CAPTURING THE SENSITIVITY OF TRANSIT BUS EMISSIONS TO CONGESTION, GRADE, PASSENGER LOADING, AND FUELS

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Introduction

Transit is considered as an environmentally friendly alternative to the passenger car in light of its lower per passenger emissions. However, due to their heavier weight, transit vehicles generate significant amounts of emissions and hence, it is important to estimate their reduction potential under various circumstances. Bus emissions can be significantly affected by their operations, age, roadway grade, passenger load, and fuel type. Due to these variations, transit could be as polluting as passenger cars on a per passenger basis (Lau et al., 2011). To date, few studies have been conducted to investigate the individual and combined effects of these variables affecting emissions.

This study investigates the effects of network congestion, roadway grade, passenger loading, fuel type, and service improvements on transit bus emissions by developing a structured sensitivity analysis that captures the effects of each variable in isolation and in combination with other variables. Our study corridor is in Montreal, Canada where transit operations are simulated. Instantaneous bus speeds are used to estimate emissions using USEPA's Motor Vehicle Emission Simulator (MOVES2010b). In this paper, we present the emission results for greenhouse gases (GHG) (in CO_2-equivalent) along the corridor in the two directions in the morning peak period.

Materials and Methods

The Cote-des-Neiges (CDN) corridor is chosen. It runs north-south with Montreal's downtown core at the south end. This makes the southbound direction more congested in the morning peak period.

The corridor experiences 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 emissions) of the buses that serve Route 165 which is 7.58 km long in the SB direction and 6.62 km in the NB direction. The route includes 35 bus stops in the SB direction and 31 stops in the NB direction. The current bus fleet runs on ultra low sulfur diesel (ULSD) with 15ppm sulfur content.

The study methodology is divided into three steps: 1) Traffic simulation, 2) Emission modeling, and 3) Sensitivity analysis. Transit emissions are estimated under a wide combination of network speeds, roadway grades, passenger loading, alternative fuels, and transit improvements using a micro-level second-by-second speed-based approach relying on MOVES2010b base emission rates.

Traffic simulation

Using the PTV VISSIM platform (version 5.40), a traffic simulation model of bus transit operations along the CDN corridor was developed for the morning peak period (7-9 AM). This model includes all of the major and minor streets and consists of 454 links, 70 signal controllers, and 239 routing decisions. A data collection campaign was conducted over three weeks during the Spring of 2011 to collect traffic volumes, turning movements at intersections and signal timings at each intersection. 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 and stop level passenger information (boarding and alighting) for the simulated route (Route 165) was obtained from the local transit operator: Société de transport de Montréal (STM). To replicate real-world bus stop dwell times, the numbers of hourly boarding passengers and percentage of alighting passengers at every bus stop were used as input.

Emission modeling

Bus emissions were estimated using MOVES2010b which has the capability of conducting macroscale, mesoscale, and microscale analysis. The microscale analysis accounts for vehicles instantantaneous speed profiles including acceleration, deceleration, cruising, and idling. In this study we use instantaneous bus speeds and simulate second-by-second emissions along the corridor. To estimate emissions at a microscale, MOVES requires the length, grade, and instantaneous bus speed profile for each road link. MOVES also relies on bus age distribution, fuel formulation, and meteorological data. Presently, 2009 and 2010 model year buses are operated along the corridor using ultra low sulfur diesel (ULSD) with a sulfur content of 15ppm. Meteorological data were collected from a nearby weather station (less than 1 km distance) and include hourly temperature (°F) and relative humidity (%). In this study we have considered the effect of passenger load. The bus weight is calculated based on the number of on-board passengers. Then following the vehicle specific power (VSP) and *opmode* distribution were calculated for each drive cycle (USEPA, 2010). Later the *opmode* distribution was used to estimate emissions.

Sensitivity analysis

A sensitivity analysis was aimed to investigate the effects of traffic load (affecting network speed), roadway grade, and passenger load on transit bus emissions. Three different traffic loadings in the traffic microsimulation model were used to achieve three network speeds of 6.35 mph, 9.51mph and 16.29 mph. To observe the grade effects, grades are considered from -7.5% to 7,5% with an increment of 2.5%. Finally passenger load effect was considered in terms of passenger load factor (PLF) whereas it is defined as the ratio of total onboard passengers to seating capacity. PLF values considered ranges from 0 to 2 with an increment of 0.5%. The sensitivity analysis was performed for the more congested southbound (SB) direction. As in the real world, different buses experience different traffic situations, it is important to consider the random traffic behavior in the traffic simulation. In order to that, for every variable and combination of variables that were tested, six different traffic simulations were conducted under six different random seeds. In each case, emissions were estimated. Based on the six different emission estimates, we computed a mean and coefficient of variation (Standard Deviation/Mean). Using all combination of speed, grade, PLF, and seed a total of 756 combinations were identified and simulated to estimate emissions.

Results and Discussion

Table 1 presents the emissions generated due to the isolated and combined effects of speed, grade, and passenger load factor (PLF). Each box represents average emissions. The average emission value for each combination were calculated based on the six bus emissions simulations in the southbound direction (normalized per bus) resulting from six model runs with varying random seeds.

It can be observed that for the same combination of grade and PLF, buses generate higher emissions under congested conditions. It could be because of lower moving speeds and higher frequency of 'stop and go' events where both of these events are associated with higher emissions rates. If we look at the effect of grade, we observe that its effect on emissions is very small when the grade is negative; and the variability in emissions (due to random seed) cancels out the effect of negative grade on emissions. As the grade increases, emissions increase rapidly. At lower speeds, the effect of increasing positive grades is more pronounced.

With the increase in PLF, bus emissions increase, but the increase is different under different grades. As an example, emissions at an average speed of 9.51 mph are very different under two different grades: +7.5% and 0%. At zero grade, the total emissions increase from 10.9 kg to 12.6 kg for PLFs of 0 and 2; an increase of 16.04%. On the other hand, at a grade of +7.5%, emissions increase by 26.96% for the same PLF change. This indicates that as the grade increases the effect of passenger load becomes more important.

Table 1 Individual and Combined Effects of Speed, Grade, and Passenger Loading

Avg. Speed (mph)	Pass. load factor (PLF)	No. of on-board passengers	Grade (%)						
			-7.50	-5.00	-2.50	0	2.50	5.00	7.50
6.35	0	1	9,850	9,846	11,152	13,614	16,923	20,040	22,757
	0.5	19	9,927	10,078	11,332	14,054	17,655	20,894	24,228
	1	38	10,005	10,262	11,512	14,630	18,366	21,812	25,433
	1.45	55	10,022	10,359	11,575	14,840	18,704	22,257	26,212
	1.5	57	10,092	10,423	11,700	15,084	19,028	23,637	26,805
	2	76	10,188	10,571	11,918	15,496	19,610	23,397	28,006
9.51	0	1	7,237	7,408	8,689	10,929	13,985	16,764	20,003
	0.5	19	7,336	7,602	8,913	11,312	14,846	18,047	21,328
	1	38	7,427	7,775	9,185	11,782	15,533	19,005	23,163
	1.45	55	7,487	7,840	9,234	12,017	15,777	19,386	23,875
	1.5	57	7,551	7,932	9,425	12,263	16,081	19,714	24,374
	2	76	7,693	8,099	9,692	12,601	16,583	20,511	25,407
16.29	0	1	4,773	4,702	5,980	8,254	10,879	13,265	17,659
	0.5	19	4,823	4,840	6,147	8,491	11,497	14,181	18,963
	1	38	4,885	4,959	6,326	8,844	12,056	15,093	20,933
	1.45	55	4,929	5,013	6,388	9,242	13,146	16,973	21,704
	1.5	57	4,980	5,079	6,488	9,192	12,505	15,701	22,182
	2	76	5,093	5,208	6,711	9,417	12,923	16,401	23,218

Conclusion

This study investigates the effects of various factors such as roadway grade, passenger loading, network congestion level, fuel type, and transit service improvements on transit bus emissions. First, a structured sensitivity analysis was performed to observe the individual and combined effects of different variables. We observe that under congested conditions buses produce higher emissions due to lower speeds, higher frequency of acceleration and deceleration events, and higher dwell times at stops. The roadway grade can significantly affect bus emissions, especially at positive grades. As the grade increases, consideration of grade becomes more significant. On the other hand, negative grade effects could be cancelled out by the randomness in the traffic simulation. Passenger load also affects bus emissions and becomes more important under high positive grades.

References

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