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Investigating the isolated and combined effects of congestion, roadway grade, passenger load, and alternative fuels on transit bus emissions

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ABSTRACT

This study investigates the isolated and combined effects of network congestion, roadway grade, passenger load, and fuel type on transit bus emissions of greenhouse gases (GHG) through a simulation of transit operations and emissions along a busy corridor. We also test the effect of changing random seed on overall corridor emissions. We observe that positive grades have strong effects on emissions. Grade also causes other variables to become important such as passenger load. While an increasing passenger load on the bus increases emissions, we observe that the addition of each passenger influences the per-passenger emissions differently depending on the bus occupancy. When the bus is less crowded each additional passenger can decrease per-passenger emissions by 5% whereas the reduction becomes 1.2% when the bus is crowded. Finally, we observe that the reduction potential of compressed natural gas (CNG) compared to conventional diesel could reach up to 40% depending on speed, grade, and passenger load. CNG benefits increase with increasing congestion, and decrease with increasing grade and passenger load. The results of this study are most relevant to transit planners in the evaluation of potential operational changes with emission reduction potential and in the allocation of alternative fuelled buses along selected transit corridors.

Introduction

With increasing concerns for greenhouse gas (GHG) emission reductions, transit is often considered as an environmentally friendly alternative to the passenger car. However, transit vehicles, due to their weight and configuration, generate large amounts of emissions. Estimating transit bus emissions is an important step in the quantification of their GHG reduction potential. Bus emissions can vary largely depending on their operations, roadway grade, passenger load, age, and fuel type. Due to these variations, transit could be as polluting as passenger cars on a per passenger basis (Lau et al., 2012). Few studies have been conducted to investigate the individual and combined effects of different variables affecting emissions. While the accuracy of emission estimates increases with the availability of detailed inputs, the collection of reliable input data is a complex, time and resource intensive exercise. Therefore, a tradeoff exists between the desired accuracy in emission estimates and the level of detail in model inputs.

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This study investigates the effects of network congestion, roadway grade, passenger load, and fuel type on transit bus emissions. It does so through a structured sensitivity analysis that captures the effects of each variable in isolation and in combination with other variables. The study also evaluates the effects of these factors under real-world operations and via four scenarios with different combinations of grade, passenger load, and fuel type (diesel and compressed natural gas). Our study area is set in Montreal, Canada where transit operations along a busy urban corridor are simulated. Instantaneous bus speeds are used to estimate emissions using the USEPA's Motor Vehicle Emission Simulator (MOVES) (USEPA, 2010a). Emissions are estimated for GHG (in CO_2-equivalent) in two different directions in the morning peak period.

Materials and methods

The study corridor is called the Cote-des-Neiges (CDN) corridor; situated in the Cote-des-Neiges/Notre-Dame-de-Grace and Ville-Marie boroughs in Montreal. It runs north–south with Montreal's downtown core located at the south end, making the southbound direction more congested in the morning peak. The corridor has one of the highest transit ridership in Montreal; buses running along it serve two metro stations and one commuter train station. The length of the corridor is about 5.1 km with various grade changes ranging from +23% to −22% in the northbound (NB) direction and +19% to −28% in the southbound (SB) direction. This study examines the total trip-level emissions (including running and idling) of the buses that serve route 165 which runs during the day. Along the route there are 35 bus stops in the SB direction and 31 stops in the NB direction. The current bus fleet operating on this route runs on ultra low sulfur diesel (ULSD) with 15 ppm sulfur content.

The study methodology is divided into four steps: (1) Traffic simulation, (2) Emission modeling, (3) Sensitivity analysis and (4) Case study. Transit emissions are estimated under a wide combination of network speeds, roadway grades, and passenger load using an instantaneous speed-based approach and taking into account the effect of random seed on emissions. In addition, bus emissions under ULSD and compressed natural gas (CNG) are compared to understand how the emission reduction potential of CNG varies across different combinations of speed, grade, passenger load, and randomness in the traffic simulation.

Traffic simulation

A traffic microsimulation model of bus operations along the CDN corridor was developed using the PTV VISSIM platform (version 5.40) for the morning peak period (7–9 AM). All of the major and minor streets are included; the network consists of 454 links, 70 signal controllers, and 239 routing decisions. Traffic volumes and turning movements were collected at each intersection over three weeks in Spring 2011. Signal timings were also collected for every signalized intersection along the corridor. Road geometry information such as number of lanes, grades, and parking lots were collected from various sources including orthophotographs and autoCAD maps and validated in the field. Finally, the bus schedule for route 165 in the morning peak period and passenger information at each bus stop (boarding and alighting) were obtained from the local transit operator Société de transport de Montréal (STM). This information was validated against onboard data collection. The numbers of hourly boarding passengers and percentage of alighting passengers at every bus stop were input in order to replicate dwell times.

Emission modeling

Emissions generated during bus operations were estimated using MOVES2010a, the latest USEPA emission modeling tool capable of conducting microscale analysis using instantaneous speed profiles of vehicles including acceleration, deceleration, cruising, and idling. This study focuses on evaluating bus emissions under different roadway characteristics and randomness in traffic simulation. It is therefore crucial to use instantaneous bus speeds and simulate second-by-second emissions along the corridor.

To estimate second-by-second emissions, MOVES requires length, grade, and instantaneous bus speed profile for each link. The link length, grade, and speed profile were obtained from the VISSIM model after each simulation. In addition to link information, MOVES also requires the following inputs: bus age distribution, fuel formulation, and meteorological data. Currently, buses of model years 2009 and 2010 are operated along the corridor. Among those, 58.39% are of model year 2010 and 41.61% are of model year 2009. Current buses run on ULSD with a sulfur content of 15 ppm. Meteorological data were input in the form of hourly temperature (°F) and relative humidity (%), collected from a nearby weather station (less than 1 km distance).

Passenger load on the bus is a contributing factor to total bus emissions and we specifically account for it in this study. In order to do that, we developed a pre-processor that extracts the speed profile of the bus (from the traffic simulation) and the passenger load per link and calculates the vehicle specific power (VSP) and operating mode (*opmode*) category of the bus. The VSP represents the tractive power exerted by a vehicle to move itself and its passengers. It is a function of instantaneous speed, acceleration, vehicle weight, and road grade as shown in Eq. (1) (USEPA, 2010b). In MOVES, an *opmode* is determined by following a combination of speed and vehicle specific power (VSP) for each second.

$$\mathrm{VSP} = \left(\frac{A}{M}\right) * v + \left(\frac{B}{M}\right) * v^2 + \left(\frac{C}{M}\right) * v^2 + (a + \mathrm{Sin}\ \theta) * v \tag{1}$$