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Energy and Air Quality Impacts of Truck-Only Lanes: A Case Study of Interstate 75 Between Macon and McDonough, Georgia

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A Research Report from the National Center for Sustainable Transportation

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TABLE OF CONTENTS

List of Tables

List of Figures

Energy and Air Quality Impacts of Truck-Only Lanes: A Case Study of Interstate 75 Between Macon and McDonough, Georgia

EXECUTIVE SUMMARY

Because heavy-duty truck operations can significantly affect traffic congestion, especially on road grade, the creation of exclusive lanes for trucks has been viewed as a potential alternative to reduce congestion delay, fuel consumption, and emissions. However, few studies have rigorously evaluated the effectiveness of truck-only lanes in achieving these benefits. This study demonstrates a model framework that combines a microscopic traffic simulation with emissions and microscale dispersion models to quantify the potential impacts of truck-only lanes on fuel consumption, emissions, and near-road pollutant concentrations. As a case study, the framework was used to evaluate a proposed $2 billion project to construct 40-miles of truck-only lanes on Interstate 75 (I-75) between Atlanta and Macon, Georgia (USA).

In line with expectations, vehicle simulation analyses revealed that constructing truck-only lanes had a large and positive predicted effect on enhancing both truck and general purpose lane (GPL) operations. On average, speeds are predicted to increase by 5.5% for trucks and 5.3% for GP lane traffic. Moving truck traffic off GPLs and into dedicated lanes enhances capacity for future increases in travel demand on both facilities. The enhanced vehicle operations, in turn, contributed to reducing the total vehicle-hours traveled (5.2% to 6.9% decrease, depending on traffic demand projections).

The study found that the enhanced vehicle operations with the installation of the truck-only lanes helped reduce the total fuel consumption by 2.8% to 3.7%, mass emissions by 2.7% (CO_2) to 8.0% (CO), and pollutant concentrations by 4.4% (NOx) to 12.8% (CO), with the magnitude of impacts varying slightly to moderately across pollutants and traffic demand projections. Reductions in pollutant concentrations are greatest near the roadway, which may be important in terms of population exposure in specific areas. In addition, the environmentally positive effects that truck-only lanes may generate are likely to increase as traffic demand continues to grow.

In conclusion, the findings of this study suggest that truck-only lanes could significantly improve the traffic flow, and reduce energy, emissions, and pollutant concentrations. The research team expects that the extensive simulation results of this study help understand the performance of truck-only lanes on a large-scale network with a heavy mixture of truck and GPL traffic. The methodology and framework developed in this study can be effectively and efficiently to a wide variety of scenarios to evaluate the environmental impacts of other transportation projects under various conditions.

Introduction

Freight transportation is a critical component of the U.S. economy. The relative importance of transportation of goods to the overall U.S. economy increased from 12 percent in 1990 to 23 percent in 2008 (USDOT 2009). Freight transportation by truck is one of the core modes of the U.S. freight system, transporting around 70 percent of all goods by weight (USDOT 2015). During the last few decades, many U.S. metropolitan areas have experienced significant growth in the volume of truck travel on their roadway networks. The ever-increasing flow of heavy commercial vehicles into congested metropolitan freeway corridors has presented a serious challenge for transportation planners (Meyer 2006). The increasing truck traffic on urban freeways can aggravate pavement deterioration, traffic congestion, fuel consumption, and vehicle emissions. Between 1990 and 2014, greenhouse gas (GHG) emissions in the transportation sector increased in absolute terms more than any other sector and represented approximately 26 percent of total U.S. GHG emissions (USEPA 2016).

Among several policy alternatives, constructing exclusive lanes for trucks on urban freeway corridors has gained attention as an alternative in cities suffering from freight truck problems. The installation of truck-only lanes can moderate traffic congestion by diverting truck movements into separate lanes. The Federal Highway Administration suggested that the installation of truck-only lanes could enhance movement of both passenger cars and trucks, and reduce both traffic congestion and vehicle emissions (Forkenbrock and March, 2005). However, no studies identified in the literature have rigorously evaluated the magnitude of these impacts of truck-only lanes at the project level. High construction costs, approximately $2.5 million per lane-mile, in addition to land acquisition costs (FDOT 2015), warrant careful evaluation of these projects with models that are able to quantify projected impacts and inform policy decisions. Particularly, quantitative research is required to test the effectiveness of constructing truck-only lanes in terms of congestion mitigation and air pollution improvement.

This study demonstrates a modeling framework that combines a microscopic traffic simulation (Vissim®), a high-resolution energy and emission model (MOVES-Matrix), and a microscale pollutant dispersion model (AERMOD) to quantify potential impacts of truck-only lanes on travel time, fuel consumption, vehicle emissions, and near road concentrations of air pollutants along a major highway. The study models vehicle operations by time of day and vehicle type (Vissim® simulation) and uses predicted onroad vehicle activity as inputs for MOVES-Matrix calculations for fuel consumption and emissions under the operational scenarios. Near-road pollutant concentrations resulting from these emissions are modeled at high spatial resolution using AERMOD and a high-resolution grid of receptors. This modeling framework was applied to a proposed construction of a 40-mile proposed truck-only lane project on the I-75 corridor stretching from Macon to McDonough, near Atlanta, Georgia (GDOT 2018; Cambridge Systematics 2016). The simulation and impact assessment modeling indicate that the truck-only lane project should significantly improve traffic flow, reduce energy consumption, reduce emissions, and reduce pollutant concentrations on the existing corridor, even as demand increases for the use of the truck-only lane and existing general purpose lane facility.

Study Area

In 2016, the Georgia Department of Transportation (GDOT) announced a $2 billion project to construct new truck-only (non-toll) lanes along a 40-mile stretch of northbound Interstate 75 (I-75) south of Atlanta (GDOT 2018; Cambridge Systematics 2016). The project is expected to alleviate traffic congestion on I-75 that has worsened in part due to increasing heavy freight demand. The fact that the metropolitan Atlanta is located along a major north-south freight corridor and is a logistics center serving international freight movement through the Ports of Savannah and Brunswick on the Georgia coast explains the significant increase in freight movement through the region and the need for focused freight policies. The proposed project is also designed to accommodate future freight traffic expected to increase significantly due to the expansion and deepening of the Port of Savannah, one of the fastest-growing seaports in the United States. The I-75 corridor is also a primary route for commuters traveling to workplaces within the metropolitan region and in downtown Atlanta. GDOT's proposed construction of 40-miles of truck-only lanes constitutes a large roadway capacity expansion along the I-75 corridor between Macon and McDonough (Figure 1). This expansion should yield significant changes in traffic conditions over a large geographic area. This study evaluates changes in congestion as well as fuel consumption and emissions after the implementation of the proposed project.

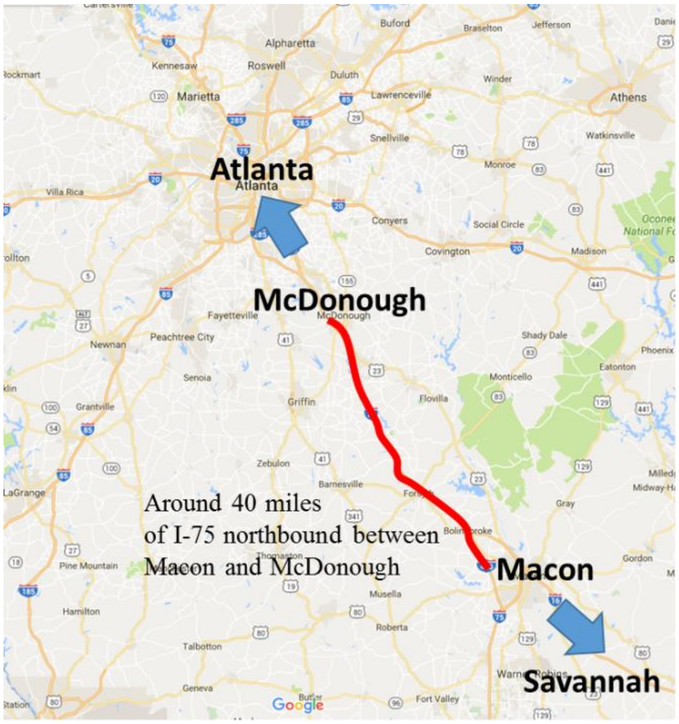


Figure 1. Proposed Truck-Only Lanes on I-75 in Georgia

Modeling Approach

The methodology developed consists of three main components: 1) microscopic traffic simulation, 2) fuel consumption and emissions modeling, and 3) microscale dispersion analysis. Figure 2 illustrates the process flow diagram for the overall modeling approach and the three separate components. The Vissim® microscopic traffic simulation is designed to simulate the movements of all vehicle types, including passenger cars and trucks, so that they can be used as input data for fuel consumption and emissions calculation. The study team first assembled relevant case study data, including traffic counts and vehicle fleet composition passing through the I-75 corridor. Based on these data, multiple Vissim® simulation runs were performed. Vissim® is one of the most popular microscopic simulation software systems, and it is capable of generating second-by-second vehicle trajectories to represent operating conditions (Xu, et al., 2016). The process then linked the Vissim® outputs with energy and emissions modules, and then the predicted emissions to the microscale dispersion model as outlined below.

While Vissim® is running, second-by-second vehicle speed and position data were extracted through Microsoft's Component Object Model (COM). The simulated vehicle speed data were used to estimate second-by-second vehicle fuel consumption and emissions by linking the data with an advanced emissions modeling tool, MOVES-Matrix (Guensler, et al., 2016; Xu, et al., 2016). MOVES-Matrix calculates pollutant emissions originating from the vehicles as a function of specific vehicle operating modes. Pollutant dispersion of these emissions was spatially simulated for a 200m grid along the affected corridor using AERMOD (USEPA, 2018a), a standard dispersion modeling tool recommended by the United States Environmental Protection Agency (USEPA). Finally, the study performed a comparative analysis of the impacts on air quality and energy consumption of the truck-only lanes between different scenarios to provide an assessment of the environmental outcomes of the project.

To assess policy implications, the study considered four different scenarios:

a) Present (current) travel demand without truck-only lanes

b) Present (current) travel demand with truck-only lanes

c) Future travel demand without truck-only lanes

d) Future travel demand with truck-only lanes

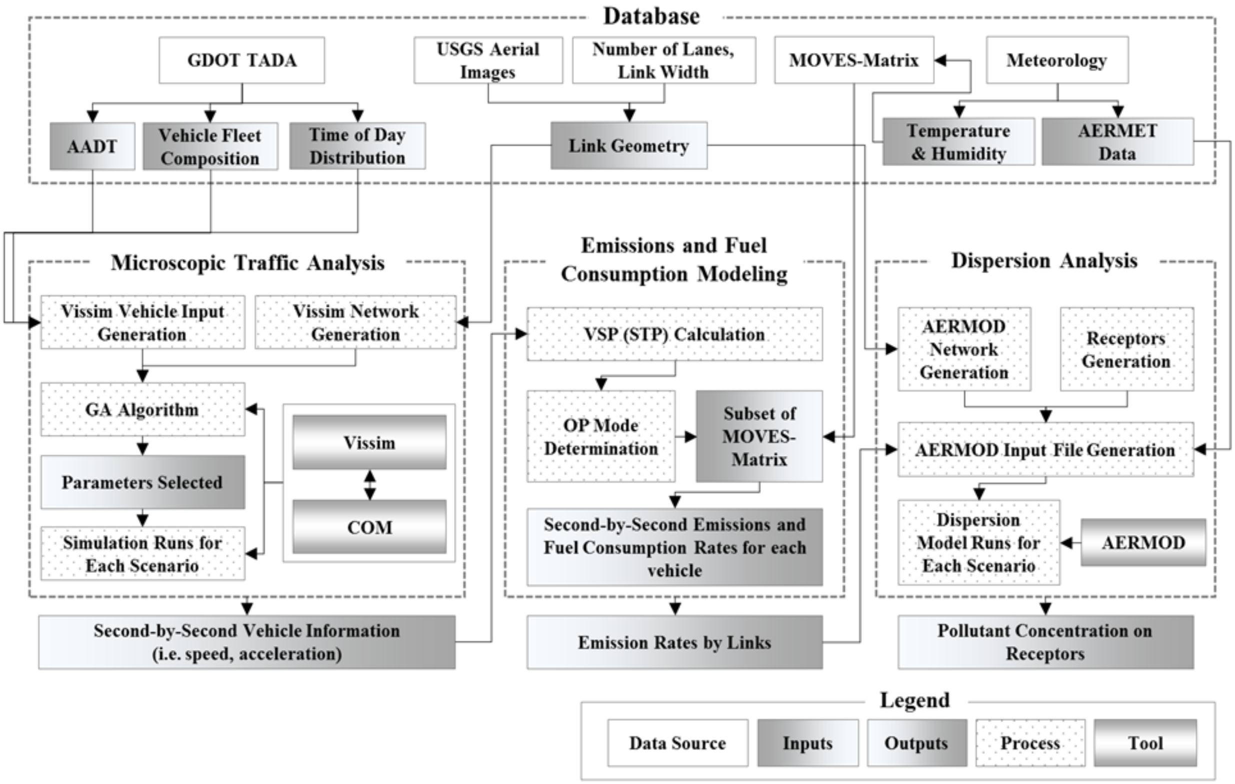


Figure 2. Flowchart of the Study Framework

Traffic Simulation

Three conditions should be met to obtain reliable outcomes from traffic simulation analysis: a) developing a fine-resolution network, b) identifying realistic vehicle inputs, and c) setting proper model parameters. This subsection describes the efforts to build appropriate Vissim® models that take vehicle inputs and a range of parameter values in a road network.

Road Network and Vehicle Inputs

The study developed a base Vissim® network that represents the present network of the I-75 corridors. To this network, the proposed truck-only lanes were added as shown in Figure 3. As noted earlier, the study area includes the northbound I-75 corridor that passes through the cities of Macon and McDonough, Georgia, as well as their connecting arterials. To construct a fine-grained road network, the research team first obtained high-resolution orthorectified aerial images (1-m pixel, August 2017) over the study area from U.S. Geological Survey (USGS, 2018). Based on these images, the team hand-digitized the geometry of the actual roads (e.g., curve radius, link length, and link width, etc.) to build the digital base network. The team also used these as background images in Vissim® (Figure 3).

Building upon the base network, the study constructed an alternative network where two dedicated truck-only lanes were appended adjacent to I-75. In addition to the truck-only lanes, the study also appended a total of five ramps connecting the I-75 with truck-only lanes (one ramp added approximately every 8 miles) to accommodate the truck fleets' needs to enter/exit the I-75 (Figure 3). As the final design of the facility is not complete at this time, the locations of these ramps were placed using engineering judgement (likely construction feasibility).

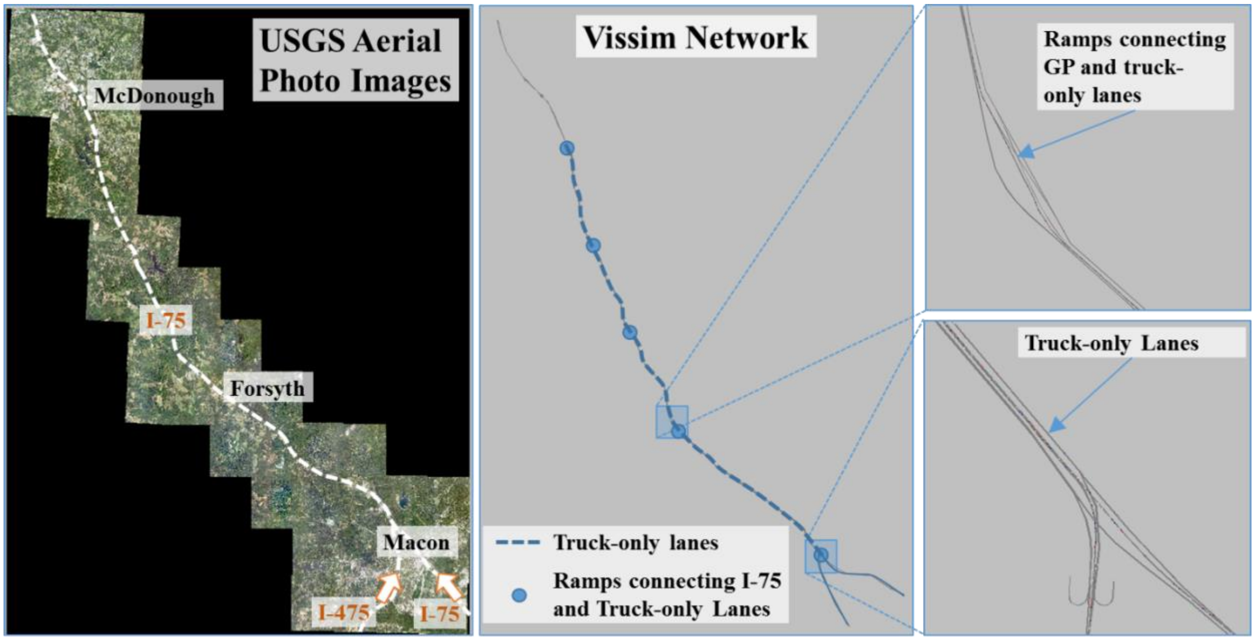


Figure 3. Vissim$^{®}$ Network Generation Process

To develop vehicle inputs designed to match with the created networks, actual traffic count data were obtained from the Georgia Department of Transportation Traffic Analysis and Data Application (GDOT-TADA) (GDOT, 2018). The database includes traffic count survey data collected on the I-75 corridors including the study area, providing annual average daily traffic (AADT) volumes for all entry/exit ramps to the I-75 corridors. Because traffic count data by time of day and by vehicle type are required for the simulation, the traffic count data from a permanent traffic count station on the main I-75 corridor in the study area (station ID: 035-0127) were also used. This station was the only source of detailed count data available for this study. The study estimated an hour-by-hour traffic distribution and vehicle fleet composition using the data collected from the permanent location (Figure 4) by first decomposing the AADTs into counts by time of day and vehicle type. The vehicle type in Figure 4 was initially classified according to the Federal Highway Administration's vehicle category classification (FHWA, 2018), and this vehicle classification was then converted into MOVES source types. Based on these decompositions, the study created a traffic simulation model to predict traffic volumes for a peak hour (i.e., from 2 p.m. to 3 p.m.) when both truck and general purpose lane vehicle (GPLV) volumes are greater than the other times of the day. Finally, the study developed a vehicle input file for the simulation model by assigning the calculated peak-hour vehicle volumes to each of vehicle entering ramps on the base network. The study also formulated different future demand scenarios by increasing the truck demand by 20%, in accordance with the GDOT's projection of the increase in truck freight demand on the I-75 corridors by 2050 (GDOT 2011).

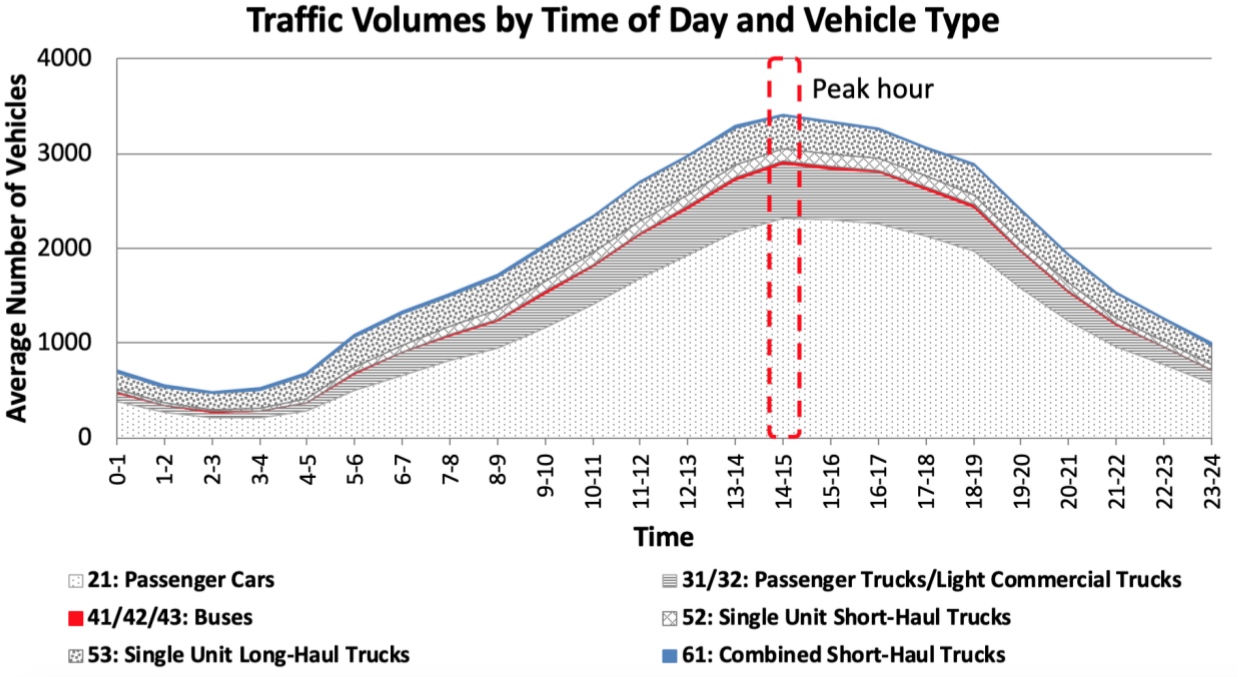


Figure 4. Hour-by-hour Traffic Volumes and Fleet Composition in the Study Area
Source: GDOT-TADA (https://gdottrafficdata.drakewell.com/publicmultinodemap.asp)

Route decisions on conflicted roads (i.e., the ratio of traffic volume into one direction to another) in the base Vissim® network were estimated using GDOT-TADA data (GDOT, 2018). Using an iterative trial-and-error approximation procedure, the study estimated route decisions that closely match the exit traffic volumes on each ramp simulated with the GDOT-TADA data. For the alternative Vissim® network where truck-only lanes were added, the study experimented with the ratio of trucks traveling on truck-only lanes to those on GP lanes so that the resulting volume estimates closely matched the truck entry/exit volumes simulated with the GDOT-TADA data. The estimated route decisions in the alternative network indicated that approximately 75% to 85% of trucks would travel through the truck-only lanes.

Vissim® Parameters

Emissions and fuel consumption rates of vehicles are affected by Vissim® parameters to some extent (Xu, et al., 2016; Song, et al., 2012). Therefore, careful selection of each parameter value is required. To estimate Vissim® parameters in a sound way, the study used a Genetic Algorithm (GenA), which has been developed and used in many traffic simulation-based research efforts (Park, et al., 2003; Chu, et al., 2004; Lee, et al., 2001). The process of parameter selection using GenA proceeds by continually comparing intermediate outcomes with observed data (i.e., travel time and speed) until those outcomes are placed within an acceptable range of error

(Park, et al., 2003). The advantage of utilizing GenA in the parameter optimization for the microscopic traffic simulation models as compared to other conventional optimization techniques (e.g., least mean-squares, maximum likelihood estimates, or hill climbing) is that GenA practically attains a better chance of exploring and exploiting global optima (Ma and Abdulhai, 2001). Because it becomes challenging to observe the actual travel time and speed of individual vehicles on the corridors, travel time estimates optimized by historical data between Macon and McDonough provided by Google® Distance Matrix API (Google® 2018) were regarded as observed data. The absolute error between the observed travel time and the simulated travel time estimate was used as a target error in GenA.

To prevent a subsequent candidate for the parameter value from deviating out of normal ranges, the team set a reasonable range for each parameter, utilizing a guideline proposed by Hunter, et al. (2017). In this way, parameter values in the next generations could be located within the reasonable ranges. Consequently, the study obtained ten different optimal parameter sets. The list of parameters and their optimal ranges are summarized in Table 1. With these different parameter sets, the study performed ten simulation runs for each scenario (i.e., present/future demands with/without truck-only lanes) with different random seeds. During the simulation, the team allowed for a one-hour initialization period because it usually takes around 45 minutes for vehicles entering the first link to exit the last link.

Fuel Consumption and Emissions Modeling

Based on the internal simulation algorithms, individual vehicles' second-by-second driving information (i.e., geographical location, driving speed/acceleration) was extracted through the Vissim® COM interface (PTV Group 2010). The vehicle trace data are then used as inputs to run MOVES-Matrix to calculate each individual vehicle's second-by-second fuel consumption and emissions. MOVES-Matrix is a model developed to better utilize the functionality of USEPA's Motor Vehicle Emission Simulator (MOVES) model (Guensler, et al., 2016; Xu, et al., 2016). An advantage of using MOVES-Matrix is that it operates 200 times faster than using the MOVES GUI and obtains exactly the same energy and emission results (Liu, et al., 2017). MOVES-Matrix contains emission rates for all combinations of vehicle types, vehicle operations, fuel types, meteorological conditions (temperature and humidity), and other variables of interest in its data matrix. Therefore, users can easily search for appropriate emission rates corresponding to the combinations matching their data. Taking full advantage of MOVES-Matrix, the team tested various combinations of different parameter sets and traffic demands for each project scenario.

Table 1. Ranges of Parameters Selected through Genetic Algorithm

Parameters		This study	Hunter et al. (2017)
Desired Speed Range (mph): mean (min, max)	**GPLVs**	81.0 (58.4, 91.4)	-
	Trucks	72.2 (49.6, 82.6)	
Number of observed vehicles		3 – 5	2 – 8
CC0 standstill distance (feet)		7.5 – 11.1	0 – 15
CC1 headway time (s)		0.47	0.4 – 2.0
CC2 following variation (feet)		10.9 – 35.4	5.0 – 39.4
CC3 threshold for entering ‘following’		−21.5	−25 – (−4)
CC4 negative following threshold		−2.51	−3 – 0
CC5 positive following threshold		2 – 3	0 – 3
CC7 oscillation acceleration (feet/s^2)		1.0 – 1.4	0 – 3
CC8 standstill acceleration (feet/s^2)		9.9 – 13.3	5 – 15
Maximum deceleration (trailing) (feet/s^2)		−14.3 – (−13.8)	−20 – (−8)
Minimum headway (front/rear) (feet)		1.51 – 4.79	1.0 – 16.4
Safety distance reduction factor		0.44 – 0.73	0.1 – 0.9
Maximum deceleration for cooperative braking (feet/s^2)		−24.9 – (−14.9)	−40 – (−14.8)

Significant improvement in efficiency is achieved by incorporating Vissim® and MOVES-Matrix through the COM interface as outlined in Xu, et al. (2016). Incorporation of MOVES-Matrix facilitated instantaneous estimations of the second-by-second emission rates of individual vehicles. The team developed a set of Python™ scripts to automatically extract second-by-second vehicle operation information from Vissim® simulation runs and pass the traces to MOVES-Matrix as input files. The scripts calculate vehicle-specific power (VSP) for each second of operation for light-duty vehicles, and scaled tractive power (STP) per second for heavy-duty vehicles, as in Equation 1 with MOVES-specific parameters by source type (Guensler, et al., 2017).

$$VSP(STP) = \left(\frac{A}{M}\right) \cdot v + \left(\frac{B}{M}\right) \cdot v^2 + \left(\frac{C}{M}\right) \cdot v^3 + \left(\frac{m}{M}\right) \cdot (a + g \cdot \sin\theta\,) \cdot v \tag{1}$$

Where:

A = rolling resistance coefficient (kW·s/m),
B = rotational resistance coefficient (kW·s^2/m^2),

C = aerodynamic drag coefficient ($kW \cdot s^3/m^3$),

m = mass of individual test vehicle (metric tonnes),

M = fixed mass factor,

v = instantaneous vehicle velocity at time t (m/s),

a = instantaneous vehicle acceleration (m/s^2),

g = gravitational acceleration (9.8 m/s^2), and

θ = fractional road grade in percent grade angle (in this study, $\theta = 0$).

In the next step, MOVES-Matrix assigns VSP (for light-duty vehicles) or STP (for heavy-duty vehicles) to their corresponding MOVES operating mode bins. The operating mode bins are then assigned to their matching fuel consumption and emission rates in MOVES-Matrix. Emission rates calculated for individual vehicles are summed for each simulation link, and in this way, the total emissions on each link are obtained. The final emissions outputs include carbon monoxide (CO), carbon dioxide (CO_2), particulate matter less than 10 microns in diameter (PM_{10}), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), oxides of nitrogen (NOx), and fuel consumption in kilojoules. The MOVES model parameters used for the emissions modeling are summarized below:

- Calendar year: 2017
- Region for requiring a subset of MOVES-Matrix: Atlanta
- Month: July
- Temperature: 90°F (average summer temperature in Forsyth, GA)
- Humidity: 50% (average summer humidity in Forsyth, GA)
- Fuel: Default fuel supply and fuel share from MOVES

Microscale Pollutant Dispersion Modeling

The next step is microscale dispersion modeling of air pollutants using AERMOD, which was developed by the USEPA to provide a practical model for use in project-level air quality impact assessments. The program is the USEPA's recommended model for use in project-level transportation conformity and hot-spot analysis (USEPA 2018). The truck-only lane study performed used the AERMOD line source dispersion to estimate the impacts of truck-only lanes on near-roadway pollutant concentrations along the corridor.

AERMOD requires various inputs including emission source rates, source geometry, meteorology, and receptor locations. The emission source rates were calculated by aggregating the second-by-second emission rates of vehicles for each link, as described in the previous section. For roadway geometry (i.e., link location, length, width, and area), the team used the same networks developed for the Vissim® models. The aggregated emission source rates of each link for each scenario were averaged over the 10 simulation runs. Then, the emission rates are divided by the area of the link. The result is emission rates per square meter that are used inside AERMOD. For meteorological conditions, the study needed a series of meteorological data including wind speed and direction, temperature, humidity, etc. The study used Georgia AERMET Meteorological Data (upper air station ID: 53819; Surface station ID: 3813) (Georgia Environmental Protection Division 2018), which are recommended by USEPA for atmospheric dispersion analysis for the State of Georgia. The study used the AERMET data of the recent three years (from 2015 to 2017) to obtain three-year average pollutant concentrations.

Selecting receptor locations in AERMOD poses a significant challenge because AERMOD run times increase exponentially as the number of emission sources and receptors increase. Thus, it was impractical to place receptors at a high spatial density in the large geographic area studied. For this reason, the team placed more receptors (200m by 200m) in the immediate areas in the vicinity of the truck-only lanes, while placing sparsely-spaced receptors (2,000m by 2,000m) in more remote areas, as shown in Figure 5. The spatial adjustment of receptor density allows for measuring pollutant concentrations at higher resolutions near the affected areas while not compromising the geographic coverage of the AERMOD model. The receptor pole heights were set at 1.5m, representing the average human head height. The entire dispersion modeling process was automated by the team’s in-house Python™ program.

Figure 5. Receptor Locations

Modeling Results

As mentioned in the modelling approach section, this study investigated the impacts of four different project scenarios on fuel consumption and vehicle emissions: a) present travel demand without truck-only lanes; b) present travel demand with truck-only lanes; c) future travel demand without truck-only lanes; and d) future travel demand with truck-only lanes. To evaluate each scenario, the study developed an automated program that integrated three modeling techniques: a) traffic demand simulation, b) fuel consumption and emissions simulation, and c) pollutant dispersion simulation. This section discusses the results of simulation analyses and provides an assessment of air pollutant concentrations.

Traffic Simulation Results

For each scenario, the study performed ten traffic simulation runs with different parameter sets obtained from the genetic analysis work. Table 2 summarizes the traffic simulation results of the I-75 corridors without and with truck-only lanes. The results suggest that installing truck-only lanes has a positive impact on the operations of both trucks and general purpose lane vehicles (GPLVs) by improving travel speed even for the scenario with increased demand. In case of the present demand scenario, separating trucks into the dedicated truck-only lanes could significantly increase the speeds of trucks and GP lane vehicles by 5.5% and 5.3%, respectively. This is likely due to the increase in road capacity (adding two more lanes for trucks) and enhanced vehicle operations by reducing conflicts between trucks and vehicles in the GP lanes.

The results also suggest that the installation of truck-only lanes is likely to mitigate the negative impacts of increasing traffic demand over time on corridor vehicle operations. The mean vehicle speed for the scenario of future traffic demand with truck-only lanes (71.4 mph) increased moderately compared to the mean vehicle speed for the scenario of present demand without truck-only lanes (68.3 mph). Improved vehicle operations leads to a reduction in fuel consumption and vehicle emissions for the current fleet.

Table 2. Descriptive Statistics of Vissim® Simulation Runs

Classification	Present Demand					
	Without Truck-only Lanes			With Truck-only Lanes		
	Trucks	GPLVs	Total	Trucks	GPLVs	Total
Vehicles	1,278.6 (8.8)	6,952.4 (33.5)	8,231 (32.6)	1,265.5 (3.6)	6,861.2 (19.9)	8,126.7 (20.3)
Vehicle Miles Traveled (miles)	31,703 (398.8)	171,212 (624.2)	202,916 (615.5)	32,629 (258.5)	169,800 (1,263.1)	202,430 (1,099.2)
Total Travel Time (hours)	506.7 (9.6)	2,464.9 (34.4)	2,971.6 (41.7)	494.1 (5.2)	2,322.0 (23)	2,816.1 (24.1)
Average Speed (mph)	62.6 (0.8)	69.5 (0.8)	68.3 (0.8)	66.0 (0.3)	73.1 (0.4)	71.9 (0.4)
Classification	**Future Demand**					
	Without Truck-only Lanes			**With Truck-only Lanes**		
	Trucks	**GPLVs**	**Total**	**Trucks**	**GPLVs**	**Total**
Vehicles	1,530.8 (8.8)	6,983.7 (29.0)	8,514.5 (35.2)	1,503.5 (7.1)	6,878.3 (24.9)	8,381.8 (28.9)
Vehicle Miles Traveled (miles)	38,031 (334.7)	171,677 (798.9)	209,708 (917.8)	38,985 (251.8)	170,335 (701.4)	209,320 (903.2)
Total Travel Time (hours)	619.4 (16.5)	2,532.2 (56.6)	3,151.6 (72.5)	591.6 (7.0)	2,341.8 (21.2)	2,933.4 (27.8)
Average Speed (mph)	61.4 (1.3)	67.8 (1.3)	66.6 (0.8)	65.9 (0.4)	72.7 (0.5)	71.4 (0.5)

Note: Values in plain texts are mean values over 10 simulation runs and the values in parenthesis are 99% confidence limits of the mean.

Emissions and Fuel Consumption Results

Table 3 summarizes the estimated total fuel consumption and emissions from the I-75 case study corridor under each scenario, obtained by summing the fuel consumption and emissions by component for all vehicles during each simulation. The results demonstrate that total fuel consumption and emissions decrease after truck-only lanes are introduced. Under the present demand scenario, the installation of truck-only lanes is expected to reduce total fuel consumption by 2.7%, CO by 6.9%, CO_2 by 2.7%, PM_{10} by 5.3%, $PM_{2.5}$ by 5.3%, and NO_x by 3.9%. Results also demonstrate that the positive effects of truck-only lanes are robust as the reductions are still observed even when traffic demand rises in the future. If truck demand on the corridors increases by 20%, the positive effects of truck-only lanes increase. In this case, the percent changes in fuel consumption and total emissions range from 3.7% (fuel consumption, CO_2 and NO_x) to 8.0% (CO).

A primary factor contributing to the enhanced vehicle operations with the introduction of truck-only lanes is likely to be the reduction in vehicle specific power (VSP) or scaled tractive power (STP) levels without sacrificing average travel speed. Higher fuel consumption and emissions rates are closely associated with high vehicle speeds, moderate accelerations at high speed, and hard accelerations at moderate speed, because vehicle acceleration requires greater engine power. Therefore, the emissions and fuel consumption rates defined in MOVES tend to decrease as VSP/STP levels decrease within specific operating speed ranges (Guensler, et al., 2017).

Table 3. Fuel Consumption and Emissions Simulation Results

Classification	**Present Demand**					
	Without Truck-only Lanes			**With Truck-only Lanes**		
	Trucks	**GPLVs**	**Total**	**Trucks**	**GPLVs**	**Total**
Total Fuel Consumption (gigajoules)	208.9 (6.3)	588.7 (4.9)	797.6 (8.2)	193.2 (2.6)	582.7 (3.9)	776.0 (3.4)
Total CO (kilograms)	29.1 (1.1)	684.0 (18.3)	713.1 (18.4)	26.8 (1.9)	637.0 (17.2)	663.8 (16.7)
Total CO$_2$ (kilograms)	15,344.6 (460.0)	42,318.9 (352.0)	57,663.5 (597.0)	14,196.6 (193.4)	41,888.3 (282.2)	56,085.0 (246.3)
Total PM$_{10}$ (grams)	1,298.3 (77.8)	757.5 (26.2)	2,055.9 (94.8)	1,241.4 (71.0)	705.6 (22.5)	1,947.0 (65.6)
Total PM$_{2.5}$ (grams)	1,193.7 (71.6)	670.8 (23.2)	1,864.5 (86.5)	1,141.3 (65.3)	624.9 (19.9)	1,766.2 (60.3)
Total NOx (grams)	32,365.7 (1,496.0)	24,924.7 (1,097.2)	57,290.4 (1,860.6)	29,890.4 (1,198.1)	25,156.8 (1,162.3)	55,047.2 (1,576.7)
Classification	**Future Demand**					
	Without Truck-only Lanes			**With Truck-only Lanes**		
	Trucks	**GPLVs**	**Total**	**Trucks**	**GPLVs**	**Total**
Total Fuel Consumption (gigajoules)	261.7 (8.9)	592.9 (6.2)	854.7 (13.5)	238.8 (2.0)	584.5 (4.1)	823.3 (5.0)
Total CO (kilograms)	35.3 (2.5)	696.7 (18.9)	732.1 (20.8)	32.2 (1.5)	641.0 (16.7)	673.3 (17.2)
Total CO$_2$ (kilograms)	19,229.8 (652.0)	42,623.0 (448.5)	61,852.8 (980.5)	17,541.1 (146.5)	42,018.6 (297.4)	59,559.7 (361.1)
Total PM$_{10}$ (grams)	1,553.9 (99.1)	769.7 (23.9)	2,323.6 (112.0)	1,470.9 (117.7)	709.7 (20.9)	2,180.7 (114.3)
Total PM$_{2.5}$ (grams)	1,428.6 (91.2)	681.6 (21.2)	2,110.2 (102.5)	1,352.4 (108.3)	628.5 (18.5)	1,980.9 (105.3)
Total NOx (grams)	39,472.3 (2,207.3)	24,153.3 (719.3)	63,625.5 (2,420.2)	36,257.3 (1,405.1)	25,018.8 (756.0)	61,276 (1,622.0)

Note: Values in plain texts are mean values over 10 simulation runs and the values in parenthesis are 99% confidence limits of the mean.

Table 4 shows the distribution of MOVES-Matrix operating mode bins and the simulated percentage of driving frequencies in each vehicle operating mode by vehicle type (truck versus GPLVs) and by project scenario. Results in Table 4 show that the likelihood of trucks operating in efficient modes (i.e. low VSP/STP values) increased after truck-only lanes were introduced. Overall, the likelihood of trucks operating at a speed greater than 50 mph with STPs lower than 6 KW/tonne increased significantly with truck-only lane implementation. In other words, truck and GPLVs were more likely to travel in stable operating modes at moderate or high speed after the truck-only lanes opened. Consequently, the total travel time decreased by 5.2% (from 2,971 hours to 2,816 hours) with traffic demand being fixed, and decreased by 6.9% (from 3,151 hours to 2,933 hours) for a 20% increase in truck travel demand when more baseline congestion occurs. The results in Table 4 also show that the frequencies of deceleration/braking and idle modes decreased after the truck-only lanes were added to the network. This means that the vehicles did not need to accelerate to reach the desired speed as frequently. In summary, the study found that the operation of truck-only lanes affects the operating modes of passing vehicles positively and that the increased efficiency of vehicle operations leads to the reduction in total fuel consumption and emissions.

Table 4. MOVES Vehicle Specific Power (VSP)/Scaled Tractive Power (STP) Operating Mode Bin Distribution by Vehicle Type and Project Scenario

Op Mode ID	Operating Mode Description	Vehicle Specific Power (VSP)	Vehicle Speed	Present Demand				Future Demand			
				Without Truck-only Lanes		With Truck-only Lanes		Without Truck-only Lanes		With Truck-only Lanes	
		(KW/tonne)	(vt, mph)	Trucks	GPLVs	Trucks	GPLVs	Trucks	GPLVs	Trucks	GPLVs
0	**Deceleration/Braking**	**-**	**-**	0.033	**0.092**	0.012	**0.061**	0.041	**0.102**	0.014	**0.065**
1	**Idle**	**-**	**-1.0≤vt<1.0**	0.001	0.001	0.000	0.000	0.002	0.002	0.000	0.000
11	**Coast**	**VSPt<0**	**0≤vt<25**	0.003	0.003	0.000	0.000	0.007	0.006	0.000	0.000
12	**Cruise/Acceleration**	**0≤VSPt<3**	**0≤vt<25**	0.006	0.003	0.000	0.000	0.011	0.006	0.001	0.001
13	**Cruise/Acceleration**	**3≤VSPt<6**	**0≤vt<25**	0.003	0.001	0.000	0.000	0.005	0.002	0.000	0.000
14	**Cruise/Acceleration**	**6≤VSPt<9**	**0≤vt<25**	0.001	0.001	0.000	0.000	0.001	0.002	0.000	0.000
15	**Cruise/Acceleration**	**9≤VSPt<12**	**0≤vt<25**	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000
16	**Cruise/Acceleration**	**12≤VSPt**	**0≤vt<25**	0.000	0.002	0.000	0.001	0.000	0.003	0.000	0.001
21	**Coast**	**VSPt<0**	**25≤vt<50**	0.004	0.003	0.002	0.001	0.004	0.004	0.002	0.001
22	**Cruise/Acceleration**	**0≤VSPt<3**	**25≤vt<50**	0.028	0.002	0.016	0.001	0.026	0.003	0.015	0.001
23	**Cruise/Acceleration**	**3≤VSPt<6**	**25≤vt<50**	0.026	0.002	0.005	0.001	0.034	0.002	0.006	0.001
24	**Cruise/Acceleration**	**6≤VSPt<9**	**25≤vt<50**	0.005	0.002	0.001	0.001	0.007	0.002	0.001	0.001
25	**Cruise/Acceleration**	**9≤VSPt<12**	**25≤vt<50**	0.003	0.002	0.000	0.001	0.003	0.002	0.000	0.001
27	**Cruise/Acceleration**	**12≤VSPt<18**	**25≤vt<50**	0.001	0.003	0.000	0.001	0.001	0.004	0.000	0.001
28	**Cruise/Acceleration**	**18≤VSPt<24**	**25≤vt<50**	0.000	0.003	0.000	0.001	0.000	0.004	0.000	0.002
29	**Cruise/Acceleration**	**24≤VSPt<30**	**25≤vt<50**	0.000	0.004	0.000	0.002	0.000	0.005	0.000	0.002

Op Mode ID	**Operating Mode Description**	**Vehicle Specific Power (VSP)**	**Vehicle Speed**	**Present Demand**				**Future Demand**			
				Without Truck-only Lanes		**With Truck-only Lanes**		**Without Truck-only Lanes**		**With Truck-only Lanes**	
		(KW/tonne)	**(vt, mph)**	**Trucks**	**GPLVs**	**Trucks**	**GPLVs**	**Trucks**	**GPLVs**	**Trucks**	**GPLVs**
30	**Cruise/Acceleration**	**30≤VSPt**	**25≤vt<50**	0.000	0.008	0.000	0.004	0.000	0.010	0.000	0.005
33	**Cruise/Acceleration**	**VSPt<6**	**50≤vt**	**0.804**	**0.096**	**0.910**	**0.070**	**0.770**	**0.100**	**0.902**	**0.074**
35	**Cruise/Acceleration**	**6≤VSPt<12**	**50≤vt**	**0.073**	**0.141**	0.047	**0.139**	**0.079**	**0.137**	**0.052**	**0.137**
37	**Cruise/Acceleration**	**12≤VSPt<18**	**50≤vt**	0.008	**0.186**	0.006	**0.203**	0.007	**0.173**	0.005	**0.201**
38	**Cruise/Acceleration**	**18≤VSPt<24**	**50≤vt**	0.001	**0.187**	0.001	**0.262**	0.001	**0.173**	0.000	**0.252**
39	**Cruise/Acceleration**	**24≤VSPt<30**	**50≤vt**	0.000	**0.084**	0.000	**0.105**	0.001	**0.079**	0.000	**0.103**
40	**Cruise/Acceleration**	**30≤VSPt**	**50≤vt**	0.000	**0.175**	0.000	**0.147**	0.000	**0.178**	0.000	**0.151**

Note: Values in bold denote that the values are greater than or equal to 0.05.

Pollutant Concentration Results

Using the calculated emissions by pollutant type presented earlier, the study analyzed the atmospheric downwind propagation of air pollutants in the study area using AERMOD. Table 5 summarizes the computed 3-year averages of 24-hour pollutant concentrations originating from the I-75 corridors under the four different scenarios. The results indicate that the pollutant concentrations are expected to decrease with the installation of truck-only lanes. When traffic demand was fixed, the average level of pollutant concentrations declined by 8.9% (CO), 6.3% (PM_{10}), 6.2% ($PM_{2.5}$), and 4.4% (NOx), somewhat varying depending on the pollutant. The reductions became even greater under a scenario with an increased traffic demand: 12.8% (CO), 7.7% (PM_{10}), 7.6% ($PM_{2.5}$), and 5.9% (NOx).

As expected, the reduction in pollutant concentrations turned out to be greater in areas adjacent to the I-75 corridors than areas farther away (Table 5). For example, under a scenario with present traffic demand, the amount of CO concentration decreased by 11.7 $\mu g/m^3$ within 0.25 miles of the I-75 corridors after construction, with the reduction decreasing with distance from the I-75 corridors, from 2.2 $\mu g/m^3$ (at 0.5 miles) to 0.25 $\mu g/m^3$ (at more than 1.0 miles). A greater extent of reduction in pollutant concentrations occurred when traffic demand increases. For example, for CO concentration, 17.9. $\mu g/m^3$ within 0.25 miles of the I-75 corridors, 2.9 $\mu g/m^3$ within 0.5 miles and 0.37 $\mu g/m^3$ for more than 1.0 miles.

The plots in Figure 6 display changes in pollutant concentrations by subtracting the concentrations after the operation of truck-only lanes from the concentrations before truck lane introduction (brighter colors mean bigger reductions). The figure illustrates that the pollutant concentrations decrease more in areas immediately adjacent to the I-75 corridor than they do in more remote areas. When future increased traffic demand was realized, the area benefitting from the installation of truck-only lanes became larger geographically. This finding supports the efficacy of the introduction of truck-only lanes to the highway corridors in terms of mitigating air pollution induced by rising truck freight demand.

Table 5. 3-Year Average of 24-Hour Pollutant Concentrations Originated from the I-75 Corridors under Different Project Scenarios

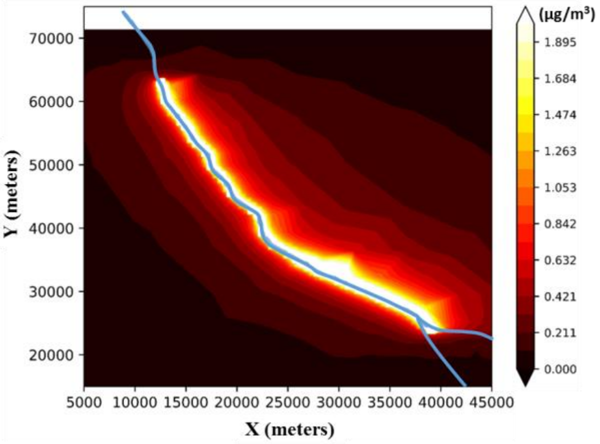
CO (µg/m^3)	Present Demand				Future Demand			
Distance from truck-only lanes	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**
< 0.25 miles	122.6168	110.9296	11.6872	0.0953	130.6787	112.7755	17.9031	0.1370
< 0.5 miles	27.5042	25.2929	2.2113	0.0804	28.9733	26.0799	2.8934	0.0999
< 1.0 miles	16.3174	14.9196	1.3977	0.0857	17.2569	15.1506	2.1063	0.1221
≥ 1.0 miles	3.0398	2.7885	0.2513	0.0827	3.2098	2.8396	0.3701	0.1153
Total	33.4898	30.5203	2.9695	0.0887	35.5120	30.9716	4.5404	0.1279

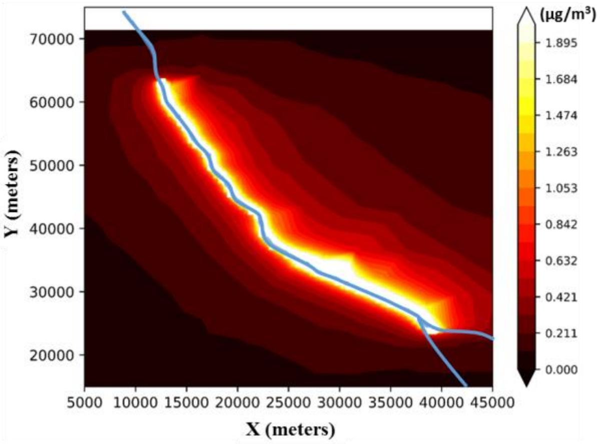
PM$_{10}$ (µg/m^3)	Present Demand				Future Demand			
Distance from truck-only lanes	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**
< 0.25 miles	0.2972	0.2759	0.0213	0.0717	0.3180	0.2924	0.0255	0.0803
< 0.5 miles	0.0819	0.0783	0.0036	0.0439	0.0884	0.0828	0.0056	0.0633
< 1.0 miles	0.0449	0.0422	0.0027	0.0601	0.0480	0.0449	0.0031	0.0645
> 1.0 miles	0.0174	0.0164	0.0010	0.0577	0.0186	0.0173	0.0013	0.0700
Total	0.0476	0.0446	0.0030	0.0626	0.0512	0.0473	0.0039	0.0765

Table 5 (Continued). 3-Year Average of 24-Hour Pollutant Concentrations Originated from the I-75 Corridors under Different Project Scenarios

PM$_{2.5}$ (µg/m^3)	**Present Demand**				**Future Demand**			
Distance from truck-only lanes	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**
< 0.25 miles	0.2695	0.2503	0.0192	0.0713	0.2886	0.2655	0.0231	0.0799
< 0.5 miles	0.0742	0.0710	0.0032	0.0434	0.0801	0.0752	0.0049	0.0614
< 1.0 miles	0.0408	0.0383	0.0024	0.0598	0.0435	0.0407	0.0028	0.0638
> 1.0 miles	0.0158	0.0149	0.0009	0.0574	0.0169	0.0157	0.0012	0.0692
Total	0.0431	0.0405	0.0027	0.0622	0.0464	0.0429	0.0035	0.0762

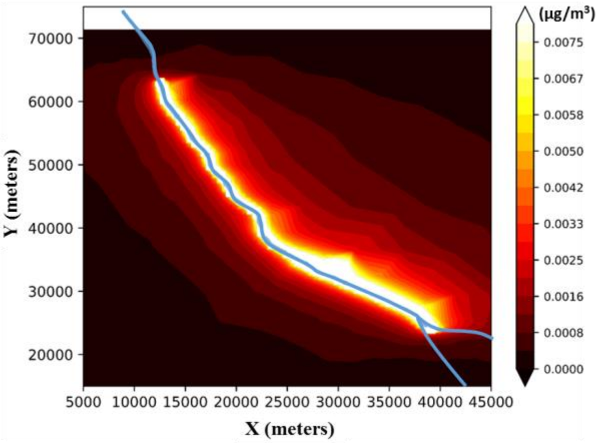
NOx (µg/m^3)	**Present Demand**				**Future Demand**			
Distance from truck-only lanes	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**	**Without Truck-only Lanes (A)**	**With Truck-only Lanes (B)**	**A-B**	**(A-B)/A**
< 0.25 miles	8.2393	7.8168	0.4225	0.0513	9.1438	8.5014	0.6424	0.0703
< 0.5 miles	2.2785	2.2128	0.0657	0.0288	2.5011	2.4092	0.0919	0.0367
< 1.0 miles	1.2493	1.1966	0.0526	0.0421	1.3759	1.3023	0.0736	0.0535
> 1.0 miles	0.4837	0.4640	0.0197	0.0408	0.5325	0.5050	0.0275	0.0517
Total	1.3218	1.2634	0.0584	0.0442	1.4600	1.3746	0.0854	0.0585

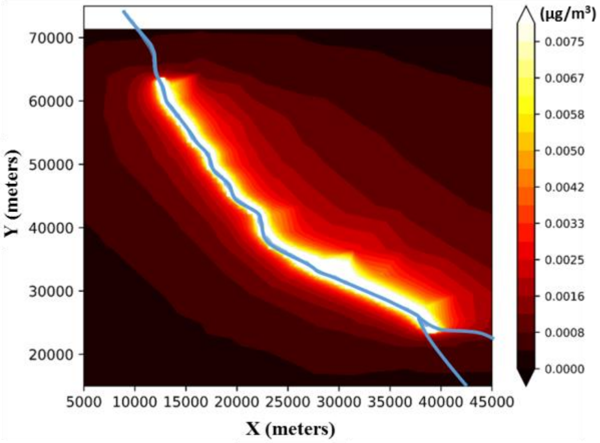




(a) CO (Present Demand)

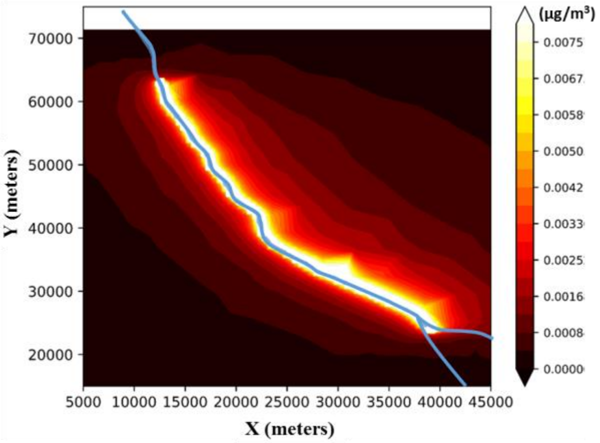
(b) CO (Future Demand)

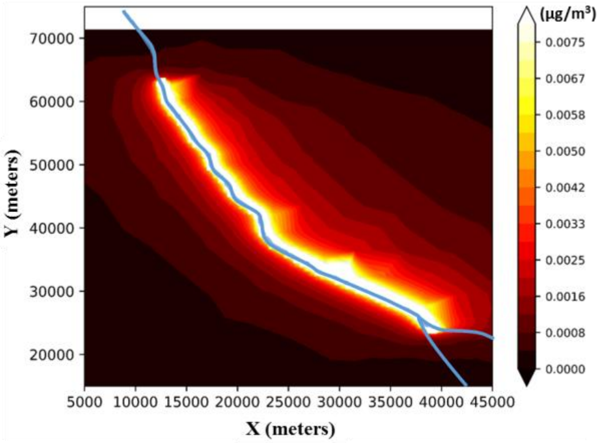




(c) PM_{10} (Present Demand)

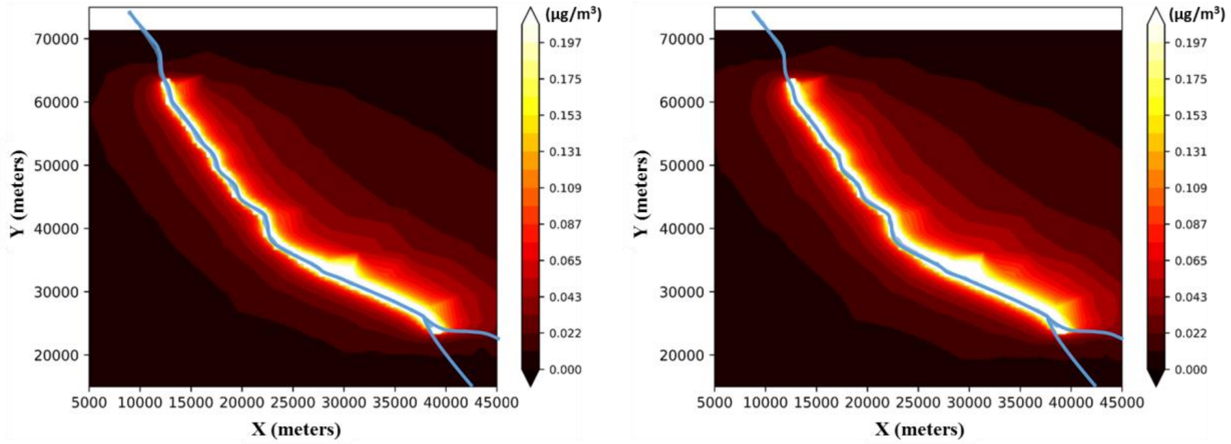
(d) PM_{10} (Future Demand)





(e) $PM_{2.5}$ (Present Demand)

(f) $PM_{2.5}$ (Future Demand)



(g) NO$_x$ (Present Demand) **(h) NO$_x$ (Future Demand)**

Figure 6. Changes in Pollutant Concentrations (μg/m^3) after Truck-only Lane Installation

Conclusions

This evaluated the energy and emissions impacts of truck-only lanes in terms of fuel consumption, mass emissions, and air pollutant concentrations. The study developed automated modeling routines that employ Vissim® microscopic traffic simulation linked with MOVES-Matrix and AERMOD models to predict energy use and resulting pollutant mass emissions and downwind pollutant concentrations (CO, PM_{10}, $PM_{2.5}$, and NOx). The integration of the three different modeling techniques enhanced the computational efficiency of the simulation analysis. As a case study, the study applied the developed program to the proposed truck-only lanes on the I-75 corridor south of Atlanta, stretching from Macon to McDonough (about 40 miles) in Georgia, USA. The study examined the changes in traffic flow, fuel consumption and emissions, and pollutant concentrations after the introduction of truck-only lanes to the road network.

Vehicle simulation analyses revealed that installing truck-only lanes had a large and positive effect on enhancing both truck lane and GPL operations (on average 5.5% and 5.3% increase in the speeds of trucks and GPLVs, respectively). Vehicle operations may not deteriorate significantly even as truck traffic demand increases in the future, because the capacity expansion provided by the truck-only lane addition improves the efficiency of vehicle movements and operations. The enhanced vehicle operations, in turn, contributed to reducing the total vehicle hours traveled (5.2% to 6.9% decrease, depending on traffic demand projections).

The study found that the enhanced vehicle operations with the installation of the truck-only lanes helped reduce the total fuel consumption by 2.7% to 3.7%, mass emissions by 2.7% (CO_2) to 8.0% (CO), and pollutant concentrations by 4.4% (NOx) to 12.8% (CO), with the magnitude of impacts varying by pollutant and traffic demand projection. The atmospheric dispersion analysis of pollutant concentrations over the study area confirmed that the pollutant concentrations were likely to decrease more significantly adjacent to the corridor than in areas farther away from the freeway. In addition, the positive effects of truck-only lanes are likely to be even greater as traffic demand increases beyond current levels.

As with any other research endeavor, this research faced some limitations. The study may not have captured detailed demand estimation and route decisions of trucks and GPLVs induced by changing conditions due to truck-only lanes. Traffic simulation analyses with better temporal resolution supported by actual traffic count data is recommended for future research to more reliably evaluate impacts. Future analyses will improve upon the simple assumption that future truck traffic will increase by 20%, and experiment with different traffic demand projections to test the robustness of the simulation results.

Despite these limitations, the research team expects that the extensive simulation results of this study help understand the performance of truck-only lanes on a large-scale network with a heavy mix of truck and general purpose lane vehicles. The methodology and framework in this study can be effectively and efficiently applied to evaluate the energy and environmental impacts of other transportation projects under a variety of operating conditions.

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