PART5-TX1: TNRCC's In-House Tool for Estimating PM-10 from In-Use Vehicles

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ABSTRACT

The Texas Natural Resource Conservation Commission (TNRCC) has an in-house modification of EPA's PART5 model for use in estimating respirable particulate matter (PM-10) from vehicle exhaust. The update is named PART5-TX1 and this paper describes the new model.

To create PART5-TX1, the PART5 model was modified to incorporate the effects of emission control equipment deterioration for most types of vehicles. Relative to PART5, the revised model provides an improved estimate of "in-use" emissions because only emissions data from "in-use" vehicles were used to develop its predictive equations. The database used for PART5-TX1 is of chassis dynamometer data from over 600 light-duty cars and trucks and over 400 heavy-duty trucks and buses. The database is set up such that it can be easily updated and incorporated into the model as new in-use data are collected. Only direct exhaust emission factors were changed in PART5-TX1. No attempt was made to change assumptions about secondary particulate formation, brake or tire wear, and dirt re-entrainment.

In general, PART5-TX1 predicts higher fleet-average emissions than EPA's PART5. Other differences between PART5 and PART5-TX1 include:

- updated particle size distribution estimates;
- the ability to estimate the effect of fuel sulfur level;
- estimates for the effects of a simple, opacity-based inspection and maintenance program for diesels or a "smoking vehicle" program for gasoline vehicles; and,
- updated heavy-duty diesel vehicle conversion factors, vehicle registration distributions, and mileage accumulations (all from MOBILE6).

INTRODUCTION

Since the release of the PART5 model in the early 1990's, researchers and modelers have noted that its assumptions are based upon very little "in-use" data. Since the mid-1990's, there has been an increase in the studies which measure in-use particulate from mobile sources (i.e., the measurements were made on vehicles that had been used in the "real world," on chassis dynamometers, using a transient, loaded-mode test.). Several of these studies attempted to validate PART5 predictions (1, 2, 3, 4). They generally found that PART5 under-predicts total emissions, yet over-predicts sulfate emissions.

Stricter ambient particulate standards, recently enacted by EPA, will likely result in many more metropolitan areas falling out of compliance with the National Ambient Air Quality Standards (NAAQS). The Texas Natural Resource Conservation Commission (TNRCC) saw the importance of updating the model upon which strategies for obtaining and maintaining NAAQS compliance would be based. TNRCC felt that a sufficient amount of time had passed since the release of PART5, and that sufficient new data was available to allow a meaningful update to the PART5 model.

In deciding the best way to update the model, Eastern Research Group and TNRCC personnel discussed the merits and feasibility of recommendations from previous researchers. We also brainstormed new recommendations specifically for TNRCC modelers. The following items were selected for implementation in PART5-TX1.

- Calculate basic emission rates and deterioration rates from "in-use" data (using age instead of odometer to estimate equipment deterioration).
- Develop "engineering judgement" assumptions to fill gaps in the "in-use" data and structure model assumptions to be easily updated by modelers.
- Allow modeling typical inspection and maintenance programs for particulate by accounting for emitter categories (such as smokers and non-smokers for gasoline vehicles).
- Update primary sulfate emissions assumptions.
- Update other basic assumptions such as particle size distributions, conversion factors for changing heavy-duty emission factors from g/bhp-hr to g/mi., and vehicle miles traveled distributions.

We did not change model features that did not affect direct exhaust emissions of particulate. We found that not enough information was available. Also TNRCC modelers thought that other models and estimation techniques are more appropriate, especially for the secondary particulate formation and dirt re-entrainment estimates.

BODY

Sources of Emissions Data

Certification emissions values reported by vehicle and engine manufacturers to the EPA were not appropriate for this analysis. Certification measurements attempt to duplicate the effects of wear and aging on vehicles. However, they cannot truly duplicate many of the effects of age (e.g., road salt corrosion over many seasons, deterioration of rubber hoses by ambient ozone, poor maintenance habits, etc.). Therefore results from those tests were not included in the database for PART5-TX1.

Previous Research

This analysis considered only emissions measurements obtained using chassis dynamometer techniques for vehicles used in commercial or private service. Efforts were made to obtain as much in-use vehicle data as possible, however, much of the requested data was never received. We decided to proceed with the data in-hand and structure the model for easy updates. TNRCC could then update the model assumptions as they receive new data.

We identified several sources of in-use particulate emissions data. The vast majority of the data is for light-duty gasoline and heavy-duty diesel vehicles. Most of the data used in this analysis came from the National Renewable Energy Laboratory Database and the following sources: References 1, 2, 3, 4, 5, and 6.

Data Collected by Southwest Research Institute for This Study

To help augment data specific to Texas vehicles and to get more information about the effect of driving patterns on emissions, TNRCC wanted to test local vehicles for this project. We recruited four, in-use, heavy-duty, vehicles from a local business, the City of Austin and a San Antonio school district. They were tested at Southwest Research Institute (SwRI) in San Antonio and their data was combined with the data we obtained from the other sources.

Emission Factors From Empirical Data

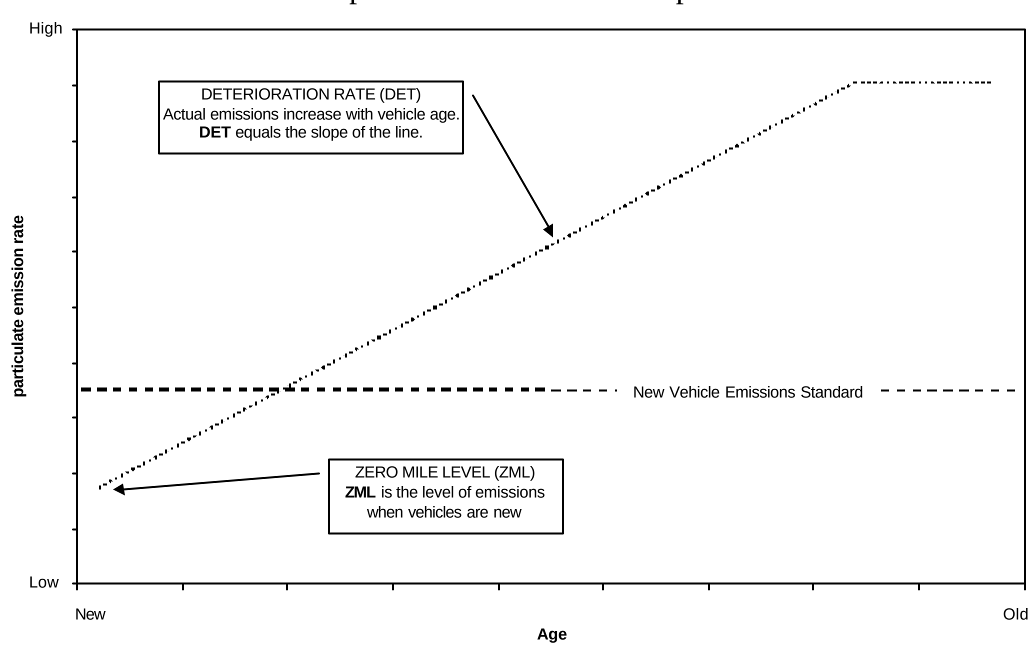
The PART5 model assumes that vehicle emission control systems do not deteriorate. A possible problem with the "no deterioration" assumption (other than it is incorrect) is that it may have a greater impact on the model predictions as the vehicle fleet gets cleaner, with newer models and better technology. Many newer technology diesel engines rely upon fairly complicated emission control systems to achieve their low, "new engine" emission levels. Although this equipment is extremely reliable, it is probably unreasonable to assume that a significant fraction won't experience deterioration during its useful life. Failure of new generation equipment will usually result in a larger percentage increase of emissions, compared to similar failures in older technology vehicles.

From the data described above we not only calculated new emission factors for the model, but also how those emission factors change as vehicles age. Using techniques like those employed by EPA in developing the MOBILE models, we calculated emission levels for new vehicles (commonly termed the "Zero Mile Level" or ZML). Similarly, we determined the rate at which emissions increase as vehicles age (commonly termed the "Deterioration Rate" or DET).

The Concepts of Zero-Mile Level (ZML) and Deterioration Rate (DET)

The concepts of ZML and DET are summarized in Figure 1, which portrays the effects of hypothetical vehicle deterioration. When a vehicle is new, its emissions should be at or below the levels dictated by new vehicle standards. As the average vehicle ages, its emissions equipment deteriorates, operating less and less efficiently and causing the emissions rate to rise.

Figure 1. Hypothetical case: the effect of vehicle emissions equipment deterioration and the concepts of ZML and DET for particulate emissions.



Wherever possible, we determined ZML and DET for each type of vehicle represented in the model and for each emissions technology group. This concept is summarized next, where we explain our model year groupings.

Determining Model Year Groups

To help determine ZML and DET from the empirical data, it is useful to group vehicles according to emission control technologies. To do this, we formed vehicle model year groups according to when the emission standards were changed. (New vehicle emission standards are the driving force behind emission control technologies.) Whenever particulate standards were phased-in over a few years, we chose the model year group cut-off to be the year when the standards came into effect for the majority of vehicles. Table 1 shows the model year groups, the applicable PM-10 standards, and the database sample size of each model year group that we used.

Table 1. Model Year Groups, their U. S. Highway Diesel Particulate Standards, and their sample size in this study.

HDDV Model Year Groups (Except Urban Bus)	**Federal PM Standards (g/bhp-hr)**	**Sample Size for This Study**
1990 and older	0.60	27
1991 – 1993	0.25	33
1994 and newer	0.10	67
Urban Bus Model Year Groups	**(g/bhp-hr)**	
1990 and older	0.60	41
1991 – 1992	0.25	53
1993	0.10	33
1994 – 1995	0.07	3
1996 and newer	0.05	24
LDGV Model Year Groups	**(g/mi)**	
1994 and older	none	659
1995 and newer	0.08	46
LDDV Model Year Groups	**(g/mi)**	
1994 and older	0.20	52
1995 and newer	0.08	3

Pre-processing the Empirical Data

Chassis dynamometer emissions are reported in units of “grams per mile” (g/mi), but heavy duty vehicle standards are set in units of “grams per brake-horsepower hour” (g/bHP-hr). For convenience, and to help normalize the effect of different drive cycles on emissions results, it was necessary to convert heavy-duty chassis dynamometer measurements to a “per brake-horsepower hour” basis. This was only necessary for heavy-duty vehicles since light-duty vehicles all used similar cycles and their standards are set in units of “g/mi.”

It is worth mentioning that this technique makes PART5-TX1 only appropriate for modeling diverse fleets. This is because many of the factors in the conversion are national fleet averages for each vehicle weight category. Thus, the closer the modeled fleet is to the national average fleet for each vehicle weight category, the more appropriate the model will be for the application. This is also true of PART5 and the MOBILE models.

To make the conversion from "g/mi" to "g/bHP-hr" we simply reversed the process used in the MOBILE model to convert "g/bHP-hr" to "g/mi." First it is necessary to determine the fuel economy (miles per gallon) of the vehicle from its emissions results. Then, data for developing the heavy-duty conversion factors in EPA's upcoming MOBILE6 model can be applied to finish the conversion. We will not give the details of the calculations here because of space constraints.

Calculating the ZMLs and DETs

After pre-processing the data, we analyzed trends in emissions to determine deterioration rates for each technology group (model year group). By plotting the data in terms of mileage and age, we determined it was best to express deterioration in terms of vehicle age. We believe this is true because odometer roll-over is not usually documented and odometer data transcription often has typographical errors. While this comparison did not conclusively prove that plotting emissions versus age is the best and only way to represent the data, we have encountered this phenomenon often enough to recommend the technique be used in this case, especially for older vehicles.

We did not entirely ignore mileage accumulation data. It was an important tool in verifying our age-based deterioration factors and in determining vehicle technology group ZMLs. The overall method for determining ZML and DET for a given technology group was as follows.

1) Determine ZML by looking at emission factors for younger vehicles. We set cutoff levels for vehicles with no deterioration at 25,000 miles or one year for gasoline vehicles and 50,000 miles or two years for diesel vehicles.
2) Using the ZML determined in step 1, calculate the age-based deterioration rate for each vehicle in the technology group using DET = (Measured Emission – ZML)/Age.
3) The technology group DET is calculated as the average DET for all vehicles in the technology group.

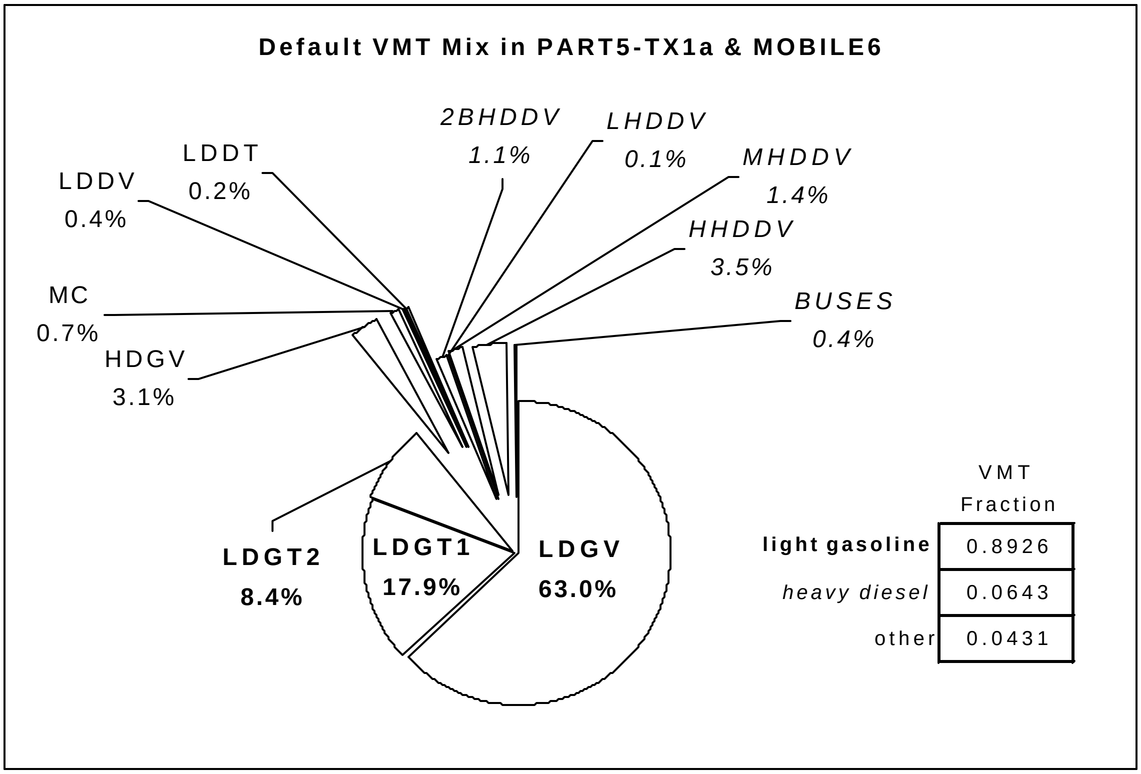
We visually evaluated where any changes in deterioration rate occurred for each vehicle group by looking at the general trends in the scatter plots. Except for the case of light-duty gasoline passenger cars, the data sets of each vehicle type and model year group were not robust enough to support a rigorous statistical evaluation of trends.

Major Vehicle Groups Versus Minor Vehicle Groups

Some vehicle groups affect the emissions inventory more than others. Therefore, assumptions for those vehicle groups are more important to the outputs of the model. For the purposes of this study we defined "major vehicle groups" as types of vehicles representing a relatively large fraction of the vehicle miles traveled for a typical fleet (e.g., light-duty gasoline cars) or types which have a high political profile (e.g., heavy heavy-duty diesel trucks). In other words, estimates of their emissions greatly influence the average predicted emissions for the fleet, or they are often considered by planners due to a high public awareness of them.

Figure 2 demonstrates the relative significance of the various vehicle groups in graphical form. The pie chart represents the default settings for total vehicle miles traveled of the fleet in the upcoming MOBILE6 model (and in PART5-TX1). Vehicle groups with a bigger piece of the pie have a larger influence on the average emissions of the fleet.

Figure 2. The relative importance of the vehicle groups: default vehicle-miles-traveled in PART5-TX1 and MOBILE6.



For the purposes of this study, we have defined light-duty gasoline powered vehicles (except motorcycles) and heavy-duty diesel vehicles as major vehicle groups. More of our effort went toward producing robust assumptions for the major vehicle groups than for the minor ones. In general, major vehicle groups were more sufficiently represented in the particulate emissions database than minor vehicle groups. So, the assumptions in the model about major vehicle groups are typically better supported than for minor vehicle groups.

The following table lists the final ZMLs and DETs for the major technology groups defined in this report. Note that DET values are changed to zero for each technology group, either as indicated by the database or at the end of the technology group's useful regulatory life. Our database demonstrated that on a fleet average basis, it is reasonable to assume that vehicles only deteriorate to a certain point, then hold steady for the rest of their use. Please refer back to Figure 1 to see the shape of a typical ZML-DET curve.

For those vehicle groups not well represented in the emissions database, we used engineering judgement to estimate ZMLs and DETs in the updated PART5-TX1. These ZML and DET values are easily updated by the modeler as new data becomes available.

Table 2. Major vehicle group ZML and DET values used in PART5-TX1.

HDDV Model Year Groups (Except Urban Bus)	**ZML (g/bhp-hr)**	**DET1 (g/bhp-hr)/yr**	**Flex Point Age (yr)**	**DET2 (g/bhp-hr)/yr**
1990 and older	0.35	0.0250	13	0
1991 – 1993	0.18	0.00436	5	0
1994 and younger	0.08	0.0357	3	0
Urban Bus Model Year Groups				
1992 and older	0.30	0.0137	9	0
1993	0.05	0.0133	9	0
1994 – 1995	0.05	0.0133	9	0
1996 and younger	0.06	0.0363	9	0
LDDV/T Model Year Groups	**(g/mi)**	**(g/mi)/yr**	**(yr)**	**(g/mi)/yr**
1994 and older	0.193	.0376	9	0
1995 and younger	0.135	.00612	9	0
LDGV/T Model Year Groups				
1994 and older	.00497	.00856	10	0
1995 and younger	.00413	.00336	10	0

Assumptions for Minor Vehicle Groups and Future Model Years

In general, the minor vehicle groups were not well represented in the database. It was necessary to make assumptions about these groups to represent them in the model. Those assumptions were based upon our knowledge of the vehicle types and similarities with other vehicle types that were well represented in the database. Since these vehicle types do not greatly influence the model outputs, assumptions about them are less critical. We do not describe them here due to space constraints.

To estimate the influence of future changes in emissions standards, we considered laws that have been promulgated and those that we judged likely to be enacted. The effects of these laws were incorporated into the default data files, which are called by the program. Since these assumptions will probably change and should be validated by the modeler, we do not describe them here. Modelers can change these assumptions in the default data files as they see fit.

Accounting for Emitter Categories to Allow Modeling Inspection and Maintenance Programs

It is useful for policy makers to be able to estimate the effects of programs for reducing pollution from high emitting vehicles. The PART5 model has no provision this. Current versions of I/M programs for particulate (the first of their kind) have identified these vehicles through visual means. In the case of diesel vehicles, an opacity measurement is usually taken using the SAE J1667 protocol. Gasoline vehicles with any visible smoke are typically considered to be high PM emitters. PART5-TX1 considers high emitters by the same criteria.

High-Emitter Assumptions for Diesel Vehicles

Several studies in recent years have attempted to correlate diesel J1667 (or similar) opacity with particulate emission level (7, 8). The task has proven difficult, with correlations ranging from weak to non-existent. Therefore, we decided to approach the first implementation of I/M programs effects in the PART5-TX1 model in a fairly simplistic manner.

In designing this feature of the model, we considered the design of current diesel inspection programs. Most of them require the SAE J1667 (snap acceleration) protocol. Typical cut points for failure of the

J1667 test were 40% opacity for 1991 to 1999 model years and 55% opacity for vehicles older than 1991. Only the J1667-based programs are modeled in PART5-TX1.

Assuming that inspection programs in the near future will continue to use similar pass/fail cut-points we said that vehicles which fail the inspection will have maximum J1677 opacity higher than 40% and that, when properly fixed, their maximum opacity will be reduced to less than 40%. Average particulate emissions for vehicles with peak opacities greater than 40% were about 60% higher than particulate emissions for similar vehicles with peak opacities less than 40%. This assumption is only valid when modeling diverse fleets of vehicles and will not be appropriate for application to small or uniform vehicle groups.

To model the effects of an opacity based I/M program, it is also necessary to estimate the occurrence of excessively smoking diesel vehicles in a typical fleet which is not subject to such an I/M program. Several researchers have attempted to estimate the fraction of diesel vehicles with high opacity which occur naturally in contemporary, no-I/M fleets (9, 10). Averages from these data sources range from 0.4 to 0.2 for studies from the mid-1990's to 0.1 to 0.08 for studies from the last two years. 0.1 is the average we used in PART5-TX1.

Since these results do not support a sophisticated interpretation, they are incorporated into the model in a simplistic way. However, analysis of the data does suggest that a more sophisticated model may be possible with more data. For example, analysis suggest that older vehicles may fail the opacity test more often than newer vehicles. For that reason, the PART5-TX1 model can be easily updated to incorporate new opacity data as they become available. There is provision in the model to specify the incidence of high opacity diesel vehicles and their emission factors relative to normal opacity vehicles for up to 18 model year groups, specified by the user.

High-Emitter Assumptions for Gasoline Vehicles

Modeling the reduction benefits of a program to identify and fix gasoline vehicles with high particulate emissions is subject to constraints similar to those of diesel vehicles. Recent studies have confirmed the intuitive assumption that gasoline vehicles with visible smoke in their exhaust emit more particulate than those without smoke (1, 3, 4). On the average, these studies indicate that a gasoline vehicle which emits significant visible smoke, also emits about 9 times more particulate than a non-smoking gasoline vehicle. As for diesel vehicles, this estimate would likely vary significantly for different model year groups. However, the current data set does not support an analysis of that detail. If future data is collected which allows that level of detail, the model has been structured to allow any modeler to update these assumptions for up to 18 model year groups.

Several researchers were identified who have estimated the occurrence of gasoline vehicles with visible smoke emissions in a typical fleet (1, 3). One study used both remote sensing and visual methods in Colorado and the other study used strictly visual methods in Southern California. The results ranged from 0.6% to 1.1% of the gasoline fleet emits visible smoke. The simplified assumption now in PART5-TX1 is that 1% of the fleet emits visible smoke. It can be changed if desired.

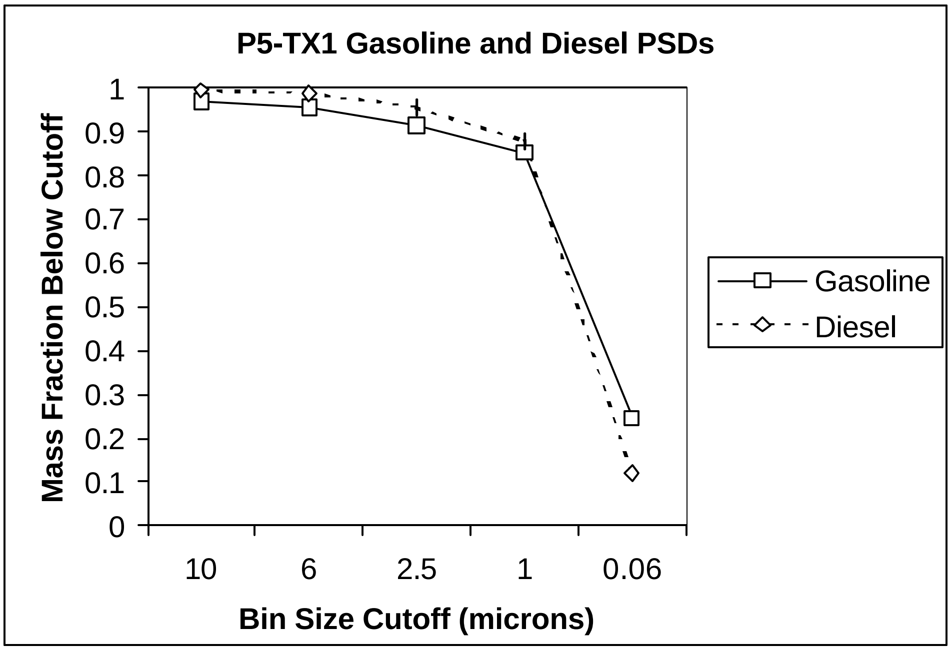
Updating Particle Size Distributions

Several recent studies have measured particle size distributions (PSD)(1, 3, 4) of gasoline and diesel particulate, so it is appropriate to update the PART5-TX1 model with the latest information. Judging from the results of these same studies, however, there is much variability in these measurements. Thus, this feature of the model is designed to be easily updated by putting the PSD data in external files which are read by the model. For PART5-TX1 only the PSD data for exhaust emissions are updated. Brake, road, and tire dust PSDs have not been updated from their PART5 values.

Data for all gasoline vehicles were combined and data for all diesel vehicles were combined to calculate new particle size distributions. There was no distinction made for vehicles of different weight classes or between gasoline vehicles with and without catalysts and those with three-way versus oxidation-only catalysts. At this point the data do not support the required analyses.

Figure 3 compares the updated particle size distributions for gasoline and diesel fuel vehicles. Although these new values are substantial changes from the PART5 values, we do not compare them to PART5 values because of the different ways they were represented in the models.

Figure 3. New particle size distributions for gasoline and diesel vehicles in PART5-TX1.



Updating Primary Sulfate Formation Assumptions

It has been generally found that PART5 over predicts the amount of sulfate particulate in the exhaust (3, 4). For example, Southwest Research Institute estimated that PART5 sulfate emissions estimates were about 9 times too high.

We incorporated the findings of these researchers by changing the way the fraction of sulfate is calculated in the model. The PART5 model estimates the weight of hydrated sulfuric acid emitted by the vehicle based upon the base sulfur level of the fuel (as dictated by the fuel standards) and the emissions control technology of the vehicle. The PART5-TX1 model first calculates a total particulate figure (using the in-use emissions data), then estimates the fraction of that particulate which is composed of hydrated sulfuric acid, based only upon the type of fuel and its sulfur content relative to a base fuel. Thus, if the modeled fuel has a sulfur concentration 20% less than the base fuel, sulfate emissions will also be 20% less.

From the results of the studies referenced immediately above we estimated that normally emitting gasoline vehicles emit about 1.5% of their particulate as hydrated sulfuric acid when using a base gasoline that is 300 ppm (by weight) sulfur. Diesel vehicles emit about 1% of their particulate as hydrated sulfuric acid when using a base diesel that is 350 ppm (by weight) sulfur.

These estimates are based upon results with significant scatter (gasoline estimates ranged from 0.7% of emissions to 2.3% of emissions and diesel estimates ranged from 0.7% to 1.2%). If future data reveal that these assumptions should be adjusted, the modeler can do so by changing the base fuel sulfur level assumptions. For example, if base sulfate emission levels should be raised by 5%, it would be accounted for by raising the base fuel sulfur concentration an equal percentage.

Overall Differences Between PART5 and PART5-TX1 Models

Table 3 compares the PART5-TX1 prediction for light-duty gasoline passenger cars (LDGVs) in the calendar year 1997 to similar predictions from the PART5 model. Results from several comparable studies are included for comparison. Relative to PART5, PART5-TX1 predicts higher emissions, which agree better with the empirical predictions of the other studies.

Table 3. Comparison of light-duty vehicle fleet exhaust PM emissions projected by PART5-TX1, PART5, and empirical studies.

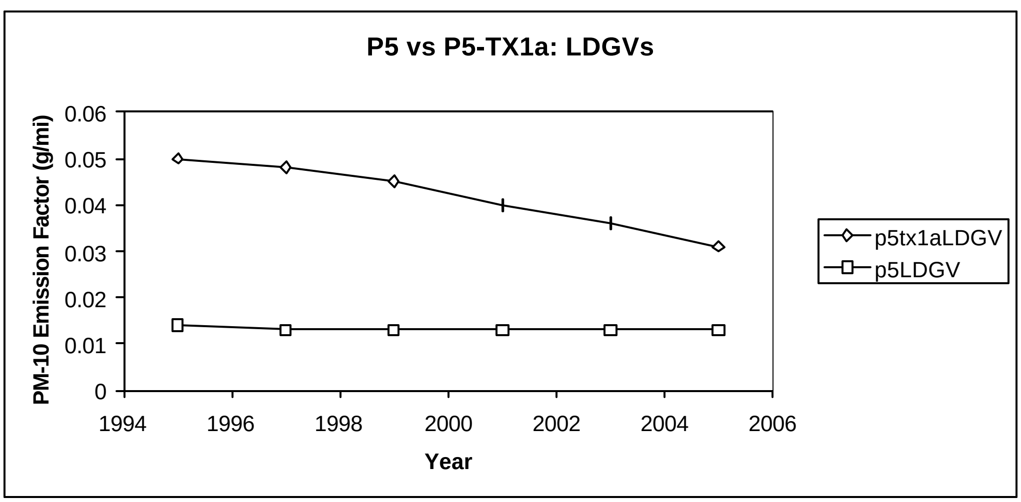
1997 Calendar Year (approx.) LDGV Fleet Emissions as Determined from Various Sources	
Source	**Emissions Rate**
Predicted by PART5-TX1	0.048 g/mi
Predicted by PART5	0.015 g/mi
Calculated by Whitney (4) (with smokers)	0.119 g/mi[a]
Calculated from Cadle (1) (with smokers)[b]	0.033 g/mi

[a] Estimate is probably high. Smoker emissions in the fleet average were apparently not weighted by VMT and are probably over-represented.

[b] VMT-weighted average was calculated by ERG from data in the referenced report. Study assumed smoker VMT = 0.9% of LDV Fleet VMT.

The graph in Figure 4 compares the old PART5 prediction for light-duty gasoline passenger cars (LDGVs) to those from the PART5-TX1 model.

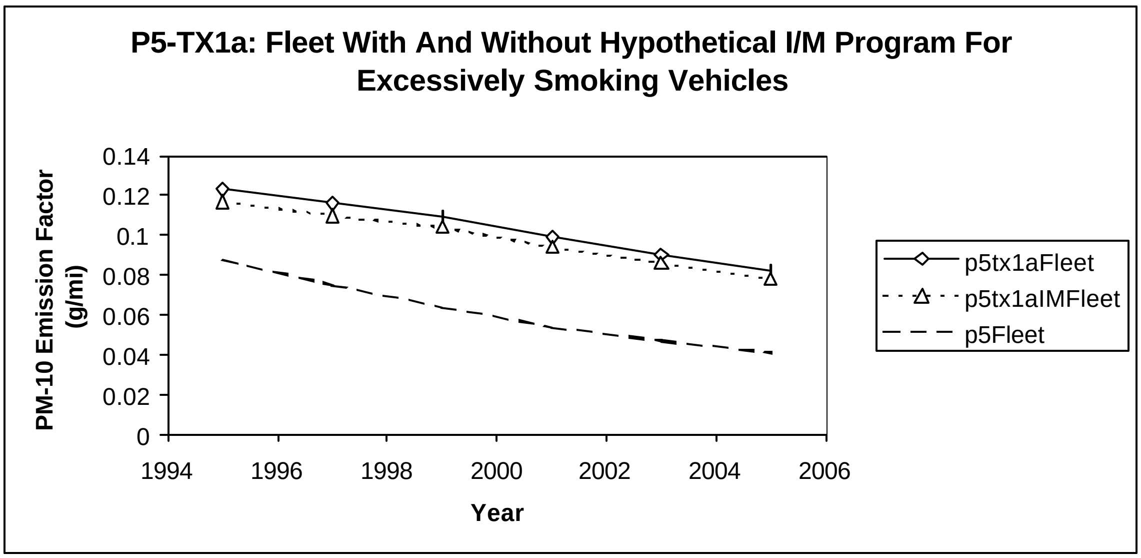
Figure 4. Comparison of light-duty vehicle exhaust PM emissions projected by PART5 and PART5-TX1.



Because we included recently developed empirical data, the comparison of results for LDGVs parallels the conclusions of recent studies: PART5 under-predicts PM-10 emissions from LDGVs (1, 3, 4). Also, by using real-world data to develop assumptions, the model now shows the "cleansing" effect of new technology vehicles entering the fleet. However, real world data had the opposite effect on heavy-duty diesel truck predictions. In that case, including the real world emissions data in the model has decreased the emissions predictions before 2001 and increased predictions after then. This effect is probably due to the low observed deterioration rates and the higher than expected "real-world" emissions of many late model HDDVs and Buses.

Figure 5 shows the results of a hypothetical case of an I/M program for smoking vehicles. The scenario models a typical fleet with and without an I/M program based upon the J1667 measurement for diesels and on the requirement that gasoline vehicles with visible smoke emissions must be fixed before being testing for gaseous emissions in the conventional I/M program. It is a simple scenario which assumes that approximately one percent of the fleet are excess smoke emitters, and that 80 percent of each kind will be found and successfully fixed, or otherwise have their excess emissions removed from the fleet emissions. The PART5-TX1a model predicts that such a program will reduce average fleet particulate emissions by about 5%.

Figure 5. Comparison of PART5-TX1 exhaust PM predictions for a typical fleet with and without an 80% effective smoke I/M program, and PART5 predictions.



CONCLUSIONS

PART5-TX1 is a more appropriate tool for estimating on-road exhaust emissions than PART5. It better reflects "real-world" emissions with better estimates of the effects of equipment deterioration and fuel sulfur level on emissions. Overall, the PART5-TX1 model predicts that vehicles will emit more exhaust PM than the PART5 model predicts. Differences in model predictions are especially significant when looking at only certain vehicle classes (e.g., light-duty gasoline).

PART5-TX1 can be used to predict the effects of diesel I/M programs that use the snap-acceleration opacity measurement. It can also predict the effect of "Smoking Vehicle" programs for gasoline vehicles.

PART5-TX1 is an "open" model, in the sense that the user can change model assumptions by changing text files called by the model as it is executed. This means that as new data are collected and more is learned about mobile source particulate emissions, PART5-TX1 can be easily updated.

Further improvements to basic features of PART5-TX1 are possible and desirable. Incorporating the effects of temperature and humidity on particulate emissions would be a large improvement to the model.

REFERENCES

[1.] Cadle, S.H., et. al. "Measurement of Exhaust Particulate Matter Emissions from In-Use Light-Duty Motor Vehicle in the Denver, Colorado Area," Final Report to CRC (Proj. No. E-24-1) by GM. 1998

[2.] Graboski, M.S. et. al. "Heavy-Duty Diesel Vehicle Testing for the Northern Front Range Air Quality Study," Final Report, Colorado State University Project. 1998

[3.] Norbeck, J.M. et. al. "Measurement of Primary Particulate Matter Emissions from Light-Duty Motor Vehicles," Final Report to CRC (Proj. No. E-24-2) by CE-CERT. 1998

[4.] Whitney, K. A. "Measurement of Primary Exhaust Particulate Matter Emissions from Light-Duty Motor Vehicles,"; Final Report to CRC (Proj. No. E-24-3) by SwRI. 1998

[5.] Cadle, S.H. et. al. "PM-10 Dynamometer Exhaust Samples Collected from In-Service Vehicles in Nevada," GM Research and Development Publication 8464. 1995

[6.] Cadle, S.H. et. al., "Particulate and Speciated HC Emission Rates from In-Use Vehicles Recruited in Orange County, CA," *Environ. Sci. Technol.*, 1997, 31:3405.

[7.] Graboski, M.S."title," *Proceedings of 8th CRC On-Road Vehicle Emissions Workshop*, San Diego, CA. 1998

[8.] Weaver, C. S. "Bangkok Particulate Study Task 4 Vehicle Emission Testing"; Final Report to World Bank by EF&EE, Inc. 1996

[9.] Gaflan, D. 2000. California's Air Resources Board, *telephone conversation between Andrew Burnette and Daryl Gaflan*.

[10.] Gourley, D. 2000. Vancouver's Air Care Program, *telephone conversation between Andrew Burnette and David Gourley*.

KEYWORDS

Mobile Source, Vehicle, Diesel, Deterioration
PM, Particulate, Smoke, Emissions
Emission Factor, Model, PART5, PART5-TX1