Quantitative Analysis of Traffic Related Air Pollution Along the Atlanta BeltLine East Side Trail

Adam Fischer

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INTRODUCTION: Air pollution in urban areas has been a growing concern in the public health sector, especially with regards to negative health effects from traffic-related air pollution.

AIM: The aim of this study is to quantify air pollution levels along the Atlanta BeltLine Eastside Trail, a popular urban trail located in Downtown Atlanta, and compare the pollution levels to measurements taken along a nearby roadway. The goal is to ultimately determine if there are any significant differences between air quality along the BeltLine and air quality along nearby roadways. No statistical significance in the data would suggest that individuals utilizing the BeltLine are exposed to the same levels of traffic-related air pollutants that are present on nearby roadways.

METHODS: Samples were collected along the Eastside Trail of the BeltLine and along neighboring roads over the course of 11 days using a mobile monitoring platform. Four parameters of air quality were measured - Optical Particle Counter (OPC) volume concentration, particle number concentration, median particle diameter, and black carbon levels. A paired t-test was conducted to assess any statistical significance between samples taken along the BeltLine versus samples taken along nearby roadways.

RESULTS: While there was some statistical significance between recorded air pollution levels for individual days, the overall results showed no statistical significance for any of the air quality parameters that were examined.

DISCUSSION: The findings of this study indicate that individuals utilizing the BeltLine have the potential to be exposed to the same levels of air pollutants found along roadways.

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B.S., GEORGIA STATE UNIVERSITY

A Thesis Submitted to the Graduate Faculty
of Georgia State University in Partial Fulfillment
of the
Requirements for the Degree

MASTER OF PUBLIC HEALTH

ATLANTA, GEORGIA
30303
Quantitative Analysis of Air Pollution Along the Atlanta BeltLine Eastside Trail

by

Adam L. Fischer

Approved:

Dr. Roby Greenwald
Committee Chair

Dr. Christina Fuller
Committee Member

July 10, 2018
Date
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Adam L. Fischer

Signature of Author
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Introduction

Built Environment

It has been well documented that the built environment of a city heavily impacts the health of its citizens. The term “built environment” refers to man-made or modified structures that provide people with living, working, and recreational spaces (OSWER US EPA, 2017). Specifically, this refers to the way in which cities are designed with regards to building design, road design, and the development of recreational areas. In looking at how individuals interact with the environment, the built environment of an area can influence numerous day to day activities in both a positive and negative manner. For instance, a positive interaction with the built environment might mean that a city is more walkable, while a negative interaction could mean that there are barriers, whether physical or non-physical, that prevent individuals from being able to walk freely throughout a city.

Because of the interconnected relationship people share with their environment, the built environment of a city not only affects how people interact with their environment on a macro level, but can also weigh heavily on the overall health of a city’s citizens. For instance, if a city is designed to rely heavily on the use of roads, with limited alternative transportation option, citizens will be forced to rely on the use of vehicles to commute around the city. This would severely limit walkability, causing increased traffic congestion and a potential increase in air pollution. Taking into consideration the relationship between the built environment and health, numerous studies have found a strong correlation between the built environment of a city and urban air quality (Hankey & Marshall, 2015). Furthermore, the heavy reliance on personal cars
as a means for transportation means that citizens might be less inclined to walk which could also lead to negative health consequences.

There has been a strong push over the past few decades for city planners and public officials to consider the health implications for the built environment when considering city modifications and expansion. By taking into account how the built environment can impact health, city planners and officials can design cities in a way which limits the negative health impacts the built environment by increasing active transport such as walking and biking. One way this is being accomplished is through the development of more bike and pedestrian friendly options for commuting around the city. This may not only decrease pollution emissions from vehicles, but also promote a healthier life style by allowing citizens the opportunity to exercise more. In the city of Atlanta, one way the built environment is being modified to promote a healthier lifestyle, allow for more transportation alternatives, and make the city more walkable is through the development of the Atlanta BeltLine.

The Atlanta BeltLine

In an effort to increase the economic development and further the aesthetic appeal of the city, the City of Atlanta adopted plans to connect neighborhoods around the city through the use of multi-use trails, parks, and pathways. This project, known as the BeltLine, is a 25-year project which will ultimately transform the city through the redevelopment of residential, transportation, and recreational spaces around downtown Atlanta (“Atlanta BeltLine Overview // Atlanta BeltLine,” n.d.). The project will ultimately transform a 22-mile loop of abandoned railroad tracks surrounding downtown Atlanta into an interconnected system of parks, trails, residential areas, and commercial developments (Ross et al., 2012). By the end of the project, the BeltLine is estimated to generate 2,100 acres of parks, including new development, 33 miles
of new multiuse trails, and 22 miles of transit. From an economic standpoint, the BeltLine is expected to generate 6,500 acres of land that can be used for housing, commercial space, or institutional space. In addition, the project is estimated to produce over 30,000 new jobs in the local area (Ross et al., 2012). Appendix A shows the design of the BeltLine as of 2018.

The idea of utilizing the existing built environment to interconnect neighbors and increase economic development is not a new idea. The idea for the Atlanta BeltLine was first explored by the City of Atlanta in the early 1990s. The original plan utilized an abandoned rail system to create a cultural loop focused on tourism around the city (“Atlanta Beltline | Health Impact Assessments - UCLA SPH,” n.d.). While this plan was ultimately abandoned, the current version of the BeltLine was developed in 1999 as part of a thesis project by then Georgia Tech graduate student Ryan Gravel (“Atlanta Beltline | Health Impact Assessments - UCLA SPH,” n.d.). Actual land acquisition for the project began in 2006, and the BeltLine Project is expected to be completed in 2030 (“Atlanta Beltline | Health Impact Assessments - UCLA SPH,” n.d.).

From a built environment standpoint, the Atlanta BeltLine poses many interesting challenges, primarily in regards to air pollution exposure. For instance, most of the BeltLine utilizes corridors that are in close proximity to heavily trafficked roads. As a result, users of the Beltline, whether cyclists or pedestrians, have the potential to come in contact with emissions from nearby vehicles. The effects of the air pollution can be further exacerbated if an individual is utilizing the BeltLine as a means of exercising. Increased heart and respiratory rates could mean that an individual exercising along the BeltLine could potentially be exposed to more air pollution, putting them at a higher risk of developing pollution related cardiovascular diseases.

**Study Goals**
In examining air pollution along the BeltLine, the research question of interest in this study is: Is there a difference in air pollution levels along the trail compared with baseline samples taken on an adjacent road, and if so, are the differences statistically significant as to suggest that air pollution levels are lower on the BeltLine than compared with neighboring roads?

It is hypothesized that the BeltLine will have a lower concentration of air pollutants than on neighboring roads.

**Literature Review**

**Urban Population & Air Pollution**

It has been well documented that the global population, as a whole, is undergoing a shift in which people are migrating more towards living in urban settings as opposed to living in rural settings. The United Nations estimates that by 2050, the urban population will reach 6.3 billion compared to the projected global rural population of 2.9 billion (“United Nations Population Division | Department of Economic and Social Affairs,” n.d.). As the world moves more towards a global society, more and more individuals are moving into urban settings. Around the world, an estimated 52% of people live in an urban setting, while in the industrialized world, this number reaches almost 78% of the population (Giles & Koehle, 2014). This rapid increase in urbanization has created a new host of public health issues, one in particular has been an increase in urban air pollution.

Urban air pollution is a complex mix of contaminants, either gases or particles, emanating from a multitude of sources. These can include emissions from cars, nearby factories, construction work, and can even be the result of atmospheric events. Air pollution can be
divided into 2 main categories- primary and secondary pollutants. Primary pollutants include air pollutants directly from an emission source, and can include gases and particles directly emitted from the tail pipe of an automobile. For this study, the primary pollutants that were examined were particle number concentration (PNC), particle matter (PM$_{2.5}$), and black carbon. Secondary pollutants are pollutants that are formed in the atmosphere through interactions of primary pollutants and various external forces. This could include generation of ozone in the atmosphere, where ozone is not emitted directly from a source, but rather formed in the atmosphere through interaction with primary pollutants and sunlight (Giles & Koehle, 2014). For this study, no secondary pollutants were examined. Understanding how pollutants are either emitted or formed could be crucial information that could be used to better control air pollution not only from a policy standpoint, but from a health standpoint as well.

The effects of exercising in heavily polluted areas, mainly urban areas, have been well studied by researchers. These effects can range from systematic disorders such as increase heart rate and lung issues, all the way down to effects on the cellular level. For instance, exposure to ultrafine particles (UFP) has been shown to increase the amount of leukocytes in the blood, as evident of an inflammatory response to air pollutants (Cole-Hunter et al., 2013).

The BeltLine poses numerous challenges for the City of Atlanta as well as its residents especially with regards to air quality along the trail. To better understand how air quality would be impacted by the BeltLine throughout the 25-year project, a thorough health impact assessment was conducted to better assess how the air quality of the city would be impacted by the trail. Researchers theorized that because of redevelopment of residential areas and an increase of transit options throughout the city, air pollution levels will actually decrease. Under the health impact assessment, air pollution is defined by the 6 criteria pollutants regulated by the National
Ambient Air Quality Standards under the Clean Air Act. The 6 criteria pollutants are ozone, lead, nitrogen dioxide, particulate matter, carbon monoxide, and sulfur dioxide (Ross et al., 2012). It is estimated that by 2030, at the end of the 25-year project, the population of Atlanta will increase from approximately 4 million to 6 million people living in the 13-county metro area (Ross et al., 2012). Even with this increase in population, researchers theorize that air pollution as a whole will decrease. While they theorize that the decrease will be marginal, it does show the positive impact the project will have on the city (Ross et al., 2012). Table 1 describes how air pollution levels would be impacted with and without the BeltLine project.

Table 1- Daily Emissions for the Atlanta BeltLine

<table>
<thead>
<tr>
<th>Daily Emissions for the Atlanta BeltLine, 2030</th>
<th>BeltLine in 2030</th>
<th>No BeltLine in 2030</th>
<th>Difference (millions of grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile Organic Compounds (VOC)</td>
<td>5,932</td>
<td>6,126</td>
<td>195</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>57,666</td>
<td>59,562</td>
<td>1,895</td>
</tr>
<tr>
<td>Nitrogen Oxides</td>
<td>11,391</td>
<td>11,766</td>
<td>374</td>
</tr>
<tr>
<td>Particulate Matter</td>
<td>248</td>
<td>256</td>
<td>8</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>274</td>
<td>283</td>
<td>9</td>
</tr>
<tr>
<td>Ammonia</td>
<td>504</td>
<td>520</td>
<td>17</td>
</tr>
</tbody>
</table>

Researchers calculated the information in Table 1 based off of 2004 emissions data from the Georgia Department of Natural Resources, and project motor vehicle traffic trends from the Atlanta Regional Commission (Ross et al., 2012). While the information displayed in Table 1 is solely a projection, it does highlight a potential key advantage of the BeltLine, in that it will decrease air pollution around the city. Even if the decrease in air pollution is marginal, the decrease could impact the city positively both in terms of aesthetic appeal and increased economic growth.

The health impact assessment goes on to make several recommendations for how the City of Atlanta can continue to improve air quality throughout construction of the BeltLine. This
includes locating residential units, schools, and daycares away from heavily trafficked roadways, continue to monitor potential pollution “hotspots”, and develop requirements for mitigation measures (Ross et al., 2012). By adhering to the recommendations made by the health impact assessment, the City of Atlanta has the potential to benefit from the full scale of the BeltLine project. It is crucial that the city recognize the need for continued research on how the BeltLine impacts various components of the city (i.e. air quality) if they hope to continue to the economic growth the city has seen in recent years.

**Particulate Matter (PM)**

Particulate matter, also known as PM, refers to a broad category of complex pollution species that can be emitted from a variety of sources. In looking at urban air pollution, particulate matter from vehicular traffic emissions constitutes the biggest portion of air pollution, both in developed and developing nations (Zhang, Khlystov, Norford, Tan, & Balasubramanian, 2017). Particulate matter is categorized not based off its geometric diameter, but off of its aerodynamic diameter. The aerodynamic diameter factors in several characteristics of the particle including density, diameter, and shape of the particle, all of which help determine where along the respiratory tract the particle will be deposited (Giles & Koehle, 2014).

Particle matter can be divided in 3 broad categories based off the aerodynamic diameter of the particle. The 3 broad categories of particulate matter are Coarse PM (aerodynamic diameter between 2.5 µm- 10µm), Fine PM (aerodynamic diameter <2.5 µm), and Ultrafine PM (aerodynamic diameter <0.1µm) (Giles & Koehle, 2014). Understanding the aerodynamic diameter of a particle is of great importance because it is the diameter of the particle that will determine where along the respiratory tract the respective particle will deposit.
Particle size not only influences where a particle will settle within the respiratory system, but also by what method. The term “total deposition” refers to the probability that a particle, once inhaled, will deposit within the respiratory system (Heyder, 2004). There are 4 main methods by which a particle can be deposited in the lungs- interception, impaction, sedimentation, and diffusion. Interception refers to a particle that is deposited when an edge of the particle comes in contact with a surface. This method is primarily important for fibers, such as asbestos. Impaction refers to particle settling where because of the size the particle is unable to bend its course of travel, and as a result gets deposit. Impaction primarily affects larger sized particles with a diameter greater than 1 µm, and plays an important role in the location these particles ultimately settle. Sedimentation refers to how gravitational forces eventually overcome the buoyancy of a particle, and the particle ultimately settles on a surface. Diffusion occurs when particles smaller than 0.5 µm act similar to gas molecules, in that their motion is random, and their settling on a surface is by chance (Government of Canada, 2018). Figure 1 illustrates how aerodynamic diameter impacts the settling patterns of a particle.
Figure 1- Total Deposition of Unit-Density Spheres in the Human Respiratory Tract Inhaled Orally At Rest (Heyder, 2004)

The aerodynamic diameter of a particle also plays an important role in determining where along the respiratory tract the particle will ultimately settle. As Figure 2 below illustrates, larger particles tend to deposit higher up in the respiratory tract where they can easily be cleared. This is not the case with smaller particles, such as ultrafine particles, which get deposited lower into the alveolar region of the lungs (Heyder, 2004).
Ultrafine particulate (UFP) matter poses a particular hazard when it comes to respiratory health because due to its small size, particles in this size range are able to travel further down into the lungs where they can reach the alveolar region. In recent years, there has been a growing body of interest into researching UFPs and how they affect human health. This recent surge in interest has been attributed to several factors. First and foremost, UFPs occur more abundantly in air than particulate matter in the other size ranges. Secondly, because of their irregular geometries, UFPs have a higher surface area to mass ratio. This high surface area to mass ratio, coupled with the abundance of UFPs in the air, UFPs have the potential to act as a carrier of hazardous gases (Sturm, 2016b). In regards to particle deposition in the lungs, research has shown that UFPs have the potential to enter the deeper regions of the lungs than other, larger particles. Particulate deposition of UFPs in the alveolar region of the lungs is further exaggerated by the smaller airway diameter located in this region of the lungs. Because of the small airway size, UFPs are subject to increased Brownian motion forces that cause greater rates
of impaction into the alveoli (Sturm, 2016a). Overall, this translates to a greater risk of adverse health effects from inhalation of UFPs.

Similar to ultrafine particles, PM$_{2.5}$ (Fine PM) is of great importance due to the noted health effects of both short-term and long-term exposure. Short-term, or acute exposure, to PM$_{2.5}$ has been shown to be associated with an increase in acute cardiorespiratory morbidity, while long term, or chronic exposure, has been shown to be strongly associated with mortality (Zhai et al., 2017). Chronic exposure to PM$_{2.5}$ has been shown to be associated with an increase in oxidative stress, inflammation, and autonomic nervous system dysfunction which can lead to various cardiovascular conditions such as stroke, myocardial infarctions, bronchitis, and asthma (Giles & Koehle, 2014).

Another important component of PM$_{2.5}$ is the chemical composition that makes up the particle matter. Numerous research studies have shown understanding the chemical composition of PM$_{2.5}$ can help researchers better understand the origin of the particulate matter. Zhang et al., in their study of PM$_{2.5}$ levels from traffic-related sources, sought to identify specific chemical species as a way to better understand how emission sources influence PM$_{2.5}$ levels. The study examined air samples taken along roadsides in Singapore, and compared these samples to background samples taken in an urban setting. Ultimately, the study found that while PM$_{2.5}$ levels collected along the road were more than double that of the background samples (28.88 µg/m$^3$ vs. 13.02 µg/m$^3$), the chemical species found in both sets of samples differed, indicating that traffic-related air pollution is comprised of a specific set of chemical species (Zhang et al., 2017). Researchers looked at organic carbon (OC) and elemental carbon (EC) levels in the samples. For both carbon species, they found levels almost 3 times higher in samples collected from the roadway than in the background samples. Samples collected on the roadway had
organic carbon levels and elemental carbon levels of 5.88 and 5.28 respectively, while background samples were 3.49 and 1.06 respectively (Zhang et al., 2017). The researchers then calculated the OC/EC ratio as a way to assess the level of secondary organic aerosols (those not emanating directly from traffic-related sources).

A study conducted by Cao et al. in 2006 found that calculating the OC/EC ratio was an effective way to assess the presence of secondary organic aerosols (Cao et al., 2006; Zhang et al., 2017). They suggested that an EC/OC ratio greater than 2 is indicative of secondary organic aerosols in PM$_{2.5}$ samples. In their study, Cao et al. found the EC/OC ratio of the collected samples was closer to 1.0, indicating that the main contributing component of PM$_{2.5}$ are primary organic aerosols. Similar to the study by Cao et al., the study by Zhang et al. found that the EC/OC ratio for roadside samples was 1.13, while the EC/OC ratio for background samples was 3.35 (Zhang et al., 2017). The researchers suggested that this low ratio indicates that the majority of PM$_{2.5}$ collected along the roadside is the direct result of primary organic aerosols from traffic congestion.

The researchers also found significantly higher levels of the trace elements Potassium, Aluminum, Iron, Calcium, and Zinc in roadside samples relative to the background samples. Another study by Kleeman et al. suggests that Aluminum, Potassium, and Zinc are emitted from both gasoline and diesel engines (Michael J. Kleeman, James J. Schauer, & Cass*, 2000). This mirrors the results from the Zhang et al study in that higher levels of these trace elements were found in roadside samples relative to the background samples.

In looking at PM$_{2.5}$ levels from a practical standpoint, the results from these studies indicate that while PM$_{2.5}$ is a complex mixture of various species, including elemental carbon, organic carbon, and numerous trace elements, PM$_{2.5}$ collected along roadsides is a good...
indication of traffic-related air pollution. Understanding the chemical species that comprise PM$_{2.5}$, as well as their ratios in collected samples, provide key information as to the source of the particulate matter. Understanding the source of the particulate matter could help address the main contributors of urban air pollution.

**Black Carbon**

Unlike PM$_{2.5}$, which refers to a broad category of particulate matter based on the aerodynamic diameter of the particle, black carbon refers to a specific category of a pollutants directly related to byproducts of combustion, specifically from diesel engines (ORD US EPA, 2014). This can include pollutants from automobiles, factories, power plants, as well as any source that utilizes fossil fuels as a power source, but primarily is used as a measure of exhaust from diesel traffic. Very similar to PM$_{2.5}$ exposure, exposure to black carbon has been shown to cause adverse health outcomes including cardiovascular and respiratory disorders (MacNaughton, Melly, Vallarino, Adamkiewicz, & Spengler, 2014).

Even though black carbon can fall under the PM$_{2.5}$ classification, depending on the aerodynamic diameter of the particle, direct measurements of black carbon levels have been identified as a more accurate representation of traffic air pollution levels. Black carbon has been widely used as a good indicator of traffic-related air pollution because it was widely variable based off of traffic patterns and congestion (Targino et al., 2016). Several studies have investigated black carbon levels in relation to traffic patterns and road types as a way to support the idea that black carbon can be used as a strong indicator of traffic-related air pollution. For instance, a study conducted by Krecl et al., found black carbon levels to be higher in road tunnels (7.50 μg/m$^3$) versus on highways (3.20 μg/m$^3$) (Krecl, Johansson, Ström, Lövenheim, & Gallet, 2014; Targino et al., 2016). Similarly, a study conducted by Hanky and Marshall found that
black carbon levels decreased around 20% simply by moving a small distance from a major road
to a smaller road (Hankey & Marshall, 2015; Targino et al., 2016). These studies indicate that a
strong spatio-temporal pattern of black carbon making it a strong indicator of traffic-related air
pollution.

Further exploring the use of black carbon as an indicator of traffic-related air pollution,
research by Targino et al. examined spatio-temporal differences in black carbon and PM$_{2.5}$ as
they relate to traffic congestion. Researchers used bicycles to be able to map pollution levels in a
mid-sized city in Brazil. While the researchers found a strong correlation between both PM$_{2.5}$
and black carbon as they relate to increased traffic congestion, the researchers found that black
carbon proved to be a better indicator of air pollution from heavy-duty diesel vehicles than
PM$_{2.5}$. The researchers also found that black carbon levels doubled at heavily trafficked
intersections and on inclined roads, as opposed to flatter areas. The researchers argue that
because of the stronger relationship between recorded black carbon levels and heavy-duty diesel
vehicle traffic, black carbon is a strong indicator of air pollution from diesel engines. This is
further backed up by their argument that dust and debris from the roadways can impact PM$_{2.5}$
levels, whereas black carbon is a direct measurement of engine combustion (Targino et al.,
2016).

As shown in previous research, black carbon is a strong indicator of traffic-related air
pollution, especially in an urban setting. Work by Targino et al., as well as various other
researchers, point to the fact that while PM$_{2.5}$ can be an effective measure of air pollution as well,
black carbon can provide valuable information about air pollution from diesel engines, making it
a stronger indicator of traffic-related air pollution.
Particle Number Concentration (PNC)

Another key indicator of overall air quality is the particle number concentration (PNC). Particle Number Concentration is a measurement of particles across a wide range of particle sizes. Typically, PNC levels include particles in the ultrafine particle (UFP) size range (less than 0.1µm), but ultimately the PNC range is dependent on the range of the instrumentation used to collect data (Quang, Hue, Thai, Mazaheri, & Morawska, 2017). Much like black carbon and PM$_{2.5}$ levels, elevated levels of PNC have been linked with adverse health outcomes, mainly cardiovascular disease and reduced lung function (Price, Arthur, BéruBé, & Jones, 2014).

Several studies have examined this link between elevated levels of PNC and adverse health outcomes. For instance, a study conducted by Klot, et al., found a strong correlation between cardiac readmissions at hospitals and high levels of PNC on the same day as the hospital admittance. The study was conducted in 5 European cities, and included a cohort of over 22,000 heart attack survivors. Results from the study showed an overall relative risk of 1.026 (Klot et al., 2005). Price et al., in their study on PNC and traffic variability interpreted the results from the European cohort study as a way to show that even if an individual spends a relatively short amount of time in an area with high PNC levels, there is an increased risk of adverse health outcomes (Price et al., 2014).

Particle Number Concentration is commonly used as an indicator of air quality because it is highly related to traffic congestion, in that increased traffic results in higher levels of PNC. This can include both exhaust and non-exhaust sources of pollution (Price et al., 2014). In fact, PNC levels and traffic congestion are so closely related that Guo et al. in their study looking at the influence of outdoor air pollution on indoor air in a school setting repeatedly found elevated levels of PNC during early morning and late afternoon hours. The authors deduced that this was
directly the result of vehicle emissions during times of high traffic (Guo et al., 2010). Furthermore, a study conducted by Schneider et al., found similar results to that of the previous study. In this study, researchers in Brazil looked at spatial variation of PNC and size distribution across various sites. Specifically, they examined PNC levels along roadsides, traffic intersections, a street canyon, and an urban background site. Researchers found the highest PNC levels in areas where traffic was heavy, with the highest readings at the intersections (Schneider, Teixeira, Silva Oliveira, & Wiegand, 2015).

Based off of the findings from these studies that looked at PNC and air quality, there is a strong relationship not only between PNC and adverse health outcomes, but between PNC levels and traffic congestion as well. Applying these results to the Atlanta BeltLine show that individuals utilizing the trail are potentially at risk for exposure to high levels of traffic-related pollution which puts individuals at a greater risk of morbidity or mortality.

Mobile Monitoring of Air Pollution

In recent years, the use of mobile air monitoring has become an accepted and widely utilized tool to research air pollution, especially in urban settings. As described by Peters et al., mobile monitoring has become an increasingly popular form of air monitoring because it allows users to “acquire air quality data at a high spatial and temporal resolution in complex urban environments” (Peters, Theunis, Van Poppel, & Berghmans, 2013). The ability to map spatial and temporal air quality data is crucial because it allows researchers to more accurately measure and analyze how air pollution can impact an urban environment rather than solely relying on fixed monitoring stations, which are not capable of fully mapping spatial distribution (Peters et al., 2013).
Mobile monitoring also allows researchers to better understand how air traffic pollutant species behave in an urban environment. For instance, Hagler et. al found that UFP and black carbon levels decreased downwind from a major roadway (Hagler, Thoma, & Baldauf, 2010). This is important to note because it shows that the best place to take UFP and black carbon readings is directly near the source, and highlights one of the advantages of mobile monitoring in that it is easier to take readings closer to the source. Taking readings near the source allow for better spatial mapping of air pollution. To the contrary however, Hagler et. al notes that PM$_{2.5}$ may have weaker spatial gradient due to secondary processes which may alter the species (Hagler et al., 2010).

Another important characteristic of air pollution that mobile monitoring allows researchers to investigate is how air pollutants behave in real world settings, specifically with regards to concentration gradients both upwind and downwind of the source. For instance, a study by Zhu et al., examined concentration gradients of air pollutants along major highways in Texas. Specifically, researchers looked at particle number concentration and PM$_{2.5}$. Researchers found that particle number concentration increased dramatically on the downwind side of the source, compared to the upwind side, with higher concentrations being recorded 100-150 meters away from the roadway. Researchers also found that smaller particles (6-25nm) decayed much faster that larger particles (100-300nm) (Zhu et al., 2009). Understanding concentration gradients of air pollutants is an important component of understanding air quality, especially as it relates to health. Brugge et al. reports that 11% of U.S. households are located within 100 meters of a 4-lane highway (Brugge, Durant, & Rioux, 2007). While this is not a large proportion of the population, this statistic does mean that people can be at risk of exposure to harmful air pollutants solely based off of where they live. In translating this to the BeltLine, it
also means that people utilizing the BeltLine have the potential to be exposed to the same air pollution levels seen along roadways since much of the BeltLine is in close proximity to major roadways.

**Materials & Methods**

**Data Collection**

To assess air pollution around the Atlanta Beltline, a single study was conducted in which 2 separate air sampling campaigns collected samples along the Beltline and along surrounding roadways in an attempt to identify any differences in air pollution between the different paths. The first study (Campaign A) looked at particle number concentration, median particle size, OPC volume concentration, and black carbon. Air samples for this study were collected over 6 separate days ranging from September 2016 through March 2018. The second air quality study (Campaign B) looked at black carbon and particle number concentration along the BeltLine and neighboring roads; however, due to issues with instrumentation, the particle number concentration results could not be reported. As a result, only the black carbon results were reported. This study collected data over 5 days ranging from November 2015 through April 2016. The East Side Trail was selected as the sampling location for the BeltLine portion of the sampling for both studies, due to the fact that the trail was completed at the time of initial sampling. Appendix B shows the map of the Eastside Trail relative to many of the nearby streets.

**Route**

In order to precisely measure air quality along the BeltLine as well as neighboring roads, a predetermined route was followed for both studies, mainly to ensure repeated measures could
be taken at the same points along the route. The route was divided into 2 loops with the Eastside BeltLine being measured during each loop. The loops were designed to specifically measure adjacent surface streets on both the east and west sides of the trail. Loop 1 focused on roads to the west of the Eastside trail of the BeltLine while Loop 2 focused on air monitoring east of the BeltLine. The only difference between the 2 monitoring campaigns was in the direction of travel along the route. Campaign A followed a clockwise direction of travel along the route, while Campaign B, monitoring only for black carbon followed a counter clockwise route. Regardless of the direction of travel, each portion of the route was monitored at least 2-3 times each trip in order to make sure that multiple air samples could be taken. Figure 3 below details the precisely followed route that was used to collect air samples along the East Side Trail. The red trail corresponds to air sampling that was conducted on nearby streets, while the green trail corresponds to sampling conducted along the BeltLine.
Figure 3- Air Sampling Route

Map courtesy of Google Maps-(“BeltLine Project,” n.d.)
Instrumentation

To assess the air quality along the BeltLine relative to adjacent surface streets, 3 parameters of air quality were recorded. These parameters included particle number concentration, PM$_{2.5}$, and black carbon. These parameters were chosen for this study because they represent a broad, overall spectrum of categories that are commonly used to quantify air pollution.

Black Carbon

Black carbon levels were measured using a microAeth AE51 personnel monitor by AethLabs (AethLabs, San Francisco). The microAeth monitor is a small, portable unit that records real time black carbon levels (“microAeth® / AE51 | AethLabs,” n.d.). The monitor measures black carbon using light emitting diodes (LEDs) fixed at the 880 nm wavelength and 2 detectors. One detector, in the sensing channel, monitors for particulate matter that is deposited on a filter, while the other detector monitors a reference point on the filter where there is no active sampling (Cai et al., 2014). The monitor continuously measures the attenuation of light through the filter, which can then be converted to measurements of black carbon. Ultimately, the black carbon measurements are based on the relationship between this light attenuation and the surface density loading of black carbon particles on the filter (Hagler, 2011). Recent research has shown that while the microAeth is an appropriate instrument to measure black carbon levels, the instrument is susceptible to electrical noise, which can give skewed results. For instance, if continuously monitoring at a very high rate, especially in areas with low black carbon, the instrument may not accurately recognize changes in light attenuation, and thus report black carbon levels as negative (Hagler, 2011). To address this issue, methods have been developed to
help account for any electrical noise that might have skewed the data. One method in particular is the Optimized Noise-reduction Averaging (ONA) algorithm, described by Hagler et al. The ONA algorithm allows for post-processing of black carbon data from the Aethalometer by conducting adaptive time averaging of the black carbon data by using the change in light attenuation through the instrument’s filter to determine the time window for averaging. This allows for significant reduction of electrical noise while still persevering any data trends that might present (Hagler, 2011). A similar algorithm to the ONA algorithm was used in this study to post-process the black carbon data. In looking specifically at the study that looked solely at black carbon levels along the BeltLine, a different methodology was used to post-process the data. Rather than applying an algorithm to reduce electrical noise, the 10-minute averages for black carbon levels were used to compute the descriptive statistics including median, standard deviation, and interquartile range. The unprocessed, raw black carbon measurements were used to compute the mean values.

For this study, 2 microAeth monitors were utilized. For Campaign A, 2 bicycles, each equipped with a black carbon monitor, started at different points along the route. For Campaign B, 1 bicycle, equipped with both black carbon monitors was utilized for comparison purposes, as it allowed for comparison of black carbon measurements at the exact same point along the route.

Particle Number Concentration

Particle number concentration data was collected using the TSI Nanoscan Scanning Mobility Particle Sizer (SMPS) (TSI Incorporated, Shoreview), which allows for measurement of the size distribution of aerosols. The SMPS works on the principle of exploiting the electrical mobility properties of a particle, properties that are based off of the size and charge state of a particle. ("NanoScan SMPS Nanoparticle Sizer 3910," n.d.)
Particulate Matter (PM$_{2.5}$)

To collect data on PM$_{2.5}$, the TSI Optical Particle Sizer (OPS) Model 3330 (TSI Incorporated, Shoreview) was utilized. The OPS 3330 is a light scattering instrument that is able to analyze particle size across 16 channels ranging from 0.3-10µm. The instrument operates by recording particles as they pass through the viewing volume of the instrument by counting individual pulses on the photodetector (“Optical Particle Sizer 3330,” n.d.).

Location Tracking

To ensure that the exact location along the predetermined route was recorded, 2 separate location tracking methods were used. One method employed the use of a GPS, which recorded exact location along the route. The specific GPS model that was used was the GlobalSat DG-100USB Datalogger (Global Sat, Taiwan). The GPS continuously recorded the location of the rider throughout the entire air sampling session. The other location tracking method involved having the rider record the time at various points along the route. The points varied, but were dependent on which loop the rider was on. The rider recorded the exact time they started a particular loop, the point they reached the mid-point (the start of the BeltLine), and the time they reached the end of a particular loop.

Analysis of Traffic Patterns

To fully understand how traffic related air pollution impacts the BeltLine, it is imperative to understand traffic patterns on the roads that are in close proximity to the BeltLine. To assess traffic patterns on roads, close by to the BeltLine, the Georgia Department of Transportation’s (GDOT) Traffic Analysis and Data Application (TADA) was utilized to access traffic counts.
around the BeltLine. The TADA database allows for users to access historical traffic count data collected by GDOT on roads throughout the State.

For this study, roads in close proximity (less than a mile) to the trail were examined. This included looking at traffic counts on roads both upwind and downwind of the trail. It is important to note that the traffic counters that were examined are not permanent monitoring stations. As a result, data is collected over the course of a few days each year, and the traffic count data is extrapolated to give an annualized daily count. Figure 4 below shows the position of the traffic counters relative to the route that was followed for air monitoring. The numbers at each monitoring station correspond to the extrapolated traffic counts for that particular monitoring station.
Figure 4- Traffic Data

Map courtesy of Google Maps- (“BeltLine Project,” n.d.)
As shown in the data from the TADA database, the roads surrounding the BeltLine vary greatly in terms of traffic usage. Captured data by the database include small neighborhood roads where yearly traffic counts were on the order of a couple of hundred all the way up more heavily trafficked roads, such as Ponce de Leon Avenue, where traffic counts reached as high as 38,100.

It is important to note that several of the roadways overlap the BeltLine at various points. For instance, the Ponce de Leon Ave. travels directly underneath of the BeltLine trail at one point. This means that as the rider is traveling on the BeltLine, they are actually taking measurements from the roadway. This could lead to higher than expected results for that particular portion of the route, and may ultimately impact study results.

**Historical Weather Data**

In addition to looking at local traffic data, historical weather data for the City of Atlanta was also examined in this study using the Georgia State University WeatherSTEM Station (“Weather Forecast & Reports - Long Range & Local,” n.d.). Weather conditions on the days that sampling occurred was researched, and recorded to possibly show any impact weather had on the sampling results. The weather parameters that were examined included average temperature, average humidity, total rainfall, and wind speed/direction. Data on weather conditions was provided by the Weather Underground Database (“Weather Forecast & Reports - Long Range & Local,” n.d.). Table 2 breaks down the weather conditions based off of the sampling date.
Weather has been shown to have a significant impact on air pollution levels, and drastic changes in meteorological conditions could alter air pollution levels significantly. For instance, Dawson et al. found that the all PM species have the potential to be impacted by wind speed, mixing height, and precipitation. Specifically, they found that the effects of temperature, wind speed, absolute humidity, mixing height, and precipitation were more likely to impact PM$_{2.5}$ levels that any other particulate species (Dawson, Adams, & Pandis, 2007).

For analyzing air pollution along the BeltLine, the average temperature, humidity, precipitation, and wind speed levels were recorded for each day of sampling. Through their research, Dawson et al. found that lower temperatures caused a larger decrease in PM$_{2.5}$ levels than in warmer months (2.9% decrease as opposed to 0.23% respectively). Researchers attribute this response to temperature to competing changes in sulfate and nitrate changes within the PM$_{2.5}$ species (Dawson et al., 2007). Researchers also found that changes in wind speed impacted PM$_{2.5}$ levels, with higher wind speeds resulting in lower readings of PM$_{2.5}$ (Dawson et al., 2007). Humidity was shown to have the greatest impact on concentrations of ammonium nitrate aerosol.

<table>
<thead>
<tr>
<th>Date</th>
<th>Average Temp</th>
<th>Average Humidity</th>
<th>Average Precipitation</th>
<th>Average Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/13/2015</td>
<td>50°F</td>
<td>54%</td>
<td>0.00 in</td>
<td>8 mph (NNW)</td>
</tr>
<tr>
<td>11/17/2015</td>
<td>60°F</td>
<td>75%</td>
<td>0.00 in</td>
<td>10 mph (East)</td>
</tr>
<tr>
<td>4/23/2016</td>
<td>66°F</td>
<td>67%</td>
<td>0.00 in</td>
<td>7 mph (NNW)</td>
</tr>
<tr>
<td>4/26/2016</td>
<td>70°F</td>
<td>68%</td>
<td>0.00 in</td>
<td>4 mph (SSW)</td>
</tr>
<tr>
<td>4/29/2016</td>
<td>72°F</td>
<td>59%</td>
<td>0.00 in</td>
<td>1 mph (WNW)</td>
</tr>
<tr>
<td>9/7/2016</td>
<td>79°F</td>
<td>61%</td>
<td>0.00 in</td>
<td>1 mph (SW)</td>
</tr>
<tr>
<td>11/9/2016</td>
<td>58°F</td>
<td>61%</td>
<td>0.00 in</td>
<td>7 mph (NNW)</td>
</tr>
<tr>
<td>11/10/2016</td>
<td>55°F</td>
<td>49%</td>
<td>0.00 in</td>
<td>2 mph (WNW)</td>
</tr>
<tr>
<td>11/11/2016</td>
<td>52°F</td>
<td>53%</td>
<td>0.00 in</td>
<td>5 mph (NW)</td>
</tr>
<tr>
<td>3/28/2018</td>
<td>62°F</td>
<td>75%</td>
<td>0.00 in</td>
<td>5 mph (SSW)</td>
</tr>
<tr>
<td>3/29/2018</td>
<td>68°F</td>
<td>79%</td>
<td>1.04 in</td>
<td>8 mph (SSW)</td>
</tr>
</tbody>
</table>
species, with higher levels of PM$_{2.5}$ correlated with higher levels of humidity. The researchers found this correlation to be stronger during the summer months when water vapor concentrations are higher (Dawson et al., 2007). Lastly, precipitation can weigh heavily on PM$_{2.5}$ levels. Specifically looking at the Southeastern region of the United States, Dawson et al. found the greatest effect of precipitation on PM$_{2.5}$ to be more predominant during the winter months, where storms typically last longer, as opposed to summer months, where convective precipitation results in short lived storms (Dawson et al., 2007).

Specifically looking at the dates that the BeltLine samples were taken, there was some wide variation in temperature and humidity levels. Temperature readings varied by about 20 degrees during the sampling period, while humidity readings varied by around 25%. Precipitation readings were all relatively low, aside from 1 day where an inch of rain was recorded; however, it is important to note that there was no noticeable rain on 3/29/2018 during sampling. Average wind speed direction varied slightly, but overall the levels were very low. Overall, the weather conditions on the days that the sampling was conducted could be described as “favorable” in that temperature and humidity were moderate, there was no precipitation, and wind speed was fairly low. This could potentially cause the results to reflect sampling in “dirtier air” since the weather conditions reported would tend to favor concentration of particles rather than dispersion.

**Results**

Following completion of air sampling along the roadway and the BeltLine, the data files from that particular day of sampling were downloaded into Microsoft Excel (Microsoft, Redmond) to allow for easy manipulation of the data. To correctly organize the data, the raw
data files were compared with either GPS data or hand written logs, to determine where along the route the measurements were taken. Based off the location that the data was collected, the data was categorized as either “BeltLine” or “Roadway”. Descriptive statistics (the mean, median, standard deviation, and interquartile range) were calculated for each measured air quality parameter on both samples taken on the roadway and the BeltLine. In addition to calculating the descriptive statistics for each of the individual days, the aggregate data was combined from all sampling dates to show the overall air quality parameters over the entirety of both studies.

Further statistical methods were utilized to assess any statistical significance difference between concentrations on the Roadway and the BeltLine. To test for statistical significance, a t-test of equal variance was used. The t-test of equal variance was used primarily to pair the measurement between BeltLine and roadway samples to assess any significant differences. The paired t-test was conducted using the statistical software package R (The R Foundation for Statistical Computing). In addition to examining individual dates, all of the collected data was aggregated to provide a comprehensive comparison between samples collected along the roadway and the BeltLine using a $\alpha=0.05$ level of significance. If the calculated value from the t-test was less than 0.05, then the value was significant, indicating a significant difference in air quality levels between the BeltLine and neighboring roadways.

The descriptive statistics, including standard deviation, median, and interquartile range (IQR) from the individual sampling dates for both sampling campaigns are displayed in Table 3. The results from the statistical t-test of the means are displayed in Table 4.

Rather than reporting the number of samples that were taken during both sampling campaigns, the total number of sampling minutes was calculated. In the case of Campaign A,
the initial results were recorded in 1-minute sampling intervals. For Campaign B, the sampling occurred in 10-second intervals. These intervals were converted into minute readings, and the number of sampling minutes from both sampling campaigns were combined to give an overall total for number of minutes sampled.

Table 3a- Descriptive Statistics- OPC Volume Concentration & Particle Number Concentration

<table>
<thead>
<tr>
<th>Date</th>
<th>On Road OPC Volume Std Dev</th>
<th>Median</th>
<th>IQR</th>
<th>On Road Number Std Dev</th>
<th>Median</th>
<th>IQR</th>
<th>On Beltline OPC Volume Std Dev</th>
<th>Median</th>
<th>IQR</th>
<th>On Beltline Number Std Dev</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/13/2015</td>
<td>256</td>
<td>256</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/17/2015</td>
<td>179</td>
<td>179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/23/2016</td>
<td>65</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4/29/2016</td>
<td>163</td>
<td>163</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/7/2016</td>
<td>52</td>
<td>52</td>
<td></td>
<td>14.7 15.7 3.66 3.43 24</td>
<td>0.81</td>
<td></td>
<td>8230 9860 8960 9160 1440 2130</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>11/9/2016</td>
<td>31</td>
<td>31</td>
<td></td>
<td>1.52 2.71 4.37 4.93 1.6</td>
<td>0.51</td>
<td></td>
<td>3000 30600 6930 7770 2700 3230</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/10/2016</td>
<td>15</td>
<td>15</td>
<td></td>
<td>0.437 0.691 7.83 9.42 0.36</td>
<td>0.71</td>
<td></td>
<td>2720 4720 11800 8360 1780 684</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/11/2016</td>
<td>22</td>
<td>22</td>
<td></td>
<td>0.478 0.938 2.69 2.62 0.72</td>
<td>0.73</td>
<td></td>
<td>5390 4450 10700 11100 1290 1870</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>3/28/2018</td>
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<td>29</td>
<td></td>
<td>0.335 0.294 3.61 3.65 0.32</td>
<td>0.44</td>
<td></td>
<td>2940 7450 11200 11600 2720 1730</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/29/2018</td>
<td>18</td>
<td>18</td>
<td></td>
<td>0.227 0.233 4.84 5.05 0.17</td>
<td>0.25</td>
<td></td>
<td>1830 3020 6570 7000 1050 3000</td>
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</tr>
<tr>
<td>All Dates</td>
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<td>1009</td>
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<td>9.57 9.3 3.79 3.88 2.59</td>
<td>1.79</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3b - Descriptive Statistics - Median Diameter & Black Carbon

<table>
<thead>
<tr>
<th>Date</th>
<th>Sampling Time (in Minutes)</th>
<th>Median Diameter (nm)</th>
<th>Black Carbon (µm$^3$·cm$^{-3}$)</th>
<th>Mean</th>
<th>Paired t-Test (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On Road</td>
<td>On BeltLine</td>
<td>Std Dev</td>
<td>Median</td>
<td>IQR</td>
</tr>
<tr>
<td>11/13/2015</td>
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<td>256</td>
<td>0.39</td>
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<td>0.314</td>
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<td>179</td>
<td>0.34</td>
<td>0.535</td>
<td>0.609</td>
</tr>
<tr>
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<td>179</td>
<td>0.55</td>
<td>2.15</td>
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<td>65</td>
<td>65</td>
<td>0.42</td>
<td>0.388</td>
<td>0.637</td>
</tr>
<tr>
<td>4/29/2016</td>
<td>163</td>
<td>163</td>
<td>0.42</td>
<td>0.388</td>
<td>0.637</td>
</tr>
<tr>
<td>9/7/2016</td>
<td>52</td>
<td>52</td>
<td>0.42</td>
<td>0.388</td>
<td>0.637</td>
</tr>
<tr>
<td>11/9/2016</td>
<td>31</td>
<td>31</td>
<td>0.42</td>
<td>0.388</td>
<td>0.637</td>
</tr>
<tr>
<td>11/10/2016</td>
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<td>15</td>
<td>0.35</td>
<td>0.735</td>
<td>1.13</td>
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<td>0.57</td>
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</tr>
<tr>
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<td>1009</td>
<td>0.66</td>
<td>0.416</td>
<td>0.754</td>
</tr>
</tbody>
</table>

Table 4 - Air Sampling Along Atlanta BeltLine Eastside Trail- Statistical Testing

<table>
<thead>
<tr>
<th>Date</th>
<th>OPC Volume Concentration (µm$^3$·cm$^{-3}$) Mean</th>
<th>Paired t-Test (p-value)</th>
<th>Number Concentration (µm$^3$·cm$^{-3}$) Mean</th>
<th>Paired t-Test (p-value)</th>
<th>Median Diameter (nm) Mean</th>
<th>Paired t-Test (p-value)</th>
<th>Black Carbon (µm$^3$·cm$^{-3}$) Mean</th>
<th>Paired t-Test (p-value)</th>
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</thead>
<tbody>
<tr>
<td>11/13/2015</td>
<td>179.3</td>
<td>0.402</td>
<td>179.3</td>
<td>0.402</td>
<td>179.3</td>
<td>0.402</td>
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<tr>
<td>11/17/2015</td>
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<td>0.728</td>
<td>179.3</td>
<td>0.728</td>
<td>179.3</td>
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<tr>
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<td>0.099</td>
<td>179.3</td>
<td>0.099</td>
<td>179.3</td>
<td>0.099</td>
<td>179.3</td>
<td>0.099</td>
</tr>
<tr>
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<td>0.401</td>
<td>179.3</td>
<td>0.401</td>
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<td>0.401</td>
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<tr>
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<td>0.728</td>
<td>179.3</td>
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Discussion

The main research question of interest in this study was- Is there a difference in air pollution levels along the trail compared with baseline samples taken on an adjacent road, and if there is a difference, are the differences statistically significant as to suggest that air pollution levels are lower on the BeltLine than compared with neighboring roads? Investigating the latter question was of great interest because any statistical significance might indicate that individuals utilizing the BeltLine are exposed to less air pollution than on neighboring roadways. Conversely, if it was shown that there was no statistical significance, this would imply that there is no difference in air pollution between the 2 locations, and that individuals utilizing the BeltLine are exposed to the same air pollution that is on the roadways. It was initially hypothesized that air pollution along the BeltLine would be lower than on neighboring roadways.

While the majority of the air sampling showed no statistical significance in regards to differences between roadway and BeltLine samples, which rejects the initial hypothesis, there were however some results that showed statistical significance between roadway and BeltLine air samples. These included Black Carbon readings on 11/15/2015, OPC Volume Concentration and Median Diameter readings on 11/10/16, Median Diameter readings on 11/11/16, and OPC Volume Concentration readings on 3/29/18.

The significant findings found on these days could point to one of two things. One possible explanation is that there is a true difference in pollution levels along the BeltLine compared to neighboring roadways. The other explanation is that there really is no difference and the significant differences arose simply because the sampling was conducted at different times. Based off of the method in which the data was collected, it is difficult to unequivocally
conclude what led to the significant findings; however, a logical interpretation would be that the differences arose because the sampling occurred at different times. In most cases, sampling was separated by around 10-15 minutes, meaning that the make-up of air that was measured had changed. This becomes apparent in looking specifically at the median diameter readings on 11/10/16 and 11/11/16. Both of these dates should statistical significance; however, a plausible explanation could be differences in sampling time. As particle species age, they tend to enlarge in size. This means that measurements taken at the same point after several minutes could result in different median diameter sizes. This is apparent in the median diameter readings on 11/10/16. The median diameter measurements taken on the BeltLine were statistically larger than measurements taken along the roadway. A plausible explanation for this could be that because of the differences in sampling time, the monitor was actually measuring older particles, which had grown in size, and the particles along the BeltLine are not typically larger in size. Interestingly, the median diameter results on 11/11/16 showed a larger median diameter on the roadway, and a smaller median diameter on the BeltLine. One plausible explanation could be that because of weather conditions on that particular day, there was not a great amount of particle dispersion, and particles aged and grew bigger closer to the road.

Regardless of any statistical significance shown on individual sampling days, the overall data did not show any statistical significance for the particular air quality parameters that were examined. If in fact there was a true difference between recorded air quality values on the BeltLine and roadway, this observation would have been shown to be more consistent and occurring on a more regular basis. While this difference wouldn’t have to occur every time sampling was conducted, it would need to occur enough to exceed the α level used in the statistical testing. This repeated difference was not observed during the study. Conversely, if
there isn’t a real difference, then by pure chance, it would be expected that air pollution levels on the BeltLine would vary, with some days being higher and others being lower compared to the roadway. The method in which samples were collected in Campaign B could be used to further investigate this claim. Since sampling for Campaign B along the BeltLine and roadway occurred at different times, a set of samples taken at one point along the BeltLine and another set of samples taken at the exact same location 30 minutes later should yield different results. This variation could be the result of a number of external influences including a change in wind speed, a change in wind direction, or a reduction/increase in traffic. Furthermore, if these results are purely the result of chance, then this trend would not be consistent across several days of sampling. This in fact what was observed during the study. Based off of this, it can be concluded that the exposure to traffic related air pollution is the same on and off of the BeltLine.

**Limitations**

One limitation of this study that could have affected the results were the weather conditions on the days that sampling was conducted. For the most part, the weather conditions on the days that sampling was conducted could be described as “fair”, in that there were no extremes in weather parameters. Examining how air pollution is affected by adverse weather conditions could provide a realistic, real world scenario of how weather conditions can impact air pollution, and ultimately alter a person’s exposure to air pollution.

Another limitation of the study is that the speed of the rider was not recorded. The speed the rider was traveling could alter how the air quality results were recorded. For instance, a rider traveling at a slow rate of speed through an area of air pollution might record higher air pollution levels than someone traveling at a faster rate of speed as it relates to how the air quality levels are recorded by the instruments. Further research could include having riders record an average
speed along the various parts of the trail, and factoring the speed into the air quality measurements. In regards to this study, it is unlikely that changes in speed along the route had any negative impact on the overall results mainly because of the sheer number of samples that were collected on the sampling dates.

One final limitation of this study are the limited air parameters that were examined. While the recorded parameters are great measurements of air quality, looking at other air quality measures could increase the chance that the results from the study are more generalizable. This could include looking at Nitrogen oxide species, another well-known traffic related air pollutant, to create a bigger overall picture of how community health along the BeltLine is impacted by nearby traffic.

Future Research

Since the construction of additional portions of the BeltLine will be an ongoing project for the next several years, continued research in air pollution along the trail will be crucial in further understanding how the built environment can affect the health of a community. From the standpoint of policy implications, understanding this relationship is imperative if the BeltLine project is to continue as planned. For instance, if it was found that air pollution along the BeltLine was putting the community at risk, city leaders might have to explore alternative options to address the potential health risk. This might include having to offset the BeltLine trail away from the road in an effort to protect trail users. This could lead to changes in trail access points, and could potential carry financial consequences.

Moving forward, continued research on the relationship between built environment and community health is vital in order to create a healthy community. This includes further research
exploring air pollution along the BeltLine, and could include looking at seasonal variation of traffic-related air pollutants. Comparing air quality samples across different seasons could provide temporal variability to show how trail users are being exposed to air pollutants over time, taking into account changes in temperature, humidity, and other weather factors that could influence air pollution levels. Another area where additional research could be considered is in the type of air pollutants that are examined. While it would be near impossible to test for every type of air pollutant, adding additional sampling parameters could help paint a more comprehensive picture of air quality throughout the city. This could include looking at other types of traffic-related air pollutants including Nitrogen oxide species, another well-known traffic-related air pollutant.

As more cities gravitate toward the idea of multi-use trails in urban settings, continued research on how the air quality of the built environment impacts community health will prove to be a crucial part of the development plan. If cities begin to understand this relationship early on in the planning and developing process, then effective steps can be taken to ensure that the relationship between built environment and community health remains a healthy one.
Appendix A - Detailed Map of BeltLine as of 2018
Appendix B- Map of The East Side Trail
Bibliography


Sturm, R. (2016b). Total deposition of ultrafine particles in the lungs of healthy men and women: experimental and theoretical results. *Annals of Translational Medicine, 4*(12). https://doi.org/10.21037/atm.2016.06.05


