Southwest Region University Transportation Center

# WORKZONE MOBILE SOURCE EMISSION PREDICTION

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RESEARCH REPORT SWUTC/92/60021-3

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CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

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The University of Texas at Austin

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# EXECUTIVE SUMMARY

Many of the nation's heavily traveled urban freeways are in the process of reconstruction or rehabilitation. These construction activities, requiring traffic to be funneled through roadway workzones, often impact the surrounding environment through their generation of excess vehicle emissions. This report describes an excess emissions prediction method, one that makes it possible for planners to compare different workzone traffic management strategies based on the predicted values.

The prediction method used relies on a newly developed computer model based on the original QUEWZ developed by C. L. Dudek and J. L. Memmott in 1984. Our revised version—dubbed QUEWZEE (because it adds *E*nergy and *E*missions)—is capable of predicting mobile source emissions at freeway workzones, given the characteristics of the workzone (such as configuration, schedules), the characteristics of traffic at the workzone (such as volume, percent trucks), and the emissions characteristics of vehicles in the area. The model gives the excess emission values for two vehicle types and three pollutant types.

The model can be used to compare the environmental impacts of various construction and traffic management strategies for the workzone. In addition, the results obtained from the model can be used to expedite construction, which in turn can help reduce air pollution. The magnitude of the emissions problem at workzones is illustrated using workzones at deficient-bridge reconstruction sites in the United States.

As to its limitations, we should point out that the model as structured cannot take into account the diversion of traffic (away from the workzone) that results when drivers seek to avoid long queues (i.e., traffic that diverts to frontage roads or to other parallel routes). For this reason, the traffic volume passing through a workzone must be considered less than typical. Further research is needed to quantify the nature of this traffic diversion.

The lack of accurate, validated models that characterize modal emissions from vehicles was underscored throughout this study. But as new data and modal emission rate models become available, the QUEWZEE model can be easily updated to incorporate the new findings.

# ABSTRACT

Traffic congestion that results from freeway reconstruction and rehabilitation work often leads to an increase in vehicle emissions within the construction workzone. In this report, the authors develop a methodology for calculating these excess emissions by modifying an established workzone user cost study. This methodology, presented in the form of a computer model, takes into account workzone configuration and traffic characteristics. Using the model, planners can compare different workzone strategies to identify the one that most effectively reduces vehicle emissions.

# ACKNOWLEDGMENTS

Support for this research project was provided by a grant from the Office of the Governor of the State of Texas, Energy Office, to the Southwest Region University Transportation Center.

We would like to cite the earlier research efforts of C. L. Dudek and J. L. Memmott, who first developed the basic QUEWZ model in 1984. Their contribution to the modeling of user costs through workzones in general forms the basis for this study.

We would also like to thank Hernán de Solminihac, who provided insight and assistance to the study while working on his doctoral dissertation (in which he modified QUEWZ to report energy consumption as an element of total vehicle operating costs).

Finally, we would like to thank Randy Machemehl, who carefully reviewed earlier drafts, helped with the methodology, and who assisted in clarifying issues related to traffic modeling.

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# CHAPTER 1. INTRODUCTION

## BACKGROUND

Air pollution, commonly referred to as "smog," is the contamination of the ambient air by chemical compounds or particulate solids in a concentration that adversely affects living organisms (Ref 1). The main air pollutants include:

- carbon monoxides (CO) — a product of the incomplete burning of fuel;
- hydrocarbons (HC) — from incompletely burned or evaporated gasoline or solvents;
- nitrogen oxides (NOx) — products of high-compression internal combustion engines;
- sulfur oxides — products of the burning of sulfur-rich fossil fuel; and
- soot-like particulates (mostly carbon particles).

These pollutant species are emitted by a variety of sources, including automobiles, industrial processes, power plants, solid waste disposal practices, and other stationary fuel combustion. As shown in Table 1.1, mobile sources, more specifically highway vehicles, generate more pollution than any other source. The problem is particularly severe on the west coast, where, for example, more than half of the air borne pollutants measured in the south coast basin of California is generated from the region's estimated 8 million automobiles (Ref 2).

Transportation planners estimate that, because the mobility needs of the U.S. population will continue to outgrow transportation system capabilities, traffic congestion will represent a perennial problem well into the next century. To again cite the California situation, average highway speeds there are expected to fall from 35 mph to 19 mph or less (assuming no changes in driver behavior or transportation policy) — a consequence of the 5 million new residents expected in that state by 2010 (Ref 4). And with this drop in average speed will come more congestion and higher pollution levels. (Interestingly, if the current level of daily vehicle miles traveled in the California region operated under consistent and free flowing speeds, mobile source emissions could be reduced by approximately 13 percent [Ref 5].)

As has been frequently noted, traffic congestion, along with its concomitant pollution, can have severe negative impacts on society: Traffic congestion can lead to substantial time losses and can limit worker productivity, while pollution can impair health and can increase environmental clean-up costs. These externalities (in economic terms) should be taken into account by policy makers and transportation planners whenever transportation system improvements are considered.

But in pursuing the ideal transportation system, planners have long recognized that trade offs are inevitable. Moreover, the complexity of the problem is such as requires the efforts of different agencies: While transportation officials look for ways to meet the mobility needs of a region's growing population, air quality officials search for ways to reduce auto emissions.

**TABLE 1.1. SOURCE AND PROPORTION OF U.S. AIR POLLUTANTS (1982)**

| Source | Pollutant (% of total) | | | | |
|---|---|---|---|---|---|
| | CO | HC | NOx | SO | Particulates |
| Mobile Sources: | 72.5 | 33.3 | 47.8 | 4.1 | 18.0 |
| Highway vehicles | 63.0 | 26.7 | 38.7 | 2.2 | 14.0 |
| Gasoline | | | | | |
| Cars | 38.1 | 16.7 | 16.6 | 0.7 | 7.1 |
| Light trucks | 11.2 | 5.6 | 5.7 | 0.2 | 2.1 |
| Heavy trucks | 12.4 | 2.8 | 2.9 | 0.1 | 0.9 |
| Motorcycles | 0.3 | 0.4 | * | 0.0 | 0.1 |
| Diesel | | | | | |
| Cars | * | * | 0.1 | * | 0.3 |
| Light trucks | * | * | * | * | 0.1 |
| Heavy trucks | 0.9 | 1.2 | 13.3 | 1.2 | 4.2 |
| Other transportation modes | 9.5 | 6.6 | 9.1 | 1.8 | 3.3 |
| Industrial Processes | 6.5 | 39.2 | 3.0 | 14.5 | 31.7 |
| Power Plants | 0.4 | 0.0 | 30.8 | 66.9 | 13.2 |
| Other Fuel Combustion | 8.5 | 11.0 | 16.9 | 14.5 | 18.5 |
| Solid Waste Disposal | 2.9 | 3.3 | 0.5 | 0.0 | 5.3 |
| Miscellaneous | 9.2 | 13.2 | 1.0 | 0.0 | 13.2 |

*Less than 0.05%
Source: Ref 3

In the face of this challenge, several wide-ranging policies are being considered by state agencies for improving air quality, mobility, or both. Although examples of such policies are briefly described here, a more detailed description can be found in the report by Cameron (Ref 5). These policies include:

- one-day restrictions whereby every private passenger vehicle will be prohibited from use one day of each work week;
- use of clean fuels and low-emission vehicles;
- use of transportation supply management techniques (e.g., widening of freeways without reconstruction and implementing freeway incident management programs);

- use of transportation demand management techniques (e.g., ridesharing, public transit use, HOV lanes, park-and-ride facilities, and parking management);
- freeway and highway capacity expansions; and
- electrification of buses and transit expansion.

This report specifically focuses on a single policy alternative: freeway and highway capacity expansion. With many of the nation's major metropolitan areas reconstructing their heavily traveled urban freeways, highway planners are finding that such improvements have substantial direct *and* indirect costs. Apart from project costs, the indirect costs borne by the adjacent communities and the environment are likely to be great, with the high traffic volumes involved leading to increased congestion, delay, and to dangerous levels of mobile source pollution in the vicinity of the work zones.

As a way of solving the complex problem of managing such projects, and to help in the evaluation of alternative construction, work zone scheduling, traffic management, and public relations strategies, a systems approach has been suggested (Ref 6). Within such an approach, the ability to predict mobile source emissions resulting from the presence of a work zone on a freeway would be a useful tool in an assessment of alternative strategies, particularly in relation to their impact on the environment. The results derived from such a model can also be used in the environmental impact statements required of state agencies to support the choice of specific strategies proposed for a given project.

## STUDY OBJECTIVES

The objectives of this study included the following:

(1) review and evaluate current techniques and models used for the prediction of mobile source emissions;

(2) develop a methodology for the quantification of mobile source emissions at work zones based on the above review;

(3) validate the methodology and implement it as a computer model; and

(4) illustrate the applications of the computer model to work zone problems.

## STUDY SCOPE

The organization of this report follows closely the order in which each of the objectives were achieved. Chapter 2 contains a review of some methodologies and models currently used for the estimation of mobile source emissions, while Chapter 3 discusses the methodology proposed for the prediction of work zone mobile source emissions. Chapter 4 describes the QUEWZ model (Ref 7) and its usefulness in the implementation of the methodology.

Chapter 5 presents the emission rate models that are to be used with the methodology. The computer model, along with sample results, is presented in Chapter 6. The application of the model in typical work zone problems is also illustrated.

Finally, Chapter 7 summarizes the results, provides some general conclusions, and makes recommendations for future research.

# CHAPTER 2. LITERATURE REVIEW

This chapter reviews some of the methodologies and models currently used to predict mobile source emissions. The magnitude and complexity of the emission prediction problem is discussed first, followed by a description of the steps involved in the pollution modeling process. Further sections discuss (1) the testing procedures used to collect emissions data, (2) emission models developed by the Environmental Protection Agency (EPA) using the data, and (3) other models developed for specific applications. A thorough understanding of these methodologies and models will be helpful in modeling the emissions at a workzone, which is the subject of subsequent chapters.

## BACKGROUND

A significant portion of the emissions in urban areas is generated by the automobile. These emissions can vary according to the type of engine, the mode of operation, the fuel composition, presence and working condition of emission control devices, atmospheric conditions, and engine tuning. As shown in Table 2.1, the effect of these variables differs from one pollutant to the other. These differences are summarized below (Ref 1):

(1) Carbon Monoxide: As the air/fuel ratio increases (i.e., as the mix goes from "rich" to "lean"), the concentration of CO decreases rapidly (leaner mixes provide more complete combustion of the fuel). This implies that while idling and decelerating, the CO concentration is very high. It decreases during acceleration and high-speed cruising. Diesel engine CO emissions are very low for all modes of operation.

(2) Hydrocarbons: HC emission is high for idling and deceleration, as opposed to cruising and acceleration. Cruising at high speeds results in a further reduction in HC emissions.

(3) Nitrogen Oxides: $NO_X$ emissions are the major contributors to photochemical smog ("Los Angeles type smog"). $NO_X$ absorbs ultraviolet portions of the solar spectrum, an action that generates high oxidant concentrations. High levels of $NO_X$ are produced during vehicle acceleration and high-speed cruising; lower concentrations exist during deceleration and idling, suggesting that these emissions are dependent on the temperature of combustion.

(4) Particulates: Particulate emissions are comprised mainly of carbon particles, lead compounds, and motor oil. Particulate emission levels are significantly higher in diesel engines than in gasoline engines.

Emissions data required to model the above variations were collected from emissions testing programs applied to individual vehicles. The models, however, were designed to predict emissions from an aggregate fleet containing vehicles of various types, ages, and operating characteristics, and which operate under conditions that differ significantly from those of the test conditions. The manner in which such complexity has been dealt with in different models is discussed below.

**TABLE 2.1. EMISSION CHARACTERISTICS WITH RESPECT TO OPERATING MODE AND ENGINE CHARACTERISTICS**

| Operating Mode or Engine Characteristics | Emission Concentration | | |
|---|---|---|---|
| | CO | HC | $NO_x$ |
| Idle | High | High | Very low |
| Acceleration | | | |
| Moderate | Low | Low | High |
| Heavy | Moderate | High | Moderate |
| Deceleration | Very high | High | Very low |
| Cruise | | | |
| Low Speed | Low | Low | Low |
| High Speed | Very Low | Very Low | Moderate |
| Effect of cold engine (warmup period) | Higher | Higher | Lower |
| Effect of higher compression ratio | Somewhat higher | Higher | Higher |
| Effect of advancing spark ignition | Higher for rich mixtures only | Somewhat higher | Higher, especially for lean mixtures |
| Effect of exhaust gas recirculation | No effect | Higher | Considerably lower |

Source: Ref 8

## MOBILE SOURCE POLLUTION MODELING

The modeling of mobile source pollution near a roadway consists of four main steps. The first step in the process involves the characterization of the traffic at the location where emissions are to be evaluated. Here we learn that the behavior of traffic varies according to the location being modeled. For example, if emissions from free flowing traffic on a highway are required, the key variable will be vehicle speeds and flow. To determine the source strength, one can use these speeds with an emission model that predicts the emissions of vehicles cruising at a given speed. On the other hand, if it is necessary to compute emissions at an intersection, then information may be required on traffic signal phasing, queue lengths, delay times, acceleration and deceleration rates, and capacity. (The traffic model required for the problem of workzone emission prediction will be the subject of the next chapter.)

The second step is the estimation of the source strength. This process is extremely difficult for mobile sources (as opposed to stationary sources) for the reasons stated in the previous section. It involves the use of an emissions model that accounts for vehicle conditions and driving patterns existing in the zone of interest. Most emission rate analysis models (both freeway and intersection air quality models) make use of the data from two major studies on mobile source emissions administered by the EPA. These models, along with their data requirements, are described in detail in the next section.

Using the emission profile outlined above, the third step models the dispersion of the emitted gases along and in the vicinity of the roadway. The dispersion of the emissions is dependent on such factors as source strength, width of roadway, wind direction and speed, source height, and mixing height. The most common dispersion model used for transportation applications is the gradient transport model.

The fourth step involves the calibration of the dispersion model using actual dispersion data collected from the location being modeled. All four steps involved in the mobile source pollution modeling process are illustrated in Figure 2.1.

The scope of this study is limited to the determination of the source strength of the emissions from traffic at a workzone. This can be used as the input for a dispersion model to predict the concentration of the pollutants at points away from the source. Hence, further discussions and analyses will be limited to topics related to emissions modeling. For a review of dispersion modeling techniques and some commonly used dispersion models, see Pasquill (Ref 9), CALINE4 (Ref 10), and HIWAY2 (Ref 11).

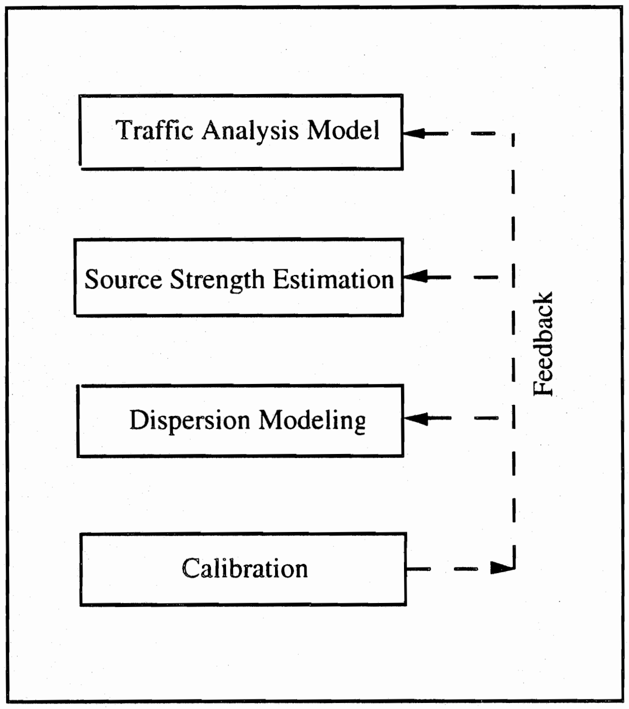


**Figure 2.1. Flow chart of the mobile source pollution modeling process.**

## EMISSIONS MODELING

As mentioned above, most emission rate analysis models (both freeway and intersection air quality models) make use of the data from two major studies on mobile source emissions administered by the EPA. The results of these studies were the Automobile Exhaust Emission Modal Analysis Model (Ref 12) and the MOBILE series of models (Refs 13-16). The development of these models involved collecting emissions data using (1) the Dynamometer Test Procedure for various vehicle categories and (2) standardized driving cycles to represent observed driving conditions.

Below, we discuss this test procedure and the two driving cycles used for model development by the EPA. Also discussed are the Modal Analysis Model and the MOBILE series of models. For specific applications, several models have been developed using a combination of these models, some of which will be discussed in the next section.

### Dynamometer Test Procedure (Ref 17)

The first step in emission modeling involves measuring vehicle exhaust emissions—i.e., carbon monoxide, unburnt hydrocarbons and oxides of nitrogen. The exhaust gases are trapped and then analyzed to determine the concentrations of each component. The system for trapping the emission is the Constant Volume Sampler System (CVS), which is defined as an SAE (Society of Automotive Engineers) recommended code of practice, and which is thus contained in the SAE Handbook (SAE J1094a). It is a complete vehicle test, one in which the wheels of the supported vehicle are positioned on the rolls of a chassis dynamometer. The rolls are connected to an absorption dynamometer and to large flywheels whose size is used to represent the inertia of the particular vehicle. The dynamometer is loaded in such a way as to simulate road travel, as defined by a prescribed driving cycle (see next section ). A schematic of the test procedure is shown in Figure 2.2.

The whole of the exhaust is discharged into an airstream and conducted through a heat exchanger (which controls the temperature) to a "Constant Volume Sampler," which is an apparatus that measures a constant volume of gas for the total duration of the test. By measuring the concentration of each pollutant component in this total volume of gas collected, the mass of each component is ascertained. As the total time of the driving cycle is represented by a particular mileage, the result is expressed in g/mile or g/kilometer. To measure the concentration, a small sample is drawn off and collected in a plastic sampling bag for analysis.

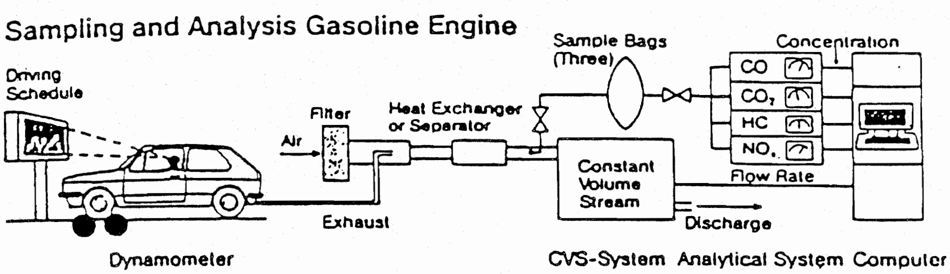


**Figure 2.2. Schematic arrangement of constant volume sampling systems (CVS) for gasoline vehicles (Ref 17).**

### Driving Cycles for Vehicle Emissions Data (Ref 18)

Vehicle emission rate models use data collected from dynamometer tests conducted on vehicles operating under standardized driving cycles. Two main types of driving cycles have been used in the emission rate models to be discussed later in this section. Both the testing programs use sequential bag sampling procedures to determine average exhaust emission rates for defined segments of the test cycle.

The main objective of the Surveillance Driving Sequence (SDS) testing program was the evaluation of emissions from on-road vehicles of various ages and maintenance conditions (Ref 12). The driving cycle consists of 37 segments, 16 of which are acceleration events, 16 deceleration events, a composite of all idle events, and 4 composite constant speed events at 15, 30, 45, and 60 mph. This driving cycle (Figure 2.3) uses relatively smooth patterns of acceleration and deceleration, with a low percentage of time spent in the idle mode (Table 2.2). Cruise events are defined as precisely constant speed operations. Vehicles tested are driven only in the hot stabilized engine condition. Dynamometer data are collected to represent average emission rates for each of the 37 segments of the cycle. Thus the results are aggregated and analyzed according to driving mode and speed.

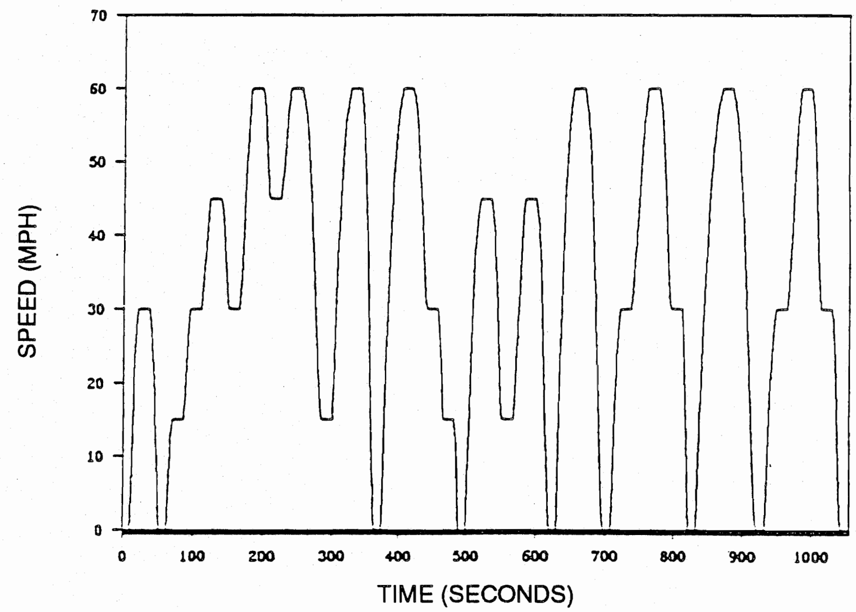


**Figure 2.3. SDS driving cycle speed profile (Ref 18).**

The Federal Test Procedure (FTP) driving cycle testing program (Ref 19) is used (1) to certify that new vehicles meet federal emission standards and (2) to evaluate emissions from on-road vehicles. In contrast to the SDS driving cycle, the FTP driving cycle (Figure 2.4) provides a somewhat irregular sequence of accelerations and decelerations. The first 505 seconds of the FTP driving cycle is defined as the starting mode component of the test. The vehicle operates in the cold start mode in this segment. The remaining 867 seconds of operation is defined as the stable mode component, with the vehicle operating in the hot stabilized mode. The FTP driving cycle has very few periods of constant speed driving and twice the percentage of vehicle idling (Table 2.3) as the SDS cycle.

**TABLE 2.2. SDS DRIVING CYCLE CONDITIONS (REF 18)**

| Driving Mode | SDS test cycle seconds | SDS test cycle percent |
|---|---|---|
| Idle | 92 | 8.7 |
| Acceleration | 315 | 29.9 |
| Cruise | 363 | 34.4 |
| Deceleration | 284 | 26.9 |
| Total | 1054 | 100.0 |
| Mean Speeds: | | |
| Acceleration | 35.4 mph | |
| Cruise | 40.1 mph | |
| Deceleration | 33.8 mph | |
| Test Cycle Mean | 33.8 mph | |
| Distance | 9.89 miles | |

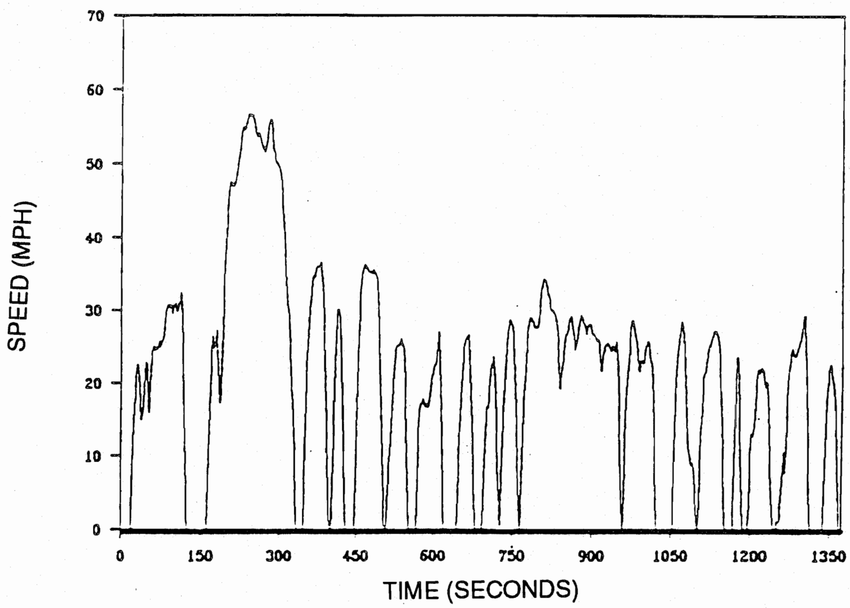


**Figure 2.4. FTP driving cycle speed profile (Ref 18).**

The full FTP testing program repeats the start mode and stable mode driving sequences. The initial cycle is begun with a cold vehicle, running the start mode and stable mode driving sequences without interruption. The vehicle then sits for 10 minutes with the engine off before the driving cycle sequence is repeated. Emissions data are aggregated and analyzed by operating mode condition (cold start, hot start, and hot stabilized modes) rather than by driving mode.

**TABLE 2.3. FTP DRIVING CYCLE CONDITIONS (REF 18)**

| | FTP start mode | | FTP stable mode | | Total FTP test | |
|---|---|---|---|---|---|---|
| Driving Mode | seconds | percent | seconds | percent | seconds | percent |
| Idle | 94 | 18.6 | 150 | 17.3 | 488 | 17.8 |
| Acceleration | 122 | 24.2 | 238 | 27.5 | 720 | 26.2 |
| Cruise* | 190 | 37.6 | 313 | 36.1 | 1006 | 36.7 |
| Deceleration | 99 | 19.6 | 166 | 19.1 | 530 | 19.3 |
| Total | 505 | 100.0 | 867 | 100.0 | 2744 | 100.0 |
| Mean Speeds: | | | | | | |
| Acceleration | 25.9 mph | | 16.9 mph | | 20.2 mph | |
| Cruise | 39.6 mph | | 24.2 mph | | 29.9 mph | |
| Deceleration | 22.7 mph | | 13.8 mph | | 17.1 mph | |
| Test Cycle Mean | 25.6 mph | | 16.0 mph | | 19.5 mph | |
| Distance | 3.59 miles | | 3.86 miles | | 14.90 miles | |

*Cruise mode defined as either a nonzero speed unchanged from the previous second or an absolute speed change of less than 1 mph from that of the previous second while the cumulative 4-second sum of speed changes totals less than 2 mph.

### Vehicle Emission Rate Models

The Environmental Protection Agency (EPA) has administered several exhaust emission studies that have resulted in the development of two distinct kinds of vehicle emission rate models: The Automobile Exhaust Modal Analysis Model and the MOBILE series of models. A brief discussion of these two models follows.

The Modal Analysis Model was developed to predict vehicle exhaust emissions over arbitrary driving sequences. By breaking the standard SDS cycle into segments or modes having specified speeds and accelerations, and noting the emissions produced in each segment, it was postulated that these segments could be recombined appropriately to form other driving sequences of interest. Based on this postulate, emission rate equations that are quadratic functions of instantaneous vehicle speed and acceleration were formulated. Coefficients for these equations were obtained by regression analysis of the emissions data collected from the SDS testing program. Separate equation coefficients were established for 11 vehicle categories according to model year groupings and location.

The original model was based on data from 1,020 light-duty vehicles tested in 1972. Tested vehicles included 15 different makes and 15 different model years (1956 through 1971). Testing was performed in six different cities, with 170 vehicles tested in each city. The data base used in the model has had limited updating, the last one (1972 through 1975 model year vehicles) occurring in 1977.

The main advantage of this model is that its focus on vehicle driving modes leads to easy correlation with traffic behavior at traffic intersections. Accordingly, this model has formed the basis for most intersection air quality modeling procedures.

Yet the model does have certain disadvantages. For example, the model gives emission rates for the light-duty vehicle fleet in a particular year only. In the first version, the model gives emission rates for the year 1972, and in the updated version, the model gives emission rates for the year 1975. This implies that the model is not capable of predicting emissions from future vehicle fleets. Also, the time history of vehicle operations is not taken into account. Hence the influence of vehicle operating mode (cold start, hot stabilized, etc.) is not reflected in the results. The SDS testing protocol used vehicles in an as-received condition, with no control exercised over major factors influencing emission rates. Since the model uses data from the SDS protocol, the results reflect this shortfall.

The MOBILE series of models which superseded the Modal Analysis Model was developed to predict current and future emissions under a variety of traffic and environmental conditions. Extensive emissions data from the FTP testing procedure were used in the development of these models. Emissions are predicted for eight categories of vehicles in the latest version of this model (MOBILE4.1): Light-duty gasoline vehicles, light-duty gasoline trucks I &II, light-duty diesel autos, light-duty diesel trucks, heavy-duty gasoline vehicles, heavy-duty diesel trucks, and motorcycles.

The basic test conditions under which light-duty vehicles are tested are as follows (Ref 20):

- ambient temperature range is 68°F to 86°F;
- absolute humidity is adjusted to 75 grains of water per pound of dry air;
- average speed is 19.6 mph with 18% idle operation;
- average percent of vehicle-miles-traveled (VMT) in a cold start operation is 20.6%;
- average percent of VMT in a hot start operation is 27.3%;
- average percent of VMT in the stabilized operation is 52.1%;

- average trip length is 7.5 miles;
- air conditioning not in use;
- vehicle contains driver and passenger (no additional load); and
- vehicle is not pulling a trailer.

The emissions calculation in the MOBILE models have been structured in the following manner. To begin with, basic exhaust emission rates are calculated from data on in-use vehicles with no observed tampering. The basic exhaust emissions are assumed to deteriorate from the zero mile level emissions at a constant deterioration rate. These basic emission rates are then corrected for observed operating modes (% hot start, % cold start, etc.) and observed ambient temperatures. Emissions offsets are added to these values to correct for all types of tampering (such as catalyst removal, air pump tampering). Model year weightings are then applied to account for the fraction of total vehicle miles driven by each model year. These weighted values are then summed over 20 model years to obtain the emission value for the given category of vehicles.

The average route speed used in the MOBILE models does not represent either an instantaneous speed or a constant speed condition. It encompasses a driving cycle (idling, acceleration, cruising and deceleration) having the identified average speed. Furthermore, the amount of idling, acceleration, cruising, and deceleration inherent in emission rates from the MOBILE series of models is not constant. The assumed mix of driving mode patterns is itself a function of average route speed.

With respect to their advantages, the MOBILE models are based on vehicle testing data that are much more extensive than those of the Modal Analysis Model. The MOBILE models consider such factors as temperature, operating mode, tampering programs, inspection, and maintenance programs in the estimation of the emissions. Because of the FTP basis of the data, these models also have future prediction capability.

The main disadvantage of the MOBILE models is their inability to estimate the emissions by mode (i.e., accel., decel.).

One of the current applications of the MOBILE models is in the preparation of the mobile source emissions inventory used as a component of State Implementation Plans. In addition to the Modal Analysis Model and the MOBILE series of models, a number of other emission and dispersion models have been developed for such specific applications as intersection air quality modeling or highway air quality modeling. Some of these will be discussed in the following section.

## INTERSECTION AIR QUALITY MODELS

The importance of modeling air quality at intersections has gained currency in recent years. This concern is attributable to the unusually high levels of pollution associated with high-traffic-volume urban intersections and with the congestion and delays concomitant with high volumes of crossing traffic. Other factors (e.g., tall buildings surrounding the intersection) act as impediments to the dispersion of the pollutants.

As was discussed above, emission levels of pollutants vary widely with the mode of operation of the vehicle. At intersections, vehicles need to decelerate to a halt near the stop line, idle at the stop line while waiting for their right of way, and accelerate to cruise speed when leaving the intersection. The proportions of each of these modes are dependent on such traffic parameters as volume, capacity, and green time. Modal emission rates are therefore required to model the air quality near intersections.

To reiterate: The Modal Analysis Model that estimates emissions by mode has had limited updating. In addition, it does not have any future year prediction capabilities. On the other hand, the MOBILE models, which do have future year prediction capabilities and which are updated frequently, do not have the ability to predict emissions by mode (except for idling emissions). Hence, the approach while modeling intersection air quality has been to use a combination of the two models, employing the adjustment procedures unique to each intersection model.

Four intersection air quality models with adjustment procedures that are representative of most models are discussed here. They are the Intersection Midblock Model (IMM) (Ref 21), MICRO2 (Ref 22), TEXIN2 (Ref 23), and CALINE4 (Ref 10). Table 2.4 summarizes the emissions adjustment procedures used in these four models.

### Intersection Midblock Model (IMM)

The basic emission model in the IMM is the 1977 update of the Modal Analysis Model. The emission rates from this model are for the 1975 vehicle fleet and are extrapolated to the 1977 fleet using MOBILE1 deterioration rates. Correction factors are then computed for these modal rates as ratios of MOBILE1 rates for actual versus base scenarios. The base scenario represents conditions in the Modal Analysis Model: a 1977 calendar year, 100 percent hot stabilized operating mode conditions, a temperature of 75°F, a light-duty vehicle fleet, and the average speed of the user-defined driving sequence. The actual scenario conditions are for the calendar year of the analysis, with the assumed vehicle mix, operating mode mix, and ambient air temperature representative of the given calendar year. The average speed is the same as that for the base scenario.

## TABLE 2.4. INTERSECTION AIR QUALITY MODEL EMISSION RATE ADJUSTMENTS

| Model | Driving Mode | Base Emission Rate | Base Rate Multiplier |
|---|---|---|---|
| **IMM** | Idle | MOBILE1 idle rate | 5 mph MOBILE1 rate ratio, actual: base scenarios |
| | Cruise | Modal Analysis Model cruise rate | MOBILE1 rate ratio for mean cruise mode speed, actual: base scenarios |
| | Acceleration | Modal Analysis Model acceleration rate | MOBILE1 rate ratio for mean acceleration mode speed, actual: base scenarios |
| | Deceleration | Modal Analysis Model deceleration rate | MOBILE1 rate ratio for mean deceleration mode speed, actual: base scenarios |
| **MICRO2** | Idle | Normalized SDS: FTP idle rate | none |
| | Cruise | Normalized SDS: FTP idle rate | none |
| | Acceleration | MOBILE scenario rate | $E=0.182-0.0079776(AS) +0.00036227[(AS)^2]$ |
| | Deceleration | Normalized SDS: FTP idle rate | none |
| **TEXIN2** | Idle | MOBILE3 idle rate | none |
| | Cruise | MOBILE3 scenario rate | none |
| | Deceleration/ Acceleration | Modal Analysis Model rates for default speed profiles | MOBILE3 rate ratio, cruise:base scenarios |
| **CALINE4** | Idle | MOBILE idle rate | none |
| | Cruise | 16.2 mph MOBILE scenario rate | $E = [0.494 +0.000227(S^2)]$ |
| | Acceleration | 16.2 mph MOBILE scenario rate | $E = 0.76[e^{(0.045AS)}]$ or $E = 0.027[e^{(0.098AS)}]$ |
| | Deceleration | MOBILE idle rate | E = 1.5 |

E = multiplier used to adjust base emission rate.
A = acceleration rate; S = speed. Units vary by model.
[a]Specific MOBILE series versions are indicated only for intersection models that code specific emission rates into the model.
Source: Ref 18

**MICRO2**

Vehicle emission rates in the MICRO2 model are based on data from 45 light-duty, 1975 vehicles tested in Denver using the SDS driving cycle. The ratio of time rate of modal emission to the average time rate of FTP emissions (termed E) was used as the dependent variable; the modal acceleration-speed product (AS) was used as the independent variable to obtain an acceleration correction factor for the MOBILE emission rates. The strong correlation between E and AS exists because of the following (Ref 22): AS is equivalent to power per unit mass. Hence the power expended by a vehicle during an acceleration event is directly related to the value of AS for the event. As power demand approaches engine capacity, a vehicle burns fuel less efficiently, resulting in higher emissions.

Internally, the MICRO2 program assumes a constant value of 80.667 $ft^2/s^3$ for the accel.-speed product, representing an average acceleration of 2.5 mph per second between 0 and 30 mph. Also, the model assumes a constant emission rate for idling, cruise, and deceleration.

**TEXIN2**

The emissions adjustment procedure in TEXIN2 is similar to that used in the IMM. No correction is applied to the idle emission rate from the MOBILE3 model. The cruise emission rate is assumed to be the same as the MOBILE3 model scenario rate, with the average route speed equal to the cruise speed.

Data from the 1977 update of the Modal Analysis Model was used to compute emissions for selected acceleration-deceleration patterns. These estimates are multiplied by correction factors from Actual:Base scenario runs of the MOBILE model, in a manner similar to that used in the IMM.

**CALINE4**

Adjustment procedures similar to that in MICRO2 are used in CALINE4. No correction is applied to idle rates from the MOBILE model. Deceleration emission rates are assumed to be 1.5 times the idle rates. This assumption was based on an analysis of data from California Air Resources Board (Ref 24), (CARB) and EPA (Ref 25). This was found to be compatible with the practice of gradually releasing the accelerator pedal during a planned deceleration.

Cruise adjustment factors are computed as a quadratic function of speed. This is consistent with the fact that the drag force on the vehicle is proportional to the square of the speed.

Acceleration mode adjustment factors are calculated as an exponential function of the acceleration-speed product (AS). These relations were derived using data from CARB and EPA.

The adjustment procedures in the models described assume that driving mode emission rates from the Modal Analysis Model respond to emission rate variables in a manner and to an extent similar to that associated with weighted composite rates from the MOBILE series of models. Since the Modal Analysis Model and the MOBILE series of models do not share a common structural or functional basis, the accuracy of the emission rates computed by the composite intersection models is questionable. A more detailed review of these intersection air quality models and their drawbacks can be found in the paper by Sculley (Ref 19).

## SUMMARY

A review of emission modeling techniques currently in use was presented in this chapter. From these discussions it can be seen that there is clearly a need for a more comprehensive modal emissions model using current emissions data. But, until such a model is developed, any meaningful emissions modeling with modal data requirements will have to make do with adjustment procedures involving the Modal Analysis Model, the MOBILE models, and other limited sets of modal emissions data that have been collected.

The traffic model for characterizing the workzone problem will be discussed in the next chapter.

# CHAPTER 3. A METHODOLOGY FOR THE PREDICTION OF WORKZONE EMISSIONS

The definition of the traffic to be modeled has a direct influence on the amount of emissions attributable to that traffic. Hence, the first step in the effort to model emissions at a workzone is to characterize, as accurately as possible, the workzone traffic. This will lead to a delineation of the areas where excess emissions occur as a result of the workzone.

The flow of traffic in the region of a workzone on a freeway is unique to the extent that it needs to be described by a combination of free flowing traffic and stop-and-go traffic. When the traffic volumes are not high enough to cause congestion and queuing, the traffic can be characterized entirely by the volume and the speeds. When congestion occurs, additional information, such as queue lengths, is also required to characterize the traffic. Hence, a traffic model that is capable of comprehensively defining the workzone problem is required.

The objective of this chapter is to present a general procedure for the calculation of workzone mobile source emissions. First, common workzone types are described; then, traffic passing through a workzone is characterized. Based on this information, a general methodology is developed. The data requirements for implementing this methodology leads to the definition of the traffic model required. The details of this model will be discussed in the next chapter.

## TYPES OF WORKZONES

A workzone, work area, and work site denote the general location of work activity or the subject of a work area traffic control (Ref 26). Urban freeways, because of their high traffic volumes, have maximum impact in terms of the amount of mobile source emissions generated at workzones. Therefore, much of the present effort will be concentrated on predicting emissions at urban freeway workzones. To begin with, it is necessary to layout the different possible workzone configurations in terms of the manner in which the work area is defined; from these configurations we will identify those workzones most commonly used in urban freeways.

Reference 1 consists of an annotated glossary of the concepts, definitions, and standard terminology currently used and advocated in traffic control for highway construction, maintenance, and related activities. The following is a list of possible workzone configurations presented in Ref 26.

(1) Closure: A closure is the taking of any portion of the roadway for the exclusive use of a work activity. Closures may involve any of the following: a shoulder; one or more lanes; any combination of lanes or shoulders, or both; a direction of a roadway; or the entire highway. The portion of the roadway remaining, if any, after the closed portion is temporarily removed from service is available for traffic passing through the work area.

(2) Lane Closure: A lane closure involves the closing of a traffic lane in such a manner that traffic is forced to move out of the closed lane and into another lane, reducing the total number of

lanes. On a multilane roadway, a merging operation is involved. On a two-lane, two-way roadway, alternating directions of traffic must use the remaining lane (typically controlled by flaggers).

(3) Traffic Shifting: Traffic shifting is the lateral displacement of one or more travel lanes from their normal travel path, an arrangement required to accommodate a work space in the roadway. All lanes are carried through and no merging operations are involved. Traffic shifting may be accomplished by several means, including lane narrowing, use of shoulders, and use of opposing roadway.

(4) Traffic Splitting: Traffic splitting is the situation encountered on a multilane roadway where open travel lanes are carried around both sides of a work space. An island work space is formed, with traffic on both sides. It is preferable to avoid this situation, where feasible, since high accident rates are associated with this workzone type.

(5) Lane Narrowing: Lane narrowing is a reduction in lane width for those lanes carried through the activity area in order to maintain the maximum number of open lanes while accommodating the needs of the work activity.

(6) Median Crossover: In the context of workzone closures, a median crossover occurs where one directional roadway is closed to traffic; that direction of travel is carried diagonally across the median onto the other directional roadway.

(7) Detour: A detour is initiated when traffic is directed to leave the normal roadway. Two types of detours are possible. An on-site detour occurs where traffic is diverted onto a temporary roadway generally constructed within or adjacent to the right-of-way or onto a frontage road. An off-site detour occurs where traffic is diverted onto another highway in order to bypass the work site.

Of the above listed closure types, the most commonly employed on urban freeways are lane closure, lane narrowing, and median crossover. Traffic shifting by itself is not usually employed. More commonly, traffic shifting and lane narrowing are adopted in combination. Construction of an on-site detour is not normally possible in an urban area because of right-of-way constraints. Off-site detours, such as major arterials, are used for traffic diversion in conjunction with lane closure and other techniques as a means of reducing the traffic demand at the workzone. In this regard, off-site detours are not stand-alone options in the urban context.

For the above stated reasons, lane closure, median crossover, and lane narrowing are the main closure types attributable to urban workzones. Accordingly, these closure types were selected to predict workzone mobile source emissions in this study.

## CHARACTERISTICS OF TRAFFIC AT A WORKZONE

Traffic passing through a workzone can be broadly characterized in three ways from the viewpoint of emission prediction:

(1) Vehicles proceeding undelayed through the workzone: When the capacity of the workzone is sufficiently greater than the demand, the vehicles passing through the workzone are processed without any delay whatsoever. In other words, the presence of the workzone has no

impact on the traffic. Because this scenario does not contribute to excess emissions over what is caused in the absence of the workzone, it need not be considered in the calculations. Very low traffic demand during off peak hours, or low traffic demand during usual high traffic periods as a result of good public information about the presence of a workzone are examples of this scenario.

(2) Vehicles proceeding through the workzone at a reduced speed: As the traffic demand at the workzone nears the capacity of the workzone, the rate at which vehicles are processed through the workzone decreases, lowering the overall speeds of vehicles. This involves a deceleration from the approach speed to a minimum speed near the workzone, an acceleration to the workzone average speed from this minimum speed, travel at a lower average speed through the workzone, and an acceleration from the workzone speed to pre-workzone speed at the end of the workzone. These actions have implications from the emissions point of view, as vehicles emit more pollutants as they decelerate and accelerate. The lower average speeds in the workzone might also result in lesser pollution when compared with the case in which vehicles proceed unhindered at higher average speeds. Hence, appropriate emissions calculations will have to be carried out for this scenario. The characteristics of this traffic behavior are illustrated in Figure 3.1, while the data required and emissions calculations to be performed for this scenario are tabulated in Table 3.1.

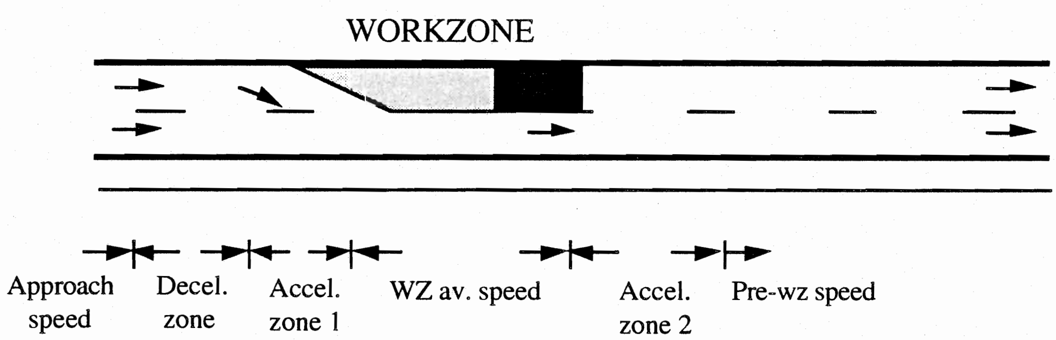


**Figure. 3.1. Traffic behavior near a workzone (no queue formation).**

(3) Vehicles stoppage near the workzone caused by queue formation: When the traffic demand at the workzone exceeds the capacity of the workzone, queue formation takes place upstream of the workzone. This occurrence is quite common when the traffic demand is at its peak. Vehicles in this situation decelerate from the approach speed until they are idling at the end of the queue; they also make short acceleration-deceleration movements (creeping motion) as they progress through the queue, accelerate to workzone speed at the beginning of the workzone, pass through the workzone at the average workzone speed, and accelerate to pre-workzone speeds at the end of the workzone. Because this scenario has the maximum impact in

terms of excess emissions calculations, an appropriate analysis will have to be carried out. The characteristics of this traffic behavior are illustrated in Figure 3.2, while the data required and emissions calculations to be performed for this scenario are tabulated in Table 3.2.

**TABLE 3.1. DATA REQUIRED AND CALCULATIONS TO BE PERFORMED FOR THE SCENARIO IN FIG. 3.1**

| Data Required | Calculations |
|---|---|
| Approach Speed | Avg. emissions associated with deceleration |
| Length of Deceleration Zone | Avg. emissions associated with lower-speed travel |
| Length of Acceleration Zone 1 | Avg. emissions associated with acceleration |
| Workzone Average Speed | |
| Length of Workzone | |
| Length of Acceleration Zone 2 | |
| Average Vehicle Emission Rates | |
| Vehicle Mix | |
| Vehicle accel-decel characteristics | |
| Traffic Data | |
| Workzone Parameters | |

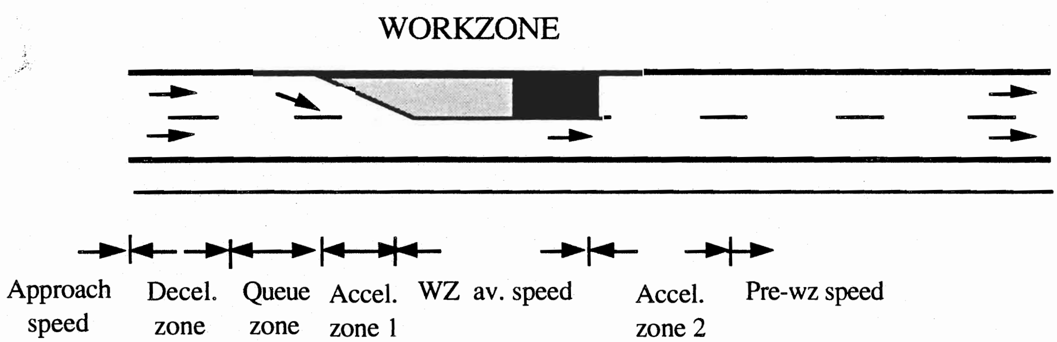


**Figure 3.2. Workzone traffic behavior associated with queue formation.**

**TABLE 3.2. DATA REQUIRED AND CALCULATIONS TO BE PERFORMED FOR THE SCENARIO IN FIG. 3.2**

| Data Required | Calculations |
|---|---|
| Approach speed | Avg. emissions associated with deceleration |
| Length of deceleration zone | Avg. emissions associated with creeping |
| Length of queue | Avg. emissions associated with lower-speed travel |
| Average queue speed | Avg. emissions associated with acceleration |
| Length of acceleration zone 1 | |
| Workzone average speed | |
| Length of workzone | |
| Length of acceleration zone 2 | |
| Vehicle mix | |
| Vehicle accel-decel characteristics | |
| Traffic data | |
| Workzone parameters | |
| Average vehicle emission rates | |

The above discussion on the characteristics of traffic flowing through a workzone gives some insight into how the emissions model can be structured based on the traffic flow. With this as the basis, a general procedure for the calculation of excess emissions resulting from the presence of a workzone will be presented in the next section.

## CALCULATION PROCEDURE

The objective of this section is to present a methodology to predict excess vehicle emissions as traffic passes through a workzone. Here, excess vehicle emissions are defined as the difference between the total emissions produced at and near the workzone (taking into account accel-decel, queue formation, etc.) minus those that would have been produced had the same number of vehicles cruised unhindered through the workzone.

The approach will be to determine the time spent by each vehicle in each mode of operation (accel, decel, cruise, queue) so that the average emission rates for each mode can be multiplied with the time spent in that mode to obtain the emission values. These emission values, when multiplied by the total number of vehicles in the analysis period, will give the total mass of pollutants. The mass of pollutants generated if the vehicles were traveling over the affected length in the absence of the workzone is also computed. The difference between the two gives the required excess emissions.

It is necessary to perform emissions calculations for only two of the three scenarios (presented in the previous section) that characterize the flow of traffic at a workzone. These two cases are dealt with independently as follows.

**Case I (no queue formation; see Fig. 3.1)**

Let T be a time period (say 30 min. or 1 hr.) over which the flow near and at the workzone, along with the workzone characteristics themselves, can be assumed to exhibit uniform features. The time period T will be the smallest unit of time for which the calculations will be performed and the values of the output variables determined. Let V (vph) be the rate of traffic flow and $C_{wz}$ (vph) the capacity of the workzone during this time period. The following notation is used in the calculations:

$T$ = time period of analysis (hrs),

$V$ = rate of traffic flow (vph),

$C_{wz}$ = capacity of the workzone in time period T (vph),

$v_a$ = workzone approach speed (mph),

$v_{min}$ = minimum speed to which vehicles decelerate before the workzone (mph),

$v_d$ = average speed through the deceleration zone (mph),

$v_{a1}$ = average speed through acceleration zone 1 (mph),

$v_{wz}$ = speed through the workzone (mph),

$v_{a2}$ = average speed through acceleration zone 2 (mph),

$d$ = *constant* deceleration rate of vehicles (ft/s$^2$),

$a$ = *constant* acceleration rate of vehicles (ft/s$^2$),

$l_d$ = distance over which deceleration occurs (ft),

$l_{a1}$ = distance over which acceleration occurs in zone 1 (ft),

$l_{wz}$ = length of workzone (ft),

$l_{a2}$ = distance over which acceleration occurs in zone 2 (ft),

$l$ = total length over which vehicles are affected due to the presence of the workzone (ft),

$t_d$ = time taken for deceleration from $v_a$ to $v_{wz}$ (sec),

$t_{a1}$ = time taken for acceleration from $v_{min}$ to $v_{wz}$ (sec),

$t_{wz}$ = time taken to pass through the workzone at $v_{wz}$ (sec),

$t_{a2}$ = time taken for acceleration from $v_{wz}$ to $v_a$ (sec),

$t$ = total time to cross length l at normal approach speeds in the absence of the workzone,

$m_{pd}$ = emission rate of pollutant p ($m_{COd}$, $m_{HCd}$, or $m_{NOxd}$) for carbon monoxides, hydrocarbons, and nitrogen oxides) emitted under deceleration at an average speed $v_d$. (gm/sec/vehicle),

$m_{pai}$ = emission rate of pollutant p ($m_{COd}$, $m_{HCd}$, or $m_{NOxd}$) emitted under acceleration at an average speed $v_{ai}$. (gm/sec/vehicle), and

$m_{pcri}$ = emission rate of pollutant p ($m_{COd}$, $m_{HCd}$, or $m_{NOxd}$) emitted while cruising at an average speed $v_{cri}$. (gm/sec/vehicle).

The time spent by each vehicle in each mode of operation can be arrived at using the following relationships developed (from kinematics) between the above defined variables for each of the zones shown in Figure 3.1.

**Deceleration Zone**

All vehicles decelerate from the approach speed to a minimum speed before the workzone. Assuming a constant rate of deceleration, for this zone:

$$l_d = 1.47^*v_a{}^*t_d + 0.5^*d^*t_d^2 \quad \text{(ft)}$$

$$t_d = \frac{1.47^*(v_{min} - v_a)}{d} \quad \text{(sec), and}$$

$$v_d = \frac{l_d}{t_d} \quad \text{(ft/sec)}$$

**Acceleration Zone 1**

All vehicles accelerate from the minimum speed to the average workzone speed. Assuming a constant acceleration rate for this zone, we arrive at the following:

$$l_{a1} = 1.47^*v_{min}{}^*t_{da1} + 0.5^*a^*t_{a1}^2 \quad \text{(ft)}$$

$$t_{a1} = \frac{1.47^*(v_{wz} - v_{min})}{a} \quad \text{(sec)}$$

$$va1 = \frac{la1}{ta1} \quad \text{(ft/sec)}$$

**Workzone**

In this zone, vehicles travel through at a reduced average speed of $v_{wz}$.

$$t_{wz} = \frac{l_{wz}}{(1.47^*v_{wz})}$$

**Acceleration Zone 2**

At the end of the workzone, all vehicles accelerate from the slower workzone speeds to pre-workzone approach speeds.

$$l_{a2} = 1.47*v_{wz}*t_{a2} + 0.5*a*t_{a2}^2 \quad \text{(ft)}$$

$$\Rightarrow t_{a2} = \frac{1.47*(v_a - v_{wz})}{a} \quad \text{(sec)}$$

$$v_{a2} = \frac{l_{a2}}{t_{a2}} \quad \text{(ft/sec)}$$

**Total**

The total length and total time over which traffic is affected by the presence of the workzone are:

$$l = l_d + l_{wz} + l_a \quad \text{(ft)}$$

$$t = \frac{l}{v_a} \quad \text{(sec)}$$

Therefore, the total emission of pollutant p (in gms) from all vehicles V resulting from the workzone will be:

$$E_{pwz} = \{m_{pd}*t_d + m_{pcr1}*t_{wz} + m_{pa1}*t_{a1} + m_{pa2}*t_{a2}\} V*T$$

Emission of pollutant p (in gms) over the length l from all vehicles V in the absence of the workzone will be:

$$E_{pn} = m_{pcr2}*t*V*T$$

Therefore, the excess emission of pollutant p (in gms) caused by the presence of the workzone will be:

$$DE_p = E_{pwz} - E_{pn}$$

**Case II (queuing occurs, see Fig. 3.2)**

As in the previous case, let T be a time period (say 30 min. or 1 hr.) over which the flow near and at the workzone, along with the workzone characteristics themselves, can be assumed to exhibit uniform features. Let V vph be the rate of traffic flow and $C_{wz}$ vph the capacity of the workzone during this time period. The following additional notation over that presented for the previous case is made use of in the following calculations:

$l_q$ = average queue length over time period T (ft),

$v_q$ = average speed of vehicles in the queue (mph),

$t_q$ = time taken to travel through the queue (sec),

$t_{a1}$ = time taken to accelerate from stopped condition to $v_{wz}$ at the beginning of the workzone (sec),

$t_{a2}$ = time taken to accelerate from $v_{wz}$ to $v_a$ (sec), and

$m_{pi}$ = mass of pollutant p ($m_{COd}$, $m_{HCd}$, or $m_{NOxd}$) emitted while idling in the queue. (gm/sec/vehicle).

The time spent by each vehicle in each mode of operation can be arrived at as in the previous case using the following relationships developed (from kinematics) between the above defined variables for each of the zones shown in Figure 3.2:

**Deceleration Zone**

All vehicles decelerate and come to a stop at the end of the queue. Therefore:

$$l_d = 1.47 * v_a * t_d + 0.5 * d * t_d^2 \quad \text{(ft)}$$

$$t_d = \frac{-1.47 * v_a}{d} \quad \text{(sec)}$$

**Queuing Zone**

Vehicles idle in the queue for an average period given by:

$$t_q = \frac{l_q}{(1.47 * v_q)} \quad \text{(sec)}$$

**Acceleration Zone 1**

At the end of the queue, vehicles accelerate from zero speed to the average workzone speed.

$$l_a = 0.5 * a * t_{a1}^2 \quad \text{(ft)}$$

$$t_{a1} = \frac{1.47 * v_{wz}}{a} \quad \text{(sec)}$$

**Workzone**

In this zone, vehicles travel through at a reduced average speed of $v_{wz}$.

$$t_{wz} = l_{wz}/v_{wz} \quad \text{(sec)}$$

### Acceleration Zone 2

At the end of the workzone, all vehicles accelerate from the slower workzone speeds to pre-workzone approach speeds.

$$l_{a2} = 1.47^*v_{wz}^*t_{a2} + 0.5^*a^*t_a^2 \quad \text{(ft)}$$

$$t_{a2} = \frac{1.47^*(v_a - v_{wz})}{a} \quad \text{(sec)}$$

### Total

The total length and total time over which traffic is affected by the presence of the workzone are:

$$l = l_d + l_q + l_{a1} + l_{wz} + l_{a2} \quad \text{(ft)}$$

$$t = \frac{l}{v_a} \quad \text{(sec)}$$

Therefore, the total emission of pollutant p (in gms) from all vehicles V resulting from the workzone will be:

$$E_{pwz} = \{m_{pd}^*t_d + m_{pi}^*t_q + m_{pcr1}^*t_{wz} + m_{pa1}^*t_{a1} + m_{pa2}^*t_{a2}\}\ V^*T$$

Emission of pollutant p (in gms) over the length l from all vehicles V in the absence of the workzone will be:

$$E_{pn} = m_{pcr2}^*t^*V^*T$$

Therefore, excess emission of pollutant p (in gms) resulting from the presence of the workzone will be:

$$DE_p = E_{pwz} - E_{pn}$$

## IMPLEMENTATION

In order to implement the methodology presented in the previous section, data on workzone capacities, speed-flow relationships at workzones, length of workzone, and length of queues will be required.

The QUEWZ model (Ref 7), which is a Queue and User Cost Evaluation Model for Work Zones, fulfills most of these data requirements. The applicability of this model to the problem at hand, together with the implementation of the methodology, is discussed in subsequent chapters.

# CHAPTER 4. THE WORKZONE TRAFFIC ANALYSIS MODEL

The implementation of the methodology described in Chapter 3 requires a comprehensive workzone traffic analysis model. And in building an emissions model, one should seek the traffic analysis model that satisfies the following data requirements:

(1) Workzone capacity
(2) Speed-Flow relationship
(3) Length of workzone
(4) Average length of the queue over time period T
(5) Average vehicle speeds in the queue
(6) Vehicle mix
(7) Acceleration and deceleration rate of vehicles
(8) Emission rates ($m_{pd}$, $m_{pa}$, $m_{pcr}$, and $m_{pi}$)

This chapter describes the development of a traffic model that fulfills these minimum requirements. To start with, the applicability of the QUEWZ model (Ref 7) to the problem at hand is discussed. Then, each of these data requirements is described in detail. Finally, the manner in which the QUEWZ model addresses these data requirements is discussed.

## APPLICABILITY OF THE QUEWZ WORKZONE MODEL

QUEWZ is a workzone model that can be used to calculate the user costs resulting from workzone lane closures. QUEWZ calculates the delay costs and speed-change cycling costs that accrue when motorists are forced to slow down to go through a workzone; it also calculates the change in vehicle running costs that occurs as motorists proceed through the workzone. If a queue forms, the delay costs, speed-change cycling costs, and change in vehicle running costs in the queue are also estimated. The model estimates the average length of queue each hour.

The model can examine a variety of workzone configurations and schedules. The configurations fall into two general categories: (1) lane closures in a single direction of travel, and (2) crossovers, where one or more lanes are closed in both directions of travel. The workzone schedules are in the form of user input times of closure. The model uses hourly traffic volumes and data concerning capacities and average speeds in and around workzone sites in Texas.

A modified version of the QUEWZ model (Ref 6) computes the excess energy consumption resulting from a workzone in terms of car fuel, car oil, truck fuel, and truck oil. This model is an appropriate building block in the context of workzone emissions prediction. The shell of the model, the associated workzone data, and the queue length estimation routine can be used for performing the necessary emission calculations stated in the previous section. The addition of emissions capabilities to the modified QUEWZ model will make it a comprehensive workzone analysis package in terms of evaluation of user impacts, energy impacts, and environmental impacts.

## DATA REQUIREMENTS

All of the data requirements stated before will be addressed in this section, both in general terms and in terms of how they are handled by the QUEWZ model.

### Workzone Capacity

Estimation of an appropriate workzone capacity is vital to the calculation procedure described in the previous chapter. The main effect of work activities on freeways is the reduction in capacity at the work sites regardless of whether the activities involve closure of one or more lanes. These reduced workzone capacity values will be useful for (1) determining queue lengths and (2) estimating approach speeds and average workzone speeds using an appropriate speed-flow curve.

The earliest study on the subject of capacities at urban freeway workzones was made by Kermode and Myyra (Ref 27). They attempted to correlate observed capacities on the San Diego expressway in California with the type of construction activity (e.g., median barrier or guard rail repair, pavement repair, mudjacking, pavement grooving, or striping). Because the capacities were estimated using 3-minute observations of maximum flow rates past the workzone, these correlations tend to overestimate the hourly capacity .

The Dudek and Richards (Ref 28) study on the impact of lane geometry on capacity at a number of work sites in Texas is probably the most complete on this subject. This study, the results of which were used in the 1985 Highway Capacity Manual (Ref 29), will be discussed in greater detail later in this section.

Dudash and Bullen (Ref 30) observed single-lane capacities during reconstruction activity on the Penn Lincoln Parkway, Interstate 376, located in Pittsburgh, Pennsylvania. Their observations were comparable to those reported in Texas and California.

Many factors that affect capacities through workzones have been identified by different authors. At the macroscopic level, capacity depends on the lane geometry (i.e., the number of lanes and the number of open lanes), the time of work, and the type of work activity. Nighttime construction activity, for example, has a greater impact on capacity than daytime operations. (Variations in lighting and motorists' uncertainty about the construction site during the night generate such impact differences.) Zhang (Ref 31) presented the following simple equation relating workzone capacity to different factors:

$$C_{wz} = f(C_b, T, N_{td}, N_o, \text{Time})$$

where

$C_{wz}$ = capacity through workzone per lane per hour,

$C_b$ = basic capacity,

$T$ = type of work,

$N_{td}$ = total number of lanes in the operation direction,

$N_O$ = number of lanes open to traffic, and

Time = day or night (time of work activity).

Furthermore, they developed a capacity matrix based on the studies by Kermode and Myyra (Ref 27), and by Dudek and Richards (Ref 28). This capacity matrix was then evaluated by experts from the Committee on Freeway Operations of the Transportation Research Board and from CALTRANS (California Department of Transportation). The best estimate of lane capacity values based on their study is presented in Table 4.1.

**TABLE 4.1. SUGGESTED RESULTING LANE CAPACITIES FOR SOME TYPICAL MAINTENANCE AND RECONSTRUCTION ACTIVITIES (REF 31)**

| No. of Lanes | | Type of work* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Normal | Open | 1 | 2 | 3 | 4 | 5 | 6 | Avg. |
| 2 | 1 | 1400 | 1400 | 1250 | 1200 | 1200 | 1350 | 1300 |
| | 2*** | 1650 | 1650 | 1650 | 1650 | 1650 | 1650 | 1650 |
| 3 | 1 | 1300 | 1050 | 1050 | 1050 | 1100 | 1350 | 1150 |
| | 2 | 1550 | 1500 | 1400 | 1300 | 1200 | 1300 | 1350 |
| | 3*** | 1700 | 1700 | 1700 | 1700 | 1700 | 1700 | 1700 |
| 4 | 1 | 1300 | 1050 | 1050 | 1050 | 1100 | 1350 | 1150 |
| | 2 | 1550 | 1500 | 1400 | 1300 | 1200 | 1300 | 1350 |
| | 3 | 1550 | 1500 | 1300 | 1300 | 1200 | 1300 | 1350 |
| | 4*** | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 |
| 5 | 1 | 1300 | 1050 | 1050 | 1050 | 1100 | 1350 | 1150 |
| | 2 | 1550 | 1500 | 1400 | 1300 | 1200 | 1300 | 1350 |
| | 3** | 1600 | 1550 | 1450 | 1400 | 1300 | 1400 | 1450 |
| | 4** | 1700 | 1650 | 1550 | 1450 | 1350 | 1450 | 1500 |
| | 5*** | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 | 1800 |

* Type of work:
1. Median barrier/guard rail repair or installation
2. Pavement repair
3. Resurfacing, asphalt removal
4. Stripping, slide removal
5. Pavement markers
6. Bridge repair

** Data not available. The capacity values are based on the values immediately above with a 6% increase.

*** Data not available. The values are based on authors' judgment.

The results of the study conducted by Dudek and Richards were used to estimate workzone capacities in the QUEWZ model. This study will now be discussed in greater detail.

Capacity studies were conducted at urban freeway maintenance and construction workzones in Houston and Dallas. Studies were conducted on five-, four-, three-, and two-lane freeway sections. Capacity data were collected at 37 work sites with ongoing work activity, and 4 work sites with no ongoing work activity. All volumes, measured while queues were formed upstream from the lane closure, essentially represent the capacity of the bottlenecks.

The average capacity for each closure situation studied is shown in Table 4.2. The data show that the average lane capacity for the 3/2 and 4/2 combinations was approximately 1500 vphpl. In comparison to this, the studies conducted at work sites with 5/2 and 2/1 closure situations indicate significant reductions in capacity. The average capacity for these two situations was approximately 1350 vphpl. Studies at 3/1 sites indicate a greater reduction in capacity. The average capacity was found to be only 1130 vphpl.

Taking into account that workzone capacities are site specific, QUEWZ gives the user the range of capacity values measured at sites in Texas for the specified workzone configuration. This gives the user some guidance in selecting a capacity value that is appropriate to the conditions for the problem at hand. The default value in the program is the average of the capacities observed at sites in Texas for the specified workzone configuration.

**TABLE 4.2. MEASURED WORKZONE CAPACITY (REF 28)**

| Number of Lanes | | | Average Capacity | |
|---|---|---|---|---|
| Normal | Open | Number of Studies | (vph) | (vphpl) |
| 3 | 1 | 5 | 1130 | 1130 |
| 2 | 1 | 8 | 1340 | 1340 |
| 5 | 2 | 8 | 2740 | 1370 |
| 4 | 2 | 4 | 2960 | 1480 |
| 3 | 2 | 8 | 3000 | 1500 |
| 4 | 3 | 4 | 4560 | 1520 |

With no ongoing work activity at the workzones, capacities were found to be approximately 90 percent of the normal capacity of 2000 vphpl. Therefore 1800 vphpl was used in the QUEWZ model for this condition.

For those lane closure combinations which did not have capacity data (i.e., 4/1, 5/1, 5/3, 5/4, 6/1, 6/2, 6/3, 6/4, 6/5 combinations), the closure capacities used in Reference 9 were used. For 4/1, 5/1, and 6/1, an average capacity of 1200 vphpl was used. For 5/3 and 6/3, 1500 vphpl was used; for 5/4 and 6/4, 1550 vphpl was used; and for 6/5, 1580 vphpl was used.

Because the study by Dudek and Richards is the most complete on this subject, and since the results have already been used successfully in the QUEWZ model and are recommended in the 1985 Capacity Manual (Ref 29), we used their results to develop the emissions model.

### Speed-flow Relationship

Using the capacity values of the normal freeway section and the freeway section with a workzone, and assuming an appropriate speed-flow relationship, the approach speed and the speed at the workzone can be evaluated. The nature of the speed-flow relationship to be assumed for this purpose will be discussed here.

In the QUEWZ model, the normal approach speed and average speed through the workzone are computed from a relationship between speed and v/c ratio similar to that presented in the 1965 HCM (Ref 32). The assumed speed-flow curve is shown in Figure 4.1. The three speed parameters, $SP_1$, $SP_2$, and $SP_3$, and the volume parameters $V_1$ and $V_2$ have preset default values that are used if the user does not specify speed and volume parameters. These default values are:

$SP_1$ = 60 mph (free flow speed)

$SP_2$ = 40 mph (level of service D/E breakpoint speed)

$SP_3$ = 30 mph (speed at capacity)

$V_1$ = 2,000 vphpl

$V_2$ = 1,600 vphpl

The user has the option of modifying the parameters to reflect the speed-volume relationship more accurately on the freeway of interest.

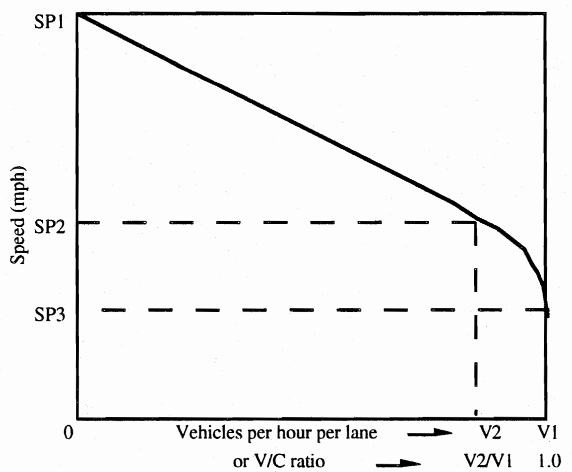


**Figure 4.1. Assumed speed-flow curve (Ref 7).**

The hourly traffic volume specified by the user is converted into a v/c ratio, and the approach speed, in mph, is calculated using the following equations based on the assumed speed-flow curve. The equations are taken from the Highway Economic Evaluation Model, HEEM (Ref 33).

$$\text{if } \frac{V_2}{V_1} >= V/C, \text{ then}$$

$$SP = SP_1 + \frac{V_1(SP_2 - SP_1)}{V_2}(V/C)$$

$$\text{if } \frac{V_2}{V_1} < V/C <= 1, \text{ then}$$

$$SP = SP_3 + (SP_2 - SP_3)\left[1 - \left\{\frac{V/C - V_2/V_1}{1 - V_2/V_1}\right\}^2\right]^{1/2}$$

if V/C > 1 or a queue is present, then

$$SP = SP_3(2 - V/C), \text{ with the speed constrained to the following range,}$$

$$20 <= SP <= SP_3$$

In the evaluation of average speed of vehicles through the workzone, there is some question about whether the speed-volume relationship for a workzone is the same as that for a normal freeway segment (Ref 34). Butler (Ref 35) concluded that the speed-volume relationship for workzones did correspond to the typical relationship for normal freeway sections in the 1965 HCM (Ref 32). Abrams and Wang (Ref 36) also used the typical relationships as the basis for their estimation of speeds through workzones. However, Rouphail and Tiwari (Ref 37) concluded that the speed-volume relationships at lane closures on four-lane freeways in Illinois differed considerably from those in the 1965 HCM (Ref 32). Additional research will be necessary to determine which conclusion is the most accurate.

The QUEWZ model calculates the average workzone speed, $SP_{WZ}$, using the same speed equations given above, assuming that the speed-flow relationship remains the same at a workzone. The same assumption will be made in the emissions modeling procedure.

**Length of Workzone**

The length of the workzone is required to define the flow of traffic around the workzone. Shorter workzones do not have as much of an effect on traffic as do long ones. Also, higher traffic volumes are affected over longer distances than are lower volumes.

The distance over which vehicles slow down through a workzone is not always the entire distance of restricted capacity (Ref 7). When the traffic volume is light, vehicles tend to slow down only when passing major work activity (e.g., paving). Hence, traffic volumes play a role in defining the length of the traffic affected by the workzone. Also, to account for the effects of average speed being reduced upstream of the workzone, some adjustment needs to be made to the actual workzone length.

Taking these factors into account, the following adjustments are made to the actual workzone length in the QUEWZ model. A distance of 0.1 miles on each side of the workzone is included. If the workzone closure is less than 0.1 miles, then the QUEWZ model assumes traffic will slow down through the entire workzone. To account for the effect of traffic volumes, the following equations are used to estimate the effective length of closure, in miles:

$$l_{WZ} = 0.1 + (WZD + 0.1)(V/C_{WZ})$$

where

WZD = length of restricted capacity around workzone, in miles.

If WZD < = 0.1, or if $V/C_{WZ} > 1$, then

$$l_{WZ} = WZD + 0.2$$

where $l_{WZ}$ is the distance all vehicles travel at the reduced average workzone speed. These assumptions regarding the workzone length can also be carried through in the emissions model.

**Average Length of Queue Over Time Period T**

When the traffic demand exceeds the capacity of the workzone, queue formation takes place. The average length of the queue over the time period T is required to calculate emissions involving idling of the vehicles while in the queue.

The QUEWZ program uses a deterministic queuing model (Ref 7) to predict the queue lengths at the workzone. The deterministic model calculates queues as a simple integral of demand minus capacity over time, and hence predicts accurately only when demand substantially exceeds capacity, which is usually the case in urban freeway workzones. This queuing model used in QUEWZ is described in this section.

The model assumes that there will be no change in demand as the queue forms, and that no traffic will divert to avoid the queue. If vehicles are assumed to arrive at a constant rate during a given hour, and then enter the workzone at a constant rate during a given hour, then the average delay for each hour a queue is present (DQUE), in vehicle hours, is simply the average of the accumulated vehicles in the queue at the beginning of hour i ($ACUM_{i-1}$) and at the end of the hour i ($ACUM_i$),

$$DQUE_i = \frac{ACUM_{i-1} + ACUM_i}{2}$$

where

$$ACUM_i = ACUM_{i-1} + VL_i - C_{WZi},$$

$C_{wzi}$ = restricted capacity through workzone (vph) for hour i, and

$VL_i$ = vehicle demand during hour i.

If the queue dissipates during hour i, then the delay calculation must be modified by the proportion of the hour that a queue was present ($PQUE_i$).

$$PQUE_i = \frac{V_{i-1} - C_{i-1}}{(C_i - C_{i-1}) - (V_i - V_{i-1})}$$

$$= \frac{ACUM_{i-1}}{C_{wzi} - VL_i}$$

Average delay is then calculated as

$$DQUE_i = \frac{ACUM_{i-1}}{2} PQUE_i$$

From this, the average length of queue $QUEL_i$ can be estimated assuming that each vehicle occupies 40 feet (including spacing between vehicles), and that vehicles in the closed lane(s) will merge to the open lane(s) after the queue has formed. In reality, the number of vehicles remaining in the closed lane(s) is a function of the sight distance to the workzone and traffic volumes.

Studies by Richards and Dudek (Ref 38) revealed that as sight distance to a lane closure decreases, more and more drivers are "trapped" in the closed lane at the taper area. Also, sight distance is more critical as traffic volumes increase.

Research by Nemeth and Rouphail (Ref 39) in the area of merging at workzones has produced the following results. Under low-volume conditions, drivers' merging patterns and travel speeds are virtually unaffected by the advance warning devices at the site. Speeds and/or lane changes are initiated only when the construction activity is actually in sight. At higher volumes, however, many drivers merge early. The study indicated that at sites experiencing approach volumes in excess of 1000 vph, it is desirable that early merging be encouraged. It is also suggested that traffic engineering measures that deter travel in the closed lane (i.e., signs saying "lane to be closed ahead") be contemplated.

The model used in the study by Nemeth and Rouphail (Ref 39) assigned a set of merge and speed stimuli to each vehicle. This assignment was based on a survey of 229 drivers conducted at several freeway construction lane-closure sites. Among the results of the survey were the following: 45.4 percent of the drivers merge at the earliest opportunity; 13.1 percent of drivers merge after having passed a few cars; 9.3 percent of drivers merge after having seen other drivers merge; 20.5 percent of drivers merge after having seen construction activity; and 11.7 percent gave no answer. But, the results of the application of the model indicated that merge patterns were dependent on traffic volumes also.

As shown by the above studies, merging of vehicles at workzones involves a complex interaction of driver behavior, sight distance to beginning of closure, and traffic volumes. As a result of this, queue lengths will not be uniform over all lanes of the freeway. Considering the uncertainties involved in the merge patterns, until further research is conducted in this area, the assumption made in the QUEWZ model that vehicles in the closed lane(s) will merge to the open lane(s) after the queue has formed seems to be a reasonable one. Based on this assumption, the queue length was estimated in the following manner in the QUEWZ model:

$$QUEL_i = \frac{40(DQUE_i)}{5280(TL)}$$

where

TL = total number of lanes upstream of the workzone.

For the hour when the queue dissipates

$$QUEL_i = \frac{40(DQUE_i)}{5280(TL)PQUE_i}$$

### Average Vehicle Speeds in a Queue

The average speed at which vehicles creep through a queue is required so that the time spent in the queue can be estimated using the speed and the length of the queue. The average speed through the queue can be estimated using a kinematic wave model developed by Messer (Ref 40) for predicting travel time on an urban freeway. The QUEWZ model uses this result to estimate the average speed ($v_q$, mph) as follows:

$$v_q = \frac{SP_1}{2}\left[1 - \left(1 - \frac{C_{wz}}{C_{ap}}\right)^{1/2}\right]$$

where

$C_{ap}$ = normal capacity (vph),

$C_{wz}$ = workzone capacity (vph), and

SP = free flow speed (mph).

### Vehicle Mix

The methodology presented in the previous chapter is also applicable to the case in which the traffic is composed of a mix of different kinds of vehicles (passenger cars, single-unit trucks, truck-trailers, etc.) which have different emission characteristics. The various parameters required for the calculations, which include the accel-decel characteristics, emission characteristics, and speeds, will have to be specified for all vehicle categories. For the purpose of our analysis, it will be sufficient to consider only two main types of vehicles: passenger cars and trucks.

### Acceleration and Deceleration Rates of Vehicles

The calculation procedure in the previous chapter assumes constant acceleration and deceleration rates for passenger cars and trucks. In actual freeway conditions, accel.-decel. characteristics will be governed by vehicle type and driver attitudes. However, by assuming appropriate average representative values for these variables, it is expected that emission characteristics at the workzone can be adequately captured.

Observed normal roadway acceleration rates for passenger cars from standing stop to 15 mph and for 10 mph increases in speed at running speeds of 20, 30, 40, 50, and 60 mph are given in Table 4.3. These acceleration rates were observed when drivers were not influenced to accelerate rapidly. They are typical of passenger cars starting up after a traffic signal turns green and those on four-lane divided highways. Observed normal deceleration rates of passenger cars are also given in Table 4.3.

Based on the values shown in Table 4.3, an average acceleration rate of 3.0 mph/s (4.5 ft/s$^2$) and an average deceleration rate of 4.0 mph/s (6 ft/s$^2$) is assumed for passenger cars. These values are consistent with the average accel.-decel. rates for 0-30 mph speed changes given in the AASHTO (Ref 41) policy for passenger vehicles at intersections.

For trucks, an average acceleration rate of 1.1 mph/s (1.6 ft/s$^2$) is assumed based on acceleration curves developed in the AASHTO policy for trucks at intersections. Also, an average deceleration rate of 1.5 mph/s (2.2 ft/s$^2$) is assumed for trucks.

**TABLE 4.3. NORMAL ACCELERATION AND DECELERATION RATES FOR PASSENGER CARS (REF 42)**

| Speed Change mph/s | Accelerations mph/s | Decelerations mph/s |
|---|---|---|
| 0-15 | 3.3 | 5.3 |
| 0-30 | 3.3 | 4.6 |
| 30-40 | 3.3 | 3.3 |
| 40-50 | 2.6 | 3.3 |
| 50-60 | 2.0 | 3.3 |
| 60-70 | 1.3 | 3.3 |

### Emission Rates ($m_{pd}$, $m_{pa}$, $m_{pcr}$, and $m_{pi}$)

The emission of each of the pollutants considered (CO, HC, and $NO_X$) varies by vehicle type and also by the mode of operation of the vehicle. These emission rates for passenger cars and trucks for different modes of operation (i.e., cruise, deceleration, idle, and acceleration) should be determined to permit application of the methodology described in the previous chapter.

As mentioned in the review of the literature, the determination of modal emissions is a complex problem, given the lack of data and models for this purpose. This problem will be addressed in Chapter 5.

## SUMMARY

The traffic analysis model required to implement the emission prediction methodology presented in the previous chapter was discussed. The data requirements for the methodology and the use of the QUEWZ model in this context were also described. Next, the emission rate models that will complete all requirements for implementation will be discussed in Chapter 5.

# CHAPTER 5. MODAL EMISSION RATE MODELING

In Chapter 2, we discussed the problems associated with obtaining modal emission rates for various pollutants. Additionally, we described the Modal Analysis Model (Ref 12), the MOBILE4.1 (Ref 16) model, and various adjustment factors of different intersection air quality models used to estimate modal emission rates. From the methodology for workzone mobile source emission prediction presented in Chapter 3 it is clear that modal emission rates similar to those used in these intersection air quality models will be required to implement the methodology.

In this chapter, we first present a summary of the general approaches used to obtain modal emission rates. This is followed by a description of the methodology used to obtain the modal emission rates for each pollutant, namely, CO, HC, and NOx. A description of the input values assumed in obtaining composite emission factors from the MOBILE4.1 model is then presented. The implementation of these models in QUEWZ will be the subject of the next chapter.

## GENERAL APPROACHES

From the discussion of the intersection air quality models presented in Chapter 2, we identified two general approaches for modeling modal emissions. Table 2.4 from Chapter 2 is reproduced here as Table 5.1 to facilitate the following discussion.

One approach has been to use modal emissions from the Modal Analysis Model and to correct this using the ratio of the results from the MOBILE model for actual and base scenarios. The base scenario is for conditions used in the Modal model, namely, a 1977 calendar year, a light-duty vehicle fleet, 100 percent hot-stabilized operating conditions, a temperature of 75°F, and the average speed of the user-defined driving sequence. The actual scenario is for the corresponding conditions in the calendar year being modeled.

This approach is used in the IMM (Ref 21) and the TEXIN2 (Ref 23) models. The main problem associated with this approach is that for every speed at which modal emissions are required, the MOBILE model must be run for the base and actual scenarios for that speed. This implies that the MOBILE model should be merged with the traffic analysis model, which in the present context is the QUEWZ (Ref 7) model. If this is carried out, the workzone model will become very bulky, will require more inputs, and will take a much longer time to run. Also, only a specific version of the MOBILE model can be coded into the workzone model. Frequent updates of the workzone emissions model will be required as the EPA updates the MOBILE model.

The second approach has been to correct (using modal correction factors) the emission rates obtained from runs of the MOBILE model. These correction factors have been derived using limited sets of emissions data from the SDS and FTP driving cycle tests (Ref 18). The correction factors are usually functions of the vehicle speed and acceleration, as can be seen in Table 5.1. This approach has been used in the MICRO2 (Ref 22) and CALINE4 (Ref 10) models.

**TABLE 5.1. INTERSECTION AIR QUALITY MODEL EMISSION RATE ADJUSTMENTS (REF 18)**

| Model | Driving Mode | Base Emission Rate | Base Rate Multiplier |
|---|---|---|---|
| **IMM** | Idle | MOBILE1 idle rate | 5 mph MOBILE1 rate ratio, actual:base scenarios |
| | Cruise | Modal Analysis Model cruise rate | MOBILE1 rate ratio for mean cruise mode speed, actual:base scenarios |
| | Acceleration | Modal Analysis Model acceleration rate | MOBILE1 rate ratio for mean acceleration mode speed, actual:base scenarios |
| | Deceleration | Modal Analysis Model deceleration rate | MOBILE1 rate ratio for mean deceleration mode speed, actual:base scenarios |
| **MICRO2** | Idle | Normalized SDS:FTP idle rate | none |
| | Cruise | Normalized SDS:FTP idle rate | none |
| | Acceleration | MOBILE scenario rate | $E = 0.182 - 0.0079776(AS) + 0.00036227[(AS)^2]$ |
| | Deceleration | Normalized SDS:FTP idle rate | none |
| **TEXIN2** | Idle | MOBILE3 idle rate | none |
| | Cruise | MOBILE3 scenario rate | none |
| | Deceleration/ Acceleration | Modal Analysis Model rates for default speed profiles | MOBILE3 rate ratio, cruise:base scenarios |
| **CALINE4** | Idle | MOBILE idle rate | none |
| | Cruise | 16.2 mph MOBILE scenario rate | $E = [0.494 + 0.000227(S^2)]$ |
| | Acceleration | 16.2 mph MOBILE scenario rate | $E = 0.76[e^{(0.045AS)}]$ or $E = 0.027[e^{(0.098AS)}]$ |
| | Deceleration | MOBILE idle rate | E = 1.5 |

E = multiplier used to adjust base emission rate.
A = acceleration rate; S = speed. Units vary by model.
[a]Specific MOBILE series versions are indicated only for intersection models that code specific emission rates into the model.

Other approaches have also been adopted for such specific uses as estimating modal emissions from diesel vehicles. For example, the TEXAS model (Refs 43 and 44) uses the following approach to model diesel vehicle emissions. Diesel vehicle emissions data from the Southwest Research Institute (Ref 45), expressed in terms of engine RPM and torque, were used to develop regression equations for emissions as a function of vehicle speed and acceleration. This was achieved through the development of a motion equation that relates the engine RPM and torque to vehicle speed and acceleration.

The CALINE4, TEXIN2, and IMM programs were developed exclusively for modeling CO hot spots at intersections. The approach used for modeling modal CO emissions for the purpose of workzone emission prediction will follow closely the approach used in MICRO2 and CALINE4. The approach used in IMM and TEXIN2 is not used for reasons stated previously.

MICRO2 is the only program among these four which models HC and NOx emissions. The modal HC and NOx emission models for the workzone problem will make use of the results from the MICRO2 model.

All the modal emission rate models in the CALINE4 and MICRO2 programs were developed using data from light-duty gasoline vehicles. But, the workzone model also requires modal emission rates for diesel trucks. It is assumed that the behavior of diesel vehicles in different modes of operation is similar to that of gasoline vehicles. Therefore, the modal correction factors developed for passenger cars can be applied to the composite emissions from trucks to obtain the modal emission values.

The following sections describe the models adopted for the workzone problem. Each pollutant, namely, carbon monoxides, hydrocarbons, and nitrogen oxides, is handled separately for convenience and clarity.

## MODAL CARBON MONOXIDE EMISSIONS

### Idle Emissions

The MOBILE4.1 model, which is the recent update of the MOBILE series of models, provides idle emission factors for the hot-stabilized mode of operation. Hot-stabilized idle emissions have been included in the MOBILE models in order to facilitate quantification of emissions resulting from idling in queues. Some examples of such situations include queues at drive-through restaurants, queues at traffic lights, and queues at toll plazas.

The idle emission rates vary with the ambient temperature, vehicle mix, vehicle tampering rates, and calendar year. The scenario used for running the MOBILE4.1 model to obtain the idle emission rates is described in detail later in this chapter.

The variation of idle emissions with speed is shown in Figure 5.1. The data for this were obtained by running the MOBILE4.1 model for the scenario described below and for different average route speeds. A sample input file to the MOBILE4.1 model and output for the scenario described below for different average route speeds and an ambient temperature of 75°F is shown in Appendix A. Also, a summary of the composite emission outputs for passenger cars and trucks is presented in Table 5.5.

All the plots in the sections that follow are for passenger car emissions only. Modal truck emissions can be obtained in the same manner by substituting the composite heavy-duty diesel vehicle emission factors for the passenger car emission factors.

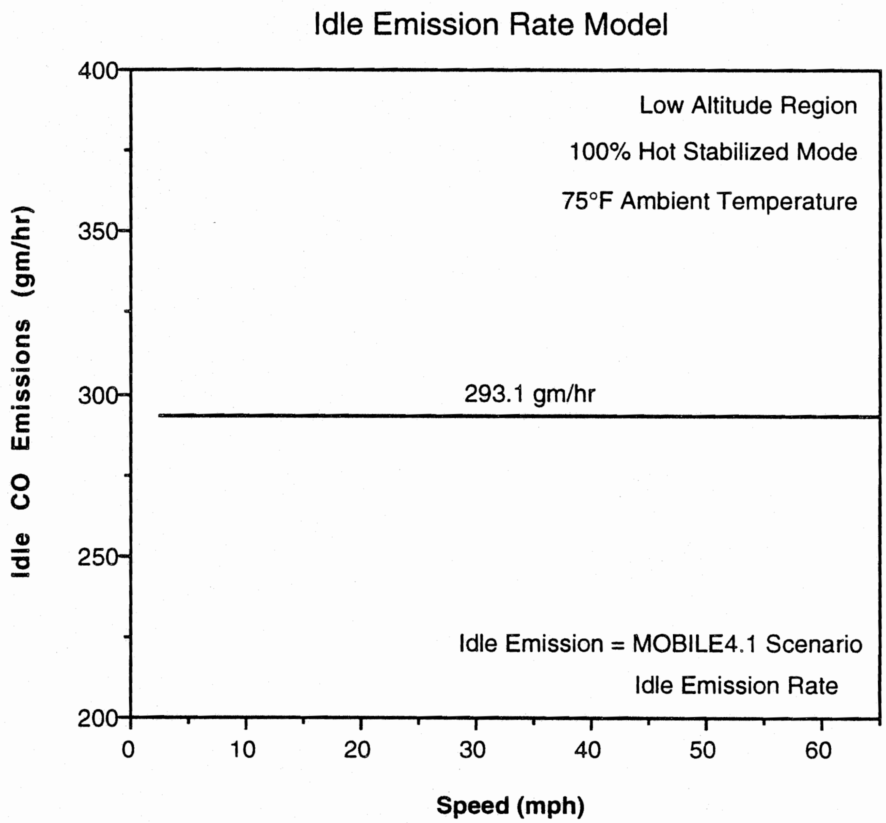


**Figure 5.1. Plot of idle carbon monoxide emission rate model for passenger cars.**

### Deceleration Emissions

The MICRO2 model assumes that emissions in the deceleration mode are constant and that they are equal to the idle emission rate. The CALINE4 model assumes not only that the deceleration mode emissions are constant, but also that they are equal to the MOBILE idle emission rate with a factor of 1.5. This was based on an analysis of the data from CARB (Ref 24). The CARB data contained deceleration emission rates that were relatively constant over the 16 deceleration modes of the SDS driving cycle. These rates were approximately 50 percent more than the idle emission rates.

This observation was found to be consistent with the practice of decelerating by gradually releasing the accelerator during a planned deceleration. In general, decelerations near a workzone can be assumed to be planned decelerations, owing to the presence of numerous signs warning the users of a workzone ahead. However, this is not true when queue formation takes place, as there are several sudden decelerations during this time. But, as an approximation, the deceleration emission rates at a workzone can be assumed to be a constant equal to 1.5 times the idle emission rates, as was done in the CALINE4 model.

The variation of deceleration emissions with speed is shown in Figure 5.2. The data are obtained in a manner similar to that described for idle emissions.

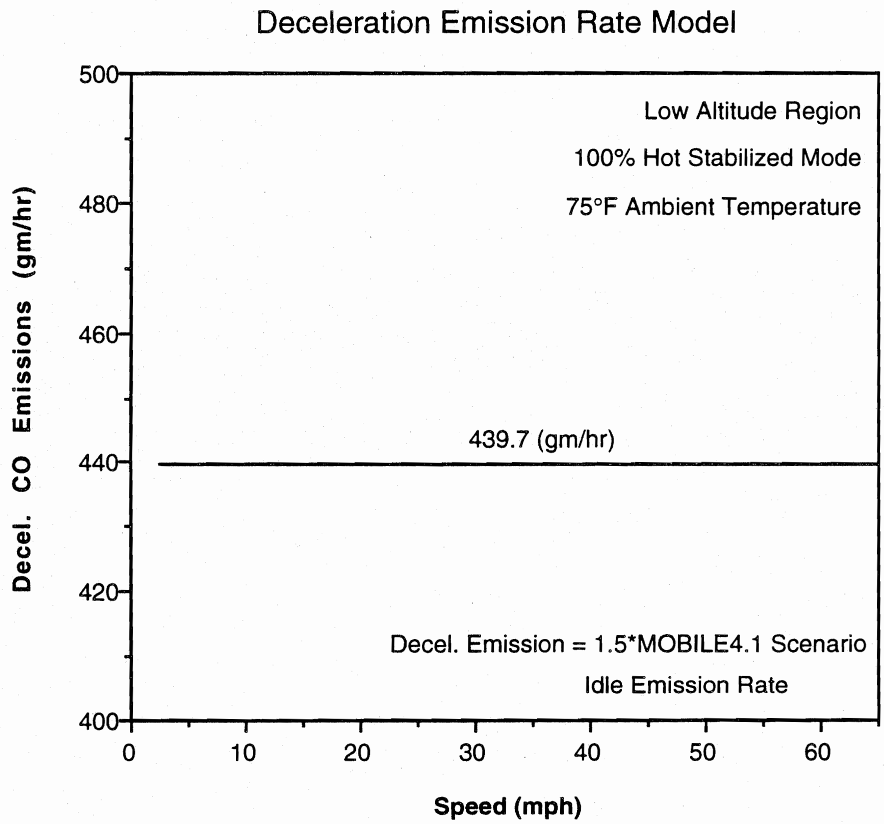


**Figure 5.2. Plot of deceleration carbon monoxide emission rate model for passenger cars.**

### Cruise Emissions

The MICRO2 model assumes that emissions in the cruise mode are constant and that they are equal to the idle emission rate. But, as a vehicle cruises at higher speeds, the CO emissions are known to increase. To account for this, the CALINE4 model uses a cruise correction factor applied to the MOBILE model scenario rate at 16.2 mph, a rate arrived at as follows.

SDS emissions test data for various idling, acceleration, cruise, and deceleration segments were given artificial time weightings to provide a simulated FTP stabilized mode sequence. Data from the cruise portion of the SDS testing cycle were then analyzed to develop correlations with the SDS simulation of the FTP stabilized mode emission rates. The dependent variable, as described above, was the ratio of SDS to FTP (simulated using SDS) emission rate. The independent variable was cruise speed. The following relationship was obtained from this analysis:

Cruise Emission Rate (gm/hr) =16.2 mph MOBILE scenario rate (gm/mi) *16.2 (mph) * (0.494 + 0.000227*$S^2$)

Because the average speed of the hot-stabilized portion of the FTP cycle is 16.2 mph, and since only the hot-stabilized portion of the FTP cycle was used in deriving this relation, the 16.2 mph MOBILE scenario rate is used.

This result is consistent with the fact that the drag force on a vehicle cruising at a speed S is proportional to the square of the speed, $S^2$. Hence, as the vehicle cruises at higher speeds, the higher drag force puts a greater load on the engine, leading to increased CO emissions.

This cruise model is used to represent cruise emissions for the workzone problem. As mentioned before, the scenario used for running the MOBILE4.1 model to get the 16.2 mph scenario rate will be described later in this chapter.

The variation of cruise emissions with speed is shown in Figure 5.3. The 16.2 mph MOBILE scenario rate was obtained by running the MOBILE4.1 model for the scenario described below and by using an average route speed of 16.2 mph.

**Acceleration Emissions**

The MICRO2 and CALINE4 models develop acceleration correction factors to the composite MOBILE emission value as a function of the product of acceleration and speed (AS). The following reasoning is given for the strong correlation between AS and the correction factor (Ref 46). The product of acceleration and speed is equivalent to power per unit mass. Therefore, the power expended by a vehicle during acceleration is proportional to AS. As power demand approaches engine capacity, vehicles tend to burn fuel less efficiently, resulting in higher carbon monoxide emissions.

The acceleration model in MICRO2, developed by The Colorado Department of Highways, was based on data from 45 light-duty 1975 vehicles tested in Denver on the SDS cycle (Ref 25). Results were analyzed using a ratio of the time rate of modal emissions and the time rate of FTP emissions. Use of this ratio allowed the direct conversion of average route speed emission factors to modal emission rates. The acceleration model developed through this analysis was:

Accel. Emission Rate (gm/hr) = MOBILE Scenario Rate (gm/mi) * S (mph) * [0.182 - 0.00798(AS) + 0.000362*(AS)$^2$]

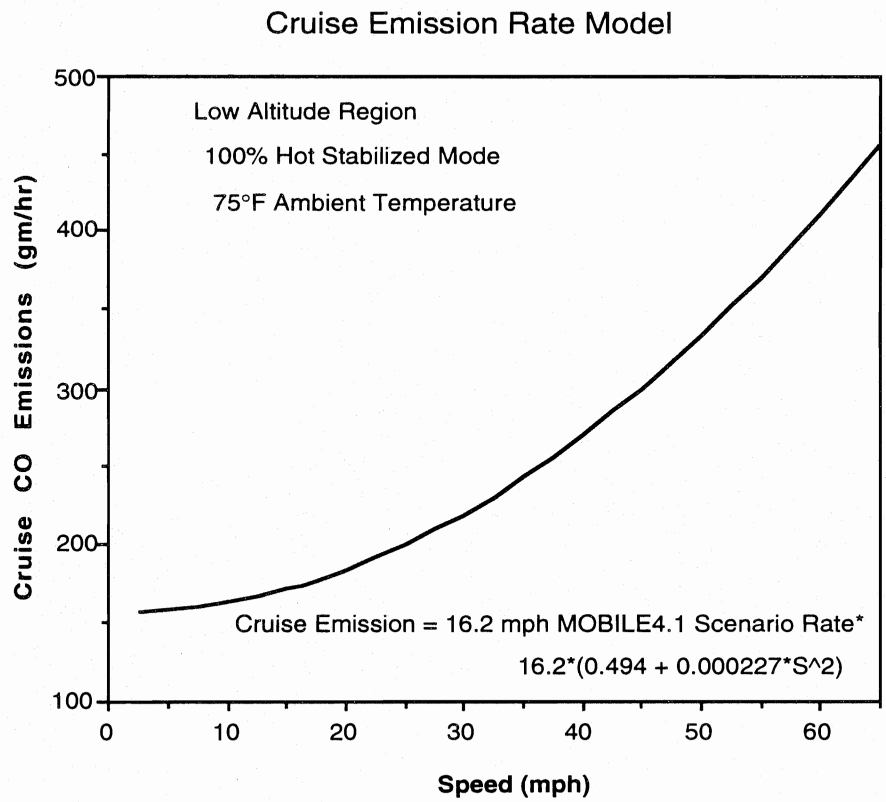


**Figure 5.3. Plot of cruise carbon monoxide emission rate model for passenger cars.**

with AS representing the product of the average acceleration and average speed for the acceleration event in units of $ft^2/sec^3$. Internally, the MICRO2 model assumes a constant acceleration-speed product of 80.6667 $ft^2/sec^3$, representing an average acceleration of 2.5 mph per second between 0 and 30 mph.

For each speed at which the acceleration emission rate is required, the MOBILE scenario rate needs to be determined for an average route speed equal to that speed. Figure 5.4 shows the variation of acceleration emissions with speed, as described by this acceleration model. The MOBILE scenario rates for each speed were determined by running the MOBILE model for the scenario described later in this chapter and for the required average route speed. The acceleration-speed product was assumed to be 97 $ft^2/s^3$, representing an average acceleration of 3.0 mph/s (4.5 ft/s$^2$) between 0 and 30 mph. This acceleration rate is consistent with the assumption made for passenger cars in section 4.2 (g) of Chapter 4.

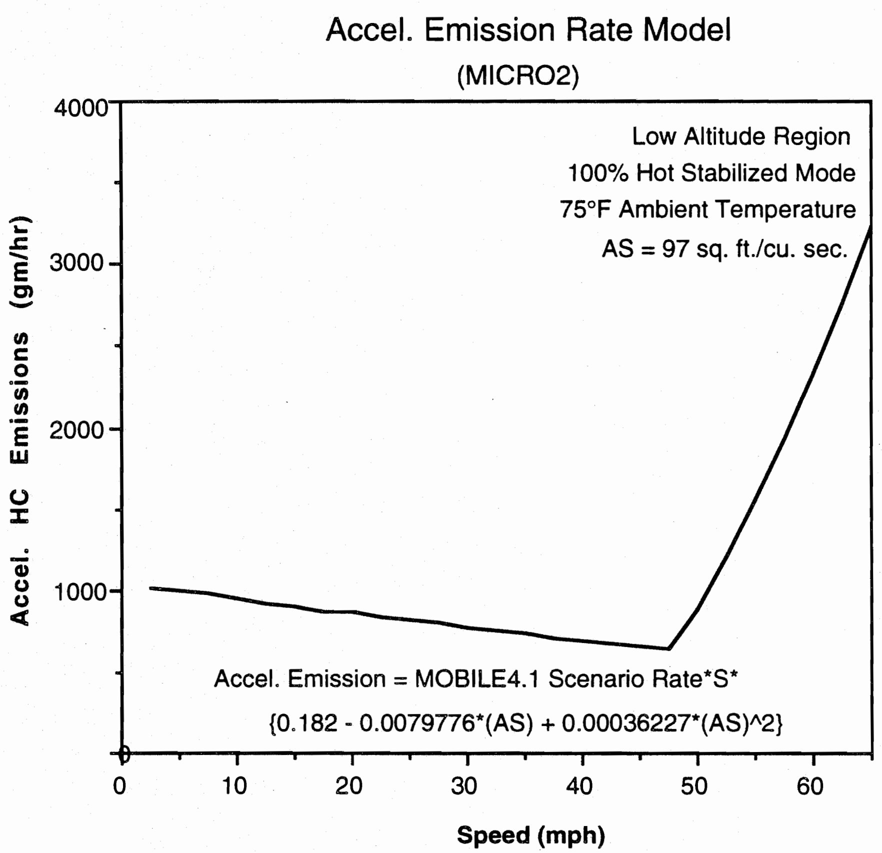


**Figure 5.4. Plot of the MICRO2 acceleration carbon monoxide emission rate model for passenger cars.**

As can be seen from Figure 5.4, as the vehicle gains momentum the emission rate of carbon monoxides decreases. When the vehicle accelerates at high speeds, the emission rate increases rapidly, a result of the very high drag forces that possibly offset the gain in momentum.

The acceleration emission model in CALINE4 is patterned after the MICRO2 model. The dependent variable is again the ratio of the modal to FTP emission rates and the independent variable is AS, the acceleration speed product. However, an exponential functional form is used for the model. Also, separate forms of the model are used depending upon the initial conditions (vehicle at rest or moving).

Similar to the procedure used for cruise emissions modeling, SDS emissions test data for various idling, acceleration, cruise, and deceleration segments were given artificial time weightings to provide a simulated FTP stabilized mode sequence. Data from the acceleration portion of the SDS cycle was than analyzed to develop correlations with the SDS simulation of the FTP stabilized mode emission rates.

The resultant acceleration models were developed from the combined CARB (Ref 24) and EPA (Ref 25) data sets (76 vehicles). The first model is for vehicles starting at rest and accelerating up to 45 mph:

$$\text{Accel. Emission Rate (gm/hr)} = \text{MOBILE Scenario Rate at 16.2 mph (gm/mi)} * 16.2 \text{ (mph)} * 0.76 * e^{(0.045AS)}$$

with AS representing the product of the average acceleration and average speed for the acceleration event in units of $mi^2/hr^2$-sec. The second model was developed for vehicles moving at speeds of 15 mph (or greater) and accelerating up to 60 mph. It was meant for handling such situations as acceleration emissions along on-ramp or weave sections. The model takes the following form:

$$\text{Accel. Emission Rate (gm/hr)} = \text{MOBILE Scenario Rate at 16.2 mph (gm/mi)} * 16.2 \text{ (mph)} * 0.027 * e^{(0.098AS)}$$

The exponential functional form of these models results in very high prediction of emissions in the acceleration mode. Hence, the acceleration model used in the MICRO2 model was used for the workzone problem also.

In summary, the modal carbon monoxide emission rate models used for workzone mobile source emissions are shown in Table 5.2.

## MODAL HYDROCARBON EMISSIONS

As mentioned previously, most modal emission modeling efforts in the past have concentrated mainly on carbon monoxide emissions. As a result, modal models for hydrocarbons and nitrogen oxides are not well developed. Therefore, to arrive at modal emission rates for the workzone model, several simplifying assumptions have been made.

As in the case for idle carbon monoxide emissions, hot-stabilized idle hydrocarbon emissions can be obtained directly from the base scenario run of the MOBILE4.1 model. The deceleration and cruise emission rates are assumed to be equal to the idle emission rate as in the MICRO2 model.

For emission of hydrocarbons under acceleration, the MICRO2 model uses correction factors to the composite MOBILE emission value as a function of the acceleration-speed product (AS). The hydrocarbon acceleration model in MICRO2 was developed in a manner similar to that described for carbon monoxide. The resulting equation is presented below.

$$\text{Accel. Emission Rate (gm/hr)} = \text{MOBILE Scenario Rate (gm/mi)} * S \text{ (mph)} * \{(0.018 + 5.266\text{x}10^{-4} (AS) + 6.1296\text{x}10^{-6} (AS)^2\}$$

**TABLE 5.2. SUMMARY OF MODAL CARBON MONOXIDE MODELS USED FOR WORKZONE MOBILE SOURCE EMISSION PREDICTION**

| MODAL CARBON MONOXIDE EMISSION RATE MODELS |
|---|
| IDLE EMISSIONS<br>= Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr) |
| DECELERATION EMISSIONS<br>= 1.5 * Idle Emissions (gm/hr) |
| CRUISE EMISSIONS<br>= 16.2 mph MOBILE4.1 Scenario Rate * 16.2 * (0.494 + 0.000227 $S^2$) (gm/hr) |
| ACCELERATION EMISSIONS<br>= MOBILE4.1 Scenario Rate * S * {0.182 - 0.0079776 AS + 0.00036227 $(AS)^2$} (gm/hr) |

Again, internally the MICRO2 model assumes a constant acceleration-speed product of 80.6667 $ft^2/s^3$, representing an average acceleration of 2.5 mph/s between 0 and 30 mph.

Figure 5.5 shows the variation of modal hydrocarbon emissions with speed, as described by the models discussed in this section. The MOBILE scenario rates for each speed were determined by running the MOBILE model for the scenario described below and for the required average route speed. As in the carbon monoxide model, the acceleration-speed product for the acceleration mode was assumed to be 97 $ft^2/s^3$, representing an average acceleration of 3.0 mph/s (4.5 $ft/s^2$) between 0 and 30 mph.

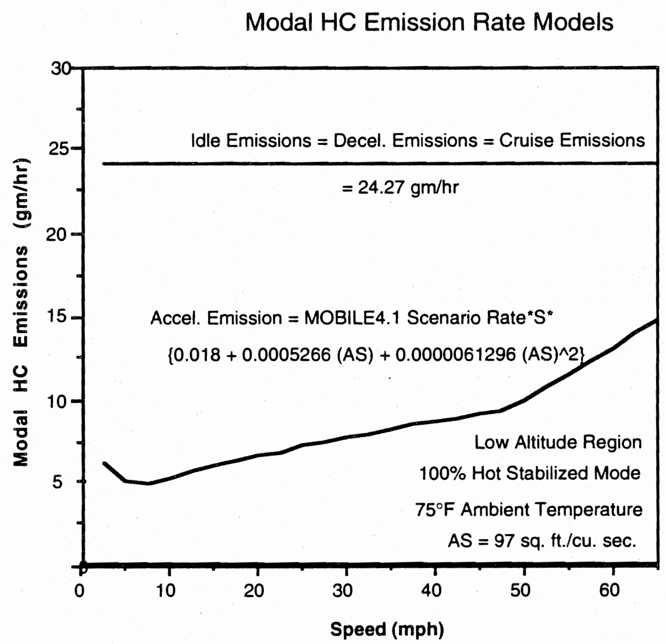


**Figure 5.5. Modal hydrocarbon emission rate models.**

In summary, the modal hydrocarbon emission rate models used for workzone mobile source emission prediction are shown in Table 5.3.

## MODAL NITROGEN OXIDES EMISSIONS

As in the case for idle carbon monoxide and hydrocarbon emissions, hot-stabilized idle nitrogen oxide emissions can be obtained directly from the base scenario run of the MOBILE4.1 model. The cruise emission rate is assumed to be equal to the idle emission rate as in the MICRO2 model.

For emission of nitrogen oxides under deceleration, the MICRO2 model uses correction factors to the composite MOBILE emission value as a function of the deceleration-speed product (AS). The nitrogen oxide deceleration model in MICRO2 was developed in a manner similar to the acceleration models for carbon monoxide and hydrocarbons. The resulting equation is presented below.

$$\text{Decel. Emission Rate (gm/hr)} = \text{MOBILE Scenario Rate (gm/mi)} * \text{S (mph)} * \{0.00143 - 1.7005\times10^{-4}\,(\text{AS})\}$$

with AS representing the product of the average deceleration and average speed for the deceleration event in units of $ft^2/sec^3$. Internally the MICRO2 model assumes a constant deceleration-speed product of 80.6667 $ft^2/s^3$, representing an average deceleration of 2.5 mph/s between 0 and 30 mph.

**TABLE 5.3. SUMMARY OF MODAL HYDROCARBON MODELS USED FOR WORKZONE MOBILE SOURCE EMISSION PREDICTION**

| MODAL HYDROCARBON EMISSION RATE MODELS |
|---|
| <u>IDLE EMISSIONS</u><br>= Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr) |
| <u>DECELERATION EMISSIONS</u><br>= Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr) |
| <u>CRUISE EMISSIONS</u><br>= Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr) |
| <u>ACCELERATION EMISSIONS</u><br>= MOBILE4.1 Scenario Rate * S * $\{0.018 - 5.266 \times 10^{-4} (AS) + 6.1296 \times 10^{-6} (AS)^2\}$ (gm/hr) |

Figure 5.6 shows the variation of modal nitrogen oxide emissions with speed for the idle, cruise, and deceleration modes, as described by the models discussed above.

The MOBILE scenario rates for each speed were determined by running the MOBILE model for the scenario described in section 5.5 and for the required average route speed. As in the carbon monoxide model, to be consistent with the passenger car deceleration rate assumed in section 4.2 (g) of the previous chapter, the deceleration-speed product for the deceleration mode was assumed to be -130 $ft^2/s^3$, representing an average deceleration of 4.0 mph/s (6.0 $ft/s^2$) between 0 and 30 mph.

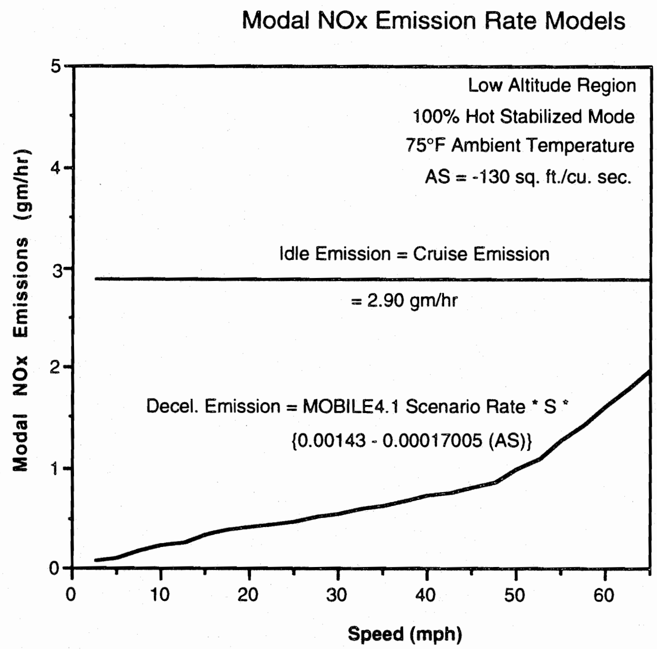


**Figure 5.6. Plot of idle, cruise, and deceleration emission rate models for nitrogen oxides.**

The acceleration model for nitrogen oxide emissions uses results from the MICRO2 model. The MICRO2 model uses correction factors to the composite MOBILE emission value as a function of the acceleration-speed product (AS). The resulting equation is presented below.

Accel. Emission Rate (gm/hr) = MOBILE Scenario Rate (gm/mi) * S (mph) *
{(0.00386 + 8.1446x10$^{-4}$ (AS))}

Again, internally the MICRO2 model assumes a constant acceleration-speed product of 80.6667 ft$^2$/s$^3$, representing an average acceleration of 2.5 mph/s between 0 and 30 mph. Figure 5.7 shows the variation of acceleration emissions with speed.

Accel. Emission Rate Model (NOx)

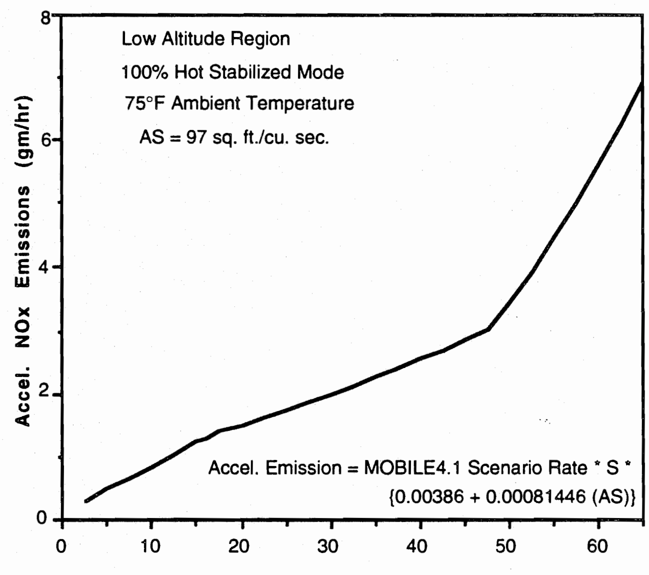


**Figure 5.7. Plot of acceleration emission rate model for nitrogen oxides.**

In summary, the modal nitrogen oxide emission rate models used for workzone mobile source emission prediction are shown in Table 5.4.

## MOBILE4.1 SCENARIO DEFINITION

The emission rate models described in the sections before apply modal correction factors to the composite emission rates from the MOBILE model to arrive at the modal emission rates. The composite emission rates used in the QUEWZ model were obtained by running MOBILE4.1, which is the latest update in the MOBILE series of models. To run the MOBILE4.1 model, reasonable assumptions have to be made regarding input variables that influence emissions so that a representation of the workzone problem is achieved. Assumptions regarding each of these variables is discussed in this section and the runs made using the values ascribed to the variables constitute the MOBILE4.1 scenario rate mentioned in the previous sections.

**TABLE 5.4. SUMMARY OF MODAL NITROGEN OXIDE MODELS USED FOR WORKZONE MOBILE SOURCE EMISSION PREDICTION**

| MODAL NITROGEN OXIDE EMISSION RATE MODELS |
|---|
| IDLE EMISSIONS<br>= Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr)<br><br>DECELERATION EMISSIONS<br>= MOBILE4.1 Scenario Rate * S * {0.00143 - $1.7005 \times 10^{-4}$ (AS)} (gm/hr)<br><br>CRUISE EMISSIONS<br>= Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr)<br><br>ACCELERATION EMISSIONS<br>= MOBILE4.1 Scenario Rate * S * {0.00386 + $8.1446 \times 10^{-4}$ (AS)} (gm/hr) |

**Average Route Speed**

One important variable which has an influence over composite emission rates from MOBILE4.1 is the average route speed. The idle emission factors do not vary with the average route speed in the MOBILE4.1 model. Hence, the idle and deceleration emission rate models require only one run of the MOBILE4.1 routine in order to obtain the idle emission factor. The cruise emission rate model requires composite MOBILE4.1 emission factor at an average route speed of 16.2 mph for reasons stated in the discussion of the cruise emission rate model. The acceleration emission rate model, however, requires composite MOBILE4.1 emission factors for a range of average route speeds from 2.5 mph to 65 mph so that the composite emission factor for any desired average acceleration mode speed can be found by interpolation. Therefore, the MOBILE model needs to be run for a range of average route speeds to fulfill the requirements of all the modal emission rate models.

**Vehicle Miles Traveled (VMT) Mix**

The VMT mix determines the fraction of VMT accumulated by vehicles of each of the eight types, namely, light-duty gasoline vehicles (LDGV), light-duty gasoline trucks 1 (LDGT1), light-duty gasoline trucks 2 (LDGT2), heavy-duty gasoline vehicles (HDGV), light-duty diesel vehicles (LDDV), light-duty diesel trucks (LDDT), heavy-duty diesel vehicles (HDDV), and motorcycles. The model gives the composite emission factors for each of these vehicle types. The VMT mix is then used to obtain a single emission factor which applies to the vehicle fleet.

Since the workzone model deals only with two kinds of vehicles, namely passenger cars and trucks, the composite emission factors corresponding to LDGV's and HDDV's will be used to represent emissions from these two vehicle types. The assumed VMT mix does not affect these individual values. Hence, any VMT mix can be assumed for the MOBILE scenario run.

**Annual Mileage Accumulation Rates and Registration Distributions**

MOBILE4.1's emission factor calculations rely in part on travel fractions for vehicles of each given age and type, which in turn are based on estimates of the average annual mileage accumulation by age (first year to 25th-and-greater years of operation) for each of the eight vehicle types, and the registration distribution by age (age 0-1 to age 24-25+) for each vehicle type, except motorcycles, for which annual mileage accumulation rates and registration distributions are only provided for the 1st to 12th and later years of operation (ages 0-1 to 11-12+).

MOBILE4.1 uses national average annual mileage accumulation rates by age and registration distributions by age, and has provisions allowing the input of locality-specific data for either or both of these (Ref 16). The EPA strongly recommends the use of the annual mileage accumulation rates by age included in MOBILE4.1. The MOBILE4.1 runs for the workzone model make use of the annual mileage accumulation rates and registration distributions included in the model.

**Operating Mode Mix**

The operating mode fraction is an important determinant of vehicle emissions. Emissions data used in the MOBILE model are collected using the FTP test cycle, which is divided into three segments, namely, cold start segment, stabilized segment, and hot start segment. Data from each of these segments reflect the fact that emissions generally are highest when a vehicle is in the cold-start mode; the vehicle, engine, and emission control equipment (particularly the catalytic converter) are all at ambient temperature and thus not performing at optimum levels. Emissions are generally somewhat lower in the hot start mode, when the vehicle is not yet completely warmed up but was not sitting idle for sufficient time to have cooled completely to ambient temperature. Finally, emissions generally are lowest when the vehicle is operating in stabilized mode, and has been in continuous operation long enough for all systems to have attained relatively stable, fully "warmed-up" operating temperatures.

It is assumed that heavily traveled urban freeways will attract vehicle trips at a more or less constant rate over distances equal to the distance at which vehicles reach the end of operation in the cold start mode (Ref 10), provided competing freeways are not close by. Hence, for the workzone emission prediction problem, all vehicles are assumed to be operating in the hot-stabilized mode.

## TABLE 5.5. SUMMARY OF MOBILE4.1 BASE SCENARIO RUNS

| Avg. Route Speed (mph) | CO (gm/mi) Cars | CO (gm/mi) Trucks | HC (gm/mi) Cars | HC (gm/mi) Trucks | $NO_x$ (gm/mi) Cars | $NO_x$ (gm/mi) Trucks |
|---|---|---|---|---|---|---|
| 2.5 | 143.27 | 39.54 | 19.47 | 5.57 | 1.34 | 27.51 |
| 5.0 | 71.04 | 32.28 | 7.91 | 4.90 | 1.13 | 24.73 |
| 7.5 | 46.06 | 26.65 | 5.17 | 4.33 | 1.06 | 22.42 |
| 10.0 | 33.56 | 22.26 | 4.22 | 3.85 | 1.02 | 20.52 |
| 12.5 | 26.12 | 18.80 | 3.62 | 3.44 | 0.99 | 18.94 |
| 15.0 | 21.22 | 16.06 | 3.20 | 3.09 | 0.98 | 17.64 |
| 16.2 | 19.41 | 14.95 | 3.04 | 2.94 | 0.97 | 17.10 |
| 17.5 | 17.73 | 13.88 | 2.88 | 2.79 | 0.97 | 16.57 |
| 20.0 | 15.27 | 12.13 | 2.60 | 2.53 | 0.89 | 15.71 |
| 22.5 | 13.28 | 10.72 | 2.42 | 2.31 | 0.86 | 15.02 |
| 25.0 | 11.67 | 9.59 | 2.27 | 2.12 | 0.84 | 14.50 |
| 27.5 | 10.33 | 8.67 | 2.15 | 1.96 | 0.82 | 14.11 |
| 30.0 | 9.20 | 7.93 | 2.04 | 1.82 | 0.80 | 13.86 |
| 32.5 | 8.24 | 7.34 | 1.94 | 1.70 | 0.79 | 13.74 |
| 35.0 | 7.42 | 6.87 | 1.86 | 1.60 | 0.78 | 13.74 |
| 37.5 | 6.73 | 6.50 | 1.79 | 1.51 | 0.77 | 13.86 |
| 40.0 | 6.13 | 6.22 | 1.72 | 1.43 | 0.77 | 14.10 |
| 42.5 | 5.62 | 6.02 | 1.66 | 1.36 | 0.76 | 14.48 |
| 45.0 | 5.18 | 5.90 | 1.61 | 1.31 | 0.76 | 15.00 |
| 47.5 | 4.80 | 5.84 | 1.56 | 1.26 | 0.77 | 15.68 |
| 50.0 | 6.24 | 5.85 | 1.58 | 1.23 | 0.83 | 16.53 |
| 52.5 | 8.14 | 5.93 | 1.61 | 1.20 | 0.90 | 17.59 |
| 55.0 | 10.03 | 6.08 | 1.64 | 1.17 | 0.98 | 18.88 |
| 57.5 | 11.92 | 6.30 | 1.68 | 1.16 | 1.06 | 20.44 |
| 60.0 | 13.81 | 6.60 | 1.72 | 1.15 | 1.13 | 22.34 |
| 62.5 | 15.71 | 7.00 | 1.76 | 1.14 | 1.21 | 24.62 |
| 65.0 | 17.60 | 7.51 | 1.80 | 1.15 | 1.29 | 27.38 |
| Idle Emissions | 293.1 gm/h | 51.18 gm/h | 24.27 gm/h | 17.37 gm/h | 2.90 gm/h | 22.32 gm/h |

Low Altitude Region; 75°F Ambient Temperature; 100% Hot-Stabilized Mode.

### Other Inputs

No inspection/maintenance program is assumed to be in operation. Also, emission rates are not corrected for air-conditioning usage, extra vehicle load, trailer towing, and humidity. No anti-tampering program is modeled.

Emissions calculations are performed for a low altitude region at an ambient temperature of 75°F for calendar year 1992.

A sample MOBILE4.1 input file and the output file for this base scenario have been included in Appendix A. A summary of the composite emission factors and the idle emission factors from the scenario runs for different average route speeds is shown in Table 5.5.

## SUMMARY

This chapter discussed the general approaches that have been used in the past to obtain modal emission rate models. In addition, the modal models for each of the pollutants, namely, carbon monoxides, hydrocarbons, and nitrogen oxides, were described. The results obtained using these models, along with the output from the MOBILE program, were presented in the form of emission plots. The final step in the workzone emissions modeling process is the implementation of these models in the QUEWZ workzone traffic analysis package. This process is discussed in the next chapter.

# CHAPTER 6. MODEL IMPLEMENTATION AND RESULTS

The incorporation of the modal emission rate models described in Chapter 5 into the methodology discussed in Chapter 3 constitutes the final step in the workzone emissions modeling process. This incorporation requires the correlation of the emission variables defined in Chapter 3 to the emission rate models discussed in Chapter 5.

In this chapter, we describe the implementation of the workzone emissions model in the QUEWZ program (Ref 7). This is followed by a discussion of the results obtained from the model and the use of the model in comparing different workzone strategies vis-`a-vis the environment.

## IMPLEMENTATION

The methodology described in Chapter 3 for workzone mobile source emission prediction requires that the following emission rate values be evaluated:

$m_{pd}$ = emission rate of pollutant p (p = carbon monoxides, hydrocarbons, or nitrogen oxides) emitted under deceleration at an average speed $v_d$. (gm/sec/vehicle)

$m_{pai}$ = emission rate of pollutant p (p = carbon monoxides, hydrocarbons, or nitrogen oxides) emitted under acceleration at an average speed $v_{ai}$. (gm/sec/vehicle)

$m_{pcri}$ = emission rate of pollutant p (p = carbon monoxides, hydrocarbons, or nitrogen oxides) emitted while cruising at an average speed $v_{cri}$. (gm/sec/vehicle)

$m_{pi}$ = mass of pollutant p (p = carbon monoxides, hydrocarbons, or nitrogen oxides) emitted while idling in the queue. (gm/sec/vehicle)

Using the emission rate models developed in the previous chapter, the following relations can be obtained for each of these pollutants and for both the vehicle types (i.e., passenger cars and trucks).

Carbon Monoxides

$m_{COi}$ = Hot Stabilized Idle Emission Rates from the Default MOBILE4.1 (Ref 16) Scenario (gm/hr).

$m_{COd}$ = $1.5 * m_{COi}$

$m_{COcri}$ = 16.2 mph MOBILE4.1 Scenario Rate * 16.2 * $(0.494 + 0.000227\ S^2)$ (gm/hr)

$m_{COai}$ = MOBILE4.1 Scenario Rate at Speed $V_{ai}$ * $V_{ai}$ * {0.182 - 0.0079776 AS + 0.00036227 $(AS)^2$} (gm/hr)

Hydrocarbons

$m_{HCi}$ = Hot Stabilized Idle Emission Rates from the Default MOBILE4.1 Scenario (gm/hr).

$m_{HCd}$ = $m_{HCi}$

$m_{HCcri}$ = $m_{HCi}$

$m_{HCai}$ = MOBILE4.1 Scenario Rate at Speed $V_{ai}$ * $V_{ai}$ * {0.018 - $5.266 \times 10^{-4}$ (AS) + $6.1296 \times 10^{-6}$ $(AS)^2$} (gm/hr)

Nitrogen Oxides

$m_{NOxi}$ = Hot Stabilized Idle Emission Rates from the Default MOBILE4.1 Scenario (gm/hr).

$m_{NOxd}$ = MOBILE4.1 Scenario Rate at Speed $V_d$ * $V_d$ * {0.00143 - $1.7005 \times 10^{-4}$ (AS)} (gm/hr)

$m_{NOxcri}$ = Hot Stabilized Idle Emission Rates from MOBILE4.1 Scenario (gm/hr)

$m_{NOxai}$ = MOBILE4.1 Scenario Rate at Speed $V_{ai}$ * $V_{ai}$ * {0.00386 + $8.1446 \times 10^{-4}$ (AS)} (gm/hr)

The acceleration and deceleration emission rate equations shown above are taken from the MICRO2model (Ref 22). As mentioned in Chapter 5, the MICRO2 model uses a constant value for the acceleration-speed product in these equations. The acceleration and deceleration values assumed for the workzone model and the AS values used for passenger cars and trucks are shown in Table 6.1.

**TABLE 6.1. ACCELERATION-SPEED PRODUCT (AS) FOR PASSENGER CARS AND TRUCKS**

| MODE | Accel. Rates (ft/s^2) | | AS (sq. ft. / cu. sec.) | |
|---|---|---|---|---|
| | Pass. Cars | Trucks | Pass. Cars | Trucks |
| Acceleration | 4.5 | 1.6 | 97.0 | 35.0 |
| Deceleration | -6.0 | -2.2 | -130.0 | -48.5 |

The other inputs that are required for implementing these models include:

- the MOBILE4.1 scenario hot-stabilized idle emission rates,
- the 16.2 mph MOBILE4.1 scenario rate for carbon monoxide, and
- the MOBILE4.1 scenario rate for speeds ranging from 0 to 65 mph for all pollutants.

The default MOBILE4.1 scenario for obtaining these inputs was defined in the previous chapter; the values of these inputs for this default scenario were shown in Table 5.5. Correction factors to be applied for scenarios other than the default scenario are discussed in the next section.

All the modal emission rate equations discussed in Chapter 5 are either assumed to be constants, or are functions of speed, except for the acceleration and deceleration emission rate models, some of which are functions of the MOBILE4.1 scenario rate also. This implies that the MOBILE model will have to be run for each speed at which acceleration and deceleration emissions are required. For ease of implementation of these models in QUEWZ, however, it is necessary to make these acceleration and deceleration emission rate models independent of the MOBILE4.1 scenario rate. Using these equivalent models, the emission rate can be determined given the speed of the vehicle in the acceleration or deceleration zone without having to run the MOBILE4.1 model to obtain the scenario rate for that speed. As an example, the equivalent emission rate model for emission of carbon monoxides under acceleration is derived here.

The emission rate model for emission of carbon monoxides under acceleration is as follows:

$$m_{COai} = \text{MOBILE4.1 Scenario Rate} * S * \{0.182 - 0.0079776\ AS + 0.00036227\ (AS)^2\}\ \text{(gm/hr)}$$

From Table 6.1., the acceleration speed product, AS for passenger cars is 97 $ft^2/s^3$. Using this value gives the following result for $m_{COai}$.

$$m_{COai} = \text{MOBILE4.1 Scenario Rate} * S * 2.816$$

The MOBILE4.1 default scenario rates for different speeds ranging from 2.5 mph to 65 mph were shown in Table 5.5. Multiplying these values by the corresponding speeds and by the factor of 2.816, a range of values $m_{COai}$ are obtained for different speeds. Regressing these values against speed gives the following equivalent model for the emission rate of carbon monoxides under acceleration (passenger cars):

$$m_{COai} = 1011.4 - 9.0*S + 0.804*S^2 - 0.04903*S^3 + 0.000729*S^4\ \text{(gm/hr)}.$$

The original model and the regressed equivalent model are shown in Figure 6.1. Similar equivalent models are obtained for emission rates of CO, HC, and $NO_X$ under acceleration and deceleration, both for passenger cars and trucks. These equivalent regression models are included in Appendix B.

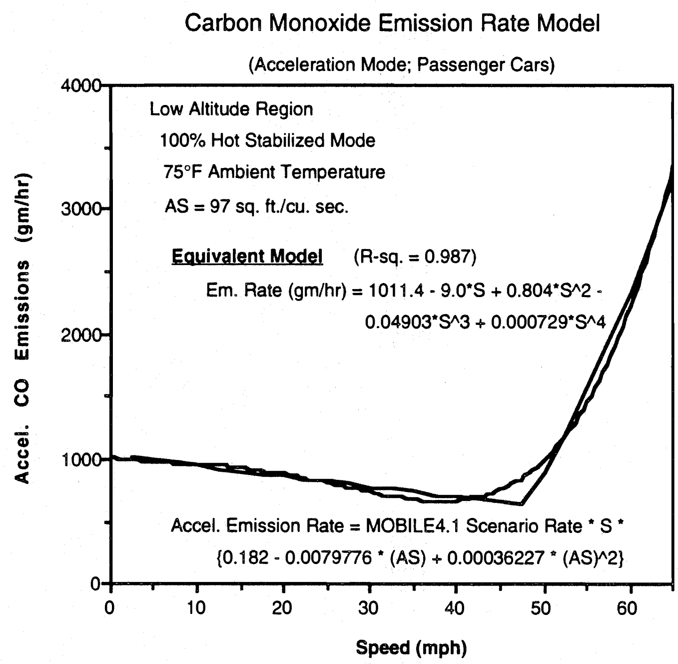


**Figure 6.1. Equivalent CO emission rate model under acceleration.**

These equivalent models have been formulated for their ease of implementation in QUEWZ and do not have any physical significance. These models derive their physical significance from the original models in the MICRO2 program. As discussed in Chapter 5, the MICRO2 model gives the emission rates in terms of the acceleration speed product, which is related to power per unit mass and hence to emissions.

## CORRECTION FACTORS

The default scenario which was used to obtain the required MOBILE4.1 outputs was described in the previous chapter. The main elements of this default scenario are as follows :

- A low altitude region is modeled,
- An ambient temperature of 75°F is used,
- All vehicles are assumed to be operating in a hot stabilized mode,
- No anti-tampering program is in effect,

- No inspection/maintenance program is in effect, and
- MOBILE4.1 default vehicle age distributions are used.

To model scenarios other than this default scenario, correction factors need to be applied to the emission rate equations used in the workzone model. Correction factors based solely on the differences between idle emissions in the default scenario versus the actual scenario being modeled are used in the emissions model. The following correction factors $k_1$, $k_2$, ..., $k_6$ are used in the model depending on the type of pollutant and the type of vehicle :

Carbon Monoxide

$$k_1 = \frac{\text{Idle CO Emission Rate for Cars in the Actual Scenario}}{\text{Idle CO Emission Rate for Cars in the Default Scenario}}$$

$$k_2 = \frac{\text{Idle CO Emission Rate for Trucks in the Actual Scenario}}{\text{Idle CO Emission Rate for Trucks in the Default Scenario}}$$

Hydrocarbons

$$k_3 = \frac{\text{Idle HC Emission Rate for Cars in the Actual Scenario}}{\text{Idle HC Emission Rate for Cars in the Default Scenario}}$$

$$k_4 = \frac{\text{Idle HC Emission Rate for Trucks in the Actual Scenario}}{\text{Idle HC Emission Rate for Trucks in the Default Scenario}}$$

Nitrogen Oxides

$$k_5 = \frac{\text{Idle } NO_x \text{ Emission Rate for Cars in the Actual Scenario}}{\text{Idle } NO_x \text{ Emission Rate for Cars in the Default Scenario}}$$

$$k_6 = \frac{\text{Idle } NO_x \text{ Emission Rate for Trucks in the Actual Scenario}}{\text{Idle } NO_x \text{ Emission Rate for Trucks in the Default Scenario}}$$

Appendices C and D summarize all the modal emission rate models, for passenger cars and trucks respectively, used for implementing the workzone emission prediction model on the QUEWZ package.

**THE QUEWZEE PROGRAM**

The methodologies and models described in the preceding chapters were implemented in the QUEWZ program. The revised version of the QUEWZ model is called QUEWZEE, indicating the additional capabilities of predicting energy values and emission values.

The emission model was appended as a separate file independent of the QUEWZ program. Changes were made in the original QUEWZ program only for the purposes of reading input data and writing the output file. The source code for the emissions procedure of the QUEWZEE program is included in Appendix E.

The only additional inputs needed by the program for emissions calculation are the hot stabilized idle emission rates of CO, HC, and $NO_x$ for passenger cars and trucks for the scenario being modeled.

The program gives an output of the carbon monoxide, hydrocarbon, and nitrogen oxide emissions for each hour that the workzone is in operation. In addition, the total daily excess emissions of these pollutants is output by the program.

## ILLUSTRATIVE EXAMPLES

In order to test the model and to illustrate its use, eight sample workzone problems were analyzed. All the sample problems use an ADT of 25,000 vehicles in each direction of the freeway. The original number of lanes, number of open lanes at the workzone, workzone length, and workzone activity period were the various parameters in these sample problems. Table 6.2 summarizes the characteristics of these problems and the corresponding results from the QUEWZEE model. Appendix F contains the complete outputs for each of these problems.

The general behavior of the emission values is the same as those of the user costs and energy values. As can be seen from Table 6.2, queuing significantly affects the excess emissions created in the workzone.

An important application of this model is in choosing between different workzone traffic management strategies. Choosing between the strategy in test problem 5 and the strategy in test problem 7 is an example of this application. The required construction work can be performed on the roadway by either closing two lanes at the same time or by closing one lane at a time and working for twice the period of time. The excess emissions due to the closure of two lanes at the same time is more than double the excess emissions from the closure of one lane at a time. In a similar manner, comparisons between various strategies can be made to arrive at optimal workzone configurations and work schedules.

Another application of this model would be in the analysis of the workzone and the elements affected by it as a system. Such a systems approach for the analysis of a workzone has been recently proposed (Ref 6). Given a major freeway or highway reconstruction or rehabilitation project, the analysis would take into account the agency costs, the business costs, the road user costs, the environmental costs, and costs to other parties (e.g., utility companies). The construction strategy that leads to a minimum system cost would then be chosen. The workzone emissions prediction model will be helpful in quantifying the environmental impacts of each strategy being considered. The results can be used as leverage for construction strategies that make use of expediting techniques.

## TABLE 6.2. SUMMARY OF INPUTS TO AND OUTPUTS FROM THE TEST PROBLEMS

| Prob. No. | No. of Lanes | No. of Open Lanes | WZ Length (mi) | Normal Capacity (vph) | Restricted WZ Capacity | | Hours of Restr. Capacity | | Hours of WZ Activity | | Longest Queue (mi) | Total Emissions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Inactivity Hrs. (vph) | Activity Hrs. (vph) | Beg. | End | Beg. | End | | CO (Kgs) | HC (Kgs) | NOx (Kgs) |
| 1 | 2 | 1 | 1.0 | 4000 | 1800 | 1485 | 8 | 17 | 9 | 16 | 0.8 | 96.5 | 9.1 | 2.0 |
| 2 | 2 | 1 | 2.0 | 4000 | 1800 | 1485 | 8 | 17 | 9 | 16 | 0.8 | 101.7 | 11.7 | 2.6 |
| 3 | 2 | 1 | 1.0 | 4000 | 1800 | 1485 | 0 | 24 | 9 | 16 | 2.2 | 449.1 | 42.3 | 9.6 |
| 4 | 2 | 1 | 2.0 | 4000 | 1800 | 1485 | 0 | 24 | 9 | 16 | 2.2 | 464.5 | 48.5 | 11.1 |
| 5 | 3 | 2 | 1.0 | 6000 | 3600 | 2970 | 8 | 17 | 9 | 16 | 0.0 | 6.7 | 0.2 | 0.0 |
| 6 | 3 | 2 | 2.0 | 6000 | 3600 | 2970 | 8 | 17 | 9 | 16 | 0.0 | 6.4 | 0.4 | 0.1 |
| 7 | 3 | 1 | 1.0 | 6000 | 1800 | 1250 | 8 | 17 | 9 | 16 | 1.6 | 449.2 | 42.6 | 9.7 |
| 8 | 3 | 1 | 2.0 | 6000 | 1800 | 1250 | 8 | 17 | 9 | 16 | 1.6 | 459.1 | 46.9 | 10.8 |

To illustrate the enormous impact that can be caused by workzones on freeways, we now provide an estimate of the excess emissions generated by workzones at reconstruction and rehabilitation sites on the nation's deficient bridge infrastructure.

The work done by Weissmann and Harrison (Ref 47) to predict user costs for similar purposes is used as the basis for this analysis. Only bridges with high traffic levels (defined by an ADT > 20,000) were considered in their analysis. Bridges with ADT between 20,000 and 30,000 were assumed to be two lanes one way, with one lane closed during work. Bridges with ADT between 30,000 and 45,000 were assumed to be three lanes one way, with two lanes closed and one lane of traffic from the bridge under construction being switched to run counterflow in the closed inside lane. Bridges with ADT greater than 45,000 were assumed to be four lanes one way, with two lanes closed during work. There were 524 deficient bridges of the two-lane kind, 297 deficient bridges of the three-lane kind, and 363 deficient bridges of the four-lane kind identified in the study. The total user costs during reconstruction work on these bridges were calculated to be approximately $6 billion.

A similar analysis is performed for the emission of carbon monoxides, hydrocarbons, and nitrogen oxides. Results of the analysis of these bridges using QUEWZEE are shown in Table 6.3.

**TABLE 6.3. PREDICTED EMISSIONS USING QUEWZEE MODEL**

| ADT | No. of Lanes[1] | No. of Def. Bridges | CO/day/ Bridge (kgs) | HC/day/ Bridge (kgs) | NOx/day /Bridge (kgs) | Total[2] CO Em. (tons) | Total[2] HC Em. (tons) | Total[2] NOx Em. (tons) |
|---|---|---|---|---|---|---|---|---|
| > 20,000 < 30,000 | 2 | 524 | 70.6 | 6.4 | 1.4 | 11098.32 | 1006.08 | 220.08 |
| > 30,000 < 45,000 | 3[3] | 297 | 41.8 | 2.0 | 0.4 | 3724.38 | 178.20 | 35.64 |
| > 45,000 | 4 | 363 | 493.3 | 46.6 | 10.9 | 53720.37 | 5074.74 | 1187.01 |
| Totals | | 1184 | | | | 68543.07 | 6259.02 | 1442.73 |

1 One lane closed for 2-lane capacity, two lanes for 4-lane capacity.
2 Total Emissions assume a 300-day contract cycle per structure.
3 Construction first rehabilitates two lanes, then the third. Two lanes always open to traffic. When only one lane is open, the matching bridge is opened to diverted traffic and both bridges are reduced to two lane travel.

The predicted carbon monoxide emissions total to 68,543 tons, hydrocarbon emissions total to 6,259 tons, and nitrogen oxide emissions total to 1,443 tons. As noted by Weissmann and Harrison, this figure is conservative, since it relates only to a subset of the rural bridge population and uses a truck ADT of 14 percent, which is lower than most interstate values.

The results presented above give an indication of the magnitude of the emissions problem at workzones.

## SUMMARY

The implementation of the workzone mobile source emission prediction model was discussed in this chapter. In addition, the use of correction factors to model scenarios other than the default scenario was described. The idle emission factors for the actual scenario will be required as inputs to QUEWZEE to apply these correction factors. The main features of the QUEWZEE model were explained and some applications of the model were described. The magnitude of the emissions problem at workzones was illustrated using workzones associated with nationwide reconstruction of deficient bridges.

# CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

As mentioned in the introduction, many of the nation's heavily traveled urban freeways are being reconstructed or rehabilitated, with such construction activities most often introducing negative impacts to the surrounding environment. Included among these negative impacts are the excess vehicle emissions generated within roadway workzones. If planners could predict these excess emissions, then they would be able to compare different workzone traffic management strategies based on the predicted values. The workzone mobile source emission prediction model developed in this study provides a means for making such comparisons.

The report authors pursued this prediction model according to the following objectives:

- review and evaluate current techniques and models used for the prediction of emissions from mobile sources,
- develop a methodology for the quantification of mobile source emissions at workzones based on the above review,
- validate the methodology and implement it as a computer model, and
- illustrate the applications of the computer model to workzone problems.

The preceding chapters have detailed the manner in which these objectives were attained. Specifically, the report detailed (1) the four steps involved in a comprehensive mobile source pollution modeling process; (2) the traffic modeling and source strength determination processes; and (3) the use of QUEWZ for modeling workzone emissions.

The study succeeded in developing QUEWZEE, a computer model that is capable of predicting mobile source emissions at freeway workzones. These predictions are based on the characteristics of the workzone (e.g., configuration and schedules), the characteristics of traffic at the workzone (such as volume, percent trucks, etc.), and the emissions characteristics of vehicles in the area. The model gives the excess emission values for two vehicle types and three pollutant types.

The model can be used for comparing the environmental aspects of construction and traffic management strategies for the workzone. Moreover, the results from the model can be used as leverage towards expedited construction strategies that help in reducing air pollution. The magnitude of the emissions problem at workzones was illustrated using workzones at deficient bridge reconstruction sites in the United States.

The model cannot, however, take into account the diversion of traffic away from the workzone caused by the formation of long queues. When queues develop upstream of the workzone, traffic diverts to frontage roads or to other parallel routes. Hence, the traffic volume passing through the workzone is less than what might ordinarily be expected. Further research is needed to quantify the nature of this traffic diversion. Currently, the traffic distribution input into the model needs to account for the amount of traffic that diverts to avoid the workzone.

The lack of accurate, validated models that characterize modal emissions from vehicles was underscored throughout this study. As new data and modal emission rate models become available, the QUEWZEE model can be easily updated to incorporate the new findings.

The increase in truck traffic on freeways has resulted in an increase in particulate emissions. The nature of these emissions needs to be explored in greater detail. Collection of particulate emissions data and quantification of the emissions by mode of operation is another area for future work.

Finally, while making enhancements to the emissions model, the trade-off between increasing the accuracy of the emission rate models and the discrimination that is reflected in the results needs to be considered.

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# APPENDIX A:

# DEFAULT SCENARIO RUNS OF THE

# MOBILE4.1 MODEL

***** BASE SCENARIO RUNS OF MOBILE4.1 FOR 75F AMBIENT TEMP. *****

Total HC emission factors include evaporative HC emission factors.

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0

2.5 mph 75F 0%CS

Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 2.5 | 2.5 | 2.5 | | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 19.91 | 22.86 | 30.97 | 0.00 | 46.08 | 1.44 | 1.93 | 5.57 | 13.65 | 18.04 |
| Exhst HC: | 7.08 | 10.17 | 14.04 | 0.00 | 16.60 | 1.44 | 1.93 | 5.57 | 9.71 | 6.88 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 11.52 | 11.31 | 14.66 | 0.00 | 22.93 | | | | | 10.02 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 143.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 39.54 | 0.00 | 129.79 |
| Exhst NOX: | 1.34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 27.51 | 0.00 | 4.74 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0

5.0 mph 75F 0%CS

Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 5.0 | 5.0 | 5.0 | | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 8.34 | 10.14 | 13.89 | 0.00 | 25.77 | 1.27 | 1.70 | 4.90 | 9.99 | 7.90 |
| Exhst HC: | 3.77 | 5.57 | 7.63 | 0.00 | 13.23 | 1.27 | 1.70 | 4.90 | 6.05 | 3.92 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 3.26 | 3.18 | 3.99 | 0.00 | 6.00 | | | | | 2.84 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 71.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.28 | 0.00 | 66.00 |
| Exhst NOX: | 1.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 24.73 | 0.00 | 4.20 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0

7.5 mph 75F 0%CS

Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 7.5 | 7.5 | 7.5 | | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 5.61 | 6.91 | 9.52 | 0.00 | 20.13 | 1.12 | 1.50 | 4.33 | 8.19 | 5.44 |
| Exhst HC: | 2.60 | 3.87 | 5.24 | 0.00 | 10.65 | 1.12 | 1.50 | 4.33 | 4.25 | 2.83 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 1.70 | 1.65 | 2.01 | 0.00 | 2.93 | | | | | 1.48 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 46.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 26.65 | 0.00 | 43.54 |
| Exhst NOX: | 1.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.42 | 0.00 | 3.83 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0

10.0mph 75F 0%CS

Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 10.0 | 10.0 | 10.0 | | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 4.65 | 5.68 | 7.84 | 0.00 | 17.46 | 0.99 | 1.33 | 3.85 | 7.21 | 4.55 |
| Exhst HC: | 2.01 | 3.02 | 4.02 | 0.00 | 8.67 | 0.99 | 1.33 | 3.85 | 3.27 | 2.25 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 1.34 | 1.28 | 1.55 | 0.00 | 2.24 | | | | | 1.16 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 33.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.26 | 0.00 | 32.09 |
| Exhst NOX: | 1.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.52 | 0.00 | 3.55 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
12.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 12.5 | 12.5 | 12.5 | | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 4.06 | 4.91 | 6.81 | 0.00 | 15.48 | 0.89 | 1.19 | 3.44 | 6.64 | 3.98 |
| Exhst HC: | 1.66 | 2.51 | 3.31 | 0.00 | 7.13 | 0.89 | 1.19 | 3.44 | 2.69 | 1.89 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 1.09 | 1.02 | 1.24 | 0.00 | 1.81 | | | | | 0.95 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 26.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.80 | 0.00 | 25.17 |
| Exhst NOX: | 0.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.94 | 0.00 | 3.32 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
15.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 15.0 | 15.0 | 15.0 | | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 3.64 | 4.38 | 6.11 | 0.00 | 13.97 | 0.80 | 1.07 | 3.09 | 6.27 | 3.56 |
| Exhst HC: | 1.42 | 2.17 | 2.84 | 0.00 | 5.92 | 0.80 | 1.07 | 3.09 | 2.33 | 1.64 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.91 | 0.82 | 1.01 | 0.00 | 1.50 | | | | | 0.79 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 21.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.06 | 0.00 | 20.55 |
| Exhst NOX: | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.64 | 0.00 | 3.14 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
16.2mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 16.2 | 16.2 | 16.2 | | 16.2 | 16.2 | 16.2 | 16.2 | 16.2 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 3.47 | 4.18 | 5.85 | 0.00 | 13.37 | 0.76 | 1.02 | 2.94 | 6.14 | 3.40 |
| Exhst HC: | 1.34 | 2.05 | 2.67 | 0.00 | 5.44 | 0.76 | 1.02 | 2.94 | 2.19 | 1.55 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.83 | 0.74 | 0.91 | 0.00 | 1.39 | | | | | 0.72 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 19.41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.95 | 0.00 | 18.83 |
| Exhst NOX: | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.10 | 0.00 | 3.07 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
17.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 17.5 | 17.5 | 17.5 | | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 3.32 | 3.98 | 5.60 | 0.00 | 12.79 | 0.72 | 0.97 | 2.79 | 6.01 | 3.25 |
| Exhst HC: | 1.26 | 1.93 | 2.51 | 0.00 | 4.97 | 0.72 | 0.97 | 2.79 | 2.07 | 1.46 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.75 | 0.66 | 0.82 | 0.00 | 1.27 | | | | | 0.65 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 17.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.88 | 0.00 | 17.23 |
| Exhst NOX: | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.57 | 0.00 | 2.99 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
20.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 20.0 | 20.0 | 20.0 | | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 3.03 | 3.54 | 5.05 | 0.00 | 11.86 | 0.65 | 0.88 | 2.53 | 5.83 | 2.97 |
| Exhst HC: | 1.10 | 1.63 | 2.11 | 0.00 | 4.21 | 0.65 | 0.88 | 2.53 | 1.89 | 1.28 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.63 | 0.53 | 0.67 | 0.00 | 1.09 | | | | | 0.55 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 15.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.13 | 0.00 | 14.86 |
| Exhst NOX: | 0.89 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.71 | 0.00 | 2.82 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
22.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 22.5 | 22.5 | 22.5 | | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.85 | 3.28 | 4.72 | 0.00 | 11.13 | 0.60 | 0.80 | 2.31 | 5.68 | 2.78 |
| Exhst HC: | 0.98 | 1.43 | 1.85 | 0.00 | 3.61 | 0.60 | 0.80 | 2.31 | 1.74 | 1.16 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.56 | 0.47 | 0.60 | 0.00 | 0.98 | | | | | 0.49 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 13.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.72 | 0.00 | 12.95 |
| Exhst NOX: | 0.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.02 | 0.00 | 2.70 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
25.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 25.0 | 25.0 | 25.0 | | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.71 | 3.07 | 4.45 | 0.00 | 10.55 | 0.55 | 0.74 | 2.12 | 5.56 | 2.63 |
| Exhst HC: | 0.89 | 1.26 | 1.63 | 0.00 | 3.13 | 0.55 | 0.74 | 2.12 | 1.62 | 1.05 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.51 | 0.43 | 0.54 | 0.00 | 0.88 | | | | | 0.44 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 11.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.59 | 0.00 | 11.40 |
| Exhst NOX: | 0.84 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.50 | 0.00 | 2.61 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
27.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 27.5 | 27.5 | 27.5 | | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.58 | 2.89 | 4.22 | 0.00 | 10.08 | 0.51 | 0.68 | 1.96 | 5.45 | 2.50 |
| Exhst HC: | 0.81 | 1.12 | 1.46 | 0.00 | 2.74 | 0.51 | 0.68 | 1.96 | 1.51 | 0.96 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.46 | 0.39 | 0.49 | 0.00 | 0.80 | | | | | 0.40 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 10.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.67 | 0.00 | 10.11 |
| Exhst NOX: | 0.82 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.11 | 0.00 | 2.54 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
30.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 30.0 | 30.0 | 30.0 | | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.47 | 2.74 | 4.03 | 0.00 | 9.70 | 0.47 | 0.63 | 1.82 | 5.36 | 2.39 |
| Exhst HC: | 0.75 | 1.00 | 1.31 | 0.00 | 2.42 | 0.47 | 0.63 | 1.82 | 1.42 | 0.89 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.42 | 0.35 | 0.45 | 0.00 | 0.73 | | | | | 0.36 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 9.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.93 | 0.00 | 9.04 |
| Exhst NOX: | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.86 | 0.00 | 2.50 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
32.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 32.5 | 32.5 | 32.5 | | 32.5 | 32.5 | 32.5 | 32.5 | 32.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.38 | 2.61 | 3.86 | 0.00 | 9.38 | 0.44 | 0.59 | 1.70 | 5.27 | 2.29 |
| Exhst HC: | 0.69 | 0.90 | 1.18 | 0.00 | 2.16 | 0.44 | 0.59 | 1.70 | 1.33 | 0.82 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.38 | 0.32 | 0.41 | 0.00 | 0.67 | | | | | 0.33 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 8.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.34 | 0.00 | 8.12 |
| Exhst NOX: | 0.79 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.74 | 0.00 | 2.47 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
35.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 35.0 | 35.0 | 35.0 | | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.30 | 2.50 | 3.72 | 0.00 | 9.11 | 0.41 | 0.55 | 1.60 | 5.20 | 2.20 |
| Exhst HC: | 0.64 | 0.82 | 1.07 | 0.00 | 1.95 | 0.41 | 0.55 | 1.60 | 1.26 | 0.77 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.35 | 0.30 | 0.38 | 0.00 | 0.62 | | | | | 0.30 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 7.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.87 | 0.00 | 7.35 |
| Exhst NOX: | 0.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.74 | 0.00 | 2.46 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
37.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 37.5 | 37.5 | 37.5 | | 37.5 | 37.5 | 37.5 | 37.5 | 37.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.22 | 2.40 | 3.60 | 0.00 | 8.90 | 0.39 | 0.52 | 1.51 | 5.14 | 2.13 |
| Exhst HC: | 0.60 | 0.74 | 0.97 | 0.00 | 1.78 | 0.39 | 0.52 | 1.51 | 1.20 | 0.72 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.31 | 0.28 | 0.35 | 0.00 | 0.57 | | | | | 0.27 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 6.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.50 | 0.00 | 6.70 |
| Exhst NOX: | 0.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.86 | 0.00 | 2.47 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
40.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 40.0 | 40.0 | 40.0 | | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.16 | 2.32 | 3.49 | 0.00 | 8.71 | 0.37 | 0.50 | 1.43 | 5.09 | 2.06 |
| Exhst HC: | 0.57 | 0.68 | 0.89 | 0.00 | 1.64 | 0.37 | 0.50 | 1.43 | 1.15 | 0.68 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.28 | 0.25 | 0.33 | 0.00 | 0.53 | | | | | 0.25 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 6.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.22 | 0.00 | 6.14 |
| Exhst NOX: | 0.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.10 | 0.00 | 2.50 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
42.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 42.5 | 42.5 | 42.5 | | 42.5 | 42.5 | 42.5 | 42.5 | 42.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.10 | 2.25 | 3.40 | 0.00 | 8.56 | 0.35 | 0.47 | 1.36 | 5.05 | 2.00 |
| Exhst HC: | 0.54 | 0.63 | 0.82 | 0.00 | 1.53 | 0.35 | 0.47 | 1.36 | 1.11 | 0.65 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.25 | 0.23 | 0.30 | 0.00 | 0.49 | | | | | 0.22 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 5.62 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.02 | 0.00 | 5.67 |
| Exhst NOX: | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.48 | 0.00 | 2.55 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
45.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 45.0 | 45.0 | 45.0 | | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.05 | 2.19 | 3.32 | 0.00 | 8.43 | 0.34 | 0.45 | 1.31 | 5.03 | 1.95 |
| Exhst HC: | 0.51 | 0.59 | 0.77 | 0.00 | 1.44 | 0.34 | 0.45 | 1.31 | 1.09 | 0.62 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.23 | 0.22 | 0.28 | 0.00 | 0.45 | | | | | 0.20 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 5.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.90 | 0.00 | 5.27 |
| Exhst NOX: | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.00 | 0.00 | 2.61 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
47.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 47.5 | 47.5 | 47.5 | | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.00 | 2.13 | 3.25 | 0.00 | 8.33 | 0.33 | 0.44 | 1.26 | 5.01 | 1.90 |
| Exhst HC: | 0.49 | 0.55 | 0.72 | 0.00 | 1.37 | 0.33 | 0.44 | 1.26 | 1.07 | 0.59 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.20 | 0.20 | 0.26 | 0.00 | 0.42 | | | | | 0.18 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 4.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.84 | 0.00 | 4.94 |
| Exhst NOX: | 0.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.68 | 0.00 | 2.70 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
50.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 50.0 | 50.0 | 50.0 | | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.01 | 2.15 | 3.27 | 0.00 | 8.24 | 0.32 | 0.42 | 1.23 | 5.09 | 1.91 |
| Exhst HC: | 0.52 | 0.58 | 0.76 | 0.00 | 1.31 | 0.32 | 0.42 | 1.23 | 1.15 | 0.62 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.18 | 0.18 | 0.24 | 0.00 | 0.38 | | | | | 0.16 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 6.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.85 | 0.00 | 6.19 |
| Exhst NOX: | 0.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 16.53 | 0.00 | 2.87 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
52.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 52.5 | 52.5 | 52.5 | | 52.5 | 52.5 | 52.5 | 52.5 | 52.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.05 | 2.19 | 3.32 | 0.00 | 8.16 | 0.31 | 0.41 | 1.20 | 5.20 | 1.94 |
| Exhst HC: | 0.57 | 0.64 | 0.83 | 0.00 | 1.27 | 0.31 | 0.41 | 1.20 | 1.26 | 0.65 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.17 | 0.16 | 0.22 | 0.00 | 0.34 | | | | | 0.14 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 8.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.93 | 0.00 | 7.85 |
| Exhst NOX: | 0.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.59 | 0.00 | 3.07 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
55.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 55.0 | 55.0 | 55.0 | | 55.0 | 55.0 | 55.0 | 55.0 | 55.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.08 | 2.23 | 3.37 | 0.00 | 8.11 | 0.30 | 0.41 | 1.17 | 5.31 | 1.96 |
| Exhst HC: | 0.62 | 0.69 | 0.90 | 0.00 | 1.25 | 0.30 | 0.41 | 1.17 | 1.36 | 0.69 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.15 | 0.15 | 0.20 | 0.00 | 0.31 | | | | | 0.13 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 10.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.08 | 0.00 | 9.52 |
| Exhst NOX: | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.88 | 0.00 | 3.31 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
57.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 57.5 | 57.5 | 57.5 | | 57.5 | 57.5 | 57.5 | 57.5 | 57.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.12 | 2.27 | 3.43 | 0.00 | 8.07 | 0.30 | 0.40 | 1.16 | 5.41 | 1.99 |
| Exhst HC: | 0.67 | 0.75 | 0.97 | 0.00 | 1.24 | 0.30 | 0.40 | 1.16 | 1.47 | 0.73 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.14 | 0.14 | 0.18 | 0.00 | 0.29 | | | | | 0.12 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 11.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.30 | 0.00 | 11.19 |
| Exhst NOX: | 1.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.44 | 0.00 | 3.58 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
60.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 60.0 | 60.0 | 60.0 | | 60.0 | 60.0 | 60.0 | 60.0 | 60.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.15 | 2.31 | 3.48 | 0.00 | 8.05 | 0.30 | 0.40 | 1.15 | 5.52 | 2.02 |
| Exhst HC: | 0.72 | 0.80 | 1.05 | 0.00 | 1.24 | 0.30 | 0.40 | 1.15 | 1.58 | 0.77 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.13 | 0.13 | 0.17 | 0.00 | 0.26 | | | | | 0.11 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 13.81 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.60 | 0.00 | 12.88 |
| Exhst NOX: | 1.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.34 | 0.00 | 3.89 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
62.5mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 62.5 | 62.5 | 62.5 | | 62.5 | 62.5 | 62.5 | 62.5 | 62.5 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.19 | 2.36 | 3.54 | 0.00 | 8.05 | 0.30 | 0.40 | 1.14 | 5.62 | 2.06 |
| Exhst HC: | 0.77 | 0.86 | 1.12 | 0.00 | 1.25 | 0.30 | 0.40 | 1.14 | 1.68 | 0.82 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.12 | 0.12 | 0.15 | 0.00 | 0.24 | | | | | 0.10 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 15.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.00 | 0.00 | 14.57 |
| Exhst NOX: | 1.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 24.62 | 0.00 | 4.25 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

Cal. Year: 1992 Region: Low Altitude: 500. Ft.
I/M Program: No Ambient Temp: 75.0 / 75.0 / 75.0 F
Anti-tam. Program: No Operating Mode: 0.0 / 0.0 / 0.0
65.0mph 75F 0%CS
Minimum Temp: 59. (F) Maximum Temp: 91. (F)
Period 1 RVP: 11.5 Period 2 RVP: 11.5 Period 2 Yr: 1988

| Veh. Type: | LDGV | LDGT1 | LDGT2 | LDGT | HDGV | LDDV | LDDT | HDDV | MC | All Veh |
|---|---|---|---|---|---|---|---|---|---|---|
| Veh. Spd.: | 65.0 | 65.0 | 65.0 | | 65.0 | 65.0 | 65.0 | 65.0 | 65.0 | |
| VMT Mix: | 0.870 | 0.000 | 0.000 | | 0.000 | 0.000 | 0.000 | 0.130 | 0.000 | |
| Composite Emission Factors (Gm/Mile) | | | | | | | | | | |
| Total HC: | 2.23 | 2.40 | 3.60 | 0.00 | 8.05 | 0.30 | 0.40 | 1.15 | 5.73 | 2.09 |
| Exhst HC: | 0.82 | 0.91 | 1.19 | 0.00 | 1.28 | 0.30 | 0.40 | 1.15 | 1.79 | 0.86 |
| Evap. HC: | 1.20 | 1.29 | 2.17 | 0.00 | 6.42 | | | | 3.48 | 1.04 |
| Refuel HC: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | 0.00 |
| Runing HC: | 0.11 | 0.11 | 0.14 | 0.00 | 0.23 | | | | | 0.10 |
| Rsting HC: | 0.11 | 0.09 | 0.10 | 0.00 | 0.13 | | | | 0.46 | 0.10 |
| Exhst CO: | 17.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.51 | 0.00 | 16.29 |
| Exhst NOX: | 1.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 27.38 | 0.00 | 4.68 |
| Hot Stabilized Idle Emission Factors (Gm/Hr) | | | | | | | | | | |
| Idle HC: | 24.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.37 | 0.00 | 23.37 |
| Idle CO: | 293.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.18 | 0.00 | 261.65 |
| Idle NOX: | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 22.32 | 0.00 | 5.43 |

# APPENDIX B:

# EQUIVALENT EMISSION RATE MODELS FOR ACCELERATION AND DECELERATION MODES

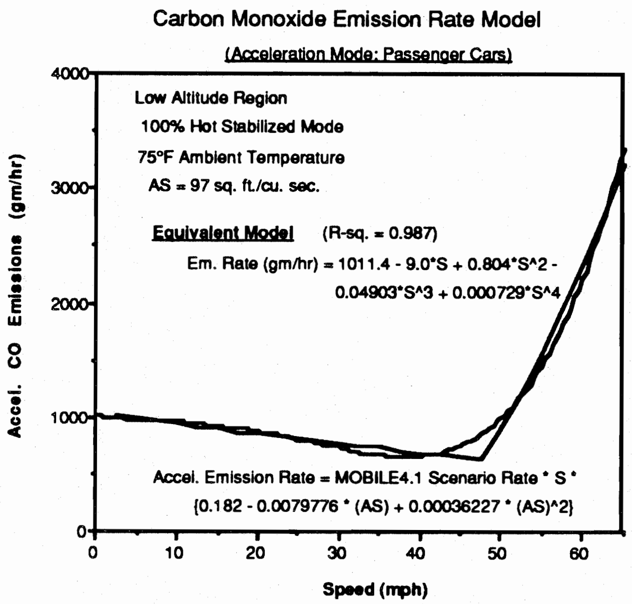


**Figure B.1. Equivalent CO Emission Rate Model Under Acceleration (Passenger Cars).**

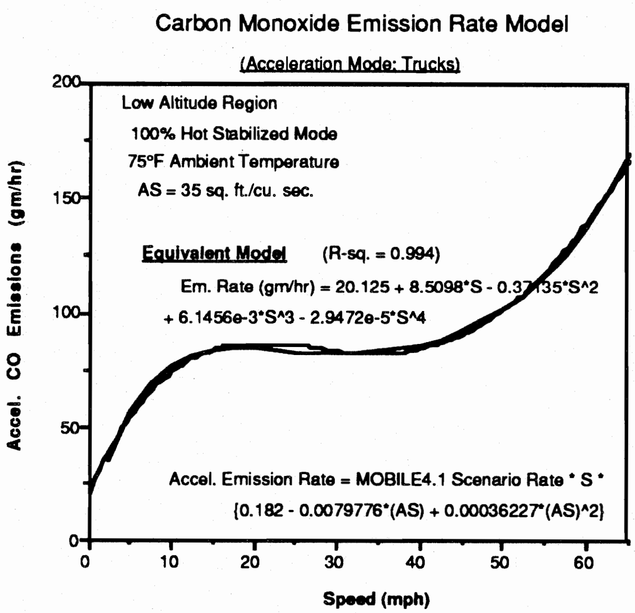


**Figure B.2. Equivalent CO Emission Rate Model Under Acceleration (Trucks).**

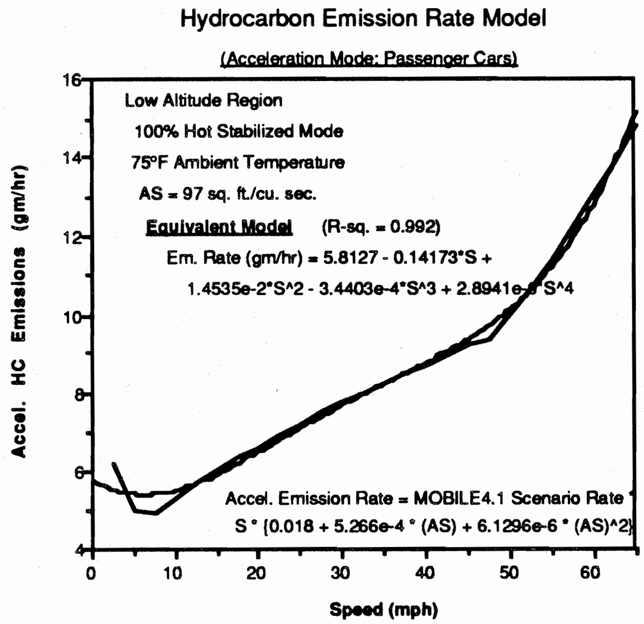


**Figure B.3. Equivalent HC Emission Rate Model Under Acceleration (Passenger Cars).**

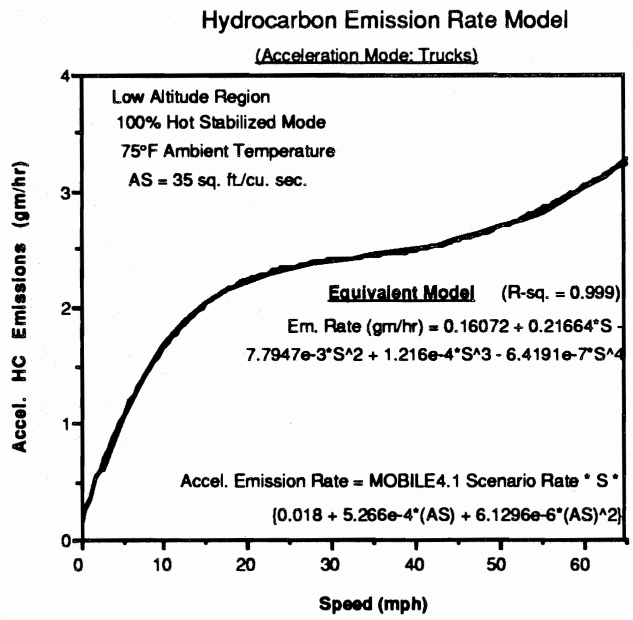


**Figure B.4. Equivalent HC Emission Rate Model Under Acceleration (Trucks).**

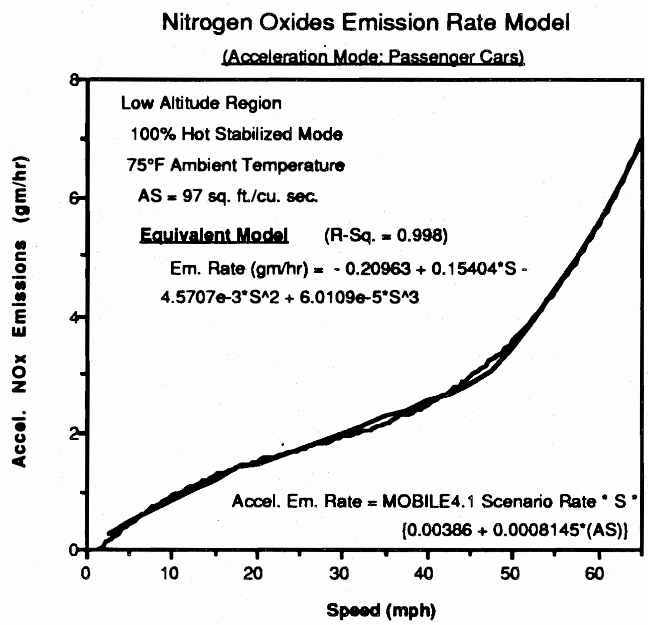


**Figure B.5.** **Equivalent $NO_x$ Emission Rate Model Under Acceleration (Passenger Cars).**

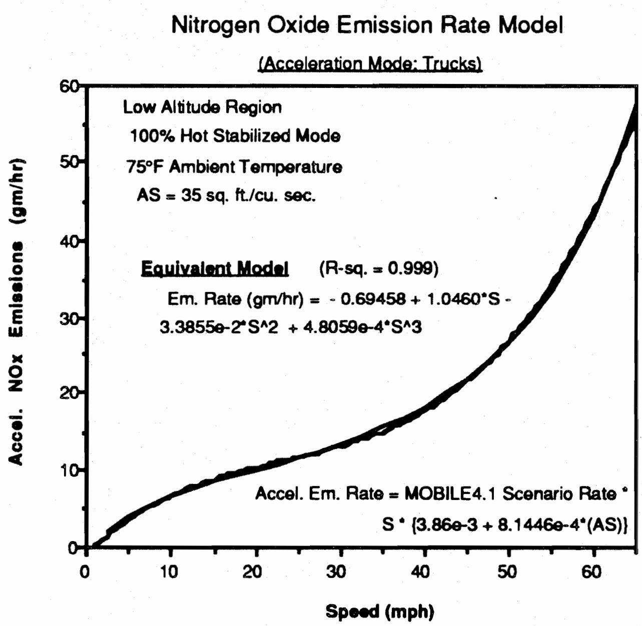


**Figure B.6. Equivalent $NO_x$ Emission Rate Model Under Acceleration (Trucks).**

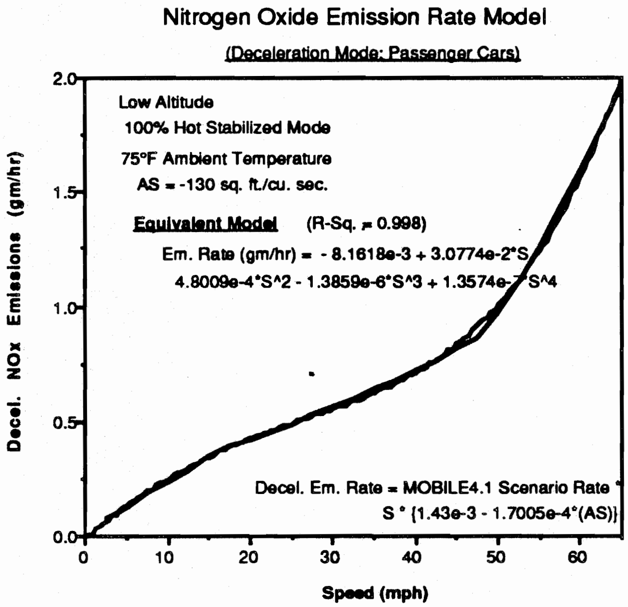


**Figure B.7. Equivalent $NO_x$ Emission Rate Model Under Deceleration (Passenger Cars).**

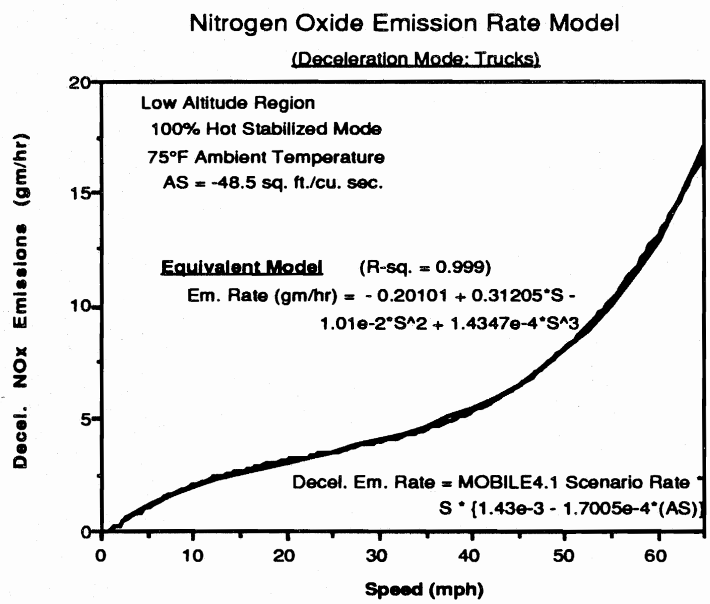


**Figure B.8. Equivalent $NO_x$ Emission Rate Model Under Deceleration (Trucks).**

# APPENDIX C:

# MODAL EMISSION RATE MODELS USED IN QUEWZEE

# (PASSENGER CARS)

## CARBON MONOXIDE

$m_{COi}$ = $k_1 * 293.1$ (gm/hr).

$m_{COd}$ = $k_1 * 1.5 * 293.1$ (gm/hr).

$m_{COcri}$ = $k_1 * 19.41 * 16.2 * (0.494 + 0.000227 V_{cri}^2)$ (gm/hr).

$m_{COai}$ = $k_1 * (1011.4 - 9.0 * V_{ai} + 0.804 * V_{ai}^2 - 0.04903 * V_{ai}^3 + 0.000729 * V_{ai}^4)$ (gm/hr).

## HYDROCARBONS

$m_{HCi}$ = $k_3 * 24.27$ (gm/hr).

$m_{HCd}$ = $k_3 * 24.27$ (gm/hr).

$m_{HCcri}$ = $k_3 * 24.27$ (gm/hr).

$m_{HCai}$ = $k_3 * (5.8127 - 0.14173 * V_{ai} + 1.4535e\text{-}2 * V_{ai}^2 - 3.4403e\text{-}4 * V_{ai}^3 + 2.8941e\text{-}6 * V_{ai}^4)$ (gm/hr).

## NITROGEN OXIDES

$m_{NOxi}$ = $k_5 * 2.9$ (gm/hr).

$m_{NOxd}$ = $k_5 * (-8.1618e\text{-}3 + 3.0774 * V_d - 4.8009e\text{-}4 * V_d^2 - 1.3859e\text{-}6 * V_d^3 + 1.3574e\text{-}7 * V_d^4)$ (gm/hr).

$m_{NOxcri}$ = $k_5 * 2.9$ (gm/hr).

$m_{NOxai}$ = $k_5 * (-0.20963 + 0.15404 * V_{ai} - 4.5707e\text{-}3 * V_{ai}^2 + 6.0109e\text{-}5 * V_{ai}^3)$ (gm/hr).

# APPENDIX D:

# MODAL EMISSION RATE MODELS USED IN QUEWZEE

# (TRUCKS)

## CARBON MONOXIDE

$$m_{COi} = k_2 * 51.18 \text{ (gm/hr).}$$

$$m_{COd} = k_2 * 1.5 * 51.18 \text{ (gm/hr).}$$

$$m_{COcri} = k_2 * 14.95 * 16.2 * (0.494 + 0.000227 V_{cri}^2) \text{ (gm/hr).}$$

$$m_{COai} = k_2 * (20.125 + 8.5098 * V_{ai} - 0.37135 * V_{ai}^2 + 6.1456e\text{-}3 * V_{ai}^3 - 2.9472e\text{-}5 * V_{ai}^4) \text{ (gm/hr).}$$

## HYDROCARBONS

$$m_{HCi} = k_4 * 17.37 \text{ (gm/hr).}$$

$$m_{HCd} = k_4 * 17.37 \text{ (gm/hr).}$$

$$m_{HCcri} = k_4 * 17.37 \text{ (gm/hr).}$$

$$m_{HCai} = k_4 * (0.16072 + 0.21664 * V_{ai} - 7.7947e\text{-}3 * V_{ai}^2 + 1.216e\text{-}4 * V_{ai}^3 - 6.4191e\text{-}7 * V_{ai}^4) \text{ (gm/hr).}$$

## NITROGEN OXIDES

$$m_{NOxi} = k_6 * 22.32 \text{ (gm/hr).}$$

$$m_{NOxd} = k_6 * (- 0.20101 + 0.31205 * V_d - 1.01e\text{-}2 * V_d^2 + 1.4347e\text{-}4 * V_d^3) \text{ (gm/hr).}$$

$$m_{NOxcri} = k_6 * 22.32 \text{ (gm/hr).}$$

$$m_{NOxai} = k_6 * (-0.69458 + 1.046 * V_{ai} - 3.3855e\text{-}2 * V_{ai}^2 + 4.8059e\text{-}4 * V_{ai}^3) \text{ (gm/hr).}$$

# APPENDIX E:

# SOURCE CODE FOR THE QUEWZEE MODEL EMISSIONS PROCEDURE

```
{ ----- MODEL FOR PREDICTION OF EXCESS EMISSIONS ----- }

procedure emissions(dir,time: integer);
var
   minspeed, lengthredspd, timedecel, timedecel_tr, lengthdecel,
   lengthdecel_tr, spddecel, spddecel_tr, timeaccel1, timeaccel1_tr,
   lengthaccel1, lengthaccel1_tr, spdaccel1, spdaccel1_tr,
   timewzone, timewzone_tr, timeaccel2, timeaccel2_tr, lengthaccel2,
   lengthaccel2_tr, spdaccel2, spdaccel2_tr, timequeue, aff_length,
   aff_length_tr, time_aff, time_aff_tr,
   idle_CO, idle_CO_tr, idle_HC, idle_HC_tr, idle_NOX, idle_NOX_tr,
   scen_CO, scen_CO_tr, corr_CO_car, corr_CO_tr, corr_HC_car,
   corr_HC_tr, corr_NOX_car, corr_NOX_tr: real;
   i : pollutant;
   em_rate : array[pollutant,mode,vehicle] of real;

begin
    { Calculation of minimum speed near the work zone }
    minspeed := speed[2,dir,time] - 2.3 - 25.7*sqr(vc[2]);
    { Accounting for the hour when queue dissipation occurs }
    if queindex = 2 then
        minspeed := minspeed*(1-queclear);
    if (queindex = 1) or (minspeed<=0) then
        minspeed := 0;
    { Calculation of effective length of closure }
    lengthredspd := 0.1 + (wzlength + 0.1)*(vc[2]);
    if lengthredspd < 0.3 then
        lengthredspd := 0.3;
    { Calculation of time and length over which deceleration occurs near WZ }
    timedecel      := 1.467*(minspeed - speed[1,dir,time])/decel_rate;
    timedecel_tr   := 1.467*0.9*(minspeed - speed[1,dir,time])/decel_rate_tr;
    lengthdecel    := 1.467*speed[1,dir,time]*timedecel +
              0.5*decel_rate*sqr(timedecel);
    lengthdecel_tr := 1.467*0.9*speed[1,dir,time]*timedecel_tr +
              0.5*decel_rate_tr*sqr(timedecel_tr);
    spddecel       := lengthdecel/(1.467*timedecel);
    spddecel_tr    := lengthdecel_tr/(1.467*timedecel_tr);
    { Calculation of time and length over which acceleration occurs ( Zone 1 ) }
    timeaccel1      := 1.467*(speed[2,dir,time] - minspeed)/accel_rate;
    timeaccel1_tr   := 1.467*0.9*(speed[2,dir,time] - minspeed)/accel_rate_tr;
    lengthaccel1    := 1.467*minspeed*timeaccel1 +
              0.5*accel_rate*sqr(timeaccel1);
    lengthaccel1_tr := 1.467*0.9*minspeed*timeaccel1_tr +
              0.5*accel_rate_tr*sqr(timeaccel1_tr);
    spdaccel1       := lengthaccel1/(1.467*timeaccel1);
    spdaccel1_tr    := lengthaccel1_tr/(1.467*timeaccel1_tr);
    { Calculation of time spent in the WZ traveling at WZ average speed }
    timewzone    := 3600*lengthredspd/speed[2,dir,time];
    timewzone_tr := 3600*lengthredspd/(0.9*speed[2,dir,time]);
    { Calculation of time and length over which acceleration occurs ( Zone 2 ) }
    timeaccel2      := 1.467*(speed[1,dir,time] - speed[2,dir,time])
            /accel_rate;
    timeaccel2_tr   := 1.467*0.9*(speed[1,dir,time] - speed[2,dir,time])
```

```
            /accel_rate_tr;
    lengthaccel2   := 1.467*speed[2,dir,time]*timeaccel2 +
            0.5*accel_rate*sqr(timeaccel2);
    lengthaccel2_tr := 1.467*0.9*speed[2,dir,time]*timeaccel2_tr +
            0.5*accel_rate_tr*sqr(timeaccel2_tr);
    spdaccel2      := lengthaccel2/(1.467*timeaccel2);
    spdaccel2_tr   := lengthaccel2_tr/(1.467*timeaccel2_tr);

{           Modal Emission Rate Calculations                }

    idle_CO     := 293.1;    { Idle Rates Obtained from Base Scenario  }
    idle_CO_tr  := 51.2;     {      Runs of the MOBILE4.1              }
    idle_HC     := 24.3;     {  Model for a Low Altitude Region,       }
    idle_HC_tr  := 17.4;     {  100 % Hot Stabilized Operation Mode    }
    idle_NOX    := 2.9;      {   and 75 F Ambient Temperature,         }
    idle_NOX_tr := 22.3;     { with no ATP or I/M Programs in Effect   }

    corr_CO_car := idleCOcar/idle_CO;       {  Correction Factors for      }
    corr_CO_tr  := idleCOtr/idle_CO_tr;     {  Scenarios Other than the    }
    corr_HC_car := idleHCcar/idle_HC;       { Base Scenario. Factors are   }
    corr_HC_tr  := idleHCtr/idle_HC_tr;     { based on the Idle Emission   }
    corr_NOX_car:= idleNOXcar/idle_NOX;     { Rates of the Actual vs the   }
    corr_NOX_tr := idleNOXtr/idle_NOX_tr;   {     Base Scenarios           }

    scen_CO    := 314.44;   {16.2 mph LDGV Scenario Rate*16.2}
    scen_CO_tr := 242.19;   {16.2 mph HDDV Scenario Rate*16.2}

    em_rate[CO,idle,carr]   := corr_CO_car*idle_CO/3600;
    em_rate[CO,decel,carr]  := corr_CO_car*1.5*idle_CO/3600;
    em_rate[CO,accel1,carr] := corr_CO_car*(1011.4 - 9.0*spdaccel1
                  + 0.804*power(spdaccel1,2)
                  - 4.903e-02*power(spdaccel1,3)
                  + 7.29e-04*power(spdaccel1,4)
               )/3600;
    em_rate[CO,accel2,carr] := corr_CO_car*(1011.4 - 9.0*spdaccel2
                  + 0.804*power(spdaccel2,2)
                  - 4.903e-02*power(spdaccel2,3)
                  + 7.29e-04*power(spdaccel2,4)
               )/3600;
    em_rate[CO,cruise1,carr] := corr_CO_car*scen_CO*(0.494 + 0.000227
                      *power(speed[2,dir,time],2))/3600;
    em_rate[CO,cruise2,carr] := corr_CO_car*scen_CO*(0.494 + 0.000227
                      *power(speed[1,dir,time],2))/3600;

    em_rate[CO,idle,truck]   := corr_CO_tr*idle_CO_tr/3600;
    em_rate[CO,decel,truck]  := corr_CO_tr*1.5*idle_CO_tr/3600;
    em_rate[CO,accel1,truck] := corr_CO_tr*(20.125 + 8.5098*spdaccel1_tr
                  - 0.37135*power(spdaccel1_tr,2)
                  + 6.1456e-03*power(spdaccel1_tr,3)
                  - 2.9472e-05*power(spdaccel1_tr,4)
               )/3600;
    em_rate[CO,accel2,truck] := corr_CO_tr*(20.125 + 8.5098*spdaccel2_tr
                  - 0.37135*power(spdaccel2_tr,2)
```

```
                + 6.1456e-03*power(spdaccel2_tr,3)
                - 2.9472e-05*power(spdaccel2_tr,4)
             )/3600;
em_rate[CO,cruise1,truck]:= corr_CO_tr*scen_CO_tr*(0.494 + 0.000227
                *power(0.9*speed[2,dir,time],2))/3600;
em_rate[CO,cruise2,truck]:= corr_CO_tr*scen_CO_tr*(0.494 + 0.000227
                *power(0.9*speed[1,dir,time],2))/3600;

em_rate[HC,idle,carr]      := corr_HC_car*idle_HC/3600;
em_rate[HC,decel,carr]     := corr_HC_car*idle_HC/3600;
em_rate[HC,accel1,carr]    := corr_HC_car*(5.8127 - 0.14173*spdaccel1
                + 1.4535e-02*power(spdaccel1,2)
                - 3.4403e-04*power(spdaccel1,3)
                + 2.8941e-06*power(spdaccel1,4)
             )/3600;
em_rate[HC,accel2,carr]    := corr_HC_car*(5.8127 - 0.14173*spdaccel2
                + 1.4535e-02*power(spdaccel2,2)
                - 3.4403e-04*power(spdaccel2,3)
                + 2.8941e-06*power(spdaccel2,4)
             )/3600;
em_rate[HC,cruise1,carr]   := corr_HC_car*idle_HC/3600;
em_rate[HC,cruise2,carr]   := corr_HC_car*idle_HC/3600;

em_rate[HC,idle,truck]     := corr_HC_tr*idle_HC_tr/3600;
em_rate[HC,decel,truck]    := corr_HC_tr*idle_HC_tr/3600;
em_rate[HC,accel1,truck]   := corr_HC_tr*(0.16072 + 0.21664*spdaccel1_tr
                - 7.7947e-03*power(spdaccel1_tr,2)
                + 1.216e-04*power(spdaccel1_tr,3)
                - 6.4191e-07*power(spdaccel1_tr,4)
             )/3600;
em_rate[HC,accel2,truck]   := corr_HC_tr*(0.16072 + 0.21664*spdaccel2_tr
                - 7.7947e-03*power(spdaccel2_tr,2)
                + 1.216e-04*power(spdaccel2_tr,3)
                - 6.4191e-07*power(spdaccel2_tr,4)
             )/3600;
em_rate[HC,cruise1,truck]  := corr_HC_tr*idle_HC_tr/3600;
em_rate[HC,cruise2,truck]  := corr_HC_tr*idle_HC_tr/3600;

em_rate[NOX,idle,carr]     := corr_NOX_car*idle_NOX/3600;
em_rate[NOX,decel,carr]    := corr_NOX_car*(-8.1618e-03
                + 3.0774e-02*spddecel
                - 4.8009e-04*power(spddecel,2)
                - 1.3859e-06*power(spddecel,3)
                + 1.3574e-07*power(spddecel,4)
             )/3600;
em_rate[NOX,accel1,carr]   := corr_NOX_car*(-0.20963 + 0.15404*spdaccel1
                - 4.5707e-03*power(spdaccel1,2)
                + 6.0109e-05*power(spdaccel1,3)
             )/3600;
em_rate[NOX,accel2,carr]   := corr_NOX_car*(-0.20963 + 0.15404*spdaccel2
                - 4.5707e-03*power(spdaccel2,2)
                + 6.0109e-05*power(spdaccel2,3)
             )/3600;
```

```
em_rate[NOX,cruise1,carr]  := corr_NOX_car*idle_NOX/3600;
em_rate[NOX,cruise2,carr]  := corr_NOX_car*idle_NOX/3600;

em_rate[NOX,idle,truck]    := corr_NOX_tr*idle_NOX_tr/3600;
em_rate[NOX,decel,truck]   := corr_NOX_tr*(-0.20101 + 0.31205*spddecel_tr
                    - 1.01e-02*power(spddecel_tr,2)
                    + 1.4347e-04*power(spddecel_tr,3)
                  )/3600;
em_rate[NOX,accel1,truck]  := corr_NOX_tr*(-0.69458 + 1.046*spdaccel1_tr
                    - 3.3855e-02*power(spdaccel1_tr,2)
                    + 4.8059e-04*power(spdaccel1_tr,3)
                  )/3600;
em_rate[NOX,accel2,truck]  := corr_NOX_tr*(-0.69458 + 1.046*spdaccel2_tr
                    - 3.3855e-02*power(spdaccel2_tr,2)
                    + 4.8059e-04*power(spdaccel2_tr,3)
                  )/3600;
em_rate[NOX,cruise1,truck] := corr_NOX_tr*idle_NOX_tr/3600;
em_rate[NOX,cruise2,truck] := corr_NOX_tr*idle_NOX_tr/3600;

if queindex = 0 then
begin
  { Calculation of total length over which traffic is affected }
  {        due to the presence of the work zone                }

  aff_length    := lengthdecel + lengthaccel1 + 5280*lengthredspd +
          lengthaccel2;
  aff_length_tr := lengthdecel_tr + lengthaccel1_tr +
          5280*lengthredspd + lengthaccel2_tr;
  time_aff      := aff_length/(1.467*speed[1,dir,time]);
  time_aff_tr   := aff_length_tr/(0.9*1.467*speed[1,dir,time]);

  { Calculation of excess emission values using emission rates }
  {                 ( no queue formation )                     }

  for i := CO to NOX do
    exc_emission[i,dir,time] := ((em_rate[i,decel,carr]*timedecel +
                    em_rate[i,accel1,carr]*timeaccel1  +
                    em_rate[i,accel2,carr]*timeaccel2  +
                    em_rate[i,cruise1,carr]*timewzone  -
                    em_rate[i,cruise2,carr]*time_aff)  *
                  (1-(trucks[dir]/100))        +
                    (em_rate[i,decel,truck]*timedecel_tr +
                    em_rate[i,accel1,truck]*timeaccel1_tr +
                    em_rate[i,accel2,truck]*timeaccel2_tr +
                    em_rate[i,cruise1,truck]*timewzone_tr -
                    em_rate[i,cruise2,truck]*time_aff_tr) *
                  (trucks[dir]/100))
                   * hrvol[dir,time]/1000;
end
else
begin

  {  Excess emissions under queueing conditions  }
```

```
        { Calculation of average speed through the queue }

        speed[3,dir,time] := (freespd/2)*(1 - sqrt(1 - capacity
                      [dir,time]/normalcapacity[dir]));

        { Calculation of time of travel through the queue (idling ) }

         timequeue := 5280*quelength[dir,time]/(1.467*speed[3,dir,time]);

        { Calculation of total length over which traffic is }
        {  affected due to the presence of the work zone  }

        aff_length    := lengthdecel + 5280*quelength[dir,time] +
                    lengthaccel1 + 5280*lengthredspd + lengthaccel2;
        aff_length_tr := lengthdecel_tr + 5280*quelength[dir,time] +
                    lengthaccel1_tr + 5280*lengthredspd +
                  lengthaccel2_tr;
        time_aff      := aff_length/(1.467*speed[1,dir,time]);
        time_aff_tr   := aff_length_tr/(0.9*1.467*speed[1,dir,time]);

        { Calculation of excess emission values using emission }
        {           rates ( queue formation occurs )            }

        for i := CO to NOX do
          exc_emission[i,dir,time] := ((em_rate[i,decel,carr]*timedecel +
                           em_rate[i,idle,carr]*timequeue   +
                           em_rate[i,accel1,carr]*timeaccel1  +
                           em_rate[i,accel2,carr]*timeaccel2  +
                           em_rate[i,cruise1,carr]*timewzone  -
                           em_rate[i,cruise2,carr]*time_aff)  *
                          (1-(trucks[dir]/100))          +
                           (em_rate[i,decel,truck]*timedecel_tr +
                           em_rate[i,idle,truck]*timequeue    +
                           em_rate[i,accel1,truck]*timeaccel1_tr +
                           em_rate[i,accel2,truck]*timeaccel2_tr +
                           em_rate[i,cruise1,truck]*timewzone_tr -
                           em_rate[i,cruise2,truck]*time_aff_tr) *
                          (trucks[dir]/100))
                           * hrvol[dir,time]/1000;
      end;

      {    Total excess emissions for the direction     }

      for i := CO to NOX do
        emission[i,dir] := emission[i,dir] + exc_emission[i,dir,time];

    end;
```

# APPENDIX F:

# OUTPUTS FROM TEST RUNS OF THE QUEWZEE MODEL

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 1
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 8.
8. End of workzone traffic control setup is 17.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 2 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 1 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 1.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1485 vphpl.

>>> INBOUND <<<>>> Total Lanes: 2 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | FUEL CAR | FUEL TR | OIL CAR | OIL TR | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 4000 | 58.2 | | | | | | | |
| 1 - 2 | 150 | 4000 | 59.1 | | | | | | | |
| 2 - 3 | 150 | 4000 | 59.1 | | | | | | | |
| 3 - 4 | 150 | 4000 | 59.1 | | | | | | | |
| 4 - 5 | 150 | 4000 | 59.1 | | | | | | | |
| 5 - 6 | 450 | 4000 | 57.3 | | | | | | | |
| 6 - 7 | 1850 | 4000 | 48.8 | | | | | | | |
| 7 - 8 | 2250 | 4000 | 46.4 | | | | | | | |
| 8 - 9 | 1075 | 1800 | 53.5 | 45.5 | 0.0 | 46.9 | 38.9 | 1.2 | 0.8 | 120 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 37.5 | 31.0 | 0.9 | 0.6 | 94 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 44.7 | 38.5 | 1.1 | 0.8 | 151 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 47.2 | 41.2 | 1.2 | 0.8 | 175 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 104.4 | 104.1 | 4.2 | 2.9 | 975 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 82.5 | 81.2 | 3.4 | 2.4 | 314 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 61.2 | 56.2 | 1.5 | 1.1 | 359 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 112.5 | 112.0 | 4.5 | 3.2 | 2082 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 134.4 | 133.3 | 5.0 | 3.8 | 5353 |
| 17 - 18 | 2150 | 4000 | 47.0 | 43.4 | 0.6 | 91.4 | 83.5 | 2.6 | 2.0 | 837 |
| 18 - 19 | 1750 | 4000 | 49.4 | | | | | | | |
| 19 - 20 | 925 | 4000 | 54.4 | | | | | | | |
| 20 - 21 | 875 | 4000 | 54.7 | | | | | | | |
| 21 - 22 | 400 | 4000 | 57.6 | | | | | | | |
| 22 - 23 | 400 | 4000 | 57.6 | | | | | | | |
| 23 - 24 | 150 | 4000 | 59.1 | | | | | | | |

THE SUM OF INBOUND Truck FUEL is 719.8 gallons.
THE SUM OF INBOUND Car FUEL is 762.6 gallons.
THE SUM OF INBOUND Truck OIL is 18.3 quarts.
THE SUM OF INBOUND Car OIL is 25.5 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 10460

>>> INBOUND <<<>>> Total lanes: 2 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | EXCESS EMISSIONS CO | HC | NOX |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 4000 | 58.2 | | | | | |
| 1 - 2 | 150 | 4000 | 59.1 | | | | | |
| 2 - 3 | 150 | 4000 | 59.1 | | | | | |
| 3 - 4 | 150 | 4000 | 59.1 | | | | | |
| 4 - 5 | 150 | 4000 | 59.1 | | | | | |
| 5 - 6 | 450 | 4000 | 57.3 | | | | | |
| 6 - 7 | 1850 | 4000 | 48.8 | | | | | |
| 7 - 8 | 2250 | 4000 | 46.4 | | | | | |
| 8 - 9 | 1075 | 1800 | 53.5 | 45.5 | 0.0 | 0.8 | 0.0 | 0.0 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 0.7 | 0.0 | 0.0 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 1.0 | 0.1 | 0.0 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 1.1 | 0.1 | 0.0 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 7.5 | 0.7 | 0.2 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 3.1 | 0.3 | 0.1 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 2.5 | 0.2 | 0.0 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 19.8 | 2.0 | 0.4 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 55.2 | 5.3 | 1.2 |
| 17 - 18 | 2150 | 4000 | 47.0 | 43.4 | 0.6 | 4.8 | 0.4 | 0.1 |
| 18 - 19 | 1750 | 4000 | 49.4 | | | | | |
| 19 - 20 | 925 | 4000 | 54.4 | | | | | |
| 20 - 21 | 875 | 4000 | 54.7 | | | | | |
| 21 - 22 | 400 | 4000 | 57.6 | | | | | |
| 22 - 23 | 400 | 4000 | 57.6 | | | | | |
| 23 - 24 | 150 | 4000 | 59.1 | | | | | |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 96.5 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 9.1 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 2.0 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 2
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 8.
8. End of workzone traffic control setup is 17.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 2 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 1 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 2.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1485 vphpl.

>>> INBOUND <<<>>> Total Lanes: 2 Work Zone Lanes: 1

| TIME | * HRLY * VOL. | *CAPACITY* * INBOUND* | APP * SPD * | ZN * SPD * | QUE * LEN * | FUEL CAR * | FUEL TR * | OIL * CAR * | OIL TR * | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 4000 | 58.2 | | | | | | | |
| 1 - 2 | 150 | 4000 | 59.1 | | | | | | | |
| 2 - 3 | 150 | 4000 | 59.1 | | | | | | | |
| 3 - 4 | 150 | 4000 | 59.1 | | | | | | | |
| 4 - 5 | 150 | 4000 | 59.1 | | | | | | | |
| 5 - 6 | 450 | 4000 | 57.3 | | | | | | | |
| 6 - 7 | 1850 | 4000 | 48.8 | | | | | | | |
| 7 - 8 | 2250 | 4000 | 46.4 | | | | | | | |
| 8 - 9 | 1075 | 1800 | 53.5 | 45.5 | 0.0 | 93.9 | 77.8 | 2.4 | 1.6 | 150 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 75.0 | 62.0 | 1.9 | 1.3 | 117 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 89.4 | 77.1 | 2.2 | 1.5 | 193 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 94.3 | 82.3 | 2.3 | 1.6 | 226 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 208.7 | 208.2 | 8.3 | 5.9 | 1319 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 164.9 | 162.3 | 6.8 | 4.8 | 412 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 122.4 | 112.3 | 3.0 | 2.1 | 472 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 225.0 | 224.0 | 9.0 | 6.4 | 2537 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 268.7 | 266.6 | 10.0 | 7.5 | 5963 |
| 17 - 18 | 2150 | 4000 | 47.0 | 43.4 | 0.6 | 182.8 | 167.1 | 5.2 | 3.9 | 868 |
| 18 - 19 | 1750 | 4000 | 49.4 | | | | | | | |
| 19 - 20 | 925 | 4000 | 54.4 | | | | | | | |
| 20 - 21 | 875 | 4000 | 54.7 | | | | | | | |
| 21 - 22 | 400 | 4000 | 57.6 | | | | | | | |
| 22 - 23 | 400 | 4000 | 57.6 | | | | | | | |
| 23 - 24 | 150 | 4000 | 59.1 | | | | | | | |

THE SUM OF INBOUND Truck FUEL is 1439.6 gallons.
THE SUM OF INBOUND Car FUEL is 1525.2 gallons.
THE SUM OF INBOUND Truck OIL is 36.6 quarts.
THE SUM OF INBOUND Car OIL is 50.9 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 12258

>>> INBOUND <<<>>> Total lanes: 2 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | EXCESS EMISSIONS CO | HC | NOX |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 4000 | 58.2 | | | | | |
| 1 - 2 | 150 | 4000 | 59.1 | | | | | |
| 2 - 3 | 150 | 4000 | 59.1 | | | | | |
| 3 - 4 | 150 | 4000 | 59.1 | | | | | |
| 4 - 5 | 150 | 4000 | 59.1 | | | | | |
| 5 - 6 | 450 | 4000 | 57.3 | | | | | |
| 6 - 7 | 1850 | 4000 | 48.8 | | | | | |
| 7 - 8 | 2250 | 4000 | 46.4 | | | | | |
| 8 - 9 | 1075 | 1800 | 53.5 | 45.5 | 0.0 | 0.8 | 0.1 | 0.0 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 0.6 | 0.1 | 0.0 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 1.0 | 0.1 | 0.0 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 1.1 | 0.2 | 0.0 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 8.5 | 1.2 | 0.3 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 3.2 | 0.4 | 0.1 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 2.6 | 0.4 | 0.1 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 21.4 | 2.6 | 0.6 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 57.7 | 6.1 | 1.4 |
| 17 - 18 | 2150 | 4000 | 47.0 | 43.4 | 0.6 | 4.8 | 0.4 | 0.1 |
| 18 - 19 | 1750 | 4000 | 49.4 | | | | | |
| 19 - 20 | 925 | 4000 | 54.4 | | | | | |
| 20 - 21 | 875 | 4000 | 54.7 | | | | | |
| 21 - 22 | 400 | 4000 | 57.6 | | | | | |
| 22 - 23 | 400 | 4000 | 57.6 | | | | | |
| 23 - 24 | 150 | 4000 | 59.1 | | | | | |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 101.7 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 11.7 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 2.6 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 3
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 0.
8. End of workzone traffic control setup is 24.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 2 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 1 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 1.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1485 vphpl.

>>> INBOUND <<<>>> Total Lanes: 2 Work Zone Lanes: 1

| TIME | * HRLY * VOL. | *CAPACITY* * INBOUND* | APP * SPD * | ZN * SPD * | QUE * LEN * | FUEL CAR * | FUEL TR * | OIL CAR * | OIL TR * | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 1800 | 58.2 | 56.0 | 0.0 | 13.2 | 8.7 | 0.3 | 0.2 | 6 |
| 1 - 2 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 6.7 | 4.2 | 0.2 | 0.1 | 2 |
| 2 - 3 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 6.7 | 4.2 | 0.2 | 0.1 | 2 |
| 3 - 4 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 6.7 | 4.2 | 0.2 | 0.1 | 2 |
| 4 - 5 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 6.7 | 4.2 | 0.2 | 0.1 | 2 |
| 5 - 6 | 450 | 1800 | 57.3 | 53.9 | 0.0 | 19.6 | 13.6 | 0.5 | 0.3 | 14 |
| 6 - 7 | 1850 | 1800 | 48.8 | 29.2 | 0.1 | 122.3 | 121.6 | 4.5 | 3.4 | 1447 |
| 7 - 8 | 2250 | 1800 | 46.4 | 22.5 | 0.8 | 146.3 | 144.7 | 5.5 | 4.1 | 5914 |
| 8 - 9 | 1075 | 1800 | 53.5 | 34.8 | 0.8 | 72.3 | 72.5 | 2.6 | 2.0 | 2890 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 37.5 | 31.0 | 0.9 | 0.6 | 94 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 44.7 | 38.5 | 1.1 | 0.8 | 151 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 47.2 | 41.2 | 1.2 | 0.8 | 175 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 104.4 | 104.1 | 4.2 | 2.9 | 975 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 82.5 | 81.2 | 3.4 | 2.4 | 314 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 61.2 | 56.2 | 1.5 | 1.1 | 359 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 112.5 | 112.0 | 4.5 | 3.2 | 2082 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 134.4 | 133.3 | 5.0 | 3.8 | 5353 |
| 17 - 18 | 2150 | 1800 | 47.0 | 24.2 | 1.7 | 140.4 | 139.0 | 5.2 | 3.9 | 10065 |
| 18 - 19 | 1750 | 1800 | 49.4 | 30.0 | 2.2 | 116.1 | 115.7 | 4.3 | 3.2 | 11661 |
| 19 - 20 | 925 | 1800 | 54.4 | 33.7 | 1.1 | 63.0 | 63.4 | 2.2 | 1.7 | 4299 |
| 20 - 21 | 875 | 1800 | 54.7 | 48.2 | 0.0 | 37.9 | 29.8 | 1.0 | 0.6 | 67 |
| 21 - 22 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 17.5 | 11.9 | 0.4 | 0.3 | 11 |
| 22 - 23 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 17.5 | 11.9 | 0.4 | 0.3 | 11 |
| 23 - 24 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 6.7 | 4.2 | 0.2 | 0.1 | 2 |

THE SUM OF INBOUND Truck FUEL is 1351.5 gallons.
THE SUM OF INBOUND Car FUEL is 1424.1 gallons.
THE SUM OF INBOUND Truck OIL is 36.2 quarts.
THE SUM OF INBOUND Car OIL is 49.5 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 45896

>>> INBOUND <<<>>> Total lanes: 2 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | EXCESS EMISSIONS CO | HC | NOX |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 1800 | 58.2 | 56.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 1 - 2 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 2 - 3 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 3 - 4 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 4 - 5 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 5 - 6 | 450 | 1800 | 57.3 | 53.9 | 0.0 | 0.2 | 0.0 | 0.0 |
| 6 - 7 | 1850 | 1800 | 48.8 | 29.2 | 0.1 | 11.6 | 1.1 | 0.2 |
| 7 - 8 | 2250 | 1800 | 46.4 | 22.5 | 0.8 | 64.1 | 6.3 | 1.4 |
| 8 - 9 | 1075 | 1800 | 53.5 | 34.8 | 0.8 | 25.7 | 2.3 | 0.5 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 0.7 | 0.0 | 0.0 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 1.0 | 0.1 | 0.0 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 1.1 | 0.1 | 0.0 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 7.5 | 0.7 | 0.2 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 3.1 | 0.3 | 0.1 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 2.5 | 0.2 | 0.0 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 19.8 | 2.0 | 0.4 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 55.2 | 5.3 | 1.2 |
| 17 - 18 | 2150 | 1800 | 47.0 | 24.2 | 1.7 | 112.9 | 10.7 | 2.4 |
| 18 - 19 | 1750 | 1800 | 49.4 | 30.0 | 2.2 | 112.5 | 10.5 | 2.4 |
| 19 - 20 | 925 | 1800 | 54.4 | 33.7 | 1.1 | 29.7 | 2.7 | 0.6 |
| 20 - 21 | 875 | 1800 | 54.7 | 48.2 | 0.0 | 0.6 | 0.0 | 0.0 |
| 21 - 22 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 0.2 | -0.0 | 0.0 |
| 22 - 23 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 0.2 | -0.0 | 0.0 |
| 23 - 24 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 449.1 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 42.3 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 9.6 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 4
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 0.
8. End of workzone traffic control setup is 24.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 2 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 1 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 2.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1485 vphpl.

>>> INBOUND <<<>>> Total Lanes: 2 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | FUEL CAR | FUEL TR | OIL CAR | OIL TR | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 1800 | 58.2 | 56.0 | 0.0 | 26.5 | 17.5 | 0.7 | 0.4 | 6 |
| 1 - 2 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 13.5 | 8.5 | 0.3 | 0.2 | 2 |
| 2 - 3 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 13.5 | 8.5 | 0.3 | 0.2 | 2 |
| 3 - 4 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 13.5 | 8.5 | 0.3 | 0.2 | 2 |
| 4 - 5 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 13.5 | 8.5 | 0.3 | 0.2 | 2 |
| 5 - 6 | 450 | 1800 | 57.3 | 53.9 | 0.0 | 39.2 | 27.2 | 1.0 | 0.6 | 15 |
| 6 - 7 | 1850 | 1800 | 48.8 | 29.2 | 0.1 | 244.5 | 243.3 | 9.0 | 6.8 | 1870 |
| 7 - 8 | 2250 | 1800 | 46.4 | 22.5 | 0.8 | 292.6 | 289.3 | 10.9 | 8.2 | 6789 |
| 8 - 9 | 1075 | 1800 | 53.5 | 34.8 | 0.8 | 144.7 | 145.0 | 5.2 | 3.9 | 2990 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 75.0 | 62.0 | 1.9 | 1.3 | 117 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 89.4 | 77.1 | 2.2 | 1.5 | 193 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 94.3 | 82.3 | 2.3 | 1.6 | 226 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 208.7 | 208.2 | 8.3 | 5.9 | 1319 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 164.9 | 162.3 | 6.8 | 4.8 | 412 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 122.4 | 112.3 | 3.0 | 2.1 | 472 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 225.0 | 224.0 | 9.0 | 6.4 | 2537 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 268.7 | 266.6 | 10.0 | 7.5 | 5963 |
| 17 - 18 | 2150 | 1800 | 47.0 | 24.2 | 1.7 | 280.7 | 278.0 | 10.4 | 7.9 | 10796 |
| 18 - 19 | 1750 | 1800 | 49.4 | 30.0 | 2.2 | 232.2 | 231.5 | 8.5 | 6.4 | 12038 |
| 19 - 20 | 925 | 1800 | 54.4 | 33.7 | 1.1 | 125.9 | 126.7 | 4.5 | 3.4 | 4383 |
| 20 - 21 | 875 | 1800 | 54.7 | 48.2 | 0.0 | 75.8 | 59.7 | 1.9 | 1.3 | 82 |
| 21 - 22 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 35.0 | 23.9 | 0.9 | 0.6 | 12 |
| 22 - 23 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 35.0 | 23.9 | 0.9 | 0.6 | 12 |
| 23 - 24 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 13.5 | 8.5 | 0.3 | 0.2 | 2 |

THE SUM OF INBOUND Truck FUEL is 2703.1 gallons.
THE SUM OF INBOUND Car FUEL is 2848.2 gallons.
THE SUM OF INBOUND Truck OIL is 72.3 quarts.
THE SUM OF INBOUND Car OIL is 99.0 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 50242

>>> INBOUND <<<>>> Total lanes: 2 Work Zone Lanes: 1

| TIME * | HRLY VOL. * | CAPACITY INBOUND * | APP SPD * | ZN SPD * | QUE LEN * | EXCESS EMISSIONS CO * | HC * | NOX * |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 1800 | 58.2 | 56.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| 1 - 2 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 2 - 3 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 3 - 4 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 4 - 5 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |
| 5 - 6 | 450 | 1800 | 57.3 | 53.9 | 0.0 | 0.2 | 0.0 | 0.0 |
| 6 - 7 | 1850 | 1800 | 48.8 | 29.2 | 0.1 | 13.0 | 1.7 | 0.4 |
| 7 - 8 | 2250 | 1800 | 46.4 | 22.5 | 0.8 | 68.3 | 7.5 | 1.7 |
| 8 - 9 | 1075 | 1800 | 53.5 | 34.8 | 0.8 | 25.9 | 2.5 | 0.6 |
| 9 - 10 | 850 | 1485 | 54.8 | 46.1 | 0.0 | 0.6 | 0.1 | 0.0 |
| 10 - 11 | 1000 | 1485 | 53.9 | 43.7 | 0.0 | 1.0 | 0.1 | 0.0 |
| 11 - 12 | 1050 | 1485 | 53.6 | 42.9 | 0.0 | 1.1 | 0.2 | 0.0 |
| 12 - 13 | 1500 | 1485 | 50.9 | 29.7 | 0.0 | 8.5 | 1.2 | 0.3 |
| 13 - 14 | 1225 | 1485 | 52.6 | 39.4 | 0.0 | 3.2 | 0.4 | 0.1 |
| 14 - 15 | 1325 | 1485 | 52.0 | 39.2 | 0.0 | 2.6 | 0.4 | 0.1 |
| 15 - 16 | 1625 | 1485 | 50.2 | 27.2 | 0.2 | 21.4 | 2.6 | 0.6 |
| 16 - 17 | 2050 | 1800 | 47.6 | 25.8 | 0.8 | 57.7 | 6.1 | 1.4 |
| 17 - 18 | 2150 | 1800 | 47.0 | 24.2 | 1.7 | 116.2 | 11.7 | 2.7 |
| 18 - 19 | 1750 | 1800 | 49.4 | 30.0 | 2.2 | 113.7 | 11.0 | 2.5 |
| 19 - 20 | 925 | 1800 | 54.4 | 33.7 | 1.1 | 29.9 | 2.8 | 0.6 |
| 20 - 21 | 875 | 1800 | 54.7 | 48.2 | 0.0 | 0.5 | 0.0 | 0.0 |
| 21 - 22 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 0.2 | 0.0 | 0.0 |
| 22 - 23 | 400 | 1800 | 57.6 | 54.6 | 0.0 | 0.2 | 0.0 | 0.0 |
| 23 - 24 | 150 | 1800 | 59.1 | 58.0 | 0.0 | 0.1 | -0.0 | 0.0 |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 464.5 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 48.5 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 11.1 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 5
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 8.
8. End of workzone traffic control setup is 17.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 3 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 2 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 1.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1485 vphpl.

>>> INBOUND <<<>>> Total Lanes: 3 Work Zone Lanes: 2

| TIME | * HRLY * VOL. * | CAPACITY* INBOUND* | APP * SPD * | ZN * SPD * | QUE * LEN * | FUEL CAR | FUEL TR | OIL CAR | OIL TR | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | | | |
| 8 - 9 | 1075 | 3600 | 55.7 | 52.8 | 0.0 | 46.0 | 32.4 | 1.2 | 0.8 | 34 |
| 9 - 10 | 850 | 2970 | 56.6 | 53.1 | 0.0 | 36.8 | 25.9 | 0.9 | 0.6 | 29 |
| 10 - 11 | 1000 | 2970 | 56.0 | 51.8 | 0.0 | 43.1 | 31.3 | 1.1 | 0.7 | 42 |
| 11 - 12 | 1050 | 2970 | 55.8 | 51.4 | 0.0 | 45.2 | 33.1 | 1.2 | 0.8 | 47 |
| 12 - 13 | 1500 | 2970 | 53.9 | 47.8 | 0.0 | 64.6 | 51.1 | 1.6 | 1.1 | 118 |
| 13 - 14 | 1225 | 2970 | 55.1 | 50.0 | 0.0 | 52.6 | 39.8 | 1.3 | 0.9 | 69 |
| 14 - 15 | 1325 | 2970 | 54.6 | 49.2 | 0.0 | 57.0 | 43.8 | 1.5 | 1.0 | 85 |
| 15 - 16 | 1625 | 2970 | 53.4 | 46.7 | 0.0 | 70.2 | 56.6 | 1.8 | 1.2 | 148 |
| 16 - 17 | 2050 | 3600 | 51.7 | 46.2 | 0.0 | 87.2 | 70.1 | 2.2 | 1.5 | 181 |
| 17 - 18 | 2150 | 6000 | 51.3 | | | | | | | |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | | | |

THE SUM OF INBOUND Truck FUEL is 384.0 gallons.
THE SUM OF INBOUND Car FUEL is 502.6 gallons.
THE SUM OF INBOUND Truck OIL is 8.5 quarts.
THE SUM OF INBOUND Car OIL is 12.8 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 755

>>> INBOUND <<<>>> Total lanes: 3 Work Zone Lanes: 2

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | EXCESS EMISSIONS CO | HC | NOX |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | |
| 8 - 9 | 1075 | 3600 | 55.7 | 52.8 | 0.0 | 0.5 | 0.0 | 0.0 |
| 9 - 10 | 850 | 2970 | 56.6 | 53.1 | 0.0 | 0.4 | 0.0 | 0.0 |
| 10 - 11 | 1000 | 2970 | 56.0 | 51.8 | 0.0 | 0.5 | 0.0 | 0.0 |
| 11 - 12 | 1050 | 2970 | 55.8 | 51.4 | 0.0 | 0.6 | 0.0 | 0.0 |
| 12 - 13 | 1500 | 2970 | 53.9 | 47.8 | 0.0 | 0.9 | 0.0 | 0.0 |
| 13 - 14 | 1225 | 2970 | 55.1 | 50.0 | 0.0 | 0.7 | 0.0 | 0.0 |
| 14 - 15 | 1325 | 2970 | 54.6 | 49.2 | 0.0 | 0.8 | 0.0 | 0.0 |
| 15 - 16 | 1625 | 2970 | 53.4 | 46.7 | 0.0 | 1.1 | 0.0 | 0.0 |
| 16 - 17 | 2050 | 3600 | 51.7 | 46.2 | 0.0 | 1.3 | 0.0 | 0.0 |
| 17 - 18 | 2150 | 6000 | 51.3 | | | | | |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 6.7 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 0.2 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 0.0 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 6
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 8.
8. End of workzone traffic control setup is 17.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 3 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 2 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone is 2.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35 is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1485 vphpl.

>>> INBOUND <<<>>> Total Lanes: 3 Work Zone Lanes: 2

| TIME | * HRLY * VOL. | *CAPACITY* * INBOUND* | APP * SPD * | ZN * SPD * | QUE * LEN * | FUEL CAR * | FUEL TR * | OIL CAR * | OIL TR * | USER * COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | | | |
| 8 - 9 | 1075 | 3600 | 55.7 | 52.8 | 0.0 | 92.0 | 64.8 | 2.4 | 1.5 | 38 |
| 9 - 10 | 850 | 2970 | 56.6 | 53.1 | 0.0 | 73.5 | 51.9 | 1.9 | 1.2 | 32 |
| 10 - 11 | 1000 | 2970 | 56.0 | 51.8 | 0.0 | 86.2 | 62.5 | 2.2 | 1.4 | 48 |
| 11 - 12 | 1050 | 2970 | 55.8 | 51.4 | 0.0 | 90.4 | 66.2 | 2.3 | 1.5 | 54 |
| 12 - 13 | 1500 | 2970 | 53.9 | 47.8 | 0.0 | 129.2 | 102.2 | 3.3 | 2.2 | 144 |
| 13 - 14 | 1225 | 2970 | 55.1 | 50.0 | 0.0 | 105.3 | 79.5 | 2.7 | 1.8 | 81 |
| 14 - 15 | 1325 | 2970 | 54.6 | 49.2 | 0.0 | 113.9 | 87.5 | 2.9 | 1.9 | 101 |
| 15 - 16 | 1625 | 2970 | 53.4 | 46.7 | 0.0 | 140.3 | 113.1 | 3.6 | 2.4 | 182 |
| 16 - 17 | 2050 | 3600 | 51.7 | 46.2 | 0.0 | 174.4 | 140.3 | 4.5 | 3.0 | 220 |
| 17 - 18 | 2150 | 6000 | 51.3 | | | | | | | |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | | | |

THE SUM OF INBOUND Truck FUEL is 768.0 gallons.
THE SUM OF INBOUND Car FUEL is 1005.2 gallons.
THE SUM OF INBOUND Truck OIL is 17.1 quarts.
THE SUM OF INBOUND Car OIL is 25.7 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 901

>>> INBOUND <<<>>> Total lanes: 3 Work Zone Lanes: 2

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | EXCESS EMISSIONS CO | HC | NOX |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | |
| 8 - 9 | 1075 | 3600 | 55.7 | 52.8 | 0.0 | 0.5 | 0.0 | 0.0 |
| 9 - 10 | 850 | 2970 | 56.6 | 53.1 | 0.0 | 0.4 | 0.0 | 0.0 |
| 10 - 11 | 1000 | 2970 | 56.0 | 51.8 | 0.0 | 0.5 | 0.0 | 0.0 |
| 11 - 12 | 1050 | 2970 | 55.8 | 51.4 | 0.0 | 0.5 | 0.0 | 0.0 |
| 12 - 13 | 1500 | 2970 | 53.9 | 47.8 | 0.0 | 0.9 | 0.1 | 0.0 |
| 13 - 14 | 1225 | 2970 | 55.1 | 50.0 | 0.0 | 0.6 | 0.0 | 0.0 |
| 14 - 15 | 1325 | 2970 | 54.6 | 49.2 | 0.0 | 0.7 | 0.0 | 0.0 |
| 15 - 16 | 1625 | 2970 | 53.4 | 46.7 | 0.0 | 1.0 | 0.1 | 0.0 |
| 16 - 17 | 2050 | 3600 | 51.7 | 46.2 | 0.0 | 1.2 | 0.1 | 0.0 |
| 17 - 18 | 2150 | 6000 | 51.3 | | | | | |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 6.4 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 0.4 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 0.1 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 7
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 8.
8. End of workzone traffic control setup is 17.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 3 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 1 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 1.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1250 vphpl.

>>> INBOUND <<<>>> Total Lanes: 3 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | FUEL CAR | FUEL TR | OIL CAR | OIL TR | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | | | |
| 8 - 9 | 1075 | 1800 | 55.7 | 45.5 | 0.0 | 48.2 | 40.6 | 1.2 | 0.8 | 135 |
| 9 - 10 | 850 | 1250 | 56.6 | 43.5 | 0.0 | 39.2 | 34.6 | 0.9 | 0.7 | 145 |
| 10 - 11 | 1000 | 1250 | 56.0 | 40.6 | 0.0 | 47.2 | 43.3 | 1.1 | 0.8 | 239 |
| 11 - 12 | 1050 | 1250 | 55.8 | 40.0 | 0.0 | 49.9 | 46.3 | 1.2 | 0.8 | 275 |
| 12 - 13 | 1500 | 1250 | 53.9 | 24.0 | 0.3 | 114.8 | 114.5 | 6.0 | 3.3 | 2976 |
| 13 - 14 | 1225 | 1250 | 55.1 | 30.0 | 0.5 | 94.5 | 94.5 | 4.9 | 2.7 | 4206 |
| 14 - 15 | 1325 | 1250 | 54.6 | 28.2 | 0.5 | 101.9 | 101.8 | 5.3 | 3.0 | 4696 |
| 15 - 16 | 1625 | 1250 | 53.4 | 21.0 | 1.0 | 124.0 | 123.5 | 6.5 | 3.6 | 8648 |
| 16 - 17 | 2050 | 1800 | 51.7 | 25.8 | 1.6 | 148.3 | 147.7 | 6.5 | 4.3 | 13308 |
| 17 - 18 | 2150 | 6000 | 51.3 | 46.2 | 1.0 | 93.1 | 86.0 | 2.6 | 2.0 | 1820 |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | | | |

THE SUM OF INBOUND Truck FUEL is 832.6 gallons.
THE SUM OF INBOUND Car FUEL is 861.1 gallons.
THE SUM OF INBOUND Truck OIL is 22.0 quarts.
THE SUM OF INBOUND Car OIL is 36.4 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 36448

>>> INBOUND <<<>>> Total lanes: 3 Work Zone Lanes: 1

| TIME * | HRLY VOL. * | CAPACITY INBOUND * | APP SPD * | ZN SPD * | QUE LEN * | EXCESS EMISSIONS CO * | HC * | NOX * |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | |
| 8 - 9 | 1075 | 1800 | 55.7 | 45.5 | 0.0 | 1.0 | 0.1 | 0.0 |
| 9 - 10 | 850 | 1250 | 56.6 | 43.5 | 0.0 | 1.0 | 0.1 | 0.0 |
| 10 - 11 | 1000 | 1250 | 56.0 | 40.6 | 0.0 | 1.6 | 0.1 | 0.0 |
| 11 - 12 | 1050 | 1250 | 55.8 | 40.0 | 0.0 | 1.9 | 0.2 | 0.0 |
| 12 - 13 | 1500 | 1250 | 53.9 | 24.0 | 0.3 | 35.6 | 3.6 | 0.8 |
| 13 - 14 | 1225 | 1250 | 55.1 | 30.0 | 0.5 | 48.6 | 4.5 | 1.0 |
| 14 - 15 | 1325 | 1250 | 54.6 | 28.2 | 0.5 | 57.7 | 5.4 | 1.2 |
| 15 - 16 | 1625 | 1250 | 53.4 | 21.0 | 1.0 | 127.8 | 12.2 | 2.8 |
| 16 - 17 | 2050 | 1800 | 51.7 | 25.8 | 1.6 | 167.9 | 15.7 | 3.6 |
| 17 - 18 | 2150 | 6000 | 51.3 | 46.2 | 1.0 | 6.3 | 0.7 | 0.1 |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 449.2 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 42.6 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 9.7 kgs.

Texas Department of Highways and Public Transportation - Q U E W Z - 8 5 v 1.0

Echo of Input Data:

1. Problem Title: TEST PROBLEM 8
2. The major highway or freeway name is IH 35.
3. Free flow speed on IH 35 is 60.0 miles per hr.
4. Level of Service D/E speed on IH 35 is 40.0 miles per hr.
5. Speed in mph at capacity after queue formation on IH 35 is 30.0.

6. Single direction closure workzone strategy.
   INBOUND direction is being considered.

7. Start of workzone traffic control setup is 8.
8. End of workzone traffic control setup is 17.
9. Start of actual work is 9.
10. End of actual work is 16.

11. Percent of 1981 dollars used to estimate current worth is 141%.

12. Idle CO emission rate for passenger cars is 293.1 gm/hr.
13. Idle CO emission rate for trucks is 51.2 gm/hr.
14. Idle HC emission rate for passenger cars is 24.3 gm/hr.
15. Idle HC emission rate for trucks is 17.4 gm/hr.
16. Idle NOx emission rate for passenger cars is 2.9 gm/hr.
17. Idle NOx emission rate for trucks is 22.3 gm/hr.
18. Total number of INBOUND lanes on IH 35 is 3 lanes.
19. Total number of OPEN INBOUND during work on IH 35 is 1 lanes.

22. Percent INBOUND trucks on IH 35 is 13.0%

24. The length in miles from beginning of taper to end of work zone
    is 2.0 miles.

25. Maximum flow per INBOUND lane before work activity on IH 35
    is 2000 vehicles per hour per lane.
27. LOS DE breakpoint volume per INBOUND lane before work activity on
    IH 35 is 1650 vehicles per hour per lane.
29. The capacity per lane of the INBOUND work zone is 1250 vphpl.

>>> INBOUND <<<>>> Total Lanes: 3 Work Zone Lanes: 1

| TIME | HRLY VOL. | CAPACITY INBOUND | APP SPD | ZN SPD | QUE LEN | FUEL CAR | FUEL TR | OIL CAR | OIL TR | USER COST |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | | | |
| 8 - 9 | 1075 | 1800 | 55.7 | 45.5 | 0.0 | 96.3 | 81.2 | 2.4 | 1.6 | 170 |
| 9 - 10 | 850 | 1250 | 56.6 | 43.5 | 0.0 | 78.5 | 69.1 | 1.9 | 1.3 | 188 |
| 10 - 11 | 1000 | 1250 | 56.0 | 40.6 | 0.0 | 94.5 | 86.7 | 2.2 | 1.6 | 318 |
| 11 - 12 | 1050 | 1250 | 55.8 | 40.0 | 0.0 | 99.9 | 92.5 | 2.4 | 1.7 | 367 |
| 12 - 13 | 1500 | 1250 | 53.9 | 24.0 | 0.3 | 229.6 | 229.0 | 12.1 | 6.7 | 3551 |
| 13 - 14 | 1225 | 1250 | 55.1 | 30.0 | 0.5 | 188.9 | 188.9 | 9.9 | 5.5 | 4503 |
| 14 - 15 | 1325 | 1250 | 54.6 | 28.2 | 0.5 | 203.8 | 203.6 | 10.7 | 5.9 | 5065 |
| 15 - 16 | 1625 | 1250 | 53.4 | 21.0 | 1.0 | 247.9 | 246.9 | 13.1 | 7.2 | 9436 |
| 16 - 17 | 2050 | 1800 | 51.7 | 25.8 | 1.6 | 296.5 | 295.4 | 13.1 | 8.5 | 13967 |
| 17 - 18 | 2150 | 6000 | 51.3 | 46.2 | 1.0 | 186.3 | 171.9 | 5.2 | 3.9 | 1844 |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | | | |

THE SUM OF INBOUND Truck FUEL is 1665.2 gallons.
THE SUM OF INBOUND Car FUEL is 1722.2 gallons.
THE SUM OF INBOUND Truck OIL is 43.9 quarts.
THE SUM OF INBOUND Car OIL is 72.8 quarts.
THE SUM OF INBOUND WORKZONE COSTS IS $ 39410

>>> INBOUND <<<>>> Total lanes: 3 Work Zone Lanes: 1

| TIME * | HRLY * VOL. * | CAPACITY * INBOUND * | APP * SPD * | ZN * SPD * | QUE * LEN * | EXCESS EMISSIONS CO * | HC * | NOX * |
|---|---|---|---|---|---|---|---|---|
| 0 - 1 | 300 | 6000 | 58.8 | | | | | |
| 1 - 2 | 150 | 6000 | 59.4 | | | | | |
| 2 - 3 | 150 | 6000 | 59.4 | | | | | |
| 3 - 4 | 150 | 6000 | 59.4 | | | | | |
| 4 - 5 | 150 | 6000 | 59.4 | | | | | |
| 5 - 6 | 450 | 6000 | 58.2 | | | | | |
| 6 - 7 | 1850 | 6000 | 52.5 | | | | | |
| 7 - 8 | 2250 | 6000 | 50.9 | | | | | |
| 8 - 9 | 1075 | 1800 | 55.7 | 45.5 | 0.0 | 0.9 | 0.1 | 0.0 |
| 9 - 10 | 850 | 1250 | 56.6 | 43.5 | 0.0 | 0.9 | 0.1 | 0.0 |
| 10 - 11 | 1000 | 1250 | 56.0 | 40.6 | 0.0 | 1.6 | 0.3 | 0.1 |
| 11 - 12 | 1050 | 1250 | 55.8 | 40.0 | 0.0 | 1.9 | 0.3 | 0.1 |
| 12 - 13 | 1500 | 1250 | 53.9 | 24.0 | 0.3 | 37.8 | 4.4 | 1.0 |
| 13 - 14 | 1225 | 1250 | 55.1 | 30.0 | 0.5 | 49.3 | 5.0 | 1.1 |
| 14 - 15 | 1325 | 1250 | 54.6 | 28.2 | 0.5 | 58.8 | 6.0 | 1.4 |
| 15 - 16 | 1625 | 1250 | 53.4 | 21.0 | 1.0 | 131.4 | 13.3 | 3.1 |
| 16 - 17 | 2050 | 1800 | 51.7 | 25.8 | 1.6 | 170.3 | 16.7 | 3.8 |
| 17 - 18 | 2150 | 6000 | 51.3 | 46.2 | 1.0 | 6.3 | 0.7 | 0.1 |
| 18 - 19 | 1750 | 6000 | 52.9 | | | | | |
| 19 - 20 | 925 | 6000 | 56.3 | | | | | |
| 20 - 21 | 875 | 6000 | 56.5 | | | | | |
| 21 - 22 | 400 | 6000 | 58.4 | | | | | |
| 22 - 23 | 400 | 6000 | 58.4 | | | | | |
| 23 - 24 | 150 | 6000 | 59.4 | | | | | |

THE TOTAL EXCESS EMISSION OF CARBONMONOXIDES (CO) IS 459.1 kgs.
THE TOTAL EXCESS EMISSION OF HYDROCARBONS (HC) IS 46.9 kgs.
THE TOTAL EXCESS EMISSION OF NITROGEN OXIDES (NOx) IS 10.8 kgs.