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Effects of vehicle technologies, traffic volume changes, incidents and work zones on greenhouse gas emissions production

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ABSTRACT

This paper quantifies the effects of newer, more efficient vehicle technologies, traffic volume changes, incidents and work zones on emissions production from on-road traffic. The effects are studied using microscopic traffic simulation and developed emissions estimation tools that together can capture emissions effects from the operating parameters of vehicles. An emissions estimation tool is used to estimate CO_2, CO, CH_4, THC, NOx, SOx, PM_{10} and $PM_{2.5}$ emissions from on-road traffic. A case study of Montgomery County, Maryland's I-270-MD-355 corridor, including connecting arterials, was conducted. This indicates that vehicle composition greatly affects the amount of emissions, and significant potential for reaching emissions reduction goals exists through improvements in vehicle mix efficiencies within the traffic composition. Further work zones and traffic incidents reduce the amount of emissions produced due to reduced average speeds, while per vehicle emissions rise over the span of the simulation network and simulation period. Models are also developed to support GHG emissions analyses for other comparable roadways.

1. Introduction

Traffic congestion has increased over past decades. This is in part due to an increase in vehicle ownership and use. However, a significant portion of this increase can be attributed to so-called non-recurring events, such as construction projects and traffic incidents. In fact, the Department of Transportation (2011) attributes approximately half of the costs of congestion to construction operations and traffic incidents. In a study from 1999, it was found that work zones and incidents were responsible for 24.3% and 45% of traffic delays (Rao et al., 2010). Therefore, a number of policies and programs have aimed to mitigate the effects of work zones on traffic congestion. Additionally, traffic incident management programs are widely implemented with the goal of reducing response time to incidents, thus, reducing incident duration and ensuing traffic delays and congestion. Many strategies that apply for incident management, such as implementing signage or traffic redirection, have application in work zone management; their impacts may differ between these applications due to differences in duration and length of affected area.

2. On-Road Simulation Emissions Estimation Model (ORSEEM)

ORSEEM is a microscopic emissions estimation tool that estimates the production of air pollutants as a function of modal vehicular parameters (e.g. velocity, acceleration, stops, starts, and idling), vehicle composition categories (e.g. passenger cars,

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trucks, semis, and buses) and class (age and tier level). It accounts for the increased prevalence of alternative vehicles on our roadways, and includes commercially available alternative fuels, like biodiesel blends, ethanol blends and reformulated gasoline. ORSEEM estimates all criteria air pollutants (except air toxics), namely CO_2, CO, CH_4, THC, NOx, SOx, PM_{10} and $PM_{2.5}$. It employs empirical formulae suggested by Barth et al. (2002), but an updated emission factors (EFs) database to account for new technologies and alternative fuels. Adjustment factors are applied to account for greater efficiencies of hybrid passenger vehicles, including both cars and light-duty trucks. Further, the impact on emissions of added power requirements due to roadway grade changes is included. This is important because a 1% increase in roadway grade can result in more than a 9% increase in fuel consumption and carbon emission rates (Park and Rakha, 2006). Moreover, an increase in emissions of 42–80% was found for some emission types resulting from increased grade-weight combinations (Fernández and Long, 1995).

Information on vehicle characteristics, including vehicle speed, acceleration and position in the network (i.e. link number), as well as study time span, is employed as input. Such information can be obtained by either utilizing a traffic simulation model, such as VISSIM, PARAMICS, or CORSIM, or through field investigation.

Building on EFs employed within MOVES, and equations and concepts used in the development of CMEM, ORSEEM uses a power-based approach to estimate emissions wherein vehicle characteristics and modal parameters, namely vehicle mass, velocity and acceleration were used to calculate vehicle specific power (VSP) demand. VSP and related instantaneous velocity were used to determine the EFs for CH_4, PM_{10}, CO_2 and SOx pollutants and subsequently the related emissions results.

It is known that vehicle emissions are a product of several operating modes, such as start exhaust, running exhaust, idle exhaust, evaporation permeation, fuel vapor venting, brake, brake wear and tire wear. Running and idle exhaust emissions are determined, as these operating modes are displayed most on highways and arterial roadways. It is also assumed that since instantaneous emission estimates are determined within ORSEEM, those emissions that result from the process of evaporating fuel in the vehicle's fuel injection system, especially between fuel pump cycles and during conditions resulting in negative power demand, are inherently captured within the results produced, either within the running exhaust emission results (when power demand is positive), or within vehicular process emissions, i.e. THC, CO, PM, and CH_4 emissions (when power demand is negative). While many factors contribute to vehicle emissions, such as engine speed, air-to-fuel ratio, fuel use and catalyst pass fraction, they are most influenced by engine power and fuel use. Thus, these variables were included in the emissions estimation process. Finally, the emissions in carbon dioxide equivalents by using appropriate 100 year global warming potentials are employed (Miller-Hooks et al., 2012).

Estimates from experiments involving ORSEEM fell within reasonable accuracy against the 2011 CAFÉ standards, but on average ORSEEM's emissions production estimates were 40% lower than national values. Fuel consumption estimates were 29% lower for LDVs. For LDTs, the values were 80% and 5% lower for emissions and fuel consumption. Such conservative estimates were likely produced, because ORSEEM uses a microscopic approach (i.e. summation of instantaneous estimates) and updated EF data for emissions and fuel consumption estimation as compared with EF data used to produce the national values. Moreover, the national values were derived from average fuel consumption estimates using a macroscopic approach based on EFs and vehicle technologies related to older data sets (Environmental Protection Agency, 2000). Thus, it was expected that the results would be lower as compared to the national values derived from average fuel consumption.

3. Case study

The impacts from older vehicular technologies, work zones, and traffic incidents on emissions quantities are investigated through simulation on a case study involving a corridor located primarily in Rockville, Maryland. Simulation runs using VISSIM (version 5.40) from PTV, Inc. replicated an hour within the morning peak period (6:00 a.m. to 9:00 a.m.). From each simulation run, information pertaining to vehicular movements on a second-by-second basis was recorded. This information was employed by ORSEEM post-simulation to provide estimates of on-road emissions from simulated roadway use. For each combination of factors considered in the simulation design, three simulation runs were made, each with a different seed value. Average results over these runs are reported. Parameters, such as driving behavior for arterials and highways, were set identically across all simulation runs. One run of the VISSIM model replicated traffic movements for 5400 s, the first 1800 s of which was the warm-up period.

The corridor spans a 7 mile stretch of I-270 (a freeway) and MD-355 (an arterial), major north–south roadways connecting the Washington Beltway (I-495) with the newly constructed Intercounty Connector (ICC), and connecting arterials. It is bounded by Montrose Road in the south end. The network depicting this corridor includes not only freeway, but arterials with signalized intersections. Just south of this location are the Nuclear Regulatory Commission's headquarters and the National Naval Medical Center in Bethesda. Moreover, the corridor is a focus of smart growth initiatives and home to several companies, medical facilities and government agencies (e.g. the Food and Drug Administration (FDA). These facilities are additional commuter traffic generators for this area.

The roadway segment consists of six interchanges connecting I-270 with local roads. The interchanges involve eight on-ramps from local roads to collector/distributor (CD) lanes, five off-ramps from the CD lanes to the local roads, four slip ramps from CD lanes to General Purpose (GP) lanes, and two slip ramps from GP lanes to CD lanes. Access to/from the 1000 foot section of the existing HOV lane that is closest to the Spur was restricted. For simplicity, continuous access was assumed. Traffic demand data for 2011 and actual traffic signal timing plans specific to the analyzed area were provided by the