IN-CABIN FINE PARTICULATE MATTER EXPOSURE DURING PARATRANSIT TRANSPORT

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16. Abstract

The effects of fine particulate matter (PM) exposure on human health depend on age as well as preexisting heart or lung diseases, and older adults are at greater risk for developing these diseases. Many older individuals have limited transportation options and may rely on mobility services, such as paratransit transport, to meet their mobility needs. Paratransit transport typically provides transportation options for older adults and individuals that cannot access the fixed-route bus or rail system. However, PM exposure during the use of paratransit services is understudied. Paratransit transport has different operating characteristics than typical fixed-route bus service. Specifically, paratransit bus transport has longer ingress and egress times, which leads to longer idling times. This project sought to characterize typical PM exposure for urban paratransit riders. To achieve the objective, the research team measured PM concentrations inside the cabin of paratransit buses for two paratransit operators in the southeast region of the United States. These field measurements included collection of the in-cabin PM2.5 and PM10 concentrations during typical daily routes. To collect these data, the research team used a GRIMM 1.109 aerosol spectrometer with isokinetic sampling pipe inside the cabin of several paratransit buses propelled by both gasoline and diesel engines. In addition to the PM measurements, the research team also analyzed anonymized data on preexisting conditions (i.e., prevalence of heart and/or lung disease) among the paratransit riders and origin-destination data to specify most likely pickup and drop-off locations. These analyses found that PM exposure for paratransit riders was dominated by exposure during pickup and drop-off operations rather than while the vehicles were in motion. These results suggest that facilities that receive paratransit passengers should be aware of potential PM sources located in the vicinity of their receiving locations.

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Executive Summary

The population of the United States is aging. The number of residents age 65 and over (older adults) grew from 35.0 million (12.4 percent) in 2000 to 49.2 million (15.2 percent) in 2016, and this group is expected to grow to 19 percent of the population by 2030. Many of these adults have limited personal transportation options and often have to rely on public services, including paratransit transport. Paratransit transport is a federally subsidized door-to-door transportation (transit) service designed to provide mobility for individuals who, due to physical or mental limitations, cannot reliably access typical fixed-route bus or rail services. While paratransit is available to anyone with these limitations, older adults are overrepresented among paratransit users. Thus, the increase in the older adult population will likely lead to more trips by paratransit operators in the coming years. Older adults are also more likely to suffer from various respiratory and cardiovascular disorders and thus tend to be more sensitive to the adverse impacts of air pollution, especially from fine particulate matter (PM). Despite this increased vulnerability, PM exposure during the use of paratransit services is understudied. A major reason why there are so few studies on PM exposure within the cabin of paratransit vehicles is the difficulty in making the PM measurements. Typically, paratransit vehicles are small, and any equipment used to monitor concentrations must not interfere with the ingress and/or egress of the passengers, many of whom have physical limitations. Likewise, these instruments must normally be autonomous (i.e., there can be no onboard operator), self-powered (i.e., battery operated), and able to operate reliably for many hours within a vibrating vehicle. This study was aimed at identifying suitable technologies to meet these operational requirements and to conduct a brief feasibility study to demonstrate that such data can be effectively collected. Both current and future applications of this technology can provide valuable information for researchers and planners alike about the potential hazards of paratransit transport.

After an initial search for suitable technologies, the research team focused on the use of a small portable aerosol spectrometer (GRIMM Technologies Model 1.109 dust monitor) and developed the necessary mounting hardware and sampling systems for deployment in paratransit buses. As a test of this system, the research team monitored PM concentrations inside the cabin of a total of four paratransit vehicles in two locations in the southeast region of the United States during typical daily routes. These data were collected for two days each in Nashville, Tennessee, and Atlanta, Georgia. The field measurements included collection of PM2.5 measurements during typical daily routes and used two gasoline-powered buses in Nashville (WeGo Public Transit) and one gasoline and one diesel bus in Atlanta (MARTA Mobility). This study found that the PM2.5 concentration increased significantly when a bus opened its doors to pick up or drop off passengers. The PM2.5 concentrations in Nashville and Atlanta were similar, with baseline concentrations of approximately 10 micrograms per cubic meter. Overall, there were consistently larger spikes in PM2.5 measurements for the Atlanta buses. The spikes in Atlanta approached or exceeded 40 micrograms per cubic meter, whereas the spikes in Nashville did not exceed 20 micrograms per cubic meter, with the exception of one large spike recorded on the first day of monitoring. The measurements also showed that elevated PM exposure can extend beyond when the doors are closed. It takes time for the particles to disseminate and the background concentration to stabilize. Due to certain characteristics of paratransit transport, such as extended idling times and elongated trip durations, paratransit riders may risk greater exposure to harmful pollutants. Riders are subject to not only pollutants emitted from the paratransit buses but also pollutants at the requested stops. Further studies can be conducted to understand the health implications of PM exposure on paratransit.

Acknowledgments

The authors would like to acknowledge the cooperation of the WeGo® and MARTA Mobility® paratransit systems in the collection of the data for this project. Without their cooperation, this project would not have been possible.

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Research Motivation

According to a report by the International Agency for Research on Cancer (IARC), outside air pollution is the leading environmental cause of chronic obstructive pulmonary disease (COPD) and cancer deaths (*1*). The World Health Organization estimates that almost 94 percent of deaths worldwide are due to COPD, lung cancers, and cardiovascular diseases (*2*). A total of 7 million premature deaths worldwide in 2012 were due to outdoor air pollution (*3*). Additionally, elderly populations are more susceptible to chronic diseases caused by air pollution (*4*).

Worldwide, the largest sources of these air-pollution-related emissions are motor vehicles. In particular, diesel-powered buses and trucks (*2*) are important sources of fine particulate matter (PM). Studies conducted by the World Health Organization concluded that atmospheric PM has increased the prominence of lung cancer (*2*). Fine particulate matter can penetrate deeply into the lungs and lead to heart and lung diseases. Any particle less than 10 micrometers in size is dangerous for human health (*5*), with the smaller ranges of particular concern. The effect of PM exposure on human health depends on age as well as preexisting heart or lung diseases (*4*).

The population of the United States is aging. The number of residents age 65 and over grew from 35.0 million (12.4 percent) in 2000 to 49.2 million (15.2 percent) in 2016 (*6*), and this group expected to grow to 19 percent of the population by 2030 (*7*). A significant portion of these older Americans either do not drive or do not have access to an automobile. In addition, physical or financial limitations can restrict access to fixed-route bus or rail transit systems or to ride-sharing services, thus further limiting personal mobility. To address these issues, virtually all transit system operators in the United States offer door-to-door on-demand transport (paratransit) for qualifying individuals. These paratransit systems typically provide transportation options for seniors and individuals that are physically or mentally disabled. Demand for these services is increasing, and the Government Accountability Office estimated a 7 percent increase in annual paratransit trips from 2007–2010 (*8*). Nonetheless, PM exposure of individuals using paratransit services is understudied, and there are reasons to believe that this exposure may be higher than would be the case for either private vehicles or traditional transit. Paratransit trips are traditionally associated with longer ingress and egress times for passengers because (a) these services are being offered to those with limited physical mobility, and (b) the use of wheelchair or passenger lifts typically requires that the vehicle be idling during this ingress/egress cycle. Thus, this study aimed to examine the extent to which individuals may be exposed to PM during typical paratransit operations.

Research Objectives

Paratransit transport typically provides transportation options for seniors and individuals that cannot access the fixed-route bus or rail system. Paratransit transport has different operating characteristics than typical fixed-route bus services. Paratransit transport has longer ingress and egress times, which lead to longer idling times and thus an increased potential for PM exposure. This project was designed to be an initial feasibility/demonstration study to (a) evaluate technologies for making passive on-road in-cabin PM concentration measurements, and (b) characterize PM exposure for a sample of typical paratransit riders to determine whether a more complete study should be undertaken.

Background Information

Study Locations

The PM exposure of paratransit riders was monitored in two large paratransit systems in the southeastern United States. These paratransit systems—WeGo Public Transit and MARTA Mobility—operate in the vicinity of Nashville, Tennessee, and Atlanta, Georgia, respectively. These systems were selected based upon the types of vehicles operated (mini-bus) and the type of engines used (gasoline for WeGo and both gasoline and diesel for MARTA Mobility). As opposed to van-type paratransit, the mini-bus allowed for greater flexibility in terms of instrument mounting and air sampling, while the presence of both diesel and gasoline engines in the study allowed for a comparison in how exposure was influenced by powerplant type. The locations for WeGo Public Transit and MARTA Mobility are illustrated in Figure 1.

WeGo Public Transit and MARTA Mobility operate similarly. Both paratransit operators offer door-to-door services. Their daily routes are variable because they are determined by requests made by riders. However, there are many commonalities between the most requested stops. The paratransit buses in both cities frequently transport people to hospitals, care facilities, and dialysis centers. Riders are exposed to particulate matter emitted by the vehicle as well as particulate matter from sources surrounding the stops.

In-cabin PM concentrations for paratransit buses were collected for two days in each city. These measurements were made continuously over the course of vehicle operations, from garage departure to return, and included measurements for all routes operated throughout the day. The Nashville (WeGo) measurements were made on two gasoline-powered mini-buses, while those conducted in Atlanta (MARTA) were made on one gasoline and one diesel mini-bus. The PM measurements were made using a GRIMM 1.109 aerosol spectrometer with an isokinetic sampling pipe and were referenced to a simultaneous global positioning system to identify the measurement locations. These measurements are discussed in more detail later in the text.

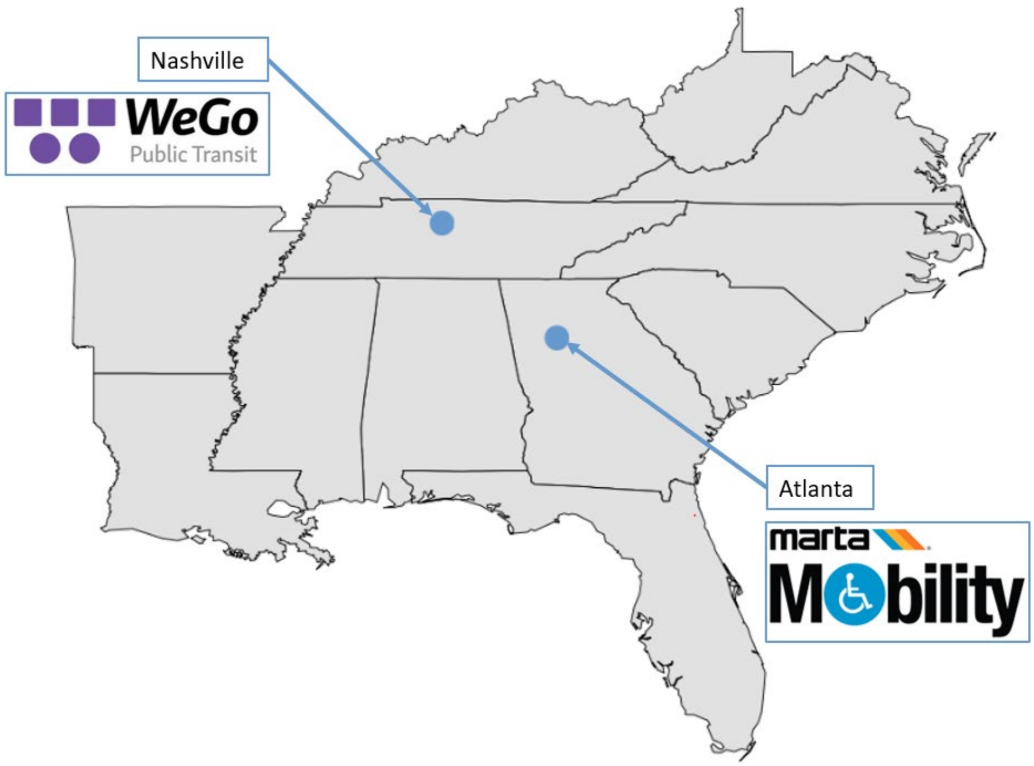

Figure 1. Study locations.

WeGo Public Transit Overview

WeGo Public Transit provides Americans with Disabilities Act (ADA)–designated service within Davidson County and the City of Nashville (*9*). Origin-destination data were used to determine the most requested paratransit pickup and drop-off locations in May 2018 to provide an overview of overall system operations that could be compared to the routes on which measurements were actually taken in order to evaluate the extent to which the measured routes represent normal system operations. Figure 2 shows the distribution of the most popular stops throughout the WeGo service area (Nashville/Davidson County). The majority of the stops were concentrated within the central business district, labeled “City of Nashville” in the figure. The agency operates 91 lift buses (*9*). All of the vehicles are fueled by gasoline.

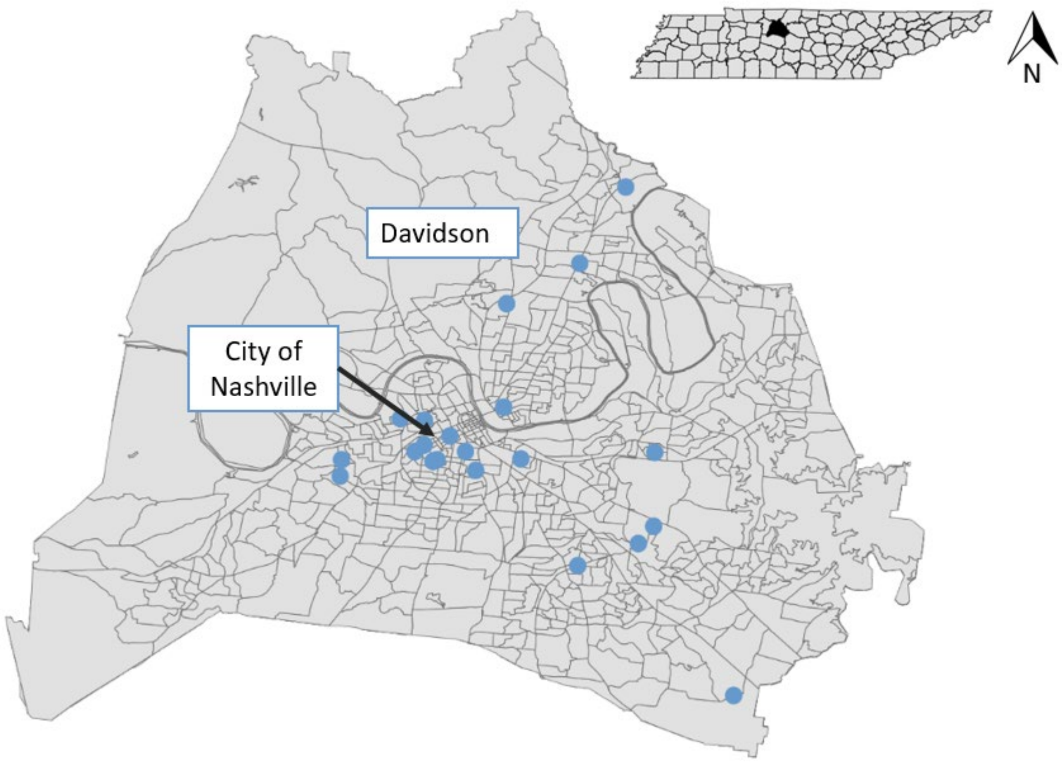

Figure 2. WeGo Public Transit most frequent stops in May 2018.

MARTA Mobility Overview

MARTA Mobility provides ADA-designated service in Fulton, DeKalb, and Clayton Counties, including the central business district for Atlanta (labeled "City of Atlanta" in Figure 3) (*10*). Origin-destination data were used to determine the most requested paratransit pickup and drop-off locations. Figure 3 shows the distribution of the most popular stops, indicated by requested frequency, for May 2018. The majority of the stops were concentrated in or near the central business district of Atlanta. The agency operates 173 lift buses (*10*). Some of the buses are fueled by gasoline and some are fueled by diesel.

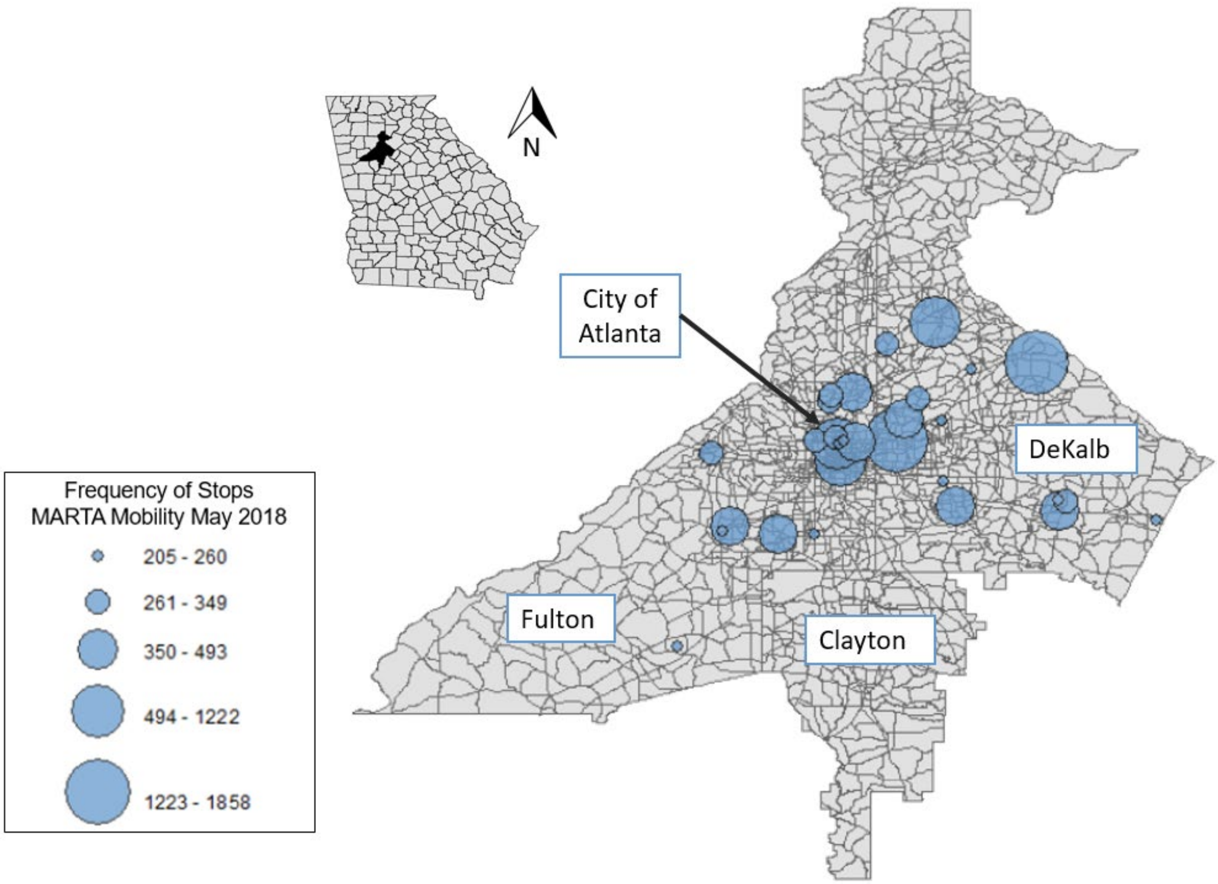

Figure 3. MARTA Mobility most frequent stops in May 2018.

Frequently Requested Stops

As described earlier, WeGo Public Transit and MARTA Mobility operate similarly. Both paratransit operators offer door-to-door services and are typically scheduled from one to five days in advance. Since the daily routes are determined by rider requests, the daily route of a particular bus is highly variable. However, across the systems, there are many similarities in terms of the types of requests received from riders. The most requested destinations for the paratransit buses in both cities tend to be hospitals, care facilities, and dialysis centers.

Origin-destination data were used to determine the most requested paratransit pickup and drop-off locations during May 2018. These anonymized data were analyzed by categorizing the most frequent stops by purpose. Figure 4 shows the most requested locations by WeGo Public Transit and MARTA Mobility riders. Over 80 percent of the stops by WeGo Public Transit were to a hospital, care facility, or dialysis center. There was a similar distribution among the most popular MARTA Mobility stops. Over 60 percent of the stops were to a hospital, care facility, or dialysis center. The stops categorized as "other" included private residences and other points of interest.

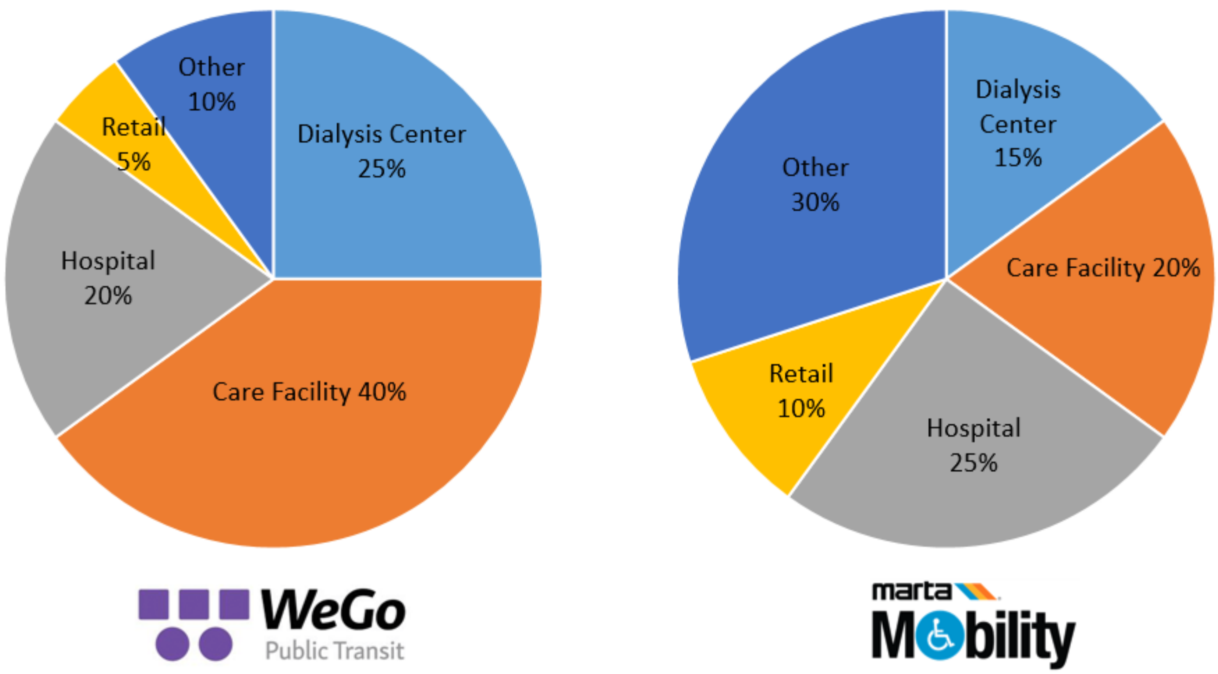

Figure 4. Comparison of most popular stops for May 2018.

Preexisting Conditions of Riders

In addition to the origin-destination data, the research team also analyzed anonymized data for preexisting medical conditions for WeGo paratransit ridership. Approximately 19 percent of ridership that reported a preexisting condition had a cardiovascular or respiratory disease (Figure 5). Cardiovascular and respiratory diseases make individuals more sensitive to air pollution (*2*, *4*). Similar anonymized data were not available for MARTA Mobility.

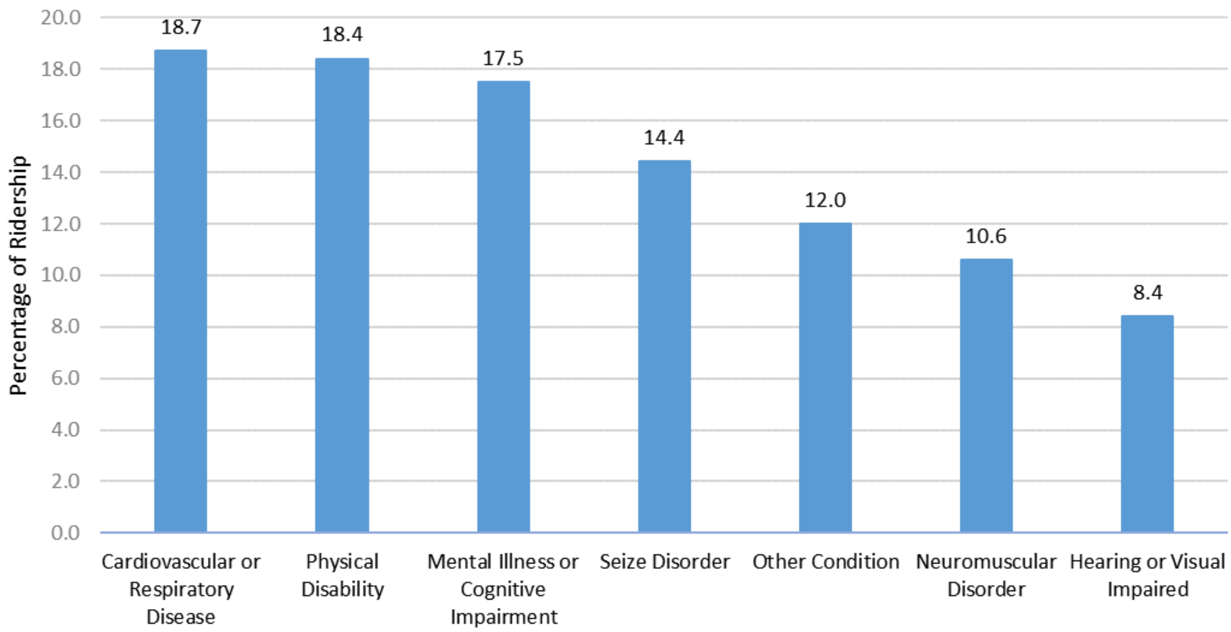

Figure 5. Preexisting medical conditions of WeGo riders.

Methodology

Instrumentation

The field measurements for PM2.5 and PM10 during transport were recorded using the GRIMM 1.109 aerosol spectrometer (Figure 6). The GRIMM 1.109 is a portable laser aerosol spectrometer. It records the mass concentration (ug/m^3). The model differentiates between sizes of particles using both size range (PM10, PM2.5, PM1) and occupational health definitions (respirable, thoracic, alveoli). For the purpose of these analyses, the size range data were used since they correspond with the U.S. Environmental Protection Agency exposure standards. The measurements are output in six-second intervals. The GRIMM 1.109 intakes air using an internal volumetric-flow-controlled pump. It scatters light from a single particle with a semiconductor laser. The particles are counted by light pulses and sorted by reduction in light intensity (*11*).

Figure 6. GRIMM 1.109 (*11*).

Experiment Setup

To collect the data, the research team placed the GRIMM 1.109 aerosol spectrometer with isokinetic sampling pipe inside the cabin of the paratransit bus. Both diesel- and gasoline-powered buses were sampled during the project, but the location of the sampler was the same in both cases. The GRIMM 1.109 was strapped to a cushion behind the driver's seat. The experiment setup is shown in Figure 7. The setup was similar on both WeGo and MARTA Mobility buses. The WeGo paratransit buses have a fare box behind the driver's seat (bottom right of Figure 7), whereas the MARTA Mobility buses have passenger seating. The monitoring device was placed at the approximate intake level of an individual seated on the bus. The research team placed the GRIMM 1.109 on the paratransit bus in the morning prior to departure from the terminal and retrieved the device after the bus returned to the terminal. Two complete days (one day per bus) were monitored for the paratransit operations in both cities.

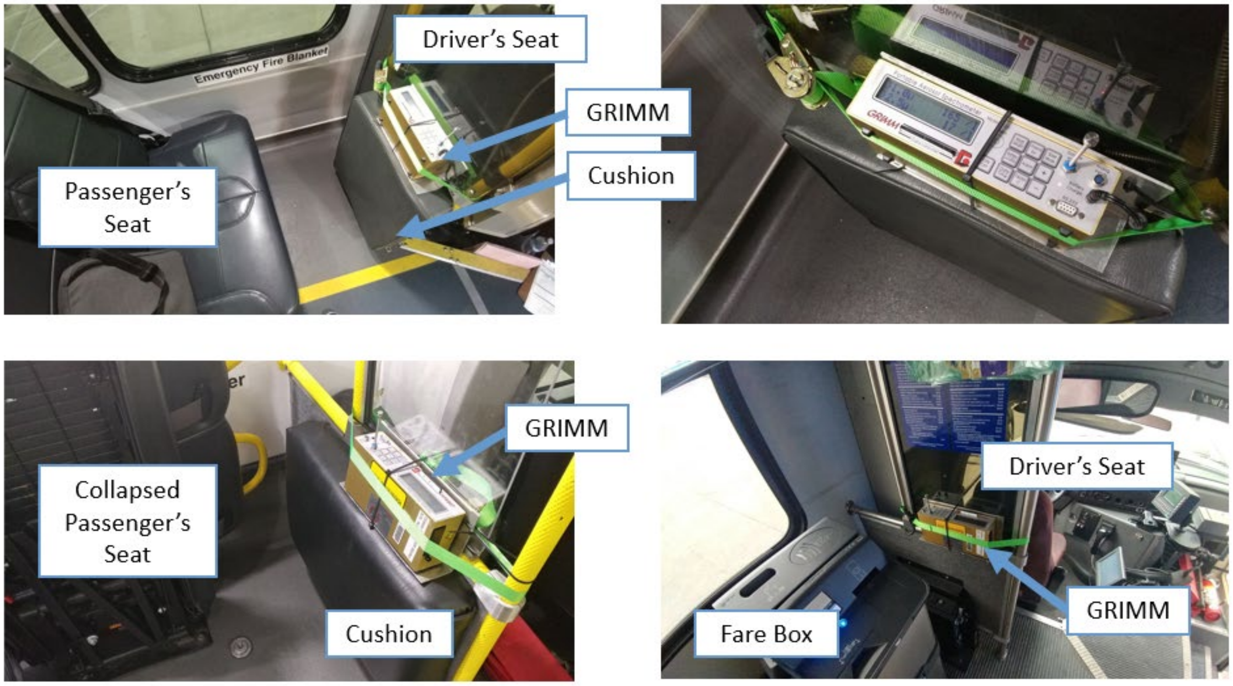

Figure 7. GRIMM placement on paratransit buses.

Examples of the paratransit buses monitored in this study are shown in Figure 8.

Figure 8. WeGo Public Transit and MARTA Mobility paratransit buses (*9*, *10*).

Results

PM Measurements

The in-cabin PM emissions were recorded in Nashville on December 4 and December 5, 2018. The PM2.5 exposure over the course of the day is shown in Figure 9, Figure 10, and Figure 11. The stop times from these days are labeled on the time series. There were spikes in the PM2.5 concentrations when the vehicle stopped and opened its doors to board passengers. During transport on December 4, there was a significant spike when the doors were open for an extended period of time at a school for students with disabilities. The school is located in a residential area with numerous area-type PM sources (e.g., fast-food restaurants, etc.) located nearby. In addition, the paratransit bus was idling at this, as well as other, stops to provide sufficient time for passengers to enter and exit the vehicle. It is likely that several sources contributed to the observed increase in in-cabin PM.

It is important to note that the scale of Figure 10 and Figure 11 are one-sixth the scale of Figure 9. PM concentrations are greatly impacted by meteorological conditions. The second day of measurements, December 5, was a snowy day with low temperatures. The change in weather significantly reduced the PM2.5 concentrations.

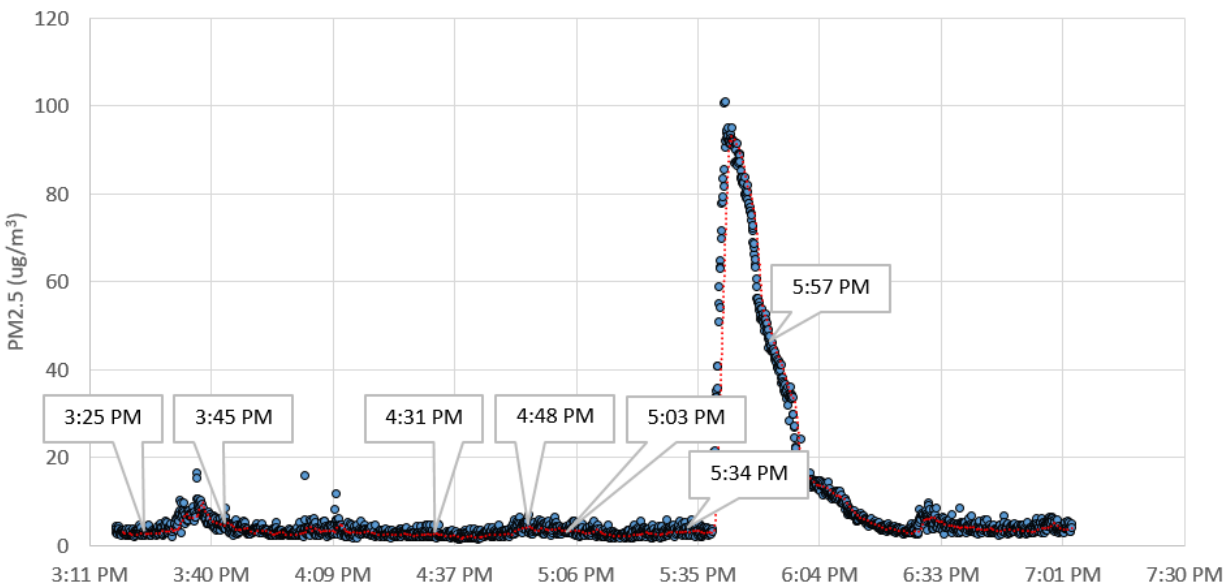

Figure 9. Nashville PM measurements from December 4, 2018.

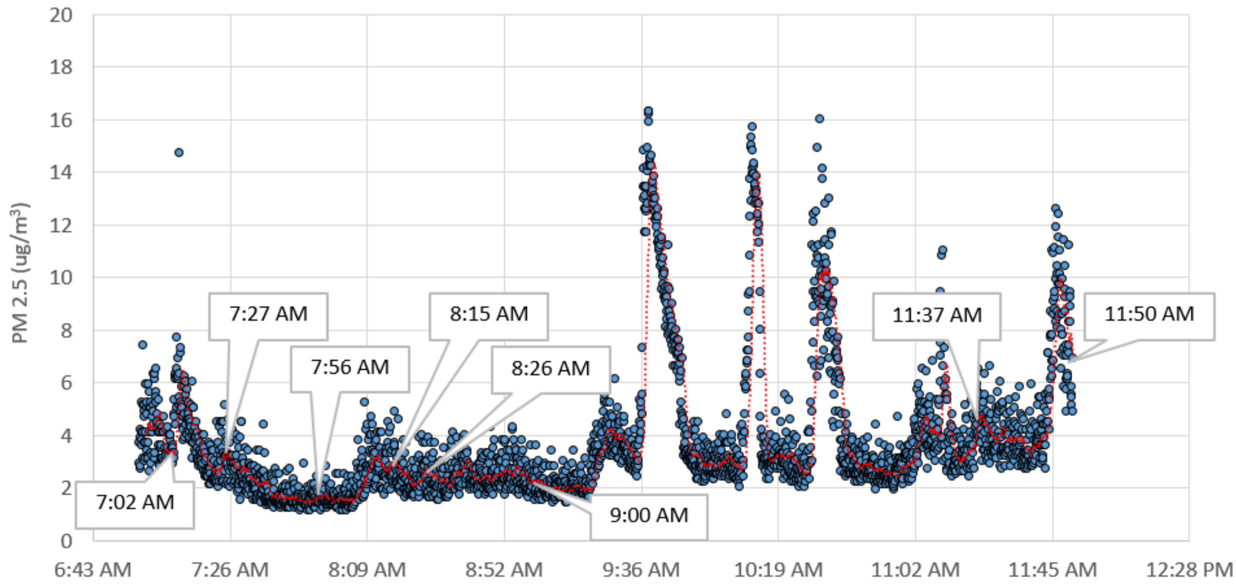

Figure 10. Nashville PM measurements from the morning of December 5, 2018.

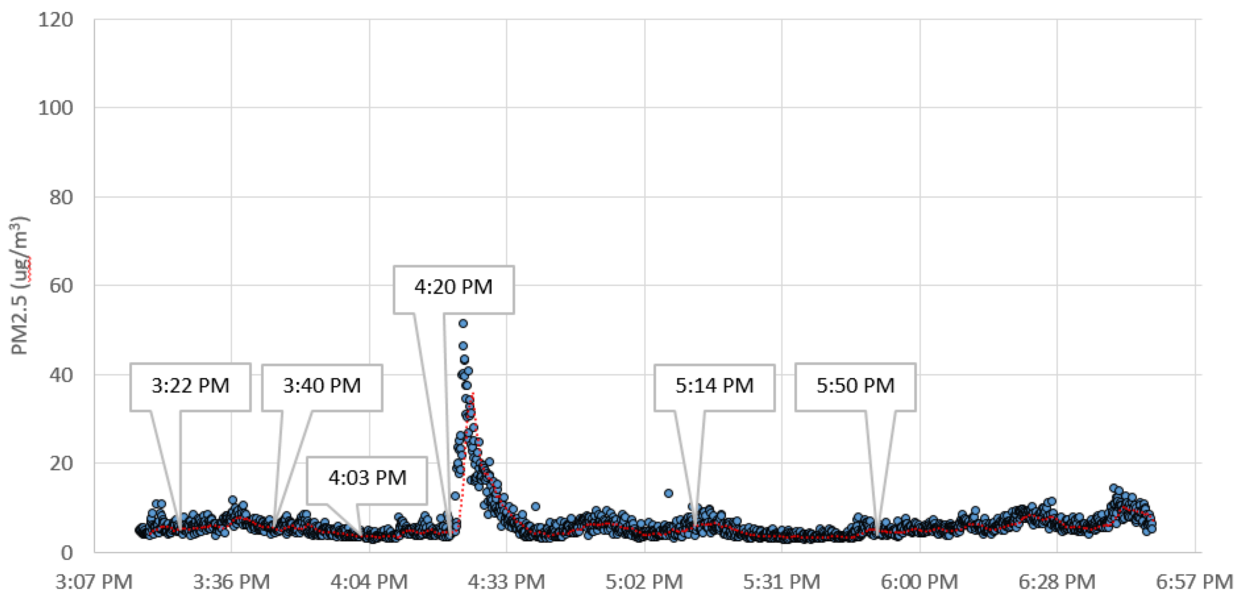

Figure 11. Nashville PM measurements from the afternoon of December 5, 2018.

The same procedure was used to collect data in Atlanta. The in-cabin PM emissions were recorded in Atlanta on October 25 and October 30, 2018. The PM2.5 exposure over the course of the day is shown in Figure 12 and Figure 14. The stop times were not provided by MARTA Mobility. The measurements from these days show the differences between PM exposure from riding a gasoline bus and a diesel bus, with the October 25 concentrations being from a gasoline vehicle and the October 30 measurements being from a diesel vehicle.

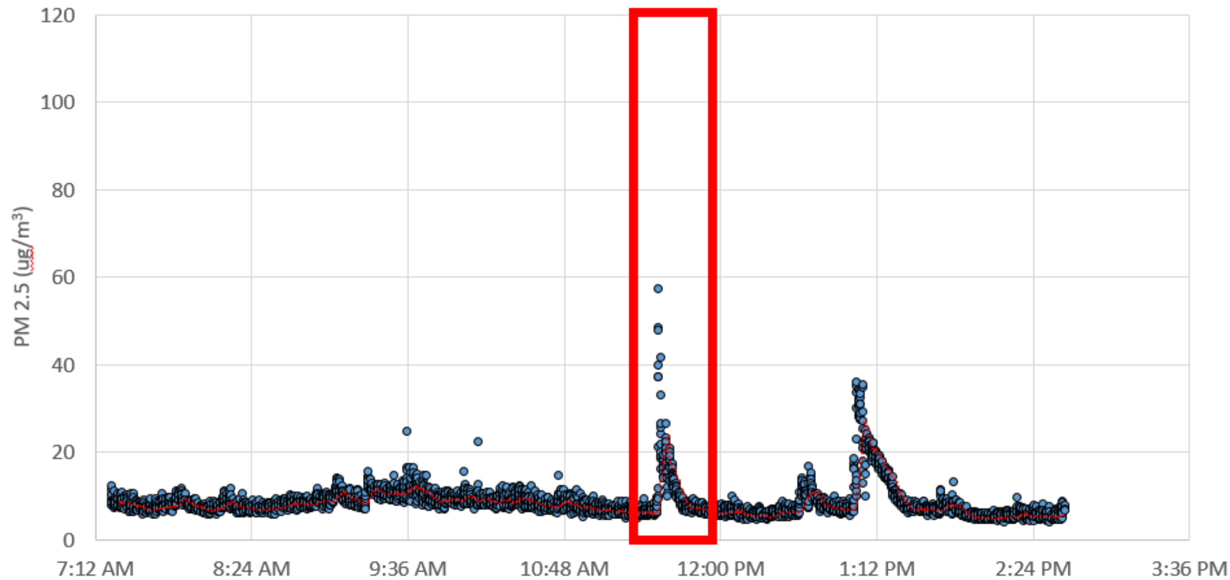

Figure 12. Atlanta PM measurements of gasoline bus on October 25, 2018.

Figure 13 shows the time series of PM2.5 concentrations on the gasoline bus. The red rectangle in Figure 12 shows the time frame that is examined in Figure 13. There was a sharp spike in PM2.5 and then a gradual dissemination of particles. It took approximately 10 minutes for the PM2.5 concentration to return to the baseline exposure.

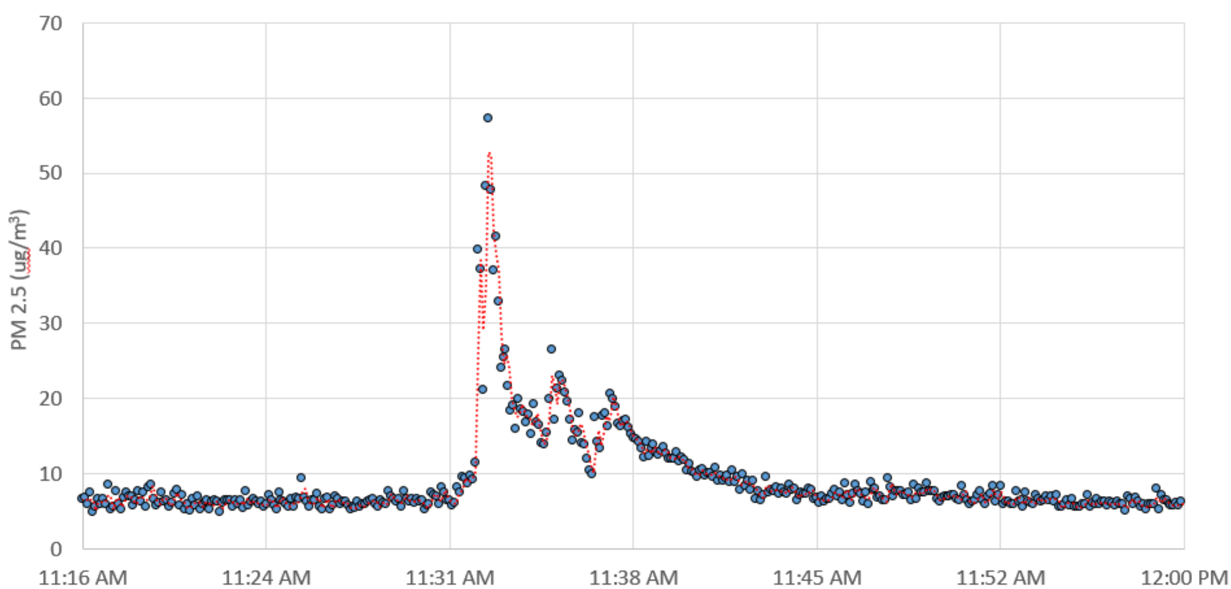

Figure 13. Short-term Atlanta PM measurements of gasoline bus on October 25, 2018.

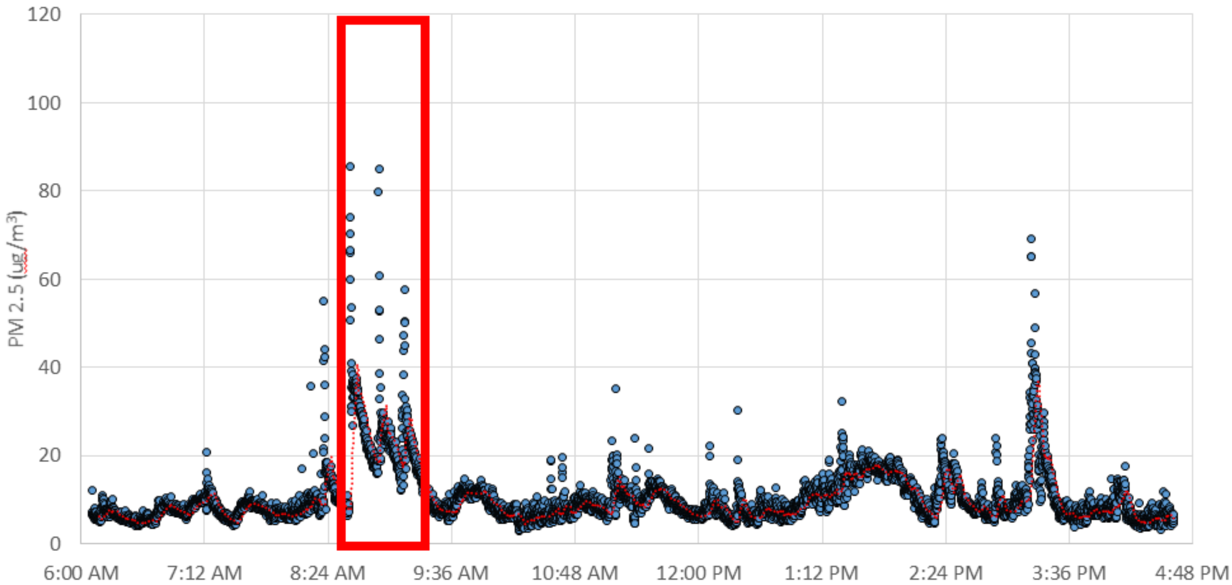

Figure 14. Atlanta PM measurements of diesel bus on October 30, 2018.

Figure 15 shows the time series of PM2.5 on the diesel bus. The red rectangle in Figure 14 indicates the time frame that is examined in Figure 15. There were a few spikes in PM2.5 concentrations followed by a gradual decay. It took approximately 50 minutes for the PM2.5 concentration to return to the baseline exposure. Elevated PM2.5 exposure was longer on the diesel bus than on the gasoline bus.

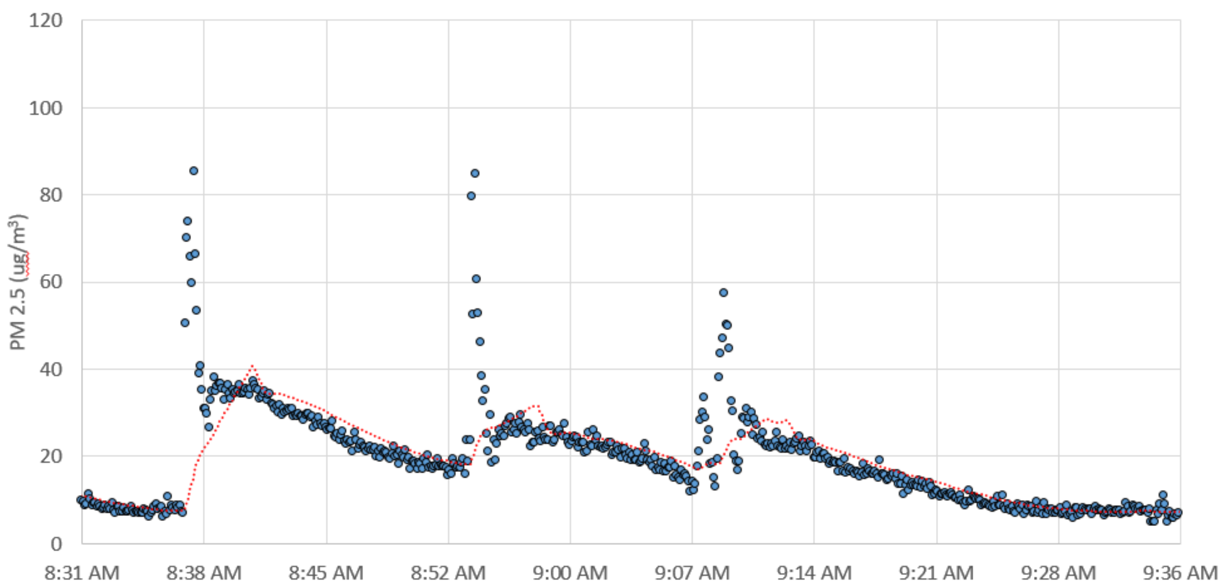

Figure 15. Short-term Atlanta PM measurements of diesel bus on October 30, 2018.

Comparison of PM Measurements from Nashville and Atlanta

The major source of variability in the observed in-cabin PM2.5 concentrations was associated with vehicle stops when the bus opened its doors to pick up or drop off passengers. During these periods, observed PM2.5 concentrations typically increased by a factor of 3 to 10 relative to baseline concentration. The PM2.5 concentrations for gasoline-powered buses in Nashville and Atlanta were observed to have a similar baseline concentration of approximately 10 micrograms per cubic meter, but the increases in concentrations associated with door openings were consistently larger for the Atlanta bus. The observed concentration increases in Atlanta approached or exceeded 40 micrograms per cubic meter, while those in Nashville, with one exception, did not exceed 20 micrograms per cubic meter.

The diesel bus measured in Atlanta had a similar initial baseline concentration, but the observed recovery period (i.e., decrease in concentrations after reclosure of the door) was much slower in the case of the diesel bus, and it is unclear if the in-cabin concentrations ever reached baseline conditions before the door was reopened for the next stop. It is unknown whether this longer recovery period was associated with the greater PM2.5 emissions from the diesel bus or with a potential difference in the ventilation system of the gasoline versus diesel bus.

Conclusions and Recommendations

This project was an initial feasibility study to determine if a dust aerosol spectrometer could be used to monitor PM exposure of riders in paratransit vehicles. The PM2.5 measurements from both Nashville and Atlanta demonstrated that the equipment could be used successfully to monitor PM exposure.

While the data collected in the project are limited (four buses over four days), some general observations should be noted regarding the design of a more complete follow-up study. The most persistent pattern observed in the data was the association between the door opening and a rapid rise in the in-cabin PM concentrations. In-cabin PM2.5 concentrations increased by up to a factor of 5 to levels well above the long-term (annual average) exposure limits and, in many cases, exceeded the 24-hour exposure limit. The measurements also showed that elevated PM exposure can extend beyond when the doors are closed. It takes time for the particles to disseminate and the in-cabin concentrations to decline to a stable baseline. Due to certain characteristics of paratransit transport, such as extended idling times and elongated trip durations, paratransit riders may risk greater exposure to harmful pollutants. Riders are subject to not only pollutants emitted from the paratransit buses but also pollutants at the requested stops. Further studies can be conducted to understand the health implications of PM exposure on paratransit riders. As the population ages, it is important to provide safe and effective paratransit services.

Outputs, Outcomes, and Impacts

Research Outputs, Outcomes, and Impacts

The results from this study were presented at the CARTEEH Transportation, Air Quality, and Health Symposium in Spring 2019 and at the Transportation Research Board annual meeting in 2020 (both available on the CARTEEH website). The findings showed that the ridership of paratransit transport is subjected to increased PM concentrations due to the longer ingress and egress times. In-cabin exposure is increased while the paratransit vehicle idles. The impacts of this study include understanding the hazards and health concerns of paratransit transport and using this information to make appropriate alterations to related services to provide safer transportation options.

Technology Transfer Outputs, Outcomes, and Impacts

The data sets from this study include in-cabin PM measurements for two days in Nashville and Atlanta. The data collection procedure can be replicated in other cities using the GRIMM 1.109. This study provides a framework for future studies that can inform decision-making about paratransit services.

Education and Workforce Development Outputs, Outcomes, and Impacts

The education and workforce development output includes the involvement of students in the project. Students held many responsibilities on this project, including analyzing the data and creating the presentation. The presentation can be used as an educational tool.

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