UNCERTAINTY IN THE EMISSION INVENTORY FOR HEAVY-DUTY DIESEL-POWERED TRUCKS

by

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<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 INTRODUCTION ........................................... Page 1</td>
</tr>
<tr>
<td>101 MOBILE SOURCE CONTRIBUTIONS TO AIR POLLUTION .......... Page 1</td>
</tr>
<tr>
<td>102 HEAVY-DUTY DIESEL TRUCK EMISSION CONTRIBUTIONS ........ Page 4</td>
</tr>
<tr>
<td>103 EMISSION TRENDS AND REGULATORY DIRECTION .......... Page 4</td>
</tr>
<tr>
<td>104 EMISSION MODELING AND POLICY CONCERNS .......... Page 6</td>
</tr>
<tr>
<td>105 REPORT ORGANIZATION ..................................... Page 7</td>
</tr>
<tr>
<td>200 BACKGROUND ................................................ Page 9</td>
</tr>
<tr>
<td>201 THE EMISSION INVENTORY PROCESS ..................... Page 9</td>
</tr>
<tr>
<td>202 EMISSION-PRODUCING VEHICLE ACTIVITY ............. Page 10</td>
</tr>
<tr>
<td>203 ACTIVITY-SPECIFIC EMISSION RATES ................ Page 13</td>
</tr>
<tr>
<td>204 EMISSION RATE CORRECTION FACTORS ............. Page 14</td>
</tr>
<tr>
<td>205 MOBILE SOURCE EMISSION FACTOR MODELS ........ Page 15</td>
</tr>
<tr>
<td>300 HEAVY-DUTY TRUCK EMISSION-PRODUCING ACTIVITY ........ Page 18</td>
</tr>
<tr>
<td>301 NUMBER OF VEHICLES .................................. Page 18</td>
</tr>
<tr>
<td>302 NUMBER OF TRIPS ..................................... Page 24</td>
</tr>
<tr>
<td>303 VEHICLE-MILES TRAVELED ............................. Page 26</td>
</tr>
<tr>
<td>304 HOURS OF ENGINE IDLING ............................ Page 31</td>
</tr>
<tr>
<td>305 OFF-ROAD HEAVY-DUTY DIESEL ACTIVITIES .......... Page 32</td>
</tr>
<tr>
<td>306 INCIDENTAL ACTIVITIES ................................ Page 33</td>
</tr>
<tr>
<td>307 ACCOUNTING FOR VEHICLE ACTIVITY DISTRIBUTION .... Page 33</td>
</tr>
<tr>
<td>400 HEAVY-DUTY TRUCK ACTIVITY-SPECIFIC EMISSION RATES .. Page 38</td>
</tr>
<tr>
<td>401 BASELINE RUNNING EMISSION FACTORS FOR VMT .... Page 38</td>
</tr>
<tr>
<td>402 USEPA CONVERSION FACTORS ........................ Page 45</td>
</tr>
<tr>
<td>403 DETERIORATION RATES ................................ Page 47</td>
</tr>
<tr>
<td>404 SPEED CORRECTION FACTORS ........................ Page 48</td>
</tr>
<tr>
<td>405 ENGINE IDLING ...................................... Page 59</td>
</tr>
<tr>
<td>406 COLD AND HOT STARTS ................................ Page 60</td>
</tr>
<tr>
<td>407 HOT SOAKS, DIURNAL EVAPORATION, AND RUNNING EVAPORATIVE LOSSES ........................................ Page 62</td>
</tr>
<tr>
<td>408 ACCELERATION ...................................... Page 62</td>
</tr>
<tr>
<td>409 TRANSPORTATION CONTROL MEASURE CORRECTIONS .... Page 64</td>
</tr>
<tr>
<td>410 FUEL PROPERTIES .................................... Page 64</td>
</tr>
<tr>
<td>500 SUMMARY OF INACCURACIES AND UNCERTAINTY .......... Page 66</td>
</tr>
<tr>
<td>501 HEAVY-DUTY TRUCK ACTIVITY ESTIMATES ........ Page 66</td>
</tr>
<tr>
<td>502 EMISSION RATES AND CORRECTION FACTORS ........ Page 67</td>
</tr>
<tr>
<td>503 TOTAL UNCERTAINTY ................................ Page 68</td>
</tr>
<tr>
<td>504 ANALYSIS OF EMISSION REDUCTION STRATEGIES .... Page 69</td>
</tr>
</tbody>
</table>
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TABLES AND FIGURES

TABLE  1  1987 California Emission Inventory .......... Page 2
TABLE  2 Transient Cycle Emission Test Results for
         Nine Medium Heavy-Duty Diesel Engines ...... Page 41
TABLE  3 Transient Cycle Emission Test Results for
         Thirteen Heavy Heavy-Duty Diesel Engines ... Page 42
TABLE  4 Light-Duty Diesel Truck Incremental Start
         Emissions (grams/trip), Hot vs Cold Start .. Page 61
TABLE  5 Selected Projects Designed to Reduce
         Uncertainty in the Emission Inventory for
         Heavy-Duty Diesel-Powered Trucks .......... Page 83

Figure  1  1987 California Emission Inventory .......... Page 3
Figure  2 Generic Mobile Source Emission Inventory
         Methodology .......................... Page 11
Figure  3 CARB's Emission Factor Model for Heavy-Duty
         Vehicles .............................. Page 16
Figure  4 CARB's Emission Factor Model for Light-Duty
         Vehicles .............................. Page 17
Figure  5 General Vehicle Class and Sub-Class
         Combinations Used by the CARB .......... Page 20
Figure  6 Volume of Large Trucks and All Vehicles:
         I-880 Northbound at 66th Avenue, Oakland ... Page 36
Figure  7 Diesel Heavy-Duty Truck Running Exhaust
         vs. Speed (Total Organic Gases) .......... Page 50
Figure  8 Diesel Heavy-Duty Truck Running Exhaust
         vs. Speed (Carbon Monoxide) ............... Page 51
Figure  9 Diesel Heavy-Duty Truck Running Exhaust
         vs. Speed (Oxides of Nitrogen) ............ Page 52
Figure 10 A Parallel Research Path ................. Page 73
Figure 11 Research Sequencing ..................... Page 84
EXECUTIVE SUMMARY

This report focuses on the sources of uncertainty in emission factors and activity estimates used by regulatory agencies to estimate the emission contribution of heavy-duty trucks. This investigation into the areas of uncertainty in the heavy-duty diesel truck emission inventory evaluates the methods and data used by regulatory agencies.

Heavy-duty trucks are a significant source of air pollutant emissions. Current estimates for California indicate that on-road heavy-duty diesel-powered vehicles, trucks greater than 8500 pounds gross vehicle weight rating, contribute approximately 2% of the total reactive organic gas, 1% of the carbon monoxide, 17% of the oxides of nitrogen, 12% of the oxides of sulfur, and 2% of the particulate matter emissions in California. However, as will be discussed in this report, these estimates are based upon suspect data and questionable cause-effect relationships.

The emissions of ozone precursors (hydrocarbons and oxides of nitrogen) from heavy-duty truck operations are forecast by the California Air Resources Board (CARB) to increase through the year 2000. The emission increase in the heavy-duty truck category is due to the projected growth in heavy-duty truck travel. Because most of the population of California lives in urban areas where ozone ambient air quality standards are being violated (CARB, 1989a; CARB, 1990a), there is growing pressure to reduce emissions from heavy-duty vehicles (as well as all other pollution sources).

Emissions from motor vehicles are a function of how, and under what conditions, the vehicles are operated. In general, mobile source emission inventories are developed by defining vehicle activities (through vehicle activity models), and coupling the activities with activity-specific emission rates (corrected for environmental conditions and trip characteristics). Thus, estimates of operating emissions from any vehicle are dependent upon two sets of parameters, emission-producing vehicle activity and activity-specific emission rates.
The emissions from individual vehicle activities are summed to determine the total emission inventory.

To accurately estimate heavy-duty vehicle emissions, and the quantity of emission reductions from proposed emission control strategies, credible methods must be employed. Otherwise, policy analysts will not be able to adequately evaluate the comparative cost-effectiveness and technical feasibility of various transportation control measures.

Although the United States Environmental Protection Agency (USEPA) and the CARB have attempted to ensure that the best available data are employed and that research projects designed to improve the methodologies are undertaken, a high degree of estimation uncertainty still persists.

The estimated emissions for heavy-duty diesel-powered trucks are uncertain due to problems with emission rate quantification, highly aggregated and inaccurate vehicle activity estimates, and omitted analysis of emission-producing vehicle activities. Specific problems include: 1) test methods used to determine emission rates are somewhat imprecise and inaccurate, 2) emission rates are based upon a non-statistically-representative number of vehicles, 3) the activity-specific emission rates employed are not representative of emissions from actual vehicle activity, 4) questionable activity-specific emission rate correction factors are employed, 5) the application of "typical" or "average" emission factors to specific vehicle activity does not represent the diversity of vehicle activity, 6) vehicle activity parameters are highly aggregated, 7) questionable surrogate indicators are used to estimate actual activity parameters (e.g. traffic counts used to estimate vehicle miles of travel are suspect), 8) the actual vehicle activities being monitored are not representative of emission-producing activities, and 9) a number of critical vehicle activities are omitted from the models.

The total amount of uncertainty may be greater than the sum of uncertainty in each step of the emission inventory preparation process. That is, uncertain vehicle activity is multiplied by
uncertain activity-specific emission rates, and is corrected by uncertain correction factors. However, it would be inappropriate to apply simple statistical formulae to the suspected ranges of uncertainty to determine what the net uncertainty is. There are simply too many unanswered questions relative to the basic applicability and usefulness of much of the data collected. That is, it is impossible to develop accurate error distributions for each parameter because insufficient information regarding the applicability of surrogate measures exists, and because modeling results have not been field verified. In essence, it is impossible to determine whether the currently estimated emissions are too high, too low, or even accurate by chance.

Policy analysts are faced with evaluating emission control measures for which the existing models are the only analytical tools available. However, the modeling results are highly uncertain because the models were only designed to roughly estimate a "bulk" emission inventory, and were never designed to evaluate the local impacts of emission control strategies. Thus, the models are not up to the task of policy analysis and must be improved. Significant modeling and data collection improvements are needed for analyzing changes in vehicle activity and activity-specific emission rates.

Current data and methodologies are clearly inadequate for designing and evaluating heavy-duty diesel truck emission control strategies. Significant improvements are needed in analyzing vehicle activity, and in deriving activity-specific emission rates and baseline emission rate correction factors. Only when improved CARB emission rates and correction factors can be coupled with improved activity estimates, will the methods be accurate enough for use in estimating corridor-specific emission effects of proposed emission control strategies.

Almost all of the discussion in this report regarding uncertainty in the heavy-duty diesel-powered truck emission inventory is also applicable to the heavy-duty gasoline-powered truck emission inventory. In fact, many of the uncertainty issues raised in this report are even applicable to the light-
duty vehicle emission inventory (although light-duty problems are generally less pervasive).

For the most part, heavy-duty diesel and gasoline truck emission inventories are more uncertain than light-duty vehicle emission inventories, due to limited heavy-duty laboratory testing of vehicles and scant knowledge about heavy-duty vehicle activity patterns. Additional concentrated research efforts are called for on all fronts of the heavy-duty emission inventory preparation methodology.

Sources of modeling uncertainty are described and discussed in this report, and a research framework designed to reduce uncertainty in the emission inventory for heavy-duty trucks is provided. The CARB is strongly encouraged to initiate its proposed research program for testing and specifying mode-specific heavy-duty truck emission rates, and emission rate correction factors. A complementary research effort to provide accurate estimates of applicable heavy-duty vehicle activities is also necessary.

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1 Sixteen detailed research projects are proposed in a separate document by the authors (Guensler, et al., 1991).
INTRODUCTION

MOBILE SOURCE CONTRIBUTIONS TO AIR POLLUTION

Currently, all of the major urban areas in California are in violation of one or more of the national ambient air quality standards for ozone, carbon monoxide, and particulate matter (CARB, 1989a; CARB, 1990a). The combustion and evaporation of motor vehicle fuels contributes significantly to high levels of pollution that can harm human health and economic productivity.

According to the California Air Resources Board's 1987 emission inventory (CARB, 1990b), approximately 37 percent of the total reactive organic gas (ROG), 58 percent of carbon monoxide (CO), 56 percent of oxides of nitrogen (NOx), 24 percent of the oxides of sulfur (SOx), and 3 percent of the particulate matter ($\text{PM}_{10}$)\(^1\) emissions in California are attributed to on-road motor vehicles. It should be noted, however, that the magnitude of emissions from the motor vehicles is the subject of ongoing research and that emissions may be significantly underestimated.\(^2\)

On-road heavy-duty diesel-powered vehicles are major contributors of NOx and SOx, contributing approximately 2% of the reactive organic gas, 1% of the carbon monoxide, 17% of the oxides of nitrogen, 12% of the oxides of sulfur, and 2% of the $\text{PM}_{10}$ emissions in California (Table 1 and Figure 1; CARB, 1990b).\(^3,4,5\) Emissions of NOx, as a precursor to the formation of photochemical smog, and the emissions of particulate matter, primarily as a nuisance pollutant,\(^6\) are the primary concerns from heavy-duty diesel trucks in most heavily urbanized areas.

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1 Less than 10 microns in diameter.
2 Results from field experiments conducted during the South Coast Air Quality Study (SCAQS) have indicated that the CARB's emission rate model used until 1990 (EMFAC7C) may have seriously underestimated in-use motor vehicle emissions (Ingalls, et. al, 1989).\(^2\) Experimental results from the SCAQS study indicated that the emissions of hydrocarbons may have been underestimated by as much as a factor of 1.4 to 6.9 (Ingalls, et. al, 1989). Although the current version of the EMFAC model (EMFAC7E) contains additional emission factors associated with running evaporative losses, and may better represent emissions from the vehicle fleet, a significant degree of uncertainty still exists.
3 As is discussed in this report, these estimates are highly uncertain.
4 It should also be noted that heavy-duty gasoline trucks are responsible for significantly higher contributions of reactive organic gases and carbon monoxide than are diesel vehicles.
5 Appendix A describes the general differences between gasoline and diesel engine emissions.
6 $\text{PM}_{10}$ is also under investigation as a toxic air contaminant.
<table>
<thead>
<tr>
<th>Category</th>
<th>ROG</th>
<th>CO</th>
<th>NOx</th>
<th>SOx</th>
<th>PM10</th>
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<td>2</td>
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<td>107</td>
<td>1,010</td>
<td>236</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,061</strong></td>
<td><strong>18,697</strong></td>
<td><strong>3,420</strong></td>
<td><strong>517</strong></td>
<td><strong>6,151</strong></td>
</tr>
</tbody>
</table>

Source: CARB, 1990a
Figure 1

1987 California Emission Inventory

- A Stationary Sources
- B Automobiles
- C Light/Medium-Duty Trucks
- D Heavy-Duty Gas
- E Heavy-Duty Diesel
- F Other Mobile Sources

TONS/DAY

POLLUTANT

PM10

SO2

NOx

CO

ROG
HEAVY-DUTY DIESEL TRUCK EMISSION CONTRIBUTIONS

Although heavy-duty truck emissions have been regulated since 1970 (White, 1982), the emissions from heavy-duty trucks have been less regulated than the emissions from other mobile sources (in terms of percentage reduction from uncontrolled emissions levels). 7

On a gram-per-mile basis, heavy-duty diesel truck emissions are significantly higher than automobiles due to heavy operating loads and power requirements, large engine sizes, and diesel combustion parameters (contributing to increased NOx emissions). Although there are relatively few heavy-duty trucks operating on the road compared to automobiles, roughly 1% to 6% of the traffic volume, depending upon location and time of day (Cambridge Systematics, 1988), the emissions from each individual truck are significantly higher than the emissions from each automobile.

EMISSION TRENDS AND REGULATORY DIRECTION

Emissions from the overall mobile source category have been decreasing over the past ten years as a result of stringent light-duty vehicle exhaust emission standards. 8 With the adoption of new low emitting vehicle requirements (CARB, 1990c) and an updated mobile source control plan, California should be able to maintain current progress in providing absolute emission reductions from motor vehicles. 9 However, with California's high population growth rate, transportation control strategies are still seen as necessary for attainment and maintenance of air quality standards in many urban areas.

The population of California has been growing at a rate of about 2% per year (about 50% of this growth resulting from migration and 50% from birth-over-death increases) (Center for Continuing Study of the California Economy, 1989). The use of

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7 Appendix B contains a summary of past and present regulatory efforts directed at heavy-duty trucks.
8 Including the implementation of inspection and maintenance programs (Austin, 1991).
9 The turnaround date for real emission reductions is beyond the 2010 planning horizon. If the zero emission vehicle implementation is enhanced, turnaround could be in the middle of the next century, or maybe never (Lovelace, 1991).
vehicles per capita (VMT/capita) is also increasing at a rapid rate, such that the total rate of VMT increase (due to the combined effects of population growth and VMT/capita growth) is approximately 5% per year (CARB, 1989b).

The absolute emissions of ozone precursors from heavy-duty truck operations are forecast by CARB emission inventory staff to continue to increase through the year 2000.\textsuperscript{10} This emission increase is due to projected growth in heavy-duty truck travel and, to some extent, due to a general increase in projected vehicle fleet congestion (which decreases travel speed and increases gram/mile emission rates for each vehicle). As heavy-duty vehicle emissions increase, and as light-duty vehicle emissions continue to decrease (as a result of more stringent vehicle emission standards; CARB, 1990c), the relative contribution of emissions from heavy-duty vehicles to the total mobile source emission inventory will continue to grow.

To service the increasing needs of a growing population, truck activity has been increasing rapidly. For example, the California Department of Transportation (Caltrans) truck-miles traveled survey indicates that truck-miles-traveled for 5+ axle heavy-duty increased by about 5% between 1985 and 1986, and more than 10% between 1986 and 1987 (Caltrans, 1988). Overall, VMT appears to be increasing by between 6% and 8% per year in all truck categories, significantly faster than the 5% annual growth rate noted for light-duty vehicles.

To counter the effects of the increasing relative emission contributions from heavy-duty trucks, the CARB and local regulatory agencies are currently evaluating emission control strategies. The general regulatory direction\textsuperscript{11} is to reduce the emission rates from heavy-duty vehicles (e.g. using onboard emission control equipment or by implementing transportation control measures), and to reduce the impact that heavy-trucks may

\textsuperscript{10} However, the rate and magnitude of the emission increase do not yet take into account the 1994 heavy-duty engine standards for new vehicles. In addition, although the low emitting light-duty vehicle standards package does not contain new requirements for California's heavy-duty diesel engines, additional diesel engine standards are likely to be developed over the next few years.

\textsuperscript{11} AB2595 Technical Advisory Committee, 1990.
have on the emissions from rest of the vehicle fleet (i.e. the congestion contribution of trucks increases the emission rates from all vehicles).

104 EMISION MODELING AND POLICY CONCERNS

The estimated contribution of heavy-duty diesel vehicles to the total mobile source emission inventory is large, as was shown in Table 1, but the problem is that much of the mobile source emission data are suspect.

The heavy-duty truck emission inventory estimates are modeled pollutant contributions, based upon assumptions and methodologies that are outlined in this document. However, as will be discussed throughout this paper, the estimates have not been verified and their accuracy is questionable.

Accurate methods are needed to estimate heavy-duty diesel emissions, and to estimate the quantity of emission reductions from proposed emission control strategies. In evaluating potential of emission control measures, specific emission reduction effects must be determined (CARB, 1990d). Without accurate emission estimation methods, the technical and economic feasibility of proposed transportation control strategies and fuel requirements cannot be accurately evaluated.

Diverse economic and social effects, and numerous other policy issues, are associated with the implementation of emission control strategies. Regulators and the regulated community are now evaluating potential emission control strategies that would affect the trucking industry, such as: requirements for new add-on control technology, mandated use of reformulated diesel and alternative fuels, implementation of regional diesel engine bans, AM/PM truck operating restrictions, off-peak shipping and receiving requirements, freight distribution center implementation, truck idling restrictions, speed limit enforcement (as an emission control), truck-accident mitigation (to improve traffic flow), dedicated truck thoroughfares, congestion pricing and other market-based incentives, and

In evaluating potential control measures for implementation, specific emission reduction effects must be determinable. Thus, models are needed that are applicable to segments of the vehicle fleet and segments of vehicle activity, capable of determining changes in vehicle activity and the net emissions effects of corridor-specific control measures.

As regulators and the regulated community struggle to determine which control measures should be implemented, a fundamental question must be answered: are the existing heavy-duty diesel vehicle emission inventory methods adequate to estimate the emission reductions from proposed transportation control measures or fuel requirements?

A fundamental understanding of the uncertainty in the emission inventory methodologies will make it possible to guide needed research efforts and to formulate policies that explicitly acknowledge existing uncertainty (Austin, 1991).

105 REPORT ORGANIZATION

The primary purpose of this project is to evaluate the methods and data currently used to estimate the emission inventory for heavy-duty diesel vehicles. This report: 1) describes the current modeling methodologies for heavy-duty diesel trucks; 2) discusses the sources of uncertainty based upon highlighted modeling deficiencies; 3) presents general conclusions related to the likely sources of greatest uncertainty; and 4) presents a research framework and suggested projects that will reduce uncertainty and lead toward the development of comprehensive modeling methodologies.\textsuperscript{12}

Almost all of the discussion in this paper regarding uncertainty in the heavy-duty diesel-powered truck emission inventory is applicable to the heavy-duty gasoline-powered truck

\textsuperscript{12} Sixteen detailed research projects, designed to address the uncertainty findings outlined in this document, are provided in a separate document by the authors (Guensler, et al., 1991).
emission inventory. In fact, many of the uncertainty issues raised in this paper are even applicable to the light-duty vehicle emission inventory (although light-duty problems are generally less pervasive). For the most part, the heavy-duty diesel truck contribution is more uncertain because laboratory testing has been limited and little is known about heavy-duty vehicle activity patterns.

This report is organized in seven major sections. Section 200 contains an overview of the emission inventory process and a general explanation of the emission inventory methodology. Section 300 is an analysis of the current vehicle activity inputs to the emission inventory process and a critique of the accuracy of data currently used in emission modeling efforts. Section 400 is an evaluation of the heavy-duty truck activity-specific emission rates and correction factors currently used in emission modeling. Section 500 is an overall assessment of uncertainty in the heavy-duty diesel vehicle emission inventory. Section 600 proposes a general research framework, and recommends further research designed to provide modeling methodologies that will: 1) reduce uncertainty in the emission inventory, and 2) be useful in evaluating the effects of proposed regulatory strategies.
The following sections discuss the general concepts used in preparing an emission inventory for motor vehicles (for light and heavy-duty, gasoline and diesel-powered vehicles). General discussions of vehicle activity and activity-specific emission rates are included. However, the specific differences between methodologies used for light-duty and heavy-duty vehicles will not be analyzed in this section. Nevertheless, a number of points will be raised in this section that will be elaborated upon in Sections 400 and 500.

THE EMission INVENTORY PROCESS

The emission inventory is an estimate of the total anthropogenic (human produced) emissions released into the atmosphere from stationary, area, and mobile sources of pollution within an air basin.

The emission inventory is coupled with air pollutant dispersion and photochemical models\(^\text{13}\) to estimate the emission reductions necessary to bring an air basin into attainment with California and national ambient air quality standards (CAAQS and NAAQS). The total emission reductions required to achieve compliance with the ambient air quality standards are estimated, then specific emission control strategies for mobile and stationary sources are developed by local regulatory agencies. The sum of the emission reductions achieved by individual control strategies yield (theoretically) the necessary overall reduction. Then, the emission inventory is used to monitor progress toward attainment of ambient air quality standards.

The emission inventory and modeling efforts are used by local agencies during the development of emission control regulations (rule development). For mobile sources, the models that are used to develop the emission inventory are often used to

\(^{13}\) Photochemical models predict the formation of smog (ozone and other oxidants) based upon the chemical reactions of pollutants in the atmosphere.
estimate the emission reduction potential of proposed regulatory control strategies. After accounting for emission category growth, regulators attempt to determine the order in which control strategy implementation will be most effective in reducing ambient concentrations of harmful pollutants.

The challenge of specifying the emission contribution of mobile sources is more difficult than for most stationary industrial sources (often reported directly to regulatory agencies). Mobile source emissions cannot be feasibly monitored while vehicle are in-use, cannot be determined through a mass balance analysis (occasionally used for industrial processes), and cannot be feasibly estimated by monitoring facility operating parameters (such as monitoring process parameters and using emission factors to estimate emissions).

**Emission Inventory Modeling**

As illustrated in Figure 2, a generic description of emission inventory modeling, emissions from any type of motor vehicle are dependent upon two sets of general parameters: emission-producing vehicle activity, and activity-specific emission rates (both are detailed in the following sections).

Mobile source emissions are calculated by estimating vehicle activities, and coupling the activities with applicable emission rates. The calculated emissions from all of the individual activities are then summed to determine the total emission inventory. The CARB's emission inventory is developed through the use of an activity model (BURDEN7C) and an emission rate model (EMFAC7E). Appendix C contains a brief description of the vehicle activity and emission rate modeling efforts that are used in the emission inventory preparation.

202 EMISSION-PRODUCING VEHICLE ACTIVITY

From an emission modeling standpoint, "emission-producing vehicle activity" can be loosely defined as any discrete vehicle attribute or use that results in emissions. Regulatory agencies
Figure 2

Generic Mobile Source Emission Inventory Methodology

ACTIVITIES
- Number of Vehicles
- Vehicle Miles Traveled and Speed Distribution
- Vehicle Idling
- Number of Trips and Start-Mode Distribution (Hot vs. Cold)

CONTROLLING FACTORS
- Speed (mph)
- Starting Mode (Hot vs. Cold)
- Temperature

Daily Vehicle Activity

Activity-Specific Emission Rates

Emission Inventory
currently define emission-producing vehicle activity in terms of four parameters: number of vehicles,\textsuperscript{14} number of trips, vehicle-miles traveled, and hours of idling.\textsuperscript{15}

The heavy-duty truck activity estimation methodology differs significantly from that of light-duty vehicles (Appendix D contains a brief description of the methodology used for light-duty vehicles). The essential difference between heavy-duty and light-duty methodologies is that heavy-duty truck activity is estimated through surrogate indicators (such as traffic counts)\textsuperscript{16} while light-duty vehicle activity may be estimated through local travel demand models.\textsuperscript{17}

Of the four activity parameters currently applicable to heavy-duty trucks (running emissions, hot starts, cold starts, and engine idling), only vehicle-miles traveled is explicitly used in the emission inventory methodology.\textsuperscript{18}

If the methodology is to yield useful results for modeling air quality effects, vehicle activity must be very specific. For example, if cold and hot engine start activities are to be discerned, vehicle activity must be examined in relation to immediately previous activities. Yet, it is not enough to simply know in general what activity occurs because the environment in which the vehicle operates greatly affects the emissions that result from specific activities (discussed in Section 204).

\footnote{The number of vehicles is an indication of the evaporative emissions. The number of vehicles is now differentiated into two categories: in-use and parked. Vehicles that are parked for two or more consecutive days generally have higher evaporative emission rates (due to saturation of the hydrocarbon canister).}

\footnote{California's emission inventory does not include hours of idling for heavy-duty trucks. In a few cases, e.g. at airports, idling may be included in local emission inventories (Wayson, 1991).}

\footnote{The use of traffic counts, such as provided by the HPMS system, to determine truck VMT is unlikely to be highly accurate. Total VMT estimates from the California HPMS system are probably plus or minus 30\% (Purvis, 1991). Principle problems with the use of HPMS include: inadequate numbers of permanent counting sites, mis-classification of roadways, numerous assumed/estimated counts, infrequent sampling periods, rough approximations that convert axle counts to VMT, assumed truck percentages by road-type (failure to account for local variation), and questionable axle count conversion algorithms (Deakin, 1987 and 1991; Purvis, 1991).}

\footnote{Urban Transportation Planning System (UTPS) models for light-duty vehicles are developed using origin-destination surveys. The models provide trip generation (based upon land-use and socioeconomic characteristics), trip distribution, mode choice, and route assignment. However, UTPS models do not include heavy-duty truck activity.}

\footnote{As will be discussed in Section 401, the running emission rate for each engine includes a weighted contribution from running the same cycle with the engine cold (weighted 1/7 cold, 6/7 hot stabilized). Although cold starts may be partially accounted for, as will be discussed later, the emission rates and weightings are highly questionable.}
203 ACTIVITY-SPECIFIC EMISSION RATES

Activity-specific emission rates describe the mass of pollutants emitted while undertaking an emission-producing activity (i.e. grams of emissions per unit of specific vehicle activity). For example, emission rates can be determined for such activities as an engine start (grams per start) or a vehicle mile traveled (grams per mile).

Emissions result from the following general vehicle activities: vehicle-miles traveled (running emissions and running evaporative losses), idling, engine starts (cold or hot start incremental emissions), engine cool-down (hot soak incremental emissions, gasoline engines only), diurnal evaporation and multi-day diurnal evaporation (gasoline engines only). Power enrichment (acceleration) is also suspected of being a discrete vehicle activity that produces significant emissions (CARB, 1991b; Groblicki, 1990; Calspan Corp, 1973; Kunselman, et al., 1974), but is not currently modeled.

For diesel-powered vehicles, emission rates would normally be determined only for the first four parameters (running VMT, idling, and start-up emissions); all evaporative losses are ignored for diesel fueled engines because they are minimal. However, of the four activities currently applicable to heavy-duty diesel trucks (running emissions, hot starts, cold starts, and engine idling) only vehicle miles traveled is currently used in estimating the emission inventory.

Vehicle emission rates are determined through laboratory testing, using the methods and procedures established by the USEPA and the CARB. The standard test procedures used for the certification of new engines are the same procedures that were used by regulatory agencies to estimate heavy-duty truck baseline emission rates and correction factors (see Appendix E). Emission rates for each vehicle and engine type are dependent upon vehicle characteristics (size, weight, etc.), engine design, and emission control technologies applied by the manufacturer to the vehicle.

19 Running evaporative losses are for gasoline engines only.
20 Discussed in Section 408.
The emission factors from subsets of vehicle types are aggregated into an average vehicle class emission factor for local areas, using vehicle registration data.\textsuperscript{21} The average vehicle class emission factors are then used in the emission inventory process, and are multiplied by vehicle class activity estimates.

204 EMISSION RATE CORRECTION FACTORS

The magnitudes of vehicle activity emission rates are influenced by the operating environment of the vehicle. In particular, engine start mode (hot and cold), vehicle speed, and operating temperature affect vehicle emission rates.

Baseline emission rates (determined through standard test procedures) are adjusted, through the use of laboratory determined correction factors, so that they may be applied to specific operating conditions. For example, baseline emission rates for light-duty vehicles must be corrected for operating temperature, average trip speed, and expected compliance with inspection and maintenance requirements. Because diesel fuel is low volatility (evaporates slowly), temperature correction factors are not applied to diesel fueled engines.

By applying correction factors to the baseline rates, outputs for specific vehicle activity under specific operating conditions can be determined.\textsuperscript{22} The sum total of all emission rate data available through the emission factor model can be conceived of as a multi-dimensional emission rate matrix. The computer program determines specific emission rates for specific vehicle classes operating under given environmental conditions. Examples of the emission rate tables for variable operating conditions are presented in Appendix F (CARB, 1986).

\textsuperscript{21} As will be discussed in Section 401, California's heavy-duty truck emission rates do not vary by local area.

\textsuperscript{22} For example, the running exhaust emissions (grams per mile) can be determined for a vehicle traveling at 30 miles per hour, with an ambient temperature of 90F, and with an assumed inspection and maintenance effectiveness of 85\%. 
MOBILE SOURCE EMISSION FACTOR MODELS

The information provided in Sections 202 to 204 of this report can be summarized in schematic diagrams. Figure 3 illustrates the components of activity-specific emission rate tables (boxes) that are coupled with applicable vehicle activities to generate emission estimates for heavy-duty vehicles. Omitted emission rates (and their corresponding activities) are represented by dashed boxes.\textsuperscript{23} Correction and conversion factors are indicated with ellipses.

Figure 3 may be compared to the analogous figure for light-duty vehicles (Figure 4). As can be seen in the diagram, additional emission-producing activities have been identified, and more correction factors are applicable to the light-duty (gasoline and diesel-powered) vehicle fleet.

\textsuperscript{23} As noted earlier, idling is sometimes included in the emission inventory (e.g. at airports).
Figure 3

CARB's
EMISSION FACTOR MODEL
Heavy-Duty Vehicles

Conversion to g/mi
(EPA Formula)

Baseline Running
Emission Rates
(g/bhp-hr)

- Inspection & Maintenance Corrections
- Speed Correction Factors

Activity-Specific
Emission Rate Tables

- Cold Start
  Emission Rates
  (g/start)
- Hot Start
  Emission Rates
  (g/start)

- Engine Idling Emission Rates (g/hr)
Figure 4

CARB's
EMISSION FACTOR MODEL
Light-Duty Vehicles

Running
Evaporation
Emission Rates (g/mi)

Baseline Running
Emission Rates
(g/mile)

Temperature
Correction
Factors

Inspection &
Maintenance
Corrections

Activity-Specific
Emission Rate
Tables

Speed
Correction
Factors

Cold Start
Emission Rates
(g/start)

Hot Start
Emission Rates
(g/start)

Hot Soak
Emission Rates
(g/soak)

Diurnal Evaporation
Emission Rates
(g/day)

Engine Idling Emission
Rates (g/hr)
Most truck activity studies in the existing literature have examined the methodologies employed to obtain estimates. That is, activity estimates achieved through varied estimation methodologies are compared with each other as an indication of whether the methods are valid. However, while the methods tested may be reliable and yield similar results, there is no means currently employed to confirm the accuracy of the estimates (i.e. are the methods true to life).

This section discusses the vehicle activity parameters that are used in the emission inventory process, current vehicle activity estimates and modeling efforts, and uncertainty associated with the activity estimates. As discussed in Sections 202 and 203, the vehicle activities that are of concern are vehicle attributes or uses that results in emissions. In general, regulatory agencies currently define important vehicle activity in terms of four parameters: number and classification of vehicles, number of trips, vehicle miles traveled, and hours of idling. In addition, acceleration, off-road activities, incidental activities, and accounting for vehicle activity distribution are discussed in this section.

301 NUMBER OF VEHICLES

In 1983, more than 570,000 California-based heavy-duty diesel and gasoline trucks were operating in California (Horie and Rapoport, 1985). In addition, more than 170,000 out-of-state-based trucks, registered outside of California but which travel a portion of their mileage within California, were operating in California (Horie and Rapoport, 1985; Sydec, 1987a,b).

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24 This total includes more than 263,000 light heavy-duty vehicles (averaging 11,000 pounds Gross Vehicle Weight (GVW)), 171,000 medium heavy-duty vehicles (averaging 21,000 pounds GVW), and 137,000 heavy heavy-duty vehicles (averaging 68,000 pounds GVW)(Horie and Rapoport, 1985).
25 Mostly heavy heavy-duty trucks.
Heavy-Duty Truck Classifications

The following vehicle classes are employed by the California Air Resources Board for on-road motor vehicles: light-duty automobiles, light-duty trucks (0 - 6000 lb gross vehicle weight rating (GVWR)), medium-duty trucks (6000 - 8500 lb GVWR), heavy-duty trucks (8500+ lb GVWR), urban buses, and motorcycles.

Vehicle classes are further segregated into vehicle technology categories, by fuel type and emission control technology. The following vehicle sub-classes are employed by the CARB for on-road motor vehicles: gasoline-powered engines with catalytic converter controls (CAT), gasoline-powered engines without catalytic converter controls (NCAT), and diesel-powered engines (DSL).

Thus, the following general vehicle class and sub-class combinations are used by the CARB (Figure 5): light-duty automobiles (CAT, NCAT, DSL); light-duty trucks (0 - 6000 lb GVWR) (CAT, NCAT, DSL); medium-duty trucks (6000 - 8500 lb GVWR) (CAT, NCAT); heavy-duty trucks (8500+ lb GVWR) (CAT, NCAT, DSL), urban buses (DSL), and motorcycles (NCAT).

Vehicle Weights

The differences in the definitions of "heavy-duty truck" among various regulatory agencies can be significant, depending upon whether weight is measured as gross vehicle weight rating (GVWR), gross vehicle weight (GVW), or unladen weight. These differences create data discrepancies and uncertainty in measurement of number and types of diesel vehicles (Nelson, et al., 1991).

The gross vehicle weight rating is assigned by the vehicle manufacturer and is based upon manufacturer-authorized hauling weight. The gross vehicle weight rating is often used by regulatory agencies to determine the applicability of motor carrier safety regulations (Nelson, et al, 1991). The

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26 GVWR means the weight in pounds of the chassis of a truck or truck tractor, including: the weight of all lubricants, fuel, the cab, body, special chassis and body equipment, and the payload as authorized by the manufacturer (Motor Vehicle Code, Section 390).
<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>CAT</th>
<th>DSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycles</td>
<td>NCAT</td>
<td></td>
</tr>
<tr>
<td>Light-Duty Autos</td>
<td>NCAT</td>
<td>CAT</td>
</tr>
<tr>
<td>Light-Duty Trucks 0 - 6000 lb</td>
<td>NCAT</td>
<td>CAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DSL</td>
</tr>
<tr>
<td>Medium-Duty Vehicles 6000 - 8500 lb</td>
<td>NCAT</td>
<td>CAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DSL</td>
</tr>
<tr>
<td>Heavy-Duty Vehicles 8500+ lb</td>
<td>NCAT</td>
<td>CAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DSL</td>
</tr>
<tr>
<td>Urban Buses</td>
<td></td>
<td>DSL</td>
</tr>
</tbody>
</table>
California Air Resources Board also uses GVWR to establish the applicability of vehicle emission certification requirements (e.g. California HSC 39033 and 39037.5).

The gross vehicle weight is the weight of the fully-laden vehicle (including freight) on the road. The typical (GVW) is estimated by the vehicle owner and reported to regulatory agencies for the purposes of weight-distance tax calculations (Nelson, et. al, 1991). The California Highway Patrol uses actual on-road gross vehicle weight to determine compliance with weight restrictions per axle under the Motor Vehicle Code.\(^{27}\)

The unladen vehicle weight is reported to the California Department of Motor Vehicles for registration fee purposes (for example, see MVC 9400). The unladen weight, or tare weight, would be the gross vehicle weight less the weight of the payload.

**Heavy-Duty Truck Engine Classifications**

The USEPA has defined three general classifications for engines used in heavy-duty trucks: light heavy-duty, medium heavy-duty, and heavy heavy-duty. The intent of the following discussion is to demonstrate that a wide variety of engine sizes are used by a wide variety of truck configurations within the heavy-duty vehicle fleet. However, there are currently no activity or emission factor estimates that are disaggregated by engine classification.

Light heavy-duty diesel engines are typically rated from 70 to 170 horsepower. Vehicle body types would range from vans trucks, recreational vehicles, and some single axle straight trucks. The GVWR of the vehicle is usually less than 19,500 pounds (40CFR86.085-2(a)(1)). Light heavy-duty engines are generally not sleeved\(^{28}\) nor designed for rebuild.

Medium heavy-duty diesel engines are typically rated from 170 to 250 horsepower. Vehicle body types include buses, tandem axle trucks, dump trucks, etc. The GVWR of the vehicle is usually from 19,500 pounds to 33,000 pounds (40CFR86.085-
2(a)(2)). Medium heavy-duty diesel engines may be sleeved and may be designed for rebuild.

Heavy heavy-duty diesel engines typically exceed a rating of 250 horsepower. Vehicle body types are typically tractor-trailer rigs, and trucks and buses used in long haul intercity operations. The GVWR usually exceeds 33,000 pounds (40CFR86.085-2(a)(3)). Heavy heavy-duty diesel engines are sleeved and designed for multiple rebuilds.

**Vehicle Registration**

Regional emission models generally rely upon vehicle registration data collected by the California Department of Motor Vehicles (DMV) to estimate the number of vehicles contributing to the mobile source emission inventory. However, this method cannot accurately account for inter-county truck use (i.e. trucks rarely operate only in the county in which they are registered, plus out-of-state-registered vehicles must be accounted for). Using registration data in any local emission calculation methodology is problematic; the on-road fleet mix is a much more important parameter.

One of the uses in the emissions models of vehicle registration data is to determine diurnal evaporative emissions. Because diurnal evaporative emissions are assumed to be insignificant for diesel engines, the total number of diesel-powered heavy-duty trucks in an air basin is not assumed to contribute directly to the emission inventory calculation.

However, vehicle registration mix contributes to emissions rates indirectly. "Average vehicle" emission rates for vehicle classes are usually calculated using the weighted registration mix of vehicles in the local area and the laboratory determined emission rates from each subset of vehicle types by model year (i.e. weighting the emission factors using registration data and

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29 Because diesel fuel has a much lower volatility than gasoline, evaporation of fuel is considered to be insignificant, and no emission factor is estimated for heavy-duty diesel truck evaporative emissions. Thus, the number of diesel trucks in the fleet is not considered to affect daily evaporative emissions. If evaporative emissions are later determined to be significant for diesel vehicles, the registration and use data of out-of-state vehicles will be highly uncertain.
local VMT fractions). Thus, the actual model year distribution and the gasoline/diesel vehicle class distribution operating in an air basin is a critical component of the analysis. Because the emission rate for the "average vehicle" in the vehicle class is used in emission inventory calculations, aggregation bias can be introduced.

Currently, only registration and sales data are used for determining heavy-duty diesel fleet composition by model year. Currently, the California registration mix for heavy-duty vehicle technology type is based upon the 1975 Polk\textsuperscript{30} truck data for Diamond-Reo, Kenworth, Mack, Peterbuilt, and White manufacturers (CARB, 1986; CARB, 1988). The truck VMT fractions were derived from the 1972 Census of Transportation and Truck Use Survey (U.S. Bureau of Census, May 1978)(CARB, 1986).\textsuperscript{31}

The VMT weighting, based upon the 1972 Census of Transportation and Truck Use Survey data, is very uncertain today due to: the limited California sampling, the age of the data, subsequent deregulation of the industry, and dramatically changed socio-economic conditions.\textsuperscript{32}

At this time, average vehicle emission rates for heavy-duty trucks are currently assumed to be constant throughout the state. Thus, California's heavy-duty truck emission rates do not vary by local area. The heavy-duty truck emission factors are scheduled to be modified to reflect the truck mix for local areas within the next few years (Lovelace, 1991).

Note also, the vehicle registration mix only includes subdivisions for heavy-duty gasoline, gasoline with catalytic controls, and diesel engines. No information regarding the engine size or payload of the vehicle is employed in current emission modeling methodologies, because there are no emission factors associated with these variables.

\textsuperscript{30} R.L. Polk and Company.
\textsuperscript{31} The VMT fractions used to weight the vehicle class emission factors for each technology type appear to be different than the VMT fractions used as activity estimates in the BURDEN model. However, this should not appreciably affect the emission rates from the heavy-duty truck vehicle class, unless a significantly higher percentage of gasoline trucks appears in either of the VMT fractions.
\textsuperscript{32} The heavy-duty truck emission factors are scheduled to be modified to reflect the truck mix for local areas within the next few years (Lovelace, 1991).
Thus, there are no data available that allow a weighting of vehicle activity by heavy-duty truck engine size or payload size, both of which are likely to play an important role in vehicle emission rates. Yet, even if more detailed emission factors were developed, activity data at the same level of detail (e.g. for truck, engine, and payload size) do not currently exist. This may be a significant problem because companies may respond to emission control measures (such as Los Angeles’ proposed peak period heavy-duty truck operating restrictions) by shifting from diesel to gasoline power, or from larger to smaller trucks, changing the composition of the heavy-duty truck fleet (AB2595 Technical Advisory Committee, 1990). Changes in the on-road fleet mix play an important role in emission impact modeling, and new models ought to be made capable of addressing fleet composition changes over time.

302 NUMBER OF TRIPS

The number of motor vehicle trips directly affects the magnitude of incremental emissions\textsuperscript{33} that occur from cold and hot starts.\textsuperscript{34} Before engines reach efficient operating temperatures (i.e. "warm-up"), combustion efficiency is somewhat lower that in normal operations and emissions are higher. Low temperatures along the cylinder walls can create a "quenching effect" that results in incomplete combustion. Thus, cold engines generally have lower initial combustion efficiency than previously warmed engines (i.e. used immediately prior to the engine start). The number of trips and engine start-mode (cold or hot) determines incremental cold and hot start emissions.

\textsuperscript{33} An engine start is responsible for an immediate emissions puff, plus an increase in running emissions during the first few miles traveled. By using the term "incremental" the entire increase in emissions associated with the engine start (i.e. the difference between the emissions that occur with a start and the emissions that would occur for the same trip with a hot stabilized engine) is being conceptualized as an emissions puff.

\textsuperscript{34} When the engine is shut down, fuel in gasoline fueled systems can evaporate, resulting in what are called hot soak emissions. For diesel engines, hot soak emissions are assumed to be insignificant due to low fuel volatility and physical fuel injection characteristics. Thus, there is no need to include hot soak emissions in the emission inventory.
Cold and hot engine starts contribute significant emissions from light-duty vehicles, including light-duty diesel vehicles, although the cold and hot start emissions are notably larger for gasoline light-duty vehicles than for diesel light-duty vehicles (see Section 406).

However, cold start and hot start incremental emission rates have not been measured in the laboratory for heavy-duty diesel or gasoline trucks, and are assumed to be an integral component of baseline running emission rates (discussed in Sections 401 and 406). Emissions resulting from the trip ends are only partially accounted for through a laboratory test for VMT emission rates, which weights emission rates for cold and hot stabilized engine starts (see section 401). However, conclusions as to the significance of cold and hot start emissions for the HD truck population would be premature.

Because there are no incremental cold start or hot start emission factors in Mobile 4 or EMFAC for heavy-duty vehicles, the number of heavy-duty diesel truck trips are currently not modeled, and trip end emissions are not quantified. Thus, the CARB and USEPA methodologies essentially assume that "trucks never stop."

One of the arguments used to justify not examining cold and hot starts in the HD truck emission inventory, is that heavy-duty truck engines are frequently idled for extended periods in lieu of turning the engine off. The emission inventory, however, does not include any contribution from engine idling either.

Cold and hot start emissions from heavy-duty vehicles are potentially significant, but incremental starting activities of heavy-duty trucks have received little attention. Reductions in engine idling (which can increase the number of incremental engine starts) are being explored as a potential control strategy (AB2595 Technical Advisory Committee, 1990). Because the tradeoffs between idling and engine starts are unclear, cold and hot start activities should receive attention in future laboratory efforts.
Assigning incremental hot and cold start emission activity to specific locations (spatial resolution) is important from an emission modeling standpoint. Spatial resolution depends entirely upon the location of a vehicle when a trip is initiated. However, as noted earlier, it is difficult if not impossible to allocate vehicle start activities based upon registration data, because trucks generally operate in areas other than those in which they are registered.

303 VEHICLE-MILES TRAVELED

As would be expected, a significant portion of the emissions resulting from a vehicle trip are directly dependent upon the number of vehicle-miles traveled. For light-duty vehicles, the percentage of the emission contribution from VMT depends upon the length of the trip. The incremental cold and hot start emissions are much more significant for shorter trips. Hence, it might be expected that if cold and hot start emission factors existed for heavy-duty vehicles that they would also be less significant than VMT-related emissions for longer trips.

The Caltrans cost allocation study, prepared by Sydec Inc., estimated the annual truck VMT (Fiscal Year 1986-87) to be approximately 13.9 billion miles. The Caltrans Truck Miles Traveled report estimated approximately 12 billion truck miles were traveled during that same period (Caltrans, 1988). The EMFAC7D/BURDEN7A model, used by the California Air Resources Board (ARB) to estimate motor vehicle emissions, indicated that 15.5 billion heavy-duty truck miles were travelled in 1986-87 (average of the 1986 and 1987 estimates).35,36,37

Until 1985, the CARB calculated the heavy-duty vehicle fleet VMT by multiplying vehicle registration data by an assumed annual

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35 The CARB currently uses EMFAC7E and BURDEN7C.
36 In Los Angeles County in 1984, heavy-duty diesel trucks were estimated to be responsible for approximately 51% of the total heavy-duty truck VMT, while heavy-duty gasoline trucks were estimated to be responsible for 47% (Horie and Rapoport, 1985). The VMT split for the entire state of California was approximately 57% diesel, 42% gasoline. The remainder of the VMT being from "other" fuels.
37 It is likely, due to increasing urban congestion and changing shipping patterns, that two-axle heavy and medium-duty gasoline trucks are capturing larger shares of the total VMT over time.
VMT per vehicle. However, there was a much greater potential error associated with using that method, because most diesel heavy-duty vehicles operate outside of their registered county.

As discussed in Appendix D, light-duty vehicle activity can be determined through a detailed modeling procedure, using outputs from Urban Transportation Planning System (UTPS) type models. However, UTPS models are not capable of modeling commercial trips. The inability of UTPS models to model commercial trips reduces the usefulness of UTPS models for future forecasts of vehicle activity, especially for heavy-duty trucks (Oliver, 1991; Horie, 1991).

Currently, the CARB estimate for heavy-duty diesel truck VMT is based upon the report Assessment of Heavy-Duty Gasoline and Diesel Vehicles in California: Population and Use Patterns, prepared by Pacific Environmental Services (PES) (Horie and Rapoport, 1985). The PES study provided estimates of heavy-duty truck VMT that were based upon VMT data generated by the Caltrans' Truck Program and Highway Performance Monitoring System as well as limited surveys. The VMT estimates were based on Caltrans traffic count data, a PES survey of 21 city and county roads, a PES telephone survey of 233 fleets, the 1976 Interstate Commerce Survey, and a 1971 University of California, Berkeley, Institute of Transportation and Traffic Engineering (ITTE) survey.

Because Caltrans surrogate data were coupled with limited supplemental interviews (without origin destination logs being obtained), it is not really clear how accurate the PES estimates were. The PES estimates for state highway travel were 9% lower than the Caltrans Truck Miles Travel estimates.

38 This is considered to be a creative and useful study, especially given the time and budget available (Grenzeback, 1991).

39 Most current truck surveys focus on focus on axle weights, not on trip patterns, because the surveys are driven by the needs of pavement and bridge engineers (Grenzeback, 1991). Only recently have concerns about localized congestion and air quality problems triggered the need to understand trip driving patterns.
1984 State Highway VMT Estimates

25 million miles per day (Horie and Rapoport, 1985)
27 million miles per day (Caltrans, 1988)

It is unclear why the 9% difference exists between Caltrans and PES estimates when the PES estimates were based upon 1985 Caltrans data. The PES study indicates that Caltrans adjust their data "slightly downward" to compensate for the fact that data are collected during summer months and likely to be slightly higher than annual daily average volumes (Horie and Rapoport, 1985). Yet, the Caltrans estimates are higher. Although the specific methods of adjustment used by PES are unclear, it is likely that supplemental TASAS and the PES survey data (which contain components reported to Caltrans by local agencies) account for the difference.

Because Caltrans surrogate data were coupled with limited supplemental interviews (without origin destination logs being obtained), it is not really clear how accurate the PES estimates were. Unfortunately, all of the existing estimates are based upon different surrogate indicators and calculation methodologies. For any vehicle activity parameter estimated through the use of surrogate indicators, a greater range of uncertainty is likely to exist. As will be discussed in more detail later, there are no methods being employed to verify the accuracy of the VMT estimates.

The PES report adds additional travel estimates for non-state-highway roads, bringing the total VMT per day estimates up from 25 million miles per day to 36 million miles per day. Non-state-highway roads would include major and minor collector streets and are not monitored for the state-highway truck VMT estimates. Thus, approximately 31% of the estimated VMT is believed to accumulate on non-state-highway roads. The non-state-highway roadway VMT was based upon Highway Performance

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40 Note that these estimates are state highway miles, in millions of miles per day. These estimates do not compare directly with the total VMT per year estimates provided on the previous page.

41 Traffic Accident Surveillance and Analysis System, another California Department of Transportation VMT database.
Monitoring System (HPMS)\textsuperscript{42} data, which allocates VMT into the twelve functional classes of roadways. Local roads in urban and rural areas, although they comprise the majority of total road miles, are assumed to yield a negligible amount of heavy-duty truck VMT and are ignored in the studies reviewed. However, the local roadway VMT, unlike the state highway VMT estimates, are aggregated for all heavy-duty trucks.

Unfortunately, local roadway estimates are based upon limited survey data provided by local municipalities and their accuracy is somewhat suspect. There appear to be a number of reasons problems with accuracy and reliability of HPMS data. For example, reported data must be used without knowing if the local agencies followed all HPMS guidelines and without knowing what actual axle correction algorithms were used to convert total vehicle axle counts into heavy-duty VMT estimates (Hu, et al., 1989). Also, the density of the HPMS monitoring network plays a role in the validity of VMT estimates. The Caltrans traffic counts used to develop the VMT estimates are not made at every site every year, only once every 2, 3, or 4 years, depending upon budget constraints (Grenzeback, 1991). Using data collected during the year, VMT estimates are extrapolated from year to year (Grenzeback, 1991) resulting in estimation error.

In the PES report, Horie and Rapoport (1985) proposed that changes to the CARB methodologies be undertaken to improve their VMT projection methodology. Since the 1984 PES projections were obtained, the CARB has abandoned their original registration and assumed VMT estimation methodology, but has not adopted the proposed PES methodology. Instead, the CARB has elected to apply annual growth factors to the 1984 projected VMT from the PES report to estimate the VMT for each of the following years.\textsuperscript{43} However, it is not clear how the CARB growth projections have affected the accuracy of the VMT estimates since 1984.

\textsuperscript{42} Described in Appendix E.

\textsuperscript{43} Growth projections are based upon linear regression of Department of Motor Vehicle registration data, assuming that truck VMT increases are proportional to registration increases (Wade, 1991).
Further complicating the VMT emission estimates is the fact that the VMT is accumulated by California certified heavy-duty trucks, and multi-state certified heavy-duty trucks. That is, some of the vehicles operated in California are already meeting more stringent emission control requirements (California certified) than some other vehicles. The VMT estimates cannot realistically be disaggregated into two vehicle certification classes and engine size classifications without a major undertaking. The Horie and Rapoport (1985) estimates, based upon weight-distance tax reporting, constitute the best effort to date. However, in light of out-of-state registration fee assessments, there may be additional uncertainty associated with the accuracy of individual reporting.

The CARB estimates used in the BURDEN model are aggregated for all heavy-duty truck engine sizes (i.e. light heavy-duty, medium heavy-duty, and heavy heavy-duty). However, the data upon which the BURDEN inputs are based (Horie and Rapoport, 1985) were disaggregated.

The Caltrans Truck Miles Traveled study data are disaggregated by number of axles (2-axle, 3-axle, 4-axle, and 5-axle). Thus, the data collected by Caltrans do not correspond directly to the light heavy-duty, medium heavy-duty, and heavy heavy-duty engine categories, nor directly to gross vehicle weight rating categories.

The Sydec report contains annual VMT estimates for single unit trucks and combination trucks (tractor+trailer) for fiscal year (FY) 1986-1987. The Exhibits found in "Section x" of the Sydec study contained tables with the number of registered vehicles and estimates of annual miles traveled. The Sydec study tables present VMT estimates by: single unit and combination unit trucks, number of vehicle axles, and gross vehicle weight. The Sydec data, if verified, could be very useful in disaggregating truck travel.

It is clear that the PES methodology is likely to yield much more accurate VMT estimates than the methods previously used by the CARB. However, by definition, the current VMT estimates can
be no better than Caltrans methodologies used to estimate heavy-duty truck VMT. In addition, because simplified growth estimates are applied to the 1984 VMT estimates to predict future year VMT, current VMT estimates may only be accurate by chance and can only become worse over time.

The non-state-highway VMT appears to be the most questionable estimate used in calculating the VMT-related emissions. These data are very rough estimates; aggregated for all heavy-duty trucks and are not field-verifiable.

The recommendations outlined in the PES report, if implemented by the CARB and Caltrans, would likely result in better VMT estimates. However, even better estimates could probably be obtained through a cooperative program with Caltrans and the California trucking industry.

However, there is still a greater question that must be answered: are the activities that should be tied directly to vehicle emissions being modeled? As will be discussed in Section 500, it may be more appropriate to model VMT activity at specific speeds and acceleration, rather than aggregate VMT at average operating speeds.

304 HOURS OF ENGINE IDLING

Even when an engine is not pulling a load, the running engine continues to emit air contaminants. The non-loaded-engine operation is known as vehicle idle (e.g. sitting at a stoplight). Heavy-duty truck engines are frequently idled for extended periods in lieu of turning the engine off.

Idling activities can be disaggregated into four general categories: idling due to severe congestion, idling due to traffic signalization, idling during pick-up and delivery of goods, and idling during the provision of necessary services (e.g. to provide out-of-vehicle electrical power or to provide necessary cabin heat or air conditioning in extreme weather).

When a diesel engine is turned off in lieu of idling, the engine must later be restarted. Thus, emission reductions from
decreased idling would be partially offset by an increase in 
incremental hot start and cold start emissions from diesel 
engines. To determine the net emission control effects of 
strategies aimed at reducing idling time, idling activity must be 
quantified not only in terms of total vehicle hours, but in terms 
of specific idling-time increments. That is, regulators must 
know the number of hours of idling activity where each vehicle 
idles five or less minutes, five to ten minutes, ten to twenty 
minutes, twenty to thirty minutes, etc.

The extent and significance of engine idling emissions was 
examined by the AB2595 Technical Advisory Committee (1990). 
Although the committee believed that the control of heavy-duty 
vehicle idling would likely result in a significant decrease in 
emissions,\(^\text{44}\) neither the vehicle activity nor the emission rates 
could be quantified. Idling activity, expressed as hours of 
engine idling, was not be quantified by the regulatory agencies 
or trucking groups represented on the committee.\(^\text{45}\) A literature 
search did not reveal data that could be used to estimate hours 
of vehicle idling, and field studies were deemed necessary.

Currently, the CARB emission inventory does not include 
contributions from engine idling. To some extent, these 
emissions are accounted for through the use of average vehicle 
speed correction factors (see Section 404). However, additional 
research on vehicle idling is warranted so that idling activity 
can be quantified.

305 OFF-ROAD HEAVY-DUTY DIESEL ACTIVITIES

Very little is known about the emission rates from off-road 
heavy-duty diesel vehicles. Off-road mobile equipment is

\(^{44}\) Because incremental cold start emissions are relatively unresearched, some policy analysts argue that 
proposed controls on heavy-duty vehicle idling cannot be justified (Austin, 1991). However, given the 
relationship between hot start and idle emissions noted for light-duty diesel vehicles, regulations that restrict 
idling of heavy-duty vehicles to less than about five to seven minutes might be justified on the premise that 
they are very likely to reduce emissions (AB2595 Technical Advisory Committee, 1990). However, the true 
tradeoff between vehicle idling and incremental emission rates remains to be determined.

\(^{45}\) The idling activity data should be fairly easy to obtain. Limited surveys of major shipping facilities 
and review of on-board computer data could provide insight into the amount of idling in California.
primarily used for farm, timber, mine, and construction activities. Preliminary estimates of the off-road emission inventory were prepared by the Radian Corporation in 1988 (Weaver, 1988). However, these estimates, as acknowledged in the Radian report, are engineering estimates only (Weaver, 1988). The report states that "additional research to confirm these estimates would be essential before any other emission standards were incorporated into law (Weaver, 1988).

Based upon the stated uncertainty of the Radian emission inventory estimates and the lack of available data for review, emissions from off-road mobile equipment were not examined as a component of this study. Research is currently being conducted in California under contract to California Air Resources Board, and will likely result in improved emission inventory estimates. When these results are available, they should be examined for methodological adequacy.

306 INCIDENTAL ACTIVITIES

Emissions from activities that are incidental to providing mobility can be a source of emissions. For example, heavy-duty trucks are often required to operate secondary engines to maintain a refrigerated unit or to provide power to extra-vehicular activities. Emission estimates from these types of activities are tabulated under the mobile equipment or area source emission inventory categories, and are not a component of the on-road mobile source emissions inventory. Thus, incidental activity was not examined as a component of this study.

307 ACCOUNTING FOR VEHICLE ACTIVITY DISTRIBUTION

For air quality impact determinations, it is necessary to specify vehicle activity by time of day and location. Emissions

\[\text{However, the emissions associated with incidental activities are not likely to be well accounted for, given the existing uncertainty in vehicle activity (Grenzeback, 1991).}\]
at night or in certain areas of the basin may not impact air quality as significantly as morning emissions in the urban centers. Hence, the spatial and temporal aspects of vehicle activity distribution are important from an air quality planning and modeling perspective.

Spatial Distribution:

Spatial distribution is necessary (as an input to photochemical grid models) to accurately model the downwind air quality effects that will result from emission control strategies. Only the Direct Travel Impact Model (DTIM), used by Caltrans, currently accounts for the spatial distribution of vehicle activity and the subsequent emissions.\(^{47}\) That is, the UTPS models that serve as light-duty vehicle activity input to DTIM are capable of producing spatially and temporally resolved vehicle activity data.\(^{48}\)

However, as discussed in Section 303, UTPS models do not account for heavy-duty vehicle activity. Hence, heavy-duty truck activity and emissions inputs to photochemical models cannot be spatially resolved through current modeling procedures.

The only photochemical model that currently employs spatially allocated mobile source emission outputs from transportation models is in the South Coast air basin, where DTIM was recently employed by the CARB to grid-based modeling inputs. In the South Coast Air Basin, heavy-duty truck traffic is apportioned to the DTIM model using light-duty vehicle traffic as surrogate indicators (SCAG, 1989).

The CARB is currently considering the replacement of DTIM-type models to improve spatially allocation of emissions and to

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\(^{47}\) The Direct Travel Impact Model is essentially an accounting program and is discussed in more detail in Appendix C.

\(^{48}\) However, the only activity data for light-duty vehicles that is spatially resolved are trip ends and VMT. As will be discussed later, speed distributions and acceleration activity, which are not components of UTPS outputs, may be critical in determining total emissions.
correct some perceived deficiencies.\textsuperscript{49} Of course, until photochemical grid models are developed for other areas in the state, spatially allocated emissions data will not be as critical.\textsuperscript{50}

**Temporal Distribution:**

Regulatory agencies are in the process of examining seasonal weekday emissions, so that emission reductions strategies can be targeted on seasonal peaks. In the future, certain transportation control measures may be designed seasonally, for example: "Christmas shopping shuttles & ski trains for winter CO highs, and extra bus service to beach/tourist spots/special events for summer ozone levels (Lott, 1990)." Thus, seasonal emission reduction strategies may also focus on reduction of VOC and/or NOx, ozone precursor, emissions.

The temporal distribution of vehicle trips and vehicle-miles traveled has not been the subject of detailed research. The majority of truck-activity studies conducted examine truck activity for less than 24 hour periods. The best available data appear to indicate that heavy-duty truck traffic (aggregated gasoline and diesel-powered vehicles) remains relatively constant throughout the day, with a slight increase after the morning peak, and a slight decrease before the evening peak (Figure 6; Cambridge Systematics, 1988).\textsuperscript{51} The data varies slightly by region and freeway segment. However, based upon these data, approximately 25\% of the daily truck VMT still appears to occur during the peak hours of 6am-9am and 3pm-6pm. These data also appears to be supported by Caltrans preliminary weigh-in-motion monitoring station data.

\textsuperscript{49} The Lake Michigan/SARMAP study currently being undertaken will expend $500,000.00 in an effort to develop a modular emission model that is user friendly. The model will be UTPS based, and will create a gridded, speciated, hourly emission inventory in GIS format files for use in photochemical modeling efforts. Under the current proposals, DTIM will be replaced by the new modular model, but the model will continue to rely on the EMFAC emission factor model (Oliver, 1991).

\textsuperscript{50} Photochemical grid models also currently exist in the Santa Barbara and Ventura County air basins, and are being developed for the San Joaquin Valley, San Francisco Bay Area, and San Diego County air basins.

\textsuperscript{51} Subsequent to the Urban Freeway Gridlock Study, JHK consultants conducted a similar study of heavy-duty truck activity on city arterial routes and noted similar results (Grenzeback, 1991).
Figure 6

VOLUME OF 3+ AXLE TRUCKS AND ALL VEHICLES: I-880 NORTHBOUND AT 66TH AVENUE, OAKLAND

Source: Cambridge Systematics, 1988
The current emission inventory models can only account for month to month changes in vehicle activity if the activity changes are input by hand. Caltrans data (VMT and fuel use) indicate that vehicle activity are not constant. For example, weekday travel during August is estimated to be 11% greater than the annual average. From a freight transportation perspective, goods movement increases significantly in the Fall, prior to the Christmas holiday season. Furthermore, freight travel is dependent upon the state of the economy (Grenzeback, 1991).

Insight into variable vehicle activity is critical in planning for attainment of the NAAQS. The majority of ozone violations occur in the early or late summer periods. Thus, the higher emission levels in August are of particular concern from the standpoint of ozone violations.
HEAVY-DUTY DIESEL TRUCK ACTIVITY-SPECIFIC EMISSION RATES

As discussed in Section 203, activity-specific emission rates express the mass of pollutants emitted while undertaking a particular vehicle activity. This section analyzes: the emission rates for specific diesel truck activities, uncertainty associated with the emission rates, emission rate correction factors that account for external influences, and problems with speed correction factors.

BASELINE RUNNING EXHAUST EMISSION FACTORS FOR VMT

Baseline vehicle class emission factors, as mentioned previously, are determined by testing numerous vehicles in the vehicle class and preparing composite, or average, emission factors for each model year. The emission rates from each of the vehicle tested are dependent upon such attributes as: fuel type, engine class, vehicle size, emission control technologies, and vehicle age or accumulated mileage. The emission control technologies used in specific vehicles are dependent upon when the vehicle was manufactured and upon what combustion parameters, engine technologies, or add-on control technologies were selected by the manufacturer to reduce emissions.

The running vehicle emission factor for any light-duty vehicle is established during the Federal Test Procedure (FTP) on a chassis dynamometer. A chassis dynamometer allows the entire vehicle to be pulled onto the test equipment. Thus, the vehicle emissions are collected while the drive shaft and wheels are actually rotating. The light-duty vehicle FTP has an overall average speed of 19.6 miles per hour, is composed of a set pattern of stops, starts, accelerations, decelerations, and constant-speed cruises, and includes a cold start mode and hot stabilized mode. Numerous tests are run to determine the average emissions within each specific vehicle class. Thousands of light-duty vehicles have been tested by the USEPA, CARB, and other groups in their ongoing testing programs.
Baseline in-use vehicle emission rates for heavy-duty diesel and gasoline vehicles are also determined through laboratory testing, using the methods and procedures developed for the certification of new engines by the Environmental Protection Agency and California Air Resources Board. Engine certification test procedures were used to derive emission factors and are described in Appendix E. Heavy-duty vehicle emission testing differs significantly from the testing of light-duty vehicles. The primary difference is that heavy-duty vehicle emission testing is conducted on an engine dynamometer, rather than a chassis dynamometer, and conversion factors are used to prepare gram/mile emission rates.\textsuperscript{52} The heavy-duty Federal Test Procedure (FTP; 40CFR86.1327-84) is based upon the application of varying brake-horsepower loads to the engine.

As with light-duty emission rate results, uncertainty exists from the outset as a function of the precision and accuracy associated with the individual sampling and test methods. For example, with NOx emission testing under the FTP, the results of repeated USEPA Federal Test Procedure runs with the same heavy-duty engine can vary by about 5-10% within the same lab and by about 5-25% from laboratory to laboratory (USEPA, 1984). This range is not atypical of many environmental analysis techniques. However, with hydrocarbon and particulate matter emission testing, the results between laboratories range by as much as a factor of two (National Research Council, 1981).

**Federal Baseline Emission Rates**

To develop the emission factors that are currently in use, a one-time heavy-duty engine testing program was conducted in 1983/84 as a cooperative effort between the USEPA and the Engine Manufacturing Association (EMA) (Platte, 1989). Under the standard heavy-duty federal test procedure (FTP), varying brake-horsepower loads are applied to the engine. Engine emission rates were determined as a function of the average brake-

\textsuperscript{52} Heavy-duty vehicle tests are also conducted at a much narrow range of temperatures (68-86 F) than are light-duty vehicle tests (Austin, 1991).
horsepower load applied to the engine during the test cycle (grams/brake-horsepower-hour), and were converted to grams/mile emission factors using a USEPA model (Machiele, 1988). The tests are run in both hot start and cold start modes, and the test results are weighted 1/7 for cold start results and 6/7 for hot start results.\textsuperscript{53}

The heavy-duty engine testing procedure employs an estimated cycle speed of 19.45 miles per hour and an approximate trip length of 6.4 miles (USEPA, 1985). Note that the speed and distance must be estimated because the test procedure applies a load to the engine, rather than testing vehicle on a chassis dynamometer. The engine cycle includes 36\% idle operation (USEPA, 1985).

In the 1983/84 tests, the USEPA tested 30 in-use heavy-duty diesel engines. The final in-use heavy-duty diesel truck emission factors are based upon the tests results for 22 (9 medium heavy-duty diesel and 13 heavy heavy-duty diesel) of the 30 engines tested.\textsuperscript{54} The heavy-duty vehicle emission factors used by the USEPA and CARB are both based upon this limited testing battery.\textsuperscript{55}

The 22 engines were accepted "as is," removed from the chassis of their respective vehicles, and tested on engine dynamometers by the U.S. Environmental Protection Agency using the new-engine transient test cycle. To simulate the actual operating climate, these engines were not tuned-up before testing. Each engine was run through the transient cycle from one to four times to generate an average emission factor for each of the four pollutants measured (HC, CO, NOx, and Particulate). Emissions were analyzed in accordance with the federal test procedures outlined in the Code of Federal Regulations (40CFR86, Subpart N; see Appendix E)

\textsuperscript{53} These splits were apparently designed to reflect the start-mode distribution thought to occur in the field. However, the hot start and cold start mode emission weighting, used to adjust the test results, are not likely to represent actual vehicle operations.

\textsuperscript{54} The data for the other engines were not used in preparing the emission rate estimates due to problems with individual test results.

\textsuperscript{55} The gasoline engines test results are not discussed in this report. However, only 18 heavy-duty gasoline engines were tested to establish heavy-duty gasoline-powered truck emission factors (USEPA, 1984).
Using the torque and RPM feedback in the test procedure, applied brake-horsepower is integrated with respect to time for the hot and cold cycles. This produces a brake-horsepower-hour value used in calculating brake specific emissions (40 CFR 86.1327-84 and 40 CFR 86.1342-84). Total emissions collected during the cycle are divided by the total integrated bhp-hr load applied to yield a grams/bhp-hr emission rate.

The range of test results for the 22 engines are provided in Tables 2 and 3. As can be noted in the tables, the range of results from the federal test procedure for similar sized engines is large. It should also be noted, however, that the engines tested had accumulated varied miles traveled (29,000 to 410,000 miles). Yet, it is unclear if the vehicle mileage accumulated was representative of the in-use vehicle fleet. Based upon the limited number of samples, and the number of variables involved, it would be inappropriate to use the test results to establish statistical relationships between engine size, accumulated mile traveled, and emission rates.

Table 2

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Range of Emissions (g/bhp-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>HC\textsuperscript{56}</td>
<td>0.72</td>
</tr>
<tr>
<td>CO</td>
<td>2.30</td>
</tr>
<tr>
<td>NOx</td>
<td>5.71</td>
</tr>
<tr>
<td>Particulate</td>
<td>0.62</td>
</tr>
</tbody>
</table>

(Source: USEPA, 1984)

\textsuperscript{56} Including methane.
\textsuperscript{57} In addition, one of the engines rated at 175 HP was listed by the USEPA as potentially over-fueled and mistimed. This engine was characterized by a NOx emission rate of 18.9 g/bhp-hr.
Table 3

Transient Cycle Emission Test Results for Thirteen Heavy Heavy-Duty Diesel Engines
(230 HP to 435 HP Rating)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Range of Emissions (g/bhp-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>HC</td>
<td>0.37</td>
</tr>
<tr>
<td>CO</td>
<td>1.55</td>
</tr>
<tr>
<td>NOx</td>
<td>6.65</td>
</tr>
<tr>
<td>Particulate</td>
<td>0.58</td>
</tr>
</tbody>
</table>

(Source: USEPA, 1984)

After the initial testing was conducted, the engines were run through maintenance procedures and then retested under the same transient cycle. The emission rate results after maintenance under the transient cycle were significantly different than the rates prior to maintenance (USEPA, 1984). However, the significant changes in emission rates after maintenance do not appear to exhibit any predictable characteristics.

Seven medium heavy-duty engines were tested before and after maintenance. The NOx emissions for some medium heavy-duty engines remained unchanged, but decreased by as much as 50% for others. Hydrocarbon emissions for some medium heavy-duty engines increased by as much as 20%, but decrease by as much as 40% for other engines (USEPA, 1984).

Six heavy heavy-duty engines were tested before and after maintenance. The NOx emissions increased for all engines tested, by as little as 10% and as much as 30%. Hydrocarbon emissions for one heavy heavy-duty engines increased by 20%, and decreased between 20% and 70% for other engines (USEPA, 1984).

58 Including methane.
59 The Code of Federal Regulations [40CFR86.085-25 (b)] outlines specific maintenance requirements that may be considered emission-related (necessary when conducting durability and exhaust emission deterioration factor testing).
It is interesting to note that USEPA emission factors are reported to "reflect zero tampering" (USEPA, 1985). Thus, it seems likely that the "after maintenance" emission rates were actually reported in the Compilation of Air Pollution Emission Factors document (USEPA, 1985).\textsuperscript{60} Hence, local emission impact estimates that rely upon the USEPA AP-42 emission factors rather than Mobile4 emission rates (e.g. an environmental impact report for an airport), may need to be reevaluated.

The baseline emission rates for heavy-duty diesel vehicles are fraught with uncertainty. The one time testing program yielded emission rates for a very limited number of vehicles and the supplemental data gathered from manufacturers may or may not be representative of the 570,000 in-use heavy-duty vehicle fleet.\textsuperscript{61} Furthermore, the emission rates generated are determined as a function of the average brake-horsepower load applied to the engine during the transient cycle test (grams/brake-horsepower-hour), and may not be representative of in-use emissions under varied operating conditions.

**California Baseline Emission Rates**

Until 1988, the California Air Resources Board used the heavy-duty diesel baseline emission factors developed by the USEPA in their California emission model (EMFAC). In 1988, based upon the results of a Radian Corporation study entitled Heavy-Duty Diesel Vehicle Inspection and Maintenance Study (Radian, 1988), the CARB modified the USEPA emission factors to reflect inspection and maintenance practices in California. The Radian emission factors were adopted directly by the California Air Resources Board, replacing the federal emission factors.

The differences between the baseline emission factors currently used by the CARB and USEPA are significant, and can be seen in the pollutant-specific tables contained in Appendix G.

\textsuperscript{60} The individuals that developed the original data at the USEPA could no longer be contacted.

\textsuperscript{61} Great efforts have been made to include representative samples of vehicle in the light-duty vehicle testing program. However, the emission rates for heavy-duty vehicles were based upon very limited testing data. The wide diversity in operation and maintenance practices, and the effects of engine rebuilding, have not been accounted for in the heavy-duty vehicle sample (Austin, 1991).
The CARB's baseline emission rates for total organic gases are 5% to 70% higher than the USEPA's for all model years (except 1984). The CARB's baseline emission rates for carbon dioxide are 30% to 50% lower than the USEPA's for all model years prior to 1987, and the same as the USEPA's for recent model years. The CARB's baseline emission rates for oxides of nitrogen are as much as 35% lower than USEPA's for model years prior to 1986, and 15% to 30% higher than the USEPA's for more recent model years.

The Radian report indicates that the modified baseline emission rates were developed through the use of a variety of sources, including: the 22-engine USEPA/EMA engine testing program results, recent federal certification test data, limited certification data reported by manufacturers to the USEPA, and NOx-particulate trade-off relationships based upon transient cycle tests developed by Radian in 1984, steady state test data for older engines, general emission trend projections, projected future certification standards, and some confidential manufacturer data provided to Radian (Radian, 1988). 62

Insufficient data were available in the Radian report to review the mal-maintenance emission factor adjustment methodology for adequacy. Without the additional confidential data, it is difficult to determine if the Radian emission factors are more accurate than the previous USEPA data. The Radian corrections, which included the addition of incremental emission corrections based upon the mal-maintenance rates, would seem appropriate. However, the accuracy of the corrections can only be determined through additional laboratory testing of in-use vehicles.

The CARB/Radian modifications to the baseline USEPA emission rates, however, do not appear to have addressed the fundamental uncertainty issues that surrounded the development of the original USEPA baseline rates (i.e. limited and unrepresentative sampling, and potential problems with the applicability of the engine dynamometer test to on-road emissions). Although the California Air Resources Board's emission factors have been

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62 The Radian report does indicate that these baseline rates should ideally be based upon Federal certification tests for each engine class, but that these data were not available.
corrected and probably improved through the results of the Radian Study, the accuracy and applicability of the emission estimates are still unclear.

Unlike the "average vehicle" emission rates for light-duty vehicles, which are calculated using the weighted registration mix of vehicles in the local area and the laboratory determined emission rates from each subset of vehicle types, average vehicle emission rates for heavy-duty trucks are assumed to be constant throughout the state. Thus, California's heavy-duty truck emission rates do not vary by local area. The heavy-duty truck emission factors are scheduled to be modified to reflect the truck mix for local areas within the next few years (Lovelace, 1991).

402 USEPA CONVERSION FACTORS

The emission rates determined from the transient cycle test (grams per brake-horsepower-hour), cannot be used directly in preparing an emission inventory. To couple the emission factor with vehicle activity, specifically vehicle-miles traveled, the USEPA developed conversion factors to change g/BHP-hr emission rates to g/mi emission rates (Machiele, 1988). The conversion factors are based upon the premise that brake-specific fuel consumption (BSFC) data (pounds of fuel/BHP-hr) gathered during transient cycle testing can be coupled with assumed fuel density (pounds/gallon) and fuel economy data (miles/gallon) for the engine class to prepare a conversion factor (BHP-hr/mi).

Brake-specific fuel consumption and fuel economy vary with gross vehicle weight and fuel type (Machiele, 1988). The BSFC data were collected during the original 1984 USEPA testing of 22 1979/80 model year engines. These data were supplemented with new vehicle BSFC specifications (manufacturers were contacted in 1987 and requested to supply BSFC data for their 1987 engines).

It is not clear if the BSFC data used to convert g/bhp-hr emission rates to g/mile emission rates were representative of engines operating in the vehicle fleet (nor is it certain that
the conversion factors developed are representative of the current fleet). Given that the BSFC data from the 1984 in-use engine tests varied from 0.398 lb/BHP-hr to 0.504 lb/BHP-hr, some uncertainty is necessarily associated with the use of the average BSFC factors.

Fuel economy (mi/gallon) data were based upon the nationwide 1982 Truck Inventory and Use Survey (TIUS) data (Machiele, 1988). Fuel economy is primarily dependent upon the engine characteristics; hence, any increase in engine-related fuel economy should be automatically compensated for by a decrease in BSFC.63 However, fuel economy is also dependent upon the operating environment (urban versus rural conditions) and vehicle load. Because no better data were available to disaggregate fuel economy data, the USEPA chose to use the TIUS fuel economy data under the assumption that the average values would likely be representative of urban fuel economy (i.e. the fuel economy effects of partial load and operation in an urban setting are offsetting).

The USEPA prepared adjustments to the non-engine-related fuel economy for future vehicle model years based upon projected effects of such factors as: decreased drag coefficient, use of advanced radial tires, weight reduction, new drivetrain lubricants, etc. (Machiele, 1988). Deregulation of the trucking industry, i.e. pricing and market entry, may have accelerated fuel economy improvements as cost reduction measures.

Specific problems with the conversion factor estimates add uncertainty to the g/mi emission rates: 1) there is uncertainty at the outset associated with the use of the measured BSFC rates from the 1984 tests (measurement uncertainty plus the question of representativeness of the data by weight class or model year), 2) there is uncertainty in the average fuel efficiency factors used, 3) the data do not account for potential changes with time and new engine technology (e.g improved injection technology) in

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63 Although engine-related fuel economy improvements were assumed to be offset by a corresponding decrease in brake-specific fuel consumption (Machiele, 1988), these projections do not account for changes in engine and drivetrain technology and computer control that may have affected the fundamental relationship between engine output (brake-horsepower) and fuel efficiency.
the BSFC/emission rate ratios, and 4) future non-engine-related fuel economy improvement projections are highly speculative in both the magnitude of the effects and the percent penetration of the improvements into the future truck fleet.

The conversion factors used to change g/bhp-hr emission rates to g/mile emission rates in the emission factor programs are another weak link in the chain. The BSFC and fuel economy data are aggregated for the fleet and may not represent in-use vehicle characteristics. Given the wide variability of the test results and the limited number of engines tested, conversion factors result in significant uncertainty.

Although the factors used to convert grams/brake-horsepower-hour emission rates to grams/mile emission rates are averaged and highly uncertain, they still must be used. Because the emissions data collected through federal test procedures are in terms of grams/brake-horsepower-hour, and because brake-horsepower-hour activity cannot be measured or estimated in the field, conversion factors must be used so that emission rates can be linked to vehicle activity. Until new test methods that provide grams/mile or grams/hour emission rates are developed, the existing data and conversion factors will continue to be used. Developing gram per mile emission rates on a chassis dynamometer would eliminate conversion factors from the process and improve emission inventory accuracy.

403 DETERIORATION RATES

Because engine emission rates are noted to increase with accumulated VMT, the Federal Register outlines the methods that must be used in establishing what are known as deterioration factors (40CFR86.085-28; see Appendix E). Because emissions from the vehicle tend to increase with vehicle age, deterioration rates are also applied to in-use VMT-related emission rates.

Deterioration factors were originally developed for the calculation of the emission rates in MOBILE4, based upon the 1984

64 Deterioration factors are used in determining new engine compliance with certification standards.
tests of the 22 engines and certification-related data submitted by manufacturers. Unfortunately, the certification data could not be reviewed for this study.

The deterioration rates used by the CARB to calculate in-use vehicle emission rates are somewhat higher than those used by the USEPA for a number of the model years. The use of higher deterioration rates results in higher in-use emission estimates. However, the significance of the rate differences cannot be analyzed without delving into the models used to calculate heavy-duty vehicle emissions. The CARB apparently adjusted the deterioration rates based upon the Radian study (1988), where Radian developed tampering adjustment factors based upon a delphi survey of truck maintenance personnel and assumed percentage increases in emissions associated with specific tampering activity. Deterioration rates do not appear to have been substantiated with additional in-use vehicle testing.

The differences between the deterioration rates currently used by the CARB and USEPA are significant, and can be seen in the pollutant-specific tables contained in Appendix H. The CARB’s deterioration rates for total organic gases are 80% lower than the USEPA’s for all model years prior to 1984, and 15% higher for all recent model years. The CARB’s deterioration rates for carbon dioxide are 100% higher than the USEPA’s for all model years prior to 1987, and the same as the USEPA’s for recent model years. 65 The CARB’s deterioration rates for oxides of nitrogen are the same as the USEPA’s for all model years.

404 SPEED CORRECTION FACTORS

The operating environment of the vehicle impacts the operating efficiency and emission rates of diesel-powered engines. To prepare the emission inventory, vehicle class emission rates are adjusted, using laboratory determined correction factors, to account for specific operating and environmental conditions. Currently, light-duty vehicle emission

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65 Note that the CARB employs lower baseline rates and higher deterioration rates.
rates are adjusted for temperature, altitude, and vehicle operating speed. However, correction factors for temperature and altitude are not applied to heavy-duty diesel emission rates because the effects of temperature and altitude on diesel emission rates are thought to be insignificant. Therefore, operating speed is the only correction factor used in the heavy-duty diesel truck emission inventory.

**Speed Effects on Emissions**

Vehicle speeds affect the gram/mile emission rates of air contaminants.\(^66\) As can be seen in Figures 7 and 8, the gram per mile emission rates of hydrocarbons (HC) and carbon monoxide (CO) decrease as vehicle speed increases (CARB, 1986; CARB, 1988).\(^67\) Thus, during hours of peak traffic, specifically the morning and evening commute hours, motor vehicles contribute more on a gram-per-mile basis to the emissions of hydrocarbons and carbon monoxide than during non-commute hours.

As can be seen in Figure 9, the gram per mile emissions of motor vehicle oxides of nitrogen (NO\textsubscript{x}) decrease as speed increases, until speed reaches approximately 30 mph, and then increases as vehicle speeds increase thereafter (CARB, 1986; CARB, 1988). The increase in emissions is assumed to result from the increase in both operating temperatures and excess oxygen in the combustion chamber at higher operating speeds.

Recent research by the California Air Resources Board indicates that the emission rates of all pollutants increase more rapidly than previously thought at speeds in excess of 55 miles per hour. In fact, the increase in HC, CO, and NO\textsubscript{x} emission rates after 55 mph is so significant that improved enforcement of speed limits has been under investigation as a viable automobile emission control strategy (CARB, 1991a).

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66 The emission rates change, but total HC and CO emissions for an hour of travel are not a strong function of travel speed. That is, gram per hour emission rates for hydrocarbons and carbon monoxide are not a strong function of operating speed (Seitz, 1989). However, changes in vehicle operating efficiency, control equipment efficiency, and temperature as a function of speed may have some impact (especially at low and high speeds).

67 The same general relationship is noted for both gasoline and diesel-powered vehicles.
Figure 8

Diesel Heavy-Duty Truck Running Exhaust vs. Speed

Carbon Monoxide

Emission Rate (g/ml)

Operating Speed (mi/hr)

Source: CARB, 1986
Derivation of Light-Duty Speed correction Factors

The speed correction factor algorithm is a regression formula derived from the plot of measured emissions versus the average speed of test cycles (USEPA, 1988). The derived correction factors are applied to baseline emission rates to create emission factors for any operating speed.

For light-duty vehicles, emission data are gathered from test vehicles under a number of different test cycles (USEPA, 1988). Speed correction factors for light-duty vehicles are derived statistically (regression analysis) from the relationship between cycle emission rate (grams/mile, from the aggregate bag sample of emissions and the total cycle distance) and average cycle speed (see Appendix C). Thus, speed corrected emission rates used in emission models are actually related to average cycle speed and not to constant-speed cruise or even instantaneous speed.

Heavy-Duty Truck Speed Correction Factors

The EMFAC7E emission factor program includes a speed correction algorithm for heavy-duty trucks. The algorithm is applied to 13 speed groups (from 5-65 mph in 5 mph increments). EMFAC generates speed correction factors only for speeds below 65 mph, all higher speeds are assumed to occur at 65 mph. Thus, heavy-duty truck emission rate uncertainty is more pronounced for high speed operations.

The speed factor (SF) regression formula used by both the USEPA and the CARB for heavy-duty diesel emission inventory preparation (USEPA, 1985; CARB, 1986) is:

\[ SF(S) = \exp(A + B\times S + C\times S^2) \]

Where \( S \) is the vehicle speed, and the empirical constants \( A, B, \) and \( C \) are pollutant dependent and assumed to be constant for all model years and truck and engine sizes. The speed correction

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68 Each of the test cycles employs a different profile of stops, starts, constant-speed cruises, acceleration, and each has a different overall average speed.
factor is applied to the baseline emission rate to generate average speed emission rates.  

Derivation of Heavy-Duty Truck Speed Correction Factors

It is unclear how USEPA staff developed the speed correction factors, given the limited data that were collected during the USEPA/EMA testing program. USEPA staff developed the original speed correction factors for Mobile 1 (one of Mobile 4’s predecessors). Although Mobile 1’s speed correction factors are still used today, the exact methodology used by the USEPA to generate the heavy-duty diesel speed correction factors is undocumented.

Laboratory data used by USEPA to develop the speed correction factors were likely the test results from the sampling of the 22 diesel and 18 gasoline engines in early 1980 (Platte, 1989). During the 1983/84 USEPA/EMA engine testing battery, the USEPA ran the 22 heavy-duty truck engines through two test cycles. The first cycle, as described previously, was the federal test procedure consisting of transient mode testing. The second cycle was the 13-mode steady test cycle used prior to 1984 to certify heavy-duty engines. Each of the test cycles provided one integrated bag sample for analyses from each engine. The average "equivalent operating speed" of the engines, based upon the BSFC correction factors, for the transient FTP is slightly different than for the thirteen mode test. In addition, there are significant differences in measured emission rate outputs (grams/bhp-hr) under the steady-state mode and transient mode tests (USEPA, 1984; National Research Council, 1981).

If the speed correction factors were developed in a manner similar to those for light-duty vehicles, a significant problem exists. The heavy-duty truck speed correction factors would have to have been based upon a regression fit for 44 data points (two data points for each engine, one for the transient test and one

69 The emission rate curves presented in Figures 7, 8, and 9 were generated from data derived from applied speed correction factors.
70 These staff members are no longer employed by the USEPA (Platte, 1989)
71 Five power modes (each at two speeds) and three idle modes (40CFR86.334-79).
for the 13-mode steady-state test, converted to grams per mile). Hence, data for only two average speeds for each engine were available for analysis. Fitting a regression curve to this limited data is problematic.

The speed correction factors were updated in 1984 when emission standards for heavy-duty vehicles were made more stringent. USEPA staff manually adjusted the emission rates downward, assuming that in-use emission rates decrease as a result of the more stringent engine standards; no additional engine tests were conducted (Platte, 1989). No documentation could be located on the exact methods used to modify the correction factors.

Problems with Heavy-Duty Truck Speed Correction Factors

The same problems noted for light-duty vehicle correction factors are also noted for heavy-duty engines. However, additional uncertainty exists in the heavy-duty truck correction factors because insufficient data was used, and the regression fit is questionable. The relatively small amounts of data used to develop speed correction factors for heavy-duty trucks, compared to the data used for light-duty vehicles, limits their applicability. For example, correction factors for high speeds would be very questionable because data at these speeds were presumably never included in establishing the regression.

The problem that is encountered in using aggregated average-speed versus emission relationships is that the relationships cannot be correlated to measurable driving conditions. The speed correction factors for 50 mph, do not yield the emissions that would occur at 50 mph, but the emissions that would occur at an average speed of 50 mph if the vehicle was operated in the same manner as it was under the certification cycle (i.e. the same number of stops and starts and the same acceleration characteristics). Thus, the important uncertainty issues are:

1. Are the emissions determined during the test representative of the actual emissions that would occur under the same conditions in the field?
2. Is the driving cycle representative of actual driving cycles in the field?

3. Are the emissions for the average speed representative of the average speed splits used in defining vehicle activity for the emission inventory calculations?

4. Is the test vehicle fleet representative of the real vehicle fleet?

5. Are the high and low speed correction factors reasonable?

It is not clear that the standard cycles and cycle correction factors can be used to establish accurate emission rates for the vehicle fleet in the field.

Application of Speed Correction Factors to Vehicle Activity
Problem 1: Speed Determinations

The first problem that surfaces in the use of speed correction factors is that the correction factors are not applied to speed-specific-vmt activity. In fact, the CARB does not estimate speed distributions on individual road links to prepare emission estimates. Instead, a bulk estimate of VMT is disaggregated into estimated speed groups based upon "engineering judgement." For areas other than the South Coast Air Basin, staff of the CARB and Caltrans72 used Highway Performance Management System (HPMS) data to estimate VMT by county, by average speed group (13 speed groups in five mile/hour increments), for different roadway types. Thus, Caltrans and CARB staff allocated speed distributions for each road-type (i.e., 5% of vmt @ 25 mph, 10% of vmt @ 30 mph, etc) in each air basin for input to the BURDEN model.

Diurnal speed distributions by road class were used in the assignment of vmt-weighted speed corrections (i.e. the percentage of time operated at the estimated speeds are allocated to the VMT by road class).

The speed distributions by road type for each air basin, although based upon Highway Performance Monitoring System data,

72 Paul Teeter of Caltrans and Dennis Wade of the CARB.
are highly uncertain. First, the vehicle activity that is sampled for HPMS is only a small fraction of California's vehicle activity. Second, the road-type speed distributions are statewide averages and are likely to differ significantly from area to area.

The South Coast Air Basin methodology employs the UTPS traffic generation and assignment model’s speed outputs for each link. Output from network activity models are used to determine appropriate speed correction factors. Correction factors for speed-specific-vmt emission rates are applied to individual roadway link vmt. The VMT and UTPS determined speed for each link are entered into the Direct Travel Impact Model (DTTIM) for emission calculation.

Using UTPS speed outputs to represent actual link speeds is problematic. The UTPS models are designed to predict vehicular volumes on specific links, usually major radial or circumferential highways (Cambridge Systematics, 1990). Vehicle speeds are calculated iteratively by the UTPS models for the purposes of assigning vehicle trips to links along the "path-of-least-resistance." However, the UTPS iterations are completely internal and may not correspond to the actual speeds experienced on the actual highway.

"Speeds developed through the modeling process serve as a means of allocating trips to balance the network. As such, they are really an input rather than an output of the model (Cambridge Systematics, 1990).

Furthermore, average speed outputs from the UTPS models are for an "average" peak hour (Grenzeback, 1991) and are not likely to be representative of all peak periods, nor of off-peak periods.

In addition, the UTPS systems do not include the contributions of heavy-duty vehicles in determining the final light-duty automobile trip assignments and link speeds. Thus, along heavily traveled truck routes, UTPS speeds that are based
upon modeled automobile traffic flow rates do not account for the present of heavy-duty vehicles.73

The temporal distribution of vehicle trips and VMT are also critical from an air quality standpoint. However, the time periods modeled by UTPS systems do not necessarily coincide with the periods of interest in air quality modeling (Cambridge Systematics, 1990). For instance, there are temporal differences between morning and afternoon peak period traffic impacts as well as seasonal VMT and speed differences.

A fundamental problem with using any type of average vehicle speeds to substitute for actual vehicle speeds lies in the fact that the speed emission relationship is non-linear. Because the emission rates from motor vehicles in grams per mile are an exponential function of speed, the differences in actual versus modeled speeds may result in significant differences in estimated emissions. The use of average speeds in modeling an exponential speed function are not likely to be accurate and should result in underestimated emissions because the higher speeds are not weighted heavily enough.

"Given the non-linear relationship of speed and emissions, the methodology by which speeds are averaged over time can result in significant underestimation of emissions (Cambridge Systematics, 1990)."

Application of Speed Correction Factors to Vehicle Activity
Problem 2: Applicability of the Correction Factors

The second problem that surfaces is the fact that the speed correction factors are developed from engine cycles and the estimated average trip speeds. These data do not correlate to the speed distributions that would be encountered on a road link. The cycle trips used to establish the correction factors74 might have varied in estimated vehicle speed from 0 mph to 60 mph, but

73 The volume of heavy-duty trucks is calculated after the fact, as a percentage of UTPS predicted vehicle trips (Grenzeback, 1991).
74 Ignoring, for now, the fact that these average speed correction factors may have been developed from a number of discrete engine operating speeds.
the average speed of the vehicles on the road link may vary from only 50 mph to 70 mph. Thus, the applicability of average speed correction factors to vehicle speed distributions on the roadways may not accurately predict emission effects.

**Speed Correction Factor Summary**

Even if the speed correction factors yielded instantaneous steady-state speed emission rates, vehicle speed distributions vary from road-type to road-type and from area to area. As would be expected, if speed correction factors are to be applied to the baseline emission rates for VMT, speed distributions on the roadway links must be known.\(^{75,76}\) Only in this manner would proper speed correction factors be applied to specific portions of the vehicle miles traveled on each link.

405 ENGINE IDLING

In California, there are currently no provisions to directly account for vehicle idle emissions. The certification cycles include periods of idling, however these are idle periods that contribute to the average speed emission rates and correction factors. Separate testing has been conducted by the USEPA and average idling emission rates are quantified in the Compilation of Air Pollutant Emission Factors (USEPA, 1985), based upon limited engine tests. However, idling emissions are generally not included in the emission inventory, because idling activity has never been quantified. Plus, idle emission factors have not been developed for a variety of heavy-duty engine classes.

\(^{75}\) Even though grams/hour emission rates are fairly constant across speeds (Seitz, 1989), the total travel time of vehicles along a network link is a non-linear function of speed. Hence, in either modeling framework (VMT or VHT), the use of average speeds in calculations will underestimate emissions.

\(^{76}\) Speed distributions for heavy-duty trucks are readily available in most states (Grenzbeck). However, if the vehicle fleet emission rates are to be disaggregated (by truck classification, or engine size), speed distributions will also need to be available on a disaggregate basis.
406 COLD AND HOT STARTS

When an engine is started, incremental emissions of all pollutants are noted. That is, after starting, engines emit elevated rates of all pollutants compared to emissions from the same engine after it has been operating for an extended period. The increased emissions generally result from decreased combustion efficiency at start-up (e.g. cylinder quenching and inefficient mixing of air and fuel).\textsuperscript{77}

The initial temperature of the engine at start-up affects the magnitude of the incremental emissions. Colder engines at ignition emit increased rates of all pollutants compared to warmed engines. Hot starts, where the engine has cooled off for less than about an hour, also result in an incremental emissions; however, the increment is much lower than for a cold start.

The incremental cold and hot start emissions from light-duty diesel vehicles play a significant role in the total emissions attributed to the light-duty diesel vehicle classes. Based upon the incremental increase in emissions for each start, the total trip emissions can be significantly impacted by the number of starts. For example, given a ten mile light-duty diesel automobile trip at an average cycle speed of 25 mph, the cold start contributes approximately 18% of the HC, 28% of the CO, and 3% of the NOx emissions (CARB, 1988). However, it should be noted that the incremental emissions from light-duty diesel vehicle cold and hot starts are much less significant than the incremental emissions from their gasoline-powered counterparts.

The incremental cold start emissions for light-duty diesel trucks are significantly lower than for catalytically controlled (CAT) light-duty gasoline-powered trucks (67% lower for NOx, 93% lower for HC, and 97% lower for CO), but are still a necessary component of the emission inventory (CARB, 1988; Table 4). Incremental hot start emissions from light-duty diesel trucks are significantly lower than cold start emissions from light-duty diesel-powered trucks (32% lower for NOx, 82% lower for HC, and

\textsuperscript{77} With new light-duty gasoline vehicles, the majority of the cold start emissions result from the fact that the catalytic converter does not operate efficiently until it has reached a specific operating temperature.
34% lower for CO), but these emissions are significant nevertheless (Table 4; CARB, 1988).

<table>
<thead>
<tr>
<th>Pollutant (grams/trip)</th>
<th>Engine type</th>
<th>NOx Hot</th>
<th>NOx Cold</th>
<th>HC Hot</th>
<th>HC Cold</th>
<th>CO Hot</th>
<th>CO Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NCAT</td>
<td>5.33</td>
<td>4.69</td>
<td>3.39</td>
<td>14.40</td>
<td>26.86</td>
<td>259.23</td>
</tr>
<tr>
<td></td>
<td>CAT</td>
<td>2.02</td>
<td>3.35</td>
<td>1.70</td>
<td>11.17</td>
<td>19.30</td>
<td>127.97</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>0.75</td>
<td>1.11</td>
<td>0.15</td>
<td>0.82</td>
<td>2.72</td>
<td>4.12</td>
</tr>
</tbody>
</table>

Source: CARB, 1988

Incremental cold start and hot start emission rates have not yet been developed for heavy-duty diesel and gasoline vehicles. The testing procedure used for engine certification and running emission rates cannot be readily adapted to yield incremental cold and hot start emission factors for heavy-duty vehicles. Because test procedures yield a single sample for analysis, they cannot be readily disaggregated to determine the incremental emission contribution.

Engine starts for heavy-duty trucks may result in significant incremental emissions. However, as noted with the light-duty vehicles, incremental cold start and hot start emissions from heavy-duty diesel trucks are expected to be much lower than for comparable gasoline engines.

One mitigating aspect of the existing emission rate modeling methods is that the certification procedure used to develop the in-use baseline emission rates is conducted in both cold and hot modes. Sample results are weighted 1/7 cold and 6/7 hot to simulate vehicle start conditions. However, three questions arise: 1) were the small number of engines tested representative, 2) is the cold/hot start ratio appropriate, and
3) is it appropriate to include these incremental emissions in an aggregated VMT emission rate?

407 HOT SOAKS, DIURNAL EVAPORATION, AND RUNNING EVAPORATIVE LOSSES

Hot soak, diurnal evaporative, and running evaporative emissions are not applicable to the diesel engine cycle, due to the low volatility of diesel fuel. If, at a later date, evaporation of diesel fuel is determined to be significant, these vehicle activities would need to be quantified.

408 ACCELERATION

Power enrichment (acceleration) is believed to be a discrete vehicle activity resulting in incremental emissions for light-duty vehicles (Groblicki, 1990; Calspan Corp, 1973; Kunselman, et al., 1974; CARB, 1991b). Recent General Motors and California Air Resources Board studies have indicated that power enrichments (high power demand and acceleration rates) in light-duty gasoline vehicles may contribute high incremental emissions, even with today's modern emission controls (Groblicki, 1990; CARB, 1991b). Acceleration emissions may be significant at freeway onramps, signalized intersections, and in congested traffic. This may be especially true for heavy-duty diesel trucks, because of their heavy operating loads and power requirements to achieve merging speeds.

Although the selection of vehicles tested in the recent CARB studies are hardly typical of the in-use light-duty fleet (due to dynamometer acceleration limitations for front-wheel drive vehicles), the results shed light on the potential effects of acceleration on incremental emissions (Lovelace, 1991). Unfortunately, there is no clear correlation between the acceleration rates and the magnitude of the incremental emissions (CARB, 1991b). Additional testing should help to explain the explicit relationships between acceleration rates and emission rates.
The California emission factors for VMT are average values that include acceleration and deceleration. However, as with the USEPA factors, acceleration and deceleration are still not explicitly accounted for.\textsuperscript{78} The federal test procedure certainly includes different numbers of stops and acceleration parameters than will be experienced in actual use.

The current modeling efforts (baseline rates and speed correction factors) do not account for increased emissions that may occur during acceleration and deceleration. Because the EMFAC emission factors for average cycle speeds do not adequately account for acceleration, it does not seem logical to apply the existing emission factors to fine tuned acceleration-related analyses such as signal timing emission reduction estimates.

From a scientific perspective, it seems more appropriate to develop new emission factors for specific acceleration rates.\textsuperscript{79} These new emission factors could be applied to acceleration activity (after studies are conducted to quantify the rates and duration of acceleration) in areas such as: urban traffic signals, freeway on-ramps, congested traffic, etc. It would also seem appropriate to disaggregate acceleration effects for vehicle loads so that a disaggregate emission inventory could be supported.

If acceleration specific emission contribution methodologies are not developed, it would seem appropriate to at least develop correction factors for vehicles operating in congested traffic. The increase in acceleration emissions would need to be quantified (requiring additional test data) and proper correction factors developed. However, this task is likely to be as difficult as the development of incremental acceleration emission methodologies anyway.

\textsuperscript{78} In fact, the emissions determined from the different light-duty cycle tests (used to develop the speed correction factors), may be correlated to the specific acceleration activities within each test cycle.

\textsuperscript{79} As will be discussed in Section 602, the California Air Resources Board is undertaking such analyses (Carlock, 1990; Lovelace, 1991).
TRANSPORTATION CONTROL MEASURE CORRECTIONS

As transportation control measures are developed, vehicle class emission factors will need to be adjusted for the effect that these control measures have on the composition of the vehicle fleet. CARB has contracted a study with Systems Applications Inc. (San Rafael, CA) designed to examine the impacts of specific TCMs. According to CARB staff, one of the goals of the project will be to examine changes in the fleet composition due to the implementation of TCMs (Carlock, 1990). Although the TCMs being examined may not be directed specifically at heavy-duty truck activity, similar studies related to the truck TCMs suggested in recent reports (AB2595 Technical Advisory Committee, 1990; Nelson, et al., 1991) should probably be undertaken.

FUEL PROPERTIES

Laboratory testing has indicated that fuel composition can have a significant effect upon emission rates for light and heavy-duty vehicles. Hence, as new fuel requirements are implemented in California (or areas of California), the effects of fuel composition on pollutant emissions is likely to be important.

Recent results of the Auto/Oil Air Quality Improvement Research Program appear to indicate that the gasoline certification fuel, used for testing in the dynamometer research, appears to be much less polluting than the average gasoline fuel currently purchased by the driving public (Coordinating Research Council, Inc., 1990). Southwest Research Institute performed limited heavy-duty diesel engine testing that indicated diesel fuel composition has an effect upon emission rates (Dietzman, et al., 1980). However, the effects of current diesel fuel compositions purchased by the public on in-use emission rates is relatively unresearched.80

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80 However, if new emission testing is undertaken with "as is" fuel (the marketplace fuel already in the vehicle), this issue is unlikely to play an important role in current emission factor uncertainty (Lovelace, 1991).
500 SUMMARY OF INACCURACIES AND UNCERTAINTY

So far, this report has critiqued the accuracy of activity data currently used in emission modeling efforts, and evaluated the heavy-duty truck activity-specific emission rates and correction factors currently used in emission modeling. The lack of emission testing data is not a limited problem, as the current problems reflect not just limited research on the part of USEPA and air quality engineers, but a broader lack of research on truck movements and travel patterns in general (Grenzebach, 1991).

Numerous assumptions and generalizations are made when generating a bulk emission inventory. Unfortunately, due to the large numbers of assumptions made and the relative uncertainty associated with each step of the emission inventory preparation process, a large amount of uncertainty exists in the heavy-duty diesel truck emission inventory methodologies. The important question to be answered is whether all avoidable uncertainty has been eliminated from the analytical methods.

Uncertainty is pervasive in all three emission calculation factors: vehicle activity, activity-specific emission rates (including the conversion factors), and baseline emission correction factors. This section of the report contains a summary and overall assessment of uncertainty in the activity and emission rate components of the heavy-duty diesel truck emission inventory. In addition, the effects of multiplicative uncertainty are discussed and conclusions are drawn about the ability to predict the effects of emission control measures that impact heavy-duty truck activity.

501 HEAVY-DUTY TRUCK ACTIVITY ESTIMATES

There are a number of major problems with the vehicle activity parameters used in modeling heavy-duty truck emission:

1. Uncertainty is associated with the use of any surrogate indicator to estimate actual activity parameters (e.g.
As new diesel fuel requirements are implemented in California (or areas of California), the variation in fuel used will affect the emission inventory. For example, emission factors are not currently available for reformulated fuels (e.g. reduced olefin content or volatility) that may be available in various areas of the state. Emission factors will need to be developed for alternative fuels and reformulated diesel that may be available in various areas of the state. Emission rates would be dependent upon the fuel combusted within the air basin (fuel sold in California and fuel carried into the basin, less fuel carried out of the basin), which can be a complicated determination.

With more stringent vehicle certification standards beginning in 1994, and federal mandates for alternative fuels, alternative fueled vehicles are expected to capture a significant market share. Research into the modal emission rates from these alternatively fueled vehicles will be very important in the evaluation of which fuels are better for air quality. Recent studies indicate that methanol buses may pollute more at low average speeds, and pollute less at high average speeds, than comparable diesel-powered buses (Santini and Rajan, 1990). Results from modal emission rate studies may indicate whether the use of methanol fuel in buses and/or automobiles should be discouraged on heavily congested routes (Santini, 1991).
traffic counts used to estimate VMT. Getting to the right answer (i.e. the actual vehicle-miles traveled by various sectors within the trucking industry) is not possible, given current levels of data collection.

2. The activity data that is used in modeling methodologies are highly aggregated (i.e. highly aggregated estimates for VMT, and average speed assumptions are currently used).

3. Heavy-duty truck activities are not estimated by current trip generation and distribution (UTPS-type) models. No detailed vehicle activity models are currently available in California for goods movement or heavy-duty trucks.

4. Current UTPS-type models do not model the vehicle activity that should be linked to activity-specific rates. Based upon the recent studies, acceleration activity and vehicle-miles traveled at constant-speed cruise may predict emissions more accurately than aggregate vehicle-miles traveled data and average speed assumptions.

5. Some potentially important emission-producing vehicle activities, specifically idling and engine starts, are currently omitted from the emission inventory models.

502 EMISSION RATES AND CORRECTION FACTORS

A number of "levels" of uncertainty exist in the use of the existing activity-specific emission factors to estimate the heavy-duty diesel truck emissions inventory:

1. Uncertainty is associated with the precision and accuracy of the test methods that were originally used to determine emission rates.

2. The testing of a non-statistically representative numbers of vehicles appears to be a major problem. Laboratory tests were never really adequate to represent the in-use vehicle fleet.
3. The conversion factors used to change laboratory data into grams/mile emission rates are undocumented and questionable.

4. It is not clear that the emission rates yielded from the limited laboratory testing are representative of emissions that occur from vehicles in the field. The aggregate emission factors do not reflect the emissions from a highly diverse (engine size, truck size, load, etc.) vehicle fleet.

5. The "average speed" emission factors, developed through the application of speed correction factors, do not appear to be applicable to specific vehicle activity.

6. The emission rates currently determined by engine dynamometer cycle testing may not be representative of the actual on-road operating emissions. Emission rates for emission-producing activities are not currently employed (e.g. idling, acceleration, etc.).

7. Fuel composition effects have not been accounted for in the current emission factors.

503 TOTAL UNCERTAINTY

Uncertainty is multiplicative in the methodologies used to develop the emission inventory. That is, uncertainty in vehicle activity is multiplied by the uncertainty in the activity-specific emission rates (that are corrected by uncertain correction factors). However, a simple statistical formula representing suspected ranges of uncertainty cannot be applied to the estimates to determine what the net uncertainty may be. There are simply too many unanswered questions related to the basic applicability and usefulness of much of the data collected, making it impossible to estimate the variance within each set of parameters.
504 ANALYSIS OF EMISSION REDUCTION STRATEGIES

Emission reductions can be achieved through control strategies that reduce either vehicle activity or the activity-specific emission rates. Strategies to reduce trip making, vehicle-miles traveled, vehicle idle time, etc., can reduce vehicle activity and, therefore, vehicle emissions. Strategies to reduce the emission rates of vehicles include: improving control technologies, introducing alternative fuels, increasing vehicle speeds (by reducing congestion or accident occurrences), minimizing stop-and-go motion, shift cold starts to hot starts, improving compliance with inspection and maintenance requirements, or changing driver behavior. However, there is a great deal of uncertainty in the average emission factors and activity estimates for heavy-duty trucks.

The modeling results are highly uncertain because the models were only designed to roughly estimate a "bulk" emission inventory (i.e. crude estimates, based upon aggregate parameters), and were never designed to provide the corridor specific effects that they are being asked to reproduce. Hence, criticizing these models for not being able to perform tasks that they were never designed to perform (i.e. evaluating the effects of transportation control measures and other policies) is irrational. Although the emission inventory modeling efforts are the best currently available, significant modeling and data collection improvements are needed if they are to be used for analyzing changes in vehicle activity and activity-specific emission rates.

Regulators and the regulated public must realize that the use of current emission models for predicting the results of heavy-duty vehicle transportation control measure and alternative fuel control strategy implementation will be fraught with uncertainty. This is not to say that relative comparisons cannot be performed, using the existing models.81 However, when such comparisons are made, one should not assume that the results are precise nor highly accurate. It does not, therefore, seem

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81 Usually, positive benefits are inferred, even though the actual reductions are indeterminate.
appropriate to place a great deal of faith in cost-effectiveness estimates that are calculated from the emission impacts predicted by current models. Furthermore, the comparison of mobile source and stationary source control strategy cost-effectiveness seems inherently improper, because of the relative uncertainty associated with the heavy-duty vehicle emission estimates.

The picture is not so bleak, however, that regulators, industry, and the general public should become disillusioned with the regulatory process. The problems with emission reduction estimation techniques can be corrected through research. Yet, the current inability to precisely predict the consequences of emission control strategies should not necessarily prevent progress toward attainment. Instead, analysts and regulators must recognize the limitations of existing data and models and take the emission reduction uncertainty into account when determining which control strategies should be implemented.
600 RECOMMENDATIONS FOR FURTHER RESEARCH

Although the USEPA and CARB have attempted to ensure that the best available data are employed and that research projects designed to improve the methodologies are undertaken, additional research is necessary to characterize the emissions from the heavy-duty diesel fleet. Improvements to methodologies are inevitable, as the CARB and regulated industry come to grips with emission inventory uncertainty.

This section of the report contains recommendations for further research that would reduce uncertainty in the emission inventory, and would improve modeling methodologies such that they might be used in estimating the effects of proposed regulatory strategies. A general research framework is discussed and research projects that should be undertaken are discussed (including those that are already being undertaken). A number of policy studies are also identified.

601 RESEARCH FRAMEWORK

A research framework is a general conceptual plan, from which a detailed research agenda can be developed and organized. The heavy-duty truck research framework is based upon fundamental principles of mobile source emission inventory modeling. The most important issue that must be addressed in determining the emission inventory for heavy-duty truck activities is "connectivity." Connectivity is the ability to link significant emission-producing activities with their corresponding activity-specific emission rates. Without connectivity, it will be impossible to accurately estimate total emissions from the heavy-duty truck category.

The logical content and progression of the research framework is: 1) to identify significant emission-producing vehicle activities for a disaggregate truck fleet\(^82\) (through additional laboratory testing), 2) to develop activity-specific

\(^{82}\) Disaggregation of the heavy-duty truck fleet is seen as critical for emission inventory accuracy.
emission rates for these emission-producing activities, 3) to
determine what activity monitoring methods currently exist and
what methods must be developed to provide emission-producing
activity data, and 4) to develop modeling capabilities for
emission-producing activity that employ data from current and
future activity monitoring systems.

A parallel research path is proposed within the framework,
to provide the data necessary to better model emission impacts
(Figure 10). Investigation and establishment of modal emission
rate models parallels research into modal activity models for the
goods movement industry. To develop these models, the proposed
plan includes the investigation of both advanced activity and
emission rate monitoring techniques. The research plan is
staged, such that incremental emission rate research results can
be used to focus activity research efforts and vice-versa. That
is, as emission-producing activities are identified and emission
rates are developed, research into vehicle activity becomes
focused. Plus, research into vehicle activity provides
information on the practical extent to which emission rates can
be disaggregated.

In discussing the rationale for the proposed research
framework above, four topics are examined. First, because
significant emission-producing activities must be identified,
vehicle emission rate testing would be conducted. Second,
comprehensive testing of the disaggregate vehicle fleet would be
conducted to determine modal emission rates for those emission-
producing activities identified as significant. Third, research
into advanced activity monitoring techniques would be conducted
to determine what data are currently available, and to determine
what additional monitoring techniques could be used to gather
additional data. Fourth, using available data and relationships
between significant emission-producing activities, activity
models would be developed for the goods movement industry.
A PARALLEL RESEARCH PATH

MODAL EMISSION TESTING

MODAL EMISSION MODELING

ACTIVITY MONITORING

ACTIVITY MODELING

IMPROVED EMISSION INVENTORY
VEHICLE EMISSION RATES

The goals of the investigation into new emission rates are twofold: 1) in the short term, to improve the certification cycle used by the EPA and CARB and to develop new chassis dynamometer cycles for heavy-duty vehicles; 2) over the long term, to develop disaggregate modal\textsuperscript{83} emission rates for heavy-duty trucks. The focus of the laboratory research is to identify the emission-producing vehicle activities that must be considered in developing the emission inventory.

By developing new in-use chassis dynamometer cycles for heavy-duty vehicles, some of the existing uncertainty in emission rates used to prepare a "bulk" emission inventory would be resolved. These cycles should be more representative of actual California driving conditions, and would include high speed operations and acceleration profiles that are more typical of California highway and local road traffic. However, much of the same aggregation bias and uncertainty in application to individual corridor specific analysis would still remain.

As a long term solution, the study of real-time emissions would be conducted. Modal emissions monitoring, would allow second-by-second pollutant emission readouts from vehicles as they proceed through various testing modes on the heavy-duty chassis dynamometer. Using new equipment and procedures, the CARB hopes to establish modal emission rates for emission-producing vehicle activities, such as constant-speed cruises, idling, and specific acceleration rates (e.g. to represent onramp acceleration or stop-and-go traffic conditions). Plus, if modal fuel consumption models are developed concurrently, the impacts of TCMs and infrastructure changes on fuel economy and greenhouse gas emissions can also be better modeled.\textsuperscript{84}

\textsuperscript{83} "Modal" is a term that is used in a number of different ways by engineers and regulatory agency staff. For mechanical engineers, modal serves as a reference to specific engine operating parameters. In previous emission testing, modal testing has often referred to the transient test cycle (FTP). To transportation planners, modal is the generic term applying to different transportation modes (auto, bus, rail, etc.). The latest use of the term "modal emission testing" is the evaluation of emission rates under specific operating parameters.

\textsuperscript{84} The California Energy Commission is likely to participate in cooperative projects to improve fuel consumption models for different transportation modes and operating conditions (Powers, 1991; CEC, 1990).
High priority should be assigned to the development of incremental emission factors for acceleration activity and the quantification of acceleration activities (e.g. metered and unmetered freeway onramps, signalized intersections, etc.).

**Current CARB Efforts**

The California Air Resources Board’s Haagen-Schmidt Laboratory in El Monte, California, has entered into a co-funded project with the Southern California Rapid Transit District to construct a heavy-duty vehicle chassis dynamometer (Carlock, 1990; Dunlap, 1990). The new chassis dynamometer will be capable of monitoring modal\(^{85}\) (second-by-second motor vehicle emission rates under specific idling, acceleration, and constant-speed operating conditions), for buses as well as heavy-duty gasoline and diesel-powered trucks.

Although the dynamometer will be used initially to examine bus emissions, it will also be used to examine HD truck emissions in late 1991. Two full time staff positions have been allocated by the State to the heavy-duty dynamometer project (Carlock, 1990).

The CARB will soon develop new in-use chassis dynamometer cycles that are more representative of actual California driving conditions (CARB, 1991c). The new cycles will include high speed operations and acceleration profiles (e.g. onramp acceleration) that are more typical of California highway and local road traffic.\(^{86}\) However, as mentioned earlier, much of the same aggregation bias and the uncertainty associated with the application to corridor-specific emission impact analysis will still remain.

As a long term solution, the CARB will begin the study of modal emissions from heavy-duty vehicles (CARB, 1991c; Lovelace,

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\(^{85}\) "Modal" is a term that is used in a number of different ways by engineers and regulatory agency staff. For mechanical engineers, modal serves as a reference to specific engine operating parameters. In previous emission testing, mode has referred to the transient test cycle. The latest use of the term "modal emission testing" is essentially a hybrid of the two previous uses. Modal testing will be the evaluation of emissions for specific vehicle and engine operating parameters.

\(^{86}\) To the extent that the operating parameters of the dynamometer equipment will support high speeds and acceleration rates.
1991). Thus, the CARB research team will endeavor to establish modal emission rates that might be linked with emission-producing activities (idling, steady-state speed, and acceleration/deceleration).

Appendix J contains the proposed CARB research efforts and comments provided by consultants at the September 1990 public meeting on the mobile source emission inventory system (CARB, 1990e). The general goal of the CARB programs is to provide methodologies that can be used to estimate emissions from drive-up windows, ramp meters, etc.

**Potential Benefits of the CARB Research Efforts**

With the advent of modal models, the correction factors for speed would be eliminated from the emission calculation methodologies. This would greatly improve emission reduction strategy analysis because average speed correction factors cannot be used to reliably estimate microscale impacts of transportation control measures. The specific emission factors for specific operating speeds and acceleration activities, if developed by the CARB, would solve a number of emission factor uncertainty problems.

In addition, the problematic use of conversion formulae for motor vehicle emission rates (grams/bhp-hr to grams/mile emission rates) will be eliminated when modal emission factors are developed. Emission factors will better relate to actual on road emission-producing activities. Plus, idling and engine start emission rates would be developed.

The general problem that is encountered in modal modeling, however, is that research is difficult, time consuming, and expensive. Furthermore, detailed modal models are likely to be computer intensive. Thus, the improvements in the emission inventory from modal modeling work are likely to be long term as new equipment and techniques are employed.

The proposed CARB comprehensive research program over the next few years should resolve a large amount of the uncertainty in the mobile source emission inventory, by addressing the
inadequacy of the existing emission rates and correction factors. The CARB studies have the potential to provide new activity-specific emission factors for heavy-duty diesel and gasoline vehicles, reducing emission factor uncertainties. Thus, the CARB research is likely to address many of the sources of uncertainty related to emission factors that are outlined in this report.

However, not all of the uncertainty issues will likely be addressed by the proposed CARB studies, given the fact that funding sources are limited and because research efforts on the activity side of the equation are not coordinated with CARB research.

**Disaggregation of Vehicle Emission Rates**

With new modal emission rate data available for all vehicle classes, not only would emission rates be provided for distinct modal operations, the emission factors could also be further disaggregated (to a much greater extent than is currently possible). New emission data from chassis dynamometers could be disaggregated and specifically linked to gross vehicle weight rating, vehicle load, fuel type, engine size/classification, truck configuration, and/or industry classification. The ability to disaggregate emission rates and activities depends upon: 1) which disaggregation criteria result in rational emission rate cutpoints, and 2) whether it is possible to disaggregate vehicle activity data into appropriate categories. Thus, operating parameters should be investigated to determine the ideal disaggregation cutpoints. With a modal emissions model, corridor specific analysis of the effects of transportation control measures targeted at fleet segments could be undertaken.

The use of truck registration data in developing the "average vehicle" emission factor should be investigated over the short term. With new disaggregate emission data becoming available from chassis dynamometers (i.e. engine size, truck size, truck load, fuel type, etc.) registration information used to disaggregate vehicle activities must be made more reliable.
Additional Modal Modeling Issues

Additional areas of investigation for emission rates are remote sensing and fuel composition. The use of data from a remote sensing program may be useful in evaluating inspection and maintenance corrections used in the vehicle fleet (Horie, 1991). In addition, as the research methodologies improve, the effects of fuel specifications and the use of alternative fuels can be further investigated on a modal basis.87

The general problem that is encountered in modal modeling, however, is that research is difficult, time consuming, and expensive. Furthermore, detailed modal models are likely to be computer intensive. Thus, the improvements in the emission inventory from modal modeling work are likely to be long term as new equipment and techniques are employed. Multi-agency and multi-interest participation in these projects are highly recommended.

The proposed CARB research program over the next few years should resolve a large amount of the uncertainty in the mobile source emission inventory, by addressing the inadequacy of the existing emission rates. The CARB studies have the potential to provide new activity-specific emission factors for heavy-duty diesel and gasoline vehicles, reducing emission factor and correction factor uncertainties.

However, the development of modal emission factors is not sufficient in itself. Activity-specific emission factors must be coupled with appropriate estimates of emission-related vehicle activities. Hence, activity estimation methodologies must also be refined. Parallel research efforts must focus on methods to estimate disaggregate vehicle activity that may be linked to the new activity-specific emission rates (e.g. idling, engine start, constant-speed cruise, and acceleration activities).

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87 Recent studies indicate that methanol buses may increase emissions at low average speeds, and reduce emissions at high average speeds, when compared to diesel. Results from modal emission rate studies may indicate whether the use of methanol fuel in buses and/or automobiles should be discouraged on heavily congested routes (Santini and Rajan, 1990).
ACTIVITY MONITORING

If data from the new modal emissions testing laboratory are to be of any use, modal vehicle activity parameters must be monitored (or modeled). If VMT cannot be disaggregated into cruise speed profiles, or if acceleration activity cannot be quantified, new modal emission factors for motor vehicles will serve little useful purpose. Hence, research into quantifying appropriate vehicle activity parameters that can be linked to modal models is likely to become an important research focus.88

The goals of the activity monitoring studies are twofold: 1) to evaluate new methods of data collection that are likely to improve estimates of heavy-duty truck emission-producing activities, and 2) to begin analyzing data that can improve today’s activity estimates and that can be used in developing tomorrow’s detailed goods movement models.

Expanded and improved methods of collecting useful and applicable data for the evaluation of before and after travel patterns would greatly improve activity forecasting. Potential advanced monitoring techniques for data collection include: heavy-duty truck onboard black-box computers, weigh-in-motion networks, smog check and roadside inspection surveys, and comprehensive automatic vehicle identification (AVI) systems. The implementation of advanced monitoring systems has the potential to provide better estimates of vehicle activity, such as vehicle speed distributions, number of trips, and VMT.

The technical and economic feasibility of collecting "black box" vehicle activity data from on-board computers should be investigated. On board computer systems would be useful in capturing actual vehicle activity and driver behavior patterns that could be used to improve the emission inventory.

Future weigh-in-motion networks may provide disaggregate speed distributions for trucks on the highway and arterial network. These speed distributions are necessary so that appropriate emission factors (grams per mile) can be assigned to

88 For example, parameters such as trip length, vehicle load, fueling frequency, and duration and frequency of vehicle non-use are important emission-related activities that should be modeled (Horie, 1991).
VMT. In addition, other monitoring techniques, such as video imaging, may be capable of providing speed distribution data. However, disaggregation of speeds for the vehicle fleet (e.g. by size, weight, configuration, etc.) may still be difficult.

Research should be conducted to determine if it is possible to use survey data to verify disaggregated VMT estimates. For example, local road VMT will always have to be estimated, but the estimates could be improved by collecting annual VMT data during annual Inspection and Maintenance (Smog Check) or roadside diesel truck inspection activities.

If privacy concerns can be addressed, AVI systems and onboard black boxes may be capable of providing much useful travel data. If coupled with locational technologies such as satellite tracking, AVI systems can be used to better understand truck travel demand and network assignment relationships.

Research should also be conducted into the feasibility of developing a "Neilson" family of trucks, from which representative vehicle activity from disaggregated truck configurations, engine classes, and industry classifications can be collected. In this scenario, "average" trucks might be selected and monitored to determine how and why typical travel patterns are undertaken. The concept of the "Neilson driving family" might also be introduced in conjunction with travel monitoring systems such as AVI or computerized black boxes.

To serve as an input to air quality models, truck traffic data must be refined so that peak period activity and off-peak activities can be disaggregated, providing better temporal resolution in the inventory. Applicable emission-producing truck activities must also be spatially disaggregated, so that emissions can be input directly into grid-based photochemical models. Without improved temporal and spatial resolution, the outputs from air quality models are more uncertain.

Monitoring system data could be used to develop and calibrate heavy-duty truck vehicle activity (or goods movement)

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89 Even if grams/hour emission factors are used, speed distributions are still necessary to determine the travel times on vehicles on the links.
models. Data related to changes in speed profiles, congestion, and delay would also be very useful. Because so many projects could benefit from improved data collection and analytical techniques, the costs and benefits of using advanced monitoring systems should be fully explored.

604 ACTIVITY MODELING

To accurately estimate emissions, emission-related vehicle activities must be modeled as well as the modal emission rates. Thus, models must be developed for the goods movement industry that will predict heavy-duty emission-related truck activities.

The goals of the activity modeling projects are twofold: 1) to develop incremental activity estimates for those emission-producing activities identified in the modal emission testing, and 2) to develop a detailed goods movement model that predicts trip generation, mode split (e.g. truck vs. rail), trip distribution, and network assignment. Modeling capabilities would be dependent upon the availability of economic information and monitoring data.

The most detailed vehicle activity data currently used in emission inventory and modeling work for light-duty vehicles are outputs from Urban Transportation Planning System (UTPS) type models. UTPS-type models are generally described by a four step process: 1) estimating trip production and attraction within small geographic zones; 2) assigning the generated trips from zone to zone; 3) assigning zone-zone trips to travel modes; and 4) assigning the vehicle trips to specific links on a network model, using flow and capacity characteristics and an iterative delay minimization process. The network data on VMT, starts, etc., can then be coupled to activity-specific emission factors.

The development of a UTPS-type goods movement model that can be coupled with the models for light-duty vehicles (to evaluate the effects of light-duty vehicle trips on heavy-duty vehicle trips, and vice-versa) should be a long range goal of the emission inventory improvement program. Using these models,
specific effects of potential transportation control measure strategies could be undertaken. Without the network models, changes in emission-producing activities (such as number of engine starts and VMT) will be difficult to determine. For example, changes in traffic volumes and congestion effects cannot be realistically quantified without detailed network models that include heavy-duty vehicles. Because motor vehicle emission control strategies are now being designed to affect tripmaking behavior, vehicle activity models must be able to predict the changes that will occur.

A goods movement model ideally would be capable of allocating emission-related transportation activities at the corridor level (by analytical grid cell). With more accurate and applicable emission rate and activity data, emission estimates can serve as accurate input for airshed photochemical models, allowing for spatial disaggregation and gridding.

The collection of data on truck movement patterns and the development of a goods movement model will satisfy transportation and economic planning needs as well as air quality needs.

605 RESEARCH PROGRESSION

The projects described in sections 602 through 604 are discussed in detail (description of research, approach and methods, and participants and resource requirements) in a separate document prepared by the authors, entitled "A Research Plan Designed to Reduce Uncertainty in the Emission Inventory for Heavy-Duty Diesel-Powered Trucks (Guensler, et al., 1991)." The project titles are listed in Table 5.

A research progression is provided to illustrate how each of the activity projects is synthesized with the results of emission modeling projects in an interactive manner (Figure 11).

As emission-producing activities are identified and as activity-specific emission rates are disaggregated for the heavy-duty diesel vehicle fleet, parallel activity efforts must also provide appropriate activity estimates. After activity
Table 5
Selected Projects Designed to Reduce Uncertainty in the Emission Inventory for Heavy-Duty Diesel-Powered Trucks

A. Vehicle Emission Rates:
1. Comparison of certification cycles to vehicle use
2. Cooperative project on ARB modal emission modeling
3. Instrumented vehicle and dynamometer comparison
4. Criteria for disaggregation by vehicle class
5. Fuel specification effects
6. Alternative fuel analysis
7. Cold and hot start emissions

B. Activity Monitoring Demonstration Projects
1. Black box data
2. Smog check and VMT data
3. Weigh-in-motion data
4. AVI Systems

C. Vehicle Activity Estimates:
1. Speed distributions
2. Acceleration distributions
3. Trip generation and distribution model
4. Idling
5. Trip ends
6. Goods Movement Model Development

D. Goods Movement Model and Modal Emission Model Coupling
Figure 11
RESEARCH SEQUENCING

BLACK BOX DATA (B-1)
CERTIFICATION CYCLE (A-1)

SMOG CHECK (B-2)

MODAL TESTING (A-2, A-4)
CYCLE DEVEL. STEADY-SPEED/IDLING ACCELERATION HOT/COLD START

ON-ROAD (A-5)
FUELS (A-6, A-7)

DISAGGREGATION (A-3)

WEIGH-IN-MOTION (B-3) AVI (B-4)

SPEED DISTRIBUTIONS (C-1)
IDLING (C-3)

ACCELERATION DISTRIBUT. (C-2)

TRIP ENDS (C-4)

GOODS MOVEMENT MODEL (C-5)
monitoring techniques are evaluated and initial activity estimates are provided, detailed activity models can be developed. Specifically, activity models that are based upon economic aspects of the goods movement industry can be developed and calibrated such that they will provide appropriate emission-producing activity estimates.

Obtaining appropriate activity output from the detailed goods movement models cannot be overemphasized. If the goods movement models are not designed concurrently with modal emission rate models, goods movement models are unlikely to provide the data that are necessary to accurately estimate emissions.

606 CRITICAL PROJECTS

Development of a new certification cycle and the undertaking of modal emission testing are clearly the most critical projects, because it is through this research that emission-producing activities will be identified, clarified, and quantified. However, modal emission modeling is clearly the most resource intensive project. In terms of activity data development, immediate investigation into the use of black-box, weigh-in-motion and smog check data are likely to provide useful and cost-effective information about current activity levels and may be used for future modeling purposes. Determining criteria upon which to disaggregate the heavy-duty truck vehicle fleet is also very important and will be dependent upon initial findings from modal emission testing and activity data investigation.

607 POLICY ASPECTS

The data collected during the 1984 USEPA/EMA in-use engine testing indicated that significant emission reductions could be
achieved. Once detailed emission rate results from the new dynamometer systems are available, improved vehicle maintenance activities can be evaluated as a means of providing cost-effective emission reductions.

Both the technical and political feasibility of data collection through automatic vehicle identification (AVI) systems should be explored. Privacy concerns must be addressed before AVI systems and onboard black boxes will be politically feasible for collecting useful travel data.

Activity of heavy-duty vehicles in high-growth areas deserves additional investigation. Plus, research into the phenomenon of latent demand may prove useful.

Once emission relationships are better understood, it might be possible to rethink emission standards for heavy-duty trucks. Production-based emission standards (grams/tone-mile) could be investigated. Even standards that relate emissions to economic value of the trip could be considered for automobiles and trucks (Grenzeback, 1991). However, efforts in this area are likely to be long in coming to the regulatory arena. Better understanding of the causal factors of emission production as well as collection of disaggregate data will probably be required before major modifications to the engine certification process or regulatory structure are likely.

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90 Although the USEPA report concluded that mal-maintenance did not result in appreciable emission increases, the data reviewed indicates that emissions before and after federal maintenance were different for some pollutants (USEPA, 1984). Furthermore, the Radian study indicated that significant emission reductions could be achieved through an I&M program (Radian, 1988). However, some questions have been raised in this report regarding the actual magnitude of the emission inventory and expected emission reductions.

91 Latent demand is the increase in demand often noted to occur when additional capacity becomes available upon a road segment. Latent demand has the potential to negate congestion reduction (speed increase) emission benefits. When transportation control measures are implemented, the effects of the measures will be diminished by some amount, depending upon the response of trip making behavior in the affected area. Although latent demand does not directly apply to goods transportation (i.e. freight demand will not likely increase or decrease as a function of available roadway capacity), if emission reduction strategies reduce freight traffic during peak periods, capacity made available on the roadway may lead to latent demand for passenger travel. However, the latent demand phenomenon is difficult to measure empirically, due to inadequate data and the inability to control for the effect of intervening variables (Grenzeback, 1991). Hence, it is unclear if research efforts are likely to be fruitful.
CONCLUSIONS

Although the USEPA and CARB have attempted to ensure that the best available data are employed and that research projects designed to improve the methodologies are undertaken, new research will yield methods that better characterize the emissions from the heavy-duty diesel fleet.

Determining what research projects should be undertaken with limited resources is a difficult task. Regulators must determine which research projects are likely to result in the most useful information, but they face this task without knowing specifically what current methodologies and assumptions result in the greatest estimation uncertainty. General difficulties in targeting the most effective research areas is coupled with the fact that emission inventory expertise incorporates two distinctly separate areas: knowledge of vehicle activity and vehicle emissions rates.

Vehicle activity and activity-specific emission rate estimates for heavy-duty vehicles could readily be improved with additional research. Research efforts should be coordinated (i.e. federal, state and local air quality and transportation planning agencies; energy agencies; local councils of governments; universities; and private industry) so that comprehensive studies provide data and information that are transferable between agencies for a variety of uses. Future research efforts will ideally include public/private/university partnerships, to the extent that such partnerships will increase research efficiency and reduce overall costs. Cost sharing on coordinated research efforts might have significant efficiency benefits.

It is easy to point fingers at the uncertainty in existing methodologies, but solving the emission inventory problems for heavy-duty diesel and gasoline vehicles is not going to be easy. Experiments that resolve modal emission effects will consume significant laboratory resources, and the development of goods movement models will be data and resource intensive. However, if we really want to approach the implementation of emission control
measures in a rational fashion, this research and development is crucial. To understand the complex relationships that determine emissions, a serious and cooperative commitment on the part of government agencies, the goods movement industry, and the research community will be required.
700 REFERENCES

AB2595 Technical Advisory Committee (1990); Guidelines for Local Air Districts Considering Transportation Control Measures Directed at Heavy-Duty Truck Operations; Business, Transportation and Housing Agency; Sacramento, CA; September 1990.

Austin, Barbara (1991); Personal Communication; Systems Applications Inc.; San Ramon, CA; February 21, 1991.


California Air Resources Board (1986); Methodology to Calculate Emission Factors for On-Road Motor Vehicles; Technical Support Division; Sacramento, CA; November 1986.

California Air Resources Board (1988); Draft Supplement to Methodology to Calculate Emission Factors for On-Road Motor Vehicles; Technical Support Division; Sacramento, CA; January 1988.

California Air Resources Board (1989a); Area Designations for State and National Ambient Air Quality Standards; Technical Support Division; Sacramento, CA; November 1989.

California Air Resources Board (1989b); The Air Pollution - Transportation Linkage; Executive Office Division, Office of Strategic Planning; Sacramento, CA; June 1989b.

California Air Resources Board (1990a); Proposed Revisions to the Area Designations: Staff Report; Technical Support Division; Sacramento, CA; September 1990.

California Air Resources Board (1990b); Emission Inventory 1987; Technical Support Division; Sacramento, CA; March 1990.

California Air Resources Board (1990c); Proposed Regulations for Low Emission Vehicles and Clean Fuels; Sacramento, CA; August 13, 1990.

California Air Resources Board (1990d); Transportation Planning Requirements of the California Clean Air Act (CCAA Guidance Paper #2); Executive Office Division; Sacramento, CA; February 1990.

California Air Resources Board (1990e); Public Meeting on the Emission Inventory Process; Technical Support and Mobile Source Divisions; Sacramento, CA; November 5, 1990.

California Air Resources Board (1991a); The 55 MPH Speed Limit - Effects on California's Air Quality, Safety, and Fuel Consumption; Executive Office Division; Sacramento, CA; for release in July 1991.

California Air Resources Board (1991b); Modal Acceleration Testing; Mailout No. 91-12; Mobile Source Division; El Monte, CA; March 20, 1991.

California Air Resources Board (1991c); Planned Air Pollution Research - 1991 Update; Sacramento, CA; April 1991.

Caltrans, California Department of Transportation (1979); A Statewide Aggregate Model for Forecasting Vehicle-miles of Travel and Fuel Consumption in California; Sacramento, CA; July 1979.

California Energy Commission (1990); Energy Efficiency Report (P400-90-003); Sacramento, CA; October 1990.

Calspan Corporation (1973); Automobile Exhaust Emission Surveillance (PB-220 775); Buffalo, NY; Prepared for the Environmental Protection Agency (Document #APTD-1544), Office of Mobile Source Air Pollution Control; Ann Arbor, MI; May 1973.


Cambridge Systematics (1990); Transportation Related Emissions Inventory Preparation (Interim Report 68D90073); Prepared for the U.S. Environmental Protection Agency; Washington, D.C.; 1990.

Carlock, Mark (1990); Personal Communication, California Air Resources Board, Mobile Source Division; El Monte, CA; March 22, 1990


Coordinating Research Council, Inc. (1990); Auto/Oil Air Quality Improvement Research Program, Technical Bulletin No. 1, Initial Mass Exhaust Emissions Results from Reformulated Gasolines; Atlanta, GA; 1990.


Deakin, Elizabeth (1991); Personal Communication; University of California, Berkeley; Berkeley, CA; May 16, 1991.

Dietzman, Harry E., Mary Ann Parness, and Ronald L. Bradow (1980); Emissions from Trucks by Chassis Version of the 1983 Transient Procedure (801371); SAE Technical Paper Series, Fuels and Lubricants; Society of Automotive Engineers; Warrendale, PA; October 1980.

Dunlap, Lauren (1990); Personal Communication; Southern California Regional Transit District; Los Angeles, CA; May 30, 1990.


Groblicki, Peter J. (1990); Presentation at the California Air Resources Board Public Meeting on the Emission Inventory Process; General Motors Research Laboratories; Warren, MI; November 5, 1990.

Guensler, Randall, Daniel Sperling, and Paul P. Jovanis (1991); A Research Plan Designed to Reduce Uncertainty in the Emission Inventory for Heavy-Duty Diesel-powered Trucks (UCD-ITS-RR-91-05); Institute of Transportation Studies; University of California, Davis; Davis, CA; May 1991.

Horie, Yuji (1991); Personal Communication; Valley Research Company; Van Nuys, CA; April 17, 1991.

Horie, Yuji, and Richard Rapoport (1985); Assessment of Heavy-Duty Gasoline and Diesel Vehicles in California: Population and Use Patterns; Pacific Environmental Services; Santa Monica, CA; July 1985.
Hu, Patricia S., Tommy Wright, Shaw-Pin Miaou, Dennis J. Beal, and Stacy C. Davis (1989); Estimating Commercial Truck VMT of Interstate Motor Carriers: Data Evaluation; Oak Ridge National Laboratory; Oak Ridge, TN; November 1989.

Ingalls, Melvin N., Lawrence R. Smith, and Raymond E. Kirksey (1989); Measurement of On-Road Vehicle Emission Factors in the California South Coast Air Basin; Southwest Research Institute; San Antonio, TX; June 1989.

Kunselman, Paul, H.T. McAdams, C.J. Domke, and M.E. Williams (1974); Automobile Exhaust Emission Modal Analysis Model; Calspan Corporation; Buffalo, NY; Prepared for the Environmental Protection Agency (Document 460/3-74-005), Office of Mobile Source Air Pollution Control; Ann Arbor, MI; January 1974.

Lilly, LRC, Editor (1984); Diesel Engine Reference Book; Butterworths; Boston MA; 1984.

Long, Jeff (1990); Memorandum from Jeff Long, Air Resources Engineering Associate, to Mark Carlock, Manager, Analysis Section; California Air Resources Board, Mobile Source Division; El Monte, CA; January 26, 1990

Lott, Donna (1990); Personal Communication; California Air Resources Board, Transportation Strategies Group; Sacramento, CA; November 1990.

Lovelace, Bill (1991); Personal Communication; California Air Resources Board; Sacramento, CA; April 1991.


Memmott, Frederick W., and Russel H. Boekenkroeger (1982); Practical Methodology for Freight Forecasting; Transportation Research Record 889; Transportation Research Board; Washington, D.C.; 1982.

National Research Council (1981); NOx Emission Controls for Heavy-Duty Vehicles; Motor Vehicle NOx Standard Committee, Assembly of Engineering, NRC; National Academy Press; Washington, D.C.; 1981.


Oliver, William (1991); Personal Communication; Radian Corporation; Sacramento, CA; April, 1991.

Platte, Lois (1989); United States Environmental Protection Agency; Ann Arbor, Michigan; Telephone Interview; November, 1989.

Powers, Nan (1991); California Energy Commission, DSPEO; Communication with Anne B. Geraghty; California Air Resources Board; Sacramento, CA; April 25, 1991.

Purvis, Charles (1990); Personal Communication; Metropolitan Transportation Commission; Oakland, CA; September 1990.

Purvis, Charles (1991); Personal Communication; Metropolitan Transportation Commission; Oakland, CA; May 16, 1991.

Reilly, John P., and Jeffery J. Hochmuth (1990); The Effects of Truck Restrictions on Regional Transportation Demand Estimates (890709); Proceedings of the 69th Annual Meeting of the Transportation Research Board; Washington, D.C.; January 1990.

Sanchez, Raul (1991); Personal Communication; California Department of Transportation; Sacramento, CA; April 1990.

Santini, Danilo J. (1991); Personal Communication; Argonne National Laboratory; Argonne, IL; April 25, 1991.

Santini, Danilo J., and J.B. Rajan (1990); A Comparison of Emissions of Transit Buses Using Methanol and Diesel Fuels; Transportation Research Record 1255; pp. 108-118; 1990.


Seitz, Leonard E. (1991); Seitz and Guensler - meeting; California Department of Transportation; Sacramento, CA; April 26, 1991.

Southern California Association of Governments (1989); An Improved Methodology for Estimating Heavy-Duty Truck VMT for South Coast Air Basin Emissions; Los Angeles, CA; December 1989.

Susnowitz, Raphael (1991); California Air Resources Board, Mobile Source Division; emission inventory evaluation meeting; February 26, 1991.

Sydec, Inc. (1987a); Highway Cost Allocation Study - Final Report (CDOT 04-38a); Prepared for the California Department of Transportation; Sacramento, CA; July 1987.

Sydec, Inc. (1987b); Highway Cost Allocation Study - Technical Report (CDOT 04-38b); Prepared for the California Department of Transportation; Sacramento, CA; July 1987.


U.S. Environmental Protection Agency, Office of Mobile Sources (1984); Test Results from the EPA/Industry Heavy-Duty Engine Testing Program; unpublished test result data; Ann Arbor, MI; 1984.

U.S. Environmental Protection Agency, Office of Mobile Sources (1985); Compilation of Mobile Source Emission Factors, AP-42, Volume II: Mobile Sources; Ann Arbor, MI; September 1985.

U.S. Environmental Protection Agency, Office of Mobile Sources (1988); MOBILE4 Workshop Handout Materials; Ann Arbor, MI; November 30, 1988.

Wade, Dennis (1991); Personal Communication; California Air Resources Board; Sacramento, CA; May 16, 1991.

Wayson, Roger (1991); Personal Communication; University of Central Florida; Orlando, FL; April 15, 1991

Weaver, Christopher S. (1988); Feasibility and Cost-Effectiveness of Controlling Emissions from Diesel Engines in Rail, Marine, Construction, Farm and Other Mobile Off-Road Highway Equipment; Prepared for the Office of Policy Analysis, USEPA (PM-221); Radian Corporation; Sacramento, CA; February 1988.
Appendix A

Gasoline Vs. Diesel Engine Combustion Product Differences

The emissions from heavy-duty diesel fueled vehicles are significantly different in mass and character than the emissions from heavy-duty gasoline fueled vehicles. Diesel fueled engines are compression-ignition rather than spark-ignition. Because diesel fuel is injected into the cylinder as a liquid, engines are operated with excess air to provide sufficient mixing for combustion (to avoid smoke and hydrocarbon emissions and to promote better fuel efficiency). Diesel engine cylinders typically run at higher pressures and temperatures than spark ignition engines (Lilly, 1984).

The presence of excess air, coupled with high combustion chamber pressures and temperatures during the power stroke, results in significantly higher diesel engine emissions of NOx than from comparable spark-ignition gasoline engines (Lilly, 1984).

The emissions of uncombusted hydrocarbons (VOC) from diesel engines are roughly equivalent to the emissions from gasoline fired spark-ignition engines (Taylor, 1985a). However, due to the low volatility of diesel fuel, evaporative VOC emissions from the fueling and operation of diesel vehicles are significantly lower (considered by regulatory agencies to be insignificant) than for gasoline engines.

Carbon monoxide emissions are generally less from diesel engines than from spark ignition engines due to the relatively efficient oxidation of CO to CO₂ in the lean burn environment (Lilly, 1984). Oxides of sulfur are substantially higher for diesel engines, based solely upon the higher sulfur content of diesel fuel.

Catalytic converters cannot be used with diesel engines due to the presence of significant excess oxygen (from excess air combustion) and particulates in the exhaust gas (Taylor, 1985a). Particulates can clog the catalyst. In addition, concentrated sulfur gases in the exhaust gas can deactivate catalytic reaction sites.
Appendix B
Regulatory Efforts Directed at California's Heavy-Duty Trucks
Source: Boyd and Guensler, 1990

The California Air Resources Board (CARB) was created by the California Legislature in 1969 to control air pollutant emissions and to improve air quality throughout the state. The CARB works closely with the United States Environmental Protection Agency (EPA) and with the 41 local air pollution control districts to improve air quality in California. The CARB has been mandated by the Legislature to endeavor to achieve the maximum degree of emission reductions possible from vehicular sources of pollution.

The CARB is charged with the duty of establishing and enforcing standards which limit pollutant emissions from motor vehicles. The principle activities of the CARB related to motor vehicle emissions include: adoption and implementation of motor vehicle emission standards, in-use performance standards, and motor vehicle fuel specifications for the control of air contaminants and sources of air pollution.

New Vehicle Certification Program:

The emission requirements for heavy-duty trucks in California are more stringent than the requirements of other states when the trucks are operated only in California. As previously mentioned, however, 50 percent of the trucks are registered to operate in multiple states and are therefore not required to meet California's more stringent standards. When the new Clean Air Act is approved by Congress, more stringent emission standards are likely to be applied to all 50 states.

Inspection and Maintenance:
California adopted a decentralized biennial inspection and maintenance (I&M) program designed to reduce emissions 25 percent. Under the "Smog Check" program, approximately 16 million vehicles are inspected biennially (almost 90 percent of the light and medium duty on-road vehicles in California).

Although heavy-duty diesel vehicles are currently exempted from the I&M program, heavy-duty gasoline trucks registered solely in California are required to participate in the biennial inspections, regardless of vehicle size or weight. January 1, 1990 marks the first year that heavy-duty gasoline vehicles have been included in the I&M program and significant emission reductions are expected. The I&M program generally includes: a visual inspection, functional emission control inspection, and tailpipe emissions tests. The tailpipe emissions must meet the age based vehicle emissions criteria for hydrocarbon and carbon monoxide emissions at idle.

Motor vehicle inspection and maintenance programs have been demonstrated to significantly reduce vehicle emissions and thereby contribute to the attainment and maintenance of ambient air quality standards. Air pollution problems in many areas of the state are of such severity and persistence that all reasonable motor vehicle air pollution control measures will be required for the indefinite future.
For diesel-powered vehicles, California will consider their inclusion the Smog Check program when subsequent emission reductions are deemed technologically and economically feasible.

**Heavy-Duty Diesel Roadside Inspections:**

In 1988, the California Legislature passed a bill that was designed to enhance California’s Smog Check Program and to provide for the adoption of a heavy-duty vehicle smoke and tampering inspection program for gasoline and diesel fueled interstate and intrastate vehicles operating in California. Under this program, inspected vehicles can be cited and required to immediately correct deficiencies specified in the citation.

Tampering with and mal-maintenance of specific engine components and mal-maintenance of the engine itself are the primary causes of excessive diesel emissions. It is anticipated that the implementation of the heavy-duty vehicle smoke and tampering inspection program will reduce emissions of NOx by 11 tons per day (2 percent of the heavy-duty diesel truck NOx emissions), reduce emissions of hydrocarbons by 9 tons per day (9 percent), and reduce emissions of particulate matter by 31 tons per day (36 percent).

A 35 percent smoke opacity limit is used for the tests. In a demonstration inspection project, approximately 240 (42 percent) of the tested vehicles failed the test procedure. A preliminary review of this data indicates that there are three primary causes of excessive smoke emissions: improper air/fuel ratio control settings, fuel injection system or fuel injection timing problems, and inadequate intake air. These problems were generally corrected with repairs costing less than $500 per vehicle.

The CARB and the California Highway Patrol plan to commence inspecting heavy-duty motor vehicles under this program during 1990. Inspections will be conducted in conjunction with safety and weight enforcement activities of the Department of the California Highway Patrol and at private facilities where fleet vehicles are serviced or maintained.

**Fuel Specification:**

Motor vehicle fuels contain many substances which become air pollutants upon either evaporation or combustion of the fuel. California regulations specify limits on the sulfur content of both unleaded gasoline and diesel fuel intended for use in motor vehicles. The limit for motor vehicle diesel fuel is 500 ppm sulfur (0.05 percent by weight) in the South Coast Air Basin and Ventura County. New limits that will take effect in 1993 will establish a this standard statewide. In California, no person shall sell, offer for sale, or supply, as a fuel for motor vehicles, any unleaded gasoline or diesel fuels that do not meet the sulfur content limits prescribed by law.

Decreases in sulfur dioxide and sulfate levels correspond to decreases in levels of particulate matter. Both the state and national standards for particulate matter of diameter 10 microns or smaller (PM10) are exceeded in most air basins. In addition, increases in sulfates impact visibility by affecting the color.
intensity and acuteness with which an observer views each object and detail in a visual scene.

In 1988, the Board approved a 10 percent limit on the aromatic hydrocarbon content of diesel fuel (or 20 percent for small refiners), effective in 1993, down from the then current level of over 30 percent.

The requirements for the sulfur and aromatic content for motor vehicle diesel fuel were expected to reduce exhaust emissions of sulfur dioxide by 80 tons per day (a 90% reduction from on-road diesel trucks and automobiles), particulate matter by 14 tons per day (a 26% reduction), and oxides of nitrogen by 53 tons per day (a 10% reduction).

**Fuel Transfer Evaporation Controls (Gasoline Fuels Only):**

California’s Phase I and II vapor recovery program reduces HC evaporative emissions by 430 tons per day (a 10% reduction in statewide HC emissions). This program employs vapor balancing or vacuum nozzles at fuel pumps and bulk transfer stations to recycle gasoline vapors. The program is well known to California motorists who use self-serve gasoline stations. The vapor recovery program not only reduces air pollution but recovers 50 million gallons of valuable fuel per year.

**Fuel Efficiency:**

In the early 1970s, pollution control for motor vehicles was primarily add-on equipment. Control technologies generally interfered with vehicle performance and gas mileage. However, modern air pollution controls are an integral part of the engine. In fact, with the advent of computer controlled engines, removal of the control equipment can result in a decrease in automobile performance. CARB is now in the process of advocating increased fuel efficiency as a control measure.

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92 However, because the average in-use fuel sulfur content is approximately 0.3%, instead of 0.5%, the reduction in sulfur dioxide is likely to be closer to 80% (Lovelace, 1991).
Appendix C
Current Activity and Emission Rate Modeling Efforts

CURRENT ACTIVITY MODELING EFFORTS
The heavy-duty truck activity estimation methodology differs significantly from that of light-duty vehicles. Appendix D contains a brief description of the methodology for light-duty vehicles. The essential difference between the heavy-duty vehicle and light-duty vehicle methodologies is that heavy-duty truck activity is estimated through surrogate indicators (such as traffic counts) while light-duty vehicle activity is usually estimated through local travel demand models.

BURDEN7C
BURDEN7C is the model used by the CARB to couple vehicle activity with the emission rates produced by EMFAC in their efforts to prepare the Statewide emission inventory. Thus, the BURDEN model is not actually used to generate vehicle activity data. Rather, the BURDEN program takes the entered activity data and couples the data with emission factors.

The vehicle activity data in the BURDEN program is coupled with EMFAC emission factors to provide the emission impact of heavy-duty trucks in all areas except the Southern California Air Basin. In Southern California, the DTIM program (essentially an accounting program which will be described in more detail in the next section) is used to provide vehicle activity data. The CARB uses the outputs from the Southern California Association of Governments (SCAG) heavy-duty truck model (discussed later) as inputs to the Caltrans' Direct Travel Impact Model in the South Coast Air Basin.

The specific methodology used by the CARB is outlined in "Methodology to Calculate Emission Factors for On-Road Motor Vehicles (CARB, 1986)." A set of emission rate "look-up" tables are created by EMFAC for: running exhaust (by average operating speed), incremental cold starts, incremental hot starts, hot
soaks, and diurnal evaporation. Examples of the tables produced by EMFAC are included in Appendix F.

EMFAC estimates vehicle travel fractions, or relative percent of vehicle activity (i.e. number of vehicles, number of trips, vehicle-miles traveled) for vehicle classes (light-duty auto, heavy-duty truck, etc.), engine types (gasoline and diesel), and control technology configurations (catalytic converter equipped, and non-catalytic converter equipped).

The heavy-duty truck registration mix, used in developing fleet mix characteristics, was estimated through the use of 1975 Polk truck data (CARB, 1986; CARB, 1988). The annual heavy-duty truck annual mileage accrual rates, used to develop weighted emission rates for an "average" truck, were derived from the 1972 Census of Transportation Truck Use Survey, U.S. Bureau of Census, May 1978 (CARB, 1986).93 The heavy-duty truck travel fractions are calculated in EMFAC, based upon annual VMT, mileage accrual rates, and registration mix (Lovelace, 1991). Then, the heavy-duty diesel truck vehicle class emission rates contained in the EMFAC tables can be weighted for heavy-duty fleet composition.

BURDEN couples the specific vehicle activity estimates for each vehicle class with the appropriate emission rates from the look-up table. Thus, specific heavy-duty truck activity must be entered in the BURDEN program. Because there are no emission factors for engine starts, the only heavy-duty truck activity that is entered into the BURDEN program is an estimate of vehicle-miles traveled and an average travel speed distribution.

The actual VMT estimates are provided to BURDEN using baseline VMT determined by Pacific Environmental Services (PES) in the 1985 study (Horie and Rapoport, 1985) and by applying growth factors to estimate later year VMT. BURDEN takes the adjusted VMT input from the PES study and calculates appropriate emissions in the air basin.

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93 In 1988, the CARB modified both the heavy-duty truck registration mix and the annual mileage accrual rates, as indicated by the change in Tables 4 and 6 of the CARB "Methodology to Calculate Emission Factors for On-Road Motor Vehicles" (CARB, 1988). Appendix D contains Tables 4 and 6 from each of the two CARB methodology papers (CARB, 1986; CARB, 1988). It is unclear what data was used to update the vehicle registration mix in 1988, as both documents claim to have used the 1975 Polk data.
Unfortunately, there is no documentation available on the BURDEN model at this time. The CARB staff are currently in the process of preparing a technical manual, but do not expect the document to be available for some time, due to current resource constraints.

DTIM

Although the DTIM model is not currently used to model heavy-duty truck activity, it is discussed here because the DTIM outputs for light-duty vehicle provide useful information. The Caltrans' Direct Travel Impact Model (DTIM) is essentially an accounting package that tracks VMT and emission impacts on a link-by-link basis. The DTIM program allows the assignment of travel and emission impacts to a grid cell (resolution of 5km x 5km) for use in a photochemical grid model. The spatial location of emissions, provided by DTIM, serves as an important input for emission inventory, planning, and air quality modeling purposes.

The Caltrans' Direct Travel Impact Model (DTIM) is completely independent from BURDEN, and each of the models use different input. However, DTIM and BURDEN follow the same general internal format and, if the same input and assumptions are used, DTIM and BURDEN would yield the same results.

The DTIM model uses traffic generation and route assignment results from Urban Transportation Planning System (UTPS) type models as inputs. However, because UTPS models are not capable of generating and assigning heavy-duty vehicle trips, DTIM does not track heavy-duty truck activity. Hence, the DTIM model does not have link specific heavy-duty vehicle activity to work with. However, as will be discussed in the next section, the SCAG improved truck activity model is to be used to allocate the total basinwide VMT (currently estimated by CARB based upon the Pacific Environmental Services study) to specific links, using traffic counts as a surrogate indicator. Using the new SCAG model, heavy-duty truck VMT activity are to be allocated to the appropriate links for use with the DTIM model.
UTPS Systems

The UTPS systems do not include trip generation rates for heavy-duty vehicle operations (see Appendix D). Thus, the traffic volumes generated and assigned on the links are passenger cars only. Since UTPS models do not include heavy-duty vehicle activity estimates, the heavy-duty activity must be either modeled through external truck activity models (based upon trip generation and an iterative assignment model that uses UTPS outputs) or through surrogate traffic count data.

PES Modeling Efforts

The Pacific Environmental Services report Assessment of Heavy-Duty Gasoline and Diesel Vehicles in California: Population and Use Patterns (Horie and Rapoport, 1985), contains VMT estimates for heavy-duty trucks based upon surrogate traffic counts and additional survey data. The authors provide heavy-duty truck VMT estimates based upon VMT data generated by the Caltrans’ Truck Program and Highway Performance Monitoring System, as well as a survey of truck operators. Estimates were based on Caltrans traffic count data, a PES survey of 21 city and county roads, a PES telephone survey of 233 fleets, the 1976 Interstate Commerce Survey, the 1971 ITTE Survey.

The PES methodology disaggregates the aggregate Caltrans VMT data and allocates the VMT to local areas, attempting to break the VMT data into heavy-duty engine classifications (light heavy-duty, medium heavy-duty, and heavy heavy-duty). The PES report indicates that the disaggregated VMT estimates should be considered more uncertain than the Caltrans estimates:

"Since the apportioning parameters themselves are subject to some errors, the resulting VMT estimates in this study are doomed to be less accurate than those given by the CALTRANS data bases (Horie and Rapoport, 1985)."

In addition, there is no way to determine if the CARB applied growth factors are appropriate for specific local areas and for all segments of a disaggregate fleet.
Caltrans Truck Miles Traveled Traffic Count Methods

The methodology employed by Caltrans to compile truck VMT estimates is based upon vehicle counts on freeways and arterials. The number of vehicles counted are coupled with link lengths to estimate on-road VMT.

Average daily traffic volumes at 3800 selected locations on the California State Highway System are coupled with the difference in milepost location (link length) to estimate truck miles traveled (Caltrans, 1988). The Caltrans truck miles traveled data are estimated to be within 5% of the Caltrans Truck Accident Surveillance and Analysis System (TASAS) estimates (Caltrans, 1988). However, the methodologies used by both systems appear to be similar and should not result in significant differences in the estimates. Thus, comparing these data will not provide insight into the accuracy of either methodology.

The Caltrans methods yield average daily travel estimates on specific monitored lengths that are to be within five percent of actual on the state highway system. The average daily travel estimates are useful for local highway planning efforts (i.e. projecting future demand for use in construction or demand management efforts).

The conversion from average daily travel counts to VMT estimates, however, does introduce an unspecified amount of uncertainty into the estimate. Given that only 30% of the heavy-duty truck VMT is estimated to occur on the interstate system (Horie and Rapoport), where the majority of traffic counts appear to be taken, the estimates of traffic on principle arterial routes (38%) may be much less certain.

Even with the extensive network and traffic counts, Caltrans personnel do not consider their methodology good enough to provide accurate VMT estimates by county (Horie and Rapoport, 1985), let alone truck activity by grid cell. Because the PES report also indicates that their estimates should be considered less certain than the Caltrans estimates, even though the spatial allocation is likely to be better than previously used by the
CARB, the accuracy of the disaggregated estimates is still very uncertain.

**SCAG Improved Heavy-Duty Truck Activity Model**

The Southern California Association of Governments (SCAG) is the agency responsible for local transportation activities. SCAG developed the local UTPS-type model that is currently employed to determine trip generation and assignment within the air basin.\(^{94}\) However, because SCAG's model cannot generate nor assign heavy-duty truck trips, alternative methods of truck trip estimation must be employed.\(^{95}\)

The county-wide VMT estimates developed by the California Air Resources Board and the Department of Transportation cannot resolve the number of trips or VMT spatially. SCAG desired to develop an alternative method for assigning heavy-duty vehicle trips and VMT in a network format. Rather than developing a trip generation and assignment model specific to heavy-duty vehicles, SCAG developed a method for assigning heavy-duty vehicle trips and VMT to the network links using light-duty vehicle VMT and actual heavy-duty vehicle traffic counts along the links (SCAG, 1989).

The California Air Resources Board uses the outputs from the SCAG heavy-duty truck model as inputs to the Caltrans' Direct Travel Impact Model in the South Coast Air Basin. DTIM allows the CARB to assign travel and emission impacts at a grid resolution of 5km x 5km for use in a photochemical grid model.

**Specialized Truck Activity (Trip Generation and Assignment) Models**

The Chicago area transit study resulted in the development of a trip generation and assignment model for goods movement in the Chicago Area (Reilly and Hochmuth, 1990). This model was

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\(^{94}\) The UTPS-type model employed by SCAG is described in detail in the Southern California Association of Governments document entitled "An Improved Methodology for Estimating Heavy-Duty Truck VMT for South Coast Air Basin Emissions," December 1989.

\(^{95}\) Urban Transportation Planning System (UTPS) type models do not contain truck activity models, and are designed to model the movement of people rather than goods and services.
used by Reilly and Hochmuth to evaluate the potential effects of heavy-duty vehicle roadway use prohibitions in the Chicago area to determine the decrease in movement efficiency (increase in VMT and decrease in operating speeds).

Memmott and Boekenkroeger (1982) have postulated that a "transport costing model" can be adapted to the estimation of freight movements. The general concept of a freight costing model is to simply to examine each commodity movement in terms of transport costs and revenues along route alternatives. Of course, for transport costing models to be used, the volumes of goods to be shipped as well as the locations of the goods shippers and receivers must be known. Hence, transport costing models could be coupled with a trip generation model to assign modes (i.e. rail versus truck) and the number of trips along links and nodes. The revenue and cost data from the transport costing model would be used much in the same manner as impedance values are used in UTPS assignments.

Because truck route decisions are based upon the existing traffic conditions, the transportation costs and subsequent route assignments would be dependent upon the volume/capacity data generated by the UTPS system. An iterative process might ensue, where UTPS and goods movement models interact in the development of traffic assignments.

Although freight movements can be modeled through truck-specific activity models, Memmott and Boekenkroeger (1982) indicate that much of the present methodology in these areas are elementary. In addition, there is a high cost associated with the development of a detailed freight movement model. The high costs of data collection associated with the development of heavy-duty truck trip generation rates was cited as the reason for the alternative development of light-duty vehicle activity surrogates to estimate link specific heavy-duty vehicle VMT in the South Coast Air Basin (SCAG, 1989).
CURRENT EMISSION RATE MODELING EFFORTS

EPA - Mobile 4

The U.S. Environmental Protection Agency prepared a mobile source emission package, Mobile 4, that is used throughout most states. However, in California, the Mobile 4 package is not used by the California Air Resources Board.

California - EMFAC/BURDEN

The CARB has developed a two component model known as BURDEN/EMFAC. The BURDEN model is an activity accounting package, used to couple estimated number of trips, hot/cold start splits, VMT, etc., with the EMFAC emission rate model. The EMFAC model provides emission factors that are coupled with the activity data in BURDEN.

The EMFAC emission rates for light-duty vehicles are California's own (not simply revisions of the USEPA's Mobile 4 data), based upon detailed laboratory testing conducted at the CARB laboratory in El Monte, CA (Lovelace, 1991). In addition, the emission factors contain internal corrections for the efficiency of the inspection and maintenance program and assumed catalyst tampering rates, based upon the Radian (1988) report.

The emission factors for heavy-duty trucks, however, were taken from Mobile 4 (see Section 4.01). The heavy-duty truck emission factors from Mobile 4 are adjusted only for tampering rates and the California fleet mix of heavy-duty gasoline and diesel vehicles.

The EMFAC model generates emission rates for the vehicle fleet. Data are available for the 25 previous model years, estimated from sales and registration data. Aggregate table matrices of emission rates are generated for a calendar year.

Emissions of lead and SOx are based upon the estimated sulfur and lead content of fuels. The lead and SOx emissions are estimated from assumed lead and sulfur content and gallons of fuel consumed (fuel consumption estimates come from VMT estimates.

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96 Some have referred to the BURDEN model as a "gold plated calculator." The model simply multiplies activity estimates by appropriate emission factors.
and the speed-related fuel efficiency algorithms in the EMFAC model). This emission estimation methodology needs to be significantly improved. ⁹⁷

**Impact Rate Summarization**

The Impact Rate Summarization (IRS) program, used by Caltrans with DTIM, composites emission rates from EMFAC by vehicle type. The IRS program uses EMFAC data to create a "look-up table" that can be used by DTIM to minimize computer time and run cost.

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⁹⁷ For example, Board of Equalization data on total California fuel sales and assumed county splits could possibly be used to improve the estimates.
Appendix D
Light-Duty Vehicle Methodologies

Light-Duty Vehicle Activity Estimates

The VMT for light-duty vehicles in the Southern California Area is estimated using a detailed Urban Transportation Planning System model of the transportation network within the air basin. This detailed network travel demand model generates trips, assigns trips from area to area, and then routes trips to the computerized highway network.

Throughout the remainder of the state, UTPS models are not yet used to develop VMT estimates for emission inventory preparation. Air basin VMT is determined by the CARB and Caltrans, based upon HPMS data and the 1979 Caltrans Statewide Aggregate Model for Forecasting VMT.

When detailed network models become available for other areas in the state, The CARB is apparently planning to use the network model outputs as inputs to DTIM (or perhaps an improved version of DTIM developed by CARB and Caltrans) for calculation and assignment of gridded emissions.

Caltrans VMT Model

The vehicle-miles of travel data used as inputs to the BURDEN model for California (except the South Coast Air Basin) are based upon the outputs from a California Department of Transportation statewide aggregate model (Caltrans, 1979). The estimated VMT function (VMT/person) employs seven variables: registered vehicles per person (registered vehicles and population), personal income, average fuel cost per mile (average fuel cost and average fuel economy), and center line miles of road. As would be expected, there are questions that arise regarding the accuracy of using aggregate values for average fuel

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98 The San Francisco area UTPS model developed by the Metropolitan Transportation Commission is not yet used for VMT inputs. There is an apparent dispute between Caltrans, CARB, and MTC, regarding the accuracy of modeled estimates. Unfortunately, there appears to be a significant difference (about 30%) between modeled VMT estimates (Purvis, 1990). Hopefully the differences can be resolved soon so that the MTC modeled data can be used.
economy and average fuel price per gallon. Thus, Caltrans uses a ratio function to help minimize the impact of aggregation errors, calculating the percentage increase in VMT/person from the baseline year of 1976.

The 1979 Caltrans model does not appear to have been calibrated using historical trip data. Rather, the model was apparently back-calibrated to match the existing VMT estimates. When the model did not adequately predict the VMT/person (Caltrans, 1979) the model was changed to provide a ratio function to estimate percent increase in personal travel. It should be noted that using the model to calculate an increase in VMT/person still does not help to determine the accuracy of the original VMT estimates. Further, the applicability of the model to today's society where trip characteristics have changed dramatically is questionable.

A useful model yielding VMT/person would be desirable to help improve the certainty in the VMT estimates used in BURDEN application. Model development and calibration should be undertaken with the use of historical trip making behavior data collected in a travel survey.

South Coast Air Basin UTPS Model

The Federal Highway Administration developed a transportation demand model known as the Urban Transportation Planning System (UTPS). The UTPS model has been adapted by many local agencies for direct application to local transportation networks. In general, the UTPS models consist of a number of components: trip generation, the number of trips to and from each zone as a function of land use and socioeconomic data; trip distribution, zone to zone trip tables based upon the gravity model; modal split, allocation of trips to modes as a function of income and differences in travel time and out-of-pocket cost; and trip assignment, based upon travel impedance (SCAG, 1989).

The UTPS models used today were not specifically developed for the preparation of emission inventories (Cambridge Systematics, 1990). The major problems with using UTPS models to
develop local VMT estimates in local air basins include:
differences in geographic modeling areas and air basin
boundaries, incomplete coverage of all roadway types
(transportation network models generally ignore minor and local
roads), and data that may not be applicable to air pollution

UTPS models are generally based upon outdated trip making
data collected from household surveys conducted in the 1960’s and

"Los Angeles is a typical example in which their
current model was developed using surveys and roadside
interviews from 1967, and which was subsequently
updated using data from the 1976 survey and the 1980
census (Cambridge Systematics, 1990)."

Travel data are prepared by the Southern California
Association of Governments (SCAG) using the SCAG Regional
Transportation Demand Model (Cambridge Systematics, 1990). The
model was developed and is operated by the Southern California
Association of Governments (SCAG). In sum, VMT is modeled as a
function of trips generated (a function of zone attributes and
demographics), and subsequent roadway link assignments (a
function of link and trip attributes) (SCAG, 1989). The SCAG
travel data outputs are coupled with the DTIM model at the CARB
to estimate the emission inventory (gridded) for the South Coast
Air Basin. The SCAG model predicts traffic volumes and speeds
for morning peak, off-peak, and evening peak travel. Local roads
are not accounted for in the SCAG model, so additional traffic
capacity are assigned to pre-existing inks to account for local

Vehicle Registration Fractions for Light-Duty Vehicles

The registration fractions for light-duty vehicles are based
upon: vehicle registration data derived from annual Polk
National Vehicle Population Profiles, vehicle sales by technology
type for each model year, and annual VMT estimates for each model
year. The DMV data are assumed to be proportional to the fraction of VMT for each vehicle class and technology.

The VMT fractions, by vehicle class, are based upon a 1978 USEPA estimate (Mobile Source Emission Factor, March 1978).

**Number of Trips for Light-Duty Vehicles**

For light-duty vehicles, the number of trips is standardized per vehicle. The number of trips per household used in UTPS models for the South Coast Air Basin and the San Diego Air Basin are based upon the 1976 statewide travel survey. In all other areas, where a UTPS model is not used, the number of trips are also based upon the 1976 travel survey and are considered to be proportional to the VMT fraction for each vehicle class by technology.

The number of daily trips per household is not based on local traffic model outputs unless the models are available and approved by the CARB. Local modeling data are currently only used in the South Coast Air Basin (Southern California Association of Governments data) and the San Diego County Air Basin (San Diego County Association of Governments data). For all other areas, the VMT estimate is provided by Caltrans from their Statewide models. All travel demand models used in California can trace their origins to Caltrans' Origin and Destination survey published in December, 1981.

The Statewide Travel Survey (1976-81) is used to estimate the number of trips made by vehicle type. However, the trip generation component of the model may be outdated for all vehicles.

**Vehicle-Miles Traveled for Light-Duty Vehicles**

Statewide VMT is estimated by Caltrans' Department of Transportation Planning (DOTP), using the Statewide Aggregate Vehicle-Miles Traveled/Vehicle Fuel Consumption (VMT/VFC) Model. The model is a regression analysis against the variables: per capita income, vehicle ownership, per-mile fuel costs, and fuel sales/availability. When Caltrans reports that VMT is up 6%,
they are basing this increase on traffic counts and estimates of local road VMT.

In projecting VMT growth, the Caltrans forecast is based on Department of Finance estimates. The Caltrans methodology may not be applicable or accurate for all areas. Some areas are growing much faster than the Statewide average (e.g. Sacramento County), while other areas are growing much slower (e.g. the Bay Area).

State Highway VMT is estimated from traffic counts and Caltrans staff feel very comfortable with their methodology. Non-State-Highway VMT is estimated by subtracting State Highway VMT from the Statewide VMT estimated by the Fuel Consumption and VMT Model (Caltrans, 1979).

The DOTP model is used to estimate VMT for the Federal Highway Administration and the data are used in part by the Federal Highway Administration to determine California's share of the federal gas tax. It is extremely unlikely that VMT estimates are manipulated for the purposes of maximizing state revenues. However, it is possible that error terms may be skewed toward the high end, and additional research into the accuracy of the estimates is warranted.

Statewide VMT numbers are heavily dominated by SCAQMD. As SCAQMD VMT approaches saturation, the overall statewide percentage increase in VMT should level off (depending upon growth rates).

Local travel demand models are used to estimate VMT when they are available. For areas with no travel demand model, an estimated percentage for that area is established from the Statewide VMT/VFC model.

The Bureau of Automotive repair is in the process of placing BAR90 units in the field for the inspection and maintenance program. The BAR90 units will report vehicle and emission data directly to the CARB for database storage and analysis. The new system appears capable of tracking actual VMT of light-duty

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99 VMT was previously 45% of the apportionment formula, and under the new act it will be 70% (Sanchez, 1991).
vehicles and gasoline-powered heavy-duty trucks (now required to participate in the California Inspection and Maintenance Program). When the new Bureau of Automotive Repair data become available, this may be an important factor for the heavy-duty gasoline vehicle emission inventory estimates as these vehicles are now required to participate in the California Smog Check program.

**Development of the Speed Correction Factors for Light-Duty Vehicles**

The speed correction factors used in Mobile 4 and EMFAC are based upon the results from vehicle certification cycle tests, plus the results from additional cycle tests (Carlock, 1990). The Federal (FTP) test is conducted with an average speed of 16 mph, the New York City Cycle averages 7 mph, the fuel economy test averages 48 mph, and the CARB’s Jeff Long Cycle averages 65 mph (a number of other cycles are performed by USEPA, from 2.5 mph to 45 mph) (Carlock, 1990).

The speed correction factor is derived by plotting total cycle emissions against the average speed that the vehicles operate during the cycle test. When the results from testing under all of the cycles are plotted (i.e. for the same vehicle at different speeds), the speed curve is generated through regression analysis. From the density function, correction factors are established that may be applied to the FTP results to obtain the estimated emission rates at any operating speed.

The CARB methodology uses a different density function than the USEPA, based upon the USEPA data and additional CARB test data. The density function essentially represents the best polynomial fit from a scatter plot of the emissions rates versus average speeds under either:

\[
SF(S) = \text{EXP}(A + B*S + C*S**2 + D*S**3 + E*S**4 + E*S**5), \text{ or } \\
SF(S) = (A + B*S + C*S**2 + D*S**3 + E*S**4 + E*S**5),
\]

depending upon the model year and pollutant.
One potentially significant concern has been raised about the statistical derivation of the speed correction factors: regression analysis on existing grams/mile data may tend to unrealistically force a statistical fit at high and low speeds (Seitz, 1989 and 1991). In MOBILE4, the EPA now bases speed correction factors upon grams/hour data, using a first order regression fit (USEPA, 1988; Seitz, 1991). The CARB performs their regression analysis upon grams/mile data, using a fifth order regression fit.

Note also that the USEPA and CARB processes assume that the average operating speed under the testing cycles are representative of the emissions that would occur from the vehicle class at these average speeds. However, each cycle test has different characteristics in terms of stops, starts, cruising periods, and rates of accelerations. Given the recent tests that indicate acceleration activity may be a significant source of emissions (Groblicki, 1990; CARB, 1991b), it is possible that the emissions determined from each separate cycle are correlated to the acceleration activity within each cycle.

The problem that is encountered in using the aggregated speed emission relationships is that the relationships developed have no relationship to actual driving conditions. The speed correction factor for 50 mph, does not yield the emissions that would occur at 50 mph, but the emissions that would occur at an average speed of 50 mph if the vehicle was operated in an identical manner to the certification procedure (i.e. the same number of stops and starts and the same acceleration rates). Thus, the important uncertainty issues are:

1. Are the emissions determined during the test representative of the actual emissions that would occur under the same exact conditions in the field?

2. Is the driving cycle representative of actual driving cycles in the field?

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100 The average emissions in grams per mile resulting from the 7.5 mph New York city cycle are assumed to be representative of an average speed of 7.5 mph. Thus, emission factors reported in EMFAC for a specific speed are presumed to represent the emissions that would occur under a driving cycle with that average speed.
3. Are the emissions for the average speed representative of the average speed splits used in defining vehicle activity for the emission inventory calculations?

4. Is the test vehicle fleet representative of the on-road vehicle fleet?

An additional area of uncertainty is the emission rate for vehicles traveling in excess of 65 miles per hour (even if the cycle correction factors were deemed applicable to real life). Recent CARB tests for automobiles indicate that emission rates for all pollutants (including NOx) increase significantly at speeds greater than 55 mph (Long, 1990; CARB, 1991a).

It is not clear that the standard cycles and cycle correction factors can be used to establish accurate emission rates for the vehicle fleet.
Appendix E
Federal and State Engine Certification
Procedures and Requirements
HEAVY-DUTY ENGINE CERTIFICATION PROCEDURES

The USEPA and CARB have periodically implemented engine certification requirements for heavy-duty trucks. In essence, for a truck to be sold for use in the United States, or in California, the new engine must meet specific emission limits, as determined through standardized test procedures. The specific federal and State test methods are outlined below:

Federal

The Code of Federal Regulations contains the USEPA certification requirements applicable to specific model year heavy-duty diesel engines. The certification standards allow maximum average emission rates for the criteria pollutants, as measured under transient test conditions.\textsuperscript{101} For example, 40CFR86.085-11 requires that exhaust emissions from new engines of model year 1985 and later engines not exceed 1.3 grams of VOC, 15.5 grams of CO, and 10.7 grams of NO\textsubscript{x} per brake horsepower-hour. The Code of Federal Regulations contains numerous additional emission rate certification requirements for engines that were developed after 1985.

The federal test procedure is the transient test used to measure the average emissions in relation to a specified cycle of heavy-duty engine work output. The USEPA Engine Dynamometer Schedule for Heavy-Duty Diesel Engines defines the normalized engine revolutions per minute and applied torque in the form of a transient cycle.\textsuperscript{102} The test takes 1200 seconds, and the normalized torque ranges from 0 to 100\% of the maximum torque (as determined during the preparation of a USEPA measured maximum torque curve) at specific RPM rates listed in the test procedure. The test procedure also includes closed rack motoring segments,

\textsuperscript{101} Transient operating conditions are defined as the specific federal test procedure outlined in 40CFR86, Subpart N, and Appendix I, paragraph (f)(2).

\textsuperscript{102} In 1985, the transient test cycle replaced the old 13-mode steady state cycle for heavy-duty engine testing that had been in use since 1973.
basically using internal engine friction or the application of external torque to change motor speed.\textsuperscript{103}

Using the torque and RPM feedback, the brake-horsepower is integrated with respect to time for the hot and cold cycles. This produces a brake-horsepower value that is used in calculating brake specific emissions (40CFR86.1327-84 and 40CFR86.1342-84).

Because engine emission rates are noted to increase with accumulated VMT, the Federal Register outlines the methods that must be used in establishing what are known as deterioration factors 40CFR86.085-28. The deterioration factor is added to new engine certification test results to adjust the certification test result emission levels upward. The final calculated values are used to determine compliance with the certification standards.

Tests conducted by the USEPA of 22 in-use engines (model years 1979 and 1980) revealed that in-use emissions for engines with as many as 400,000 miles continued to comply with the new engine certification standards. Deterioration factors were developed for the calculation of the emission rates in MOBILE4, based upon the tests of the 22 engines plus certification-related data submitted by manufacturers. Unfortunately, the certification data used to develop the deterioration rates could not be reviewed as a component of this study.

State

The certification requirements in the state of California are very similar to those of the USEPA. The federal test procedure is used in the state certification program. The only apparent differences that exist are: 1) the final certification limits from some pollutants are lower in California (Appendix E), and 2) the state uses different deterioration factors.

\textsuperscript{103} "Motoring" means driving the engine by means of an electric motor or other source of outside power (Taylor, 1985a).
Appendix F
Examples of EMFAC Emission Rate Tables
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Units: Grams per mile
MCY: All

Notes:
- The table provides emission rates for various pollutants under different conditions.
- The data includes measurements for total organic gases, carbon monoxide, and oxides of nitrogen.
- The table compares emission rates for light duty autos, light duty trucks, medium duty trucks, and heavy duty trucks.
- The units are in grams per mile, and the data is presented for various speeds in miles per hour (MPH).
- The table includes data for NCA, CAT, and DIESEL types of vehicles.
## Table 1 (Contd): Running Exhaust Emission Rates at 75 Deg F

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### TIRE WEAR

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### FUEL CONSUMPTION (Based on Questionable Data)

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Appendix G
Baseline Emission Rates (Zero Mile)
Table G-1
Current Baseline Emission Rates
Total Organic Gases (TOG)
(g/mi)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering
adjustment. However, tampering effects are not
clearly defined.
Table G-2

Current Baseline Emission Rates
Carbon Monoxide (CO)
(g/mi)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering
adjustment. However, tampering effects are not
clearly defined.
Table G-3

Current Baseline Emission Rates
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(g/mi)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering
adjustment. However, tampering effects are not
clearly defined.
Table G-4

Current Baseline Emission Rates
Particulate Matter (PM)
(g/mi)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering
adjustment. However, tampering effects are not
clearly defined.
Appendix H
Deterioration Rates
Table H-1

Current Deterioration Rate
Total Organic Gases (TOG)
(g/mi/10,000 miles)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering adjustment. However, tampering effects are not clearly defined.
Table H-2

Current Deterioration Rate
Carbon Monoxide (CO)
(g/mi/10,000 miles)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering
adjustment. However, tampering effects are not clearly defined.
Table H-3

Current Deterioration Rate
Oxides of Nitrogen (NOx)
(g/mi/10,000 miles)

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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering adjustment. However, tampering effects are not clearly defined.
Table H-4
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Sources: USEPA (1985), Rates reflect zero tampering
CARB November (1986), Rates may include a tampering
adjustment. However, tampering effects are not
clearly defined.
Appendix I
A Discussion of Temperature, Altitude, and Humidity Correction Factors

Temperature Correction Factors

The fuel properties are related to the evaporation rate and the fuel combustion by-products. Evaporation is dependent upon the percentage of lighter end compounds in the fuel mixture. Temperature is the primary operating condition that affects the evaporation of fuels. As temperature increases, the evaporation of the lighter end compounds in the fuel mixture increases. Reformulated gasoline, such as Atlantic Richfield company's EC-1, are manufactured by removing the light ends such as butane and propane (as well as some of the more photochemically reactive olefinic compounds) to provide a gasoline that will evaporate more slowly and whose combustion by-products will be less influential in ozone formation.

When gasoline engines cool down, hot soak emissions are released. A hot soak is the evaporation of uncombusted fuel from the fuel injection or carburetion areas. Preliminary back-of-envelope calculations indicate that four minutes of idling are approximately equal to one hot start and hot soak in an automobile. However, no emission factors are available to compare idling to hot starts for heavy-duty diesel vehicles.

Temperature correction factors are not applied to heavy-duty diesel truck emission rates. Because the volatility of diesel fuel is extremely low, fuel evaporative emissions should be low and relatively unaffected by operating temperatures. With respect to combustion emissions, operating temperature is thought to have little effect upon exhaust emissions:

"The emissions of HDDVs [heavy-duty diesel vehicles] may be somewhat dependent upon temperature, but that dependence is thought to be much less for diesel vehicles than for gasoline vehicles. Also, the USEPA has no data on emissions from diesel vehicles at different temperatures. Therefore, the temperature
coefficients for HDDVs are all zeros, and result in a conversion factor [in Mobile4] of unity at all temperatures (USEPA, 1985)."

The fact that no data are available on temperature dependence of heavy-duty diesel vehicle emissions, indicates that inherent uncertainty exists.

Temperature is input only once per day in BURDEN/EMFAC. In other words, the BURDEN model pulls emission factors from the EMFAC temperature tables based upon a single temperature (i.e. only one time per day modeled). The problem here is that the temperature changes throughout the day in relation to cold starts and running evaporative losses. Although this factor is likely to be significant only for gasoline-powered catalytic converter-equipped vehicles, the temperature may play an important role in cold start emissions from diesel vehicles. No laboratory results are available at this time for the heavy-duty diesel vehicles.

**Altitude**

Altitude affects the density of the intake air into any internal combustion engine. The effects of the effects of altitude on emissions are not accounted for in the existing emission inventory. Although, these effects are expected to be small, the fact that altitude is coupled with heavy-loads and power enrichment in the Tahoe Air Basin and the South Coast AQMD Grapevine area may be significant. Additional research in this area might be considered.

**Humidity**

The NOx emission rates determined during the heavy-duty diesel engine test cycle are not corrected for humidity (USEPA, 1985). The question of whether NOx emissions should be corrected for humidity is very complex, although much more so for gasoline engines than for diesel engines. The humidity of the combustion air effects the combustion performance of the engine and may affect the emissions generated by the combustion process. For diesel engines, humidity affects the engine efficiency, due to a change in dry fuel-air ratio and a change in the thermodynamic
characteristics of the gases before and after combustion (Taylor, 1985b). Note that because the diesel engine employs compression ignition, the effects of humidity on diesel efficiency may not be significant:

"Although no test data are available, it seems safe to conclude that the low air-fuel ratios used for diesel engine humidity has little effect on indicated efficiency and therefore little effect upon performance (Taylor, 1985b)."

An increase in the humidity could affect the emissions of pollutants that result from combustion. The presence of water vapor may slightly decrease the combustion temperature as latent heat is absorbed by the water. Thus, in high humidity atmospheres, the production of NOx may be decreased slightly, although to what extent is unclear.
Appendix J
Proposed CARB Research Projects
Outlined in the September 1990 Public Meeting
(CARB, 1990e).
Public Meeting on the Emission Inventory Process

Table of Contents

I. Introduction

II. Presentation Summaries
   A. Point and Area Sources
   B. Motor Vehicle Sources

III. Public Comments and Suggestions

IV. Discussion of Significant Comments and Suggestions

Enclosures

I. Announcements and Agendas
II. Presentation Slides
III. Letters Received by ARB
IV. List of Documents Available
Report on the Emission Inventory Public Meeting

I. Introduction

The emission inventory staff of the Air Resources Board's (ARB) Technical Support Division and Mobile Source Division conducted a public meeting to discuss the criteria pollutant inventory program. The primary purpose of the meeting was to provide an opportunity for the public to comment on the inventory and express its views on priorities for future work. The meeting was held on September 4 and 5, 1990, in Sacramento, California. This report documents the exchange of information and views which occurred among meeting attendees and the staff's responses to the most significant comments and suggestions.

The meeting was organized in response to a growing level of public support for an improved emission inventory. Members of local air pollution control districts, industry representatives, and consultants have expressed a desire to contribute to the inventory development process with the purpose of producing a more accurate and useful inventory. This interest has been demonstrated through numerous written and oral comments and suggestions in the past. Recently, the inventory has become even more important with the enactment of the California Clean Air Act and the emission reduction requirements of the Act. This meeting provided a forum for discussing the inventory, its uses, and the need for improvement.

Each meeting day focused on specific components of the inventory: point and area sources on the first day and motor vehicle sources on the second day. In order to enhance understanding of the inventory program, the staff began each day with an overview of the inventory development process. Each presentation included a discussion on how the inventory process currently works, recent improvements to the inventory, current efforts and future areas of emphasis specific to the day's topic. After these brief presentations, there was an open discussion to entertain suggestions and answer questions.

The meeting proved to be productive for the staff, and feedback indicates that it was well received by the public. It is the staff's intent to continue the open dialogue process in the future through additional public meetings and perhaps small group discussions with those who are interested in specific aspects of the inventory. Additionally, the Emission Inventory Technical Advisory Committee, a group comprised of ARB and district inventory personnel who have discussed many of these issues in the past, will continue to do so in the future. Finally, as a direct result of the September meeting, the staff is developing an emission inventory plan which will outline a schedule for specific inventory improvement projects. We anticipate this plan will be available to the public after January 1991.
As noted above, the purpose of this report is to document the September meeting. The remaining discussion is presented as follows: a brief summary of the staff presentations; a summary of the written and oral comments received prior to, during and since the meeting; and a discussion of the comments which are deemed most significant by the staff and are judged to have the highest priority for incorporation into the near-term improvement program.

Additionally, the following items are enclosed with this report: the meeting announcements and agendas, the overhead slides used in the staff presentations, letters from the public, and a list of publications available from the Emission Inventory Branch of the ARB.

II. Presentation Summaries

A. Point and Area Sources

Presentations and discussions on the first day of the public meeting concentrated on point and area sources. First, an overview of the emission inventory process was presented. Then, specific inventory elements were discussed, including point sources, area sources, forecasting, and gridding and planning inventories. The following is a condensed version of each presentation. Copies of the overhead slides which were used in the presentations are included in the enclosures.

1. Emission Inventory Process Overview - The emission inventory is an estimate of the quantity of pollutants emitted over a period of time; it is not an actual count or measurement. These estimates are stored with other inventory information in the ARB's Emission Data System (EDS), which contains the baseyear and forecast databases and the gridding subsystem. Major categories of emissions include point sources, area sources and motor vehicle sources. Major tasks and responsibilities for compiling the inventory are shared by the ARB, districts, facilities and various supporting agencies. Information can be retrieved from EDS in a variety of ways such as specifying emitter type, geographic area or source category.

2. Point Sources - Point sources are sizable stationary emission sources (emitting 25 tons per year or more) at specific locations. Information such as facility name and location, device description and source emissions is maintained in EDS for each facility. All of this information is supplied by the districts. An emission estimate is calculated for each process at a facility using the process rate and emission factor. Recent improvements to the point source inventory include the addition of 10 to 25 tons per year point sources. Also, inventories will be published annually starting with the 1989 calendar year inventory.
3. **Area Sources** - Area sources are small sources not large enough to be considered point sources as well as sources that cover a large geographical area such as wildfires. There are approximately 200 area source categories. The responsibility for estimating emissions from these categories is divided approximately two thirds to one third between the ARB and districts, respectively. Recently, windblown dust emissions were added to the inventory and we are in the process of adding biogenic emissions. Temporal profiles have also been refined.

4. **Forecasting** - Emission forecasts are used to predict the magnitude of emissions in future years. Future year baseline emissions are determined by multiplying current baseline emissions by factors for the predicted growth rate and control effectiveness of current control measures. Growth categories are based primarily on Standard Industrial Classification (SIC) Codes or Activity Codes. Control effectiveness is determined by the district's and ARB's estimate of actual effectiveness. Backcasting to prior years is also done to update inventories as methodologies improve.

Recently the ARB published forecasted average annual emission trends for criteria pollutants for years 1975 through 2010 (by five year increments). A rule tracking system is being developed and will be completed in the near future.

5. **Gridding** - A gridded inventory is a set of records that is used as input to photochemical air quality models. The emissions are estimated on an hourly basis to approximate the episode being modeled, such as an August weekday in 1987. The emissions in a broad geographic area are apportioned into smaller areas, or grid cells. Point sources are gridded using facility and stack locations. Area sources, estimated by county and air basin, are gridded using spatial surrogates (population, employment, size of agricultural orchards, etc.). On-road motor vehicle emissions are gridded using a program called the Direct Travel Impact Model (DTIM). DTIM is a program that merges the network and highway assignment files from a transportation demand model, the composite vehicle emission rates from EMFAC, spatially and temporally resolved temperatures, and an extensive input parameter file to calculate emissions by grid cell by hour. Day-specific point source data for large facilities is frequently substituted for average daily emissions.

Recent improvements to gridded inventories include incorporation of unique area source disaggregation distributions for several air basins. Also, spatial disaggregations in multiple future years from South Coast Air Basin transportation models were included.

6. **Planning Inventories** - Planning inventories are a refinement of annual average inventories. Unlike annual average inventories which represent emissions as being equal every day of the year, planning inventories better characterize emissions that occur during periods of exceedances. Planning inventories differ from annual average inventories in the following four ways: 1) planning inventories are necessary only for those areas of the state that are designated as non-attainment for state standards and are prepared only for non-attainment pollutants, 2) point source emission estimates represent "average annual operating day" emissions
during the year, 3) area source emissions represent "average seasonal operating day" emissions, and 4) motor vehicle emission estimates represent "typical episodic day" emissions. Planning inventories are used for developing plans pursuant to the California Clean Air Act.

Planning inventories have been developed for 1987 as the base year and are forecasted for the years 1994, 1997, 2000 and 2010 using the same growth and control data as were used to forecast annual average emissions.

Several improvements to the inventory database which will affect planning inventories are anticipated in the near future. They include revised EMFAC and BURDEN data, point and area source climatic adjustment factors and regionally specific temporal profiles. EMFAC and BURDEN are described in Section B below.

B. Motor Vehicle Sources

Motor vehicle emissions were the focus of attention on the second day of the meeting. Presentations began with an overview of motor vehicle emission modeling, followed by a summary of CALIMFAC and emission factor adjustments, EMFAC7E and BURDEN7C changes, current and near-term projects and modeling changes. The following are abstracts of the motor vehicle presentations given by the staff of the ARB. Copies of overhead slides which were used in the presentations are included in the enclosures.

1. Motor Vehicle Emission Inventory Process Overview - The motor vehicle emission inventory, like the other major components of the emission inventory, is based on estimated emission factors and estimated activity. The ARB uses an emission factor model, EMFAC, and an activity model, BURDEN, to provide these estimates. A third model, CALIMFAC, provides basic emission rates to be input to EMFAC. CALIMFAC calculates base emission rates; EMFAC makes appropriate corrections to those rates and provides emission factors by operating mode. These emission factors are used in BURDEN, which supplies activity data for operating modes such as starts, running, and trip ends.

2. CALIMFAC and Emission Factor Adjustments - EMFAC7E, the latest version of EMFAC, incorporates a number of changes from its predecessor, EMFAC7D. One of the major differences is the development of base emission rates using CALIMFAC. CALIMFAC delivers to EMFAC two sets of rates - one with the effects of the vehicle inspection and maintenance (I/M) program and one without. This is a significant departure from the previous version in which I/M benefits were calculated outside of the EMFAC model. Speed and temperature correction factors have also been updated for EMFAC7E. The speed correction regime is extended significantly to 55 mph from the EPA's factors which only go to 55 mph. Temperature corrections are provided for evaporative emissions for the first time. Also included are running evaporative emissions with associated correction factors.

3. Changes to EMFAC and BURDEN - Because BURDEN produces the emission inventory using rates from EMFAC, BURDEN has been modified to use the new emission factors from EMFAC. BURDEN has been updated with new
activity data and includes running evaporative emissions and emissions from urban buses as separate categories.

A version of BURDEN has been developed that can produce planning inventories. These are temperature adjusted inventories that are produced by dividing a day into six periods with specific temperatures and rates of activity assigned to each of the periods. These inventories were developed to more accurately reflect emissions that occur on days of representatively poor air quality.

4. **Current and Near-Term Projects** - The ARB staff has committed to a number of projects to improve the inventory. These projects include the improvement of basic emission factors, correction factors and activity data. Many of the projects will be useful in revising the ARB's motor vehicle emission inventory modeling process (see No. 5 below). A list of the projects is included with the enclosures under Day 2, Section V, slides.

5. **Long Term Projects and Modeling Changes** - The ARB is proposing significant changes to the motor vehicle emission modeling process. Chief among the proposed changes are the development of a modal model, improved driving cycle or cycles, and a grid-based activity model. A model of this type could reflect conditions that are outside the domain of the Federal Test Procedure (FTP) driving cycle. The model could also be used to reflect driving conditions or patterns in sub-county sized areas and provide an inventory that would reflect county-specific conditions.

**III. Public Comments and Suggestions**

Table 1 is a summary of the written and oral comments received. Some of the comments were made several times and on both days. Some were discussed at length during the meeting; others were mentioned only briefly in letters and were not raised by the public during the meeting. In order to provide some structure to the comments, they are presented here in three major categories: general issues, point and area source issues including projections and gridding, and motor vehicle issues.

Within each category, the comments are prioritized to reflect the significance of the issue and the staff's commitment for further study based on available resources. The guidelines used in establishing priorities are as follows:

**Priority 1** - These are considered top priority projects and are either currently budgeted or are anticipated near-term (one to two years) improvements.

**Priority 2** - These are second level priorities and are anticipated to be addressed over the next three to five years.

**Priority 3** - These are third level priorities which have either already been addressed or for which adequate resources do not currently exist to support investigation during the next five years.
IV. Discussion of Significant Comments and Suggestions

A. Comments on Priority 1 Projects

The following discussion addresses the Priority 1 comments. These are the projects that are currently budgeted or are expected to be addressed within two years.

1. General

Emission Inventory Plan - The staff is committed to developing a multi-year inventory improvement plan with a public availability date in early 1991. We do not believe, however, that such a plan should be presented to the Air Resources Board for approval. As recognized by many of those who work with inventories, the inventory process and any plan related to it is a constantly evolving process with changing priorities and direction as new issues arise. It is not prudent to have to return to the Board each time a modification, however minor, is made.

Uncertainties and Validation Studies - The staff is in full agreement that a means for determining the level of accuracy or uncertainty of the inventory is desirable. Efforts to do this have been attempted by districts, consultants and the ARB in the past with little success. The size and complexity of the inventory precludes any single simplified approach. We are committed to further explore this issue in the near-term, recognizing that different approaches may be necessary for different source categories.

Special validation studies may help in providing some insight into the degree of uncertainty of the inventory. Such studies can apply to the entire inventory or to a specific component of the inventory. We are currently looking at the possibility of conducting one or more special studies.

Quality Assurance - The current budget year includes resources for expanding the quality assurance program conducted by the ARB. The emphasis will be on area sources and temporal data improvements. While improved quality assurance will not assist in quantifying the uncertainties in the inventory, it will improve the accuracy and thus reduce the overall uncertainty.
Emission Estimation Documentation - Improved and expanded documentation continues to be one of the top priorities in the emission inventory program. Although much has been documented (see Enclosure), more work remains. Two new documents, one on EMFAC and a second on area source methodologies, are expected to be released soon. Other documents that are being developed include documentation for BURDEN and a user's guide to EMFAC.

Emission Inventory Advisory Committee - The success of the September public meeting demonstrates that the continued public process is beneficial and advisable. The public forum serves as a valuable opportunity for exchange and open discussion, and the staff intends to periodically conduct additional meetings. We are not convinced, however, that a formal public advisory committee will provide benefits beyond those of the open meetings.

2. Point and Area Sources

Biogenic Emissions - The staff plans to incorporate into the inventory the data on biogenic emissions developed by the South Coast Air Quality Management District and data developed during the implementation of the San Joaquin Valley Study. A study to evaluate the biomass densities of certain high-emitting species is expected to be funded by the ARB during the 1991-1992 fiscal year. The data from that study will also be incorporated into the biogenic emissions estimation method.

Growth and Control Factors - A rule tracking subsystem of the forecasting system is being developed that can be used to track each district's rulemaking and the effectiveness of the implementation and enforcement of each rule. This subsystem will then be used to keep the forecasts current and accessible for use in tracking the 5 percent emission reduction required by the California Clean Air Act.

A number of data management companies compile various indicators for California which are used by major businesses in the state to forecast trends in the private sector. Information will be purchased and incorporated into the forecasting system to assist in keeping the forecasts current and responsive to economic changes in the state.

3. Motor Vehicles

Evaluation and Clarification of EDS, EMFAC and BURDEN - The staff is developing documentation for both EMFAC and BURDEN. A description of the EDS is contained in the "Air Pollution Emission Inventory Program," February 1988, which describes the ARB's emission inventory program.
**Transportation Models** - The staff agrees that better transportation models would provide better data for use in generating on-road motor vehicle emission inventories. However, in the two cases in which area-specific travel demand model data are used by the ARB for inventory estimates (South Coast Air Basin and San Diego Air Basin), the VMT data generated by those models agree reasonably well with that developed by using the Caltrans statewide model disaggregated to those specific areas.

**Vehicle Database** - The staff is planning to include additional model year vehicles in the vehicle distribution and, as part of the long range modeling strategy, to incorporate unregistered vehicles into the data base.

**Emission Factors and Driving Cycles** - As discussed at the public meeting, the staff's long range strategy for motor vehicle emissions modeling includes the development of modal emission factors that can be composited for a variety of driving cycles, and the development of more representative driving cycles. The long range strategy discussed at the meeting addresses a number of emission factor development topics that have either not been addressed in the past or only partially addressed.

**Validation** - The ARB staff is investigating the validation of the entire emission inventory as well as individual components of the inventory.

**Agricultural Engine Emissions** - As part of the regulatory development process, the ARB staff is developing updated inventories for this category as well as other off-road vehicles and other mobile sources.

**B. Comments on Priority 2 and 3 Projects**

As noted, projects that will be addressed in three to five years were assigned a priority 2 level. Projects that are not to be budgeted or which are already completed or well underway were assigned a priority 3 level. The following discussion addresses a number of these projects. We have not addressed all of them because many are still in the conceptual stages. All of the projects in priority 2 and 3 levels will be evaluated further as we develop the plan.

1. **Point and Area Sources**

**NOx Sources** - We have not designated this as a first level priority item because we believe this issue is already being addressed. Beginning with the 1989 inventory year, sources down to 10 tons per year are being incorporated into the point source inventory.

**Fugitive Refinery Emissions** - It is not clear exactly what is meant by this comment because little detail was provided. However, it is worth noting that one current project is designed to evaluate various climatic effects on specific point and area source categories. This includes looking at not only temperature but also wind and rainfall.
Dil Storage Tanks - Again, the exact issue here is unclear; however, a new method for estimating emissions from external floating roof storage tanks was released by EPA earlier this year and all districts have been provided a copy.

2. Motor Vehicles

Modular Modeling - As presented during the discussion of the ARB's long-term modeling strategy, the ARB staff is proposing extensive revisions to current methods. These revisions include separate modules for specific vehicle operating modes and kinds of vehicle activities.

High Emitters - As part of the long-range strategy, we are proposing to include estimates of the emission contribution of unregistered vehicles. These vehicles may be classified as high emitters. We are also testing emissions from "junkers" obtained from the Unocal old vehicle purchase program.

Gridding - The long-range strategy includes an element to provide emission estimates on a sub-county basis to reflect activity that may significantly deviate from the average such that the appropriate emissions factors can be applied.
### Table 1

<table>
<thead>
<tr>
<th>Discussion Category</th>
<th>Priority</th>
<th>Public Comments and Suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>1</td>
<td>Emission Inventory Plan - The ARB needs a published emission inventory plan. Several attendees feel that submittal of a prioritized plan to the Board is necessary. Also, a prioritized list should be made of area source categories which need further improvement.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Uncertainties - The ARB needs to commit resources to the determination of uncertainties. This should be a standard component of the inventory development process. Performance evaluation techniques should also be developed. In addition, the ARB needs to pursue reconciliation between the emission inventory and ambient data.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Validation Studies - Special studies should be undertaken to validate the inventory. Developing the means for performing mass balance calculations is one approach that should be pursued. Reconciliation of ambient air ratios to emissions ratios is another approach.</td>
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<tr>
<td></td>
<td>1</td>
<td>Quality Assurance - The quality assurance system needs improvement.</td>
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<tr>
<td></td>
<td>1</td>
<td>Emission Estimation Documentation - There is need for a published document which contains emission estimation techniques and guidelines.</td>
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<td></td>
<td>1</td>
<td>Emission Inventory Advisory Committee - An emission inventory advisory committee similar to the modeling advisory committee needs to be appointed.</td>
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<td></td>
<td>2</td>
<td>Day Specific Inventories - There was interest expressed in the preparation of day specific inventories. Contractors also would appreciate published guidance on the process. Day specific data should be collected at the same time as field studies.</td>
</tr>
</tbody>
</table>
Reconciliation - The ARB needs to pursue reconciliation between the criteria and toxics inventories.

VOC Reactivities - VOC reactivities need improvement.

Speciation - There was some discussion on the importance of speciation versus analysis of the magnitude of emissions. Attendees disagreed on the order in which these tasks need to be addressed.

Allowable Emissions - A complete account of allowable emissions should be included in the inventory.

Draft Inventories - The ARB should publish interim draft inventories as new data (including new source estimates) are available so that the data can be used in a more timely manner.

Planning Inventories - There should be a cautionary statement for running loss emissions in planning inventories because a small sample size was used to collect data.

Biogenics - Biogenic emission factors need refinement.

Growth and Control Factors - Growth and control factors are weak and need to be refined.

PM10 Inventory - The PM10 inventory needs further development. The effects of temperature on fugitive emissions should be determined.

New Source Review - New facilities should be included in forecasting. The ARB essentially 'grows' existing facilities by a certain factor; different controls may be present on existing and new sources. The New Source Review needs to be incorporated in some way.

Backcasting - The ARB should backcast inventories as methodologies improve.

NOx Sources - Small NOx area sources need to be converted to point sources.

Fugitive Refinery Emissions - The effects of temperature variations on fugitive refinery emissions need to be examined.

Oil Storage Tanks - Investigation of AP-42 assumptions for oil storage tanks is necessary.
Oil Well Emission Factors - Cyclicly steamed oil well emission factors may be too low.

Domestic Cooking - Domestic cooking emissions need to be inventoried.

Geogenics - Geogenic emission factors need refinement.

EDS, EMFAC and BURDEN - EDS, EMFAC and BURDEN should be evaluated and clarified.

Transportation Models - Transportation models need improvement to obtain reliable activity data.

Driving Cycles - Driving cycles need to be improved to reflect on-road driving habits. Manufacturers have confirmed that systems are calibrated to FTP conditions; off-cycle conditions must be addressed. Emissions from off-cycle power enrichment events (fuel dumping) need to be quantified.

Vehicle Database - All vehicles should be included in modeling (including >25 years of age and unregistered vehicles).

Emission Factors - The complete process for estimating motor vehicle emission factors needs thorough re-examination. Procedures for developing future emission factors need to be selected.

Validation - Operational validation of the model is needed.

Agricultural Engine Emissions - The ARB should develop estimates of agricultural engine emissions.

Modular Modeling - A modular modeling system is needed.

High Emitters - The contribution of high emitters to the motor vehicle emission inventory should be investigated.

Evaporative Emissions - Improvements should be made in the determination of evaporative emission processes.

Vehicle Miles Traveled - A better estimate of VMT needs to be produced.

Gridding - Improved gridded emission inventories should be developed for motor vehicles.
Data Units - Data should be developed on a per unit time, mass basis.

Motor Vehicle Emissions Speciation - Further ROG speciation is needed, as well as bag specific profiles.