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Implications of driving style and road grade for accurate vehicle activity data and emissions estimates

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ABSTRACT

Real-world vehicle operating mode data (2.5 million 1 Hz records), collected by instrumenting the vehicles of 82 volunteer drivers with OBD datalogger and GPS while they drove their routine travel routes, were analyzed to quantify vehicle emissions estimate errors due to road grade and driving style in rural, hilly Vermont. Data were collected in winter and summer for MY 1996 and newer passenger cars and trucks only. EPA MOVES2010b was used to estimate running exhaust emissions associated with measured vehicle activity. Changes in vehicle specific power (VSP) and MOVES operating mode (OpMode) due to proper accounting for real-world road grade indicated emission rate errors between 10% and 48%, depending on pollutant, chiefly because grade-related changes in VSP could shift activity by as many as six OpModes, depending on road type. The correct MOVES OpMode assignment was made only 33–55% of the time when road grade was not included in the VSP calculation. Driving style of individual drivers was difficult to assess due to unknown traffic operations data, but the largest differences between individual drivers were observed on rural restricted roads, where traffic conditions and control have minimal impact. The results suggest the importance of (1) measuring and incorporating real-world road grade in order to correctly assign MOVES emission rates; and (2) developing a driving style typology to account for differences in the MOVES emissions estimates due to driver variability.

Introduction

Motor vehicle emissions are a primary concern because of their potential detriment to local air quality and global atmospheric conditions. Although significant progress has been made to limit the pollutant emissions from individual vehicles, emissions from conventional gasoline-powered light-duty motor vehicles remain a concern as they are the most prevalent mode of passenger transport in the U.S. and account for the majority of petroleum consumption (EPA, 2009). In an effort to improve the fidelity of emissions estimates from mobile sources, the Environmental Protection Agency developed the Motor Vehicle Emission Simulator (MOVES). MOVES is capable of emissions estimates at a range of spatial (national, county, and project-level) and temporal scales and is a required tool for state implementation plans, transportation project conformity, and air quality compliance.

At the project-level scale, MOVES inputs can consist of a simple average speed, a speed-time trajectory, or a distribution of vehicle specific power (VSP), which is a surrogate for the resistances a vehicle must overcome for propulsion. Combined with

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speed, the VSP activity is classified, or binned, into 23 "running" operating modes for which corresponding emissions rates by vehicle type, vehicle age, fuel type, emission control technology, and atmospheric conditions are provided. In the real-world, these speed-time trajectories would be expected to vary based on the individual's driving style. For instance, a driver that tends to accelerate or brake hard would have a different speed–time trace than a driver that slowly approaches their target speed or brakes well in advance of an intersection or impedance. Note that both of these drivers may have the same average link speed that would be assigned in a traffic simulation model, a potential source of vehicle trajectories especially for project-level MOVES. In addition, the vehicle trajectory approach is generally applied without regard for an important term in the calculation of vehicle specific power: road grade.

Based primarily on the relationship between vehicle operating modes and tailpipe emissions, the MOVES model has been populated with empirical data. Because the predominant sources for empirical emissions data are laboratory-based dynamometer studies, real-world factors such as road grade and driving style are largely unmeasured. Some in-vehicle portable emissions measurement systems (PEMS) and road side studies have filled gaps on the relationship between real-world activity and emissions, but these studies are limited to monitoring a single vehicle at a time or many vehicles at a single spatial location.

Limited research has been conducted to date to quantify the uncertainty introduced to vehicle activity by the real-world factors of driving style and road grade and the associated implications for emissions estimates. This paper aims to broaden understanding and answer the following questions based on on-road data collected from 82 drivers during routine travel in real world conditions: (1) how important is road grade in estimating accurate, real-world vehicle activity and emissions, especially for areas with hilly terrain?, and (2) what is the uncertainty in vehicle activity and emissions estimates due to individual driving style?

Literature review

A review of literature targeted research to date on (1) the relationship of individual driving style to tailpipe emissions, (2) road grade and its relationship to tailpipe emissions, and (3) methods of improving activity inputs for emissions estimation models through traffic simulation and emission model integration.

Driving style

There have been relatively few attempts to link an individual's driving style, aggressivity, or eco-driving to changes in tailpipe emissions or fuel consumption (Barth and Boriboonsomsin, 2009; Belz and Aultman-Hall, 2011; Frey et al., 2008; Holmén and Niemeier, 1998; Jackson et al., 2006; Nam et al., 2003). Techniques aimed at changing driving style, such as eco-driver training or in-vehicle driver feedback technologies, have been of increasing interest. These approaches are intended to alter an individual's driving style to yield savings in fuel use or tailpipe pollutants, with data collection targeting the efficacy of the method. For instance, real-time eco-driving guidance to drivers along different simulated congestion conditions has been shown to reduce fuel consumption and carbon dioxide (CO_2) emissions by 10 to 20% (Barth and Boriboonsomsin, 2009). However, these studies do not give a good indication of the diversity of driving styles for all vehicle operators in the system.

Comparison of multiple drivers along a replicate route is one method used to better understand the variability in driving style. Although frequency of activity in seven distinct operating modes was shown to be consistent across 24 drivers in a single vehicle (model year 1996) along the same route, the intensity of emission events in these operating modes varied greatly across drivers (Holmén and Niemeier, 1998). This work suggested that the route was more indicative of the mode distribution than the individual driving style (Holmén and Niemeier, 1998). A later study of 20 different drivers on a single route in one test vehicle (model year 1999) resulted in a wide range of tailpipe emissions across drivers, and also identified the importance of the interaction between driver and road type (Jackson et al., 2006). In essence, a driver with wide variability of a particular pollutant on one road type may have narrow variability on another road type (Jackson et al., 2006). Testing across segments of the population could lead to certain categories or types of drivers with characteristic behaviors. For instance, a comparison of older and younger drivers operating their own vehicles indicated that, on average, younger drivers' activity was more frequently in higher emitting VSP bins compared to their older counterparts on the same route (Belz and Aultman-Hall, 2011).

Another methodology utilized to gain insights on driving style has been to disaggregate driving style at the trip level. For instance, one approach looked at the driving styles of three different drivers controlling for route, vehicle, travel direction, and time of day (Frey et al., 2008). Driving style across the different drivers on average introduced variability for different pollutants, with 5% for CO_2 and up to 108% for carbon monoxide (CO) (Frey et al., 2008). In a similar study, an "aggressivity" factor was defined based on speed and acceleration, with the goal of capturing the range of driving styles and the upper and lower bounds of associated tailpipe emissions (Nam et al., 2003). In this case, aggressive driving produced increased CO and hydrocarbon (HC) emissions by almost one order of magnitude, as well as slightly increased fuel consumption, CO_2, and oxides of nitrogen (NO_x) (Nam et al., 2003).

A common limitation among these studies was the small number of drivers and trips sampled, with authors recognizing the need for an increased sample of drivers (Jackson et al., 2006).