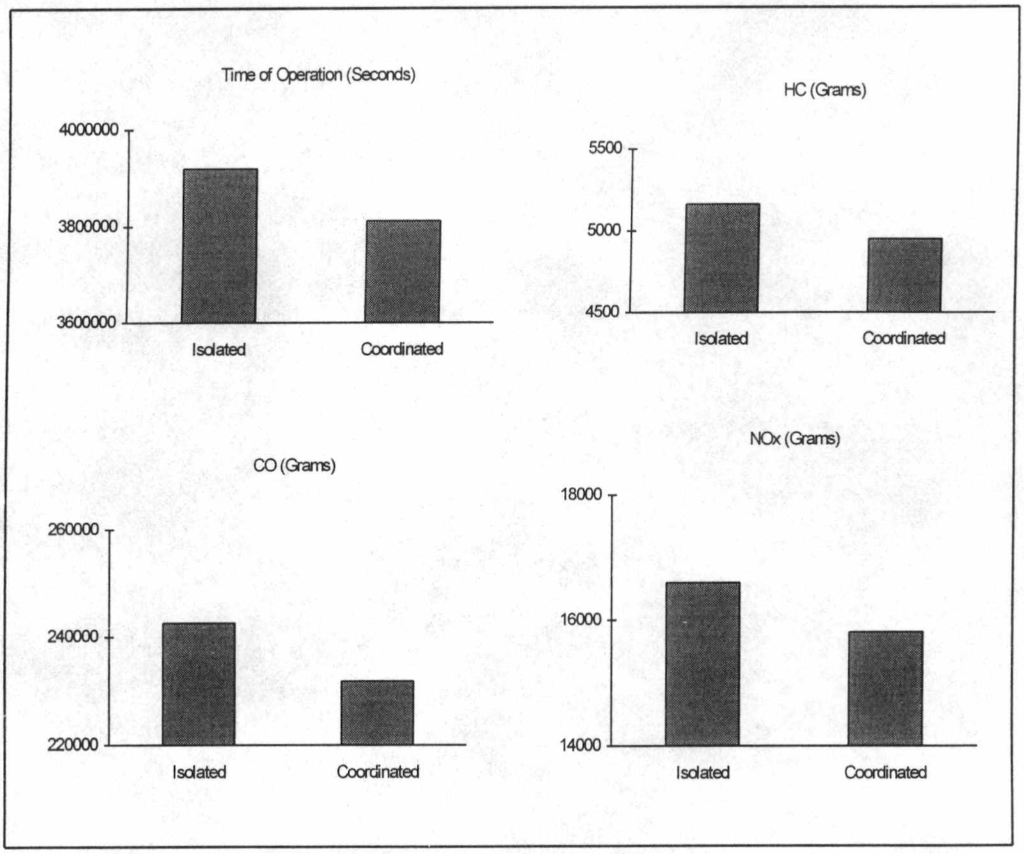

Figure 6.5

Comparison of Emissions (Modal Approach)

Evaluation Using Average Speed Approach (MOBILE5)

The average speed approach of "MOBILE5a model" was utilized to analyze the impact of the same traffic improvement strategy (signal coordination) for the case study described earlier in this chapter. A flow chart outlining the process that was used to estimate the impact of such traffic improvement is presented in Figure 6.6. The total emissions in Kilograms due to the traffic signal coordination over the entire network were obtained using the following steps:

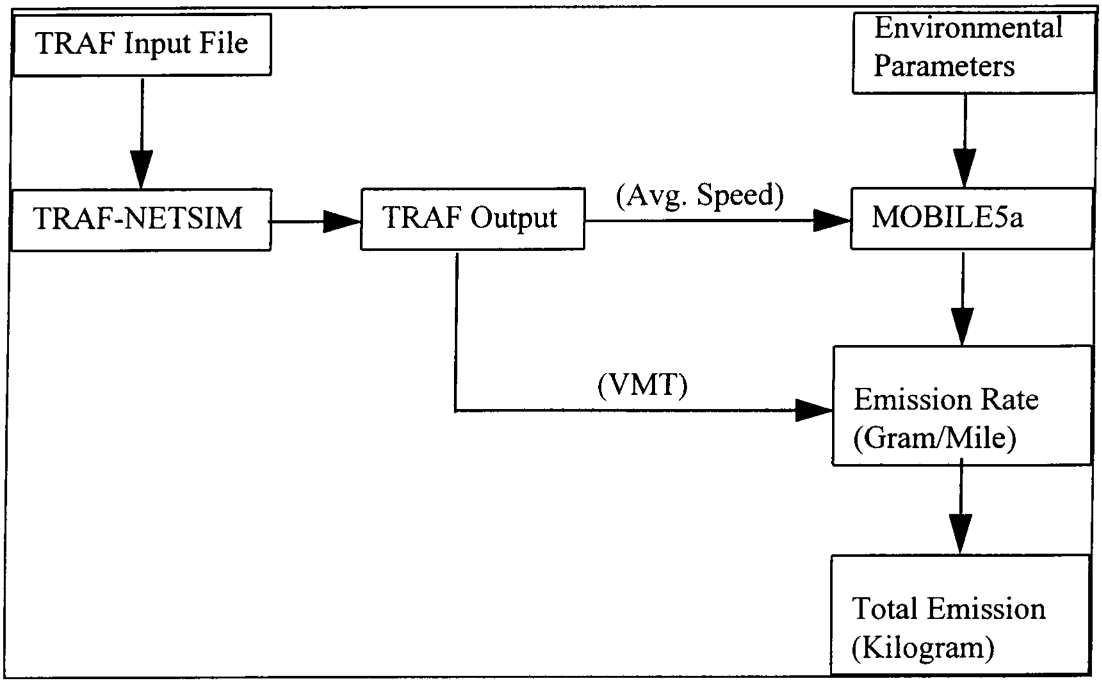

Figure 6.6

Average Speed Approach Process

Step I: Obtaining Relevant Traffic Parameters Using TRAF-NETSIM

TRAF-NETSIM reports speed and VMT on each link of the network. These parameters are defined as below:

Vehicle Miles of Travel: This is the cumulative distance accrued over the duration of study by all vehicles that traverse a link. It is estimated by taking into consideration, the movement of each vehicle while responding to the traffic control devices.

Link speed This is ratio of the cumulative distance traveled by all the vehicles on a link to the cumulative time the vehicles spend traversing the link during the period of study. Thus, it is the space mean speed, which is sensitive to any variation in the performance of highway.

Step II: Obtaining Emission Rates (ERs)

MOBILE5a was employed to estimate emission rates (ERs). Considerable care was exercised in the specification of various parameters in the Local Area Parameter (LAP) record. These parameters reflect the average conditions under which the emission values in TRAF-NETSIM were obtained. MOBILE5a was executed for 100 percent hot stabilized light duty passenger vehicles. The average speed for each link as well as the overall network average speed for both isolated and coordinated operation were input to the program to obtain ERs. The model was executed using the appropriate registration distribution by age, for each vehicle model year. The registration distribution by age is presented in Table 6.5.

Table 6.5

Registration Distribution By Age

Vehicle Model Year	Registration Distribution
1981	0.166
1982	0.50
1983	0.167
1984	0.167

The actual mileage's on the six vehicles were not available; therefore, MOBILE5a (national average) annual mileage accumulation rates were utilized. The minimum and maximum temperatures, the base year and in-use Reid Vapor Pressure (RVP) are presented in Table 6.6.

Table 6.6

MOBILE5a Local Area Parameters

Minimum Temperature	**60° F**
Maximum Temperature	**77° F**
Base RVP	**11.5**
In Use RVP	**11.5**
Calendar Year	**1984**

Based on the above conditions, emission rates (ERs) expressed in grams per vehicles mile of travel for each link and for the overall average network were computed by MOBILE5a. This computation was made for both isolated and coordinated operations.

Step III: Obtaining Cumulative Emission of Pollutants

The ERs obtained in step II for each link on the network for both isolated and coordinated operation were multiplied with its respective VMT to obtain the cumulative emissions. Thus, the quantity of emissions were determined at each link level and also for the overall average network condition. These are presented in Table 6.6. In addition, Table 6.7 includes the space mean speed for each link in the network for both scenarios (isolated Vs coordinated operation).

Table 6.7

Summary of Results For The Two Cases Using Average Speed Approach

Link	Speed (MPH)		Vehicle Miles of Travel (VMT)		MOBILE Estimated Rates for Isolated Case Grams/Mile			MOBILE Estimated Rates for Coordinated Case Grams/Mile			Estimated Emissions Isolated Case (Grams)			Estimated Emissions Coordinated Case (Grams)		
	Isolated	Coordinated	Isolated	Coordinated	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
(1,2)	2.4	2.5	225.66	220.2	2.6	43.27	1.02	2.6	43.27	1.02	586.716	9764.3082	230.1732	572.52	9528.054	224.604
(2, 31)	20.9	19.5	239.82	244.86	0.41	5.82	1.28	0.43	6.03	0.67	98.3262	1395.7524	306.9696	105.2898	1476.5058	164.0562
(31, 32)	22.8	22.6	236.46	243.24	0.39	5.55	0.69	0.39	0.39	0.69	92.2194	1312.353	163.1574	94.8636	94.8636	167.8356
(32, 33)	24.3	24.2	241.92	244.38	0.37	5.37	0.7	0.37	5.38	0.7	89.5104	1299.1104	169.344	90.4206	1314.7644	171.066
(33, 3)	9.8	7.9	253.44	251.82	0.75	11.45	0.72	0.9	14.07	0.75	190.08	2901.888	182.4768	226.638	3543.1074	188.865
(3, 34)	19.5	19.4	203.16	186	0.43	6.03	0.67	0.44	6.06	0.67	87.3588	1225.0548	136.1172	81.84	1127.16	124.62
(34, 35)	25.6	24.8	39.42	36.18	0.35	5.23	0.71	0.36	5.31	0.7	13.797	206.1666	27.9882	13.0248	192.1158	25.326
(35, 4)	9.9	19.2	231.36	225.12	0.74	11.34	0.72	0.44	6.11	0.67	171.2064	2623.6224	166.5792	99.0528	1375.4832	150.8304
(4, 5)	17.5	14.9	305.28	278.04	0.47	6.66	0.68	0.53	7.72	0.69	143.4816	2033.1648	207.5904	147.3612	2146.4688	191.8476
(5, 63)	23.6	24.7	443.7	446.64	0.38	5.45	0.7	0.36	5.33	0.7	168.606	2418.165	310.59	160.7904	2380.5912	312.648
(63, 6)	6.4	11.6	190.32	211.38	1.09	17.24	0.78	0.65	9.76	0.71	207.4488	3281.1168	148.4496	137.397	2063.0688	150.0798
(6, 7)	11.1	11.6	510.18	502.2	0.68	10.17	0.71	0.65	9.76	0.71	346.9224	5188.5306	362.2278	326.43	4901.472	356.562
(7, 8)	15.8	16.6	658.74	693.36	0.51	7.31	0.69	0.49	6.99	0.68	335.9574	4815.3894	454.5306	339.7464	4846.5864	471.4848
(8, 9)	25.6	25.4	575.52	595.86	0.35	5.23	0.71	0.36	5.25	0.71	201.432	3009.9696	408.6192	214.5096	3128.265	423.0606
(9, 8)	3.8	3.9	796.02	806.28	1.71	27.93	0.87	1.75	28.65	0.88	1361.1942	22232.8386	692.5374	1410.99	23099.922	709.5264
(8, 7)	12.2	14.7	795.24	952.86	0.62	9.31	0.7	0.54	7.82	0.69	493.0488	7403.6844	556.668	514.5444	7451.3652	657.4734
(7, 6)	16.1	13.4	660.18	624.96	0.5	7.19	0.68	0.58	8.52	0.7	330.09	4746.6942	448.9224	362.4768	5324.6592	437.472
(6, 82)	24.7	24.3	136.68	126.48	0.36	5.3	0.7	0.37	5.37	0.7	49.2048	728.5044	95.676	46.7976	679.1976	88.536
(82, 5)	12.6	15	535.8	521.4	0.61	9.03	0.7	0.53	7.67	0.69	326.838	4838.274	375.06	276.342	3999.138	359.766
(5, 4)	15.9	16.5	395.7	380.16	0.51	7.27	0.69	0.49	7.02	0.68	201.807	2876.739	273.033	186.2784	2668.7232	258.5088
(4, 34)	18.6	17.1	304.14	292.86	0.45	6.29	0.68	0.48	6.8	0.68	136.863	1913.0406	206.8152	140.5728	1991.448	199.1448
(34, 3)	8.7	11.1	175.14	192.24	0.83	12.83	0.7	0.68	10.17	0.71	145.3662	2247.0462	129.6036	130.7232	1955.0808	136.4904

Link	Speed (MPH)		Vehicle Miles of Travel (VMT)		MOBILE Estimated Rates for Isolated Case Grams/Mile			MOBILE Estimated Rates for Coordinated Case Grams/Mile			Estimated Emissions Isolated Case (Grams)			Estimated Emissions Coordinated Case (Grams)		
	Isolated	Coordinated	Isolated	Coordinated	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
(3, 33)	21.8	22.2	245.4	233.16	0.4	5.68	0.69	0.39	5.63	0.69	98.16	1393.872	169.326	90.9324	1312.6908	160.8804
(33, 32)	24.5	25.6	233.46	216.72	0.37	5.35	0.7	0.35	5.23	0.71	86.3802	1249.011	163.422	75.852	1133.4456	153.8712
(32, 31)	24.7	24.2	200.76	190.92	0.36	5.3	0.7	0.37	5.38	0.7	72.2736	1070.0508	140.532	70.6404	1027.1496	133.644
(31, 2)	10.5	8.4	166.56	174.54	0.71	10.72	0.71	0.74	13.27	0.9	118.2576	1785.5232	118.2576	129.1596	2316.1458	148.359
(2, 1)	25.3	25.5	121.68	122.4	0.36	5.26	0.71	0.36	5.24	0.71	43.8048	640.0368	86.3928	44.064	641.376	86.904
(12, 2)	9.5	10	85.2	86.34	0.77	11.79	0.73	0.74	11.23	0.72	65.604	1004.508	62.196	63.8916	969.5982	62.1648
(2, 12)	25.9	25.6	78.96	82.86	0.35	5.2	0.71	0.35	5.23	0.71	27.636	410.592	56.0616	29.001	433.3578	58.8306
(11, 31)	9.4	9.3	13.08	12.48	0.78	11.91	0.73	0.78	12.04	0.73	10.2024	155.7828	9.5484	9.7344	150.2592	9.1104
(31, 11)	26.5	26.2	18.78	17.52	0.35	5.14	0.71	0.35	5.17	0.71	6.573	96.5292	13.3338	6.132	90.5784	12.4392
(19, 32)	10.7	12.1	11.34	11.34	0.7	10.53	0.71	0.63	9.38	0.7	7.938	119.4102	8.0514	7.1442	106.3692	7.938
(32, 19)	25.9	26.5	7.32	7.92	0.35	5.2	0.71	0.35	5.14	0.71	2.562	38.064	5.1972	2.772	40.7088	5.6232
(20, 33)	6.4	10.1	9.66	10.2	1.09	17.24	0.78	0.73	11.13	0.72	10.5294	166.5384	7.5348	7.446	113.526	7.344
(33, 20)	27.9	27.4	16.2	15	0.33	5.02	0.72	0.34	5.06	0.72	5.346	81.324	11.664	5.1	75.9	10.8
(13, 3)	6.9	7.8	42.6	40.32	1.02	16.03	0.77	0.91	14.24	0.75	43.452	682.878	32.802	36.6912	574.1568	30.24
(3, 13)	25.9	26.1	28.86	32.22	0.35	5.2	0.71	0.35	5.18	0.71	10.101	150.072	20.4906	11.277	166.8996	22.8762
(21, 34)	10.9	14.1	5.7	5.7	0.69	10.35	0.71	0.56	8.13	0.69	3.933	58.995	4.047	3.192	46.341	3.933
(34, 21)	26.8	26.6	4.92	4.38	0.34	5.11	0.71	0.34	5.13	0.71	1.6728	25.1412	3.4932	1.4892	22.4694	3.1098
(14, 4)	10.3	9.2	25.56	25.02	0.72	10.92	0.72	0.8	12.16	0.73	18.4032	279.1152	18.4032	19.7658	304.2432	18.2646
(4, 14)	27	26.8	39.6	40.74	0.34	5.09	0.71	0.34	5.11	0.71	13.464	201.564	28.116	13.8516	208.1814	28.9254
(15, 5)	9.6	8.3	55.74	3.47	0.76	11.68	0.73	0.86	13.42	0.74	42.3624	651.0432	40.6902	2.9842	46.5674	2.5678
(5, 15)	22.7	20.8	75.48	69.66	0.39	5.56	0.69	0.41	5.83	0.68	29.4372	419.6688	52.0812	28.5606	406.1178	47.3688
(60, 15)	19.5	20	30.24	29.52	0.43	6.03	0.67	0.42	5.96	0.68	13.0032	182.3472	20.2608	12.3984	175.9392	20.0736
(15, 60)	25.1	25.1	14.1	13.86	0.36	5.28	0.71	0.36	5.28	0.71	5.076	74.448	10.011	4.9896	73.1808	9.8406
(63, 42)	23.7	25.9	81.18	89.88	0.37	5.44	0.7	0.35	5.2	0.71	30.0366	441.6192	56.826	31.458	467.376	63.8148
(16, 6)	7.4	7.7	107.4	105.12	0.95	14.98	0.76	0.92	14.42	0.75	102.03	1608.852	81.624	96.7104	1515.8304	78.84
(6, 16)	25.9	25.7	79.68	72.48	0.35	5.2	0.35	0.35	5.22	0.71	27.888	414.336	27.888	25.368	378.3456	51.4608
(61, 16)	26.4	26.3	135	135	0.35	5.15	0.71	0.35	5.16	0.71	47.25	695.25	95.85	47.25	696.6	95.85

Link	Speed (MPH)		Vehicle Miles of Travel (VMT)		MOBILE Estimated Rates for Isolated Case Grams/Mile			MOBILE Estimated Rates for Coordinated Case Grams/Mile			Estimated Emissions Isolated Case (Grams)			Estimated Emissions Coordinated Case (Grams)		
	Isolated	Coordinated	Isolated	Coordinated	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
(16, 61)	14.9	15.4	92.04	94.8	0.53	7.72	0.69	0.52	7.49	0.69	48.7812	710.5488	63.5076	49.296	710.052	65.412
(62, 61)	18	17.9	84.12	84.12	0.46	6.49	0.68	0.46	6.52	0.68	38.6952	545.9388	57.2016	38.6952	548.4624	57.2016
(61, 62)	25.6	25.5	38.52	40.8	0.35	5.23	0.71	0.36	5.24	0.71	13.482	201.4596	27.3492	14.688	213.792	28.968
(41, 61)	5.3	5.3	23.52	5.85	1.29	20.7	0.81	1.29	20.79	0.81	30.3408	486.864	19.0512	7.5465	121.6215	4.7385
(61, 41)	22	22	24.84	25.08	0.4	5.66	0.69	0.4	5.66	0.69	9.936	140.5944	17.1396	10.032	141.9528	17.3052
(41, 42)	27.7	28.2	15	15.12	0.34	5.03	0.72	0.33	4.99	0.72	5.1	75.45	10.8	4.9896	75.4488	10.8864
(17, 7)	8.4	9	86.94	85.8	0.85	13.27	0.7	0.81	12.42	0.73	73.899	1153.6938	64.3356	69.498	1065.636	62.634
(7, 17)	25.5	25.5	131.1	138.9	0.36	5.24	0.71	0.36	5.24	0.71	47.196	686.964	93.081	50.004	727.836	98.619
(18, 8)	8	8.1	72.72	73.86	0.89	13.9	0.75	0.88	13.74	0.74	64.7208	1010.808	54.54	64.9968	1014.8364	54.6564
(8, 18)	26.3	26	103.2	103.14	0.35	5.16	0.71	0.35	5.19	0.71	36.12	532.512	73.272	36.099	535.2966	73.2294
(22, 2)	7.2	7	76.14	76.14	0.98	15.38	0.76	1	15.81	0.76	74.6172	1171.0332	57.8664	76.14	1203.7734	57.8664
(2, 22)	26.1	26	107.46	109.68	0.35	5.18	0.71	0.35	5.19	0.71	37.611	556.6428	76.2966	38.388	569.2392	77.8728
(70, 32)	8.5	6.7	13.08	13.62	0.85	13.12	0.7	1.04	16.49	0.77	11.118	171.6096	9.6792	14.1648	224.5938	10.4874
(32, 70)	27.4	27.2	22.5	23.16	0.34	5.06	0.72	0.34	5.08	0.72	7.65	113.85	16.2	7.8744	117.6528	16.6752
(29, 33)	5	8.2	10.2	10.8	1.36	21.91	0.82	0.87	13.58	0.74	13.872	223.482	8.364	9.396	146.664	7.992
(33, 29)	26.4	25.5	14.76	14.28	0.35	5.15	0.71	0.36	5.24	0.71	5.166	76.014	10.4796	5.1408	74.8272	10.1388
(23, 3)	7.3	6.4	49.98	47.7	0.97	15.18	0.76	1.09	17.24	0.78	48.4806	758.6964	37.9848	51.993	822.348	37.206
(3, 23)	25.3	25.9	54.12	51.3	0.36	5.26	0.71	0.35	5.2	0.71	19.4832	284.6712	38.4252	17.955	266.76	36.423
(30, 34)	7.5	3.8	13.62	12.48	0.94	14.79	0.75	1.75	28.65	0.88	12.8028	201.4398	10.215	21.84	357.552	10.9824
(34, 30)	25.9	26.5	32.64	29.34	0.35	5.2	0.71	0.35	5.14	0.71	11.424	169.728	23.1744	10.269	150.8076	20.8314
(24, 4)	6.7	6.8	47.7	50.58	1.04	16.49	0.77	1.03	16.26	0.77	49.608	786.573	36.729	52.0974	822.4308	38.9466
(4, 24)	26.6	26.5	67.2	69.18	0.34	5.13	0.71	0.35	5.14	0.71	22.848	344.736	47.712	24.213	355.5852	49.1178
(25, 5)	5.3	4.8	58.08	59.28	1.29	20.7	0.81	1.41	22.8	0.83	74.9232	1202.256	47.0448	83.5848	1351.584	49.2024
(40, 25)	25.2	25.2	64.92	64.92	0.36	5.27	0.71	0.36	5.27	0.71	23.3712	342.1284	46.0932	23.3712	342.1284	46.0932
(40, 43)	10.8	11	73.38	73.38	0.69	10.44	0.71	0.68	10.26	0.71	50.6322	766.0872	52.0998	49.8984	752.8788	52.0998
(43, 44)	22.2	21.7	39.9	40.32	0.39	5.63	0.69	0.4	5.7	0.69	15.561	224.637	27.531	16.128	229.824	27.8208
(44, 43)	6.7	7.4	19.98	21.36	1.04	16.49	0.77	0.95	14.98	0.76	20.7792	329.4702	15.3846	20.292	319.9728	16.2336

Link	Speed (MPH)		Vehicle Miles of Travel (VMT)		MOBILE Estimated Rates for Isolated Case Grams/Mile			MOBILE Estimated Rates for Coordinated Case Grams/Mile			Estimated Emissions Isolated Case (Grams)			Estimated Emissions Coordinated Case (Grams)		
	Isolated	Coordinated	Isolated	Coordinated	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
(43, 45)	20.5	20.7	28.98	29.46	0.42	5.88	0.68	0.41	5.85	0.68	12.1716	170.4024	19.7064	12.0786	172.341	20.0328
(45, 26)	20.9	21.1	46.92	46.92	0.41	5.82	0.68	0.41	5.79	0.68	19.2372	273.0744	31.9056	19.2372	271.6668	31.9056
(26, 45)	20.4	20.8	29.52	28.8	0.42	5.89	0.68	0.41	5.83	0.68	12.3984	173.8728	20.0736	11.808	167.904	19.584
(45, 43)	7.4	8	19.08	16.38	0.95	15.0	0.76	0.89	13.9	0.75	18.126	285.8184	14.5008	14.5782	227.682	12.285
(43, 46)	22.2	22.3	28.2	28.2	0.39	5.63	0.69	0.39	5.62	0.69	10.998	158.766	19.458	10.998	158.484	19.458
(46, 43)	7.2	7	13.2	13.2	0.98	15.38	0.76	1	15.81	0.76	12.936	203.016	10.032	13.2	208.692	10.032
(26, 81)	17.5	17.3	16.98	16.98	0.47	6.66	0.68	0.47	6.73	0.68	7.9806	113.0868	11.5464	7.9806	114.2754	11.5464
(81, 6)	2.5	2.5	13.68	11.64	2.6	43.27	1.02	2.6	43.27	1.02	35.568	591.9336	13.9536	30.264	503.6628	11.8728
(81, 82)	13	12.8	19.86	20.28	0.59	8.77	0.7	0.6	8.9	0.7	11.7174	174.1722	13.902	12.168	180.492	14.196
(6, 26)	16.3	17.5	43.8	49.68	0.5	7.1	0.68	0.47	6.66	0.68	21.9	310.98	29.784	23.3496	330.8688	33.7824
(27, 7)	8	8.3	143.16	126.72	0.89	13.9	0.75	0.86	13.42	0.74	127.4124	1989.924	107.37	108.9792	1700.5824	93.7728
(7, 27)	26.5	26.3	76.68	73.68	0.35	5.14	0.71	0.35	5.16	0.71	26.838	394.1352	54.4428	25.788	380.1888	52.3128
(28, 8)	8	8	117.06	117.06	0.89	13.9	0.75	0.89	13.9	0.75	104.1834	1627.134	87.795	104.1834	1627.134	87.795
(8, 28)	26	26	114.9	119.16	0.35	5.19	0.17	0.35	5.19	0.71	40.215	596.331	19.533	41.706	618.4404	84.6036
(126, 26)	24.3	24.4	38.46	38.46	0.37	5.37	0.7	0.37	5.36	0.7	14.2302	206.5302	26.922	14.2302	206.1456	26.922
(26, 126)	24.8	24.5	59.28	63.54	0.36	5.31	0.7	0.37	5.35	0.7	21.3408	314.7768	41.496	23.5098	339.939	44.478
(155, 41)	20.1	20.1	34.62	34.62	0.42	5.94	0.68	0.42	5.94	0.68	14.5404	205.6428	23.5416	14.5404	205.6428	23.5416
Sum					**58.63**	**896.6**	**955.2**	**57.88**	**881.01**	**938.89**	**8100.8628**	**123615.47**	**8984.7498**	**7913.655**	**119459.09**	**8942.6389**
Network	**11.4**	**11.8**	**12369.42**	**12465.36**	**0.55**	**6.50**	**0.72**	**0.53**	**6.29**	**0.72**	**6,803.18**	**80,401.23**	**8,905.98**	**6,606.64**	**78,407.11**	**8,975.06**

Results of Average Speed Approach

A summary of the cumulative hourly emissions on a link by link basis for the two cases (isolated Vs coordinated operation) is presented in Table 6.8.

Table 6.8

Summary of Cumulative Hourly Emissions for All Links of Network (Kilogram)

Scenario Type	HC	CO	NO_x
Isolated Operation	8.10	123.62	8.98
Coordinated Operation	7.91	119.46	8.94
Cumulative Benefits	+0.19	+4.16	0.04
% Reduction	2.35	3.37	0.45

+ Indicates a Reduction

Table 6.8 indicates a decrease in HC, CO, and NOx emissions due to the implementation of signal coordination strategy on the arterial. The percent reductions were 2.40%, 3.48%, and 0.04% in HC, CO, and NOx, respectively. The reduction of NOx was not as significant as HC and CO. This is because the base emission rates of all three pollutants in MOBILE model are a function of speed. For HC and CO, the emissions rates in the MOBILE model decrease with the increase in speed. However, that is not the case for NOx. Beyond a particular average speed range, the NOx emissions rates increase with the increase in average speed.

A summary of the network cumulative hourly emissions results using the network- wide average speed for the two cases (isolated Vs coordinated operation) are presented in Table 6.9.

Table 6.9

Summary of Network Cumulative Hourly Emissions Results Using Network Average Speed (Kilogram)

Scenario Type	HC	CO	NO_x
Isolated Operation	6.80	80.40	8.91
Coordinated Operation	6.61	78.41	8.97
Cumulative Benefits	+0.19	+1.99	-0.06
% Reduction	2.80	2.48	-0.67

+ Indicates a Reduction

- Indicates an Increase

The results of the aggregate approach of computation using the network average speed were similar to those of the link-by-link approach. This is particularly true for HC and CO. However, this was not the case for NOx emissions. The average speed approach using the network average speed did not show a reduction in NOx emission. Table 6.8 indicates a percent reduction of 0.45 in NOx emission, while Table 6.9 indicates an increase of NOx emissions (0.67%) when implementing signal coordination on the arterial. Another difference of using link by link analysis (shown in Table 6.8) is that the percent reduction in CO emissions is higher than what was found using network average speed (3.37% versus 2.48%), respectively.

SUMMARY

In this chapter, the effects of a traffic improvement strategy on exhaust emission level using "modal" and "average speed" approaches were evaluated. The coordination of signal operation along an arterial road was analyzed. As a part of this effort, TRAF-NETSIM output was customized to report the cumulative pollutant emission and duration of each driving mode. According to the traffic MOEs, there was considerable benefit due to the improvement strategy (coordination of signals). The total number of vehicle seconds over the entire network is reduced. Speeds on the arterial links were improved. In addition, it was observed from this study that the acceleration mode was the largest contributor of exhaust emissions among all driving modes.

When using the average speed approach, there was a difference in the cumulative quantity of emissions when the calculation was based on link by link speeds versus the network average speed. The percent reductions of both CO and NOx were more significant when using link by link speed analysis. The average speed approach reported a negative benefit (an increase) in NOx emission (-0.67) when average network speed was used.

A summary of the percent reductions in cumulative hourly emissions for the two different approaches "modal" versus "average speed" due to the implementation of signal coordination on the arterial are presented in Table 6.10.

Table 6.10

Percent Reductions in Network Cumulative Hourly Emissions for Two Different Approaches

Approach		HC	CO	NO_x
Modal		4.26	4.44	4.88
Average Speed	Link by Link Speed	2.35	3.37	0.45
	Network Average Speed	2.80	2.48	-0.67

From Table 6.10, the percent reductions due to signal coordination using the modal approach were larger than those of the network average speed approach by 1.46%, 1.96%, and 5.55% for HC, CO, and NOx, respectively. These differences in benefits are significant, especially for NOx (5.80%). Similar trends were found when comparing the percent reductions based on the modal approach with link by link average speed approach.

CHAPTER 7

Evaluation of the Effect of Driver Type (Aggressive VS Uniform) Distribution on Emission Level Using Modal Approach

Driving behavior varies from person to person and affects the operation of highway systems considerably. It has been recognized that variations in driving behavior are not well represented by a fixed drive cycle like the Federal Test Procedure (FTP). Some driving maneuvers involve high speeds and accelerations, putting heavy loads on engines and thereby causing very high emissions. If an analysis of cumulative emissions are made on the basis of the driving mode for every second of vehicle operation, the impact of driver characteristics on the mobile emissions can be quantified. The main objective of this analysis is to verify the validity of assuming uniform driver behavior in the estimation of mobile source emissions. As a byproduct of this effort, a synthesis of cumulative emissions of three pollutants (HC, CO and NO_x) on the basis of driving modes is made. In this Chapter, a simulation based approach to determine the impact of driver behavior on emission level utilizing the same case study described in the previous chapter is presented.

Selection of a Suitable Technique

Various field techniques including instrumented vehicle studies and chase car studies are used by researchers to study modal emissions. It is very difficult to duplicate human responses to innumerable traffic situations and run experiments. These field techniques are cumbersome, expensive, very difficult to be repeated. A suitable simulation program that can realistically simulate human responses provides an alternative means to evaluate transportation and environmental aspects of highway operation. TRAF-NETSIM was considered a suitable simulation tool for the proposed analysis involving driving behavior.

TRAF-NETSIM's ability to simulate the behavior of the driver population distinguishes it among simulation programs. A unique feature of the program is that the user can specify ten types of drivers with various driving attributes with regard to different driving maneuvers. TRAF-NETSIM also offers the user to avail of the ten default options for driver types. These values are used in this research effort. A summary of the values that define various driving maneuvers of each driver type is presented in Table 7.1.

The user can input data on various driving maneuvers to simulate real-world highway operations. For example, the user can specify acceptable gaps (in tenths of a second) in near-side cross traffic for vehicles at a stop sign and for far-side cross traffic. The drivers' responses during the amber phase (the transition of the signal to the red indication) are a function of acceptable deceleration of the lead moving vehicle. The user can also input acceptable left-turn gaps during a permitted movement and right-turn-on-red maneuvers (both in tenths of a second). The user can specify the start-up lost time. Start-up lost time is the time spent by the first vehicle in queue before it avails of the right of way, and it is expressed in tenths of a second in TRAF-NETSIM. The program's lane-changing logic can be exploited by the user through the specification of a percentage of cooperative drivers. Various thresholds can be defined by the user to simulate the driver motivation to acquire mobility.

Table 7.1

Summary of Maneuver Attributes for Various Types of Drivers Embedded in NETSIM [1]

Driving Maneuver	Driver Type I	Driver Type II	Driver Type III	Driver Type IV	Driver Type V	Driver Type VI	Driver Type VII	Driver Type VIII	Driver Type IX	Driver Type X
1	56	50	46	42	39	37	34	30	26	20
2	12	21	26	31	35	39	42	46	49	51
3	21	18	15	12	9	7	6	5	4	4
4	78	66	60	54	48	45	42	39	36	27
5	100	88	80	72	64	60	56	52	48	36
6	75	81	91	94	97	100	107	111	117	127
7	218	140	125	118	102	86	78	63	47	23
8	170	120	120	110	100	100	90	70	70	50

Driving Maneuver 1: Acceptable gap (in tenths of a second) for near-side cross traffic for vehicles at a stop sign (Record type 142)

Driving Maneuver 2: Additional time (in tenth of a second) for far-side cross traffic in acceptable gap for vehicles at a stop sign (Record Type 143)

Driving Maneuver 3: Amber phase response (in fpss) (Record type 144)

Driving Maneuver 4: Left-turn gap (in tenths of a second) (Record type 145)

Driving Maneuver 5: Acceptable gap (in tenths of a second) for oncoming traffic for right-turners (Record type 145)

Driving Maneuver 6: Free-flow speed (ft/sec) percentages (Record type 147)

Driving Maneuver 7: Start-up lost time (in tenths of a second) (Record type 149)

Driving Maneuver 8: Queue discharge headways (in tenths of a second) (Record type 149)

Specification of Driver Population

Depending on the aggressiveness of the driver, the driving maneuvers will be different under a similar traffic flow situation for different drivers. In a highway system operating under similar traffic flow conditions, different driver populations may be expected to cause different amounts of emissions of pollutants. In order to test this hypothesis, two mixes of driver population were identified: "uniform" and "aggressive." In the uniform mix of drivers, all ten types of drivers are specified in equal proportions.

[1] Source: TRAF-NETSIM User Manual

As for the aggressive driver mix, all drivers on the network are specified to be type X (ten).

A highway network with an identical fleet of vehicles operating under a similar traffic control system is simulated two times. First time, the driver population has a uniform mix of all ten types of drivers. In the second run of simulation, all drivers are specified as aggressive. The results of the two simulation runs are to be compared from both transportation and environmental perspectives.

Identification of Suitable MOEs

A comparative study is made for each link of the network and also the network as a whole. Suitable MOEs (from traffic and environmental perspectives) are identified to evaluate the impact of different mixes of driver types on mobile source emissions. The results are presented below:

1. Traffic MOEs:

Delay has been widely recognized as the most critical MOE to evaluate the performance of a highway system from a traffic engineering perspective. The delay on a link is the difference between actual travel time and free-flow time for all vehicles that enter the link during the period of study. This is expressed as vehicle-minutes in the output reported by TRAF-NETSIM. Besides link based comparisons, the cumulative value of delay for all vehicles on all links during the study period is also quantified by TRAF-NETSIM.

The average speed of a highway link is helpful to determine the performance of all vehicles on the link on an aggregate basis. The average speed on a link is the ratio of the total distance to the total travel time spent by all vehicles traversing the link. This is expressed as miles per hour (mph) in the output reported by TRAF-NETSIM program.

2. Environmental MOEs:

TRAF-NETSIM reports emission rates of all three pollutants for every link in grams/second. These values are determined for every second of vehicle operation from the emission rates (a function of speed and acceleration of the vehicle) embedded in the program.

As a part of this study, the program was enhanced to report the cumulative emission of pollutants for various driving modes. Four modes were identified for this purpose. They are acceleration, declaration, cruise and idling. The program reported the cumulative time of all vehicles in each mode (in vehicle-seconds) along with cumulative emissions (in kilograms) of all modes combined.

Evaluation of Case Study

The highway network operation was simulated one time for each mix of driver population. A comparative study of the results of the two simulation runs is presented as follows:

1. Traffic MOEs

In this section, a comparative analysis from traffic engineering perspective is presented. The average link speeds with aggressive driver population is always higher than those with a uniform mix of driver population. As may be expected in real world situations, aggressive drivers in the simulation run attained higher speeds.

The speed limit input to the program for all links on the arterial is 35 mph. The program allows the aggressive drivers to attain a maximum of 39.5 mph. None of the links attained that maximum possible speed. This may be due to vehicles stopping at the traffic control devices.

The delay on the majority of links is less for aggressive drivers than that for the uniform driver mix. As speeds went up, the travel time of vehicles is reduced. This resulted in a reduction of delay on various links. This is found to be true across a number of links irrespective of the traffic control system on the link.

In TRAF-NETSIM the response of drivers to the onset of the amber indication is expressed in terms of an acceptable deceleration. The attendant logic applies only to the lead moving vehicle in a lane that has no queue at the instant the signal turns amber. The deceleration that is required for the vehicle to stop is readily calculated, knowing the current position and speed of the vehicle. Using the maneuver attributes for various driver types embedded in the model, a decile statistical distribution is entered, to determine whether the acceptable deceleration extracted from this distribution exceeds the required value . If so, the vehicle will stop; otherwise, it will continue through the intersection. From the results of simulation, it is observed that aggressive drivers tend to continue through intersections more often than the drivers of a uniform mix in response to an amber indication. In addition, at the intersections with stop sign control on cross-streets, aggressive drivers are quicker to find gaps in the traffic to get on to the traffic stream and move quickly.

A comparison of the cumulative delay of all vehicles on all links for both driver types is presented in Figure 7.1. The cumulative delays for aggressive drivers and uniform mix are 11,560 vehicle-minutes and 17,946 vehicle-minutes respectively. There is a significant reduction in delay when all drivers are aggressive. The cumulative delay of all vehicles on the highway network decreased by 35.5% when all drivers are aggressive in comparison with that with a uniform mix of drivers.

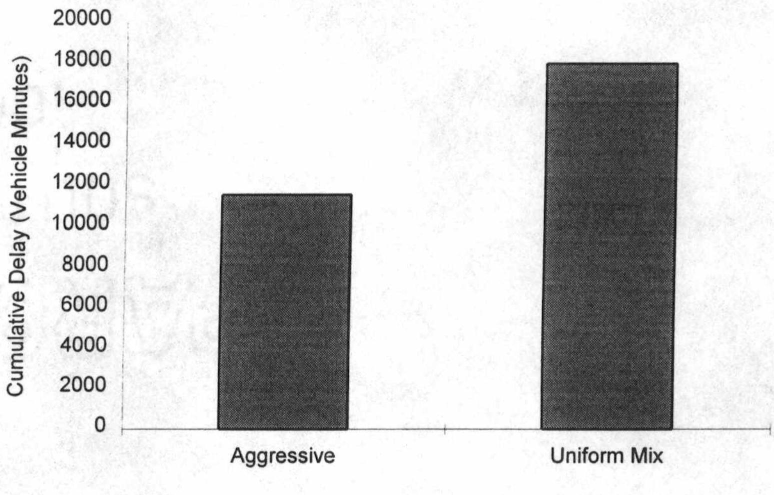

Figure 7.1

A comparison of Delay for Different Driver Populations

Environmental MOEs

A summary of cumulative emission values of all three pollutants along with the number of vehicle-seconds of various driving modes for uniform driver mix and aggressive drivers is presented in Tables 7.2 and Table 7.3 respectively.

Table 7.2

Summary of Environmental MOEs for Uniform Driver Mix

Mode of Operation	Vehicle-Seconds of Operation	Quantity of HC Emission in Kilograms	Quantity of CO Emission in Kilograms	Quantity of NO_x Emission in Kilograms
Deceleration	483024	0.32	2.02	0.13
Acceleration	636960	3.65	255.74	12.59
Cruise	393516	0.21	2.50	0.36
Idling	744780	0.22	2.23	0.22
Cumulative Value	2258280	4.40	262.50	13.30
Average Rate (grams/veh-sec)		0.001948	0.116239	0.005889

Table 7.3

Summary of Environmental MOEs for Aggressive Drivers

Mode of Operation	Vehicle-Seconds of Operation	Quantity of HC Emission in Kilograms	Quantity of CO Emission in Kilograms	Quantity of NO_x Emission in Kilograms
Deceleration	340314	0.26	1.39	0.10
Acceleration	649056	5.39	418.52	17.54
Cruise	221304	0.13	1.50	0.36
Idling	637098	0.19	1.91	0.19
Cumulative Value	1847772	5.97	423.32	18.19
Average Rate (grams/veh-sec)		0.003226	0.2229013	0.009844

These data are represented in pie charts in Figure 7.2 and Figure 7.3, clearly identifying the contribution of each mode.

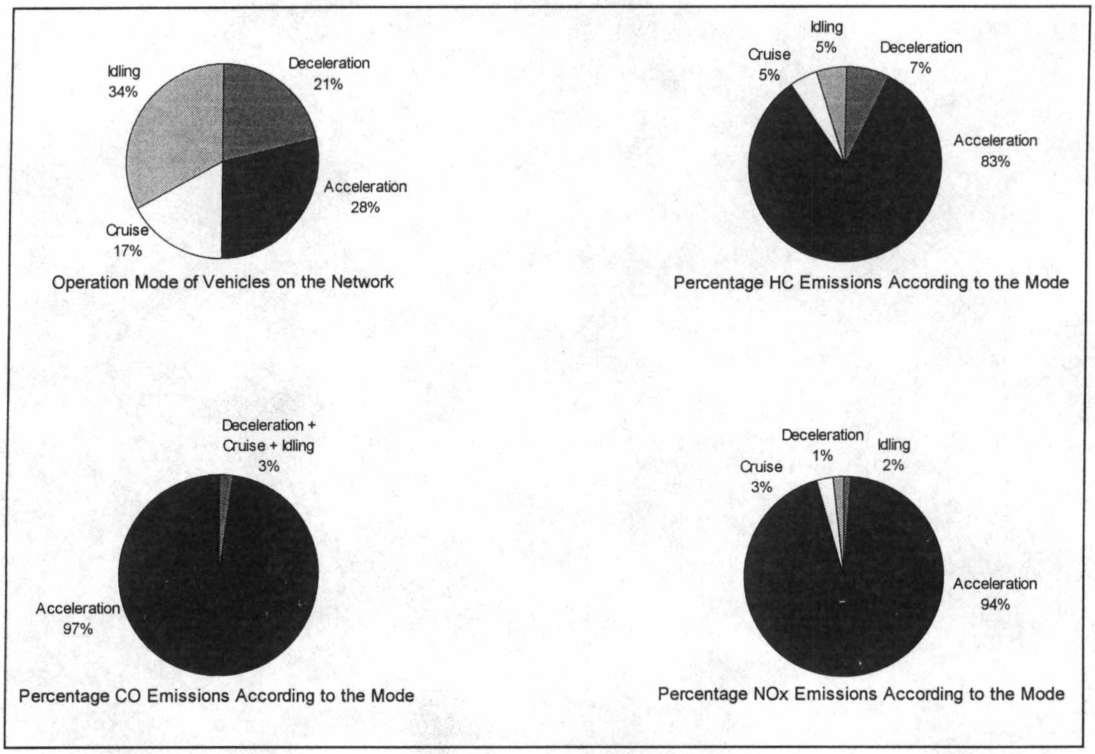

Figure 7.2

A Synthesis of Environmental MOEs for the Uniform Driver Population

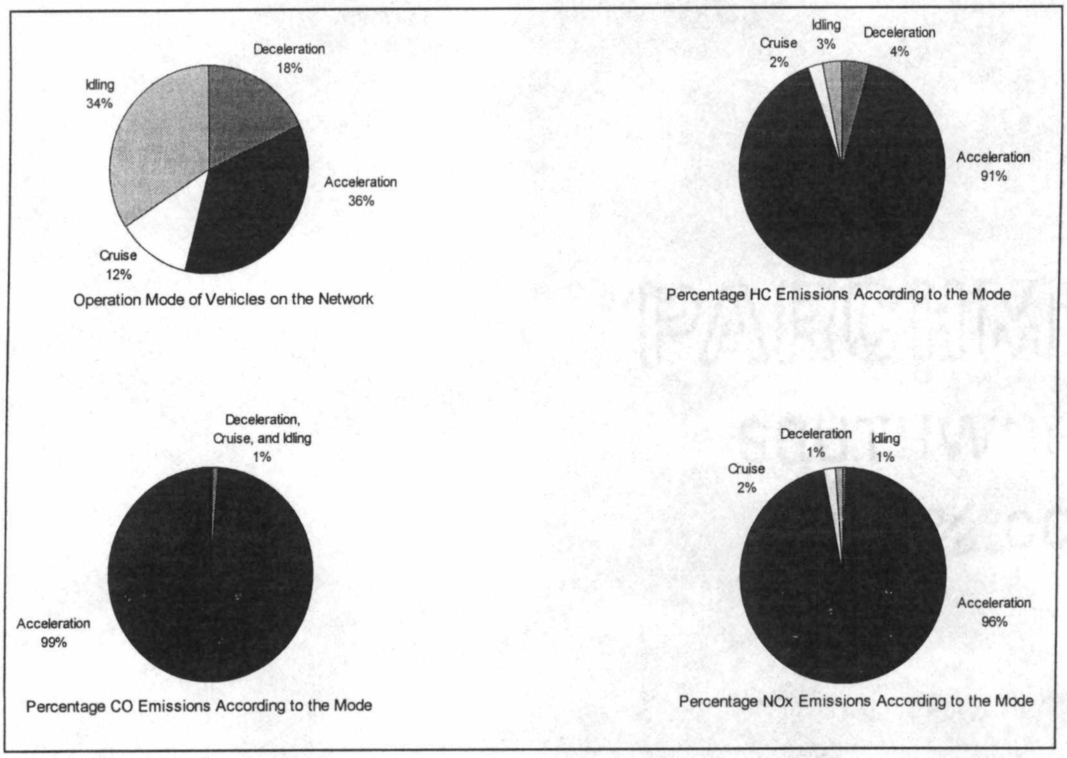

Figure 7.3

A Synthesis of Environmental MOEs for the Aggressive Driver Population

Idling mode has the highest vehicle-seconds of operation when the arterial is operating under uniform driver mix. However, the quantity of emissions for all three pollutants for that particular mode is the lowest among all modes. Acceleration is the second longest mode under which vehicles operated with uniform mix of drivers. The percentage of cumulative quantities emitted during the acceleration mode is equal to 83% for HC, 97% for CO, and 95% for NOx. It is clear that a major quantity of pollutants is emitted during the acceleration mode. Though the deceleration mode accounted for 21% of the time, its contribution is not as much as acceleration. The cruise mode contributed the lowest amount of pollutants.

When the highway system operated under all aggressive drivers, the mode that recorded the longest time was acceleration. Interestingly, the duration of idling remained at approximately 34% of the time of vehicle operation for both types of drivers. This implied that aggressive drivers used acceleration to attain more mobility at the cost of cruise. This is reflected in the quantities of emissions of all three pollutants. Of all the modes, acceleration remained the major contributor of all three pollutants.

A comparison of cumulative values for the entire duration of simulation is presented in Figure 7.4. According to the comparison of cumulative quantities for the duration of the study as presented in Figure 7.4, the aggressive driver population contributed greater quantities of pollutants. The cumulative vehicle-seconds of operation decreased a significant 18.1%, which resulted from the savings in delay achieved by the quick maneuvers of the aggressive drivers. The average emission rates per vehicle-second of operation for the duration of study were compared for the two types of driver population. Figure 7.5 presents such a comparison. The average emission rates per vehicle-second of operation were higher for the aggressive driver group. The largest increase occurred for CO (192%), and a similar increase occurred for NO_x (167%) and HC (165%).

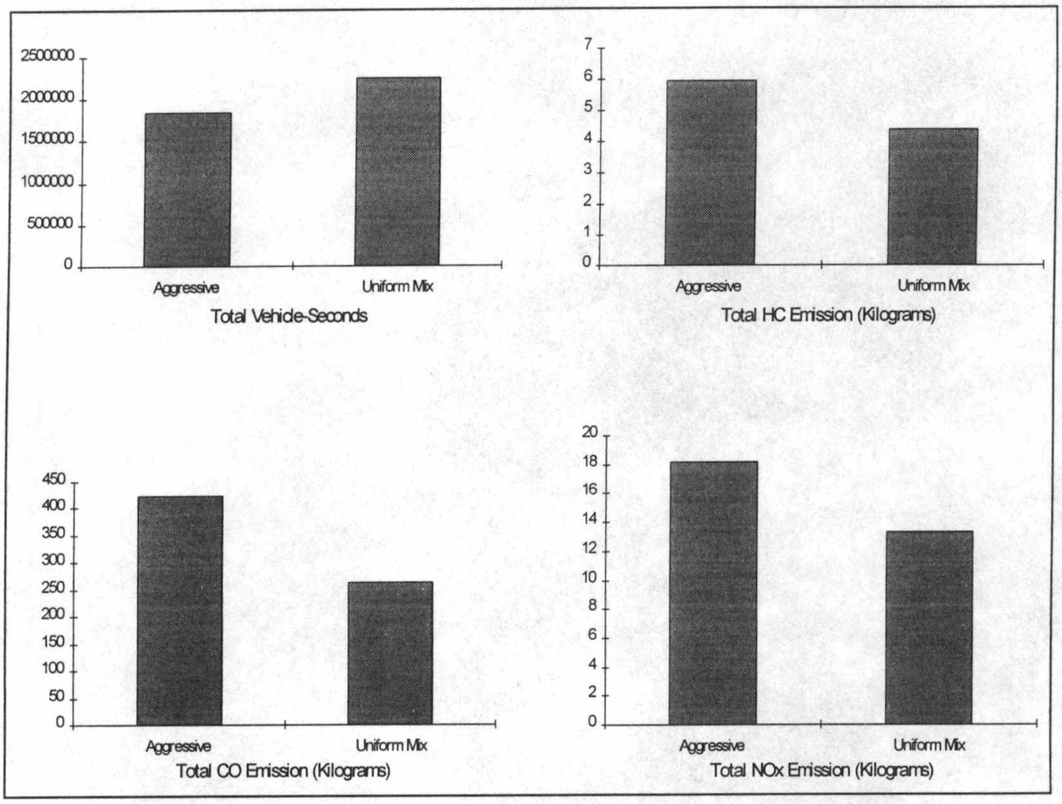

Figure 7.4

A Comparison of Environmental MOEs for Different Driver Populations

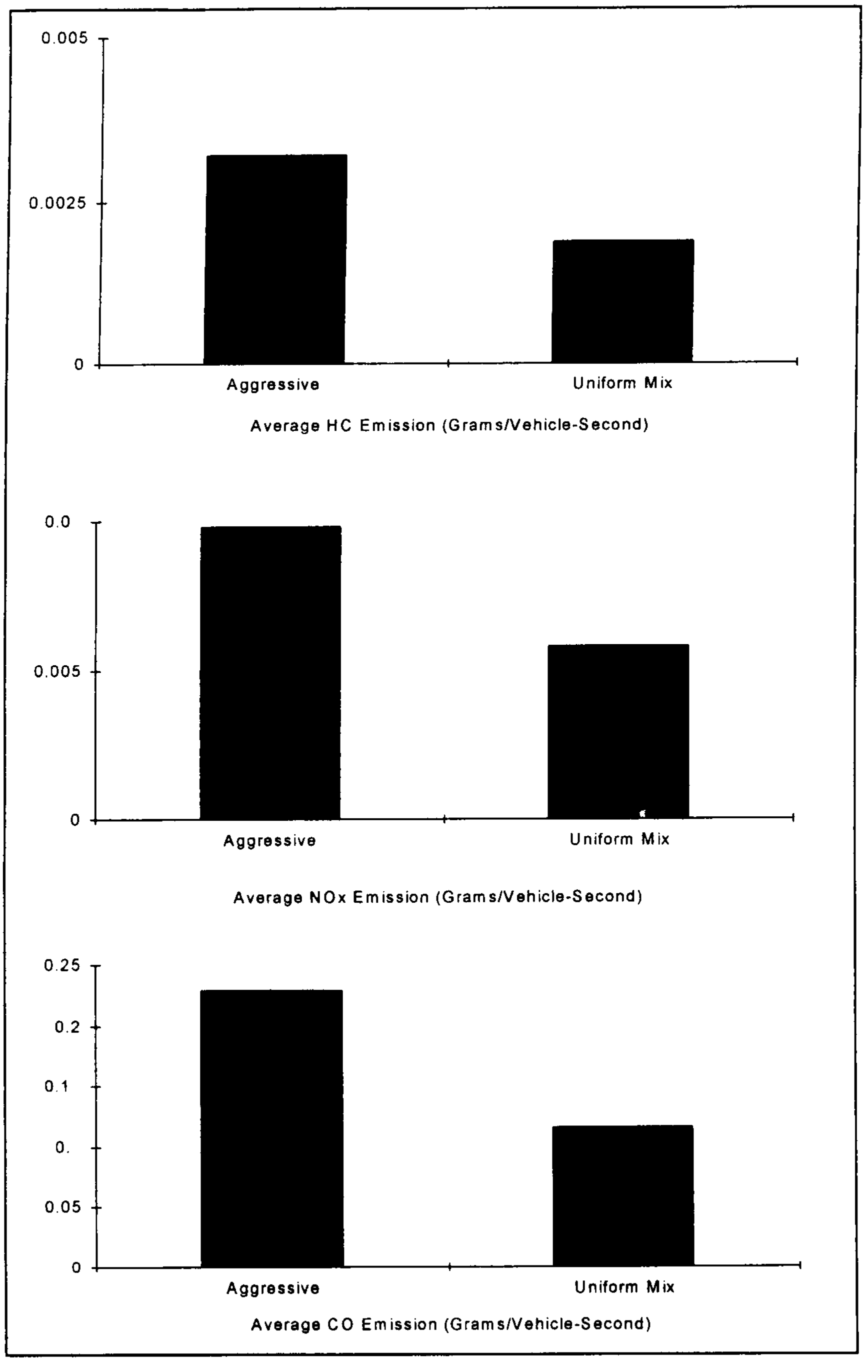

Figure 7.5

A Comparison of Average Emission Rates for Different Driver Populations

SUMMARY

The major emphasis of this chapter is to show that the non-uniformity of driver population can cause substantial difference in emissions estimation. A simulation-based procedure for quantifying the effect of driver behavior on mobile source emission level was used. Various Measures of Effectiveness (MOEs) to evaluate the highway network operation from environmental perspective were identified. Two mixes of driver characteristics were selected: "uniform" and "aggressive." For a highway network operating under similar conditions, the effect of two types of drivers on the emission of pollutants were evaluated. Based on the simulation analysis, it was determined that different driver mix with different acceleration/deceleration patterns will result in substantially different amount of emissions.

Chapter 8

Conclusions and Recommendations

This study identified the strengths and limitations of the "modal" and "average speed" approaches for vehicle exhaust emission estimation. To make a valid comparison between the two approaches, the hot-stabilized portion (Bag 2) of the FTP cycle was used as a common platform to calibrate the two independent approaches.

Baseline Comparison of Average Emission Rates from a Modal Approach and an Average Speed Approach

The second by second profile of the FTP cycle was synthesized using the modal emission rates of TRAF-NETSIM. The cumulative emissions of all three pollutants (CO, HC, and NOx) were quantified for each driving mode. Next, the average FTP emission rates of MOBILE5a were compared with the modal emission rates embedded in TRAF-NETSIM.

The modal-based synthesis produced interesting results. With respect to the duration of different driving operating modes, vehicles spent the highest number of seconds in the cruise mode. This was followed by the acceleration, idling, and deceleration modes, respectively. The longest duration of cruise mode did not produce the largest quantity of HC, CO, and NOx.

During the acceleration mode, vehicles produced the most HC emissions (56.1%). Similarly, the highest amount of CO and NOx were emitted -- 64.9% and 83.5%

respectively-- during the acceleration mode. From this study, one can conclude that the quantities of pollutants emitted during a particular mode were not proportional to the duration of that mode. This implies that if the driving modes of vehicles operating on highways are different from those in the FTP drive cycle, the level of HC, CO, and NOx emissions will be different.

Under similar conditions with respect to various factors that influence exhaust emission rates, the average emission rates reported by MOBILE5a for the FTP cycle were greater than the average emission rates obtained from TRAF-NETSIM. Within the operating range of the FTP hot-stabilized portion, the emission rates for HC and CO obtained from MOBILE5a -- 2.09 mg/sec and 31.25 mg/sec respectively-- were at least 3 times higher than TRAF-NETSIM emission rates -- 0.66 mg/sec and 10.07 mg/sec respectively. However, for NOx, these rates were approximately one and half higher -- 3.01 mg/sec versus 1.95 mg/sec. A part of the differences in average emission rates between the two approaches may be due to the fact that the actual mileage's of vehicles used in ORNL testing were not available. Therefore, the default values for the mileage accrual rate in MOBILE5 were used. Of note, actual mileage is a critical input for making corrections to the base emission rates, included in MOBILE. In addition, the base emission rates of MOBILE are obtained within a temperature range of 68°F to 86°F to ensure the consistency of test results.

The speed and acceleration profiles of various vehicles may vary with the driver behavior, the type of traffic control operation, and traffic volume. When the profiles are different, the duration of modes and the limits of modes will also be different. A fixed drive cycle with a fixed duration of each driving mode will not be representative of such vehicle operations. Any analytical model that is dependent on a fixed drive cycle will not be able to make a realistic estimation of emissions under different driving environment.

Development and Analysis of Modal Adjustment Factors

This study developed modal adjustment factors (MAFs) for each pollutant, which was defined as the ratio of the actual emission rate embedded in NETSIM for a specified combination of acceleration and speed to the average FTP emission rate of the pollutant. This study illustrated that MAFs varied widely — from 0.3 to more than 150 times — implying that the average FTP emission rates are not truly representative of modal rates within the considered ranges of speed and acceleration.

Although the MAFs of certain pollutants vary widely across various speeds and accelerations, a specific trend can be associated with the mode. The MAFs consistently increased with the increase in speed. However, the variation was not very large for either the deceleration mode or the cruise mode. The MAFs for the acceleration mode were very large, implying that the FTP average emission rates were a poor representation of the acceleration mode. This is particularly true for high speeds (>50 ft/sec) and high accelerations (>5 ft/sec^2).

Evaluation of the Impact of a Traffic Engineering Strategy on Emissions Using Modal Approach (TRAF-NETSIM) and Average Speed Approach (MOBILE5a)

Although, the effect of the driving mode of vehicle operation on emission is recognized, limited attempt has been made to quantify the benefits due to traffic improvement strategies using the modal approach. Chapter 6 of the report demonstrated the use of both "modal" and "average speed" approaches for the evaluation of the impact of a traffic improvement strategy on emissions from light duty gasoline vehicles. The traffic improvement strategy that was analyzed was the coordination of traffic signal operation along an arterial road. A simple case involving an arterial operation was selected to achieve this objective. The determination of driving mode related data via field measurements is a cumbersome and expensive process. Consequently, a simulation technique was employed to perform the modal emission analysis. The analysis was performed using TRAF-NETSIM for the modal approach and MOBILE5a was used for the average speed approach.

A "before" and "after" study, was performed using the two different approaches. With respect to the modal approach, the driving mode of each vehicle for every second of operation (acceleration, deceleration, cruise and idling) was recorded using TRAF-NETSIM. This information was used to quantify the emission associated with each mode of operation. The traffic Measures of Effectiveness (MOEs) for the "before" and "after" situations of the traffic improvement strategy were compared. The increase in mobility due to the traffic improvement strategy was assessed, and the emissions rates were synthesized on the basis of various modes. The analysis identified which mode was the major contributor of exhaust vehicle emission.

Considerable care was exercised in the specification of various parameters in MOBILE5a's Local Area Parameter (LAP) record. The values of these parameters reflected the average conditions under which the emission values in TRAF-NETSIM were obtained. Various output parameters from TRAF-NETSIM were used as inputs to MOBILE5a to obtain emission rates for all three pollutants. These parameters are: average links speeds on each link in the network, and network wide average speed. The following conclusions were drawn from the results of analysis:

- Although the duration of the acceleration mode was not the longest of all the modes, the acceleration mode was the largest contributor of exhaust emissions.
- The exhaust emission rates resulting from the acceleration mode were greater than the combined emissions from the other three modes. This was true with and without the coordination of traffic signals.
- Although the duration of the idling mode was longer than that of acceleration, the emissions during idling were considerably less.
- Based on the traffic MOEs, the improvement strategy (i.e., the coordination of signals) provided substantial benefits. This was particularly evident in the reduction of the total number of vehicle seconds over the entire network. In addition, the number of stops as well as the delay was reduced. Furthermore,

the speeds on the arterial links improved, and the mobility improved considerably over the entire network.

- While the duration of the cruise mode increased slightly, the duration of the other three modes (acceleration, deceleration, and idling) decreased as a result of the coordination of signals.
- Based on the modal approach, there was a substantial reduction in the cumulative hourly emission for all three pollutants due to the implementation of signal coordination. The percent reductions were 4.26%, 4.44%, and 4.88% for HC, CO, and NOx respectively.
- Similar results were found when executing MOBILE5a using link by link speeds as well as network average speed for HC and CO. However, this was not the case for NOx emissions. The average speed approach using the network average speed did not show a reduction in NOx emissions.
- One difference in using link by link speeds when executing MOBILE5a is that, the percent reduction in CO emissions is higher than what was found using network average speed (3.37% versus 2.48%), respectively.
- Based on the average speed approach, the cumulative hourly emissions indicate a decrease in HC and CO emissions due to the implementation of signal coordination -- a percent reduction of 2.80% for HC and 2.48% for CO. However, there was a slight increase in NOx emissions (0.67%).
- The estimated benefit of signal coordination using the modal approach was larger than those of the average speed approach. The difference in 'percent reductions' were 1.46%, 1.96%, and 5.55% for HC, CO, and NOx, respectively.
- The average speed approach reported a negative benefit (an increase) for NOx (-0.67%) due to signal coordination.

Evaluation of the Effect of Driver Type (Aggressive vs. Uniform) Distribution on Emission Level Using a Modal Approach

The base emission rates of EPA's MOBILE model for estimating the emissions from mobile sources are based on a standardized drive cycle, and it does not account for the fact that driving behavior is not uniform across the driver population, and that this nonuniformity can cause substantial difference in emissions.

This study developed a simulation-based procedure for quantifying the effect of driver behavior on mobile source emissions. Two mixes of driver populations were selected: uniform and aggressive. In the uniform mix, all ten types of drivers recognized in TRAF-NETSIM model are specified in equal proportions. As for the aggressive mix, all drivers on the network are specified to be type X (ten), that is all are assumed to be aggressive. For a highway network operating under similar conditions, the effects of these two types of drivers on exhaust emissions were evaluated.

The following conclusions and recommendations are based on the results of this study. When drivers are aggressive on arterial roads, the efficiency of the traffic system increased. The speeds on the majority of links were considerably higher. Delay and the number of stops decreased. Aggressive drivers were specified to attain speeds that were 27% higher than the posted speed limits on varies links. The simulation indicated that with aggressive drivers there was low start-up lost time at intersections, quick amber-phase response, and short queue discharge headways. Similarly at traffic stop signs, aggressive drivers are specified to take reasonable risks to find acceptable gaps in the traffic. Although the arterial system was actually designed for the posted speed limit, it was found to perform better with aggressive drivers, and the cumulative delay decreased by 33%.

From an air quality perspective, the status of the environment was unfavorable with aggressive drivers. The cumulative emissions with aggressive drivers increased. The cumulative emissions for HC, CO, and NOx increased by 26%, 37%, and 27%, respectively. The average emission rates per vehicle-second of operation were higher for the aggressive driver group. The largest increase occurred for CO (192%), and a similar increase occurred for NO_x (167%) and HC (165%). These results demonstrate that the emissions increased significantly when all drivers were aggressive. In addition, the results support the hypothesis that an assumption of uniform driver behavior across the entire driver population may cause an error in the estimation of exhaust emissions.

Summary of Conclusions

According to the synthesis of the emissions by mode, acceleration was identified as the major contributing source of emissions among the driving modes of vehicles. High accelerations under particular speeds can cause a large increase in the emission of pollutants. In addition, acceleration alone may be responsible for more than 90% of total emissions.

It should be noted that this study is limited to nonfreeway arterial operations only. Because freeway operation is different with respect to acceleration and speed, a similar analysis should be performed to evaluate freeway operation to gain a more comprehensive understanding of the characteristics of modal emissions.

The base emission rates in the MOBILE model depend on the data from the FTP drive cycle. Future efforts to enhance the FTP drive cycle should include the impact of driver behavior on the base emission rates. This would result in more realistic estimation of mobile source emissions under different driving environments.

In conclusion, the finding of this study may have implications for the air quality assessment of transportation control measures (TCM's). Under the Congestion Mitigation and Air Quality Improvement (CMAQ) program, TCM's projects are eligible for funding when a net reduction in emissions of all three pollutants (HC, CO, and NOx) can be attained. Some TCM's projects that are not considered for funding under the current "average speed" may now be found eligible using the modal approach. The current average speed approach usually often shows that higher vehicle speed increases NOx emissions while reducing VOC and CO emissions. This "NOx dilemma" may not be valid in all cases.

REFERENCES

1. TRB (1995), Transportation Research Board; Expanding Metropolitan Highways, Implications for Air Quality and Énergy Use; (Special Report 245); Washington, D.C., 1995
2. Federal Test Procedure, Code of Federal Regulations, Title 40, Parts 86-99 (portion of CAR which contains the Federal Test Procedure), Office of the Federal Register, 1989.
3. R. Guensler, "Transportation Data Needs for Evolving Emission Inventory Models", Institute of Transportation Studies, University of California, Davis, CA, 1993.
4. Volpe National Transportation Systems Center, U.S. Department of Transportation, "Evaluation of Mobile Vehicle Emission Model", DOT-VNTSC-FHWA-94-8, 1994
5. D. Eisinger, "Preview of MOBILE', in Proceeding of Transportation Modeling: Tips and Trip-UPS, San Mateo, CA, 1993.
6. J. Markey, "Federal Test Procedure Review Project: Technical Report", Technical Report # EPA 420-R-93-007, Certification Division, Office of Mobile Sources, Us EPA, 1993.
7. M. Carlock, "Overview of On-Road Emissions Inventory Models", in Proceeding of Transportation Modeling: Tips and Trip-Ups, San Mateo, CA, 1993.
8. Presented material at the Fourth CRC-APRAC On-Road Vehicle Emissions Workshop, San Diego, CA, 1994.
9. N. A. Kelly and P.J. Groblicki, "Real-World Emissions from a Modern Production Vehicle Driven in Los Angeles", Journal of the Air & Waste Management Association, Vol.43, pp. 1351 - 1357, October, 1993.

10. R. N. McGill, J.T. Hooker, and J. W. Hodgson, "Fuel Consumption and Emission Values for Traffic Models", Report No. FHWA/RD-85/053, Federal Highway Administration, 1985.

11. U.S. Department of Transportation, Federal Highway Administration, "CORSIM User Manual", Version 1.0, 1996.

12. Shui-Ying Wong, "TRAF-NETSIM, How it Works, What it Does", ITE Journal, April, 1990.

13. H. Chen and C. Thor, "Understanding the Cumulative Statistics from TRAF-NETSIM", PC-TRANS, The University of Kansas Transportation Center, Vol., 4, No. 2, 1990.

14. R. Guensler and A. B. Geraghty, "A Transportation / Air Quality Research Agenda for The 1990's", Research Report, UCD-ITS-RR-91-03, April, 1991.

15. Leonard E. Seitz (1989); California Methods for Estimating Air Pollutant Emissions from California Motor Vehicles (89-7.4); Proceeding of the 82nd Annual Meeting of the Air and Waste Management Association; Pittsburgh, PA; June 1989.

16. TRB (1985), Transportation Research Board; Highway Capacity Manual (Special Report 209); Washington, D.C., 1985.

APPENDICES

Appendix I

EPA Urban Dynamometer Driving Schedule

(4) Information on where altitude performance adjustment instructions may be obtained or include the actual altitude performance adjustment instructions;

(5) The new tuneup specifications (if changed from the original label specifications) at the applicable altitude.

Subpart AA—Reporting and Recordkeeping Requirements for Part 86

§ 86.2500 Reporting and recordkeeping requirements.

All reporting and recordkeeping requirements contained in part 86, except for those requirements contained in subparts G and K, have been approved by the Office of Management and Budget under control number 2060-0104.

(Secs. 202, 203, 206, 207, 208, 301a, Clean Air Act, as amended; 42 U.S.C. 7521, 7522, 7525, 7541, 7542, 7601a)

[50 FR 10648, Mar. 15, 1985]

APPENDICES

APPENDIX I TO PART 86—URBAN DYNAMOMETER SCHEDULES

(a) EPA Urban Dynamometer Driving Schedule for Light-Duty Vehicles and Light-Duty Trucks.

EPA URBAN DYNAMOMETER DRIVING SCHEDULE

[Speed versus Time Sequence]

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
0	0.0	1	0.0	2	0.0
3	0.0	4	0.0	5	0.0
6	0.0	7	0.0	8	0.0
9	0.0	10	0.0	11	0.0
12	0.0	13	0.0	14	0.0
15	0.0	16	0.0	17	0.0
18	0.0	19	0.0	20	0.0
21	3.0	22	5.9	23	8.6
24	11.5	25	14.3	26	16.9
27	17.3	28	18.1	29	20.7
30	21.7	31	22.4	32	22.5
33	22.1	34	21.5	35	20.9
36	20.4	37	19.8	38	17.0
39	14.9	40	14.9	41	15.2
42	15.5	43	16.0	44	17.1
45	19.1	46	21.1	47	22.7
48	22.9	49	22.7	50	22.6
51	21.3	52	19.0	53	17.1
54	15.8	55	15.8	56	17.7
57	19.8	58	21.6	59	23.2
60	24.2	61	24.6	62	24.9
63	25.0	64	24.6	65	24.5
66	24.7	67	24.6	68	24.7
69	24.6	70	24.6	71	25.1

EPA URBAN DYNAMOMETER—Continued DRIVING SCHEDULE

[Speed versus Time Sequence]

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
72	25.8	73	25.7	74	25.4
75	24.9	76	25.0	77	25.4
78	26.0	79	26.0	80	25.7
81	26.1	82	26.7	83	27.5
84	28.6	85	29.3	86	29.8
87	30.1	88	30.4	89	30.7
90	30.7	91	30.5	92	30.4
93	30.3	94	30.4	95	30.8
96	30.4	97	29.9	98	29.5
99	29.8	100	30.3	101	30.7
102	30.9	103	31.0	104	30.9
105	30.4	106	29.8	107	29.9
108	30.2	109	30.7	110	31.2
111	31.8	112	32.2	113	32.4
114	32.2	115	31.7	116	28.6
117	25.3	118	22.0	119	18.7
120	15.4	121	12.1	122	8.8
123	5.5	124	2.2	125	0.0
126	0.0	127	0.0	128	0.0
129	0.0	130	0.0	131	0.0
132	0.0	133	0.0	134	0.0
135	0.0	136	0.0	137	0.0
138	0.0	139	0.0	140	0.0
141	0.0	142	0.0	143	0.0
144	0.0	145	0.0	146	0.0
147	0.0	148	0.0	149	0.0
150	0.0	151	0.0	152	0.0
153	0.0	154	0.0	155	0.0
156	0.0	157	0.0	158	0.0
159	0.0	160	0.0	161	0.0
162	0.0	163	0.0	164	3.3
165	6.6	166	9.9	167	13.2
168	16.5	169	19.8	170	22.2
171	24.3	172	25.8	173	26.4
174	25.7	175	25.1	176	24.7
177	25.0	178	25.2	179	25.4
180	25.8	181	27.2	182	26.5
183	24.0	184	22.7	185	19.4
186	17.7	187	17.2	188	18.1
189	18.6	190	20.0	191	22.2
192	24.5	193	27.3	194	30.5
195	33.5	196	36.2	197	37.3
198	39.3	199	40.5	200	42.1
201	43.5	202	45.1	203	46.0
204	46.8	205	47.5	206	47.5
207	47.3	208	47.2	209	47.2
210	47.0	211	47.0	212	47.0
213	47.0	214	47.2	215	47.4
216	47.9	217	48.5	218	49.1
219	49.5	220	50.0	221	50.6
222	51.0	223	51.5	224	52.2
225	53.2	226	54.1	227	54.6
228	54.9	229	55.0	230	54.9
231	54.6	232	54.6	233	54.8
234	55.1	235	55.5	236	55.7
237	56.1	238	56.3	239	56.6
240	56.7	241	56.7	242	56.5
243	56.5	244	56.5	245	56.5
246	56.5	247	56.5	248	56.4
249	56.1	250	55.8	251	55.1
252	54.6	253	54.2	254	54.0
255	53.7	256	53.6	257	53.9
258	54.0	259	54.1	260	54.1
261	53.8	262	53.4	263	53.0
264	52.6	265	52.1	266	52.4
267	52.0	268	51.9	269	51.7
270	51.5	271	51.6	272	51.8
273	52.1	274	52.5	275	53.0
276	53.5	277	54.0	278	54.9

(Speed versus Time Sequence)

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
279	56.4	280	56.6	281	56.0
282	56.0	283	55.8	284	55.2
285	54.5	286	53.6	287	52.5
288	51.5	289	51.5	290	51.5
291	51.1	292	50.1	293	50.0
294	50.1	295	50.0	296	49.6
297	49.5	298	49.5	299	49.5
300	49.1	301	48.6	302	48.1
303	47.2	304	46.1	305	45.0
306	43.8	307	42.6	308	41.5
309	40.3	310	38.5	311	37.0
312	35.2	313	33.8	314	32.5
315	31.5	316	30.6	317	30.5
318	30.0	319	29.0	320	27.5
321	24.8	322	21.5	323	20.1
324	19.1	325	18.5	326	17.0
327	15.5	328	12.5	329	10.8
330	8.0	331	4.7	332	1.4
333	0.0	334	0.0	335	0.0
336	0.0	337	0.0	338	0.0
339	0.0	340	0.0	341	0.0
342	0.0	343	0.0	344	0.0
345	0.0	346	0.0	347	1.0
348	4.3	349	7.6	350	10.9
351	14.2	352	17.3	353	20.0
354	22.5	355	23.7	356	25.2
357	26.6	358	28.1	359	30.0
360	30.8	361	31.6	362	32.1
363	32.8	364	33.6	365	34.5
366	34.6	367	34.9	368	34.8
369	34.5	370	34.7	371	35.5
372	36.0	373	36.0	374	36.0
375	36.0	376	36.0	377	36.0
378	36.1	379	36.4	380	36.5
381	36.4	382	36.0	383	35.1
384	34.1	385	33.5	386	31.4
387	29.0	388	25.7	389	23.0
390	20.3	391	17.5	392	14.5
393	12.0	394	8.7	395	5.4
396	2.1	397	0.0	398	0.0
399	0.0	400	0.0	401	0.0
402	0.0	403	2.6	404	5.9
405	9.2	406	12.5	407	15.8
408	19.1	409	22.4	410	25.0
411	25.6	412	27.5	413	29.0
414	30.0	415	30.1	416	30.0
417	29.7	418	29.3	419	28.8
420	28.0	421	25.0	422	21.7
423	18.4	424	15.1	425	11.8
426	8.5	427	5.2	428	1.9
429	0.0	430	0.0	431	0.0
432	0.0	433	0.0	434	0.0
435	0.0	436	0.0	437	0.0
438	0.0	439	0.0	440	0.0
441	0.0	442	0.0	443	0.0
444	0.0	445	0.0	446	0.0
447	0.0	448	3.3	449	6.6
450	9.9	451	13.2	452	16.5
453	19.8	454	23.1	455	26.4
456	27.8	457	29.1	458	31.5
459	33.0	460	33.6	461	34.8
462	35.1	463	35.6	464	36.1
465	36.0	466	36.1	467	36.2
468	36.0	469	35.7	470	36.0
471	36.0	472	35.6	473	35.5
474	35.4	475	35.2	476	35.2
477	35.2	478	35.2	479	35.2
480	35.2	481	35.0	482	35.1
483	35.2	484	35.5	485	35.2

Speed versus Time Sequence)

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
486	35.0	487	35.0	488	35.0
489	34.8	490	34.6	491	34.5
492	33.5	493	32.0	494	30.1
495	28.0	496	25.5	497	22.5
498	19.8	499	16.5	500	13.2
501	10.3	502	7.2	503	4.0
504	1.0	505	0.0	506	0.0
507	0.0	508	0.0	509	0.0
510	0.0	511	1.2	512	3.5
513	5.5	514	6.5	515	8.5
516	9.6	517	10.5	518	11.9
519	14.0	520	16.0	521	17.7
522	19.0	523	20.1	524	21.0
525	22.0	526	23.0	527	23.8
528	24.5	529	24.9	530	25.0
531	25.0	532	25.0	533	25.0
534	25.0	535	25.0	536	25.6
537	25.8	538	26.0	539	25.6
540	25.2	541	25.0	542	25.0
543	25.0	544	24.4	545	23.1
546	19.8	547	16.5	548	13.2
549	9.9	550	6.6	551	3.3
552	0.0	553	0.0	554	0.0
555	0.0	556	0.0	557	0.0
558	0.0	559	0.0	560	0.0
561	0.0	562	0.0	563	0.0
564	0.0	565	0.0	566	0.0
567	0.0	568	0.0	569	3.3
570	6.6	571	9.9	572	13.0
573	14.6	574	16.0	575	17.0
576	17.0	577	17.0	578	17.5
579	17.7	580	17.7	581	17.5
582	17.0	583	16.9	584	16.6
585	17.0	586	17.1	587	17.0
588	16.6	589	16.5	590	18.5
591	16.6	592	17.0	593	17.6
594	18.5	595	19.2	596	20.2
597	21.0	598	21.1	599	21.2
600	21.6	601	22.0	602	22.4
603	22.5	604	22.5	605	22.5
606	22.7	607	23.7	608	25.1
609	26.0	610	26.5	611	27.0
612	26.1	613	22.8	614	19.5
615	16.2	616	12.9	617	9.6
618	6.3	619	3.0	620	0.0
621	0.0	622	0.0	623	0.0
624	0.0	625	0.0	626	0.0
627	0.0	628	0.0	629	0.0
630	0.0	631	0.0	632	0.0
633	0.0	634	0.0	635	0.0
636	0.0	637	0.0	638	0.0
639	0.0	640	0.0	641	0.0
642	0.0	643	0.0	644	0.0
645	0.0	646	2.0	647	4.5
648	7.8	649	10.2	650	12.5
651	14.0	652	15.3	653	17.5
654	19.6	655	21.0	656	22.2
657	23.3	658	24.5	659	25.3
660	25.6	661	26.0	662	26.1
663	26.2	664	26.2	665	26.4
666	26.5	667	26.5	668	26.0
669	25.5	670	23.6	671	21.4
672	18.5	673	16.4	674	14.5
675	11.6	676	8.7	677	5.8
678	3.5	679	2.0	680	0.0
681	0.0	682	0.0	683	0.0
684	0.0	685	0.0	686	0.0
687	0.0	688	0.0	689	0.0
690	0.0	691	0.0	692	0.0

EPA URBAN DYNAMOMETER—Continued
DRIVING SCHEDULE
[Speed versus Time Sequence]

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
693	0.0	694	1.4	695	3.3
696	4.4	697	6.5	698	9.2
699	11.3	700	13.5	701	14.6
702	16.4	703	16.7	704	16.5
705	16.5	706	18.2	707	19.2
708	20.1	709	21.5	710	22.5
711	22.5	712	22.1	713	22.7
714	23.3	715	23.5	716	22.5
717	21.6	718	20.5	719	18.0
720	15.0	721	12.0	722	9.0
723	6.2	724	4.5	725	3.0
726	2.1	727	0.5	728	0.5
729	3.2	730	6.5	731	9.6
732	12.5	733	14.0	734	16.0
735	18.0	736	19.6	737	21.5
738	23.1	739	24.5	740	25.5
741	26.5	742	27.1	743	27.6
744	27.9	745	28.3	746	28.6
747	28.6	748	28.3	749	28.2
750	28.0	751	27.5	752	26.8
753	25.5	754	23.5	755	21.5
756	19.0	757	16.5	758	14.9
759	12.5	760	9.4	761	6.2
762	3.0	763	1.5	764	1.5
765	0.5	766	0.0	767	3.0
768	6.3	769	9.6	770	12.9
771	15.8	772	17.5	773	18.4
774	19.5	775	20.7	776	22.0
777	23.2	778	25.0	779	26.5
780	27.5	781	28.0	782	28.3
783	28.9	784	28.9	785	28.9
786	28.8	787	28.5	788	28.3
789	28.3	790	28.3	791	28.2
792	27.8	793	27.5	794	27.5
795	27.5	796	27.5	797	27.5
798	27.5	799	27.6	800	28.0
801	28.5	802	30.0	803	31.0
804	32.0	805	33.0	806	33.0
807	33.6	808	34.0	809	34.3
810	34.2	811	34.0	812	34.0
813	33.9	814	33.6	815	33.1
816	33.0	817	32.5	818	32.0
819	31.9	820	31.6	821	31.5
822	30.6	823	30.0	824	29.9
825	29.9	826	29.9	827	29.9
828	29.6	829	29.5	830	29.5
831	29.3	832	28.9	833	28.2
834	27.7	835	27.0	836	25.5
837	23.7	838	22.0	839	20.5
840	19.2	841	19.2	842	20.1
843	20.9	844	21.4	345	22.0
846	22.6	847	23.2	848	24.0
849	25.0	850	26.0	851	26.6
852	26.6	853	26.8	854	27.0
855	27.2	856	27.8	857	28.1
858	28.8	859	28.9	860	29.0
861	29.1	862	29.0	863	28.1
864	27.5	865	27.0	866	25.8
867	25.0	868	24.5	869	24.8
870	25.1	871	25.5	872	25.7
873	26.2	874	26.9	875	27.5
876	27.8	877	28.4	878	29.0
879	29.2	880	29.1	881	29.0
882	28.9	883	28.5	884	28.1
885	28.0	886	28.0	887	27.6
888	27.2	889	26.6	890	27.0
891	27.5	892	27.8	893	28.0
894	27.8	895	28.0	896	28.0
897	28.0	898	27.7	899	27.4

EPA URBAN DYNAMOMETER—Continued
DRIVING SCHEDULE
[Speed versus Time Sequence]

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
900	26.9	901	26.6	902	26.5
903	26.5	904	26.5	905	26.3
906	26.2	907	26.2	908	25.9
909	25.6	910	25.6	911	25.9
912	25.8	913	25.5	914	24.6
915	23.5	916	22.2	917	21.6
918	21.6	919	21.7	920	22.6
921	23.4	922	24.0	923	24.2
924	24.4	925	24.9	926	25.1
927	25.2	928	25.3	929	25.5
930	25.2	931	25.0	932	25.0
933	25.0	934	24.7	935	24.5
936	24.3	937	24.3	938	24.5
939	25.0	940	25.0	941	24.6
942	24.6	943	24.1	944	24.5
945	25.1	946	25.6	947	25.1
948	24.0	949	22.0	950	20.1
951	16.9	952	13.6	953	10.3
954	7.0	955	3.7	956	0.4
957	0.0	958	0.0	959	0.0
960	2.0	961	5.0	962	8.6
963	11.9	964	15.2	965	17.5
966	18.6	967	20.0	968	21.1
969	22.0	970	23.0	971	24.5
972	26.3	973	27.5	974	28.1
975	28.4	976	28.5	977	28.5
978	28.5	979	27.7	980	27.5
981	27.2	982	26.8	983	26.5
984	26.0	985	25.7	986	25.2
987	24.0	988	22.0	989	21.5
990	21.5	991	21.8	992	22.5
993	23.0	994	22.8	995	22.8
996	23.0	997	22.7	998	22.7
999	22.7	1000	23.5	1001	24.0
1002	24.6	1003	24.8	1004	25.1
1005	25.5	1006	25.6	1007	25.5
1008	25.0	1009	24.1	1010	23.7
1011	23.2	1012	22.9	1013	22.5
1014	22.0	1015	21.6	1016	20.5
1017	17.5	1018	14.2	1019	10.9
1020	7.6	1021	4.3	1022	1.0
1023	0.0	1024	0.0	1025	0.0
1026	0.0	1027	0.0	1028	0.0
1029	0.0	1030	0.0	1031	0.0
1032	0.0	1033	0.0	1034	0.0
1035	0.0	1036	0.0	1037	0.0
1038	0.0	1039	0.0	1040	0.0
1041	0.0	1042	0.0	1043	0.0
1044	0.0	1045	0.0	1046	0.0
1047	0.0	1048	0.0	1049	0.0
1050	0.0	1051	0.0	1052	0.0
1053	1.2	1054	4.0	1055	7.3
1056	10.6	1057	13.9	1058	17.0
1059	18.5	1060	20.0	1061	21.8
1062	23.0	1063	24.0	1064	24.8
1065	25.6	1066	26.5	1067	26.8
1068	27.4	1069	27.9	1070	28.3
1071	28.0	1072	27.5	1073	27.0
1074	27.0	1075	26.3	1076	24.5
1077	22.5	1078	21.5	1079	20.8
1080	18.0	1081	15.0	1082	12.3
1083	11.1	1084	10.6	1085	10.0
1086	9.5	1087	9.1	1088	8.7
1089	8.6	1090	8.8	1091	9.0
1092	8.7	1093	8.6	1094	8.0
1095	7.0	1096	5.0	1097	4.2
1098	2.6	1099	1.0	1100	0.0
1101	0.1	1102	0.6	1103	1.6
1104	3.6	1105	6.9	1106	10.0

EPA URBAN DYNAMOMETER—Continued DRIVING SCHEDULE

[Speed versus Time Sequence]

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
1107	12.8	1108 ...	14.0	1109 ...	14.5
1110	16.0	1111 ...	18.1	1112 ...	20.0
1113	21.0	1114 ...	21.2	1115 ...	21.3
1116	21.4	1117 ...	21.7	1118 ...	22.5
1119	23.0	1120 ...	23.8	1121 ...	24.5
1122	25.0	1123 ...	24.3	1124 ...	24.8
1125	25.0	1126 ...	25.4	1127 ...	25.8
1128	26.0	1129 ...	26.4	1130 ...	26.6
1131	26.9	1132 ...	27.0	1133 ...	27.0
1134	27.0	1135 ...	26.9	1136 ...	26.8
1137	26.8	1138 ...	26.5	1139 ...	26.4
1140	26.0	1141 ...	25.5	1142 ...	24.6
1143	23.5	1144 ...	21.5	1145 ...	20.0
1146	17.5	1147 ...	16.0	1148 ...	14.0
1149	10.7	1150 ...	7.4	1151 ...	4.1
1152	0.8	1153 ...	0.0	1154 ...	0.0
1155	0.0	1156 ...	0.0	1157 ...	0.0
1158	0.0	1159 ...	0.0	1160 ...	0.0
1161	0.0	1162 ...	0.0	1163 ...	0.0
1164	0.0	1165 ...	0.0	1166 ...	0.0
1167	0.0	1168 ...	0.0	1169 ...	2.1
1170	5.4	1171 ...	8.7	1172 ...	12.0
1173	15.3	1174 ...	18.6	1175 ...	21.1
1176	23.0	1177 ...	23.5	1178 ...	23.0
1179	22.5	1180 ...	20.0	1181 ...	16.7
1182	13.4	1183 ...	10.1	1184 ...	6.8
1185	3.5	1186 ...	0.2	1187 ...	0.0
1188	0.0	1189 ...	0.0	1190 ...	0.0
1191	0.0	1192 ...	0.0	1193 ...	0.0
1194	0.0	1195 ...	0.0	1196 ...	0.0
1197	0.2	1198 ...	1.5	1199 ...	3.5
1200	6.5	1201 ...	9.8	1202 ...	12.0
1203	12.9	1204 ...	13.0	1205 ...	12.6
1206	12.8	1207 ...	13.1	1208 ...	13.1
1209	14.0	1210 ...	15.5	1211 ...	17.0
1212	18.6	1213 ...	19.7	1214 ...	21.0
1215	21.5	1216 ...	21.8	1217 ...	21.8
1218	21.5	1219 ...	21.2	1220 ...	21.5
1221	21.8	1222 ...	22.0	1223 ...	21.9
1224	21.7	1225 ...	21.5	1226 ...	21.5
1227	21.4	1228 ...	20.1	1229 ...	19.5
1230	19.2	1231 ...	19.6	1232 ...	19.8
1233	20.0	1234 ...	19.5	1235 ...	17.5
1236	15.5	1237 ...	13.0	1238 ...	10.0
1239	8.0	1240 ...	6.0	1241 ...	4.0
1242	2.5	1243 ...	0.7	1244 ...	0.0
1245	0.0	1246 ...	0.0	1247 ...	0.0
1248	0.0	1249 ...	0.0	1250 ...	0.0
1251	0.0	1252 ...	1.0	1253 ...	1.0
1254	1.0	1255 ...	1.0	1256 ...	1.0
1257	1.6	1258 ...	3.0	1259 ...	4.0
1260	5.0	1261 ...	6.3	1262 ...	8.0
1263	10.0	1264 ...	10.5	1265 ...	9.5
1266	8.5	1267 ...	7.6	1268 ...	8.8
1269	11.0	1270 ...	14.0	1271 ...	17.0
1272	19.5	1273 ...	21.9	1274 ...	21.8
1275	22.2	1276 ...	23.0	1277 ...	23.6
1278	24.1	1279 ...	24.5	1280 ...	24.5
1281	24.0	1282 ...	23.5	1283 ...	23.5
1284	23.5	1285 ...	23.5	1286 ...	23.5
1287	23.5	1288 ...	24.0	1289 ...	24.1
1290	24.5	1291 ...	24.7	1292 ...	25.0
1293	25.4	1294 ...	25.6	1295 ...	25.7
1296	26.0	1297 ...	26.2	1298 ...	27.0
1299	27.8	1300 ...	28.3	1301 ...	29.0
1302	29.1	1303 ...	29.0	1304 ...	28.0
1305	24.7	1306 ...	21.4	1307 ...	18.1
1308	14.8	1309 ...	11.5	1310 ...	8.2
1311	4.9	1312 ...	1.6	1313 ...	0.0

EPA URBAN DYNAMOMETER—Continued DRIVING SCHEDULE

[Speed versus Time Sequence]

Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)	Time (sec.)	Speed (m.p.h.)
1314	0.0	1315 ...	0.0	1316 ...	0.0
1317	0.0	1318 ...	0.0	1319 ...	0.0
1320	0.0	1321 ...	0.0	1322 ...	0.0
1323	0.0	1324 ...	0.0	1325 ...	0.0
1326	0.0	1327 ...	0.0	1328 ...	0.0
1329	0.0	1330 ...	0.0	1331 ...	0.0
1332	0.0	1333 ...	0.0	1334 ...	0.0
1335	0.0	1336 ...	0.0	1337 ...	0.0
1338	1.5	1339 ...	4.8	1340 ...	8.1
1341	11.4	1342 ...	13.2	1343 ...	15.1
1344	16.8	1345 ...	18.8	1346 ...	19.5
1347	20.3	1348 ...	21.3	1349 ...	21.9
1350	22.1	1351 ...	22.4	1352 ...	22.0
1353	21.6	1354 ...	21.1	1355 ...	20.5
1356	20.0	1357 ...	19.6	1358 ...	18.5
1359	17.5	1360 ...	16.5	1361 ...	15.5
1362	14.0	1363 ...	11.0	1364 ...	8.0
1365	5.2	1366 ...	2.5	1367 ...	0.0
1368	0.0	1369 ...	0.0	1370 ...	0.0
1371	0.0	1372 ...	0.0	....	....

The diagrams below show the range of acceptable speed tolerances for typical points. The curve on the left is typical of portions of the speed curve which are increasing or decreasing throughout the 2 second time interval. The curve on the right is typical of portions of the speed curve which include a maximum or minimum value.

Appendix II

EMISSION TABLES EMBEDDED IN TRAF-NETSIM

HC Emission Rate (grams/sec)*10^{-4}

Speed (ft/sec)	Acceleration (ft/sec²)																					
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
0	3	3	3	3	3	3	3	3	3	3	4	4	5	7	8	8	9	10	10	10	10	10
1	3	3	3	3	3	3	3	3	3	3	4	4	5	7	7	7	8	9	10	12	13	13
2	3	3	3	3	3	3	3	3	3	3	3	4	5	7	8	8	8	8	9	11	14	17
3	3	3	3	3	3	3	3	3	3	3	3	4	6	7	8	8	9	9	10	12	14	18
4	3	3	3	3	3	3	3	3	3	3	4	5	6	8	9	9	10	10	11	13	15	19
5	3	3	3	3	3	3	3	3	3	3	4	5	7	9	10	11	11	12	13	15	17	21
6	3	3	3	3	3	3	3	3	3	3	4	5	7	10	11	12	13	14	15	17	20	24
7	3	3	3	3	3	3	3	3	3	3	4	5	8	11	12	14	14	16	18	20	24	28
8	3	3	3	3	3	3	3	3	3	3	4	6	8	12	14	15	16	18	20	24	28	32
9	3	3	3	3	3	3	3	3	3	3	4	6	9	12	15	16	18	20	24	28	32	37
10	3	3	3	3	3	3	3	3	3	3	5	6	9	13	15	17	19	22	27	32	36	41
11	3	3	3	3	3	3	3	3	3	3	5	7	9	13	16	19	21	25	30	36	41	46
12	3	3	3	3	3	3	3	3	3	3	5	7	10	14	17	20	22	27	34	40	45	51
13	4	4	4	4	4	4	4	4	4	4	5	7	10	14	18	20	23	29	37	44	49	56
14	4	4	4	4	4	4	4	4	4	4	5	7	10	15	18	21	25	32	40	49	54	63
15	4	4	4	4	4	4	4	4	4	4	6	8	11	15	19	22	27	34	44	53	58	72
16	4	4	4	4	4	4	4	4	4	4	5	8	11	16	19	23	29	37	48	55	62	82
17	4	4	4	4	4	4	4	4	4	4	6	9	12	16	20	24	31	40	51	59	68	78
18	4	4	4	4	4	4	4	4	4	4	6	9	13	16	20	26	33	43	55	63	76	79
19	4	4	4	4	4	4	4	4	4	4	6	9	13	16	21	28	36	47	60	68	80	80
20	4	4	4	4	4	4	4	4	4	4	6	9	14	17	22	30	39	52	63	72	80	80
21	4	4	4	4	4	4	4	4	4	4	6	10	14	18	24	32	42	56	66	77	80	80
22	4	4	4	4	4	4	4	4	4	4	6	10	14	18	26	34	47	62	71	83	83	83
23	4	4	4	4	4	4	4	4	4	4	7	10	14	19	26	37	52	69	76	88	88	88
24	4	4	4	4	4	4	4	4	4	4	7	11	15	20	28	41	57	74	83	93	93	93
25	4	4	4	4	4	4	4	4	4	4	7	10	15	21	30	45	63	80	91	98	98	98
26	4	4	4	4	4	4	4	4	4	4	7	11	16	22	31	49	69	85	98	101	101	101
27	4	4	4	4	4	4	4	4	4	4	7	11	16	23	33	54	74	89	103	103	103	103
28	4	4	4	4	4	4	4	4	4	4	8	12	17	24	35	59	78	92	105	105	105	105
29	4	4	4	4	4	4	4	4	4	4	8	12	17	25	37	63	81	95	106	106	106	106
30	4	4	4	4	4	4	4	4	4	4	9	13	17	27	39	65	84	99	107	107	107	107
31	5	5	5	5	5	5	5	5	5	4	9	13	18	28	46	66	87	102	107	107	107	107
32	5	5	5	5	5	5	5	5	5	5	9	13	18	26	49	68	90	105	107	107	107	107
33	5	5	5	5	5	5	5	5	5	5	9	14	19	27	51	71	93	108	108	108	108	108
34	5	5	5	5	5	5	5	5	5	5	9	14	19	27	54	74	96	110	110	110	110	110
35	6	6	6	6	6	6	6	6	6	5	10	15	19	28	56	76	100	114	114	114	114	114
36	6	6	6	6	6	6	6	6	6	5	10	15	20	29	60	81	106	119	119	119	119	119
37	6	6	6	6	6	6	6	6	6	5	10	15	20	30	64	87	113	124	124	124	124	124
38	7	7	7	7	7	7	7	7	7	5	10	16	21	32	68	94	121	128	128	128	128	128
39	7	7	7	7	7	7	7	7	7	6	10	16	22	33	73	99	128	131	131	131	131	131
40	8	8	8	8	8	8	8	8	8	6	11	17	21	35	78	104	133	134	134	134	134	134

HC Emission Rate (grams/sec)*10^{-4}

Speed (ft/sec)	Acceleration (ft/sec^2)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
41	8	8	8	8	8	8	8	8	8	5	11	17	22	37	83	109	137	136	136	136	136	136
42	9	9	9	9	9	9	9	9	9	5	11	17	23	52	88	115	140	140	140	140	140	140
43	10	10	10	10	10	10	10	10	10	5	12	18	24	54	94	122	146	143	143	143	143	143
44	10	10	10	10	10	10	10	10	10	6	12	18	25	57	102	131	153	147	147	147	147	147
45	10	10	10	10	10	10	10	10	10	6	11	19	26	48	110	140	161	152	152	152	152	152
46	11	11	11	11	11	11	11	11	11	6	11	19	27	51	117	148	162	162	162	162	162	162
47	11	11	11	11	11	11	11	11	11	6	12	20	28	54	120	153	163	163	163	163	163	163
48	11	11	11	11	11	11	11	11	11	6	12	20	29	58	122	155	162	162	162	162	162	162
49	11	11	11	11	11	11	11	11	11	5	12	21	30	62	124	155	158	158	158	158	158	158
50	11	11	11	11	11	11	11	11	11	5	12	22	32	65	127	155	154	154	154	154	154	154
51	11	11	11	11	11	11	11	11	11	5	12	22	33	69	128	152	148	148	148	148	148	148
52	11	11	11	11	11	11	11	11	11	5	12	23	35	75	134	153	151	151	151	151	151	151
53	11	11	11	11	11	11	11	11	11	6	12	24	37	80	135	153	153	153	153	153	153	153
54	12	12	12	12	12	12	12	12	12	6	13	21	39	85	134	153	153	153	153	153	153	153
55	12	12	12	12	12	12	12	12	12	6	13	22	42	90	136	149	149	149	149	149	149	149
56	13	13	13	13	13	13	13	13	13	6	13	22	45	94	139	147	147	147	147	147	147	147
57	13	13	13	13	13	13	13	13	13	6	13	22	48	100	143	146	146	146	146	146	146	146
58	13	13	13	13	13	13	13	13	13	6	13	23	51	106	146	146	146	146	146	146	146	146
59	14	14	14	14	14	14	14	14	13	6	14	23	55	111	143	143	143	143	143	143	143	143
60	14	14	14	14	14	14	14	14	13	6	14	24	59	115	138	138	138	138	138	138	138	138
61	14	14	14	14	14	14	14	14	13	6	14	25	63	118	136	136	136	136	136	136	136	136
62	14	14	14	14	14	14	14	14	13	6	14	26	68	120	137	137	137	137	137	137	137	137
63	14	14	14	14	14	14	14	14	13	6	15	27	73	121	140	140	140	140	140	140	140	140
64	14	14	14	14	14	14	14	14	13	6	15	28	78	121	139	139	139	139	139	139	139	139
65	14	14	14	14	14	14	14	14	13	6	16	29	83	120	136	136	136	136	136	136	136	136
66	14	14	14	14	14	14	14	14	13	7	16	31	87	117	131	131	131	131	131	131	131	131
67	13	13	13	13	13	13	13	13	12	7	17	32	92	118	133	133	133	133	133	133	133	133
68	13	13	13	13	13	13	13	13	12	7	17	34	97	119	133	133	133	133	133	133	133	133
69	13	13	13	13	13	13	13	13	12	7	18	35	102	121	131	131	131	131	131	131	131	131
70	13	13	13	13	13	13	13	13	11	7	18	37	108	126	130	130	130	130	130	130	130	130
71	13	13	13	13	13	13	13	13	11	8	18	39	114	147	153	153	153	153	153	153	153	153
72	14	14	14	14	14	14	14	14	11	8	19	41	120	153	159	159	159	159	159	159	159	159
73	15	15	15	15	15	15	15	15	11	8	19	44	126	159	165	165	165	165	165	165	165	165
74	15	15	15	15	15	15	15	15	11	8	20	47	132	164	170	170	170	170	170	170	170	170
75	15	15	15	15	15	15	15	15	11	9	20	50	138	169	172	172	172	172	172	172	172	172
76	15	15	15	15	15	15	15	15	11	9	21	54	143	173	175	175	175	175	175	175	175	175
77	15	15	15	15	15	15	15	15	11	9	21	57	148	177	178	178	178	178	178	178	178	178
78	14	14	14	14	14	14	14	15	11	9	22	62	151	178	178	178	178	178	178	178	178	178
79	14	14	14	14	14	14	14	15	11	10	22	79	154	177	178	178	178	178	178	178	178	178
80	14	14	14	14	14	14	14	15	12	10	23	83	155	176	176	176	176	176	176	176	176	176

HC Emission Rate (grams/sec)*10^{-4}

Speed (ft/sec)	Acceleration (ft/sec^2)																					
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
81	15	15	15	15	15	15	15	15	12	10	27	87	156	174	175	175	175	175	175	175	175	175
82	15	15	15	15	15	15	15	16	12	11	28	91	156	174	174	174	174	174	174	174	174	174
83	16	16	16	16	16	16	16	17	12	11	29	95	157	173	174	174	174	174	174	174	174	174
84	16	16	16	16	16	16	16	17	12	12	30	98	157	172	173	173	173	173	173	173	173	173
85	16	16	16	16	16	16	16	17	12	12	32	102	162	170	171	171	171	171	171	171	171	171
86	16	16	16	16	16	16	16	17	12	13	33	105	159	168	169	169	169	169	169	169	169	169
87	16	16	16	16	16	16	16	17	12	13	35	105	152	162	163	163	163	163	163	163	163	163
88	16	16	16	16	16	16	16	17	12	13	36	109	152	154	154	154	154	154	154	154	154	154
89	16	16	16	16	16	16	16	16	12	13	37	113	151	154	154	154	154	154	154	154	154	154
90	16	16	16	16	16	16	16	17	12	13	38	116	151	154	154	154	154	154	154	154	154	154
91	16	16	16	16	16	16	16	17	12	13	38	118	151	153	153	153	153	153	153	153	153	153
92	16	16	16	16	16	16	16	17	12	14	39	121	151	153	153	153	153	153	153	153	153	153
93	16	16	16	16	16	16	16	16	12	14	40	134	153	153	153	153	153	153	153	153	153	153
94	16	16	16	16	16	16	16	16	12	14	41	135	154	154	154	154	154	154	154	154	154	154
95	15	15	15	15	15	15	15	16	13	15	42	135	156	156	156	156	156	156	156	156	156	156
96	15	15	15	15	15	15	15	16	13	15	44	136	157	157	157	157	157	157	157	157	157	157
97	15	15	15	15	15	15	15	16	13	16	46	138	158	158	158	158	158	158	158	158	158	158
98	16	16	16	16	16	16	16	17	13	16	52	140	158	158	158	158	158	158	158	158	158	158
99	16	16	16	16	16	16	16	17	13	16	53	127	143	143	143	143	143	143	143	143	143	143
100	16	16	16	16	16	16	16	17	13	16	68	129	144	144	144	144	144	144	144	144	144	144
101	16	16	16	16	16	16	16	17	13	16	69	131	145	145	145	145	145	145	145	145	145	145
102	16	16	16	16	16	16	16	17	14	16	70	132	146	146	146	146	146	146	146	146	146	146
103	16	16	16	16	16	16	16	16	14	17	71	134	146	146	146	146	146	146	146	146	146	146
104	16	16	16	16	16	16	16	16	14	18	74	135	145	145	145	145	145	145	145	145	145	145
105	16	16	16	16	16	16	16	16	14	20	76	136	144	144	144	144	144	144	144	144	144	144
106	16	16	16	16	16	16	16	16	14	22	79	136	143	143	143	143	143	143	143	143	143	143
107	16	16	16	16	16	16	17	16	14	25	82	147	152	152	152	152	152	152	152	152	152	152
108	16	16	16	16	16	16	17	16	14	25	84	148	152	152	152	152	152	152	152	152	152	152
109	16	16	16	16	16	16	17	15	14	25	87	149	152	152	152	152	152	152	152	152	152	152
110	16	16	16	16	16	16	17	15	14	26	91	151	154	154	154	154	154	154	154	154	154	154

CO Emission Rate (grams/sec)*10^{-3}

Speed (ft/sec)	Acceleration (ft/sec^2)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
0	3	3	3	3	3	3	3	3	3	3	4	6	8	12	14	19	27	30	30	30	30	30
1	3	3	3	3	3	3	3	3	3	3	4	6	8	11	13	15	18	22	29	42	46	46
2	3	3	3	3	3	3	3	3	3	3	4	7	10	12	15	16	18	21	25	33	46	73
3	3	3	3	3	3	3	3	3	3	3	5	8	12	15	18	20	21	23	27	33	43	67
4	3	3	3	3	3	3	3	3	3	3	5	9	14	18	22	24	25	27	31	35	44	63
5	3	3	3	3	3	3	3	3	3	3	5	11	17	22	26	29	30	32	35	40	48	65
6	3	3	3	3	3	3	3	3	3	3	6	12	19	26	30	34	34	36	40	46	55	73
7	3	3	3	3	3	3	3	3	3	3	6	13	21	30	33	38	38	39	45	53	65	85
8	3	3	3	3	3	3	3	3	3	3	7	13	21	31	36	40	40	43	51	63	78	101
9	3	3	3	3	3	3	3	3	3	3	8	13	21	31	38	41	42	47	59	75	94	122
10	3	3	3	3	3	3	3	3	3	3	8	13	19	29	38	42	44	52	69	88	111	144
11	3	3	3	3	3	3	3	3	3	4	9	13	18	28	38	42	45	57	80	102	129	167
12	4	4	4	4	4	4	4	4	4	4	9	13	17	27	38	42	48	64	91	118	151	193
13	4	4	4	4	4	4	4	4	4	4	9	14	17	27	38	43	51	71	102	139	175	224
14	4	4	4	4	4	4	4	4	4	4	10	14	17	27	37	44	56	80	116	166	204	267
15	4	4	4	4	4	4	4	4	4	4	10	15	17	26	36	45	61	89	135	190	233	334
16	4	4	4	4	4	4	4	4	4	4	10	15	17	26	37	49	69	102	160	216	267	406
17	4	4	4	4	4	4	4	4	4	5	10	15	18	26	38	54	79	118	187	247	312	378
18	4	4	4	4	4	4	4	4	4	5	10	14	18	27	40	61	92	139	219	285	367	387
19	4	4	4	4	4	4	4	4	4	5	12	14	19	27	43	68	104	165	256	327	405	405
20	4	4	4	4	4	4	4	4	4	5	12	13	19	28	48	77	118	195	287	364	415	415
21	5	5	5	5	5	5	5	5	5	6	12	13	20	30	55	87	136	230	318	403	423	423
22	5	5	5	5	5	5	5	5	5	6	12	13	20	33	64	101	162	279	359	445	445	445
23	5	5	5	5	5	5	5	5	5	6	12	13	21	36	65	119	196	345	409	480	480	480
24	5	5	5	5	5	5	5	5	5	6	12	13	22	39	74	143	238	394	470	528	528	528
25	5	5	5	5	5	5	5	5	5	7	13	14	23	44	84	172	288	451	540	578	578	578
26	5	5	5	5	5	5	5	5	5	7	13	14	25	50	97	207	345	508	603	619	619	619
27	4	4	4	4	4	4	4	4	4	7	13	15	27	57	112	246	403	561	656	656	656	656
28	4	4	4	4	4	4	4	4	4	7	13	15	29	59	130	288	460	610	692	692	692	692
29	5	5	5	5	5	5	5	5	5	7	12	16	31	66	150	330	514	659	726	726	726	726
30	5	5	5	5	5	5	5	5	5	7	13	17	33	74	171	363	566	703	748	748	748	748
31	5	5	5	5	5	5	5	5	5	7	13	18	36	84	226	396	616	740	763	763	763	763
32	5	5	5	5	5	5	5	5	5	7	13	19	39	78	245	430	666	774	782	782	782	782
33	5	5	5	5	5	5	5	5	5	7	13	20	42	86	264	466	719	812	812	812	812	812
34	5	5	5	5	5	5	5	5	5	7	14	21	45	94	285	506	772	849	849	849	849	849
35	5	5	5	5	5	5	5	5	5	7	14	23	48	102	308	459	826	890	890	890	890	890
36	5	5	5	5	5	5	5	5	5	7	14	24	52	111	335	505	887	939	939	939	939	939
37	5	5	5	5	5	5	5	5	5	7	14	26	56	121	367	554	953	988	988	988	988	988
38	5	5	5	5	5	5	5	5	5	7	14	27	63	133	402	606	1025	1034	1034	1034	1034	1034
39	5	5	5	5	5	5	5	5	5	7	14	28	67	146	440	658	1089	1073	1073	1073	1073	1073
40	4	4	4	4	4	4	4	4	4	7	14	30	53	161	485	712	1132	1109	1109	1109	1109	1109

CO Emission Rate (grams/sec)*10^{-3}

Speed (ft/sec)	Acceleration (ft/sec^2)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
41	4	4	4	4	4	4	4	4	4	7	15	31	57	180	531	770	1167	1149	1149	1149	1149	1149
42	4	4	4	4	4	4	4	4	4	7	15	32	62	266	580	835	1199	1193	1193	1193	1193	1193
43	4	4	4	4	4	4	4	4	4	7	15	34	68	278	644	919	1249	1244	1244	1244	1244	1244
44	4	4	4	4	4	4	4	4	4	7	15	35	75	295	729	1028	1339	1312	1312	1312	1312	1312
45	4	4	4	4	4	4	4	4	4	7	14	38	83	280	844	1164	1446	1399	1399	1399	1399	1399
46	4	4	4	4	4	4	4	4	4	7	14	40	94	312	964	1303	1520	1520	1520	1520	1520	1520
47	4	4	4	4	4	4	4	4	4	7	14	43	93	348	1042	1403	1542	1542	1542	1542	1542	1542
48	4	4	4	4	4	4	4	4	4	7	14	45	103	388	1095	1444	1500	1500	1500	1500	1500	1500
49	4	4	4	4	4	4	4	4	4	5	15	49	114	429	1137	1441	1416	1416	1416	1416	1416	1416
50	4	4	4	4	4	4	4	4	4	5	15	55	126	473	1192	1412	1330	1330	1330	1330	1330	1330
51	4	4	4	4	4	4	4	4	4	5	15	62	141	520	1283	1381	1303	1303	1303	1303	1303	1303
52	4	4	4	4	4	4	4	4	4	6	16	67	160	578	1345	1367	1328	1328	1328	1328	1328	1328
53	4	4	4	4	4	4	4	4	4	6	17	71	181	638	1325	1364	1362	1362	1362	1362	1362	1362
54	4	4	4	4	4	4	4	4	4	6	17	52	207	700	1275	1368	1368	1368	1368	1368	1368	1368
55	4	4	4	4	4	4	4	4	4	5	17	55	237	761	1249	1346	1346	1346	1346	1346	1346	1346
56	4	4	4	4	4	4	4	4	4	5	18	59	271	820	1255	1334	1334	1334	1334	1334	1334	1334
57	4	4	4	4	4	4	4	4	4	5	18	62	309	884	1279	1329	1329	1329	1329	1329	1329	1329
58	4	4	4	4	4	4	4	4	4	5	19	66	273	951	1297	1297	1297	1297	1297	1297	1297	1297
59	4	4	4	4	4	4	4	4	4	6	20	70	310	1010	1243	1243	1243	1243	1243	1243	1243	1243
60	4	4	4	4	4	4	4	4	4	6	21	75	352	1059	1170	1170	1170	1170	1170	1170	1170	1170
61	4	4	4	4	4	4	4	4	4	6	22	81	398	1080	1124	1124	1124	1124	1124	1124	1124	1124
62	4	4	4	4	4	4	4	4	4	6	24	87	447	1093	1149	1149	1149	1149	1149	1149	1149	1149
63	4	4	4	4	4	4	4	4	4	7	25	95	497	1100	1192	1192	1192	1192	1192	1192	1192	1192
64	4	4	4	4	4	4	4	4	4	7	27	104	546	1099	1173	1173	1173	1173	1173	1173	1173	1173
65	4	4	4	4	4	4	4	4	4	7	29	113	592	1087	1134	1134	1134	1134	1134	1134	1134	1134
66	4	4	4	4	4	4	4	4	4	7	31	124	635	1097	1135	1135	1135	1135	1135	1135	1135	1135
67	5	5	5	5	5	5	5	5	4	8	33	135	677	1091	1123	1123	1123	1123	1123	1123	1123	1123
68	5	5	5	5	5	5	5	5	4	8	35	148	718	1086	1105	1105	1105	1105	1105	1105	1105	1105
69	5	5	5	5	5	5	5	5	5	8	37	163	762	1090	1085	1085	1085	1085	1085	1085	1085	1085
70	5	5	5	5	5	5	5	5	5	9	39	180	812	1103	1080	1080	1080	1080	1080	1080	1080	1080
71	5	5	5	5	5	5	5	5	5	9	41	198	867	1148	1136	1136	1136	1136	1136	1136	1136	1136
72	5	5	5	5	5	5	5	5	6	10	43	218	927	1172	1165	1165	1165	1165	1165	1165	1165	1165
73	5	5	5	5	5	5	5	5	6	10	45	240	994	1211	1212	1212	1212	1212	1212	1212	1212	1212
74	5	5	5	5	5	5	5	5	6	10	48	264	1068	1270	1273	1273	1273	1273	1273	1273	1273	1273
75	5	5	[illegible]	5	5	5	5	5	6	11	51	291	1140	1335	1331	1331	1331	1331	1331	1331	1331	1331
76	5	5	5	5	5	5	5	5	7	11	54	319	1207	1391	1383	1383	1383	1383	1383	1383	1383	1383
77	5	5	5	5	5	5	5	5	7	11	57	350	1261	1427	1420	1420	1420	1420	1420	1420	1420	1420
78	6	6	6	6	6	6	6	5	8	11	59	388	1304	1440	1433	1433	1433	1433	1433	1433	1433	1433
79	6	6	6	6	6	6	6	6	8	12	62	466	1335	1433	1427	1427	1427	1427	1427	1427	1427	1427
80	6	6	6	6	6	6	6	5	8	12	65	507	1354	1417	1412	1412	1412	1412	1412	1412	1412	1412

CO Emission Rate (grams/sec)*10^{-3}

Speed (ft/sec)	Acceleration (ft/sec^2)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
81	5	5	5	5	5	5	5	5	9	13	96	550	1363	1406	1400	1400	1400	1400	1400	1400	1400	1400
82	5	5	5	5	5	5	5	5	9	13	102	596	1365	1397	1390	1390	1390	1390	1390	1390	1390	1390
83	5	5	5	5	5	5	5	5	9	14	109	643	1363	1389	1381	1381	1381	1381	1381	1381	1381	1381
84	5	5	5	5	5	5	5	4	10	15	118	692	1356	1376	1369	1369	1369	1369	1369	1369	1369	1369
85	5	5	5	5	5	5	5	4	10	15	128	740	1366	1356	1350	1350	1350	1350	1350	1350	1350	1350
86	5	5	5	5	5	5	5	4	10	15	138	788	1344	1337	1331	1331	1331	1331	1331	1331	1331	1331
87	5	5	5	5	5	5	5	4	11	15	148	838	1314	1313	1308	1308	1308	1308	1308	1308	1308	1308
88	5	5	5	5	5	5	5	4	11	15	157	885	1299	1353	1353	1353	1353	1353	1353	1353	1353	1353
89	5	5	5	5	5	5	5	4	11	16	165	926	1298	1360	1360	1360	1360	1360	1360	1360	1360	1360
90	5	5	5	5	5	5	5	4	12	16	173	960	1300	1363	1363	1363	1363	1363	1363	1363	1363	1363
91	5	5	5	5	5	5	5	4	12	17	181	989	1307	1357	1357	1357	1357	1357	1357	1357	1357	1357
92	5	5	5	5	5	5	5	4	13	17	190	1014	1318	1347	1347	1347	1347	1347	1347	1347	1347	1347
93	5	5	5	5	5	5	5	4	14	18	198	1234	1338	1339	1339	1339	1339	1339	1339	1339	1339	1339
94	5	5	5	5	5	5	5	4	14	19	209	1221	1342	1342	1342	1342	1342	1342	1342	1342	1342	1342
95	5	5	5	5	5	5	5	4	15	20	219	1220	1357	1357	1357	1357	1357	1357	1357	1357	1357	1357
96	4	4	4	4	4	4	4	4	15	22	228	1233	1363	1363	1363	1363	1363	1363	1363	1363	1363	1363
97	4	4	4	4	4	4	4	4	16	23	237	1260	1357	1357	1357	1357	1357	1357	1357	1357	1357	1357
98	4	4	4	4	4	4	4	4	16	25	365	1306	1363	1363	1363	1363	1363	1363	1363	1363	1363	1363
99	4	4	4	4	4	4	4	3	17	27	373	1046	1060	1060	1060	1060	1060	1060	1060	1060	1060	1060
100	4	4	4	4	4	4	4	4	18	28	488	1080	1092	1092	1092	1092	1092	1092	1092	1092	1092	1092
101	4	4	4	4	4	4	4	4	20	30	493	1119	1130	1130	1130	1130	1130	1130	1130	1130	1130	1130
102	4	4	4	4	4	4	4	5	22	32	498	1159	1167	1167	1167	1167	1167	1167	1167	1167	1167	1167
103	4	4	4	4	4	4	4	6	23	35	512	1195	1198	1198	1198	1198	1198	1198	1198	1198	1198	1198
104	4	4	4	4	4	4	4	7	26	39	530	1226	1224	1224	1224	1224	1224	1224	1224	1224	1224	1224
105	4	4	4	4	4	4	4	8	29	46	554	1251	1243	1243	1243	1243	1243	1243	1243	1243	1243	1243
106	4	4	4	4	4	4	4	9	32	55	580	1269	1258	1258	1258	1258	1258	1258	1258	1258	1258	1258
107	4	4	4	4	4	4	4	11	36	67	608	1241	1231	1231	1231	1231	1231	1231	1231	1231	1231	1231
108	4	4	4	4	4	4	4	12	36	68	629	1262	1252	1252	1252	1252	1252	1252	1252	1252	1252	1252
109	4	4	4	4	4	4	4	14	35	69	652	1281	1274	1274	1274	1274	1274	1274	1274	1274	1274	1274
110	4	4	4	4	4	4	4	16	35	70	679	1304	1299	1299	1299	1299	1299	1299	1299	1299	1299	1299

NOx Emission Rate (grams/sec)*10^{-4}

Speed (ft/sec)	Acceleration (ft/sec²)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
0	3	3	3	3	3	3	3	3	3	3	3	5	11	19	26	53	81	125	135	142	142	142
1	3	3	3	3	3	3	3	3	3	3	3	5	11	18	24	42	61	91	100	114	131	131
2	3	3	3	3	3	3	3	3	3	3	3	5	11	18	24	38	50	70	81	93	111	145
3	3	3	3	3	3	3	3	3	3	3	3	6	13	18	24	36	45	60	71	83	98	127
4	2	2	2	2	2	2	2	2	2	2	3	8	14	20	26	36	46	58	70	81	95	120
5	2	2	2	2	2	2	2	2	2	2	3	9	16	24	29	39	50	62	75	86	101	125
6	2	2	2	2	2	2	2	2	2	2	4	10	18	30	34	44	57	70	83	96	113	137
7	2	2	2	2	2	2	2	2	2	2	4	12	21	35	39	48	64	79	94	108	127	152
8	2	2	2	2	2	2	2	2	2	2	5	15	24	37	43	52	71	90	106	121	141	164
9	2	2	2	2	2	2	2	2	2	2	6	18	26	38	47	55	79	102	119	136	156	177
10	2	2	2	2	2	2	2	2	2	2	7	21	29	40	51	61	89	115	133	151	173	189
11	2	2	2	2	2	2	2	2	2	2	9	23	32	43	56	70	101	129	150	170	190	197
12	2	2	2	2	2	2	2	2	2	2	11	24	34	47	62	82	116	144	168	190	207	209
13	2	2	2	2	2	2	2	2	2	2	12	25	36	53	70	96	132	160	186	210	221	223
14	2	2	2	2	2	2	2	2	2	2	13	28	39	58	78	111	148	177	204	230	233	235
15	2	2	2	2	2	2	2	2	2	2	14	24	43	64	88	126	164	193	220	240	241	245
16	2	2	2	2	2	2	2	2	2	2	14	26	43	71	99	141	180	208	234	244	246	251
17	2	2	2	2	2	2	2	2	2	3	15	28	47	79	111	158	196	222	243	248	250	253
18	2	2	2	2	2	2	2	2	2	3	15	29	51	90	124	175	212	234	250	254	257	258
19	2	2	2	2	2	2	2	2	2	3	15	31	56	98	139	192	226	245	258	261	264	264
20	2	2	2	2	2	2	2	2	2	3	11	34	62	108	155	209	237	253	263	266	268	268
21	2	2	2	2	2	2	2	2	2	4	14	[illegible]	69	119	171	224	248	261	267	270	271	271
22	2	2	2	2	2	2	2	2	2	4	14	43	71	128	189	239	258	269	272	276	276	276
23	2	2	2	2	2	2	2	2	2	5	15	45	78	137	191	253	267	277	280	283	283	283
24	2	2	2	2	2	2	2	2	2	5	16	45	85	145	207	266	275	284	287	290	290	290
25	2	2	2	2	2	2	2	2	2	5	16	33	92	155	223	277	283	290	294	297	297	297
26	2	2	2	2	2	2	2	2	2	6	17	35	100	166	237	285	290	296	300	302	302	302
27	2	2	2	2	2	2	2	2	2	6	17	39	110	179	248	291	296	301	307	307	307	307
28	2	2	2	2	2	2	2	2	2	7	18	44	120	194	257	296	302	307	312	312	312	312
29	1	1	1	1	1	1	1	1	1	7	19	49	131	206	265	299	306	311	316	316	316	316
30	1	1	1	1	1	1	1	1	1	7	20	54	141	216	271	300	306	312	316	316	316	316
31	2	2	2	2	2	2	2	2	2	7	21	59	153	225	290	298	304	310	313	313	313	313
32	2	2	2	2	2	2	2	2	2	8	22	64	166	227	294	295	301	308	309	309	309	309
33	2	2	2	2	2	2	2	2	2	8	23	59	177	236	296	295	300	308	308	308	308	308
34	2	2	2	2	2	2	2	2	2	8	24	64	188	245	299	298	302	309	309	309	309	309
35	2	2	2	2	2	2	2	2	2	6	26	68	198	254	304	302	305	311	311	311	311	311
36	3	3	3	3	3	3	3	3	3	7	27	73	210	262	311	307	309	315	315	315	315	315
37	3	3	3	3	3	3	3	3	3	7	28	78	221	270	320	314	315	319	319	319	319	319
38	3	3	3	3	3	3	3	3	3	7	29	83	233	278	329	322	323	326	326	326	326	326
39	3	3	3	3	3	3	3	3	3	7	30	88	231	286	340	332	333	336	336	336	336	336
40	3	3	3	3	3	3	3	3	3	7	31	94	202	294	350	344	347	347	347	347	347	347

NOx Emission Rate (grams/sec)*10^{-4}

Speed (ft/sec)	Acceleration (ft/sec²)																					
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
41	3	3	3	3	3	3	3	3	3	6	32	101	210	303	360	356	360	361	361	361	361	361
42	3	3	3	3	3	3	3	3	3	6	34	108	217	331	369	366	373	375	375	375	375	375
43	3	3	3	3	3	3	3	3	3	7	40	120	225	342	377	373	383	389	389	389	389	389
44	3	3	3	3	3	3	3	3	3	7	46	128	232	352	382	378	392	402	402	402	402	402
45	4	4	4	4	4	4	4	4	4	8	34	137	239	338	384	381	398	411	411	411	411	411
46	4	4	4	4	4	4	4	4	4	9	38	146	246	345	381	379	380	380	380	380	380	380
47	4	4	4	4	4	4	4	4	4	10	37	155	251	352	378	375	377	377	377	377	377	377
48	4	4	4	4	4	4	4	4	4	11	40	165	257	359	377	374	377	377	377	377	377	377
49	4	4	4	4	4	4	4	4	4	12	49	175	262	364	380	378	381	381	381	381	381	381
50	4	4	4	4	4	4	4	4	4	14	54	185	267	368	385	385	387	387	387	387	387	387
51	4	4	4	4	4	4	4	4	4	14	51	195	271	369	361	363	363	363	363	363	363	363
52	4	4	4	4	4	4	4	4	4	14	55	201	275	362	357	359	359	359	359	359	359	359
53	4	4	4	4	4	4	4	4	4	14	56	206	280	365	360	362	362	362	362	362	362	362
54	4	4	4	4	4	4	4	4	4	14	62	194	284	368	362	365	365	365	365	365	365	365
55	4	4	4	4	4	4	4	4	4	14	67	199	289	371	365	368	368	368	368	368	368	368
56	4	4	4	4	4	4	4	4	4	14	72	205	294	373	368	371	371	371	371	371	371	371
57	4	4	4	4	4	4	4	4	4	14	76	211	300	377	373	375	375	375	375	375	375	375
58	4	4	4	4	4	4	4	4	4	14	81	217	304	383	388	388	388	388	388	388	388	388
59	4	4	4	4	4	4	4	4	4	15	86	223	308	389	392	392	392	392	392	392	392	392
60	3	3	3	3	3	3	3	3	4	15	91	230	314	397	398	398	398	398	398	398	398	398
61	3	3	3	3	3	3	3	3	3	16	97	236	320	403	406	406	406	406	406	406	406	406
62	3	3	3	3	3	3	3	3	3	16	103	243	326	409	414	414	414	414	414	414	414	414
63	3	3	3	3	3	3	3	3	3	17	111	250	333	417	423	423	423	423	423	423	423	423
64	3	3	3	3	3	3	3	3	3	18	118	257	339	424	434	434	434	434	434	434	434	434
65	3	3	3	3	3	3	3	3	3	18	124	264	346	432	446	446	446	446	446	446	446	446
66	3	3	3	3	3	3	3	3	3	19	130	272	352	457	469	469	469	469	469	469	469	469
67	3	3	3	3	3	3	3	3	3	20	135	278	357	471	480	480	480	480	480	480	480	480
68	2	2	2	2	2	2	2	2	3	22	139	285	363	482	486	486	486	486	486	486	486	486
69	2	2	2	2	2	2	2	2	3	23	143	292	367	489	491	491	491	491	491	491	491	491
70	2	2	2	2	2	2	2	2	3	24	147	298	372	379	496	496	496	496	496	496	496	496
71	2	2	2	2	2	2	2	2	3	26	152	304	376	384	387	387	387	387	387	387	387	387
72	2	2	2	2	2	2	2	2	4	27	158	310	381	390	393	393	393	393	393	393	393	393
73	2	2	2	2	2	2	2	2	4	28	164	316	385	396	401	401	401	401	401	401	401	401
74	2	2	2	2	2	2	2	2	4	29	171	322	388	401	406	406	406	406	406	406	406	406
75	2	2	2	2	2	2	2	2	4	29	178	327	390	405	408	408	408	408	408	408	408	408
76	2	2	2	2	2	2	2	2	4	31	185	332	389	404	405	405	405	405	405	405	405	405
77	2	2	2	2	2	2	2	2	4	32	193	335	387	401	402	402	402	402	402	402	402	402
78	2	2	2	2	2	2	2	2	4	35	200	337	383	399	400	400	400	400	400	400	400	400
79	2	2	2	2	2	2	2	2	4	38	207	362	378	396	397	397	397	397	397	397	397	397
80	2	2	2	2	2	2	2	2	4	43	214	361	375	395	396	396	396	396	396	396	396	396

NOx Emission Rate (grams/sec)*10^{-4}

Speed (ft/sec)	Acceleration (ft/sec^2)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
81	2	2	2	2	2	2	2	2	5	48	245	361	374	395	396	396	396	396	396	396	396	396
82	1	1	1	1	1	1	1	2	5	53	251	361	374	397	397	397	397	397	397	397	397	397
83	1	1	1	1	1	1	1	2	5	59	258	361	373	397	398	398	398	398	398	398	398	398
84	1	1	1	1	1	1	1	1	5	66	265	362	372	398	399	399	399	399	399	399	399	399
85	1	1	1	1	1	1	1	1	6	73	271	362	393	399	399	399	399	399	399	399	399	399
86	1	1	1	1	1	1	1	1	6	80	277	362	394	400	400	400	400	400	400	400	400	400
87	1	1	1	1	1	1	1	1	7	87	281	340	374	381	382	382	382	382	382	382	382	382
88	1	1	1	1	1	1	1	1	7	94	284	343	349	349	349	349	349	349	349	349	349	349
89	1	1	1	1	1	1	1	1	8	102	286	346	350	351	351	351	351	351	351	351	351	351
90	1	1	1	1	1	1	1	1	9	110	287	349	352	353	353	353	353	353	353	353	353	353
91	1	1	1	1	1	1	1	1	10	117	287	352	354	354	354	354	354	354	354	354	354	354
92	1	1	1	1	1	1	1	1	10	124	287	355	355	355	355	355	355	355	355	355	355	355
93	1	1	1	1	1	1	1	1	11	130	287	351	357	357	357	357	357	357	357	357	357	357
94	1	1	1	1	1	1	1	1	12	136	289	353	359	359	359	359	359	359	359	359	359	359
95	1	1	1	1	1	1	1	1	13	142	290	356	361	361	361	361	361	361	361	361	361	361
96	1	1	1	1	1	1	1	2	14	149	290	360	364	364	364	364	364	364	364	364	364	364
97	1	1	1	1	1	1	1	2	16	156	290	365	367	367	367	367	367	367	367	367	367	367
98	1	1	1	1	1	1	1	2	17	164	292	372	372	372	372	372	372	372	372	372	372	372
99	1	1	1	1	1	1	1	2	19	172	293	389	393	393	393	393	393	393	393	393	393	393
100	1	1	1	1	1	1	1	2	21	180	317	397	399	399	399	399	399	399	399	399	399	399
101	1	1	1	1	1	1	1	2	23	189	320	405	406	406	406	406	406	406	406	406	406	406
102	1	1	1	1	1	1	1	2	25	198	324	414	415	415	415	415	415	415	415	415	415	415
103	1	1	1	1	1	1	1	2	27	208	331	423	426	426	426	426	426	426	426	426	426	426
104	1	1	1	1	1	1	1	2	30	217	337	434	438	438	438	438	438	438	438	438	438	438
105	1	1	1	1	1	1	1	2	33	225	345	446	450	450	450	450	450	450	450	450	450	450
106	1	1	1	1	1	1	1	3	36	233	354	458	462	462	462	462	462	462	462	462	462	462
107	1	1	1	1	1	1	1	3	39	240	362	356	360	360	360	360	360	360	360	360	360	360
108	1	1	1	1	1	1	1	3	41	245	368	360	363	363	363	363	363	363	363	363	363	363
109	1	1	1	1	1	1	1	3	44	248	372	364	367	367	367	367	367	367	367	367	367	367
110	1	1	1	1	1	1	1	3	48	251	373	368	370	370	370	370	370	370	370	370	370	370

Appendix III

Modal Adjustment Factors For:

Hydrocarbon (HC);

Carbon Monoxide (CO); and

Nitrogen Oxide (NOx)

HC Modal Adjustment Factors

Speed (ft/sec)	Acceleration (ft/sec^2)																					
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.54	0.64	0.82	1.04	1.13	1.25	1.42	1.53	1.55	1.57	1.57	1.57
1	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.53	0.63	0.80	1.00	1.09	1.10	1.16	1.32	1.50	1.83	1.97	1.97
2	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.53	0.64	0.83	1.01	1.14	1.15	1.16	1.26	1.42	1.68	2.04	2.63
3	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.53	0.66	0.87	1.06	1.23	1.27	1.28	1.35	1.52	1.74	2.06	2.65
4	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.53	0.70	0.92	1.15	1.35	1.43	1.47	1.54	1.72	1.93	2.25	2.80
5	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.54	0.74	0.99	1.29	1.51	1.63	1.68	1.79	1.98	2.21	2.56	3.12
6	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.56	0.77	1.06	1.46	1.69	1.85	1.91	2.05	2.29	2.58	2.99	3.60
7	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.58	0.82	1.15	1.62	1.87	2.07	2.17	2.34	2.66	3.03	3.54	4.21
8	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.61	0.86	1.23	1.74	2.04	2.27	2.44	2.66	3.09	3.57	4.16	4.85
9	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.64	0.90	1.30	1.83	2.20	2.45	2.69	3.00	3.56	4.16	4.79	5.54
10	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.68	0.95	1.36	1.90	2.33	2.63	2.91	3.35	4.07	4.76	5.45	6.24
11	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.72	0.99	1.42	1.97	2.45	2.80	3.11	3.69	4.58	5.35	6.12	6.88
12	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.76	1.02	1.46	2.05	2.57	2.96	3.31	4.04	5.08	5.97	6.80	7.61
13	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.79	1.04	1.49	2.13	2.70	3.08	3.53	4.40	5.54	6.65	7.44	8.45
14	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.82	1.08	1.54	2.21	2.78	3.19	3.77	4.75	6.04	7.41	8.09	9.45
15	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.57	0.85	1.23	1.62	2.28	2.83	3.31	4.02	5.12	6.57	7.91	8.68	10.86
16	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.59	0.81	1.28	1.71	2.34	2.88	3.46	4.32	5.53	7.16	8.35	9.31	12.41
17	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.61	0.84	1.34	1.82	2.40	2.94	3.66	4.65	5.98	7.74	8.87	10.22	11.80
18	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.62	0.86	1.31	1.89	2.46	3.04	3.91	5.01	6.51	8.35	9.54	11.38	11.91
19	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.64	0.88	1.35	1.97	2.43	3.17	4.20	5.39	7.12	9.00	10.24	12.02	12.02
20	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.65	0.86	1.40	2.04	2.53	3.36	4.49	5.82	7.79	9.45	10.87	12.00	12.00
21	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.66	0.88	1.45	2.10	2.64	3.59	4.80	6.35	8.45	9.95	11.63	12.08	12.08
22	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.66	0.91	1.50	2.11	2.75	3.85	5.17	7.01	9.32	10.66	12.53	12.53	12.53
23	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.65	0.98	1.55	2.18	2.86	3.92	5.61	7.77	10.40	11.52	13.19	13.19	13.19
24	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.64	1.01	1.61	2.24	2.99	4.18	6.14	8.63	11.16	12.52	13.96	13.96	13.96
25	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.64	1.04	1.57	2.31	3.13	4.45	6.75	9.52	12.02	13.66	14.68	14.68	14.68
26	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.63	1.07	1.63	2.38	3.28	4.72	7.42	10.42	12.82	14.72	15.20	15.20	15.20
27	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.63	1.11	1.69	2.44	3.46	5.00	8.12	11.14	13.41	15.52	15.52	15.52	15.52
28	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.63	1.16	1.76	2.50	3.66	5.29	8.81	11.70	13.86	15.75	15.75	15.75	15.75
29	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.64	1.27	1.82	2.56	3.84	5.56	9.42	12.20	14.36	15.99	15.99	15.99	15.99
30	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.65	1.30	1.88	2.62	4.04	5.81	9.73	12.65	14.84	16.08	16.08	16.08	16.08
31	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.67	1.34	1.94	2.67	4.24	6.92	10.00	13.09	15.30	16.07	16.07	16.07	16.07
32	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.69	1.37	2.01	2.75	3.90	7.41	10.30	13.52	15.76	16.10	16.10	16.10	16.10
33	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.72	1.39	2.07	2.80	4.01	7.72	10.63	13.96	16.26	16.26	16.26	16.26	16.26
34	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.74	1.42	2.14	2.84	4.13	8.06	11.09	14.47	16.60	16.60	16.60	16.60	16.60
35	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.73	1.45	2.20	2.89	4.26	8.47	11.47	15.12	17.15	17.15	17.15	17.15	17.15
36	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.76	1.48	2.27	2.96	4.40	8.97	12.25	15.99	17.89	17.89	17.89	17.89	17.89
37	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.79	1.51	2.33	3.05	4.57	9.58	13.17	17.08	18.63	18.63	18.63	18.63	18.63
38	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	0.81	1.54	2.38	3.18	4.77	10.26	14.13	18.27	19.28	19.28	19.28	19.28	19.28
39	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	0.83	1.58	2.44	3.30	5.00	10.95	14.98	19.28	19.77	19.77	19.77	19.77	19.77
40	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	0.83	1.61	2.49	3.20	5.25	11.69	15.71	20.07	20.18	20.18	20.18	20.18	20.18
41	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	0.83	1.64	2.53	3.32	5.55	12.46	16.44	20.57	20.55	20.55	20.55	20.55	20.55
42	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	0.82	1.68	2.59	3.43	7.85	13.27	17.34	21.14	21.01	21.01	21.01	21.01	21.01
43	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	0.83	1.75	2.68	3.57	8.21	14.21	18.42	22.03	21.57	21.57	21.57	21.57	21.57
44	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	0.83	1.78	2.71	3.72	8.59	15.29	19.68	23.02	22.11	22.11	22.11	22.11	22.11
45	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	0.84	1.70	2.81	3.91	7.17	16.52	21.06	24.17	22.83	22.83	22.83	22.83	22.83
46	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61	0.85	1.72	2.87	4.13	7.65	17.59	22.26	24.47	24.47	24.47	24.47	24.47	24.47
47	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63	0.86	1.74	2.95	4.21	8.17	18.14	23.02	24.61	24.61	24.61	24.61	24.61	24.61
48	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	0.87	1.76	3.03	4.39	8.71	18.44	23.35	24.33	24.33	24.33	24.33	24.33	24.33
49	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	0.78	1.78	3.12	4.58	9.27	18.67	23.39	23.80	23.80	23.80	23.80	23.80	23.80
50	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	0.79	1.80	3.24	4.78	9.84	19.06	23.35	23.15	23.15	23.15	23.15	23.15	23.15
51	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	0.81	1.83	3.38	5.01	10.44	19.30	22.91	22.27	22.27	22.27	22.27	22.27	22.27
52	1.64	1.64	1.64	1.64	1.[illegible]4	1.64	1.64	1.64	1.64	0.83	1.86	3.50	5.26	11.29	20.17	23.02	22.70	22.70	22.70	22.70	22.70	22.70
53	1.68	1.68	1.68	1.68	1.[illegible]8	1.68	1.68	1.68	1.68	0.84	1.86	3.62	5.55	12.02	20.32	23.08	23.07	23.07	23.07	23.07	23.07	23.07
54	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.74	0.84	1.89	3.19	5.89	12.77	20.25	22.99	22.99	22.99	22.99	22.99	22.99	22.99
55	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.81	0.83	1.93	3.25	6.27	13.48	20.43	22.51	22.51	22.51	22.51	22.51	22.51	22.51

HC Modal Adjustment Factors

Speed (ft/sec)	Acceleration (ft/sec²)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
56	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.89	0.83	1.95	3.32	6.70	14.19	20.93	22.18	22.18	22.18	22.18	22.18	22.18	22.18
57	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.95	0.84	1.98	3.38	7.18	15.03	21.57	22.05	22.05	22.05	22.05	22.05	22.05	22.05
58	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	1.99	0.85	2.01	3.45	7.63	15.99	21.97	21.97	21.97	21.97	21.97	21.97	21.97	21.97
59	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	1.99	0.87	2.04	3.53	8.23	16.78	21.48	21.48	21.48	21.48	21.48	21.48	21.48	21.48
60	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	1.98	0.89	2.07	3.63	8.83	17.39	20.85	20.85	20.85	20.85	20.85	20.85	20.85	20.85
61	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	1.96	0.91	2.12	3.74	9.51	17.73	20.44	20.44	20.44	20.44	20.44	20.44	20.44	20.44
62	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	1.94	0.93	2.17	3.88	10.27	18.01	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64
63	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	1.93	0.94	2.23	4.04	11.06	18.22	21.03	21.03	21.03	21.03	21.03	21.03	21.03	21.03
64	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	1.93	0.96	2.30	4.22	11.78	18.23	20.90	20.90	20.90	20.90	20.90	20.90	20.90	20.90
65	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06	1.93	0.97	2.38	4.41	12.46	18.02	20.41	20.41	20.41	20.41	20.41	20.41	20.41	20.41
66	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	1.91	0.99	2.46	4.61	13.13	17.55	19.78	19.78	19.78	19.78	19.78	19.78	19.78	19.78
67	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	1.84	1.01	2.53	4.82	13.81	17.76	20.04	20.04	20.04	20.04	20.04	20.04	20.04	20.04
68	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.79	1.04	2.59	5.06	14.55	17.99	20.04	20.04	20.04	20.04	20.04	20.04	20.04	20.04
69	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.75	1.08	2.65	5.31	15.34	18.30	19.66	19.66	19.66	19.66	19.66	19.66	19.66	19.66
70	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.73	1.13	2.69	5.59	16.19	18.91	19.60	19.60	19.60	19.60	19.60	19.60	19.60	19.60
71	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	1.71	1.17	2.75	5.90	17.10	22.16	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02
72	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	1.70	1.20	2.81	6.25	18.00	23.02	23.91	23.91	23.91	23.91	23.91	23.91	23.91	23.91
73	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	1.70	1.23	2.89	6.64	18.91	23.89	24.83	24.83	24.83	24.83	24.83	24.83	24.83	24.83
74	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	1.70	1.25	2.98	7.08	19.83	24.74	25.54	25.54	25.54	25.54	25.54	25.54	25.54	25.54
75	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.32	1.71	1.28	3.07	7.56	20.72	25.49	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88
76	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.32	1.72	1.31	3.16	8.07	21.54	26.11	26.33	26.33	26.33	26.33	26.33	26.33	26.33	26.33
77	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.28	1.72	1.35	3.24	8.63	22.23	26.64	26.79	26.79	26.79	26.79	26.79	26.79	26.79	26.79
78	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.24	1.73	1.39	3.31	9.32	22.77	26.74	26.86	26.86	26.86	26.86	26.86	26.86	26.86	26.86
79	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.24	1.73	1.44	3.38	11.88	23.15	26.68	26.77	26.77	26.77	26.77	26.77	26.77	26.77	26.77
80	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.27	1.73	1.50	3.46	12.54	23.40	26.43	26.51	26.51	26.51	26.51	26.51	26.51	26.51	26.51
81	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.33	1.74	1.56	4.04	13.14	23.51	26.24	26.31	26.31	26.31	26.31	26.31	26.31	26.31	26.31
82	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.42	1.74	1.63	4.19	13.72	23.55	26.14	26.20	26.20	26.20	26.20	26.20	26.20	26.20	26.20
83	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.51	1.75	1.70	4.37	14.28	23.59	26.07	26.14	26.14	26.14	26.14	26.14	26.14	26.14	26.14
84	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.56	1.75	1.77	4.58	14.80	23.66	25.92	26.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
85	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.57	1.75	1.84	4.81	15.29	24.33	25.64	25.75	25.75	25.75	25.75	25.75	25.75	25.75	25.75
86	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.55	1.75	1.89	5.04	15.78	23.90	25.32	25.44	25.44	25.44	25.44	25.44	25.44	25.44	25.44
87	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.52	1.76	1.92	5.25	15.86	22.84	24.36	24.50	24.50	24.50	24.50	24.50	24.50	24.50	24.50
88	2.39	2.39	2.39	2.39	2.39	2.39	2.39	2.49	1.76	1.94	5.43	16.44	22.85	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25
89	2.39	2.39	2.39	2.39	2.39	2.39	2.39	2.48	1.77	1.97	5.56	16.95	22.82	23.26	23.26	23.26	23.26	23.26	23.26	23.26	23.26	23.26
90	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.49	1.79	1.99	5.67	17.40	22.73	23.19	23.19	23.19	23.19	23.19	23.19	23.19	23.19	23.19
91	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.50	1.80	2.02	5.76	17.83	22.69	23.06	23.06	23.06	23.06	23.06	23.06	23.06	23.06	23.06
92	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.49	1.82	2.06	5.86	18.23	22.77	22.98	22.98	22.98	22.98	22.98	22.98	22.98	22.98	22.98
93	2.39	2.39	2.39	2.39	2.39	2.39	2.39	2.47	1.84	2.10	6.00	20.25	23.01	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02	23.02
94	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.44	1.87	2.15	6.18	20.30	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20	23.20
95	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.42	1.90	2.21	6.40	20.37	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47
96	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.42	1.93	2.28	6.63	20.51	23.66	23.66	23.66	23.66	23.66	23.66	23.66	23.66	23.66	23.66
97	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.45	1.96	2.35	6.87	20.74	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73	23.73
98	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.49	1.97	2.39	7.80	21.13	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80
99	2.39	2.39	2.39	2.39	2.39	2.39	2.39	2.54	1.99	2.41	8.01	19.11	21.53	21.53	21.53	21.53	21.53	21.53	21.53	21.53	21.53	21.53
100	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.54	2.00	2.40	10.19	19.37	21.71	21.71	21.71	21.71	21.71	21.71	21.71	21.71	21.71	21.71
101	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.52	2.02	2.39	10.36	19.66	21.89	21.89	21.89	21.89	21.89	21.89	21.89	21.89	21.89	21.89
102	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.50	2.04	2.42	10.52	19.92	21.98	21.98	21.98	21.98	21.98	21.98	21.98	21.98	21.98	21.98
103	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.47	2.05	2.51	10.76	20.15	21.95	21.95	21.95	21.95	21.95	21.95	21.95	21.95	21.95	21.95
104	2.42	2.42	2.42	2.42	2.42	2.42	2.43	2.44	2.07	2.69	11.07	20.33	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86
105	2.43	2.43	2.43	2.43	2.43	2.43	2.45	2.41	2.10	2.98	11.44	20.44	21.72	21.72	21.72	21.72	21.72	21.72	21.72	21.72	21.72	21.72
106	2.43	2.43	2.43	2.43	2.43	2.43	2.47	2.38	2.13	3.35	11.84	20.47	21.52	21.52	21.52	21.52	21.52	21.52	21.52	21.52	21.52	21.52
107	2.45	2.45	2.45	2.45	2.45	2.45	2.51	2.37	2.16	3.73	12.28	22.07	22.94	22.94	22.94	22.94	22.94	22.94	22.94	22.94	22.94	22.94
108	2.44	2.44	2.44	2.44	2.44	2.44	2.50	2.34	2.15	3.77	12.67	22.26	22.93	22.93	22.93	22.93	22.93	22.93	22.93	22.93	22.93	22.93
109	2.44	2.44	2.44	2.44	2.44	2.44	2.50	2.31	2.13	3.81	13.14	22.47	22.97	22.97	22.97	22.97	22.97	22.97	22.97	22.97	22.97	22.97
110	2.43	2.43	2.43	2.43	2.43	2.43	2.49	2.29	2.13	3.88	13.73	22.77	23.12	23.12	23.12	23.12	23.12	23.12	23.12	23.12	23.12	23.12

CO Modal Adjustment Factors

Speed (ft/sec)	Acceleration (ft/sec²)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.60	0.79	1.19	1.39	1.89	2.68	2.98	2.98	2.98	2.98	2.98
1	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.60	0.79	1.09	1.29	1.49	1.79	2.18	2.88	4.17	4.57	4.57
2	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.70	0.99	1.19	1.49	1.59	1.79	2.09	2.48	3.28	4.57	7.25
3	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.50	0.79	1.19	1.49	1.79	1.99	2.09	2.28	2.68	3.28	4.27	6.65
4	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.50	0.89	1.39	1.79	2.18	2.38	2.48	2.68	3.08	3.48	4.37	6.26
5	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.50	1.09	1.69	2.18	2.58	2.88	2.98	3.18	3.48	3.97	4.77	6.45
6	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.60	1.19	1.89	2.58	2.98	3.38	3.38	3.57	3.97	4.57	5.46	7.25
7	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.60	1.29	2.09	2.98	3.28	3.77	3.77	3.87	4.47	5.26	6.45	8.44
8	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.70	1.29	2.09	3.08	3.57	3.97	3.97	4.27	5.06	6.26	7.75	10.03
9	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.79	1.29	2.09	3.08	3.77	4.07	4.17	4.67	5.86	7.45	9.33	12.12
10	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.79	1.29	1.89	2.88	3.77	4.17	4.37	5.16	6.85	8.74	11.02	14.30
11	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.89	1.29	1.79	2.78	3.77	4.17	4.47	5.66	7.94	10.13	12.81	16.58
12	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.89	1.29	1.69	2.68	3.77	4.17	4.77	6.36	9.04	11.72	15.00	19.17
13	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.89	1.39	1.69	2.68	3.77	4.27	5.06	7.05	10.13	13.80	17.38	22.24
14	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.99	1.39	1.69	2.68	3.67	4.37	5.56	7.94	11.52	16.48	20.26	26.51
15	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.99	1.49	1.69	2.58	3.57	4.47	6.06	8.84	13.41	18.87	23.14	33.17
16	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.99	1.49	1.69	2.58	3.67	4.87	6.85	10.13	15.89	21.45	26.51	40.32
17	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	0.99	1.49	1.79	2.58	3.77	5.36	7.85	11.72	18.57	24.53	30.98	37.54
18	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	0.99	1.39	1.79	2.68	3.97	6.06	9.14	13.80	21.75	28.30	36.44	38.43
19	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.19	1.39	1.89	2.68	4.27	6.75	10.33	16.39	25.42	32.47	40.22	40.22
20	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.19	1.29	1.89	2.78	4.77	7.65	11.72	19.36	28.50	36.15	41.21	41.21
21	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	1.19	1.29	1.99	2.98	5.46	8.64	13.51	22.84	31.58	40.02	42.01	42.01
22	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	1.19	1.29	1.99	3.28	6.36	10.03	16.09	27.71	35.65	44.19	44.19	44.19
23	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	1.19	1.29	2.09	3.57	6.45	11.82	19.46	34.26	40.62	47.67	47.67	47.67
24	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	1.19	1.29	2.18	3.87	7.35	14.20	23.63	39.13	46.67	52.43	52.43	52.43
25	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.29	1.39	2.28	4.37	8.34	17.08	28.60	44.79	53.62	57.40	57.40	57.40
26	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.29	1.39	2.48	4.97	9.63	20.56	34.26	50.45	59.88	61.47	61.47	61.47
27	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.29	1.49	2.68	5.66	11.12	24.43	40.02	55.71	65.14	65.14	65.14	65.14
28	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.29	1.49	2.88	5.86	12.91	28.60	45.68	60.58	68.72	68.72	68.72	68.72
29	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.19	1.59	3.08	6.55	14.90	32.77	51.04	65.44	72.10	72.10	72.10	72.10
30	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.29	1.69	3.28	7.35	16.98	36.05	56.21	69.81	74.28	74.28	74.28	74.28
31	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.29	1.79	3.57	8.34	22.44	39.32	61.17	73.49	75.77	75.77	75.77	75.77
32	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.29	1.89	3.87	7.75	24.33	42.70	66.14	76.86	77.66	77.66	77.66	77.66
33	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.29	1.99	4.17	8.54	26.22	46.28	71.40	80.64	80.64	80.64	80.64	80.64
34	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.39	2.09	4.47	9.33	28.30	50.25	76.66	84.31	84.31	84.31	84.31	84.31
35	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.39	2.28	4.77	10.13	30.59	45.58	82.03	88.38	88.38	88.38	88.38	88.38
36	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.39	2.38	5.16	11.02	33.27	50.15	88.08	93.25	93.25	93.25	93.25	93.25
37	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.39	2.58	5.56	12.02	36.44	55.01	94.64	98.11	98.11	98.11	98.11	98.11
38	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.39	2.68	6.26	13.21	39.92	60.18	101.79	102.68	102.68	102.68	102.68	102.68
39	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.39	2.78	6.65	14.50	43.69	65.34	108.14	106.55	106.55	106.55	106.55	106.55
40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.39	2.98	5.26	15.99	48.16	70.71	112.41	110.13	110.13	110.13	110.13	110.13
41	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.49	3.08	5.66	17.87	52.73	76.46	115.89	114.10	114.10	114.10	114.10	114.10
42	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.49	3.18	6.16	26.42	57.60	82.92	119.07	118.47	118.47	118.47	118.47	118.47
43	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.49	3.38	6.75	27.61	63.95	91.26	124.03	123.54	123.54	123.54	123.54	123.54
44	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.49	3.48	7.45	29.29	72.39	102.09	132.97	130.29	130.29	130.29	130.29	130.29
45	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.39	3.77	8.24	27.81	83.81	115.59	143.59	138.93	138.93	138.93	138.93	138.93
46	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.39	3.97	9.33	30.98	95.73	129.39	150.94	150.94	150.94	150.94	150.94	150.94
47	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.39	4.27	9.24	34.56	103.48	139.32	153.13	153.13	153.13	153.13	153.13	153.13
48	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	1.39	4.47	10.23	38.53	108.74	143.40	148.96	148.96	148.96	148.96	148.96	148.96
49	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.49	4.87	11.32	42.60	112.91	143.10	140.62	140.62	140.62	140.62	140.62	140.62
50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.49	5.46	12.51	46.97	118.37	140.22	132.08	132.08	132.08	132.08	132.08	132.08
51	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.49	6.16	14.00	51.64	127.41	137.14	129.39	129.39	129.39	129.39	129.39	129.39
52	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	1.59	6.65	15.89	57.40	133.57	135.75	131.88	131.88	131.88	131.88	131.88	131.88
53	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	1.69	7.05	17.97	63.36	131.58	135.45	135.25	135.25	135.25	135.25	135.25	135.25
54	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	1.69	5.16	20.56	69.51	126.61	135.85	135.85	135.85	135.85	135.85	135.85	135.85
55	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.69	5.46	23.54	75.57	124.03	133.66	133.66	133.66	133.66	133.66	133.66	133.66

CO Modal Adjustment Factors

Speed (ft/sec)	Acceleration (ft/sec^2)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
56	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.79	5.86	26.91	81.43	124.63	132.47	132.47	132.47	132.47	132.47	132.47	132.47
57	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.79	6.16	30.69	87.79	127.01	131.98	131.98	131.98	131.98	131.98	131.98	131.98
58	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	1.89	6.55	27.11	94.44	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80
59	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	1.99	6.95	30.78	100.30	123.44	123.44	123.44	123.44	123.44	123.44	123.44	123.44
60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	2.09	7.45	34.96	105.16	116.19	116.19	116.19	116.19	116.19	116.19	116.19	116.19
61	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	2.18	8.04	39.52	107.25	111.62	111.62	111.62	111.62	111.62	111.62	111.62	111.62
62	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	2.38	8.64	44.39	108.54	114.10	114.10	114.10	114.10	114.10	114.10	114.10	114.10
63	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	2.48	9.43	49.35	109.24	118.37	118.37	118.37	118.37	118.37	118.37	118.37	118.37
64	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	2.68	10.33	54.22	109.14	116.48	116.48	116.48	116.48	116.48	116.48	116.48	116.48
65	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	2.88	11.22	58.79	107.94	112.61	112.61	112.61	112.61	112.61	112.61	112.61	112.61
66	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	3.08	12.31	63.06	108.94	112.71	112.71	112.71	112.71	112.71	112.71	112.71	112.71
67	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.79	3.28	13.41	67.23	108.34	111.52	111.52	111.52	111.52	111.52	111.52	111.52	111.52
68	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.79	3.48	14.70	71.30	107.85	109.73	109.73	109.73	109.73	109.73	109.73	109.73	109.73
69	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.79	3.67	16.19	75.67	108.24	107.75	107.75	107.75	107.75	107.75	107.75	107.75	107.75
70	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.89	3.87	17.87	80.64	109.53	107.25	107.25	107.25	107.25	107.25	107.25	107.25	107.25
71	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.89	4.07	19.66	86.10	114.00	112.81	112.81	112.81	112.81	112.81	112.81	112.81	112.81
72	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.99	4.27	21.65	92.06	116.39	115.69	115.69	115.69	115.69	115.69	115.69	115.69	115.69
73	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.99	4.47	23.83	98.71	120.26	120.36	120.36	120.36	120.36	120.36	120.36	120.36	120.36
74	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	0.99	4.77	26.22	106.06	126.12	126.42	126.42	126.42	126.42	126.42	126.42	126.42	126.42
75	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.60	1.09	5.06	28.90	113.21	132.57	132.17	132.17	132.17	132.17	132.17	132.17	132.17	132.17
76	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.09	5.36	31.68	119.86	138.13	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34
77	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.70	1.09	5.66	34.76	125.22	141.71	141.01	141.01	141.01	141.01	141.01	141.01	141.01	141.01
78	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.79	1.09	5.86	38.53	129.49	143.00	142.30	142.30	142.30	142.30	142.30	142.30	142.30	142.30
79	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.79	1.19	6.16	46.28	132.57	142.30	141.71	141.71	141.71	141.71	141.71	141.71	141.71	141.71
80	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.50	0.79	1.19	6.45	50.35	134.46	140.71	140.22	140.22	140.22	140.22	140.22	140.22	140.22	140.22
81	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.89	1.29	9.53	54.62	135.35	139.62	139.03	139.03	139.03	139.03	139.03	139.03	139.03	139.03
82	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.89	1.29	10.13	59.19	135.55	138.73	138.03	138.03	138.03	138.03	138.03	138.03	138.03	138.03
83	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.89	1.39	10.82	63.85	135.35	137.93	137.14	137.14	137.14	137.14	137.14	137.14	137.14	137.14
84	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.99	1.49	11.72	68.72	134.66	136.64	135.95	135.95	135.95	135.95	135.95	135.95	135.95	135.95
85	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.99	1.49	12.71	73.49	135.65	134.66	134.06	134.06	134.06	134.06	134.06	134.06	134.06	134.06
86	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.99	1.49	13.70	78.25	133.47	132.77	132.17	132.17	132.17	132.17	132.17	132.17	132.17	132.17
87	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.09	1.49	14.70	83.22	130.49	130.39	129.89	129.89	129.89	129.89	129.89	129.89	129.89	129.89
88	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.09	1.49	15.59	87.88	129.00	134.36	134.36	134.36	134.36	134.36	134.36	134.36	134.36	134.36
89	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.09	1.59	16.39	91.96	128.90	135.05	135.05	135.05	135.05	135.05	135.05	135.05	135.05	135.05
90	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.19	1.59	17.18	95.33	129.10	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35
91	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.19	1.69	17.97	98.21	129.79	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76
92	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.29	1.69	18.87	100.70	130.88	133.76	133.76	133.76	133.76	133.76	133.76	133.76	133.76	133.76
93	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.39	1.79	19.66	122.54	132.87	132.97	132.97	132.97	132.97	132.97	132.97	132.97	132.97	132.97
94	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.39	1.89	20.75	121.25	133.27	133.27	133.27	133.27	133.27	133.27	133.27	133.27	133.27	133.27
95	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.40	1.49	1.99	21.75	121.15	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76
96	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.49	2.18	22.64	122.44	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35
97	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.59	2.28	23.54	125.12	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76	134.76
98	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.59	2.48	36.25	129.69	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35	135.35
99	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.30	1.69	2.68	37.04	103.87	105.26	105.26	105.26	105.26	105.26	105.26	105.26	105.26	105.26	105.26
100	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.79	2.78	48.46	107.25	108.44	108.44	108.44	108.44	108.44	108.44	108.44	108.44	108.44	108.44
101	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.99	2.98	48.96	111.12	112.21	112.21	112.21	112.21	112.21	112.21	112.21	112.21	112.21	112.21
102	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.50	2.18	3.18	49.45	115.09	115.89	115.89	115.89	115.89	115.89	115.89	115.89	115.89	115.89	115.89
103	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.60	2.28	3.48	50.84	118.67	118.97	118.97	118.97	118.97	118.97	118.97	118.97	118.97	118.97	118.97
104	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.70	2.58	3.87	52.63	121.75	121.55	121.55	121.55	121.55	121.55	121.55	121.55	121.55	121.55	121.55
105	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.79	2.88	4.57	55.01	124.23	123.44	123.44	123.44	123.44	123.44	123.44	123.44	123.44	123.44	123.44
106	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.89	3.18	5.46	57.60	126.02	124.93	124.93	124.93	124.93	124.93	124.93	124.93	124.93	124.93	124.93
107	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.09	3.57	6.65	60.38	123.24	122.24	122.24	122.24	122.24	122.24	122.24	122.24	122.24	122.24	122.24
108	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.19	3.57	6.75	62.46	125.32	124.33	124.33	124.33	124.33	124.33	124.33	124.33	124.33	124.33	124.33
109	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.39	3.48	6.85	64.75	127.21	126.51	126.51	126.51	126.51	126.51	126.51	126.51	126.51	126.51	126.51
110	0.40	0.40	0.40	0.40	0.40	0.40	0.40	1.59	3.48	6.95	67.43	129.49	129.00	129.00	129.00	129.00	129.00	129.00	129.00	129.00	129.00	129.00

NOx Modal Adjustment Factors

Speed (ft/sec)	Acceleration (ft/sec²)																					
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.14	0.24	0.59	0.98	1.31	2.70	4.16	6.42	6.94	7.29	7.29	7.29
1	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.14	0.24	0.54	0.90	1.22	2.14	3.13	4.65	5.14	5.84	6.71	6.71
2	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.28	0.57	0.91	1.24	1.92	2.56	3.57	4.14	4.79	5.69	7.43
3	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.33	0.64	0.94	1.25	1.84	2.32	3.06	3.66	4.26	5.02	6.51
4	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.14	0.39	0.73	1.04	1.33	1.87	2.35	2.98	3.60	4.17	4.86	6.17
5	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.16	0.44	0.83	1.23	1.50	2.01	2.56	3.17	3.83	4.43	5.16	6.43
6	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.18	0.51	0.95	1.51	1.74	2.23	2.90	3.57	4.27	4.94	5.78	7.05
7	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.21	0.61	1.08	1.77	2.01	2.47	3.28	4.07	4.81	5.56	6.50	7.78
8	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.25	0.75	1.21	1.90	2.22	2.65	3.66	4.64	5.42	6.23	7.21	8.43
9	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.31	0.92	1.34	1.96	2.39	2.83	4.07	5.25	6.08	6.95	8.01	9.08
10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.38	1.07	1.49	2.04	2.59	3.11	4.56	5.90	6.83	7.77	8.86	9.71
11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.47	1.18	1.63	2.20	2.86	3.57	5.19	6.60	7.69	8.71	9.72	10.09
12	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.55	1.24	1.75	2.43	3.18	4.20	5.95	7.37	8.63	9.73	10.64	10.73
13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.64	1.28	1.86	2.71	3.56	4.93	6.79	8.21	9.55	10.78	11.32	11.42
14	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.67	1.42	2.00	2.99	4.01	5.70	7.61	9.09	10.47	11.80	11.93	12.05
15	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.69	1.24	2.19	3.29	4.51	6.47	8.42	9.90	11.30	12.30	12.36	12.56
16	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.13	0.72	1.33	2.19	3.63	5.06	7.25	9.25	10.66	11.98	12.52	12.60	12.87
17	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.14	0.77	1.41	2.38	4.08	5.68	8.08	10.07	11.37	12.44	12.73	12.85	12.99
18	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.15	0.79	1.47	2.61	4.61	6.36	8.96	10.88	12.01	12.82	13.04	13.20	13.25
19	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.16	0.78	1.58	2.87	5.00	7.12	9.85	11.56	12.55	13.23	13.38	13.54	13.54
20	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.18	0.56	1.74	3.18	5.56	7.93	10.70	12.17	12.99	13.49	13.63	13.75	13.75
21	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.71	1.97	3.51	6.08	8.79	11.49	12.73	13.36	13.68	13.86	13.91	13.91
22	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.21	0.72	2.18	3.65	6.56	9.68	12.26	13.24	13.78	13.96	14.17	14.17	14.17
23	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.76	2.28	3.99	7.01	9.80	12.99	13.71	14.23	14.34	14.53	14.53	14.53
24	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.26	0.80	2.32	4.33	7.45	10.63	13.64	14.09	14.57	14.72	14.89	14.89	14.89
25	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.28	0.83	1.67	4.72	7.94	11.43	14.19	14.50	14.88	15.07	15.21	15.21	15.21
26	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.30	0.85	1.81	5.15	8.53	12.13	14.61	14.86	15.17	15.40	15.47	15.47	15.47
27	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.32	0.89	2.00	5.63	9.20	12.72	14.95	15.20	15.45	15.73	15.73	15.73	15.73
28	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.34	0.93	2.23	6.16	9.96	13.20	15.18	15.48	15.72	15.99	15.99	15.99	15.99
29	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.35	0.97	2.50	6.71	10.57	13.58	15.32	15.67	15.94	16.19	16.19	16.19	16.19
30	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.37	1.01	2.78	7.24	11.09	13.88	15.38	15.71	16.00	16.22	16.22	16.22	16.22
31	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.38	1.06	3.04	7.83	11.55	14.86	15.27	15.59	15.91	16.06	16.06	16.06	16.06
32	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.39	1.11	3.29	8.49	11.64	15.07	15.15	15.43	15.79	15.86	15.86	15.86	15.86
33	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.40	1.16	3.04	9.09	12.11	15.16	15.14	15.38	15.77	15.77	15.77	15.77	15.77
34	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.41	1.22	3.26	9.64	12.58	15.34	15.29	15.48	15.83	15.83	15.83	15.83	15.83
35	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.33	1.31	3.49	10.18	13.02	15.60	15.50	15.65	15.97	15.97	15.97	15.97	15.97
36	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.34	1.37	3.73	10.76	13.44	15.94	15.75	15.85	16.14	16.14	16.14	16.14	16.14
37	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.34	1.43	3.98	11.34	13.84	16.39	16.08	16.15	16.38	16.38	16.38	16.38	16.38
38	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.35	1.48	4.23	11.95	14.24	16.90	16.51	16.55	16.73	16.73	16.73	16.73	16.73
39	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.35	1.52	4.51	11.84	14.66	17.43	17.05	17.10	17.21	17.21	17.21	17.21	17.21
40	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.37	1.57	4.83	10.37	15.10	17.97	17.65	17.78	17.82	17.82	17.82	17.82	17.82
41	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.28	1.64	5.18	10.75	15.55	18.48	18.24	18.47	18.51	18.51	18.51	18.51	18.51
42	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.30	1.75	5.56	11.15	17.00	18.93	18.75	19.11	19.23	19.23	19.23	19.23	19.23
43	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.33	2.03	6.17	11.53	17.55	19.31	19.12	19.66	19.94	19.94	19.94	19.94	19.94
44	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.37	2.36	6.55	11.91	18.06	19.58	19.39	20.12	20.60	20.60	20.60	20.60	20.60
45	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.42	1.76	7.01	12.28	17.33	19.67	19.51	20.43	21.07	21.07	21.07	21.07	21.07
46	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.47	1.92	7.47	12.63	17.70	19.56	19.43	19.47	19.47	19.47	19.47	19.47	19.47
47	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.52	1.92	7.96	12.86	18.08	19.39	19.25	19.34	19.34	19.34	19.34	19.34	19.34
48	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.56	2.05	8.45	13.17	18.42	19.31	19.19	19.31	19.31	19.31	19.31	19.31	19.31
49	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.60	2.54	8.95	13.44	18.69	19.47	19.39	19.54	19.54	19.54	19.54	19.54	19.54
50	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.70	2.79	9.48	13.67	18.85	19.74	19.73	19.83	19.83	19.83	19.83	19.83	19.83
51	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.71	2.60	9.98	13.90	18.92	18.51	18.62	18.61	18.61	18.61	18.61	18.61	18.61
52	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.71	2.81	10.31	14.13	18.55	18.31	18.43	18.43	18.43	18.43	18.43	18.43	18.43
53	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.71	2.89	10.55	14.36	18.73	18.44	18.59	18.59	18.59	18.59	18.59	18.59	18.59
54	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.72	3.15	9.92	14.59	18.88	18.56	18.73	18.73	18.73	18.73	18.73	18.73	18.73
55	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.72	3.42	10.21	14.83	19.02	18.70	18.87	18.87	18.87	18.87	18.87	18.87	18.87

NOx Modal Adjustment Factors

Speed (ft/sec)	Acceleration (ft/sec²)																				
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12
56	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.73	3.68	10.51	15.08	19.14	18.87	19.02	19.02	19.02	19.02	19.02	19.02	19.02
57	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.73	3.91	10.81	15.36	19.34	19.12	19.21	19.21	19.21	19.21	19.21	19.21	19.21
58	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.74	4.14	11.12	15.58	19.63	19.88	19.88	19.88	19.88	19.88	19.88	19.88	19.88
59	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.76	4.39	11.45	15.82	19.97	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11
60	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.78	4.66	11.78	16.10	20.34	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42
61	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.18	0.80	4.96	12.12	16.41	20.66	20.81	20.81	20.81	20.81	20.81	20.81	20.81	20.81
62	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.17	0.83	5.30	12.47	16.73	20.99	21.23	21.23	21.23	21.23	21.23	21.23	21.23	21.23
63	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.17	0.87	5.67	12.83	17.07	21.37	21.69	21.69	21.69	21.69	21.69	21.69	21.69	21.69
64	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.17	0.90	6.03	13.19	17.40	21.76	22.25	22.25	22.25	22.25	22.25	22.25	22.25	22.25
65	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.17	0.94	6.36	13.56	17.73	22.14	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86
66	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.17	0.98	6.65	13.93	18.03	23.42	24.07	24.07	24.07	24.07	24.07	24.07	24.07	24.07
67	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.17	1.04	6.91	14.28	18.32	24.16	24.59	24.59	24.59	24.59	24.59	24.59	24.59	24.59
68	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.17	1.10	7.13	14.62	18.60	24.73	24.94	24.94	24.94	24.94	24.94	24.94	24.94	24.94
69	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.17	1.18	7.34	14.95	18.84	25.07	25.19	25.19	25.19	25.19	25.19	25.19	25.19	25.19
70	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.17	1.25	7.56	15.27	19.07	19.45	25.44	25.44	25.44	25.44	25.44	25.44	25.44	25.44
71	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.18	1.32	7.80	15.59	19.29	19.69	19.83	19.83	19.83	19.83	19.83	19.83	19.83	19.83
72	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.18	1.38	8.09	15.90	19.52	20.00	20.17	20.17	20.17	20.17	20.17	20.17	20.17	20.17
73	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.19	1.42	8.42	16.21	19.75	20.33	20.56	20.56	20.56	20.56	20.56	20.56	20.56	20.56
74	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.19	1.46	8.77	16.51	19.90	20.59	20.83	20.83	20.83	20.83	20.83	20.83	20.83	20.83
75	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.19	1.51	9.14	16.79	19.99	20.78	20.92	20.92	20.92	20.92	20.92	20.92	20.92	20.92
76	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.20	1.57	9.51	17.02	19.96	20.72	20.78	20.78	20.78	20.78	20.78	20.78	20.78	20.78
77	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.20	1.66	9.88	17.20	19.83	20.56	20.61	20.61	20.61	20.61	20.61	20.61	20.61	20.61
78	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	1.79	10.24	17.30	19.62	20.46	20.50	20.50	20.50	20.50	20.50	20.50	20.50	20.50
79	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.22	1.97	10.60	18.57	19.40	20.33	20.36	20.36	20.36	20.36	20.36	20.36	20.36	20.36
80	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.22	2.18	10.96	18.52	19.24	20.26	20.28	20.28	20.28	20.28	20.28	20.28	20.28	20.28
81	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.24	2.44	12.56	18.50	19.17	20.28	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
82	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.25	2.73	12.89	18.50	19.16	20.33	20.36	20.36	20.36	20.36	20.36	20.36	20.36	20.36
83	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.26	3.05	13.23	18.52	19.15	20.38	20.42	20.42	20.42	20.42	20.42	20.42	20.42	20.42
84	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.28	3.38	13.58	18.55	19.10	20.41	20.45	20.45	20.45	20.45	20.45	20.45	20.45	20.45
85	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.30	3.73	13.91	18.57	20.16	20.44	20.48	20.48	20.48	20.48	20.48	20.48	20.48	20.48
86	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.33	4.08	14.19	18.58	20.18	20.49	20.53	20.53	20.53	20.53	20.53	20.53	20.53	20.53
87	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.35	4.45	14.41	17.42	19.17	19.53	19.57	19.57	19.57	19.57	19.57	19.57	19.57	19.57
88	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.38	4.84	14.59	17.57	17.90	17.90	17.90	17.90	17.90	17.90	17.90	17.90	17.90	17.90
89	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.42	5.23	14.68	17.74	17.97	17.99	17.99	17.99	17.99	17.99	17.99	17.99	17.99	17.99
90	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.45	5.63	14.71	17.91	18.05	18.08	18.08	18.08	18.08	18.08	18.08	18.08	18.08	18.08
91	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.49	6.01	14.69	18.06	18.13	18.16	18.16	18.16	18.16	18.16	18.16	18.16	18.16	18.16
92	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.54	6.36	14.69	18.21	18.22	18.23	18.23	18.23	18.23	18.23	18.23	18.23	18.23	18.23
93	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.58	6.67	14.74	17.99	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31
94	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.63	6.97	14.81	18.09	18.40	18.40	18.40	18.40	18.40	18.40	18.40	18.40	18.40	18.40
95	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.68	7.28	14.85	18.25	18.51	18.51	18.51	18.51	18.51	18.51	18.51	18.51	18.51	18.51
96	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.08	0.73	7.62	14.88	18.46	18.65	18.65	18.65	18.65	18.65	18.65	18.65	18.65	18.65	18.65
97	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.80	7.99	14.88	18.72	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81
98	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.09	0.88	8.39	14.98	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05
99	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.09	0.96	8.81	15.04	19.95	20.14	20.14	20.14	20.14	20.14	20.14	20.14	20.14	20.14	20.14
100	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.09	1.06	9.25	16.24	20.34	20.44	20.44	20.44	20.44	20.44	20.44	20.44	20.44	20.44	20.44
101	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.09	1.16	9.71	16.42	20.76	20.82	20.82	20.82	20.82	20.82	20.82	20.82	20.82	20.82	20.82
102	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10	1.27	10.18	16.64	21.21	21.29	21.29	21.29	21.29	21.29	21.29	21.29	21.29	21.29	21.29
103	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.11	1.40	10.65	16.96	21.70	21.85	21.85	21.85	21.85	21.85	21.85	21.85	21.85	21.85	21.85
104	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.12	1.53	11.11	17.31	22.27	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46	22.46
105	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.12	1.67	11.54	17.71	22.88	23.07	23.07	23.07	23.07	23.07	23.07	23.07	23.07	23.07	23.07
106	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.13	1.82	11.95	18.14	23.49	23.67	23.67	23.67	23.67	23.67	23.67	23.67	23.67	23.67	23.67
107	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.14	1.99	12.33	18.57	18.25	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47
108	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.14	2.11	12.54	18.85	18.44	18.62	18.62	18.62	18.62	18.62	18.62	18.62	18.62	18.62	18.62
109	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.15	2.25	12.70	19.07	18.66	18.80	18.80	18.80	18.80	18.80	18.80	18.80	18.80	18.80	18.80
110	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.16	2.45	12.87	19.11	18.88	18.97	18.97	18.97	18.97	18.97	18.97	18.97	18.97	18.97	18.97

VITA

Aladdin Barkawi was born in Amman, Jordan in October of 1962. After a brief period in Amman, his family moved to Kuwait, where he attended grammar, middle, and high schools. In 1984, he graduated from The University of South Alabama with a Bachelor's degree in Civil Engineering. Following his college degree, he worked for several international consulting firms. During this period, Aladdin worked in several major projects such as: Mini-Abdulla refinery project (Kuwait), I-66 widening project, and Dulles Toll Road project. While maintaining a full time job, Mr. Barkawi enrolled in the Civil Engineering Masters program at the University of Maryland as a part-time student. In 1989, he joined the Federal Highway Administration (FHWA), Eastern Federal Land Highway Division, as a Highway Engineer for their Design Division. He was responsible for the design of several highway projects through varied types of terrain, from preliminary line and grade stage through the completion of plans, special provisions and estimates. In 1990, Mr. Barkawi graduated from The University of Maryland with a M.S. in Civil Engineering. In 1994, Mr. Barkawi was selected for the FHWA Academic Study Program to pursue his Ph.D. at The University of Tennessee, Knoxville.

Presently, Mr. Barkawi is a highway research engineer with FHWA's Intelligent Systems and Technology (IST) Research Division in McLean, Virginia. He is working in the Advanced Traffic Management Systems (ATMS) team with several responsibilities in the Intelligent Transportation System (ITS) program.

Aladdin reside with his wife, Rosana and his two children, Lina and Omar, in Ashburn, Virginia.