COMPARATIVE ANALYSIS OF THE EPA OPERATING MODE GENERATOR WITH REAL WORLD OPERATING MODE DATA

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ABSTRACT

In June 2012, the Environmental Protection Agency (EPA) released the “Operating Mode Distribution Generator” (OMDG) a tool for developing an operating mode distribution as an input to the Motor Vehicle Emissions Simulator model (MOVES). The tool converts basic information about traffic operations – idle time, grade, and average speed – into an operating mode distribution. This tool is designed to make project-level analyses for CO and PM hot-spots easier to conduct with basic traffic activity data.

This paper compares the operating mode distributions obtained from this tool with those measured on a vehicle instrumented with the Total On-Board Tailpipe Emissions Measurement System (TOTEMS). TOTEMS generates a wealth of data, including a vehicle’s speed, idle time, and link grade – all of the inputs necessary to run the OMDG. The comparison is made for 4 signalized intersections on an urban arterial in Burlington, Vermont.

This analysis shows that the OMDG, when compared to 31 test runs of an instrumented vehicle, was more accurate under circumstances of no to low grade and higher congestion (higher stop time). Estimation inaccuracies are most critical for specific operating modes -- for CO under high VSP conditions; for PM$_{10}$ under braking conditions (i.e. VSP <0).

This investigation has developed a method for quantitatively evaluating tools designed to simplify a mobile emissions analysis. Future work will include the development of models for estimating operating modes of a traffic stream using traffic microsimulation and highlighting those parameters that are most critical to calibrate for obtaining an accurate operating mode distribution estimate.
INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has published guidance for performing “project-level” transportation conformity analysis of PM$_{10}$, PM$_{2.5}$, and CO “hot-spots” – sub-regional areas where local pollution concentrations might exceed National Ambient Air Quality Standards [7]. To quantify emissions impacts from hot-spots, EPA requires use of the Motor Vehicle Emission Simulator (MOVES). Current regulations will require that MOVES be applied for “hotspot” analysis beginning in December 2012.

The development of MOVES creates a new era in mobile source modeling that brings with it some significant modeling challenges, particularly in developing accurate inputs. Key among the inputs for a project-level analysis is the traffic activity data. MOVES provides three methods for supplying traffic activity data — average speeds, time-speed trajectories (link drive schedules), and operating mode distributions. However, prior research has concluded that, of these three methods, providing an operating mode distribution of the traffic stream results is the most direct method for taking advantage of the drive schedule data programmed into MOVES [2, 3, 4]. When using the other two approaches — average speed or the link drive schedule -- MOVES translates the input data into an operating mode distribution resulting in some loss of accuracy.

There are many methods for estimating an operating mode distribution, including traffic microsimulation modeling. However, some of these methods can be quite sophisticated and, hence, costly. Further, as described below, there are questions raised in prior research regarding the suitability of traffic microsimulation for accurately replicating the operating modes of a traffic stream. For these reasons there is interest in developing simpler analytical methods for developing traffic activity data inputs to MOVES. Simpler analytical methods would be more affordable and easier to execute by agency staff tasked with performing or peer-reviewing a project-level analysis.

To advance the objective of having an analytically accessible traffic activity model, the EPA developed the MOVES Operating Mode Distribution Generator (OMDG). The OMDG enables the analyst to input basic data on traffic operations — average speed of the vehicle stream, time spent idling (as a fraction of the total travel time), and average grade of the roadway — and obtain a corresponding operating mode distribution. Using the OMDG can greatly simplify the preparation of traffic activity data for input into MOVES. As the OMDG is a modeling tool that simplifies the approach, a key question relates to the accuracy of the OMDG’s output. How much, if any, accuracy is sacrificed through the process of simplifying the traffic activity modeling?

This paper examines this question by comparing the operating mode distribution from a real-world instrumented vehicle with that obtained using the OMDG. We seek to understand how much CO and PM$_{10}$ emissions accuracy is sacrificed through simplifying the traffic activity input data with the OMDG.

BACKGROUND

A number of studies have researched the preparation of traffic activity data as inputs to mobile source air quality models. Several of these have evaluated the use of microsimulation modeling for this purpose.

Chamberlin et al. [5,6] showed that microsimulation models could be used to develop traffic activity inputs to MOVES for analyzing the emissions impacts of traffic operational changes such as signal optimization or changes to an intersection control. The authors showed how microsimulation modeling could be used to prepare traffic activity data for each of the three input methods MOVES supports: average speed, link drive schedule, and operating mode distribution. The research concluded that operating mode distributions provide the most direct method of utilizing MOVES modal approach to emissions generation.

Other research has raised questions regarding the suitability of traffic microsimulation modeling for producing accurate traffic modal information. Hallmark and Guensler [7] compared the speed-acceleration distributions obtained from traffic activity data developed using the
NETSIM microsimulation model with field data obtained with a laser range finder (LRF). The LRF data enabled the calculation of speed and acceleration for a sample of vehicles observed traversing a signalized intersection. The speed-acceleration distributions of sampled vehicles were calculated and compared against the distributions of similar vehicles modeled in the microsimulation. The analysis concluded that NETSIM, at default driver parameter inputs, does not adequately simulate instantaneous modal vehicle activity at intersection approaches. For mid-block operations, field data exhibited greater speed/acceleration variability than generated by NETSIM.

Viti et al. [8] estimated traffic stream operating modes at a signalized intersection using image processing. Their work compared the results of two microsimulation software packages and confirmed that the default driver acceleration parameters are not accurate representations of real-world operational activity data. Specifically, default microsimulation driver behavior parameters assume higher acceleration rates of unconstrained (non-following) vehicles, leading to an overestimation of emissions impacts.

Song et al. [9] reinforced this finding further when they evaluated the use of VISSIM to adequately replicate the operating modes of a real-world traffic stream obtained from an instrumented vehicle. They focused on vehicle specific power (VSP) as the most critical explanatory variable. The research team evaluated over 8,800 speed segments (>500,000 seconds of real-world speed data) to develop normal distributions of VSP by 2 mph speed bins. A simulation test bed was constructed in VISSIM and calibrated to average speed and flow. The simulation test bed indicated that microsimulation overestimated the fraction of vehicle flow in lower and higher VSP bins, resulting in significant errors in emissions estimates when compared to real-world data. The analysis went further to adjust 6 driver behavior parameters to determine whether the statistical fit between the real world and simulated VSP data could be improved. The authors concluded that traditional calibration methods could not improve the accuracy of replicating VSP distributions of real-world data.

In summary, foregoing research has evaluated the suitability of microsimulation modeling for generating traffic activity data inputs for MOVES. There is general concern that these methods may be beyond the capabilities of many agencies tasked with either conducting or peer reviewing a project-level analysis using MOVES. Furthermore, much of the previous research questions the ability to calibrate microsimulation models to the operating modes of the real-world traffic stream.

To address these concerns, Papson et al. [10] developed a streamlined methodology which associates traffic activity with time spent in one of four “modes” – cruise, deceleration, acceleration, idle – using Webster’s equations for time-distance relationships at intersections. The authors developed quantitative relationships to translate “time in mode” into emissions outputs for signalized intersections. This work represents one method for simplifying the traffic activity inputs to MOVES, basing an input operating mode distribution on a standard traffic engineering analysis (level of service).

In one of the early research studies for establishing the process of conducting a project-level analysis using MOVES, Pechan et al. [11] developed activity profiles for a number of facilities where a project-level emissions analysis may be required. These included freeway on-ramps, freeway-to-freeway interchanges, and signalized arterials. The authors developed default VSP profiles for these situations from which operating mode distributions could be estimated for input into MOVES.

EPA’s newly released methodology – the MOVES Operating Mode Distribution Generator – is a further attempt to simplify the process of producing traffic activity inputs for MOVES. The OMDG is designed to simplify the approach to estimating operating modes based on average intersection approach speeds. In doing so, the OMDG is designed to provide a more accurate estimate of a traffic stream’s operating mode distribution than would be the case assuming a simple average speed for all approach traffic.

Acknowledging that any modeling exercise is a simplification of real world dynamics, the research presented in this paper seeks to identify the strengths and weaknesses of the OMDG tool.
for producing accurate traffic activity inputs to MOVES. The existence of highly detailed traffic
activity data from an instrumented vehicle enables an analysis of the accuracy of the OMDG for
replicating a real-world operating mode distribution given the relatively coarse traffic activity input
data required by the OMDG.

REAL-WORLD DATA

This research leverages part of a dataset developed at the University of Vermont
Transportation Air Quality Laboratory using an on-board instrumentation package, TOTEMS,
developed to quantify the following vehicle emissions and performance metrics at one second
resolution while a test vehicle is driven on the real-world road network: tailpipe gas and particle
pollutant emission rates, vehicle position, engine operating parameters, ambient environment and
instrument conditions. All devices are powered by an on-board battery system to prevent additional
loads on the vehicle engine. Details on the TOTEMS instrumentation can be found in previous
work [12,13,14]. In this study, only vehicle activity and road grade data were used to address the
research questions.

Vehicle position was measured using two GPS receivers mounted on the roof of the test
vehicle. A Garmin GPS16-HVS receiver was used to provide primary location data and its Fugawi
software synchronized computer clocks. A Geostats Geologger model DL-04, Version 2.4 served as
a backup receiver. Speed and acceleration were determined based on vehicle speed data collected at
>3 Hz by a Toyota TechStream OBD-II scantool. Scantool data were averaged to 1 Hz resolution to
match that of the GPS receivers. Data were validated using range checking for individual scantool
parameters; ArcGIS was used to remove erroneous locations outside a 25m route buffer.

Road grade was measured using the gyroscopic system of the Vermont Agency of
Transportation ARAN van (Automated Road Analyzer; www.fugroroadware.com) at 0.002 mile
spatial resolution. The test vehicle was a model year 2010 Toyota Camry conventional gasoline
sedan driven by a single driver over a 32 mile driving route through Chittenden County Vermont.
The vehicle weight with TOTEMS instruments, battery power system, driver and passenger was
~300 pounds over vehicle curb weight. Prior to data collection, the vehicle was driven on a 2.5-mile
warm-up route so that engine coolant temperature was equal for cold and warm test dates over the
study period (February 2010 to September 2011). Thirty-one repeated runs of the entire 32-mile
route were used for this analysis. Temperature and relative humidity were logged with Onset
HOBO loggers mounted both inside and outside the vehicle.

Vehicle specific power (VSP) was calculated from the measured vehicle speed, computed
acceleration, and road grade joined to the vehicle’s 1Hz lat/long GPS position using ESRI ArcMAP
version 9 software.

\[
VSP = n^{-1}(av + bv^2 + cv^3 + mva + gmv\sin[\tan^{-1}(gG/100)])
\]

where

- VSP = vehicle specific power (kW/metric ton)
- n = 1.4788 (fixed mass factor)
- a = 0.156461
- b = 0.00200193
- c = 0.000492646
- v = speed in meters per second
- a = acceleration in meters per second per second
- m = 1.55001585 (vehicle mass in metric tons)
- g = 9.81 (acceleration of gravity)
- G = road grade in percent
DESCRIPTION OF THE URBAN ARTERIAL TEST BED

For this study a 0.70 mile portion of the 32-mile vehicle circuit was chosen as a test bed. This specific portion represents a signalized urban arterial corridor with moderate to high congestion. Hence, significant idling time can be encountered along its length, making it a good candidate for evaluating the OMDG.

The test bed (Figure 1) is in Burlington, Vermont, and begins just south of North Street and extends southward to south of Main Street. The corridor passes through five signalized intersections: Sherman Street, Pearl Street, Cherry Street, College Street, and Main Street, from north to south. Between North Street and Sherman Street, the corridor is one-way in the south bound direction and has two lanes. Between Sherman Street and Main Street the corridor has two lanes in each direction. For the purposes of this research the corridor has been divided into 6 segments of lengths ranging from 400 to 800 feet, five of which contain a signalized intersection (Table 1).

The corridor is an urban arterial with a posted speed limit of 30 mph. Development along the corridor is relatively dense and urban in nature, except for along the west side between Sherman Street and College Street, where there is a park. Between North Street and Pearl Street (Segments 1 and 2) the corridor is relatively level, but between Pearl Street and Main Street the corridor has a significant downslope. On its 32-mile trial circuit, the TOTEMS vehicle progressed from north to south, from segments 1-6 sequentially.

Table 2 shows the key operating characteristics of the TOTEMS vehicle over each of the 6 Battery Street segments, providing the portion of the link travel time spent idling and the average vehicle speed. These two operating parameters are featured as they are inputs to the Operating Mode Distribution Generator.

Four of the six segments were selected for the comparative analysis described in this research. Segment 1 did not include a major intersection and thus would not include significant idling time, an essential input to the OMDG for this analysis. Segment 4 was also dropped from the analysis because its 6% grade was outside the grade thresholds supported by the OMDG [4].

Segments 2, 3, 5, and 6 are considered suitable for this comparative analysis for the following reasons:

1. They incorporate a signalized intersection and, as a result, have a non-zero idling fraction.
2. They include grade effects within the -5 to +5% thresholds supported by the OMDG.
3. They have varying amounts of main-and side-street traffic providing variability in the traffic conditions encountered along each segment.
Figure 1: Test Bed Urban Arterial, Battery Street in Burlington, Vermont, Showing Six Segments (four of which are used for the comparative analysis).

Table 1: Key Characteristics of the Battery Street Segments

<table>
<thead>
<tr>
<th>Segment</th>
<th>Length (feet)</th>
<th>Grade (southbound)</th>
<th>Cross Street</th>
<th>Control</th>
<th>Major Street</th>
<th>Cross Street</th>
<th>Daily Entering Vehicles</th>
<th>Daily Entering Vehicles</th>
<th>Analyzed</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>650</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4,300</td>
<td>-</td>
<td>No</td>
<td>No major intersection</td>
</tr>
<tr>
<td>2</td>
<td>650</td>
<td>0.5</td>
<td>Sherman St</td>
<td>Signal</td>
<td>9,000</td>
<td>5,000</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>-3.3</td>
<td>Pearl St</td>
<td>Signal</td>
<td>15,100</td>
<td>2,400</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>800</td>
<td>-6.2</td>
<td>Cherry St</td>
<td>Signal</td>
<td>16,100</td>
<td>1,700</td>
<td>No</td>
<td>Grade outside of range of tool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>450</td>
<td>-4.6</td>
<td>College St</td>
<td>Signal</td>
<td>13,900</td>
<td>2,800</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>400</td>
<td>-2.6</td>
<td>Main St</td>
<td>Signal</td>
<td>10,000</td>
<td>6,800</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: TOTEMS Real-World Vehicle Operating Parameters by Street Segment

<table>
<thead>
<tr>
<th>Segment</th>
<th>Portion Time Idling</th>
<th>Average Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>0.400</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>0.100</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>0.025</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>0.055</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>0.320</td>
<td>11</td>
</tr>
</tbody>
</table>

DATA PROCESSING

The key question of this research is determining how well the simplifying analytics of the Operating Mode Distribution Generator can replicate operating modes from a real-world instrumented vehicle. It is assumed that some amount of data accuracy will be sacrificed for the greater simplicity in traffic activity inputs required by the OMDG. Thus, the key comparison is between the operating mode distributions produced by the OMDG with the real-world operating mode distribution of the TOTEMS vehicle. A second set of comparisons is made for hot-spot emissions – PM$_{10}$ and CO.

The OMDG has three main inputs: average speed, percent time idling, and average grade. These were calculated for each of the four segments using the data from the TOTEMS vehicle, averaging across 31 separate runs through the Battery Street test bed. The OMDG input values for each of four segments were used to generate the operating mode distributions for each of the four segments 2, 3, 5, and 6. The operating mode distributions generated by the OMDG were then compared to the actual operating mode distributions calculated from the 31 TOTEMS vehicle trials for each of the four segments.

For the emissions analysis, these OMDG operating mode distributions and the TOTEMS real-world operating mode distributions were run in MOVES2010a assuming two year old vehicles of source type 21 (passenger vehicles). The MOVES emissions estimates were for Chittenden County, VT, during an 8:00 am hour in July of 2012. Estimates were for the running exhaust, tire wear, and brake wear emission processes.

ANALYSIS OF RESULTS

Operating Mode Distribution Comparison. Operating mode distributions generated by OMDG for the TOTEMS data were in agreement with the OpMode frequencies computed directly from TOTEMS raw data for some for some segments and not others (Figure 2). The discrepancies between OMDG and mean TOTEMS OpModes could often be significant and outside a 95% confidence interval for the mean of the real-world data. For example, OpModes 0 and 11 showed large deviations from measured values for Segments 2, 3, 5 and 6. OpMode 21 differences were greatest for Segment 3. These OpModes which show frequency differences between OMDG and TOTEMS are expected to also result in differences in emission rates. However, the quantitative significance of any single operating mode on segment (link) emissions depends on the specific emission factor associated with that operating mode within MOVES. Thus, it is important to also compare computed emission rates to quantify the overall net effect of discrepancies in segment operating mode distributions.
Figure 2. Segment 2, 3, 5, 6 Operating Mode Distributions, OMDG (triangles) vs TOTEMS (circles). Error bars show 95% confidence interval of the mean of the TOTEMS vehicle over 31 trial runs.

Emission Rates. The end goal of a project-level analysis is to estimate emissions, so an appropriate way to evaluate the performance of the OMDG is to compare MOVES emissions estimates based on the OMDG results to estimates based on the TOTEMS real-world operating mode distributions.

Overall emissions analysis by arterial segment (Figure 3) shows that the OMDG over-estimates CO emissions by about 30 percent or more for segments 3, 5, and 6, but roughly matches the TOTEMS estimates for segment 2. For PM$_{10}$, the OMDG and TOTEMS estimates are basically the same for segments 2, 3, and 6, but the OMDG under-estimates for segment 5 by about 10%. The OMDG performs better for PM$_{10}$ (under-estimating by 10 percent for one segment), than for CO (over-estimating by 30 percent for three segments).

The difference in performance could be explained by the difference in variability of emission rates between PM$_{10}$ and CO. The raw MOVES emission rates by operating mode for PM$_{10}$ vary from about 0.3 to 2.4 grams per vehicle-hour (Figure 4). For CO, the emission rates by operating mode vary from about 0.3 to 800 grams per vehicle hour (Figure 4), making it more sensitive to errors in the operating mode distribution estimates. PM$_{10}$ emission rates by operating mode are less variable and, hence, more forgiving of errors in the operating mode distribution, resulting in better performance.
Another useful comparison to make is performance by segment within one pollutant type. For CO, the OMDG performed well for segment 2, and not as well for segments 3, 5 and 6 (Figure 3). To investigate the reasons for the difference in performance, we introduce the weighted emission rate, which is the product of the raw emission rate and fraction of VHT within each operating mode bin for a particular operating mode. The weighted emission rate indicates the amount of pollution in one vehicle-hour that can be attributed to a particular operating mode. The sum of all weighted emission rates across all operating modes is the overall emission rate for the vehicle-hour. Errors in the weighted emission rates (arising from errors in operating mode distribution) contribute to the error in the overall segment emission rate.

Investigating the weighted emission rates for CO shows that much of the error associated with segments 3, 5 and 6 can be attributed to over-estimating the distribution for operating mode 30 (Figure 5), which is the highest power-output operating mode for 25-50 mph speeds, and has the highest emission rate of any operating mode (more than 800 grams per vehicle-hour – about three times higher than the second highest emission rate). With such a high emission rate, even small errors in estimating the distribution for operating mode 30 will have a large effect on emissions estimates. In fact the absolute errors for operating mode 30 are small – less than one percent. But the magnifying effect of the large emission rate results in high emissions estimate errors.

The distribution for operating mode 30 is not as severely over-estimated for segment 2 as for the other segments (see Figure 5). One possible explanation is that the OMDG performs better for more moderate grades than for more severe grades. The MOVES default operating mode distributions (which are used by the OMDG) were developed to represent average conditions. As the traffic conditions being modeled depart from the average, the emissions estimates will become worse. Segment 2 has an average grade of 0.5 percent, but the segments 3, 5 and 6 have grades of -3.3, -4.6, and -2.6 percent. It is possible that the more severe grades depart too much from average conditions to allow accurate emissions estimates.

For PM$_{10}$, the OMDG performed well for segment 2, 3, and 6 (Figure 3). However, looking at the weighted emission rates by operating mode (Figure 6) shows that for segments 3 and 6, the good fit results from relatively severe errors of opposite sign canceling each other out, which leaves only segment 2 as a truly good fit.

The main sources of error for PM$_{10}$ are OpModes 11 and 21, which are VSP<0 coasting modes for speed ranges 1-25 and 25-50 mph, respectively; and OpMode 0, which is braking. These PM$_{10}$ OpModes with high error are distinct from that for CO (OpMode 30) suggesting a significant contribution from brake and tirewear PM$_{10}$ emissions. For segments 3, 5, and 6 braking emissions are over-estimated and coasting are under-estimated (Figure 6) by OMDG. This may partly reflect the operational environment of the test bed. As the TOTEMS vehicle travels south along the 0.7 mile testbed, it enters and travels through a coordinated-signalized corridor. The first coordinated signal it encounters at Sherman Street in Segment 2; once the vehicle leaves the intersection at Sherman Street, it is unlikely to encounter a red light at a downstream intersection, which would result in less braking than for average conditions. On the other hand, arrivals at Sherman Street in Segment 2 are not coordinated, and so are more likely to encounter a red light, which may result in an operating mode distribution that is closer to the average.
Figure 3. Segment CO and PM$_{10}$ MOVES Emission Rates, OMDG (triangles) vs TOTEMS (circles).

Figure 4. Raw CO and PM$_{10}$ MOVES Emission Rates by OpMode.

Figure 5. Segment Weighted CO Emission Rates, OMDG (triangles) vs TOTEMS (circles).
Figure 6. Segment Weighted PM\textsubscript{10} Emission Rates, OMDG (triangles) vs TOTEMS (circles)
CONCLUSIONS

There is a desire to develop turnkey tools for developing traffic activity inputs to MOVES, particularly in light of current federal regulations requiring project-level hot spot analysis. Prior research has concluded that traffic microsimulation models are good candidates for developing these inputs. However, developing these models can be expensive and time consuming. Further, there are questions raised in the research regarding the applicability of default driver behavior assumptions embedded in microsimulation models, which can cause significant deviation of the simulated operating mode distribution from that of a real-world traffic stream.

In response, EPA has developed the Operating Mode Distribution Generator (OMDG), an Excel-based tool for estimating an operating mode distribution using coarser traffic activity inputs. The research presented in this paper seeks to identify the strengths and limitations of the OMDG in replicating an operating mode distribution from real-world data obtained from an instrumented vehicle driving along a signalized urban arterial. The research establishes the following:

1) For many operating modes the OMDG was a good predictor when compared with those obtained from the instrumented vehicle for all segments;

2) While no generally applicable rule can be distilled for where disagreement occurred, the data analysis points to specific operating modes where estimation error is more common and most critical in determining emissions impacts.

3) Estimation error for PM\textsubscript{10} stems from errors in operating modes associated with braking (i.e. operating mode bins 1, 11, and 21). Due to the high PM\textsubscript{10} emission factors associated with these operating mode bins, small errors in estimating this operating mode will result in large errors in emissions estimates. Future studies should examine the relative PM\textsubscript{10} contributions from running exhaust, tire and brake wear emissions in these modes.

4) Estimation error for CO is associated with errors in the high acceleration operating modes (i.e. mode bins 29 and 30). Due to the high CO emission factors associated with these operating mode bins, even small errors in estimating this operating mode will result in large errors in emissions estimates.

5) Test bed arterial segments with higher grade had poorer results in estimating operating modes than the one segment (Segment 2) with a relatively flat grade.

Overall, OMDG enables simplified operating mode distribution inputs to MOVES. However, analysts must recognize that individual pollutant emission rates have different sensitivities to certain operating modes, as shown here. Future research is needed to better calibrate simplified models like OMDG to better capture real-world vehicle activity and associated emissions near intersections. Future refinements of tools like OMDG could be validated for their emissions accuracy using the methodology outlined in this work.

ACKNOWLEDGMENT

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