Data Needs for a Proposed Modal Heavy-Duty Diesel Vehicle Emission Model

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Chunxia Feng, Seungju Yoon, and Randall Guensler

School of Civil and Environmental Engineering, Georgia Institute of Technology
790 Atlantic Drive Atlanta, GA 30332-0355

ABSTRACT

Heavy-duty diesel vehicle (HDDV) operations are a major source of pollutant emissions in major metropolitan areas. Accurate estimation of heavy-duty diesel vehicle emissions is essential in air quality planning efforts because highway and non-road heavy-duty diesel emissions account for a significant fraction of the oxides of nitrogen (NOx) and particulate matter (PM) emissions inventories. Yet, major modeling deficiencies in the current MOBILE6.2 modeling approach for heavy-duty diesel vehicles have been widely recognized for more than ten years. While the most recent MOBILE6.2 model integrates marginal improvements to various internal conversion and correction factors, fundamental flaws inherent in the modeling approach still remain. This paper proposes a modal HDDV modeling approach designed to predict second-by-second emissions from onroad vehicle operations. The modeling approach should provide a significant improvement in HDDV emissions modeling compared to the current average speed cycle-based emissions models. However, this modeling approach requires extensive data collection and analytical efforts to implement the new modeling regime.

KEY WORDS

Modal Emissions Modeling and Heavy-Duty Diesel Vehicles
INTRODUCTION

Heavy-duty diesel vehicle (HDDVs) operations are a major source of nitrogen oxides (NOx) and particulate matter (PM) emissions in metropolitan areas nationwide. Although HDDVs constitute a small portion of fleet activity in vehicle miles traveled (VMT), they typically contribute more than 45% of NOx and 75% of PM among on-road mobile emission sources (1). In current regional and microscale modeling conducted in every state except California, HDDV emissions rates are taken from the U.S. Environmental Protection Agency’s (EPA’s) MOBILE6.2 model (2). MOBILE6.2 emission rates are derived from baseline emission rates (gram/brake-horsepower-hour) developed in the laboratory using engine dynamometer test cycles. These work-based emission rates are then modified through a series of conversion and correction factors so that approximate emission rates in units of grams/mile can be applied to onroad vehicle activity (vehicle-miles of travel), as a function of temperature, humidity, altitude, average vehicle speed, etc. (3). The conversion process used to translate laboratory emission rates to on-road emission rates employs fuel density, brake specific fuel consumption, and fuel economy for each HDDV. However, the emission rate conversion process does not appropriately account for the impacts of roadway operating conditions on brake-specific fuel consumption and fuel economy.

The Georgia Institute of Technology (Georgia Tech) research team in the School of Civil and Environmental Engineering has recently developed a new modal HDDV emissions modeling approach. This model differs from other proposed modal models (4) in that the modeling framework first predicts second-by-second engine power demand as a function of vehicle operating conditions and then applies brake-specific emission rates to these activity predictions. On-road operating modes, such as cruise, acceleration, deceleration, and motoring/idling are integral in the power demand functions, as are other relevant factors such as vehicle weight, road grade, road surface type, etc. However, to properly address HDDV emissions for on-road activity and to overcome uncertainties in emissions estimation, the new modeling approach requires that a variety of new data to be collected and analyzed. In this paper, the researchers address new data needs to develop and implement in the proposed modal modeling approach.

MODAL EMISSION MODEL

Modal Activity

The MOBILE6.2 emission rate model is designed to predict emission rates in grams per mile, so that on-road vehicle activity (vehicle-miles) can be linked with applicable emission rates. Modal emission rate models for light-duty vehicles predict emission rates in grams/second as a function of a variety of specific modal vehicle activities, such as vehicle cruise, acceleration, deceleration, and idling activities. In these light-duty vehicle modal models, emission rates vary widely as a function of the mode of operation (5, 6). The modal HDDV emissions model developed by the Georgia Tech research team currently developing is somewhat different than those being developed for the light-duty
fleet, because this HDDV model is designed to predict second-by-second power demand (which can vary widely with on-road operating conditions) and then link the modal activity to fairly stable horsepower-specific emission rates. In this modeling regime, emission rates are first established for various heavy-duty technology groups (engine and vehicle family, displacement, certification group, drivetrain, fuel delivery system, emission control system, etc.) based upon statistical analysis of standard engine dynamometer certification data, or on-road emission rate data when available (7, 8). The emission rates in the basic modal emission rate model are work-related emissions rates, expressed in units of grams/bhp-sec. The linear or polynomial functions provide grams/bhp-sec as a function of engine load (bhp). The more advanced emission rate modules include exceptions to the linear or polynomial functions (i.e. elevated gram/bhp-sec emission rates under specific engine load conditions).

The other major component of the modeling approach is the module to predict engine power demand. Engine power demand (bhp) is predicted as a function of vehicle technology characteristics, vehicle operating conditions, environmental conditions, and freight/passenger loading. The on-road engine power demand for each second of vehicle operation can then be linked to the applicable emissions rate (g/bhp-sec) to predict emissions for each second of on-road vehicle operation. The hourly emissions contribution from each link in the transportation system can be established by summing the emissions for each vehicle (or vehicle technology group) operating on the link in that hour.

**Engine Power Demand Function**

The vehicle drivetrain (engine, transmission, drive shaft, rear differential, axles, and wheels) is designed to convert engine torque into useful tractive force at the wheel-to-pavement interface. When the tractive force is greater than the sum of forces acting against the vehicle, the vehicle accelerates in the direction of travel. Given that on-road speed/acceleration patterns for HDDVs can be observed (or empirically modeled), the modal modeling approach works backwards from observed speed and acceleration to estimate the tractive force (and power) that was available at the wheels to meet the observed conditions. Then, working backwards from tractive force, the model accounts for additional power losses that occurred between the engine and the wheels to predict the total brake-horsepower output of the engine. Force components that reduce available wheel torque and tractive force include:

- Aerodynamic drag, which depends on the frontal area, the drag coefficient, and the square of the vehicle speed
- Tire rolling resistance, which is determined by the coefficient of rolling resistance, vehicle mass, and road grade (where the coefficient of rolling resistance is a function of: tire construction and size; tire pressure; axle geometry, i.e., caster and camber; and whether the wheels are driven or towed)
- Grade load, which is determined by the roadway grade and vehicle mass
- Inertial load, which is determined by the vehicle’s mass and acceleration
The tractive force required at the interface between the tires and the road to overcome these resistive forces and provide vehicle acceleration can be described by (9):

\[
F_T = F_D + F_R + F_W + F_I + ma
\]  

(Equation 1)

Where,
- \(F_T\) is the tractive force available at the wheels (lbf)
- \(F_D\) is the force necessary to overcome aerodynamic drag (lbf)
- \(F_R\) is the force required to overcome tire rolling resistance (lbf)
- \(F_W\) is the force required to overcome gravitational force (lbf)
- \(F_I\) is the force required to overcome inertial loss (lbf)
- \(m\) is the vehicle mass (lbm)
- \(a\) is the vehicle acceleration (ft/sec\(^2\))

Load prediction models could employ a wide variety of aerodynamic drag (10) and rolling resistance functional forms, some of which may be more appropriate for certain vehicle designs and at certain vehicle speeds. Note that vehicle mass is a critical parameter that must be included in the load-based modeling approach. Therefore, estimates of gross vehicle weight must be included in any transit (vehicle weight plus passenger loading) or heavy-duty truck (vehicle weight plus cargo payload) application. The following subsections describe each force in the Equation 1, taken from Yoon et al. (11).

**Aerodynamic Drag Force (F\(_D\))**

As a vehicle moves forward through the atmosphere, drag forces are created at the interface of the front of the vehicle and by the vacuum generated at the tail of the vehicle. In fact, the flow of the air around the vehicle creates a very complex set of forces providing both resistance to forward motion and vehicle lift. The sum of the drag forces is typically aerodynamic drag, which is a function of air density, aerodynamic drag coefficient, vehicle frontal area, and effective vehicle velocity.

\[
F_D = \left(\frac{\rho}{2g}\right) \times C_d \times A_f \times V_e^2
\]  

(Equation 2)

Where:
- \(\rho\) is the air density (lb/ft\(^3\))
- \(g\) is the acceleration of gravity (32.2 ft/sec\(^2\))
- \(C_d\) is the aerodynamic drag coefficient
- \(A_f\) is the bus frontal area (ft\(^2\))
- \(V_e\) is the effective bus velocity (ft/sec)

**Rolling Resistance Force (F\(_R\))**

Rolling resistance force is the sum of the force required to overcome the combined friction resistance at the tires. Tires deform at their contact point with the ground as they roll along the roadway surface. Rolling resistance is caused by contact friction, the tires’ resistance to deformation, aerodynamic drag at the tire, etc. The force required to overcome rolling resistance can be expressed with rolling resistance coefficient, vehicle weight, and road grade.
\[ F_R = C_r \times m \times g \times \cos(\theta) \]  
(Equation 3)

Where: \( C_r \) is the rolling resistance coefficient  
\( \theta \) is the road grade (degree)

**Gravitational Weight Force (\( F_W \))**

The gravitational force components account for the effect of gravity on vehicle weight when the vehicle is operating on a grade. The grade angle is positive on uphill grades (generating a positive resistance) and negative on downgrades (creating a negative resistance).

\[ F_W = m \times g \times \sin(\theta) \]  
(Equation 4)

**Drivetrain Inertial Loss (\( F_I \))**

The engine, transmission, drive shaft, axles and wheels are all in rotation. The rotational speed of each component depends upon the transmission gear ratio, the final drive ratio, and the location of the component in the drive train (i.e. the total gear ratio between each component and the wheels). The rotational moment of inertia of components in the drivetrain constitutes a resistance to change in motion. The torque delivered by each rotating component to the next component in the power chain (engine to clutch/torque converter, clutch/torque converter to transmission, transmission to drive shaft, drive shaft to axle, axle to wheel) is reduced by the amount necessary to increase angular rotation of the spinning mass during vehicle acceleration. Given the torque loss at each component, the reduction in motive force available at the wheels due to inertial losses along the drivetrain can be modeled with the following equation.

\[ F_I = \frac{a \times I_{EFF}}{r^2} = \frac{a \times [(I_w + (G^2_d \times I_D)) + (G^2_I \times G^2_E) \times (I_E + I_T)]}{r^2} \]  
(Equation 5)

Where:  
\( a \) is the acceleration in the direction of vehicle motion (ft/sec^2)  
\( I_{EFF} \) is the effective moment of inertia (ft-lb-ft-sec^2)  
\( I_w \) is the rotational moment of inertia of the wheels and axles (ft-lb-ft-sec^2)  
\( I_D \) is the rotational moment of inertia of the drive shaft (ft-lb-ft-sec^2)  
\( I_T \) is the rotational moment of inertia of the transmission (ft-lb-ft-sec^2)  
\( I_E \) is the rotational moment of inertia of the engine (ft-lb-ft-sec^2)  
\( G_I \) is the gear ratio at the engine transmission  
\( G_d \) is the gear ratio in the differential  
\( r \) is wheel radius (ft)

Using the equations outlined above, the total engine power demand, which is the combination of tractive power and auxiliary power demands, can be expressed as:
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\[ P = \left[ \frac{V}{550} \times (F_D + F_R + F_w + F_i + ma) \right] + AP \]  
\[ \text{Equation 6} \]

Where: 
- \( V \) is the vehicle speed (ft/s) 
- \( AP \) is the auxiliary power demand (bhp) 
- \( 550 \) is the conversion factor to bhp

### Emission Rate Derivation

Heavy-duty engines are certified in the laboratory by the USEPA for emissions performance under standardized engine test procedures (12). Engines are tested on engine dynamometers (rpm and torque conditions applied to the engine on a set schedule) in accordance with federal testing procedures (13). Such certification tests are designed to reflect the range of on-road activity that a vehicle will experience. For each engine, the certification test yields an average gram/bhp-hr emission rate for the test, and this value must fall below specific new engine and in-use standards established by regulation.

The basic application of the modal model incorporates a simple emission rate modeling approach. Emission rates in gram/bhp-sec for a given bhp load are multiplied by the predicted engine power demand (bhp) for each second of vehicle operation. Technology groups (i.e. vehicles that perform similarly on the certification tests) are established based upon the engine and control system characteristics and each technology group is assigned a constant g/bhp-sec emission rate based upon regression tree and other statistical analysis of certification data. Under the assumption that engine testing cycles represent the typical modal activities undertaken by on-road vehicles, such emission rates are applied to on-road activity data. Given the large repository of certification data, detailed statistical analysis of the certification test results can be used to obtain applicable emission rates for these statistically derived vehicle technology groups. The data required for analysis must come from chassis dynamometer (the engine remains in the vehicle and the vehicle is tested on a heavy-duty treadmill) and onroad test programs in which second-by-second gram/second emission rate data have been collected concurrently with axle-hp loads. A linear, polynomial, or generalized relationship is established between gram/second emission rate and tractive horsepower (axle horsepower). Sufficient testing data are required to establish statistically significant samples for each technology group. Figure 1 illustrates a polynomial relationship between NOx emission and axle-horsepower for a truck on a chassis dynamometer testing cycle (14).
For some engines, researchers have noted that certain onroad operating conditions can lead to significant deviations (e.g. quantum leaps) in gram/bhp emission rates. In the more advanced implementation of the modal model, analyst will examine detailed modal emission rate data collected from the instrumented onroad fleet and identify and map the exceptions to linear or polynomial gram/bhp-sec emission rates for various engine technologies. The mapping will provide incremental additions to the modal emission rates for the specific conditions under which emissions exceptions occur. These modal exceptions will be modeled statistically, based upon analysis of on-road second-by-second emission rate data. Because preliminary analyses indicate that some engines may jump to higher emission rates after an extended period of cruise operation, a time element may be a required modeling component for some vehicle technology groups. Reasonably accurate driving trace data will be needed both for the prediction of the second-by-second engine load for application to linear gram/bhp-sec emission rates, as well as for use in the prediction of excess gram/bhp-sec emissions related to specific operating conditions. As with the simplified model, corrections associated with environmental conditions and high-emitter status will also need to be integrated into the emission rate assignment subroutines.

Heavy-duty chassis dynamometers can now accommodate transit vehicles, and second-by-second laboratory test data are now available from transit vehicles and heavy-duty trucks on a variety of chassis testing cycle. As more and more chassis dynamometer data become
available every year, researchers can continue to improve the emission rate relationships
and identify emission-rate exception conditions (which might not even be noticed in
engine-only dynamometer testing). Comprehensive modal models for HDDVs will only
become accepted for regulatory use, when a significantly larger on-road data collection
effort is programmed by the regulatory agencies (i.e. the USEPA and USDOT) and
detailed data analyses are completed.

DATA NEEDS

The HDDV modal model requires a variety of parameters to estimate instantaneous engine
power demand. Load parameters can be grouped by: 1) vehicle technology groups,
including vehicle type, make, model year, engine type, transmission type, frontal area, drag
coefficient, rolling resistance, vehicle maintenance history, etc.; 2) vehicle payload factors,
including passenger load and freight load; 3) roadway characteristics, including road grade
and possibly pavement surface roughness; and 4) onroad load parameters, based upon
vehicle speed and acceleration profile and environmental conditions.

Vehicle Technology Groups

The effect of vehicle class on emissions is significant. Five main factors that cause a
vehicle to demand engine power are vehicle speed, vehicle acceleration, drivetrain inertial
acceleration, weight, and road grade. As the required power and work performed by the
vehicle increases, the amount of fuel burned to produce that power also increases, and the
applicable emission rates also generally increase. Thus, emissions vary as a function of
vehicle class and vehicle configuration. The higher truck classes with larger engines are
heavier and, thus, typically produce more emissions. Vehicle configurations with large
frontal areas and high drag coefficients will yield higher emissions when operated at higher
speeds.

The concept of vehicle technology groups is to identify and track subsets of vehicles that
have similar on-road load responses and similar laboratory emission rate performance.
The basic premise is that vehicles in the same heavy-duty vehicle class, employing similar
drivetrain system, and of the same size and shape have similar load relationships. There is
also an important practical consideration in establishing vehicle technology groups;
researchers need to be able to identify these vehicles in the field during traffic counting
exercises.

The starting point for technology group criteria is a visual classification scheme. Yoon, et
al. developed a new HDV visual classification scheme call the X-scheme based on the
number of axles and gross vehicle weight ratings (GVWR) as a hybrid scheme between the
FHWA truck and EPA HDV classification schemes (15). With field-observed HDV
volumes, emissions rates estimated using the X-scheme were 34.4% and 32.5% higher for
NOx and PM, compared to using the standard EPA guidance. That was because the X-
scheme more realistically reflects vehicle composition in the field than does the standard
EPA guidance, which shifted heavy-HDV volumes into light- or medium-HDV volumes.
21% more frequently than the X-scheme. Figure 2 shows X-scheme classes and their typical figures.

Figure 2: The X Classes and Typical Vehicle Configurations

<table>
<thead>
<tr>
<th>X Class</th>
<th>EPA Class</th>
<th>Typical Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>HDV2b, HDV3, HDV4, HDV5, HDV6, HDV7</td>
<td>![Typical Figures]</td>
</tr>
<tr>
<td>X2</td>
<td>HDV8a</td>
<td>![Typical Figures]</td>
</tr>
<tr>
<td>X3</td>
<td>HDV8b</td>
<td>![Typical Figures]</td>
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</tbody>
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Vehicle age and model year effects are accounted for because some vehicle models have much lower average emissions. As the vehicles age, engine wear and tear will lead to higher emission rates under typical operating conditions. Information on vehicle age can be obtained from registration database using vehicle identification numbers and truck manufacturer records. The registration database can be sorted by calendar year and show vehicle registered in the given year by model year. However, given the differences noted between field-observation fleet composition and registration data in the light-duty fleet (16), significant additional research efforts designed to model the on-road subfleet composition (classifications and model year distributions) are even more warranted for HDVs. In addition, appropriate datasets that include detailed information on engine type, transmission type, etc. will be needed to appropriately subdivide the observed on-road groups and continue to develop respective emission rate. The data collection challenge in this area is daunting, but it is worth to perform once to provide a library of information that can be used in a large number of modeling applications.

Emitter Classification

The vast majority of heavy-duty vehicles are normal emitters, but a small percentage of vehicles are high-emitters under every operating condition, typically because they have been tampered with or they are malfunctioning (i.e. defective or mal-maintained engine sensors or actuators). As the vehicle ages, general engine wear and tear will increase
emission rates moderately due to normal degradation of emissions controls of properly functioning vehicles. On the other hand, as vehicles age, the probability that some of the vehicles will malfunction and produce significantly higher emissions (i.e. become high-emitters). Probability functions as to the classification of vehicles within specific model years (and later, within specific statistically-derived vehicle technology groups) are currently being developed through the assessment of certification testing and various roadside emissions tests.

On-road Driving Trace (sec-by-sec) and Speed/Acceleration Profile

Vehicle speed and acceleration are integral components to the estimation of vehicle road load, and therefore engine load. A variety of tools are available for collecting second-by-second vehicle activity from the onroad operating fleet. Laser rangefinders are one tool for efficiently recording second-by-second data from thousands of onroad vehicles (17, 18). However, remote sensing is limited to areas where line of sight from observer to vehicle travel is safe and unobstructed. Onboard vehicle instrumentation has recently been deployed in the Atlanta light-duty fleet (19), the Atlanta transit fleet (20) and the California Heavy-duty fleet (4) to track second-by-second vehicle activity. While onboard instrumentation is limited by the number of vehicles instrumented, large amounts of data from various locations in the city can be collected by the instrumented fleet. As such technologies become more pervasive in the fleet, very rich data sets of on-road activity can be provided for modal modeling.

Vehicle Payload

Passenger and freight payloads together with the tear vehicle weight contribute to the demand for power that must be supplied to produce the tractive force needed to overcome inertial and drag forces. Passenger loading functions for transit operations can be obtained through analysis of fare data or on-board count programs. On the heavy-duty truck side, on-road freight weight distributions by vehicle class can be derived from roadside weigh stations studies. Ahanotu conducted detailed weigh-in-motion studies in Atlanta and found that reasonable load distributions by truck class and time of day could be applied in such a modal modeling approach (21). Although additional field studies are warranted to examine the stability of the Atlanta results over time and the transferability of findings in Atlanta to other metropolitan areas (especially considering the potential variability in commodity transport, such as agricultural goods that may occur in other areas) the modeling methodology seems appropriate.

Roadway Characteristics

The three basic geometric elements of a roadway are the horizontal alignment, the cross-slope or amount of super-elevation and the longitudinal profile or grade. Among them, the grade has been shown to have significant impact on engine load and vehicle emissions. However, other roadway characteristics, such as lane width, are also noted to have a significant impact on the speed-acceleration profiles of heavy-duty vehicles (17) and can therefore affect engine load. Road grade is a required element for the modal model and must be coded for the modeled infrastructure.
Correction Factors & Environmental Factors

The current MOBILE6.2 model includes correction factors to account for the impact of environmental and onroad operating conditions on vehicle emission rates. Speed correction factors, emission rate impacts associated with increases or decreases in average vehicle speeds relative to the certification test speeds, have been eliminated in the modal modeling regime because emissions are now predicted directly as a function of engine load (and vehicle speed is included in the calculation of engine load). However, the environmental factors (altitude, temperature, and humidity) are not included in any the current model algorithms. Given the lack of compelling additional data available for analysis, the researchers propose to continue to use the embedded MOBILE6.2 corrections for these three environmental parameters. However, preliminary analyses of the data and methods used to derive the MOBILE6.2 environmental correction factors indicate that the embedded equations in MOBIL6.2 probably need to be revisited.

Drivetrain Power Loss & Inertial Losses

After engine horsepower at the output shaft has been reduced by power losses associated with fluid pressures, operation of air conditioning, and other accessory loads, there is still an additional and significant drop in available power from the engine before reaching the wheels. Power is required to overcome: mechanical friction within the transmission and differential, internal working resistance in hydraulic couplings, and friction of the vehicle weight on axle bearings. The combined effect of these components is parameterized as drivetrain efficiency. However, the more difficult and more significant component of power loss in the drivetrain is associated with the inertial resistance of drivetrain components rotational acceleration.

A heavy-duty truck drivetrain is significantly more massive than its light-duty counterpart. The net effect of drivetrain inertial losses when operating in higher gears on freeways, may not be significant enough to be included in the model (relative to the other load-related components in the model for these heavy vehicles). However, recent studies appear to indicate very high truck emission rates (gram/second) in “creep mode” stop and start driving activities noted in ports and rail yards. This may indicate that the high inertial loads for low gear, low speed, acceleration operations may contribute significantly to emissions from mobile sources in freight transfer yards and therefore should not be ignored.

The inertial losses are a function of a wide variety of physical drivetrain characteristics (transmission and differential types, component mass, etc.) and on-road operating conditions. To refine the use of inertial losses in the modal model, new drivetrain testing data designed to evaluate the inertial losses for various engine, drive shaft, differential, axle, and wheel combinations and to establish generalized drivetrain technology classes. Then, gear selection probability matrices for each drivetrain technology class, and gear and final drive ratio data can be provided in lookup tables for model implementation, in place of the inertial assumptions currently employed.
Preliminary Analysis Results

The research team examined a set of test data for a 1990 Kenworth T800 tractor truck collected by USEPA in 2001. The vehicle was operated at predetermined steady state modes of 15, 35, 55, 65 mph as well as accelerations and decelerations between each mode. Data were recorded on a second-by-second basis and researchers examined the relationship between NOx production (in units of g/s) and rear axle power of vehicle based on this set of chassis dynamometer testing data. The actual speed-time profile is shown in Figure 3.

Figure 3: Speed Profile of Steady State Test for a Heavy-Duty Truck (EPA, 2001)

The axle power (AHP) estimated by the road load equation shown below is the theoretical power demand at the rear axle for the given speed and acceleration conditions to be met. The spikes in axle-hp in Figure 4 occur due to the high acceleration rates and deceleration rates demanded by the driving schedule. The regression equation shown on Figure 1 can now be used to predict NOx as a function of axle power. Instantaneous NOx emissions obtained from regression equation are shown in Figure 5. Since regression equations did not provide prediction for negative power, NOx emissions were set to idle rate for negative rear axle power. Additional research into the relationship between emission rates at idle and under motoring conditions are necessary.
Figure 4: Instantaneous Theoretical Axle Power Demand for the Steady State Test
\((C_r=0.012, C_D=0.99, A=46\text{in}^2)\)

Figure 5: Instantaneous Theoretical NOx Emissions for the Steady State Test using the Second Order Polynomial Regression Fit
Figure 6: Difference between Predicted and Measured NOx emission rate (g/s) vs. Measured Power (bhp)

The analysis illustrated above provides a generalized example of model approach. In the current iteration of the modal activity-based HDDV emissions model, the Georgia Tech research team is using MOBILE6.2 emissions rates for each vehicle type until better data become available (22). The research team is currently assembling laboratory and chassis emission testing data from various sources and is planning to work with agencies and research groups to incorporate new heavy-duty vehicle emissions and modal activity-based power demand data from ongoing and future testing programs.

CONCLUSIONS

The proposed modeling approach is expected to significantly improve the accuracy of emissions evaluation for heavy-duty diesel vehicles (HDDVs). Emissions from HDDVs are more likely to be a function of brake-horsepower load on the engine (especially for NOx) than light-duty gasoline vehicles, because instantaneous emissions levels of diesel engine are highly correlated with the instantaneous work output of the engine. Diesel engine work at high compression ratios of 14:1 to as high as 25:1 (significant excess air) and do not suffer from the same air:fuel ratio issues that gasoline engines do. Diesel engines take in air, compress the air, and inject fuel to initiate combustion. In gasoline engines, one rapid acceleration event disturbing the air:fuel balance can cause as much pollution as the entire remaining trip (a small percentage of a gasoline vehicle’s activity can account for a large share of the vehicle’s emissions).
There are several key features that make the modal modeling approach more appropriate for emissions prediction than current emission rate modeling tools:

- Modal models take into account most of the factors in the heavy-duty diesel vehicle operation environment that affect emissions, such as vehicle age, engine type, transmission type, fuel type, on-road driving conditions, and roadway characteristics.
- The statistical approach avoids extrapolation with correction factors beyond ranges under which test data were collected.
- Components employed within modal models are much easier to verify with field and laboratory tests and therefore to improve when field tests do not corroborate model data, algorithms, or assumptions. For example, second-by-second vehicle and engine data can be readily collected in field studies, aerodynamic and rolling resistance equations can be tested in the laboratory and on test tracks, and PEMS emissions monitoring devices can be deployed to collect second-by-second emission rate data.

The major improvement of the proposed model is in the area of roadway characteristics (primarily grade) and the ability to model specific engines and transmissions. Implementation of models that are much more detailed than the MOBILE6.2 emission rate model will require extensive data collection efforts, both in terms of emission rate development and characterization of the fleet and on-road operating parameters necessary to develop estimates of real-time engine loads. The top five data needs are:

- On-road emissions testing as a function of engine load
- Technology subgroup development (data and statistical grouping)
- Roadway characteristic data
- Modal activity
- Inertial loads

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