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TECHNICAL PAPER

Understanding the emission impacts of high-occupancy vehicle (HOV) to high-occupancy toll (HOT) lane conversions: Experience from Atlanta, Georgia

Yanzhi (Ann) Xu, Haobing Liu, Michael O. Rodgers, Angshuman Guin, Michael Hunter, Adnan Sheikh, and Randall Guensler

School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, USA

ABSTRACT
Converting a congested high-occupancy vehicle (HOV) lane into a high-occupancy toll (HOT) lane is a viable option for improving travel time reliability for carpools and buses that use the managed lane. However, the emission impacts of HOV-to-HOT conversions are not well understood. The lack of emission impact quantification for HOT conversions creates a policy challenge for agencies making transportation funding choices. The goal of this paper is to evaluate the case study of before-and-after changes in vehicle emissions for the Atlanta, Georgia, I-85 HOV/HOT lane conversion project, implemented in October 2011. The analyses employed the Motor Vehicle Emission Simulator (MOVES) for project-level analysis with monitored changes in vehicle activity data collected by Georgia Tech researchers for the Georgia Department of Transportation (GDOT). During the quarterly field data collection from 2010 to 2012, more than 1.5 million license plates were observed and matched to vehicle class and age information using the vehicle registration database. The study also utilized the 20-sec, lane-specific traffic operations data from the Georgia NaviGAtor intelligent transportation system, as well as a direct feed of HOT lane usage data from the State Road and Tollway Authority (SRTA) managed lane system. As such, the analyses in this paper simultaneously assessed the impacts associated with changes in traffic volumes, on-road operating conditions, and fleet composition before and after the conversion. Both greenhouse gases and criteria pollutants were examined.

Implications: A straight before-after analysis showed about 5% decrease in air pollutants and carbon dioxide (CO_2). However, when the before-after calendar year of analysis was held constant (to account for the effect of 1 yr of fleet turnover), mass emissions at the analysis site during peak hours increased by as much as 17%, with little change in CO_2. Further investigation revealed that a large percentage decrease in criteria pollutants in the straight before-after analysis was associated with a single calendar year change in MOVES. Hence, the Atlanta, Georgia, results suggest that an HOV-to-HOT conversion project may have increased mass emissions on the corridor. The results also showcase the importance of obtaining on-road data for emission impact assessment of HOV-to-HOT conversion projects.

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Introduction

Nationwide, there is growing trend in using managed lane concepts to improve freeway operations (U.S. Department of Transportation [USDOT], 2012). As of 2012, there were 14 managed lanes with congestion pricing in the United States (General Accounting Office [GAO], 2012). More than 40 high-occupancy toll (HOT) and express lane facilities are currently in operation, under construction, or being planned in the United States (Perez et al., 2012). In Georgia, carpool lanes on I-85 were converted to HOT lanes in 2011, three new HOT projects are currently under development (GDOT, 2015), and more than $16 billion in managed lanes projects are planned for the metro Atlanta region (HNTB Corporation, 2010). In the United States, managed lane projects are often considered as candidates for the Congestion Mitigation and Air Quality Improvement (CMAQ) program funding (Battelle and Texas A&M Transportation Institute, 2014). In theory, by providing reliable travel times for carpools, the parallel goals of reducing congestion and pollutant emissions can be achieved by managed lanes projects. However, the emission impact of high-occupancy vehicle (HOV)-to-HOT conversions and managed lane projects that add new capacity has not been thoroughly assessed. The lack of

CONTACT Haobing Liu haobing.liu@gatech.edu 790 Atlantic Drive, School of Civil and Environmental Engineering, Georgia Tech, Atlanta, GA, 30332, USA.
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quantification of emission impacts of HOT projects can create policy challenges for agencies making transportation funding choices.

The goal of this paper is to perform a before-and-after case study for a HOV-to-HOT lane conversion project in Atlanta, Georgia (GA). In 2011, the existing Atlanta HOV lane in I-85 north of Atlanta was converted from a traditional two-person carpool lane into a HOT lane, to help ensure travel time reliability for carpools. The HOV-to-HOT conversion spanned approximately 15 miles along I-85, from just south of the I-85/I-285 interchange to just north of State Route 316 in Atlanta, GA. This project was a true carpool lane conversion, adding no new lanes to the corridor. The HOT lane now requires carpools to have three or more persons per vehicle (HOT-3). Increasing the carpool requirement to three persons will decrease carpool lane demand (Poole and Orski, 2000), presumably because it is more difficult for commuters to form three-person carpools. To fill the available capacity on a HOT lane, an electronic tolling system was introduced, and vehicles with one or two persons can pay the toll to use the lane. The toll is variable and set as a function of congestion on the general purpose lanes, so that demand for the lane does not exceed lane capacity. That is, the toll increases with congestion so that fewer drivers will elect to pay the toll and move into the managed lane. The Georgia Tech research team collected license plate and vehicle occupancy data at five sites: Chamblee-Tucker Road, Jimmy Carter Boulevard, Beaver Ruin Road, Pleasant Hill Road, and Old Peachtree Road. This case study examines a 1-mile section immediately north of Jimmy Carter Boulevard. This section was chosen based on its central location relative to the entire project corridor and the quality of available data provided by the Center Way video detection system (VDS) station located inside this 1-mile section. Figure 1 provides an overview of the project area.

Literature review

Detailed air quality analyses are generally required for major transportation projects by the National Environmental Policy Act (NEPA) and U.S. Environmental Protection Agency/Federal Highway Administration (EPA/FHWA) transportation and air quality conformity regulations. For major transportation projects, NEPA requires the federal agency to prepare an environmental assessment (EA) and publish a finding of no significant impact (FONSI) or to prepare a full environmental impact statement (EIS) that compares the predicted environmental impacts of the preferred alternative with the no-action alternative and other alternatives evaluated by the agency. These environmental analyses must be conducted prior to the selection of the preferred alternative. To the extent HOV-to-HOT conversion projects impact traffic operations, such as speeds and volumes, and vehicle fleet characteristics, such as age and class distributions, air quality impacts may arise due to the associated changes in vehicle mass emissions.

Nationwide, a few studies have evaluated the impact of HOT lanes on corridor performance factors that influence vehicle emissions, such as traffic volumes, vehicle speeds, and fleet composition, but not directly on mass emissions. K.T. Analytics, Inc., and Cambridge Systematics, Inc. (2008) summarized findings from multiple HOT projects and reported well-documented favorable effects on travel and traffic. In terms of individual projects, Cambridge Systematics, Inc. (2006) evaluated changes in traffic volumes and speeds for the I-394 MnPass managed lanes in Minneapolis, Minnesota, and found that the corridor experienced an increase in both operating speeds and volumes after the HOV-to-HOT lane conversion, but the impact varied depending on the configurations of the managed lanes. Based on a license plate study, Barth et al. (2001)

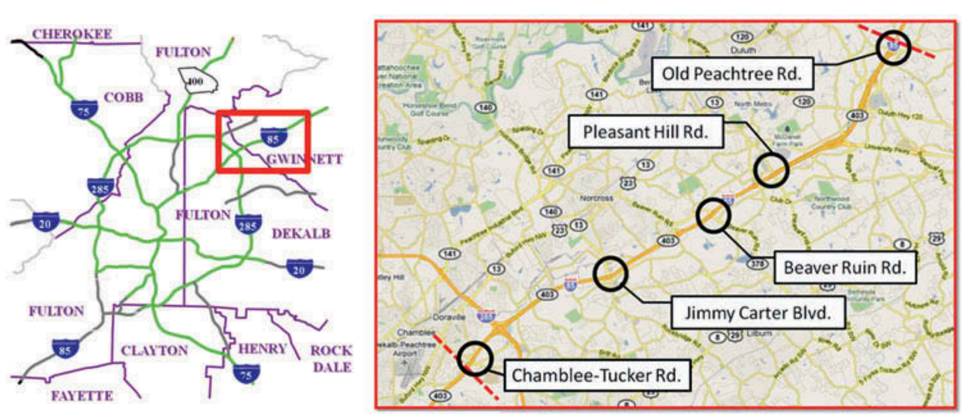

Figure 1. Study area and data collection sites.

examined the fleet composition characteristics in general purpose lanes and HOT lanes on SR91 in southern California and found that the HOT lanes observed a higher share of newer model year vehicles than the general purpose lanes.

In recent years, a few studies have been published on various impacts of the I-85 HOV-to-HOT lane conversion project in Atlanta, GA. Khoeini and Guensler (2014a) assessed traveler response to the HOV-to-HOT conversion in multiple market segments and found significant changes in the sociodemographic characteristics of managed lane users before and after the conversion. Khoeini and Guensler (2014b) examined fleet composition in light of HOT lane user income levels and noted changes in vehicle fleet composition (in vehicle type and age) before and after the conversion. Toth et al. (2014) examined the HOV-to-HOT conversion impacts on effective capacity and reported small increases in both speed and effective capacity in the HOT lanes and the left-most general purpose lane after the conversion. The aforementioned findings suggest that vehicle mass emissions are likely to change after the conversion, but the direction of change depends on the interaction among multiple factors and, therefore, is not readily clear without detailed emission analysis.

Kall et al. (2009) estimated the potential emission impact of the I-85 HOV-to-HOT conversion in Atlanta, GA, using the MOBILE6 model and projected changes in traffic operations based upon preimplementation modeling and predicted that the conversion would result in very small changes in vehicle emissions. However, these predictions were never verified with real-world data after the facility opened. A comprehensive before-and-after emission analysis is warranted to simultaneously assess the changes in traffic operations as a result of the HOV-to-HOT lane conversion. The methodology and project-level emission results presented in this paper can help guide planning and evaluation of future projects.

Methodology

This study employed Motor Vehicle Emissions Simulator (MOVES2014) (EPA, 2014) for project-level analysis. As the federally approved vehicle emission model, MOVES is capable of estimating air pollutant and greenhouse gas emissions for customized local inputs. MOVES input data include on-road vehicle type distribution, age distribution, operational speed, traffic volume, fuel property, inspection and maintenance (I/M) strategy, and meteorology data and calendar year. MOVES stores default fuel, I/M, and meteorology information that corresponds to each county and specific calendar year. Such information was fixed for the year and month of interest in this research (winter and spring of 2011 and 2012). The raw vehicle activity data, based on which vehicle type and age distributions, operational speed, and traffic volume were processed, were collected during the Georgia Tech HOV-to-HOT performance evaluation study (Guensler et al., 2013). The team worked with the Georgia Department of Transportation (GDOT) from 2010 to 2012 to collect traffic volume data and vehicle fleet characteristics. Traffic operations data, including traffic volumes by lane and speed, were derived from the intelligent transportation system (ITS) machine vision system known as Georgia NaviGAtor, which is operated by GDOT. To monitor vehicle fleet composition, more than 1.5 million license plates were observed and matched to the vehicle registration database to obtain vehicle class and model year information. Table 1 provides an overview of the data sources and the corresponding data collection periods. The following sections describe the data and processing methods in detail. Key data inputs derived from the methodology described in this section are summarized in Table 2.

On-road fleet composition

On-road vehicle class distributions and age distributions were derived from high-definition videos collected in the field by the Georgia Tech research team. Video data collected at Jimmy Carter Boulevard (JCB) were used to generate source type distributions and vehicle age distributions for the MOVES model. On-road license plates data were collected for peak directions, i.e., southbound in the morning (7:00 a.m. to

Table 1. Overview of data sources.

Input	Data source	Collection period
Vehicle type distribution	Field-captured video manual count	2.5 hr of video observation in winter morning peak periods
Age distribution	Field-captured license plates	397,702 plate observations Winter: Before conversion: 3 days After conversion: 3 days
Traffic volume	NaviGAtor machine vision system:	2011, January–August 2012, January–August
Operating speed	Traffic volumes and spot speed data in 5-min averaging bins	Every Monday–Friday (Holidays excluded) Peak hours (7:00–9:00 am, 4:30–6:30 pm)

Table 2. Summary of key data inputs.

Lane	Fleet	Before		After	
HOV/HOT lane	Fleet composition				
	% Passenger cars	46.4		54.0	
	% Light-duty trucks	49.5		43.3	
	% Buses	1.5		1.7	
	Heavy-duty trucks	2.6		0.9	
	Passenger cars, % ages 0–9	73.4		80.1	
	Light-duty trucks, % ages 0–9	75.2		83.3	
		SB_AM	NB_PM	SB_AM	NB_PM
	Fleet activity				
	Average speed (mph)	40	34.5	38.3	37.8
	Average volume (veh/hr)	1266	1370	1234	1328
General purpose lane	Fleet composition				
	% Passenger cars	54.5		50	
	% Light-duty trucks	39.5		43.4	
	% Buses	0.0		0.0	
	% Heavy-duty trucks	6.0		6.6	
	Passenger cars, % ages 0–9	72.7		69.6	
	Light-duty trucks, % ages 0–9	76.3		70.2	
		SB_AM	NB_PM	SB_AM	NB_PM
	Fleet activity				
	Monthly average speed (mph)	40.9	37.2	35.8	36.2
	Monthly average volume (veh/hr)	9264	8566	8548	8399
All lanes	Fleet composition				
	% Passenger cars	53.5		50.5	
	% Light-duty trucks	40.8		43.4	
	% Buses	0.2		0.2	
	% Heavy-duty trucks	5.6		5.8	
	Passenger cars, % ages 0–9	72.8		70.9	
	Light-duty trucks, % ages 0–9	76.2		71.9	
		SB_AM	NB_PM	SB_AM	NB_PM
	Fleet activity				
	Average speed (mph)	40.8	36.8	36.1	36.4
	Average volume (veh/hr)	10,530	9936	9782	9727

Note: SB_AM = Southbound A.M. peak hours; NB_PM = Northbound P.M. peak hours.

9:00 a.m.), and northbound in the evening (4:30 p.m. to 6:30 p.m.). As mentioned earlier, JCB was chosen as a representative site due to its central location along the HOT lane and its proximity to Center Way station, where representative video data, traffic volumes, and operating speeds were extracted. Video processing of vehicle class and age distributions was very labor-intensive. Given resource constraints, the research team processed video data for February 2011 and February 2012 and assumed the same vehicle class and age distributions for the rest of the study period.

Data processing for source type distribution involved three steps. Vehicle class distributions were derived from video using the method developed by Liu et al. (2015). First, broad classifications of passenger cars, light-duty trucks, buses, and heavy-duty trucks were manually counted from video data, based on visual classification. The rationale for visual classification using video data is that the local vehicle registration database does not provide information on out-of-state vehicles, resulting in a significant underestimation of heavy-duty trucks. To reduce error, a tablet-based traffic counting application was utilized to facilitate the classification counts (Toth et al., 2013). Due to the large amount of labor involved with manual counting, only winter morning sessions were tabulated for these broad vehicle classes. Second, license plate data were used to further derive detailed light-duty vehicle class and age distributions. The Georgia Tech team used high-definition video systems to record vehicle license plates at the five sites. Videos were then manually transcribed by undergraduate students using proprietary video processing software developed at Georgia Tech (D'Ambrosio, 2011). The transcribed license plates were matched to the motor vehicle registration database to return vehicle characteristics, including model year, fuel type, and body style. The vehicles were first classified into the Highway Performance Monitoring System (HPMS) vehicle class distribution (Federal Highway Administration, 2013). The HPMS classification was then translated into MOVES source types through a process published by the EPA (2015). Light-duty vehicle age distributions were also developed in this second step. Finally, because the match between HPMS vehicle class and MOVES source types does not provide sufficient detail to break the vehicles into the 13 MOVES input source types, the 2011 13-county Atlanta regional source type distribution, obtained from the Georgia Environmental Protection Division, was used to approximate the ratios between passenger trucks and light commercial trucks, between the three bus types (intercity buses, transit buses, and school buses), and for the heavy-duty truck types. With regard to age distributions for heavy-duty vehicles, the Atlanta regional distributions were applied to transit buses, school buses, and short-haul single-unit and combination trucks. National default age distributions were applied to intercity buses and long-haul single-unit and combination trucks. Figure 2 summarizes the steps to obtain vehicle class distributions and age distributions.

On-road vehicle class distributions

Figure 3 summarizes the results of vehicle class distributions. After the HOV-to-HOT conversion, more passenger cars (54.0%, up from 46.4%), fewer light-duty trucks (43.3%, down from 49.5%), and fewer heavy-duty trucks (0.9%, down from 2.6%) were using the managed lane. The share of buses increased slightly due to an increase in express bus service concurrent with HOT lane implementation (Castrillon et al., 2014). Express buses dominate freeway bus activity. In the general purpose lanes, the share of passenger cars decreased from 54.5% before to 50.0% after, light-duty trucks increased from 39.5% before to 43.4% after, and heavy-duty trucks increased from 6.0% before to 6.6% after. In total, the share of heavy-duty trucks on the corridor increased slightly, from 5.6% to 5.8%, and the share of light-duty trucks increased from 40.8% before conversion to 43.4% after conversion.

On-road vehicle age distributions

For light-duty vehicles, including passenger cars, passenger trucks, and light commercial trucks, age distributions were derived from license plates matched to the local registration database. Using the observed license plates for age distribution inputs ensured that the on-road fleet composition was reflected in the project-level analysis. For heavy-duty vehicles, default distributions were employed due to the lack of available registration data as stated earlier.

Figure 4 shows the resulting age distributions for all vehicle types. Vehicles in the HOT lanes had a higher percentage of newer vehicles than did the HOV lanes (see also Khoeini and Guensler, 2014b). The general purpose lanes saw a slight decrease in the percentage of newer passenger cars and light-duty trucks. For all lanes combined, the average vehicle age of the fleet on the corridor increased by about 0.25 yr between 2011 (before conversion) and 2012 (after conversion), which can be largely attributed to the region-wide trend for Atlanta residents to hold on to their vehicles. A slight shift in older vehicles from the HOV lane to the general purpose lanes did appear to occur.

On-road fleet activity

This analysis made extensive use of intelligent transportation system (ITS) data for on-road fleet activity. About 80,000 5-min-resolution speed and volume pairs were utilized from the Georgia NaviGAtor ITS machine vision

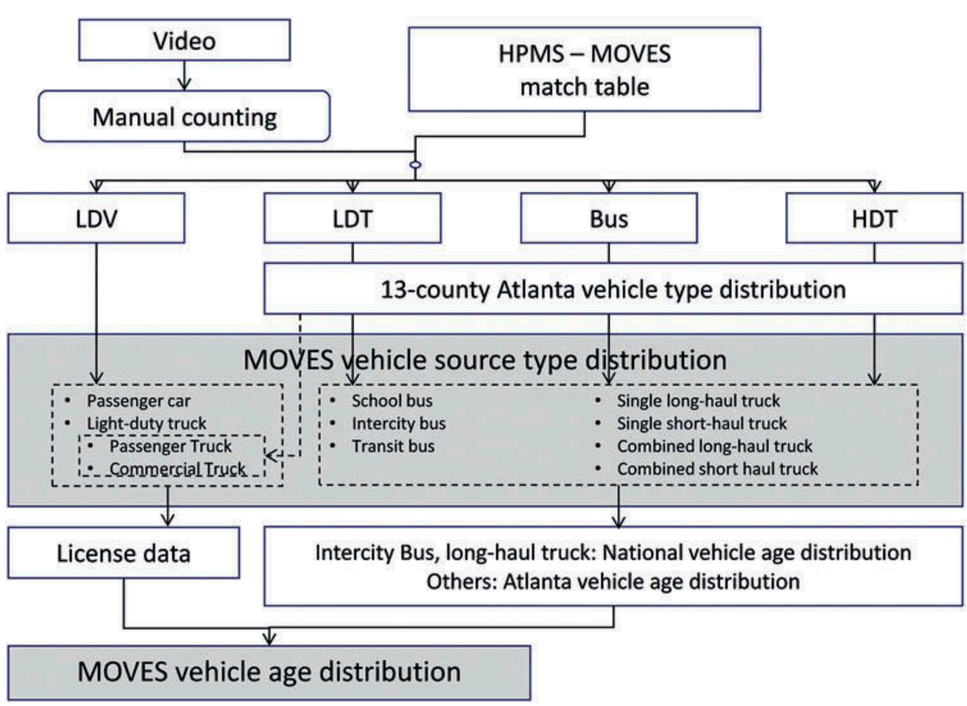

Figure 2. Vehicle classification and age distribution process.

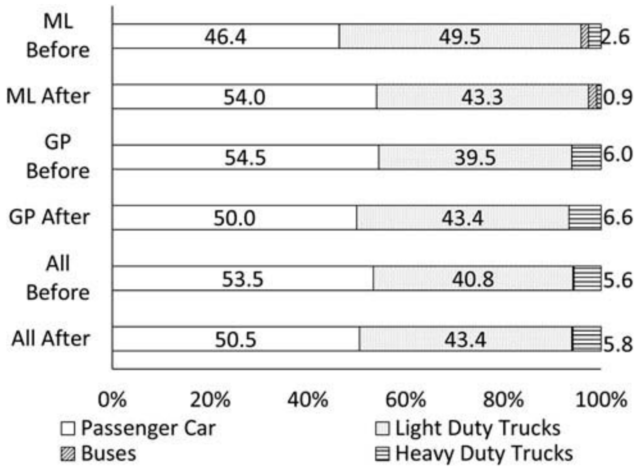

Figure 3. Vehicle class distributions.

system, operated by GDOT. The NaviGAtor system includes traffic volumes and spot speed data, by lane, at 20-sec resolution, based on VDS data. The speed and volume data used in this analysis were aggregated to 5-min bins over an entire month from Monday to Friday for the peak hours of interest. To account for variability, fleet activity data were extracted for January to August 2011 and January to August 2012. Data from September to December were excluded because the fall season was not representative of typical operations. During the fall immediately after the HOT lane opened, the HOT lane was underutilized, leading to unstable traffic conditions in the corridor. As more users opted in to the system (a user account and Peach Pass electronic toll tag are required for access) and toll prices stabilized, the performance of the lane had substantially improved by January 2012. Using 5-min speed and volume data retained the resolution of on-road speed distributions that are reflective of the variability in operating conditions typically observed during peak hours.

To provide an overview of the speed and volume changes before and after the HOV-to-HOT conversion, hourly volumes and space mean speeds averaged from January to August are summarized in Figure 5 and Figure 6, respectively. In the HOT lanes, the peak direction average speeds improved in the evening peak and slightly decreased in the morning peak. In the general purpose lanes, speeds decreased in both morning and evening peaks. In terms of total volumes, morning peaks saw a 7% decrease and evening peaks saw a 2% decrease. All of these differences are statistically significant ($\alpha = 0.05$; see Table 3). Scatterplots of the speed-volume pairs as shown in Figure 7 reveal complex changes of traffic flow relationships before and after the conversion, further underscoring the need to simultaneously assessing speed and volume impacts on emissions using a large sample of high-resolution data. A more comprehensive study of vehicle throughput indicated that the total volumes across all lanes decreased by about 5% (with a larger decrease in the morning than in the afternoon) after the HOV-to-HOT conversion (Guensler et al., 2013).

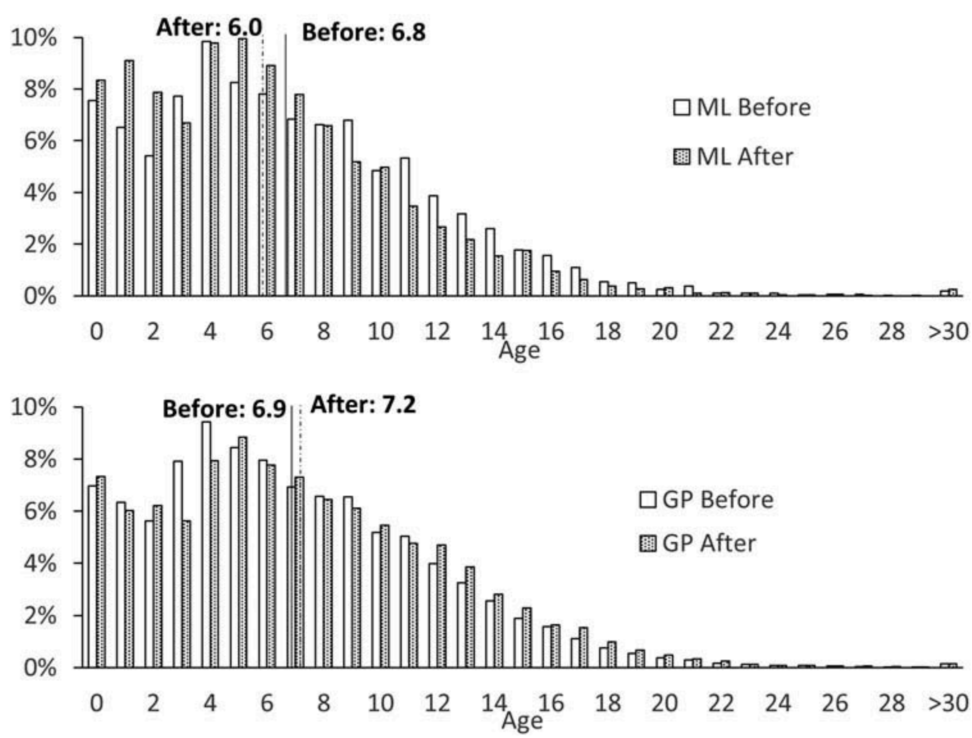

Figure 4. Vehicle age distributions.

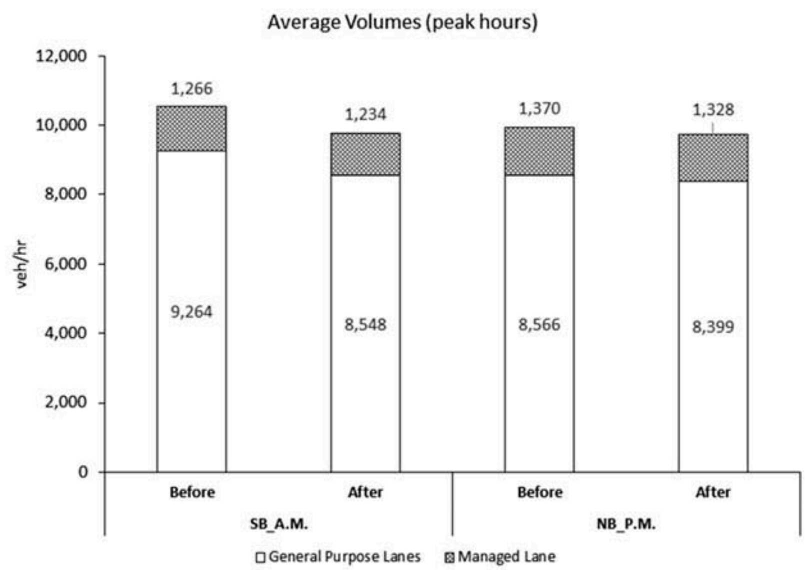

Figure 5. Traffic volumes.

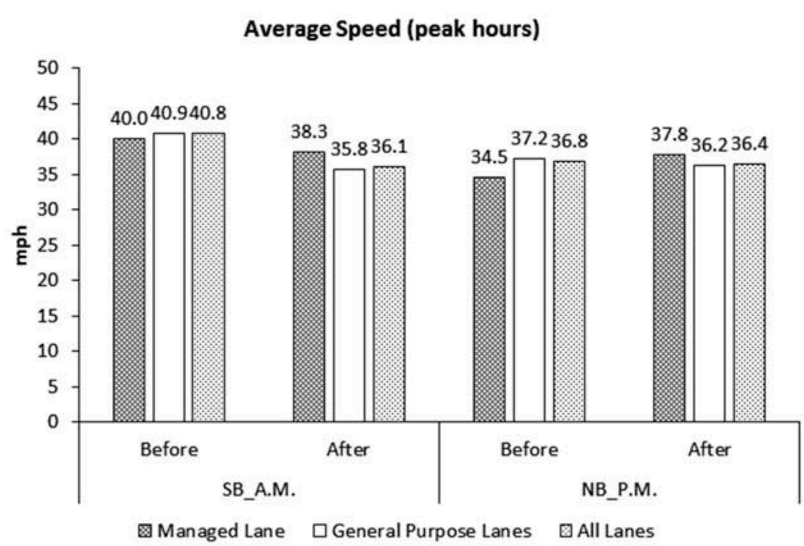

Figure 6. Operating speeds.

Table 3. Results from *t* tests on before-and-after fleet activity.

Lane	Speed change (mph) (*p* value)	Volume change (veh/hr) (*p* value)
General purposed lanes—a.m.	−5.1 ($p < 0.0001$)	−716 ($p < 0.0001$)
General purposed lanes—p.m.	−1 ($p = 0.014$)	−167 ($p = 0.003$)
Managed lane—a.m.	−1.7 ($p < 0.0001$)	−32 ($p < 0.0001$)
Managed lane—p.m.	+3.3 ($p < 0.0001$)	−42 ($p < 0.0001$)

Results

The inputs described in the Methodology section were carefully prepared for MOVES project-level analysis. Changes in mass emissions were estimated utilizing lane-by-lane 5-min-resolution vehicle space mean speed and volume pairs. For each lane and each hour of analysis, MOVES was run 12 times at the speed and volume for a specific 5-min period, and 5-min mass emissions were aggregated to total emissions from the 12 runs.

The resulting emissions obtained from these runs reflected intricate relationships among the factors influencing vehicle emissions. For example, vehicle emission rates generally increase with vehicle age and vehicle size. Conversely, emission rates generally decrease with vehicle speeds. For example, Figure 8 shows the relationship between $PM_{2.5}$ (particulate matter with an aerodynamic diameter ≤2.5 μm) emission rates and vehicle speeds as extracted from MOVES using the fleet mix observed in the general purpose lanes. The sudden decrease in $PM_{2.5}$

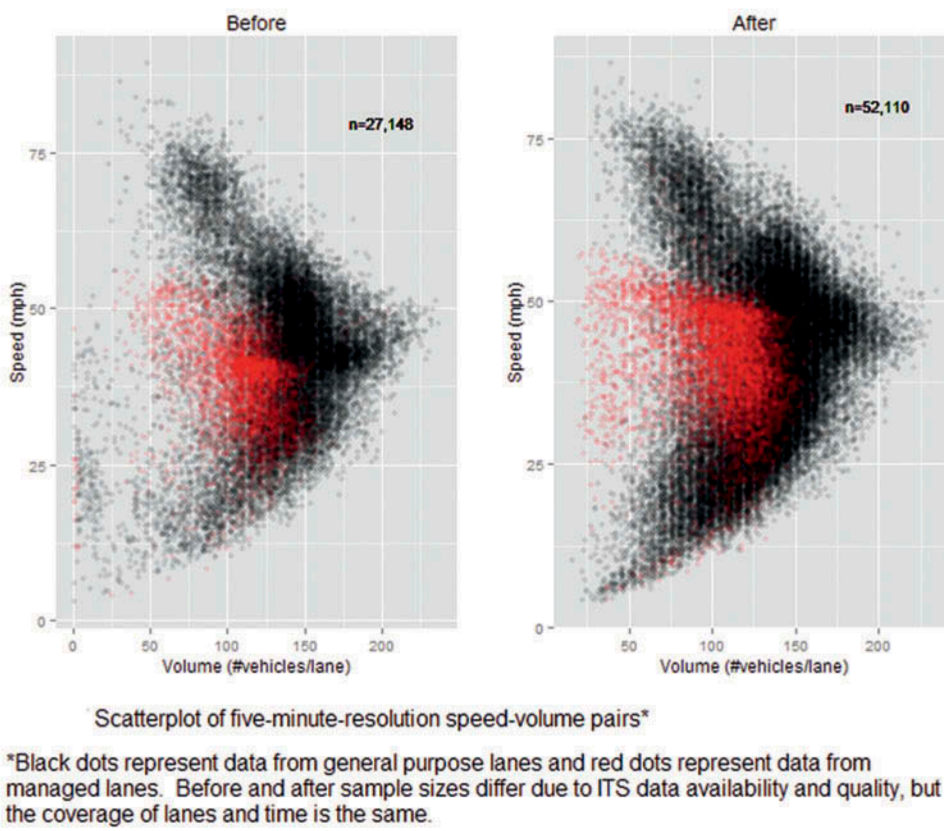

Figure 7. Scatterplot of 5-min-resolution speed-volume pairs.

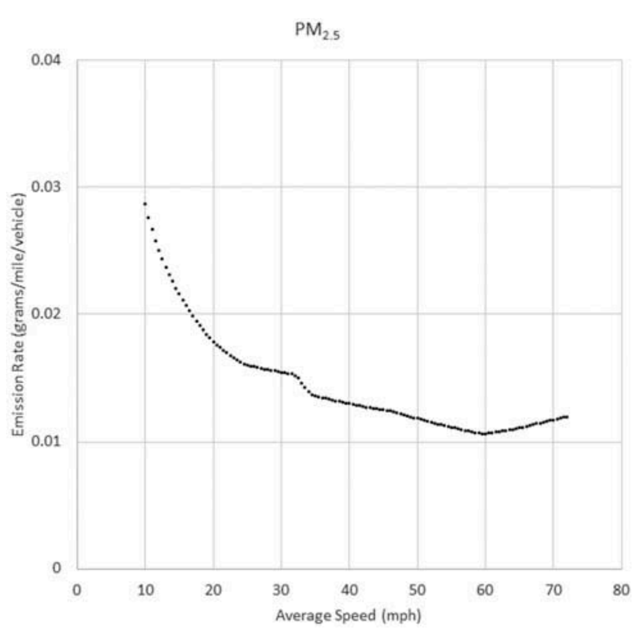

Figure 8. Relationship between $PM_{2.5}$ emission rate and average speed in MOVES.

emission rates at about 35 mph is attributable to the underlying changes in duty cycles at this speed cut point. Similar discontinuity can be found for other pollutants too, but the magnitude of such discontinuity differs from pollutant to pollutant. Further complicating the matter is that these impacts are not linearly additive. As such, careful interpretation is warranted when analyzing emission results from a complex project such the HOV-to-HOT lane conversion. The sections below first present the aggregate emission results and then analyze the marginal contributions to emission changes from each input category.

Changes in mass emissions: Peak of the peak

Table 4 summarizes the mass emission results by HOV/HOT lanes, general purpose lanes, and the sum of all lanes. Within the managed lane, emissions decreased by about 40% for hydrocarbon (HC), nitrogen oxides (NO_x), and $PM_{2.5}$, almost 30% for carbon monoxide (CO), and about 10% for carbon dioxide (CO_2). Such decrease can be largely attributable to the newer and lighter fleet operating in the HOT lane as compared with the HOV lane. The general purpose lanes mostly saw a slight increase in mass emissions, depending on the time of day. Because there are multiple general purpose lanes (six lanes southbound and five lanes northbound) and only one managed lane in each direction, mass emissions during the peak of the peak for all lanes on the 1-mile segment of analysis generally decreased by a small percentage for criteria pollutants and CO_2 after the HOV-to-HOT conversion.

Table 4. Change in peak time and direction mass emissions before and after HOV-to-HOT conversion.

Lane	HOV/HOT lane			General purpose lanes			All lanes		
Phase	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
HC									
Units	g/hr	g/hr	%	g/hr	g/hr	%	g/hr	g/hr	%
a.m.	163	99	−38.9	1183	1207	2.0	1345	1306	−2.9
p.m.	206	116	−43.8	1227	1252	2.1	1433	1368	−4.5
CO									
Units	kg/hr	kg/hr	%	kg/hr	kg/hr	%	kg/hr	kg/hr	%
a.m.	3.7	2.7	−26.2	26.9	26.4	−1.9	30.5	29.1	−4.8
p.m.	6.0	4.3	−28.7	35.9	36.4	1.5	41.9	40.7	−2.9
NO_x									
Units	g/hr	g/hr	%	g/hr	g/hr	%	g/hr	g/hr	%
a.m.	932	552	−40.7	8217	7937	−3.4	9149	8489	−7.2
p.m.	1101	645	−41.4	8011	8096	1.1	9112	8741	−4.1
$PM_{2.5}$									
Units	g/hr	g/hr	%	g/hr	g/hr	%	g/hr	g/hr	%
a.m.	25	16	−38.3	251	255	1.5	276	270	−2.2
p.m.	30	17	−43.2	250	251	0.7	279	268	−4.0
CO_2									
Units	kg/hr	kg/hr	%	kg/hr	kg/hr	%	kg/hr	kg/hr	%
a.m.	549	506	−8.0	4124	4023	−2.5	4674	4529	−3.1
p.m.	675	597	−11.6	4232	4273	1.0	4907	4870	−0.8

Note. Site of analysis: 1-mile segment at Jimmy Carter Boulevard. Summer meteorological conditions.

Marginal contributions

The changes in mass emissions shown in Table 4 resulted from complex interactions among multiple data inputs. To further examine the marginal impact of individual inputs, changes in mass emissions were estimated separately for each of the following inputs by holding everything else (fuel, temperature, humidity, and I/M programs) constant. That is, this analysis of marginal contributions was carried out in five steps:

(1) Start with mass emissions before the HOV-to-HOT lane conversion in 2011.
(2) Model emissions with 5-min speed and volume pairs in 2012; all other inputs remain the same as in Step 1.
(3) Model emissions with 2012 source type distributions; all other inputs remain the same as in Step 2.
(4) Model emissions with 2012 age distributions; all other inputs remain the same as in Step 3.
(5) ***Change the calendar year in the MOVES runs to 2012; all other inputs remain the same as in Step 4. The results of Step 5 are the mass emissions after the HOV-to-HOT lane conversion in 2012.***

Figures 9 to 13 summarize the resulting relative contributions to changes in mass emissions of HC, CO, NO_x, $PM_{2.5}$, and CO_2, respectively, from each input, based on the summer morning peak scenario for all lanes. Two major trends emerge from these charts.

First, MOVES appears to have embedded a large decrease in emission rates associated with fleet turnover. With the calendar year held constant, the study site would see an increase of about 10% in mass emissions for all air pollutants, and a slight increase in CO_2 emissions. However, after accounting for the calendar year effects associated with fleet turnover and technological advances embedded in MOVES, the estimated mass emissions showed little change before and after the HOV-to-HOT conversion.

Second, each individual input affects emissions differently for air pollutants and CO_2. Regarding fleet composition, the shift to larger vehicles after the HOV-to-HOT conversion led to an increase in mass emissions for both air pollutants and CO_2; the shift to older vehicles contributed to an increase in air pollutant emissions but had little impact on CO_2 emissions. Changes in fleet activity appeared to have led to reduction in fuel consumption (hence the CO_2 reduction), most likely due to decreases in traffic volumes during the peak hours in the peak direction, but had very little impact on air pollutants.

Discussion

After the HOV-to-HOT conversion project, the study corridor underwent complex changes in on-road fleet composition and fleet activity. In the managed lanes, vehicles became newer and smaller after the conversion. In the general purpose lanes, on the contrary, there were more light- and heavy-duty trucks, as well as older vehicles after the project. It is not clear whether the changes in fleet composition in the general purpose lanes were associated with tolling or indicative of region-wide trends. The managed lanes saw speed improvements during the afternoon peak, but speed decreases during the morning peak. Speeds in general purpose lanes decreased. Traffic volumes decreased in all lanes for the study period, but this decrease might

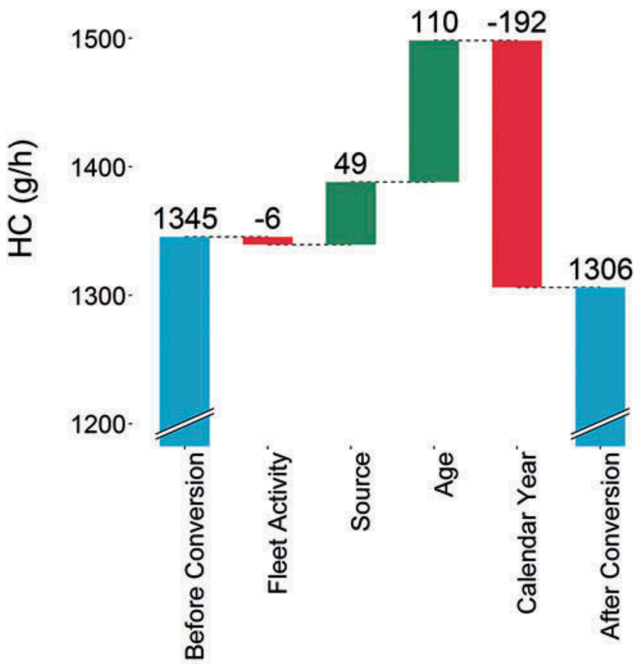

Figure 9. Marginal contributions to changes in HC.

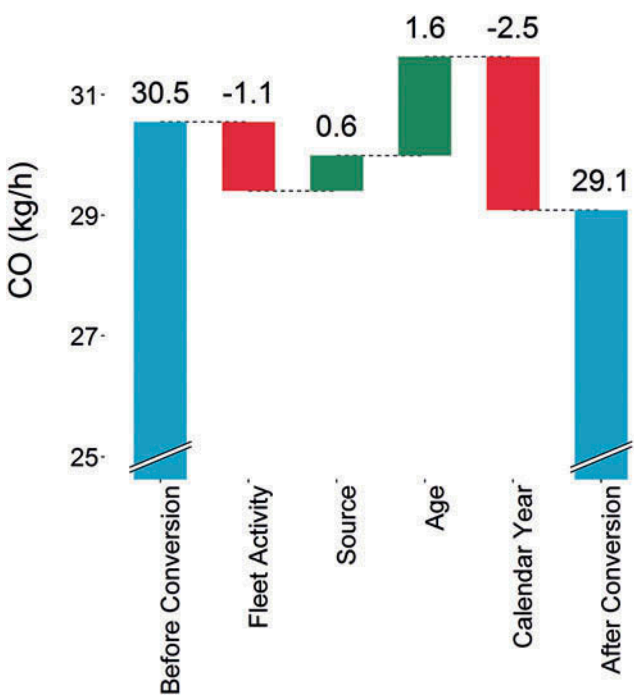

Figure 10. Marginal contributions to changes in CO.

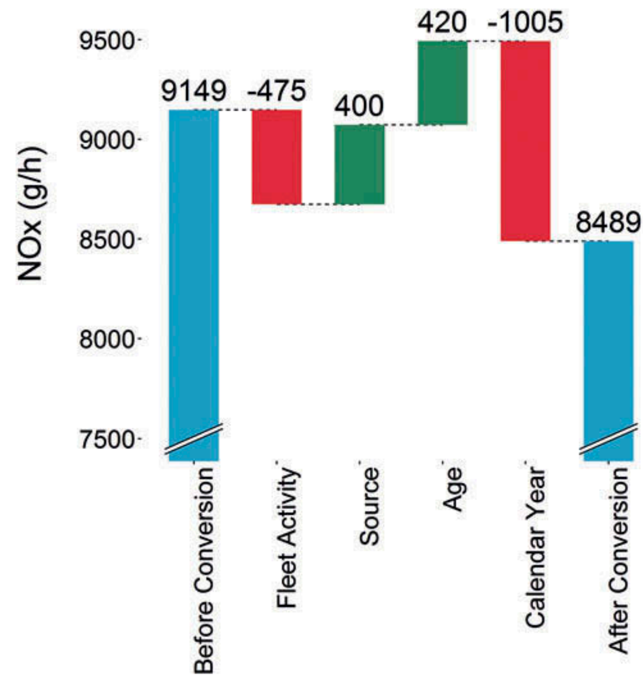

Figure 11. Marginal contributions to changes in NO_x.

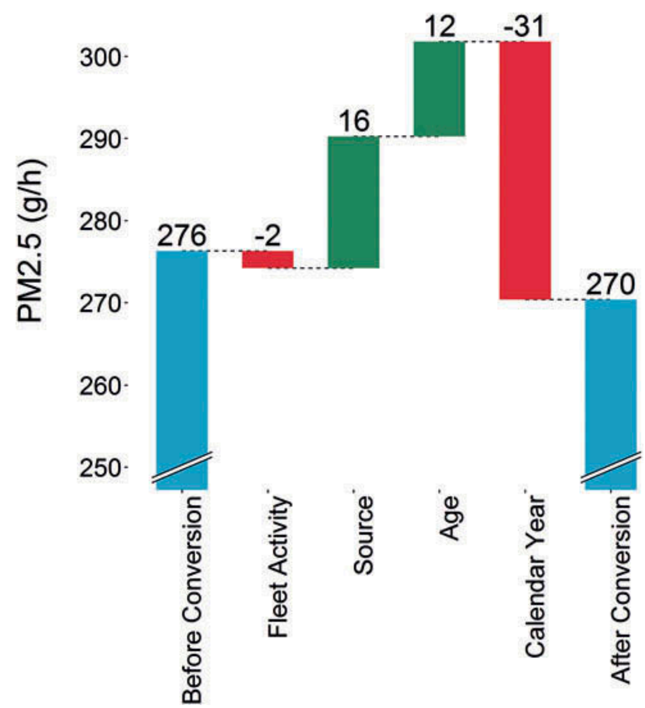

Figure 12. Marginal contributions to changes in $PM_{2.5}$.

have reflected a similar pattern in the metro Atlanta region from 2011 to 2012. Evaluation of the emission impacts requires the simultaneous assessment of changes in all data inputs. The analyses in this paper reported the predicted emission changes for a 1-mile segment of the project corridor, employing multiple data sources. This section includes discussion about (1) the data and methodology and (2) the estimated changes in mass emissions.

Data and methodology

As illustrated in Figure 10, individual data inputs affect mass emissions in different directions and magnitudes.

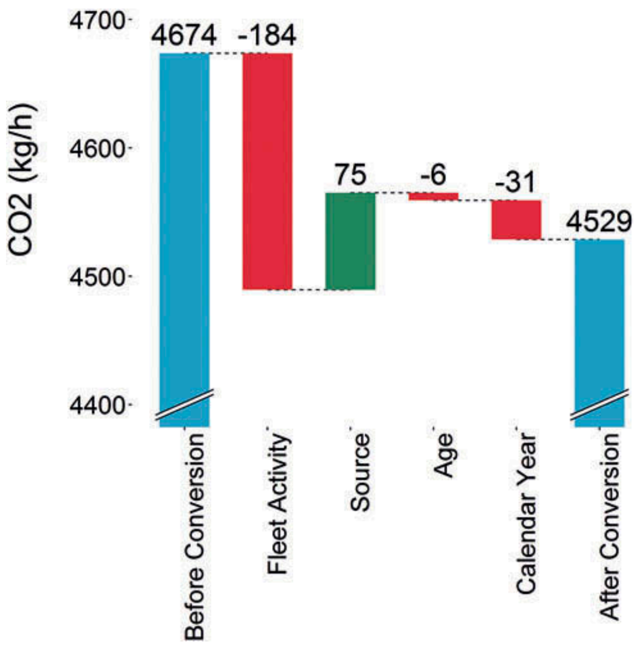

Figure 13. Marginal contributions to changes in CO_2.

The overall changes in emissions were a result of interactions among multiple data inputs. In this analysis, multiple data sources were employed, including

- ITS machine-vision system data for traffic volumes and operating speeds
- Field data collection for fleet composition, which further included
  - Manual, high-resolution video data for broad vehicle classification counts
- License plate data contained within the videos, transcribed and matched to the local registration database for detailed light-duty vehicle classification and age distributions

The rich data sources enabled the application of high-resolution data to emission analysis. Field observations were essential for fleet composition inputs. As seen in this case study, both vehicle class and age distributions underwent changes before and after the HOV-to-HOT conversion, and the directions of changes were different in the managed lanes from the general purpose lanes. Detailed data obtained from the field made it possible to reflect these changes in the emission analysis. However, it is also important to note that errors or biases in any of the input data could potentially bias the emissions estimates.

The emission analyses in this paper utilized EPA's MOVES model, which is the federally approved emission model for regulatory analysis. The modeling results need to be interpreted in light of the modal modeling scheme in MOVES. Fundamentally, MOVES models emissions through operating mode bins based on speed and vehicle-specific power (VSP). MOVES derives operating mode distributions from vehicle duty cycles. When an analyst provides MOVES with a speed distribution, as most practitioners would do and this paper has done, MOVES approximates the operating mode distributions by associating each speed range and source type with a default duty cycle. Therefore, at certain speed cut points, one would observe larger changes in emission rates than at other speeds, as shown in Figure 8. Such sudden changes in emission rates could inflate the resulting changes in mass emissions occurring around speed cut points where MOVES switches to a different duty cycle. Ideally, a study should use observed speed/acceleration distributions to obtain field-observed VSP operating mode bin distributions rather than relying on the internal MOVES cycles and cycle weightings for congested freeway conditions. However, currently, to obtain field-observed duty cycles is cost prohibitive, so this paper has employed high-resolution speed distributions as a second-best option. The authors acknowledge that the predicted emission changes around the emission rate discontinuity may not be real, but that such are the results one would obtain from MOVES.

HOV-to-HOT conversion impacts on emissions

This case study examined the changes in mass emissions for a 1-mile segment of the I-85 HOT corridor during peak hours in both directions. The 1-mile segment, situated in the middle of the HOV-to-HOT conversion project limits, is representative of the operating conditions within the project limits (Guensler et al., 2013). The peak hour and direction are the most sensitive to fleet composition and activity changes attributable to the conversion project. It is expected that the changes in emissions when both the peak and off-peak conditions are considered will be less in magnitude than the changes shown in this case study.

Multiple areas of uncertainty still remain. Most importantly, the changes in traffic patterns induced by an HOV-to-HOT conversion project are yet to be well understood. Changes in weaving patterns have been observed, and it is possible that destructive weaving activity (where vehicles cross many lanes to reach an exit and create congestion waves while seeking gaps in traffic) may be causing performance impacts on the facility (Toth, 2014). Relatedly, changes in vehicle ingress and egress may have occurred and thereby impacting vehicle duty cycles. It is also likely that the project impacts are not confined to the corridor itself. Given the observed decrease in corridor travel, which was larger than experienced at other control locations (Guensler et al., 2013), travel patterns may have shifted, especially on adjacent roadways parallel to the project corridor and/or perhaps to the shoulders of the peak period. A comprehensive study of household travel behavior was not conducted (i.e., a panel study), so these hypotheses could not be tested. An emission analysis conducted at the corridor level is not able to capture the regional or subregional impacts associated with the conversion project. Second, HOT lane operations are complex and affected by many factors, such as the magnitude of the variable tolls, overall economic conditions, and public acceptance levels. These factors are outside the scope of a typical emission assessment but will nonetheless impact the emission results. The postconversion activity and speed data employed in this case study were collected during the first year after of the opening of the HOT lane, during which period the public outreach effort was still ongoing and the agencies were still learning to price the lane for optimal operating conditions. It is expected that the HOT operations will continue to improve, resulting in a potentially different picture on emission impacts. A follow-up study of performance in later years is recommended.

Conclusion

This paper compared the changes in mass emissions before and after the HOV-to-HOT lane conversion on I-85 in northeast metro Atlanta. At first glance, the results from real-world on-road license plate data and VDS speed and volume information supported the predictions in a previous study (Kall et al., 2009) that the HOV-to-HOT lane conversion would not significantly increase mass emissions. However, a closer look at marginal contributions to emission changes from each modeling input reveals that corridor-level air pollutant emissions appear to have decreased after HOT implementation at the site of analysis (Jimmy Carter Boulevard) but may not have decreased as significantly as would have been expected from normal fleet turnover. Calendar year held constant, mass emissions at the analysis site during peak hours showed up to 11% increase in air pollutants. However, calendar year considered, the modeled mass emissions showed between 2% and 7% decrease in air pollutants, due to the large percentage decrease in criteria pollutants associated with a calendar year change in MOVES. Fleet turnover effects notwithstanding, CO_2 emissions did decrease, mostly attributable to changes in fleet activity, but it is not clear whether the HOV-to-HOT conversion project has caused such changes. The Atlanta, GA, case study results suggest that the direction of emission impacts from an HOV-to-HOT conversion project is not readily clear. Additional analyses are still warranted. The findings underscore the importance of using project-specific data with rigorous quality assurance and quality control (QA/QC).

Even if the HOT project has yielded corridor-level emissions that are slightly higher than would normally have been expected (and planned for in the air quality management plan), the travel reliability benefits provided to three-person carpools and express buses are likely to be worthwhile from a transportation policy perspective. Ongoing and detailed analysis of HOT facility impacts on corridor and regional emissions appears warranted for system expansions, given these findings. This way, air quality management plans can be updated as needed to ensure that planned emission reductions in the State Implementation Plan (SIP) are achieved.

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About the authors

Yanzhi (Ann) Xu is a Research Engineer II in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA.

Haobing Liu is a Ph.D. student and graduate research assistant in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA.

Michael O. Rodgers is a principal research scientist in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA.

Angshuman Guin is a senior research engineer in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA.

Michael Hunter is an associate professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA.

Adnan Sheikh received his doctorate in transportation systems engineering from the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA

Randall Guensler is a professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology in Atlanta, GA.

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