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CAV Systems Incorporating Air Pollution Information from Traffic Congestion

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CAV Systems Incorporating Air Pollution Information from Traffic Congestion

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16. Abstract

The economic impact of air pollution due to motor vehicles by 2030 will be 100 billion dollars, and the public health impacts from traffic pollution will grow to 17 billion dollars. The transportation industry also faces the challenge of monitoring and controlling greenhouse gases (GHGs). CSU studied criteria air pollutants (CAPs)under different traffic congestion scenarios along selected freeways in Ohio. The study captured pollution intensities in different seasons, representing different atmospheric stabilities and concentrations of criteria air pollutants and greenhouse gases as a function of traffic densities. Our prior work determined typical hot spots in Ohio along freeways prone to high traffic densities and possible congestion. MOVES was used to generate these scenarios to assess vehicle emissions in a simulated traffic congestion scenario across interstate intersections. ODOT traffic data was used for these scenarios. The resulting air pollutants and greenhouse gases from emissions were determined using a dispersion model. Concentrations of the air pollutants were compared with NAAQS. An MS EXCEL-based model was developed to assess the severity of air pollution. Our methodology adequately provided a framework to estimate CAPs and GHGs across interstate interchanges where the traffic densities are high, and the congestion in these areas leads to elevated levels of these pollutants. We observed that long-haul trucks contribute to lower NOx levels and lower CO levels than their road and passenger cars counterparts. Morning traffic produced lower pollutant concentrations than those in the evenings. We built a model app to forecast air quality for congested areas (primarily interstate intersections) on freeways. CAV technology will be deployed to communicate information to travelers on freeways on radio channels approaching these congested areas. The mobile air quality app deployed on board CAV can update the models with traffic data to assess the lowering of emissions and GHGs due to replacing conventional vehicles with CAVs or those that run on renewables. CAV may facilitate vehicle-to-vehicle communications of air quality to alert vehicles approaching congested intersections.

17. Key Words On-road mobile source pollution, interstate interchanges, criteria air pollutants, greenhouse gases, mobile air quality app	**18. Distribution Statement** No restrictions.

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CAV Systems Incorporating Air Pollution Information from Traffic Congestion

K.V. Nedunuri and R. Kandiah

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1 Introduction

The economic impact of air pollution due to motor vehicles by 2030 will be 100 billion dollars, and the public health impacts from traffic pollution will grow to 17 billion dollars. President Biden proposed to spend 620 billion dollars in service of improving air quality, reducing congestion, and limiting greenhouse gas emissions (GHGs). If a small fraction (5%) is autonomous vehicles (CAV), vehicle emissions of the entire fleet are reduced by 15% (for CO2) and 73% (for NOx) (Stern et al., 2019). Our ongoing study uses air emission and dispersion models to examine air pollutants and greenhouse gas emissions from vehicles across congested highways. We developed a web-based mobile app that alerts passengers in vehicles approaching congested highway intersections of air quality. We hypothesize that when the mobile air quality app is deployed on board the CAV, it will additionally update the models with traffic data to assess the lowering of emissions and GHGs due to replacing conventional vehicles with CAVs or those that run on renewables. CAV may facilitate vehicle-to-vehicle communications of air quality to alert vehicles approaching the congested interstate intersections.

2. Objectives

This research supports the CAV development by CCAT at the University of Michigan on developing a methodology to assess the improvements in air quality and reduction in greenhouse gases through a gradual replacement of fossil-based on-road vehicles with the CAVs operated by electric vehicles. The study's goal is to monitor these improvements in highly traffic-congested areas and contribute to the development of CAVs equipped with the capability to augment their efforts on enabling mobility with improvements in air quality. Three project objectives – two technical and one educational- were laid out in this project. The technical objective was to assess air quality emissions (US EPA priority pollutants and greenhouse gases (GHG) in the most congested areas within Ohio along interstate intersections and develop an air quality app to alert vehicles approaching the intersections and deploy it on CCAT CAVs. The technical objectives were combined with the educational objective that focused on training undergraduate students in sustainable transportation through curriculum enhancements and summer undergraduate research at the NEXTRANS partner institutions. The following objectives were developed to accomplish the goal of the study.

1. Assessment of air quality across interstate interchanges,
2. Development of a mobile app to monitor air quality, and
3. Capacity building and workforce development of an HBCU in transportation-related environmental engineering field

3 Modeling

Near ground, ambient air concentrations of Criteria Air Pollutants (CAPs: CO, NO_x, SO_2, PM_{10}, and $PM_{2.5}$) regulated by the National Ambient Air Quality Standards (NAAQS) and greenhouse gases (GHGs: CO_2, CH_4, and N_2O) were determined along congested interstate intersections in Ohio using a simple line dispersion model.

3.1 Using Ohio Traffic Information Management System to obtain traffic densities

Our earlier studies across Ohio roadways focused on identifying the highest emission levels of CAPs (hotspots). We used ANNs and self-organizing maps to cluster road lengths and areal segments based on traffic volume and emissions. The hotspots identified were Cleveland (Cuyahoga County), Columbus (Franklin County), Cincinnati (Hamilton County), Dayton (Montgomery County), Toledo (Lucas County), and Akron (Summit County), all of which contain urban districts. Specifically, the study revealed that road lengths contribute to higher emissions than area segments. The intestate routes in urban communities were identified as the highest polluted group (Kandiah, 2010).

Reducing emissions across interstates, particularly those segments that pass through interstate interchanges near urban districts, will improve air quality and public health. Interstate interchanges I-75 and I-70 in Dayton, I-71 and I-75 in Cincinnati, I-70 and I-72 in Columbus, I-90 and I-71 in Cleveland, and I-90 and I-75 in Toledo were selected. Ohio Transportation Data Management System (TDMS) provided traffic densities (see Figure 1), which included traffic counts by annual average daily traffic (AADT) and volumes classified further by vehicle types and hourly counts (Figure 2). Passenger cars and long-haul trucks were considered in this study to assess air quality since these vehicles were significant contributors. AADT was monitored over seven increments, capturing the most hourly traffic over the day.

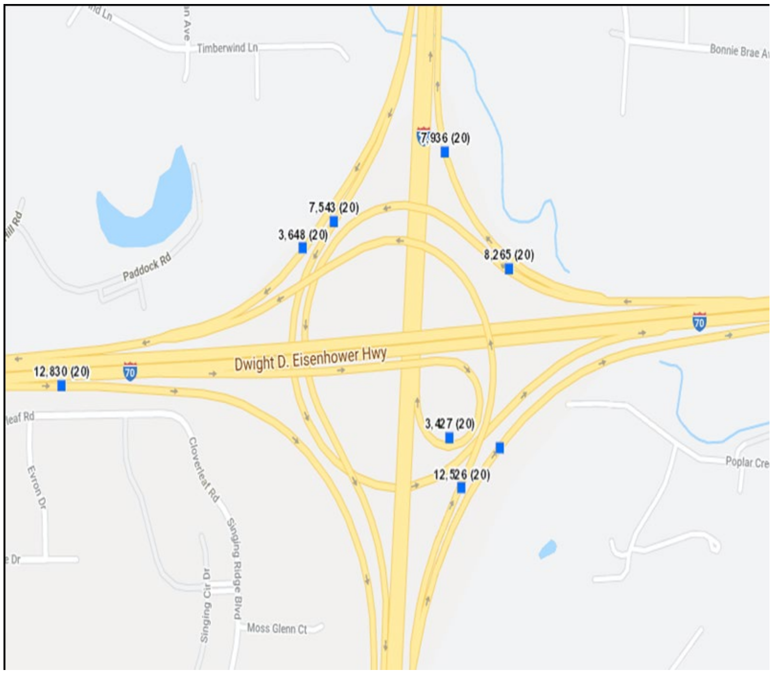


Figure 1. Real-time traffic counts at the I-75/I-70 Interstate Intersection in Dayton, OH, on a Spring day in 2019

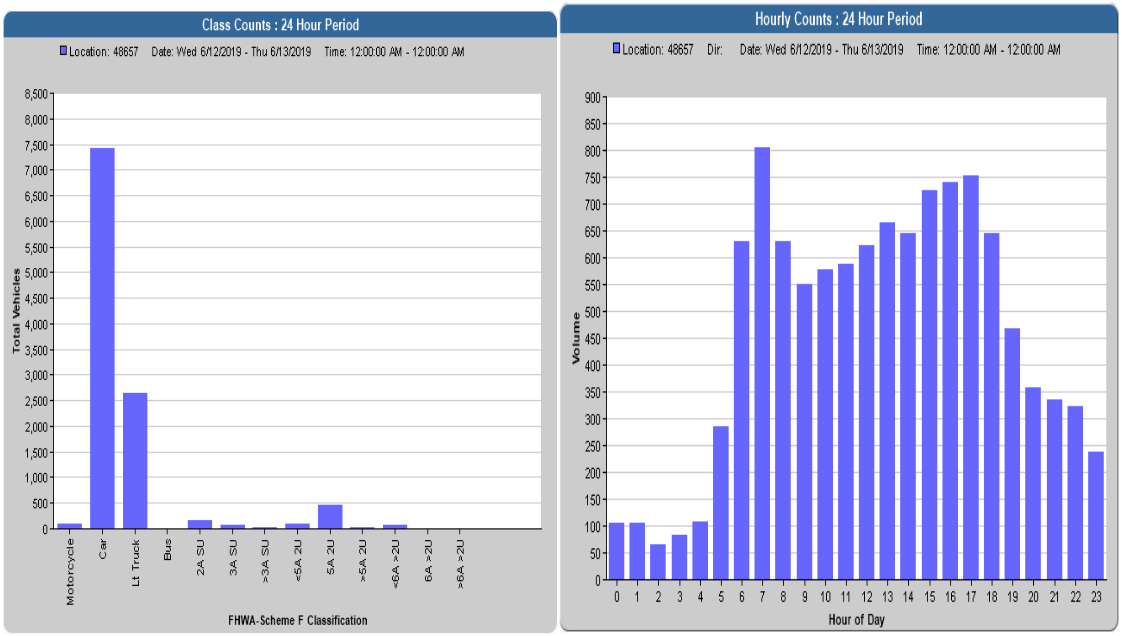


Figure 1. Traffic volume collected at I-75/I-70 Interchange based on vehicle type (left) and times of the day (right)

3.2 Using MOVES to estimate CAPs and GHGs

Motor Vehicle Emission Simulator (MOVES) (US EPA, 2022) was used to estimate on-road criteria air pollutants and greenhouse gases. Gasoline-run passenger vans and diesel-run long haul trucks were chosen to represent vehicles across the selected interstate intersections in Ohio to conservatively estimate the emissions released from the vehicles. A county-level resolution comprising rural restricted, rural unrestricted, urban restricted, and urban unrestricted roads was chosen to represent these vehicles' emissions best. CO_2, CH_4, and N_2O were the greenhouse gases (GHGs); the criteria air pollutants were CO, NO_2, and $PM_{2.5}$. Emissions were calculated in Winter and Spring. The month of January for winter/fall and June for Spring/summer were chosen as representative months in their respective seasons. MOVES calculated emissions for two days each month, one day representing a weekday while the other representing a weekend day and reported them in grams emitted per vehicle per mile traveled.

3.3 Using Finite line dispersion models to estimate near-ground ambient air concentrations of CAPS and GHGs

We reviewed the applicability of line dispersion models proposed by Wang and Rote (1975), Venkatram et al. (2009), Richmond-Bryant et al. (2011), and Yanosky et al. (2018) for estimating pollutant concentrations along the interstate intersections. Wang and Rote's (1975) model is a 1-D simple analytical solution to a rigorous Gaussian model to simulate a finite line dispersion applicable to aircraft runways. Venkatram et al. (2009) estimated VOCs within a 100-m distance from roadways using the 3-D Gaussian model simplified to consider the near-ground lateral and longitudinal dispersion. Richmond-Bryant (2011) used these models in the city roadways to estimate the black carbon from vehicular idling during school dismissals. Traffic intensity and daily local meteorology were incorporated into line dispersion models to assess near-road traffic-related PM 2.5 levels. The 1-D line dispersion models from these studies were adopted in our research to derive a simple model where the wind direction was assumed perpendicular to the line source to mimic near-ground emissions (CAPs and GHGs) from a congested interstate intersection. Such a simplification of the model may not yield accurate results. However, it would provide a decent approximation that a mobile app would require much greater computational speeds while estimating CAPs and GHGs in real time based on acquiring meteorological data available through weather apps.

The line dispersion model calculates near-ground ambient air concentration on the interstate, as given below.

$$C(x) = \frac{2q}{\sqrt{2\pi}} \cdot \frac{1}{\sigma_z . u}$$

Where q is the emission rate per unit distance g/m.s (or mile) obtained from MOVES, u is the wind speed perpendicular to the vehicles on the highway, σz is the Gaussian Dispersion Coefficient, and *C(x)* is ground-level air pollutant concentration of the receptor at a distance x from the road.

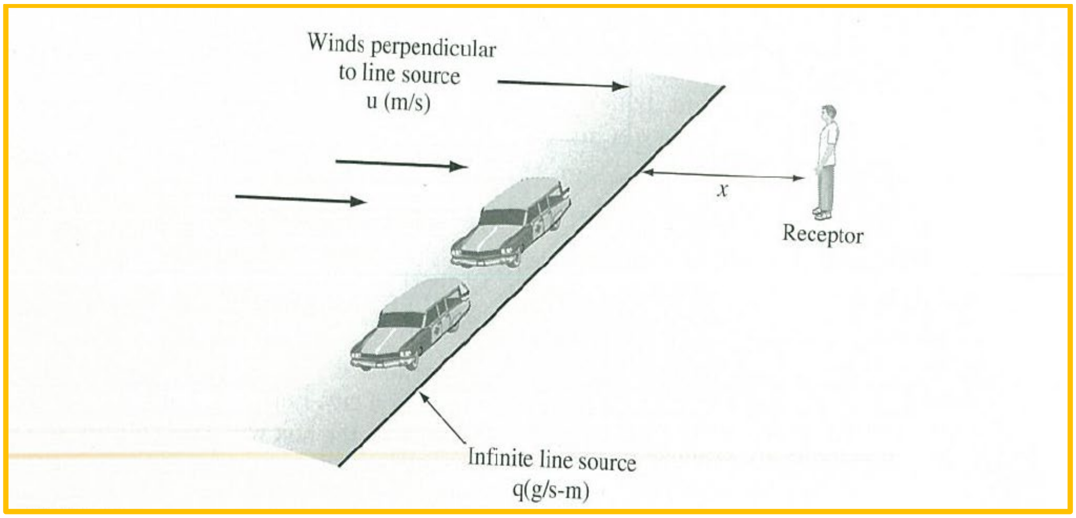


Figure 2. A conceptual traffic representation of passenger cars along interstate interchanges to calculate ambient air concentrations of CAPs and GHGs

4 Methodology

Concentrations were determined by calculating the mass flux of each pollutant emitted by major vehicle types (diesel heavy-load trucks and gasoline passenger cars) passing through a particular intersection. Fluxes were determined based on emissions from an average vehicle traveling per mile using the US EPA's MOVES (mobile vehicle emission simulator) model. Traffic densities (number of vehicles across the intersection) were obtained from ODOT's TDMS system based on AADT (average annual daily traffic load and near real-time traffic density whenever available). We adopted a decoupled approach in solving MOVES and dispersion models. A mobile app on CAVs passing the intersection received real-time weather data (temperature, weather conditions, wind speed) and estimated air pollutants and GHGs using the simple dispersion model. Intense emission calculations were done offline using MOVES for the period under consideration, and the app retrieved the results from a web server. The air quality concentrations will be passed on to CAVs and other vehicles approaching the congested intersection.

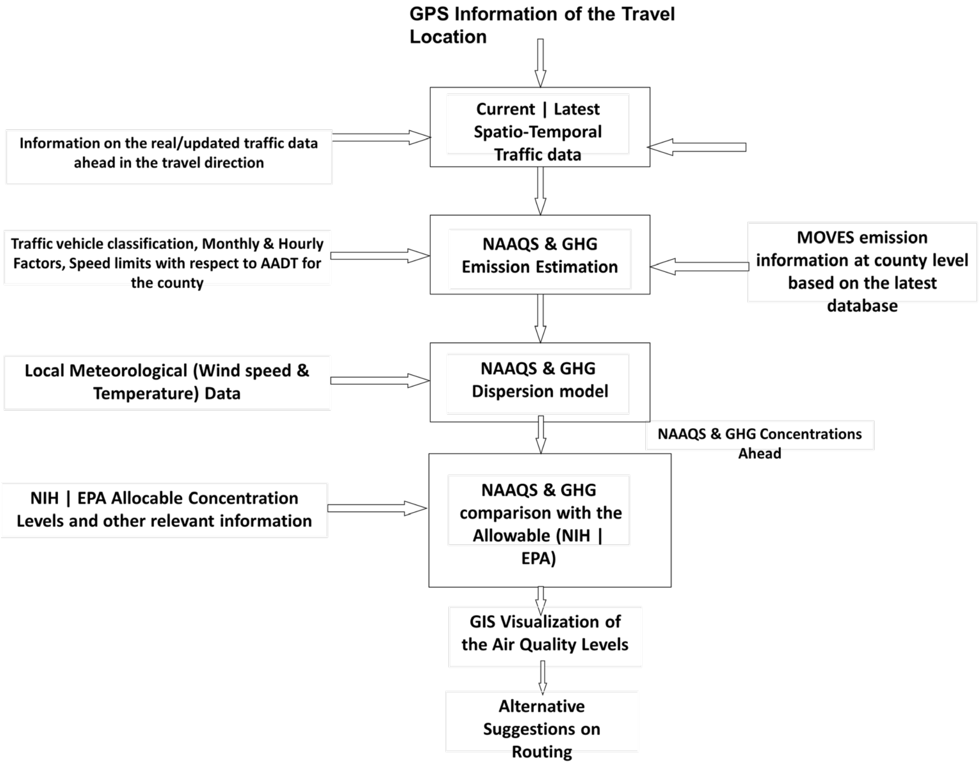


Figure 3. Overall computational methodology for estimating CAPs and GHGs across interstate interchanges

5 Results

5.1 Objective 1: Assessment of air quality across interstate interchanges

We assessed the air quality across previously described interstate interchanges across Ohio by estimating near-ground CAPs and GHGs. We will discuss our findings for the interchanges across Montgomery County, one of the busiest counties in Ohio. The summer and winter months were included to capture the trends across the year. Although we have measured these gases across seven time periods during any day, only morning (6 A.M.–noon) and evening (Noon-6:00) were illustrated here to capture accumulations from rush hour traffic and the extent of air pollution as a worst-case scenario.

We plotted the results on bar graphs showing concentrations of CAPs and GHGs on the y-axis and the names of the selected pollutants on the x-axis. We presented near-ground concentrations of the pollutants in the morning and evening. Fig. 5a shows higher NOx concentrations from the long-haul trucks compared to passenger vans in Montgomery County across the I70/I75 exchange. CO concentrations are higher for gasoline-run passenger vans in summer. CO concentrations were below the 1-hour NAAQ standard of 35 ppm. NO_2 values are way below the 1-hour NAAQ standard of 225 ppm for passenger vans. Fig. 5b shows higher NOx concentrations from the long-haul trucks compared to passenger vans in

Montgomery County across the I70/I75 exchange. CO concentrations are lower for diesel-run trucks than gasoline-run passenger vans in winter. In winter, concentrations are greater in the evenings compared to mornings. CO concentrations were below the 1-hour NAAQ standard of 35 ppm. NO_X values are way below the 1-hour NAAQ standard of 225 ppm for passenger vans.

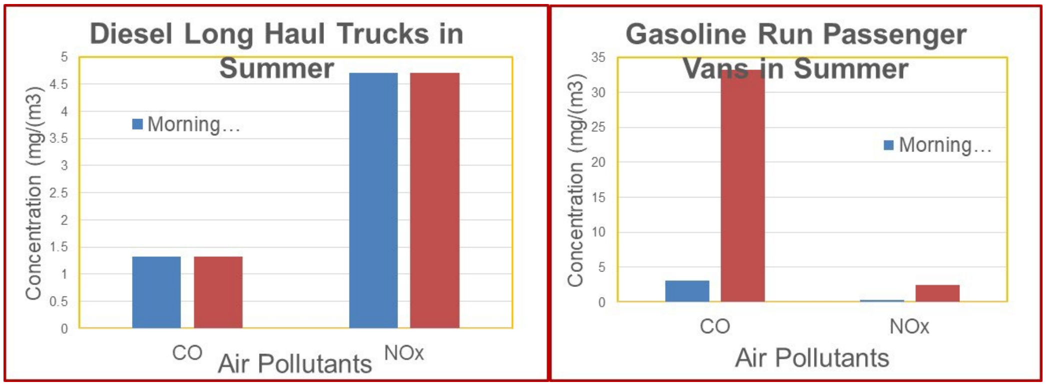


Figure 4a. Near-ground ambient air concentrations of selected CAPs across the I70/I75 interstate interchange

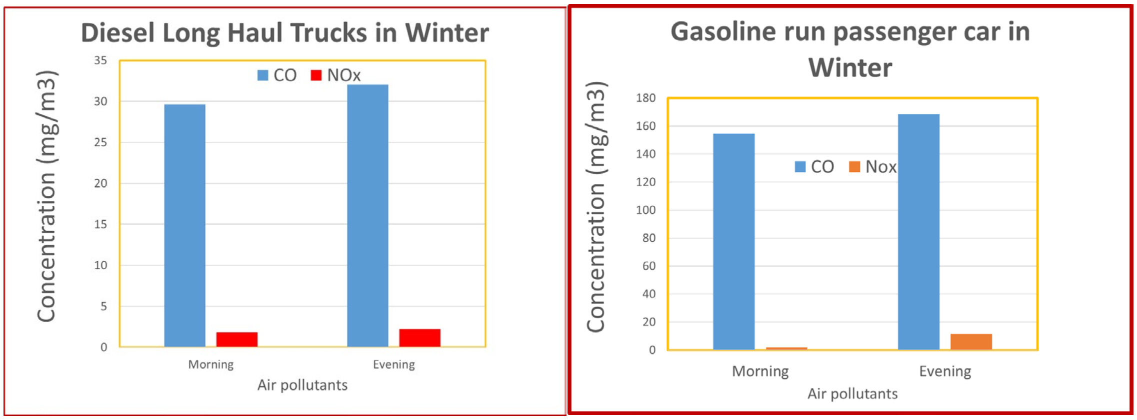


Figure 5b. Near-ground ambient air concentrations of selected CAPs across the I70/I75 interstate interchange

This study also assessed the release of GHGs across interstate interchanges as the transportation sector contributed to about 21% of total GHGs in the US in 2021 (US EPA, 2023). The study revealed that passenger cars and medium and heavy-duty trucks that burn diesel or gasoline significantly contribute to the transportation industry. Most GHG emissions come from releasing carbon dioxide, although methane emissions also contribute in smaller quantities.

Figure 6 shows GHG releases into the atmosphere at the I-70/I-75 interchange in 2022. Although we generated emissions data throughout the day, we only discussed emissions during peak hours in the morning and evening. GHG releases from diesel trucks are less than those of gasoline passenger cars. However, the differences are more pronounced in summer. Morning releases are slightly lower than winter releases. GHG releases from passenger cars are higher in winter than in summer (Figures 6a and 6b). As we introduce CAVs into road transportation, our study can address lowering GHGs and CAPs, leading to better air quality and mitigation of impacts on climate change.

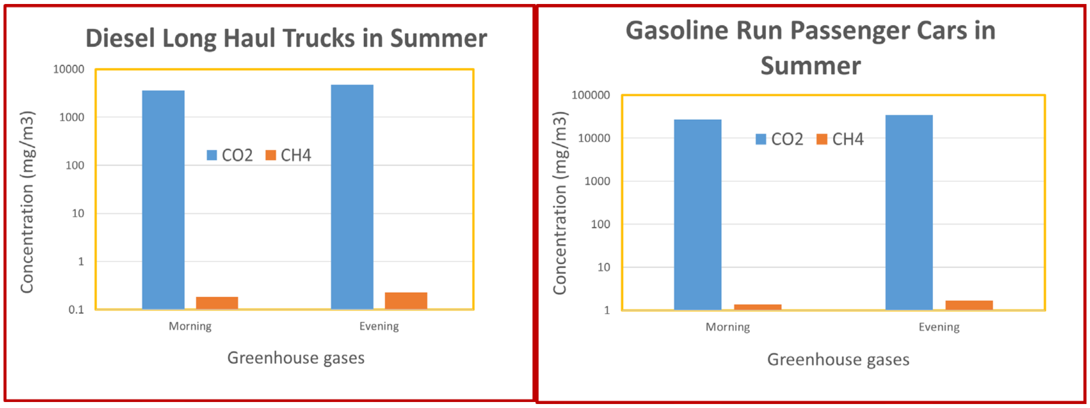


Figure 6a. Near-ground ambient air summer concentrations of selected GHGs across the I70/I75 interstate interchange

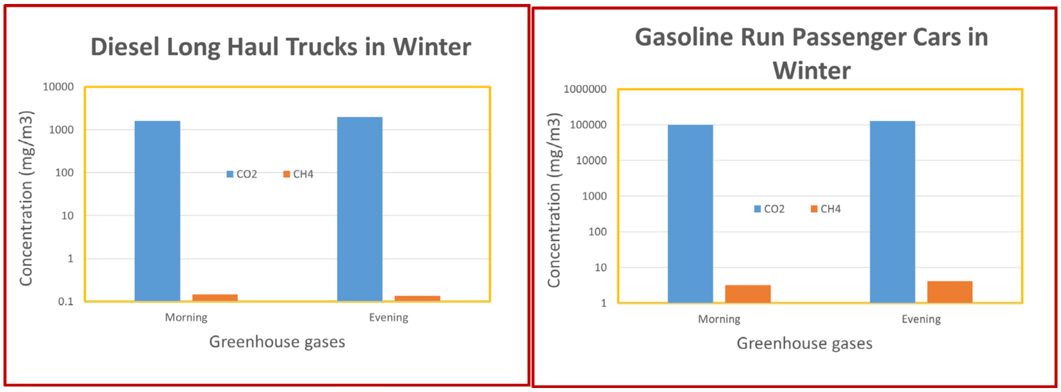
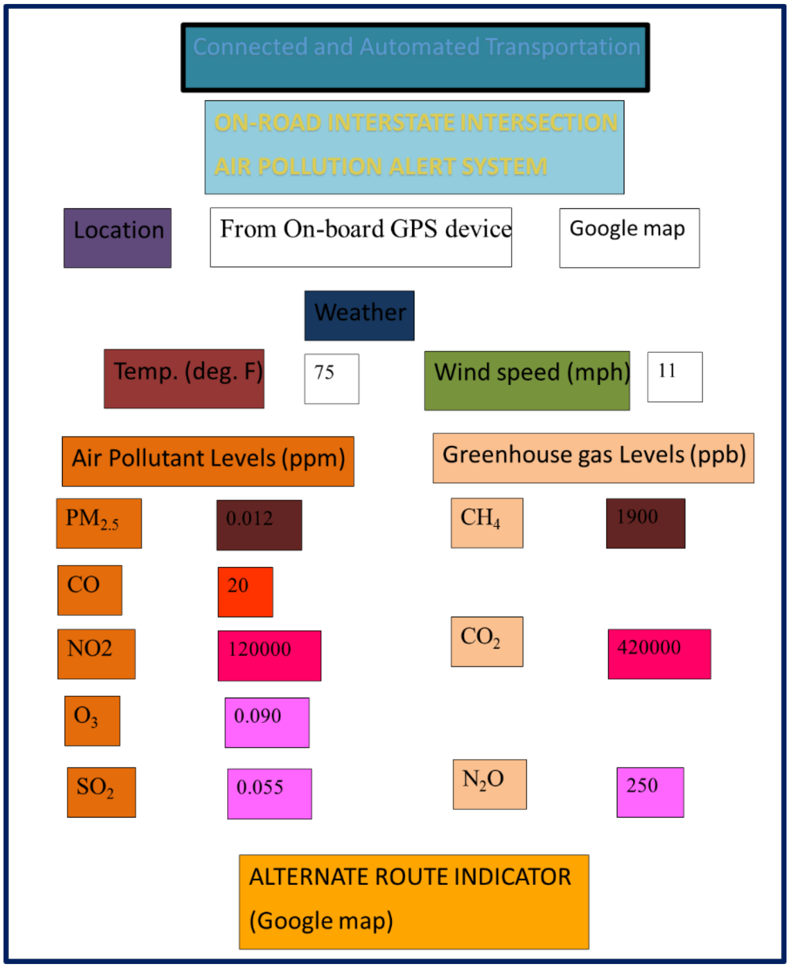


Figure 6b. Near-ground ambient air winter concentrations of selected GHGs across the I70/I75 interstate interchange

5.2 Mobile app development

We developed an Android app using Java and Kotlin to calculate and display estimated emission air quality levels to drivers from their vehicles on predefined roads and intersections of Ohio approaching interstate interchanges. The app uses cached emission data on a data server as an MS EXCEL spreadsheet from CCAT technical PIs as a proof of concept. Using GPS, it extracts meteorological data from a weather app in the region. The program on the data server uses the combined information to calculate CAPs and GHGs, and the app displays it when installed on an Android mobile phone (Figure 7). CSU student researchers are engaged to be part of the App development and demonstration. The initial version of the app has the following features.

1. It has a graphic user interface (GUI) for displaying temperature, wind speed, and Air Pollutant Levels (ppm) in $PM_{2.5}$, CO, NO_2, O_3, and SO_2 using offline data.
2. It has a One-button access to Weather.com for quick weather checks.
3. Direct access to a cached database for emission data calculation and weather app (ongoing activity)



Connected and Automated Transportation

ON-ROAD INTERSTATE INTERSECTION AIR POLLUTION ALERT SYSTEM

Location: From On-board GPS device | Google map

Weather

Temp. (deg. F): 75

Wind speed (mph): 11

Air Pollutant Levels (ppm)		Greenhouse gas Levels (ppb)	
$PM_{2.5}$	0.012	CH_4	1900
CO	20		
NO2	120000	CO_2	420000
O_3	0.090		
SO_2	0.055	N_2O	250

ALTERNATE ROUTE INDICATOR (Google map)

Figure 7. Android-based GUI of Mobile Air Quality App showing ambient air concentrations of air pollutants and greenhouse gas levels across the selected interstate interchages in Ohio

5.3 Capacity building

The ABET-accredited environmental engineering program at CSU enhanced its *ENE 3305 Air Quality Engineering* course curriculum by infusing it with content on transportation-related air quality studies. The Noise and Air Quality Engineering laboratory has added equipment to monitor CAPs and GHGs. The lab acquired an engine exhaust analyzer, upgraded sensors for monitoring CAPs, and a PM2.5 monitoring instrument. CSU received a data server that will serve as a back-end processor and data storage and retrieval system for the mobile app to run the offline emission calculations and provide necessary data to predict the air quality. In the future, we will use the server to obtain data from the mobile app deployed on CAVs.

6. Findings

Our methodology adequately provided a framework to estimate CAPs and GHGs across interstate interchanges where the traffic densities are high, and the congestion in these areas leads to elevated levels of these pollutants. We observe that long-haul trucks contribute to lower NOx levels and lower CO levels than their road and passenger cars counterparts. Morning traffic produced lower pollutant concentrations than those in the evenings.

7. Challenges

Our original plan to outsource mobile app development immediately during and after COVID-19 consumed much time and did not work eventually since the third-party vendor withdrew from their commitment. Later efforts to identify in-house expertise and engage the computer science faculty and students further delayed the app development.

8. Recommendations

Project PIs submit the following recommendations to continue effective contributions from CSU to CCAT.

- PIs request the center's assistance in app deployment on CCAT-developed CAVs
- The project supported training minority students through minority-serving institutions with their niche research areas with the help of large institutions to bring equity concerning demography in the workforce.
- CCAT uniquely introduced the HBCU conference, which allowed the sharing and collaboration of CCAT R1 institutions with HBCUs to reduce gaps in access, equity, and representation of underserved minorities in CAV development.
- The university benefitted from the waiver of the non-federal matching support, which allowed it to provide student support and capacity building effectively.

9 Outputs, Outcomes, and Impact

9.1 Outputs

- Presentation and Paper: Board 108: Ramanitharan Kandiah and Krishna Kumar Nedunuri. 2023. Enhancing Environmental Engineering Curriculum for the Transportation Industry. Environmental Engineering Division (ENVIRON) Poster Session, 2023 ASEE Annual Conference & Exposition, Baltimore, MD. June 25-28, 2023. https://peer.asee.org/board-108-enhancing-environmental-engineering-curriculum-for-the-transportation-industry
- Presentation: Jalen Smith, Ramanitharan Kandiah, and Krishna Kumar Nedunuri. 2022. Impacts of External Factors On-Road Emissions in Montgomery County, Ohio. *Technological Advances in Science, Medicine and Engineering Conference (TASME 2022)*. Virtual. August 28-29, 2022
- Presentation: Adelynn Reeves and Ramanitharan Kandiah. 2022. Environmental Impacts of Renewable Energy and Social Equity. *Technological Advances in Science, Medicine and Engineering Conference (TASME 2022)*. Virtual. August 28-29, 2022 (Oral)
- Presentation: Abstract included in the Central State University Booklet for Internship and Research Review Students' Presentation of 2022 Summer Work held on October 19, 2022, Central State University: Jalen Smith, Ramanitharan Kandiah, and Krishna Kumar Nedunuri. 2022. Impacts of External Factors On-Road Emissions in Montgomery County, Ohio.
- Award-winning Undergraduate Student Poster: Jalen Smith, Kimberly Smith, R. Kandiah, K.V. Nedunuri, D. Cao, CAV systems incorporating air quality from traffic congestion, 2023 Global Symposium on Mobility and Innovation, University of Michigan, M City and UMTRI, Ann Arbor, MI, April 4-5.

- Central State University TRB scholars secured the fourth Honorable Mention position in the 2019 EESF/AEESP Student Social Media Competition.
- On the Road to the CCAT Global Symposium Presentation. 2020.

9.2 Outcomes

- Ramanitharan Kandiah was a Co-Chair for the Civil Engineering Track for the *Technological Advances in Science, Medicine and Engineering Conference (TASME 2022)*. Virtual. August 28-29, 2022
- Ramanitharan Kandiah reviewed papers for TRB 2023 Conference
- Visited MCITY and met with other HBCU Transportation researchers and students (September 8-9, 2022)
- Thirteen engineering students attended Franklin County Engineer's HBCU Civil Engineering Career Expo on September 26, 022, to learn about careers in Civil Engineering, including the careers and opportunities in transportation.
- CSU career fair, the MDOT visit, and student participation (October 11-13, 2022)
- Trained six undergraduate environmental engineering students on transportation careers focused on sustainability, environmental impacts, and climate change.
- Three students who served as undergraduate research assistants graduated with degrees in environmental engineering.
- The sustainability of transportation solutions also demands social equity and accessibility. The underserved populations live in neighborhoods close to areas most affected by air pollution. However, their representation in the transportation industry workforce, involvement in research and development, or accessibility to education, particularly in transportation or environmental engineering, is limited. CSU contributed to an increase in diversity in workforce development by involving its students in transportation-related academic training/research in environmental engineering.
- Through internships and serving as RAs, students participated in the center's research activities at CeSU, CCAT partner institutions, Purdue University, and ODOT (Ohio Department of Transportation).

9.3 Impact

- This work's long-term impact is focused on reducing traffic congestion and improving air quality, public health, and wellness.
- It assists the transportation industry in assessing the greenhouse gas emissions from on-road vehicles across highly traffic-congested areas across interstate interchanges near urban centers.
- Access for Underrepresented Minorities to Transportation Research and Innovation
- CSU is a Region 5 HBCU involved in transportation research, contributing to the sustainability of the transportation sector. It took a leadership role in expanding the influence of the University of Michigan's CCAT to HBCUs involved in transportation education and research. The following activities showcase CSU's involvement.

- Dr. Nedunuri was an Invited Panel Member at USDOT Center for Connected Multimodal Mobility's (C2M2) 5th Annual Fall Conference on October 15, 2021, in Clemson, South Carolina. Discussed U Michigan and CSU model in "Developing Meaningful HBCU – UTC Partnerships for the Future."
- Dr. Ramanitharan Kandiah was invited to present Minorities & HBCU Participation in Transportation Research in the 2022 Global Symposium on Connected and Automated Vehicles & Infrastructure. April 12-13, 2022, University of Michigan, Ann Arbor, MI.
- HBCU Clean Energy and Climate Coalition Meeting (for collaborative proposal: The Environmental Justice Thriving Communities Technical Assistance Centers Program)
- Midwest Environmental Justice Thriving Communities Meeting (for collaborative proposal: The Environmental Justice Thriving Communities Technical Assistance Centers Program)
- HBCU Clean Energy and Climate Coalition Meeting (American Made Program - Application Workshop)

Acknowledgments

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