Texas
Transportation
Institute

Collection and Analysis of School Bus Emissions and Activity Data Using PEMS Equipment and GPS Units

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

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COLLECTION AND ANALYSIS OF SCHOOL BUS EMISSIONS AND ACTIVITY DATA USING PEMS EQUIPMENT AND GPS UNITS

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843

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BACKGROUND

The Texas Commission on Environmental Quality (TCEQ) works with local planning districts, the Texas Department of Transportation (TxDOT), and the Texas Transportation Institute (TTI) to provide on-road mobile source emissions inventories of air quality pollutants. TxDOT typically funds transportation conformity determinations required under 40 CFR part 93. TCEQ funds mobile source inventory work in support of the Federal Clean Air Act Amendment (CAAA) requirements, such as attainment of the National Ambient Air Quality Standards (NAAQS, 42 USCA 7409), and the study and control of hazardous air pollutants (HAP), including those from motor vehicles and/or motor vehicle fuels (as mandated under CAAA sections 202 and 211).

Texas emissions inventory development includes inventory development, methodology updates, data gathering, analysis and assessment, and planning for future requirements. In addition to meeting the basic inventory development requirements, Texas has consistently used state-of-the-art methodologies and up-to-date data sets to develop highly detailed, completely defensible on-road mobile State Implementation Plan (SIP) inventories. This level of commitment requires constant update of emissions inventory and control strategy reduction estimates to include the latest methodologies and data. Because of the lead time needed for data collection, analysis, and utilization, future data needs must be determined early enough for data collection to be accomplished in a timely manner.

While Texas currently is at the forefront in the use of locality specific data to develop the high quality inventories used in Texas SIPs, as new inventory development tools are released new opportunities are generated for improving the quality of Texas mobile source inventories. The release of MOBILE6/6.2/6.2.03 presented both a challenge to develop, and an opportunity to take advantage of, expanded local data inputs. The U.S. Environmental Protection Agency's (EPA) next generation mobile emissions factor model, the Multi-scale Motor Vehicles and Equipment Emission System (MOVES), will offer an even more comprehensive opportunity to use local data in the development of mobile emissions estimates. Although both models may be used without local information, extensive use of local data provides the ability to improve the performance of the photochemical modeling, and fine tuning the analysis of the impact of control strategies offers a strategic advantage for Texas air quality planners. TCEQ has already gathered and incorporated some new data sources into MOBILE6/6.2/6.2.03. Additional opportunities are available if new data sources can be assessed and implemented. To maintain the Texas leadership position in the development of mobile inventories, and to fully take advantage of the opportunities that the capabilities of MOBILE6/6.2/6.2.03 and MOVES offer, it is necessary to obtain more information concerning the local activity.

Currently, on-road mobile inventories are developed using activity information from travel demand models and emissions rate information developed using the EPA emissions factor model MOBILE6/6.2/6.2.03. The emissions data in MOBILE6/6.2/6.2.03 is based upon dynamometer testing over standard drive cycles. It is EPA's plan to replace MOBILE6 with a new emissions factor model based on in-use measurements of vehicle emissions using portable emissions measurement systems (PEMS). EPA has stated that being able to test vehicles, both on-road and non-road, while they are being operated in real world use, can advance the understanding of how, when, and where emissions are emitted. EPA is currently the lead agency for emissions factor measurement, however, they have encouraged broad participation in emissions measurement and standards development by universities and other agencies based on PEMS technologies.

Therefore, to fully utilize the capabilities of MOBILE6/6.2/6.2.03 and to prepare Texas to be in position to use MOVES effectively, new information concerning locality-specific in-use activity and emissions information for on-road and non-road vehicles is required. TTI has extensive background in data collection, data analysis, computer code development, emissions inventory development, travel demand modeling and transportation conformity. In Fiscal Year 2003, the feasibility and value of a PEMS-based on-board emissions measurement data collection program for Texas was demonstrated and TTI's capability in this area established. This work order provides for continuation of the implementation of the use of PEMS technology in Texas emissions inventory refinement strategy, as well as determining the potential of using PEMS technology for evaluating emissions control programs.

This work order provides for the equipping of a select group of representative school buses with state-of-the-art SEMTECH D/S portable emissions measurement system units to measure emissions and Global Position System (GPS) units to track location data. Data from the units were collected over several days during actual operations on the real world school bus routes and at a test track. The data were utilized to characterize school bus drive cycles and emissions profiles.

TASK DESCRIPTION

The accuracy of oxides of nitrogen (NOx) and volatile organic compounds (VOC) emissions estimates is critical in SIP modeling and control strategy development. This project is part of the ongoing efforts to ensure that mobile source emissions inventories are based on the most current information available. The information provided by this project will significantly advance current knowledge of school bus emissions and possible control techniques. The results of this project will put TCEQ in an advantageous position to address concerns about school bus emissions and to conduct additional data collection to determine the effects of retrofits, fuel formulations, school bus operating profile modification, school bus loads, or other emissions control techniques.

This task provides for the collection and analysis of school bus exhaust emissions and operating profile data. The data were be collected by equipping school buses with PEMS equipment and GPS units. General school bus fleet characteristics were determined and used to recruit school buses for data collection that represent the general fleet. The vehicles were driven over the normal school bus routes and on a test track at TTI. After the data were collected, the TTI research team developed and produced time sequential emissions estimates and activity profiles for the school buses. The team also developed corresponding MOBILE6.2.03-based emissions estimates using the current practice for on-road mobile inventory development. The PEMS and MOBILE6.2.03 emission estimates were compared.

To achieve maximum flexibility for subsequent analysis and utilization, the on-road mobile source emissions data and inventory estimates collected or calculated under this task, are provided in a format consistent with current PEMS data collection efforts for MOVES, to the extent that these have been determined by EPA. The format has been agreed upon by the TCEQ and TTI project managers. The following activities were completed under this task.

- Compile and document school bus fleet characteristics.
- Recruit school buses representative of the fleet identified in the first activity and equip the buses with GPS units. Drive the buses over their real world routes and collect GPS data. Collect or determine fuel characteristics, ambient conditions, and vehicle characteristics. Use the real world route data to establish typical school bus drive cycles.
- Equip the same, or a similar group, of school buses with PEMS equipment and GPS units. Operate the buses at the TTI test track using the typical drive cycle(s) determined in the previous activity. Determine fuel characteristics, ambient conditions, and vehicle characteristics.
- Analyze all the PEMS and GPS data from the real world routes and test track. Determine the emissions from the buses for a typical drive cycle and the emissions characteristics for notable school bus operating modes.
- Using the fuel characteristics, ambient conditions, and vehicle characteristics, develop an inventory using MOBILE6.2.03 and standard inventory development practice. Compare the emissions measured by the PEMS equipment and the emissions estimated using MOBILE6.2.03.
- Prepare emissions estimate summary files for each school bus activity mode and for the representative activity profile identified under the second activity. The emissions estimates summary files will be consistent with the capability of the PEMS technology to provide second-by-second emissions, engine operating parameters, and ambient conditions.
- Prepare documentation, complete and self contained, including electronic data files, consistent in format and level of detail in the latest TTI emissions estimation reports.

DELIVERABLES

Deliverables are in an informal Technical Note format (a narrative in memorandum format which explains the task, the approaches used, and the findings) provided to the Project Manager in WordPerfect format and supported by electronic document files. (There are no FORTRAN source code and executable files associated with this task.) Five copies are provided. One of the copies is a loose-bound original suitable for copying. Electronic copies of all materials related to the task report, to document results and conclusions (e.g., data, work files, text files, etc.), or developed as work products under this contract were supplied at the conclusion of the project or earlier, as requested by the TCEQ staff. CD-ROM or other electronic media are used to record the data and supporting documentation.

ACKNOWLEDGMENTS

This document reports the results of emissions testing performed by a team of TTI researchers. Josias Zietsman, Ph.D. was the leader of the team. He was assisted by Mohamadreza Farzaneh, Ph.D., Ed Brackin, Mark Ojah, A. J. Rand, and Meghan Wieters, all of TTI.

A number of organizations and individuals contributed to this effort. The support of the Caldwell Independent School District (ISD) was critical. Randall Berryhill, Bill Broaddus, Pam Nichols, Henry Washington, Craig Ayers, and Rhonda Homeyer were especially helpful. Technical support was provided by John Storey and Doh-Won Lee, of Oakridge National Laboratory. The fuels used for testing were provided by Valero's Three Rivers Refinery and JAM Distributors.

Martin Boardman, of TTI, provided the comparison of PEMS-based in-use emissions rates and MOBILE6.2.0.3-estimated emissions rates. Dennis Perkinson, Ph.D., of TTI, is the principle investigator for this project. Mary McGarry-Barber is the TCEQ project manager.

INTRODUCTION

Exhaust emissions are related to vehicle operation characteristics (e.g., from a cold start, in idle, cruising, accelerating, decelerating). Vehicle exhaust emission rates thus differ by drive cycles (speed-time curves) comprised of these sucomponents in varying proportions depending on the typical vehicle use and driving conditions. MOBILE6, however, does not include options for modeling heavy-duty vehicle emissions rates for different drive cycles. The MOBILE6 heavy-duty diesel vehicle (HDDV) grams per mile (g/mi) emissions levels are derived from heavy-duty diesel engine (HDDE) certification test emissions data (*1*). The standard dynamometer test cycle in the heavy-duty engine (HDE) certification procedure (transient engine federal test protocol [FTP]) was developed to reflect congested and non-congested urban and freeway driving behavior, with a cold start and a hot start. The transient engine FTP-based MOBILE6 emissions rates, however, may not necessarily be characteristic of select in-use vehicle applications. Drive cycle is one major factor among several factors that affect the production and the estimation of on-road vehicle exhaust emissions.

This study compares average exhaust emissions rates developed using second-by-second in-use emissions data acquired from diesel school buses using a PEMS, to corresponding MOBILE6 estimations. PEMS tests were performed for a select set of five buses representing the typical diesel-fueled Texas school bus fleet under typical operation, powered by two different TxLED fuels, during Summer 2006. NOx, HC, and CO emissions estimates were developed for the comparison. The study showed that the MOBILE6 emissions rates estimated for the Texas diesel school bus fleet are all significantly higher than the emissions rates produced by the sample fleet as measured with the PEMS.

Development of the emissions rates using PEMS is first discussed followed by MOBILE6 emissions rate development, comparison of the results, discussion of differences, findings and conclusions.

PEMS-BASED IN-USE EMISSIONS ESTIMATES

Development of PEMS-based vehicle exhaust emissions estimates for this analysis required selection of test vehicles representative of the Texas diesel school bus fleet, development of school bus-specific drive cycles, development of a test sequence and protocol appropriate for acquiring in-use emissions data from buses powered by different fuels, execution of the test runs (acquisition of in-use vehicle data via PEMS unit and associated equipment), and processing of the collected data.

These task activities were performed by the TTI research team in conjunction with the separate Texas diesel school bus emissions study sponsored by and documented for the Capitol Area Council of Governments (CAPCOG). The CAPCOG study report (*2*) was the basis for much of the detail, including excerpts, in this section.

The following sections summarize the test site, dates and conditions; test vehicles; test fuels; drive cycles; test equipment, test protocol, test data, and emissions results.

Test Site, Dates, and Conditions

The emissions tests were performed at the Riverside Campus of the Texas A&M University System, located in Bryan Texas. This 2,000-acre former Air Force base includes a roadway network and several idle aircraft runways on which the buses were driven for emissions testing.

The testing was performed over the period July 11 through July 14, 2006 during the daytime from around 8:00 a.m to 4:00 p.m. The average ambient conditions for the test period ranged from temperatures in the high-70s to mid-90s (degrees Fahrenheit) with relative humidity in the mid-40s to low-90s (based on National Climatic Data Center [NCDC] weather station data from the nearby Easterwood Airport in College Station).

Test Vehicles

Five diesel school buses were tested, representing a sampling of the Texas fleet. Each bus belonged to a model year group designed to reflect different control and engine technology categories, as adopted from TTI’s report *School Bus Emissions Reduction Program*, prepared for TxDOT (*3*). The CISD provided the buses for the study. Table 1 lists the individual test buses by model year, their represented model year groups, and estimated fleet shares.

Table 1
Test Buses, Represented Model Year Groups, and Fleet Distribution

Test Bus - Model Year	Bus Number	Group Represented	Percent of Texas Fleet[1]
1987	Bus 3	1978-1989	24%
1990	Bus 21	1990-1993	17%
1997	Bus 20	1994-1998	28%
2000	Bus 30	1999-2000	14%
2004	Bus 6	2001+	17%

[1] Texas Nonattainment and Early Action Compact (EAC) area fleet distribution estimates from TTI's School Bus Emissions Reduction Program study (*3*).

All the buses were equipped with in-line, six-cylinder International engines (Series D466 and D466E). All buses were type C's based on their passenger seat capacity (*4*). Type C school buses typically range between 23,500 to 29,500 lbs. gross vehicle weight rating (GVWR) (*5*). Each bus was loaded with 56 50-lb. sand bags (2,800 lbs.) to replicate an average loading situation (approximately equal to 30 children on-board).

Test Fuels

The tests were performed for the following two fuels:

- Fuel 1: TxLED specification fuel provided by Valero's Three Rivers Refinery; and
- Fuel 2: TxLED compliant fuel provided by JAM Distributors.

Critical fuel property values from the certificate of analysis provided with each of the two fuels tested are provided in Table 2. The fuel provided by Valero's Three Rivers Refinery was formulated to TxLED cetane number and aromatic HC content value specifications, and the JAM Distributors fuel was considered TxLED compliant by alternative means within the TxLED rules (*6*). Both fuels were in the ultra low sulfur diesel fuels category.

Table 2
Test Fuel Properties

Property	**Fuel 1 (Valero's Three Rivers Refinery)**	**Fuel 2 (JAM Distributors)**
Cetane Index	55.5	45.1 - 45.6
Aromatics, vol%	5.24	34.0
Sulfur, ppm	0.30	5.0

Drive Cycles

TTI researchers developed two drive cycles for this study, one each for rural and urban areas. The drive cycles were developed to reflect typical school bus driving, to be easy to follow, and to fit the available test track.

Prior to emissions testing, four CISD school buses were equipped with GPS units for a complete school day to track morning and afternoon bus routes. Two bus routes covered mainly rural areas, while the other two bus routes serviced urban areas. Researchers analyzed the speed profiles of all the buses and each cycle was separated into sub-cycles corresponding to different driving conditions. Each sub-cycle was further examined and average time spent in cruise, average speed, average idle duration, number of stops, and total time spent in the sub-cycle was calculated. This information was then used in conjunction with the synthetic cycle developing method illustrated by Dion et al. (*7*) and the constraint of the maximum available straight test track (6,000 ft.) to build the drive cycles. Figures 1 and 2 show the developed cycles used in this study for the rural and urban conditions, respectively.

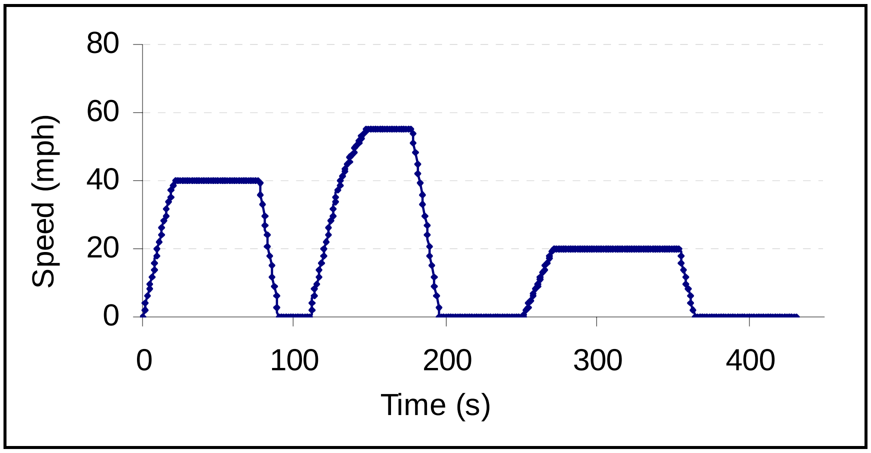

Figure 1. Synthetic Driving Cycle Representing Rural Driving Conditions *(2)*.

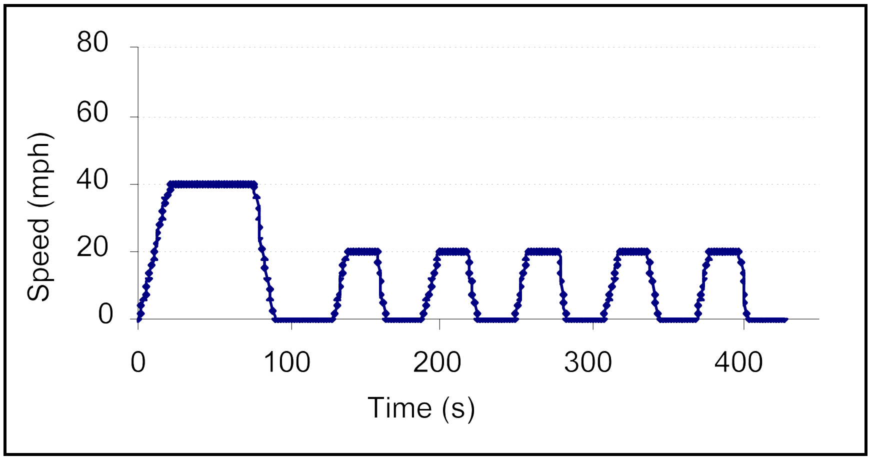

Figure 2. Synthetic Driving Cycle Representing Urban Driving Conditions *(2)*.

Both cycles consisted of three components; 1) cruising; 2) acceleration and deceleration; and 3) idling. The cruising portion of the rural cycle included a 40 mph cruise segment, a 55 mph segment, and a 20 mph segment. The 55 mph component reflected driving on a highway. The 55 mph maximum speed is set by law and some of the buses were equipped with a governor that does not allow the bus to go faster than 55 mph. The 40 mph element represented driving on rural arterials and the 20 mph component represented driving conditions on rural access roads (possibly dirt roads). The cruising part of the urban cycle consisted of a 40 mph component for urban arterials/streets and five short 20-mph elements reflecting driving short distances in a neighborhood and picking up schoolchildren.

Since only one driver was used in the test, the driver's natural acceleration and deceleration behavior was considered close to real world driving behavior. The driver was instructed to accelerate and decelerate as he/she would usually do while safely driving on a street or highway. The idling portions of the cycles reflected the amount of time that buses remained idle due to traffic control, congestion, and picking up children. A researcher on board the bus provided instructions to the driver for following the target driving profile. These instructions included: 1) the starting of acceleration and the target speed; 2) the time interval of each cruising speed and when to begin deceleration; and 3) the duration of idle period. The researcher was checking the speed at each step periodically to ensure that the driver was following the instructions.

The relative split between urban and rural area vehicle miles traveled by Texas school buses is 72 percent and 28 percent, respectively, as indicated in TTI's study of school bus emissions reduction programs (*3*). These proportions were used to combine the urban and rural cycle emissions into the Texas representative emissions rates.

Test Equipment

The PEMS unit used in this study was the state-of-the-art SEMTECH D/S unit manufactured by SENSORS Inc. The SEMTECH D/S unit includes a set of gas analyzers, an engine diagnostic scanner, a GPS, an exhaust flow meter, and embedded software.

Gas analyzers measured the concentrations of NOx (NO and nitrogen dioxide[NO_2]), total HC, CO, carbon dioxide (CO_2), and oxygen (O_2) in the vehicle exhaust. The engine scanner was connected to vehicle engine control module (ECM) via a vehicle interface (VI) and provided speed, engine speed (RPM), torque, and fuel flow. SEMTECH D/S used the Garmin International, Inc. GPS receiver model GPS 16 HVS to track the route, elevation, and ground speed of the vehicle under test on a second-by-second basis. The SEMTECH D/S used the SEMTECH EFM electronic exhaust flow meter to measure the vehicle exhaust flow. The SEMTECH D/S and the post-processor application software used this exhaust mass flow information to calculate exhaust mass emissions for all measured exhaust gases. The SEMTECH D/S used embedded software, which controlled the connection to external computers via a wireless or Ethernet connection, to provide the real-time control of the instrument. A Panasonic Toughbook laptop was used to connect to the SEMTECH D/S and to control the unit.

Test Protocol

The study team developed a test protocol that would provide the best opportunity to test emissions differences resulting from using different diesel fuels. The effect of fuel was captured by driving the test vehicles powered by Fuel 1 on the test track according to the synthetic rural and urban cycles, and then repeating the test runs for the test vehicles powered by Fuel 2. To maintain consistency between each run, a professional school bus driver working for CISD was used for all the test runs. Each vehicle/fuel/drive cycle combination included three runs and for each run the emissions, engine, and speed data were collected on a second-by-second basis. There were a total of 60 runs for the analysis (3 runs x 5 buses x 2 fuels x 2 drive cycles = 60). All buses were warmed up for at least 20 minutes before each run.

Test Data

The data recorded by the SEMTECH D/S unit were in second-by-second format. From the array of information that the SEMTECH D/S unit recorded in its output (emissions, ambient conditions, and vehicle parameters) the following information was extracted and used in this study:

- engine parameters (if a VI was available) such as engine speed, throttle position, and engine load for data quality checking;
- second-by-second vehicle speed from GPS in mph; and
- emissions mass rates in grams per second (g/s).

The data were then cleaned and observations that were not part of the desired drive cycles were removed. The length of the idle segments for each section of the cycles were examined and the extra records (i.e., the extra data recorded beyond the number of seconds in target driving cycles) were eliminated to provide cycles which were comparable to each other.

Texas Representative Diesel School Bus In-Use Emissions Rates

The NOx, HC, and CO emissions mass rates (g/s) were converted to accumulated emissions rates (g/mi) for each run and cycle. The individual bus rates were combined for each test cycle using the fleet fractions presented in Table 1, and the Texas urban and rural school bus VMT proportions (72 percent urban, 28 percent rural) were used to combine the urban and rural fleet average emissions rates into Texas representative emissions rates.

Table 3 and Table 4 summarize the resulting Texas representative diesel school bus in-use emissions rates for the two TxLED fuel, along with Texas representative school bus average idling emissions rates (mg/s).

Table 3
Texas Representative Diesel School Bus Fleet In-Use Tailpipe Emissions Rates[1] –
TxLED Specification Fuel (Valero's Three Rivers Refinery)

Pollutant	Cycle (g/mi)	Idle (mg/s)
NOx	3.151	7.502
HC	0.259	0.628
CO	0.687	1.269

[1] Composed across test fleet and urban/rural drive cycles (drive cycle composite average speed is 18.6 mph).

Table 4
Texas Representative Diesel School Bus Fleet In-Use Tailpipe Emissions Rates[1] – TxLED Compliant Fuel (JAM Distributors)

Pollutant	Cycle (g/mi)	Idle (mg/s)
NOx	3.200	7.507
HC	0.261	0.649
CO	0.811	1.499

[1] Composed across test fleet and urban/rural drive cycles (drive cycle composite average speed is 18.6 mph).

Appendix A includes a summary of the average fleet in-use emissions rates for the two TxLED fuels by individual drive cycles along with the average idle emissions rates and average emissions rates for the stable cruising speeds within each of the drive cycles.

MOBILE6 EMISSIONS ESTIMATES

The approach with MOBILE6 was to develop the test case emissions rates following current emissions inventory procedures. This was performed for the most part with a few deviations to include: producing emissions factors only for the model years of interest (i.e., five test bus model years) and combining them externally to produce the fleet average results (rather than the typical internal model application of travel fractions by 25 vehicle ages); modeling emissions factors only for the average speeds of interest (rather than developing detailed emissions factors for all MOBILE6 speed bin average speeds); and modeling 24-hour rates (since the heavy-duty diesel by-model-year emissions rates for single average speeds produced by MOBILE6 do not vary by hour). Key average speeds selected for the comparison were the Texas representative (urban/rural composite) drive cycle average speed and 2.5 mph (needed for idle emissions rates calculations).

The steps in producing the MOBILE6-based representative Texas diesel school bus fleet emissions factors included identification and acquisition of appropriate model input parameter values, development and external application of model year-specific NOx correction factors, combining individual model year results into fleet averages, and calculation of idling emissions rates.

The information used in the development of the emissions estimates for this analysis included:

- emissions source: analysis was limited to diesel engine school buses;
- pollutants analyzed are total hydrocarbons (HC), carbon monoxide (CO) and NOx;

- emissions for each activity scenario were developed on a time scale agreed to by the TCEQ and TTI project managers;

- the vehicles used in the study were diesel school buses. The selected test vehicles were representative of a general school bus fleet. All emissions related vehicle characteristics were recorded as part of the data collection process;

- the fuel source is noted in the report. Fuels compliant with both the Federal Ultra Low Sulfur Diesel and the Texas Low Emission Diesel (TxLED) fuel requirements were used. Fuel characteristics were provided by the supplier. These fuel characteristics were used when developing MOBILE6.2.03 based emissions estimates;

- Emissions Factor Model: the latest model officially released by EPA, MOBILE6.2.03 (September 24, 2003 release), was used to develop the current practice emissions estimates for school buses to compare to the PEMS emissions data;

- climate inputs: temperature, humidity, barometric pressure, sunrise/sunset times as agreed upon with TCEQ, consistent with ambient conditions at the test site, were used to develop the current practice emissions estimates;

- registration distributions: registration distributions consistent with the age distribution of the test vehicles were developed and used;

- state programs: no inspection and maintenance (I/M) or anti-tampering programs (ATP) were modeled;

- FMVCP: effects of all federal motor vehicle control programs for 2006 were modeled;

- HDDV defeat device and mitigation programs: these inputs do not effect the results for school buses, therefore MOBLE6.2.03 default inputs were used;

- VMT: actual drive cycle VMT was used; and

- VMT mix: not needed.

MOBILE6 Basic Emissions Rates

The basic exhaust emissions rates in MOBILE6 consist of a zero mile level (ZML) rate (g/mi) and an additive deterioration rate (DR) based on accumulated miles (g/100,000 mi). The EPA's method for development of heavy-duty diesel HC, CO, and NOx basic emissions rates pertinent to this analysis, summarized below, is provided in the MOBILE6 technical document on update of heavy-duty emissions levels for model years 1988-2004 (*1*).

MOBILE6 basic exhaust emissions rates for HDDVs are based on emissions data collected from HDE certification tests. Manufacturer's perform FTPs for different engines and model years as required to certify new engines to federal emissions standards. The EPA developed

FTPs for HDEs (*8*) rather than for heavy-duty vehicles (those exceeding 8,500 GVWR), since HDEs are used for many different applications. Under highway HDDE certification requirements, HDDEs are tested on engine dynamometers, using the HDDE FTP transient cycle (*9*). EPA developed this cycle to account for typical heavy-duty truck and bus activity on roads in and around urban areas (*10*). Manufacturers provide HDDE certification data (including new engine ZML and additional deterioration at the regulatory useful life mileage) to EPA in units of grams per brake-horse power hour (g/bhp-hr).

The primary HDDE test fuel (as specified in 40CFR86.1313) is commercially designated as Type 2-D grade, or the predominant in-use fuel. The CFR test fuel specifications provide fuel property ranges that change by model year group. For example, the specified cetane number range for 1991-1997 model years is 40-48, with the upper limit changed to 50 for 1998 and later model years. The sulfur content specified is 800-1200, 300-500, and 7-15 ppm for model years 1991-1993, 1994-2006, and 2007 and later model years, respectively. Aromatics content, however, is unchanged for 1991 and newer model years, specified as a minimum of 27 percent by volume.

The test specifications for ambient conditions (40CFR86.1330) generally indicate: ambient and intake air should be 77 degrees Fahrenheit plus or minus 9 degrees Fahrenheit (for engines with temperature dependent emissions control devices, otherwise temperature should be greater than 68 degrees Fahrenheit); barometric pressure during test procedure should not deviate more than 1 inch Hg from initial value; no control of air humidity is required. NOx emissions values, however, must be corrected to reflect a standard of 75 grains of water per pound of dry air (40CFR86.1342-90(8)(i)).

EPA used newly available HDDE certification data (for model years 1988 through 1995) as the basis for developing the basic emissions rates in MOBILE6 for the 1988-2004 model year HDDVs. EPA weighted these new certification data by engine sales and rated power for each model year within each of the four service classes shown in Table 5.

Table 5
HDDE Service Classes and Regulatory Useful Life

Service Class[1]	Description (lbs. GVWR)	Regulatory Useful Life (miles)
Light HDDE	8,500-19,500	110,000
Medium HDDE	19,501-33,000	185,000
Heavy HDDE, Urban Bus	>33,000	290,000[2]

[1] Urban bus does not generally include school buses or inter-city buses.

[2] Under the 2004-and-later standards, the useful life for heavy HDDEs is 435,000 miles.

For each service class EPA further combined the sales and power-weighted model-year-specific emissions data by averaging the individual model year emissions values within model year groups stratified to represent changes in emissions standards (ending with the 1994-97 model year group, based on the latest data). The 1998-2004 model year basic emissions rates were estimated from the 1994-97 model year group values. The diesel school bus basic emissions rates for1988 and later model years in MOBILE6 are based on the g/bhp-hr basic emissions rates produced in this way for the Medium HDDE service class.

Since there were no new CO standards during 1988-2004, EPA estimated basic rates for 1998 and later model years as equal to the 1994-97 model year group base rates. HC basic emissions levels for 1998-2003 model years were estimated as equal to the 1994-97 model year group emissions values. Basic NOx values for 1998-2003 model years were estimated as the product of 1994-97 model year group value and the ratio 1998-to-1997 g/bhp-hr NOx emissions standard. The 2004 NOx and HC basic emission rate values were based on the 2004 combined standard split used in the “2004 heavy-duty rule” regulatory impact analysis (*11*), including an assumed compliance safety margin at regulatory useful life.

The engine dynamometer-based basic emissions rates were converted from the power-based reference frame inherent in the engine certification data to distance-based units for use in VMT activity-based inventory development. EPA developed and used conversion factors based on fuel density, fuel consumption and fuel economy information to produce the miles-based basic emissions rates in MOBILE6. The conversion factor expression is:

$$\text{Conversion Factor (bhp-hr/mi)} = \frac{\text{Fuel Density (lb/gal)}}{\text{BSFC (lb/bhp-hr)} \times \text{Fuel Economy (mi/gal)}} \qquad \text{(Equation 1)}$$

Where: BSFC is brake-specific fuel economy (*12*).

MOBILE6 Modeling Parameters

The MOBILE6 model is equipped with national default modeling values for a range of conditions that affect emissions, and includes options for applying alternative data for characterizing different (e.g., local) scenarios. In the case of HDDVs, however, non-default input options affecting modeled emissions factors (i.e., internal processing and adjustments to MOBILE6 base emissions rates) are more limited than for other vehicle classes.

The MOBILE6 diesel school bus (HDDBS vehicle class) emissions factors were developed without any local input data affecting the emissions factor values output by the model, except for average speed. Post-processing of the MOBILE6 emissions factors was performed, however, using current SIP inventory procedures to incorporate alternate fuels (TxLED) and meteorological effects on NOx emissions factors.

The MOBILE6 model functions and associated command/input options are divided into the following categories:

- Pollutants and Emissions Rates;
- External Conditions;
- Vehicle Fleet Characteristics;
- Activity;
- State Programs;
- Fuels; and
- Alternative Emissions Regulations and Control Measures.

The following is a brief discussion of the modeling setups (i.e., user-specified commands and input parameters values, MOBILE6 defaults) within each of the model sections. More detailed information on the various inputs and options may be found in the MOBILE6 user's guide (*15*). MOBILE6 was run to produce July 2006 daily, arterial road type, exhaust emissions factors for select average speeds for the HDDBS vehicle class, for the model years tested with PEMS: 1987, 1990, 1997, 2000, and 2004.

Table 6 describes the Pollutants and Emissions Rates commands. The inputs of importance are pollutants modeled (HC, CO, and NOx) and the HC species (total hydrocarbons, since this the HC species measured by the PEMS unit).

Table 6
MOBILE6 Pollutants and Emissions Rates

Command	Function/Description	Input Parameter Source/Value
POLLUTANTS	Defines the basic set of pollutants to report.	HC, CO, NOx.
EXPRESS HC AS THC	One of five commands used to specify the HC species (non-methane HC [NMHC], non-methane organic gases [NMOG], total HC [THC], total organic gases [TOG], VOC) to report in exhaust emissions output.	"THC" command used.
PARTICULATES	Enables particulate matter (PM) and related emission factor calculations.	Not used.
PARTICULATE EF	Provides the location of the files that contain the particulate emissions factors when PARTICULATES is used.	
PARTICLE SIZE	Specifies the maximum particulate size cutoff value in micrometers used by MOBILE.	
NO REFUELING	Directs MOBILE6 not to calculate refueling emissions factors.	
AIR TOXICS	Enables calculation of, and specifies which air toxic emission factors (six explicit pollutants) to calculate.	
ADDITIONAL HAPS	Allows entry of emissions factors or air toxic ratios for calculation of additional user-defined air toxic pollutant emissions factors.	
MPG ESTIMATES	Allows entry of alternate fuel economy performance data by vehicle class and model year.	Not applied, thus MOBILE6 defaults were used, with no effect on this analysis.

Table 7, External Conditions, includes calendar year and month of evaluation and meteorological conditions. The year and month of evaluation affect fleet turnover and the fleet mix of technologies (which are dependent on model year), as well as vehicle age and added emissions from the mileage accumulation and deterioration rates. The meteorological inputs in MOBILE6 do not affect diesel vehicle emissions factors from the model, however, the altitude parameter does. In this case, the MOBILE6 default altitude was used (low, or approximately 500 feet above sea level), which is appropriate for this analysis (the other choice is high, or approximately 5,500 feet above sea level, or about 4,500 feet higher than the test site).

Table 7
MOBILE6 External Conditions

Command	Function/Description	Input Parameter Source/Value
CALENDAR YEAR	Calendar year for which emissions factors are to be calculated. (Needed to run model.)	2006.
EVALUATION MONTH	Provides option of calculating January 1 or July 1 fleet composition emissions factors for calendar year.	7 (July).
MIN/MAX TEMPERATURE	Sets minimum and maximum daily temperatures.	Not used.
HOURLY TEMPERATURES	Allows temperatures input for each hour of day. (Required to run model if MIN/ MAX TEMPERATURE command is not used.)	Input values developed from National Climatic Data Center (NCDC) hourly data for College Station, Easterwood Airport, period 7/11-14/06. No effect on MOBILE6 diesel vehicle emissions factors.
ALTITUDE	Specifies high- or low-altitude for modeling area.	Not applied. MOBILE6 default, low altitude, suitable for modeling in Texas, was used.
ABSOLUTE HUMIDITY	Used to specify daily average humidity (directly affects NOx emissions). MOBILE6 also converts absolute humidity to heat index, which affects HC and CO for the portion of the fleet that MOBILE6 determines is using air conditioning.	Not used.
<u>Environmental Effects on Air Conditioning</u>: CLOUD COVER PEAK SUN SUNRISE/SUNSET	Commands used by MOBILE6 to model the extent of vehicle air-conditioning usage. Specifies average percent cloud cover for day. Specifies mid-day hours with peak sun intensity. Allows user to specify time of sunrise and sunset.	Not applied. MOBILE6 defaults were used, with no effect on results.
RELATIVE HUMIDITY	Specifies use of 24 hourly relative humidity values entered by user; performs hour-specific calculations with hourly values rather than using single daily default absolute humidity value.	See HOURLY TEMPERATURES.
BAROMETRIC PRES	Specifies use of user input daily average barometric pressure for use with hourly relative humidity to calculate hourly absolute humidity.	See HOURLY TEMPERATURES.

Table 8 describes the Vehicle Fleet Characteristics options in MOBILE6. For this particular analysis, the MOBILE6 defaults were all used for internal model calculations. MOBILE6 may be used to produce aggregate average emissions factors for a vehicle class fleet (composed of travel fraction-weighted model year-specific emissions factors), or average vehicle class emissions factors for each model year. The latter method was used for this case. Model year-specific NOx emissions factors were then post-processed (discussed later) and the results were combined (using the fleet fractions by age-group used in PEMS study fleet average emissions calculations) to produce Texas representative diesel school bus emissions rates. The travel fractions used in MOBILE6 to weight model-year-specific emissions factors for a vehicle class are the product of miles traveled and registration fraction by model year, normalized across the vehicle class fleet. For school buses, the MOBILE6 default annual mileage accumulation rates (as used for this comparison) are constant across vehicle age, thus the registration distributions by age (or model year) are equivalent to the travel fractions by age.

Table 8
MOBILE6 Vehicle Fleet Characteristics

Command	Function/Description	Input Parameter Source/Value
REG DIST	Allows the user to supply registration distributions by age for any of the 16 composite (combined gasoline and diesel) vehicle types.	Not applied. The MOBILE6 defaults were used, with no effect on results since model year-specific emissions factors were used and combined externally.
DIESEL FRACTIONS	Permits user to supply locality-specific diesel fractions for 14 of the 16 composite vehicle categories by age.	Not applied. The MOBILE6 defaults were used, with no effect on results since only model-year-specific diesel school bus emissions factors were used.
MILE ACCUM RATE	Allows the user to supply the annual mileage accumulation rates by vehicle type and age.	Not applied. The MOBILE6 defaults were used. For school buses, the default value (9,939 miles/year) is constant across vehicle ages.
NGV FRACTION	Lets user specify percent of natural gas vehicles (NGV) in the fleet by type and age certified to operate on either compressed or liquefied natural gas.	Not applied. The MOBILE6 default, zero percent, was used.
NGV EF	Permits the user to enter alternate NGV emissions factors for each of the 28 vehicle types, for running and start emissions.	Not applied. The MOBILE6 default, none, was used.

Table 9 lists the MOBILE6 Activity input parameter options. The only command applied from this section of the model was the AVERAGE SPEED command. This command and associated parameters overrides the MOBILE6 speed distribution default, allowing the modeling of a single average speed for all arterial or freeway road types. MOBILE6 bus emissions factors do not vary between freeway and arterial roadway classes, thus, arterial emissions factors were modeled for key average speeds: 2.5 mph needed for estimating MOBILE6-based idling emissions factors, and 18.6 mph, the estimated Texas school bus urban/rural composite in-use driving cycle average speed. The assumed drive-cycle average speed for the HDDV base rates in MOBILE6 is 20 mph. Thus, to model different average speeds (e.g., 2.5 mph or 18.6 mph), MOBILE6 applies internal speed correction factors.

Table 9
MOBILE6 Activity

Command	Function/Description	Input Parameter Source/Value
AVERAGE SPEED	Allows a single average speed for combined freeways and arterials for the entire day.	Set up to produce Arterial emissions factors for average speeds of 2.5 mph and 18.6 mph.
SPEED VMT	Allows user to allocate VMT by average speed (14 pre-selected: 2.5 and 5 through 65 at 5 mph increments) for arterials and freeways for each hour of the day.	Not used.
VMT FRACTIONS	Used in MOBILE6 to weight the emissions of various vehicle types into average rates for groupings of vehicle classes.	
VMT BY FACILITY	VMT fractions by MOBILE6 road type combine the four road type emissions factors into the "all road types" emissions factors.	
VMT BY HOUR	Allows VMT fractions allocation by hour-of-day; applied in conversion of grams per hour (g/hr) to g/mi, as well as in weighting of hourly g/mi rates to produce daily emissions factors.	Not applied. The MOBILE6 default was used.
STARTS PER DAY	Lets user specify the average number of engine starts per vehicle per day by vehicle types for weekend days and weekdays.	Not applicable to heavy-duty vehicles in MOBILE6.
START DIST	Allows user to allocate engine starts by hour of the day for weekend days and weekdays.	
SOAK DISTRIBUTION	Allows use of alternate vehicle soak duration distributions for weekend days and weekdays.	Not applicable to diesel vehicles in MOBILE6.
HOT SOAK ACTIVITY	Allows users to specify a hot soak duration distribution for each of 14 daily time periods for weekend days and for weekdays.	
DIURN SOAK ACTIVITY	Allows user set diurnal soak time distributions for each of 18 daily time periods.	
WE DA TRI LEN DI	Specifies alternate fractions of VMT that occur during trips of various durations at each hour of the average weekday.	
WE EN TRI LEN DI	Specifies hourly alternate fractions of VMT for trips of various lengths for weekend days.	
WE VEH US	Directs MOBILE6 to use weekend activity data.	Not used.

The MOBILE6 State Programs input options (Table 10) were not relevant to diesel buses and were not used for the analysis. The TxLED fuel was used in the PEMS emissions tests, but MOBILE6 does not include alternate diesel fuel parameter options pertinent to this analysis, thus TxLED effects on NOx were included as a post-processing step.

Table 10
MOBILE6 State Programs

Command	Function/Description	Input Parameter Source/Value
STAGE II REFUELING	Allows modeling of at-the-pump refueling emissions.	Not used.
ANTI-TAMP PROG	Allows user to model impacts of an ATP.	
I/M PROGRAM, etc.	Used to model exhaust/evaporative I/M program effects.	

Although there are many alternate gasoline fuel parameter input options to MOBILE6, there is only one for diesel fuel, average sulfur content, which has no effect on MOBILE6 HC, CO, and NOx emissions factors. Thus, the only non-default fuel parameter applied (Table 11) was gasoline Reid Vapor Pressure (RVP), because it is a required input in order to run the model.

Table 11
MOBILE6 Fuels

Command	Function/Description	Input Parameter Source/Value
FUEL PROGRAM	Allows specification of one of four fuel program options, with no effect on diesel vehicle emissions.	Not applied. MOBILE6 default was used.
FUEL RVP	Allows user to specify gasoline RVP for area being modeled (required for running the model).	Used 7.8 psi (no effect on diesel vehicle emissions factors).
SULFUR CONTENT	Allows conventional gasoline alternate sulfur content for calendar years through 1999.	Not used.
DIESEL SULFUR	Allows use of average diesel fuel sulfur level for all calendar years. Required if PARTICULATES command is used. No affect on HC, CO, NOx, or air toxics (except if calculated as ratio to PM).	
OXYGENATED FUELS	Allows modeling of oxygenated gasoline effects on exhaust for all gasoline-fueled vehicle types. Not for use with AIR TOXICS command.	
SEASON	Identifies effective season for RFG calculation regardless of month modeled.	
GAS AROMATIC% GAS OLEFIN% GAS BENZENE% E200 E300 OXYGENATE RVP OXY WAIVER	Used only with AIR TOXICS command.	

Alternative Emissions Regulations and Control Measures (Table 12) were not used in the analysis. It should be noted that the application of HDDV Nox Off-Cycle effects and mitigation program effects in MOBILE6 excludes the bus vehicle classes.

Table 12
MOBILE6 Alternative Emissions Regulations and Control Measures

Command	Function/Description	Input Parameter Source/Value
NO CLEAN AIR ACT	Models vehicle emissions as if the Federal Clean Air Act Amendments of 1990 had not been implemented.	Not used.
HDDV NOx Off-Cycle Emissions Effects: NO DEFEAT DEVICE NO NOX PULL AHEAD NO REBUILD REBUILD EFFECTS	 Turns off NOx off-cycle emissions effects. Turns off NOx reduction effects of pull-ahead program. Turns off NOx reduction effects of rebuild program. Allows user to change rebuild program effectiveness rate.	
Tier 2 Emission Standards and Fuel Requirements: NO TIER2 T2 EXH PHASE-IN T2 EVAP PHASE-IN T2 CERT	 Disables Tier 2 requirements. Allows alternate Tier 2 exhaust standard phase-in. Allows alternate Tier 2 evaporative standard phase-in. Allows alternate Tier 2 50,000-mile certification standards.	
94+ LDG IMPLEMENTATON	Allows use of alternate 1994 and later fleet penetration fractions for LDGVs under the Tier 1, NLEV (or California LEV 1), and Tier 2 emissions standard programs.	
NO 2007 HDDV RULE	Disables 2007 HDV emissions standards.	

In addition to the MOBILE6 inputs used as described above, MOBILE6 detailed database output options were used to produce daily, vehicle class-, model year-, emissions type-, facility type-specific emissions factors, including the key average speed scenarios. Table 13 summarizes the emissions factors produced using MOBILE6 prior to NOx corrections.

Table 13
MOBILE6 Unadjusted July 2006 Diesel School Bus Emissions Factors

		Emissions Factors (g/mi) by Model Year					
Pollutant	**Average Speed (mph)**	**1987**	**1990**	**1997**	**2000**	**2004**	**Composite[1]**
THC	2.5	3.66	3.19	2.10	2.08	1.16	2.50
	18.6	1.75	1.52	1.00	0.99	0.55	1.19
CO	2.5	28.76	16.90	9.07	8.81	8.46	14.99
	18.6	9.47	5.56	2.99	2.90	2.78	4.93
NOx	2.5	22.43	23.35	24.18	19.35	11.01	20.70
	18.6	13.16	13.70	14.19	11.35	6.46	12.15

[1] Model year rates were combined using the same fleet fractions used to combine the individual test bus in-use emissions rates (in ascending order by model year: 0.24, 0.17, 0.28, 0.14, and 0.17).

MOBILE6 NOx Emissions Factor Adjustments

According to current emissions inventory methods, the MOBILE6 NOx emissions factors were adjusted to account for alternate temperature/humidity effects and to account for the effects of TxLED fuel. The TxLED NOx benefit used was 6.2 percent, which is the EPA estimate for HDDVs without EGR systems (the case for all of the test buses) (*16*). The humidity/temperature effects on NOx (i.e., NOx correction factors) were calculated using local area hourly meteorological data for the test period in two equations (i.e., one for 1993 and earlier model years, and the other for 1994 and later model years) recommended by the Southwest Research Institute (*17*). The hourly average temperature, humidity and barometric pressure were calculated for the four-day test period. Hourly correction factors were then calculated and average correction factors for the daily test period (8 a.m. through 4 p.m.) were calculated.

Table 14
NOx Correction Factors for MOBILE6 HDDV Emissions Factors

HDDV NOx Correction Factors For			
Model Year	**Temperature and Humidity Effects**	**TxLED Fuel Effects**	**Combined Effects**
1987, 1990	0.91268	0.93800	0.85609
1997, 2000, 2004	0.91485	0.93800	0.85813

MOBILE6 Emissions Rates Results

Additionally, MOBILE6 idle emissions factors were calculated for the comparison. The idle emissions factor estimates were calculated using the EPA method for estimating MOBILE6-based idling emissions factors (*18*). The idling emissions factors were computed by multiplying the 2.5 mph MOBILE6 g/mi emissions factor by the speed (2.5 mph) and then converting from grams per hour (g/hour) to grams per second (g/sec). Table 15 shows the MOBILE6 emissions rates, including idling rates, with NOx corrections applied for TxLED fuel and temperature/humidity effects.

Table 15
MOBILE6 July 2006 Diesel School Bus Emissions Factors – with NOx Corrections for TxLED Fuel and Temperature/Humidity Effects

		Emissions Factors[1] by Model Year					
Pollutant	**Average Speed (mph)**	**1987**	**1990**	**1997**	**2000**	**2004**	**Composite[2]**
THC	Idle	0.00254	0.00222	0.00146	0.00144	0.00080	0.00173
	2.5	3.66	3.19	2.10	2.08	1.16	2.50
	18.6	1.75	1.52	1.00	0.99	0.55	1.19
CO	Idle	0.01997	0.01174	0.00630	0.00612	0.00587	0.01041
	2.5	28.76	16.90	9.07	8.81	8.46	14.99
	18.6	9.47	5.56	2.99	2.90	2.78	4.93
NOx	Idle	0.01333	0.01388	0.01441	0.01153	0.00656	0.01232
	2.5	19.20	19.99	20.75	16.60	9.45	17.75
	18.6	11.27	11.73	12.18	9.74	5.54	10.41

[1] Idle rates are in units of g/sec and emissions rates by "non-zero" average speeds are in units of g/mi.
[2] Model year rates were combined using the same fleet fractions used to combine the individual test bus in-use emissions rates (in ascending order by model year: 0.24, 0.17, 0.28, 0.14, and 0.17).

COMPARISONS

The following compares the Texas representative diesel school bus fleet in-use emissions rates and corresponding MOBILE6-estimated emissions rates. The in-use NOx, HC and CO emissions rates for each of the TxLED fuels (from Tables 3 and 4) are compared to the corresponding MOBILE6-based estimates (from Table 15).

PEMS In-Use versus MOBILE6 Estimated Emissions Rates

Table 16 compares the MOBILE6-estimated and PEMS-in-use HC, CO, and NOx emissions rates estimates for the Texas School Bus representative fleet.

Table 16
In-Use[1] and MOBILE6 Emissions Rates for Texas Diesel School Buses

Pollutant[3]	Speed (mph)	Fleet Emission Rates[2]		
		MOBILE6	PEMS,V	PEMS,J
NOx	Cycle Average 18.6 (g/mi)	10.414	3.151	3.200
HC		1.190	0.259	0.261
CO		4.934	0.687	0.811
NOx	Idle 0.0 (mg/s)	12.325	7.502	7.507
HC		1.734	0.628	0.649
CO		10.407	1.269	1.499

[1] In-use (PEMS) rates are average Texas school bus fleet urban and rural drive cycle composites.

[2] Average Texas school bus fleet rates for both MOBILE6 and in-use are individual model year composites based on the same set of fleet fractions. “PEMS,V” and “PEMS,J” are emissions data based on Valero fuel (TxLED specification) and JAM Distributors fuel (TxLED compliant), respectively.

[3] MOBILE6 NOx rates were adjusted for both TxLED fuel effects and temperature/humidity effects.

The difference between the MOBILE6-based emissions rates and in-use PEMS data-based rates shown in Table 7 may be attributed to several factors. These include:

- extent of start emissions;
- comparability of drive cycles;
- conversion from engine emissions to vehicle emissions;
- vehicle/engine data aggregations; and
- fuel parameters.

Start Emissions: The MOBILE6 HDDV exhaust emissions rates include both running emissions and a vehicle start increment. The transient engine FTP emissions from which the model basic emissions rates were derived are composed of emissions including a cold start and a hot start (*13*). The engine dynamometer test sequence includes the 20-minute drive cycle run twice with a 20-minute hot soak in between. Emissions for the initial cycle are measured beginning with a cold engine start, and emissions for the second cycle are measured from the hot start following the soak. The aggregate emissions are calculated as a composite equal to 1/7 cold start cycle emissions plus 6/7 hot start cycle emissions.

For the in-use emissions tests, the buses were warmed up for at least 20 minutes before testing. No start emissions increment was included in the PEMS-based, in-use emissions rates. These additional start emissions in MOBILE6 contribute to the higher MOBILE6 bus rates. But since the transient cycle is 20 minutes and start emissions durations are relatively short, and the cold start cycle fraction of transient FTP emissions is small, the impact is probably small.

Drive Cycles: As seen in the PEMS emissions data for individual Texas urban and rural driving cycles (Appendix A), variation in drive cycle (Figures 1 and 2) can have a substantial effect on average emissions. The urban cycle average g/mi emissions are higher for all three pollutants for both fuels. The average relative increase (urban to rural) for the two fuels is about 12 percent for NOx and HC and about 18 percent for CO. The relative target time in modes (idle, transient, cruise, respectively) for urban cycle is about 39 percent, 25 percent, and 36 percent, and for rural is about 34 percent, 27 percent, and 39 percent. The average speed for urban and rural drive cycles, respectively, is 17.5 mph and 21.5 mph.

A direct comparison of the FTP transient engine cycle with the Texas school bus drive cycles cannot be made due to the difference in reference frames, i.e., engine speed and torque versus vehicle speed. The FTP transient engine cycle is based on the EPA Urban Dynamometer Driving Schedule for Heavy-Duty Vehicles (UDDS chassis dynamometer driving cycle) though, which has an average speed of about 19 mph (*10*) (Figure 3). Comparing the UDDS to the synthetic Texas urban and rural school bus cycles (Figures 1 and 2) shows that the UDDS is composed of relatively less cruising speeds than the Texas urban and rural school bus cycles. The relatively low proportion of cruise components relative to other modes can contribute to the higher MOBILE6 emissions rates.

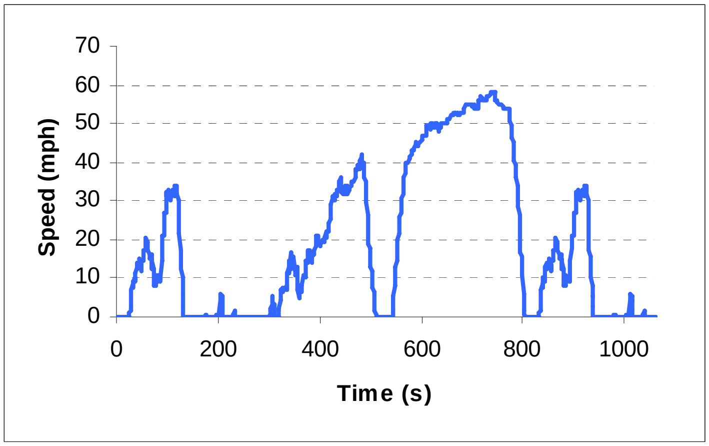

Figure 3. EPA Urban Dynamometer Driving Schedule for Heavy-Duty Vehicles.(*14*)

Conversion of Engine Emissions to Vehicle Emissions: For MOBILE6, new conversion factors (Equation 1) for the individual heavy-duty vehicle classes were estimated (*12*). Varying the elements of the conversion factor in the direction of higher fuel density (single value for all diesel conversion factors) and lower BSFC and/or fuel economy (both by model year and vehicle class) would produce a higher conversion factor, and thus g/mile emissions factor result, and vice versa. For example, this effect is evident by comparing the conversion factors for the 1996 model year HDDBS from MOBILE6 and from the prior version of MOBILE. The newer fuel economy and BSFC estimates are lower, i.e., 6.18 versus 9.87 mi/gal, and 0.384 to 0.444 lb/bhp-hr, respectively. Fuel density estimates are about the same, with former of 7.11 versus 7.099 lb/gal (*12*). The result is an increase from 1.62 to 2.99 bhp-hr/mi in the conversion factors (assumed to be an improvement due to use of more recent data), or about 82 percent, which translates to a similar increase in the calculated g/mi emissions factors. Any ambiguity in the base g/bhp-hr emissions factor (e.g., due to poor representation of particular in-use drive cycle) might be compounded by imprecision in the conversion factors. The conversion factor is therefore a possible source of difference between MOBILE6 and in-use PEMS emissions estimates.

Vehicle/Engine Aggregation: Another aspect of the difference in the PEMS, in-use and MOBILE6 estimated emissions rates, is in the engine certification data sample size and aggregation levels used for MOBILE6. In MOBILE6, the emissions data are from a broadly-defined category of engines, rather than the narrow and tightly-focused fleet represented in the Texas school bus test. In MOBILE6, the engine emissions data are weighted by sales and power rating, then averaged within model year groups that reflect uniform exhaust standards for each pollutant (e.g., for each pollutant, 1994-97 MOBILE6 school bus basic emissions rates are the same). The MOBILE6 HDDBS emissions rates were developed from the medium HDDE (19,501-33,000 GVWR) service class category.

The five buses (individual model years listed in Table 1) that were tested in-use with PEMS were all Type C with very similar engine specifications and gross weights including simulated passenger loads. Thus, the MOBILE6 basic emissions rates represent a more broadly defined class of vehicles, compared to the Texas bus test fleet, which is much more tightly defined.

Fuel Parameters: Differences in fuels affect emissions. The in-use emissions results for two fuels (Tables 3 and 4) with similar properties, show close results for NOx, HC, and CO. (Typically, CO estimates show more variation than NOx and HC.).

In MOBILE6 the effects of diesel fuel may be considered the average affect of all of the individual test fuels (40CFR86.1313, generally designated as commercial Type 2-D grade, or the predominant in-use fuel at the time of testing) used in the FTP emissions data and used in the basic emissions rates in MOBILE6. A major change in the Type 2-D test fuel specifications (fuel property ranges) has been reduced sulfur content. The average test fuel effects in MOBILE6, with NOx adjusted for TxLED effects, may produce some differences in HC, CO, and NOx exhaust emissions as compared to the emissions from the two fuels used in the in-use emissions tests.

Note that emissions are directly affected by ambient conditions. MOBILE6 diesel classes assume certification standard conditions, with no alternate options in the model. Though, temperature/humidity corrections to NOx are factored into the MOBILE6 rates. However, the small size of the PEMS fleet may have exaggerated the impact of ambient conditions.

FINDINGS

MOBILE6 emissions estimates are by definition aggregations and not very representative of tightly-defined vehicle fleets and duty cycles. The Texas representative school bus in-use test fleet HC, CO, and NOx emissions rates developed with PEMS were substantially lower than the corresponding MOBILE6 estimations.

- Start emissions are included in the MOBILE6 emissions, but not in the in-use emissions estimates. Due to the length of the FTP transient engine cycle, however, the start emissions increment may be relatively small.

- Transient HDDE engine certification test cycle and the Texas representative diesel bus in-use drive cycles are different. The transient engine test was based on the UDDS, which was developed from several in-use urban and freeway driving profiles, and generally includes few stable speed segments relative to transients and idle, whereas stable speeds segments are a significant portion of the Texas bus cycles.

- The conversion factor from average medium-duty service class g/bhp-hr to diesel school bus g/mi basic emission rates may significantly contribute to higher MOBILE6 rates.

- MOBILE6 uses engine emissions data aggregated within HDDE service duty classes and model year groups, which may not necessarily well represent particular individual model year vehicles.

CONCLUSIONS

Based on the findings of this comparative analysis, the following could improve MOBILE6 estimates.

- The TTI *School Bus Emissions Reductions* report (*3*) includes annual mileage accumulation and age distributions estimates for Texas school buses. These should be considered for use as input to MOBILE6 for Texas emissions inventory modeling in place of the national defaults.

- Attempt to improve the HDE conversion factor for diesel school buses in MOBILE6. Acquire Texas diesel school bus fuel economy data by model year, if available, and recalculate the MOBILE6 HDE conversion factors used in MOBILE6.

- Investigate hot and cold start effects on diesel school bus exhaust emissions, as well as determine if data are available to determine the extent of start emissions increment in the MOBILE6 HDDV basic emissions rates (sample of certification data used to produce the MOBILE6 basic emissions rates).

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APPENDIX A
PEMS EMISSIONS RESULTS FOR TWO TXLED FUELS

Texas Representative Diesel School Bus Fleet In-Use Tailpipe Emission Rates[1] – TxLED Specification Fuel (Valero's Three Rivers Refinery)

Pollutant	Speed[2]	Rural	Urban	Composite
NOx	Cycle	2.931	3.237	3.151
	Idle	0.00797	0.00732	0.00750
	20 mph	2.031	1.367	1.553
	40 mph	1.759	1.970	1.911
	55 mph	2.010	--	2.010
HC	Cycle	0.244	0.265	0.259
	Idle	0.000655	0.000618	0.000628
	20 mph	0.289	0.227	0.244
	40 mph	0.172	0.126	0.139
	55 mph	0.156	--	0.156
CO	Cycle	0.647	0.702	0.687
	Idle	0.00138	0.00123	0.00127
	20 mph	0.666	0.488	0.538
	40 mph	0.273	0.206	0.225
	55 mph	0.450	--	0.480

[1] Emissions rate units are grams/mile except for Idle rates which are grams/second.

[2] Cycle average speeds are 17.5 mph, 18.6 mph, and 21.5 mph, respectively for urban, composite, and rural cycles. The 20 mph, 40 mph, and 55 mph speeds are stable, cruising speeds within the cycles.

Texas Representative Diesel School Bus Fleet In-Use Tailpipe Emission Rates[1] – TxLED Compliant Fuel (JAM Distributors)

Pollutant	Speed[2]	Rural	Urban	Composite
NOx	Cycle	2.923	3.308	3.200
	Idle	0.00819	0.00724	0.00751
	20 mph	1.969	1.609	1.710
	40 mph	1.929	1.886	1.886
	55 mph	1.909	--	1.909
HC	Cycle	0.235	0.272	0.261
	Idle	0.000681	0.000637	0.000649
	20 mph	0.266	0.232	0.241
	40 mph	0.141	0.126	0.130
	55 mph	0.160	--	0.160
CO	Cycle	0.680	0.861	0.811
	Idle	0.00149	0.00150	0.00150
	20 mph	0.683	0.592	0.618
	40 mph	0.272	0.279	0.277
	55 mph	0.474	--	0.474

[1] Emissions rate units are grams/mile except for Idle rates which are grams/second.

[2] Cycle average speeds are 17.5 mph, 18.6 mph, and 21.5 mph, respectively for urban, composite, and rural cycles. The 20 mph, 40 mph, and 55 mph speeds are stable, cruising speeds within the cycles.