Bridge to Clean Air

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1 Executive Summary

This report is the product of the first stage of a multi-year project with Rice University and Air Alliance Houston that aims to implement an air remediation and pollution awareness project on Interstate Highway 59 in Houston, Texas. This report details the findings, analysis, and recommendations of a Houston Action Research Team (HART) of four undergraduate students. The team used equipment from the City of Houston to sample air proximate to the Hazard Street Bridge over US-59 (a sunken traffic hotspot) during morning and afternoon rush hours in March 2016. Using various statistical analyses, the team was able to characterize the air pollution at the site, specifically with regards to concentrations of $PM_{2.5}$, PM_{10}, and NO_2. Ultimately, the team determined that both $PM_{2.5}$ and NO_2 concentrations at the bridge site were at notably high levels. Moreover, the highest, most concerning concentrations occured during the morning sampling periods. Therefore, this report recommends that air remediation equipment be designed that can target $PM_{2.5}$ and NO_2 in the morning in order to better the health of the populations near and at the site, as well as further research regarding levels of air pollutants along Houston highways, especially segments that are adjacent to residential areas.

2 Introduction

2.1 Overview

When we think about air pollution, the image that typically comes to mind is that of dense, gray smog over an urban skyline. We tend to visualize the hazy environment of industrial China, or the bleak skies of Los Angeles.

Figure 1: Los Angeles Skyline

Research has shown that air quality here in Houston is having negative health effects on residents [13]. The two most prominent sources of air pollution are industrial fixtures such as chemical plants and refineries, and mobile sources such as cars, trains, and ships. While there are systems in place intended to mitigate air pollution from stationary sources, relatively little consideration has been given to mobile source remediation. What's more, the problem of mobile source pollution has historically been approached through mobile remediation devices which are built in or attached to the source. Mobile source pollution has never been seriously targeted with a fixed site filtration device. Our long-term goal is to install (if it is deemed feasible and efficient) a stationary system that both filters mobile pollution and informs motorists about currrent pollution levels at a major traffic hotspot in Houston. First, however, we must investigate the feasibility of this concept. Can a stationary remediation system help mitigate the air pollution in and around our busy roadways? And could such a system make motorists more aware of the health effects they are causing? Our project is the first phase of a long-term effort to address these questions and devise some potential solutions.

2.2 Inspiration

The Bridge to Clean Air project was inspired by a billboard in Peru which has an imbedded filtration system that is able to clean the surrounding air at a rate similar to that of 1,200 trees actively intercepting airborne particulate and absorbing greenhouse gases.

Figure 2: Air Filtration Billboard in Lima, Peru

This billboard was erected in order to purify the air in the area which was known to be unclean due to neighboring construction projects. This system is a step away from a traditional air purification system as its focus is to purify ambient air rather than the emmisions of a specific source. While the overarching goal of our three phase project is not to replicate the billboard, the goal of phase two of the project will be to install a stationary device at the Hazard Street Bridge over Highway 59 that will work in a similar way, filtering the ambient air to improve air quality for those living in the surrounding areas. Our system will also be educational in nature, incorporating an LED light system that will communicate real-time air quality levels to drivers. However, the key difference between the Bridge to Clean Air project and the billboard installed in Peru is that the billboard filters pollution from fixed construction sites while our device will be designed to filter pollution from mobile sources, specifically vehicles on the highway.

2.3 Timeline

This report represents the first part of the larger, collaborative project between Rice University's Center for Civic Leadership and Air Alliance Houston, supported through a multi-year grant by the Baxter Trust. Our Rice University Houston Action Research Team (HART) was tasked with collecting and analyzing air quality data from the Hazard Street Bridge over US-59 in order to determine baseline pollutant levels before the design and installation of a filtration device. We chose to sample the air specifically for particulate matter (PM) and nitrogen dioxide, as these pollutants are linked to various human health issues and are known to be associated with mobile sources such as cars. In this report, we provide information regarding the concentrations of these pollutants at the site, as well as some environmental factors that effect when the concentrations are highest. As such, this data collection and analysis phase is critical to the design of any potential filtering or awareness device.

Over the course of the next academic year, a team of undergraduate engineers from Rice University will be asked to design and construct the device as part of a senior engineering design project. The goal is to have the device installed during the summer of 2017. Then, during the 2017 school year, another team of student researchers will analyze the air quality at the site while the air filtering system is operating, following the same methods used by our team. If that team finds significant decreases in air pollution levels compared to our pilot study, we will conclude that the device is effective, and consider spreading the prototype to other traffic hotspots in Houston and potentially other cities around the country.

3 Background

3.1 Understanding Air Pollution

Air pollution levels are associated with a variety of factors, including proximity to sources of pollutants, chemical and physical processes in the atmosphere, and the existence of treatment systems. Fixed site industrial facilities are a major cause of air pollution, as evidenced in East Asia where rapid industrialization has led the region to have some of the highest levels of air pollution in the world [1]. Similarly, the Air Quality Index (AQI) map shows that west Houston, which is primarily residential and commercial, has better air quality than the eastern part of the city which has many industrial facilities including refineries and the Houston Ship Channel.

However, among all pollution sources, mobile sources carry a particularly heavy weight. Nationwide, mobile sources are responsible for about 75 percent of carbon monoxide emissions and more oxides of nitrogen emissions than fixed sources [2]. In urban areas, mobile sources can even contribute more than 90 percent of all carbon monoxide pollution. In a typical urban area, mobile sources contribute to at least half of the hydrocarbon and nitrogen oxide pollutants [2].

Various particles in the air contribute to this pollution. We are specifically concerned with particulate matter ($PM_{2.5}$: 2.5 micrometers or less in diameter, and PM_{10}: 10 micrometers or less in diameter), and nitrogen dioxide (NO_2), both of which are common mobile pollutants. The EPA 24-hour standard is 35 micrograms per cubic meter for $PM_{2.5}$, 100 micrograms per cubic meter for PM_{10}, and 100 parts per billion for NO_2 [7].

3.2 Health Effects

Air pollution has serious health effects and has a disproportionately larger impact on people of lower socioeconomic status who live near highways [8]. Air pollution can cause serious lung problems, cancer related diseases, and even affect human longevity [9]. Air pollutants affect different organs and systems in the human body. Since the level of air pollution is higher close to highways and in the industrial areas, people who live near such areas are more likely to suffer from health problems caused by pollutants [8]. Research has shown that living close to traffic is associated with an increased risk of coronary mortality, whereas moving away from traffic is associated with a decreased risk [8]. For those moving closer to traffic during the exposure period, the risk of Coronary Heart Disease mortality increased 23% as compared with the unexposed [8].

3.3 Factors that Influence Air Quality

There are a variety of factors that determine daily and seasonal fluctuations of air pollutant concentrations. In particular, the effects of the following factors are especially important to understand when designing a pollution mitigation system.

3.3.1 Time of Day

The morning and afternoon rush hours coincide with the general daily patterns of NO_2 and $PM_{2.5}$ fluctuations. Figure 3 is a typical example of daily variation of NO_2 and $PM_{2.5}$ sampled in the Hamilton Metropolitan area in Ontario, Canada. The daytime maximum of pollution occurs around 8 am, which coincides with the morning peak traffic hours. The nighttime maximum happens around 8 pm, which is two hours after the afternoon rush hours. The pollution level drops during nighttime, reaches minimum at around 4am, and then increases again due with the start of the morning rush hour [10].

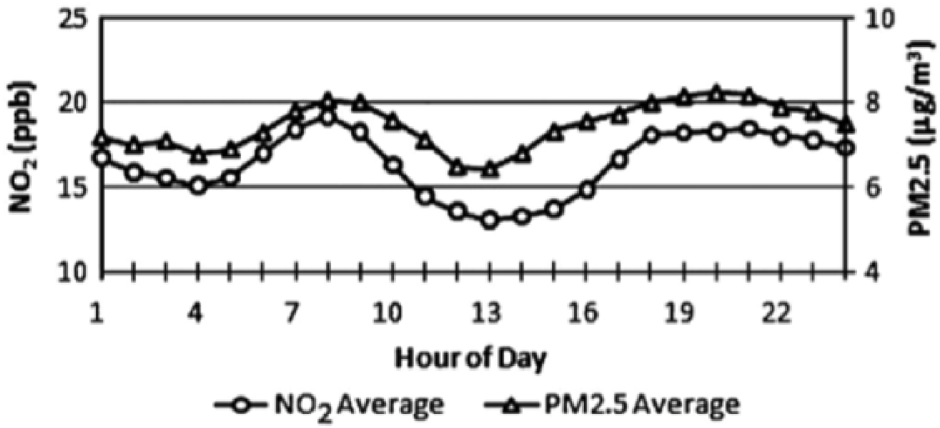

Figure 3: Time Series of Pollutant Concentrations

3.3.2 Wind

Wind speed and direction affect pollutant levels by dissipating industrial pollutants and complicating the pollutant distribution of downwind areas. In addition, wind causes mobile pollutants to quickly disperse from the highways where they are first emitted. However, wind is very difficult to predict and varies significantly locally, as well as over time.

3.3.3 Temperature Inversions

Temperature inversions also play a major role in elevating the pollution conditions. The temperature inversion occurs at the troposphere, the region of the atmosphere nearest to the Earth's surface, where the normal decrease in temperature with height switches to the temperature increasing with height [11]. Temperature inversions can trap pollutants below the inversion and allow them to build up by constraining vertical airflow. The nighttime inversions generally contribute to 49% increase in NO2 and 54% increase in $PM_{2.5}$. The daytime inversion results in an 11% increase in NO_2 but a 14% decrease in $PM_{2.5}$ [11]. The pollution level rise during nighttime inversions is much higher than that during daytime, which is due to the fact that the mixing height is lower and the air is more stable. The unexpected decrease in $PM_{2.5}$ during daytime inversion periods is most pronounced in summer with the increased mixing height and the increased volume of air available for mixing. The low mixing layer weakens the impact of the temperature inversions [11]. Figure 4 shows a typical example of the comparison of $PM_{2.5}$ data from ground monitors for day and night, normal and inversion scenarios.

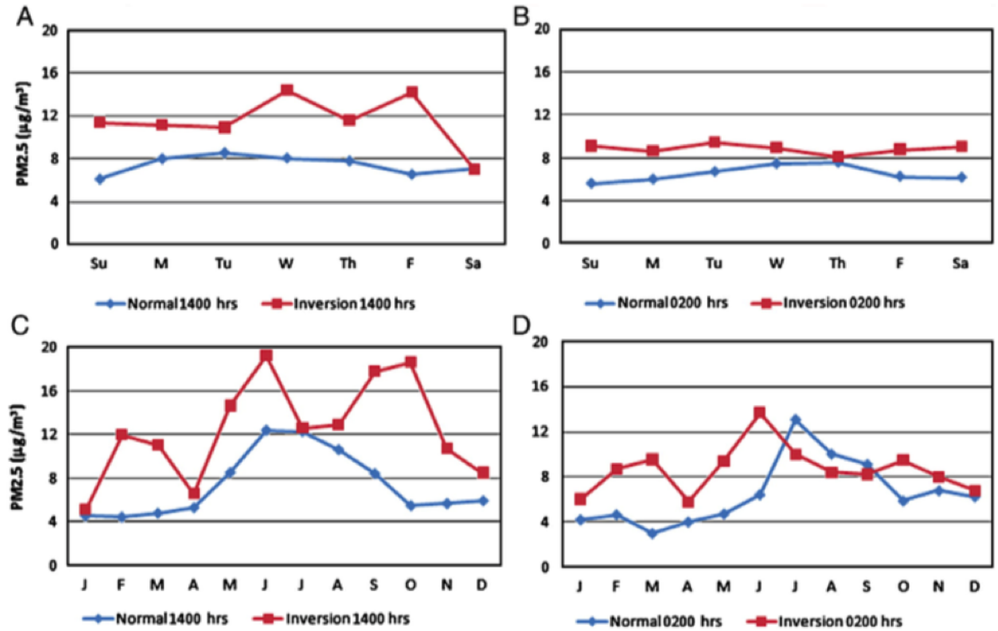

Figure 4: Effects of Temperature Inversions

4 Methodology

4.1 When and Where We Sampled

The air sampling for this project took place along US-59 Highway at the Hazard Street Bridge crossing. This segment of US 59 has three lanes, one HOV lane and two others, with traffic flowing east and west. We chose to sample air at the Hazard Street Bridge over US 59 since it is one of the most congested roadways in Houston, and even in Texas. Because of the heavy traffic, an air treatment system to reduce vehicle pollution could be especially beneficial to public health. Also, this segment of US 59 highway is near residential areas, including Poe Elementary School, making it of particular interest in terms of potential public health effects. Our specific sampling location was on the south side of the highway near the traffic lane that runs east.

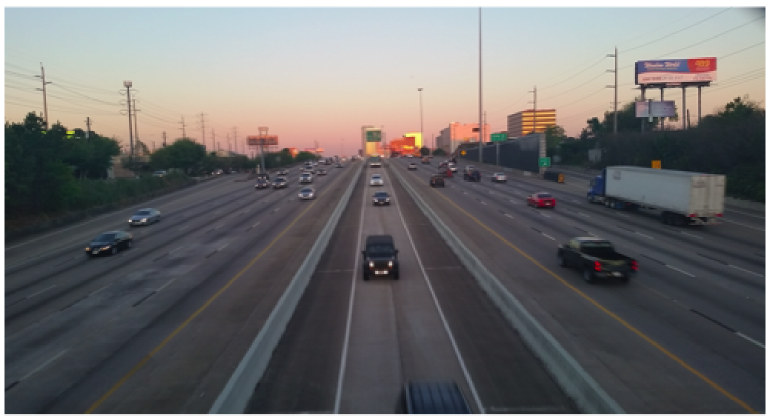

Figure 5: US 59 from the Hazard Street Bridge

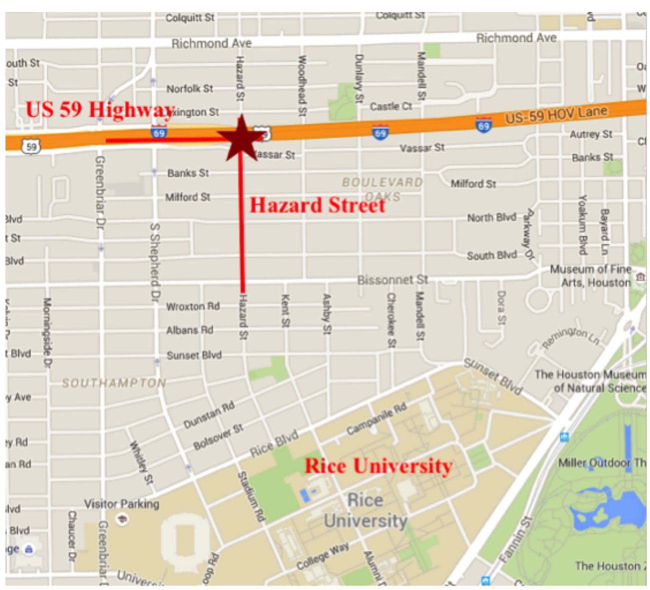

Figure 6: Site Locations

In order to sample the air, we set up a Portable Laser Aerosol spectrometer, a Dust Monitor

Model 1.109 for $PM_{2.5}$, and a Teledyne API Model T500U CAPS NO_2 Analyzer for NO_2. A photograph of the equipment and the set up can be seen in Figure 7.

Figure 7: Sampling Devices on Site

We sampled air at the bridge during the morning and evening rush hour periods. These periods were selected as they are the times when the most vehicle traffic is passing under the bridge. The times of the sampling were from 5:00 am to 9:00 am and from 3:00 pm to 7:00 pm.

4.2 Traffic, Temperature, and Wind Speed Metrics

In addition to sampling the air, we monitored the traffic congestion because we wanted to determine the degree to which pollution levels varied relative to highway congestion levels. Traffic was recorded every fifteen minutes according to the color coded system on Google Maps: green, orange, red and dark red. The colors correspond to traffic congestion, with green denoting minimal congestion and dark red denoting extreme congestion. These colors were recorded as the numbers 1, 2, 3, and 4, respectively, for our purposes. In order to compensate for the fact that the monitoring equipment was located on the south side of the highway, the traffic value is a weighted average of the four lanes.[1]

We also gathered wind speed and temperature levels for the times that we sampled as both of these factors impact air quality. Temperature across the city is relatively similar, so we used data from Weather Underground's website wunderground.com, whose data comes from the National Weather Service (NWS). We also wanted to include wind speed in our analysis, despite it being highly erratic around the city as it is influenced by micro factors such as buildings. Wind speed data also came from Weather Underground using city averages. Given that wind speed is highly localized and the wind speed monitoring equipment is not directly beside the air monitoring site, this data might not be as precise or as reliable as it is in other air quality research.

[1] The inbound lanes were weighted at 60% to the outbound lanes 40%. This would produce a slightly higher estimate of congestion in the morning and slightly lower estimate in the afternoon. The effects of weighting however were minimal in the period we examined.

4.3 Comparison Sites

In order to compare the air quality at the Hazard Street Bridge to other locations in the Houston area, we collected data from the TCEQ monitors at Clinton Drive and at Park Place, two sites widely considered to be some of the most polluted areas in the Houston metropolitan area. Finding evidence that the Hazard Street Bridge has higher concentrations of pollutants than these other two sites would provide evidence that the levels of pollutants at the Hazard Street bridge merit concern, and would help justify the location's necessity for a remediation system.

Figure 8 shows the locations of the three sites from which we have data: our site at the Hazard Street Bridge (left), the site at Clinton Drive (upper right), and the site at Park Place (bottom right). The area around Clinton Drive is already widely known to the public to be a place of high pollution levels because of the high concentration of industrial plants. The Park Place site is a residential area near an industrial area with several oil refineries, and is also surrounded on three sides by major highways.

Unfortunately, since the monitors at the Clinton Drive and Park Place sites measure NO_x rather than NO_2, we weren't able to accurately compare the NO_2 data from the Hazard Street Bridge to the comparison sites. However, the $PM_{2.5}$ data from the comparison sites proved extremely value in our analysis of particulate matter concentrations at the Hazard Street Bridge.

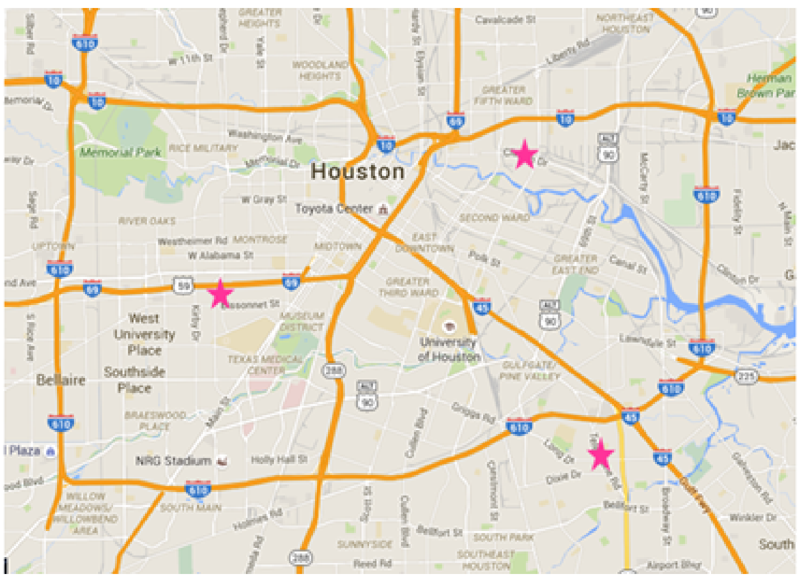

Figure 8: Hazard St. and Comparison Sites

5 Data Analysis

We now present the results of our air sampling data analysis, beginning first with nitrogen dioxide and then moving to particulate matter.

5.1 NO_2 Analysis

We begin by exploring the nitrogen dioxide data collected from our site. We will investigate NO_2 in relation both to the EPA standard of 100 parts per billion (ppb) and to a recent study that suggests NO_2 levels of 18 ppb can be harmful to human health when occuring together with an elevated cumulative eight hour max of ozone [13]. We will also examine the effects of other factors on our observed concentrations. Note that all units are in parts per billion.

5.1.1 Exploratory Analysis

Minimum	1.779
25th Percentile	7.347
Median	16.850
Mean	17.270
75th Percentile	27.140
Maximum	55.380

Table 1: NO_2 Summary Statistics

As is clear from Table 1, although none of our observations are above the EPA standard of 100ppb, nearly half of our observations are above 18ppb.

5.1.2 Comparison to EPA Standard

With such a large number of data points, we can run standard hypothesis testing and create a confidence interval based on the calculated Z-statistic. Units are in parts per billion.

95% Confidence Interval of Mean	(16.1 , 18.5)

Given that our confidence interval includes 18ppb, this analysis raises further concern. We next investigate some of the various environmental factors that affect NO_2 concentration variations.

5.1.3 NO_2 and Wind

Figure 9 shows the results from our NO_2 level sampling, grouped by time (morning or evening), against the corresponding wind speed. We see that NO_2 generally decreasese as wind speed increases. However, the times with the most wind are in the afternoon while most of the morning time is not windy, so here we must be cautious, questioning whether the higher NO_2 levels are caused by time (in the morning) or by lower wind speed. Undoubtedly, however, higher NO_2 levels are most commonly found on mornings with lower wind speeds.

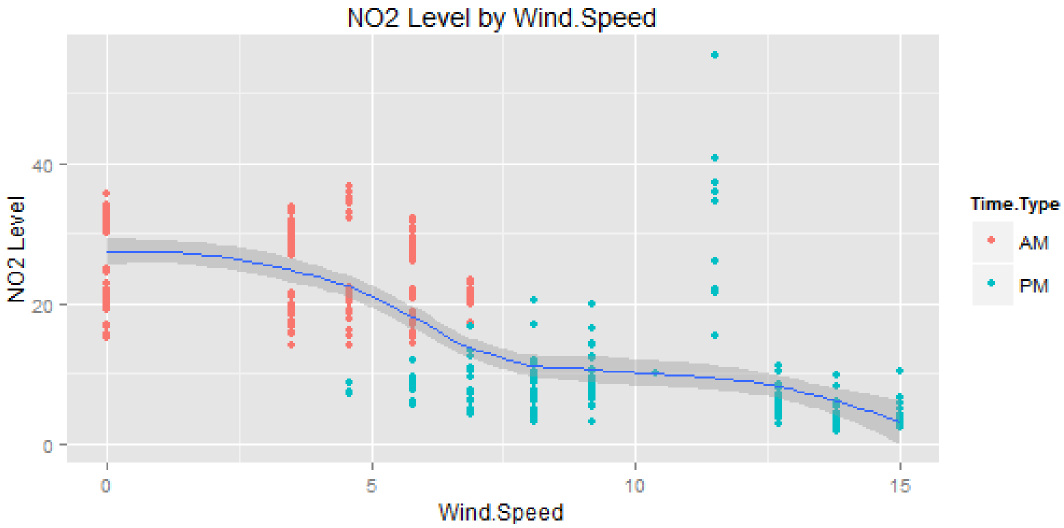

Figure 9: NO_2 Concentrations by Wind Speed

5.1.4 NO_2 and Traffic

We turn next to the relationship between traffic congestion and $PM_{2.5}$ levels. Immediately noticeable in Figure 10 is that traffic is much more congested in the afternoon than in the morning. Recall that our traffic heuristic ranges from 1 (no congestion) to 4 (extreme congestion).

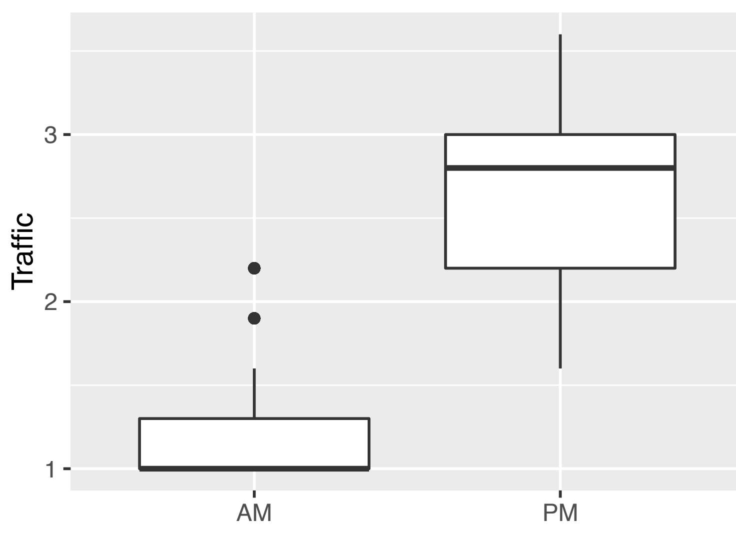

Figure 10: Traffic Congestion by Time of Day

However, when we observe boxplots of our NO_2 data seperated by time of day (Figure 11), we see that the median, or midpoint, of the morning data is almost twenty parts per billion higher than the median of the afternoon data. Although there are a handful of high concentration outliers in the afternoon data, on the whole, the morning is when NO_2 concentrations are highest.

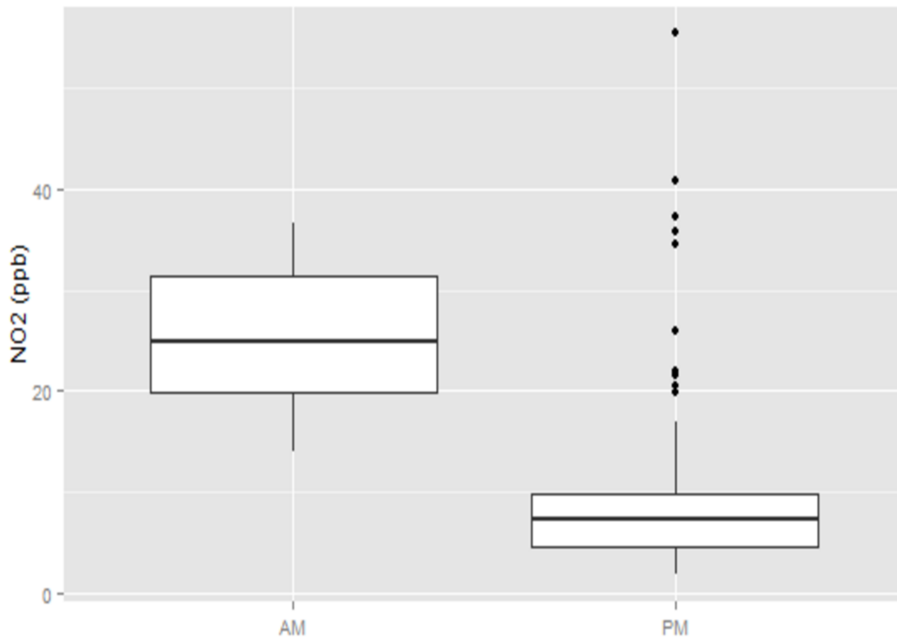

Figure 11: NO_2 Concentrations by Time of Day

Indeed, both the mean and median of the morning data significantly exceed 18ppb, the level at which, as a recent study suggests, gives cause for public health concerns. Thus, we are unable to conclude that higher traffic congestion results in higher NO_2 concentrations. We turn next to the variable of temperature.

5.1.5 NO_2 and Temperature

As we have just seen, we typically observe higher NO_2 concentrations in the morning hours than in the afternoon. We now examine how temperature factors in to this relationship. When we look at NO_2 concentrations in relation to the temperature at the time the data point was recorded (Figure 12), we can discern a slight trend: higher temperatures seem to have slightly lower concentrations.

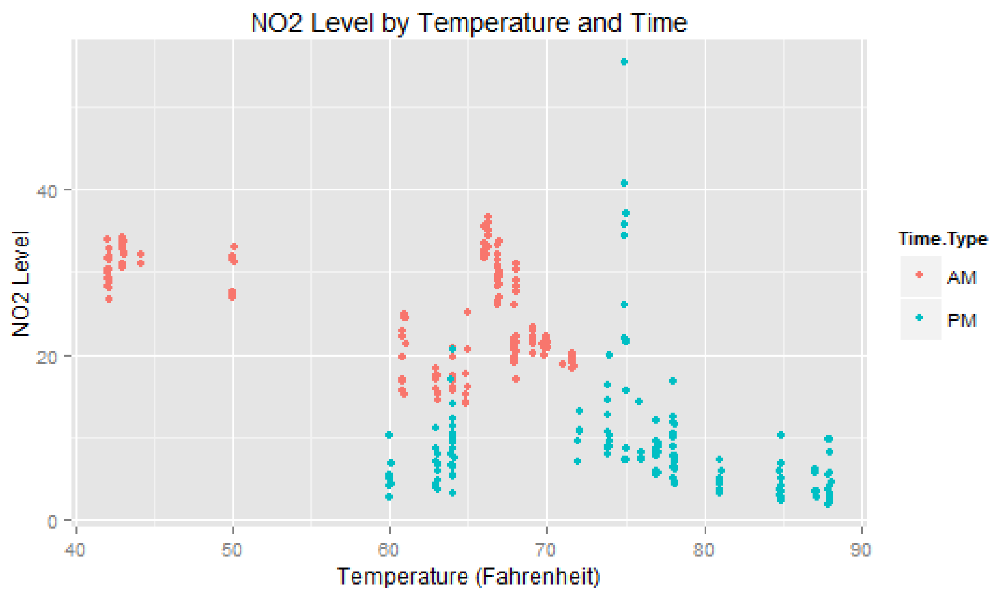

Figure 12: NO_2 Concentrations by Temperature

However, this trend is not strong enough for us to establish much of a correlation, much less a causation. Further research could provide deeper insight into this relationship, but for our purposes, we cannot conclude that temperature has a substantial effect on NO_2levels.

5.1.6 NO_2 Takeaways

Though our observed concentrations of NO_2 are not a cause for concern in relation to the EPA 24-hour standard of 100ppb, a good deal of our data does exceed the suggested level of 18ppb. In addition, we found higher levels of NO_2 at the Hazard Street Bridge than were present at our two comparison sites, which are both well-known for their high levels of air pollution. Further, it is clear from our data that the morning hours are in greater need of remediation than the afternoon hours. Though we saw some slight trends for both temperature and wind speed in relation to the NO_2 concentrations, neither trend was strong enough to justify only filtering NO_2 at certain temperatures or certain wind speeds. If NO_2 concentrations exceeding 18ppb do indeed pose public health risks, we suggest that NO_2 be targeted for remediation in the morning at the Hazard Street Bridge site.

5.2 PM_{10} Analysis

According to the EPA, the 24-hour standard for PM_{10} levels is 130 micrograms per cubic meter. Observing Figure 13, it is clear that such concentrations of PM_{10} at the Hazard Street Bridge never seriously approach this level. The horizontal red line in Figure 13 represents the 130 micrograms per cubic meter 24-hour standard.

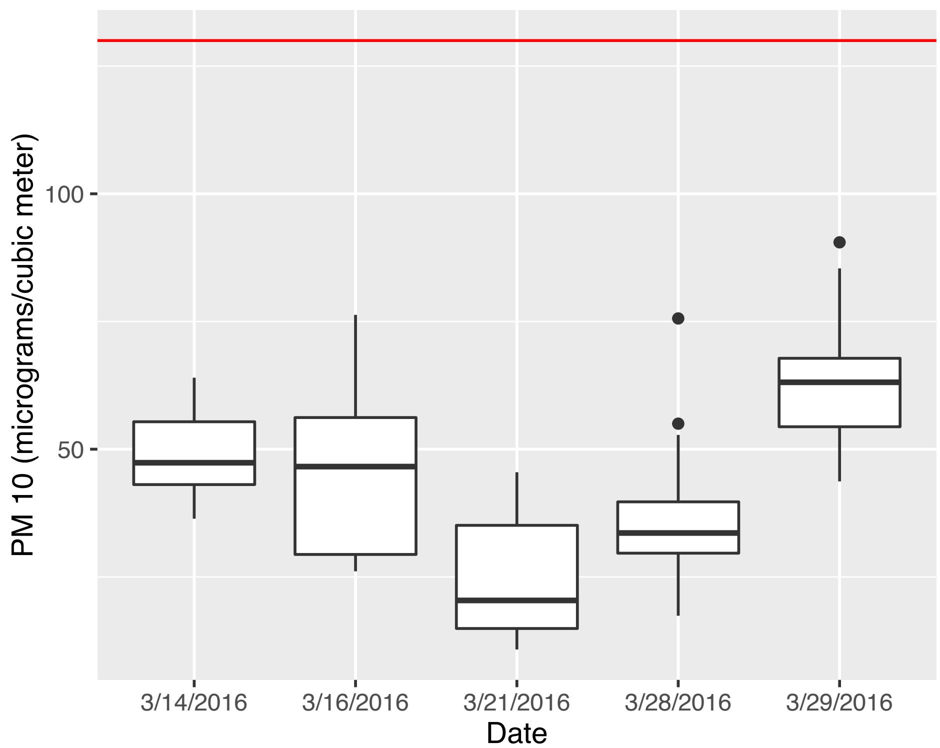

Figure 13: PM_{10} Concentrations by Day

None of our observations even reached 100 micrograms per cubic meter. Thus, according to our data, PM_{10} is not in dangerously high levels of concentration at our site, and it does not necessitate action.

5.3 $PM_{2.5}$ Analysis

As previously stated, $PM_{2.5}$ is directly associated with a variety of human health effects, most predominantly cardiovascular and respiratory issues. According to the EPA, the 24-hour standard for $PM_{2.5}$ is 35 micrograms per cubic meter. Once again, we proceed to investigate the significance of its concentration at the Hazard Street Bridge site, beginning with exploratory data analysis of the 237 data points we collected. All units are in micrograms per cubic meter.

5.3.1 Exploratory Analysis

Minimum	6.70
25th Percentile	19.33
Median	25.60
Mean	27.73
75th Percentile	39.15
Maximum	57.50

Table 2: $PM_{2.5}$ Summary Statistics

Table 2 shows that while the mean of the data collected is below the 24-hour standard of 35 micrograms per cubic meter, over 25% of our data was at levels above this standard.

5.3.2 Comparison to EPA Standard

With such a large number of data points, we can run standard hypothesis testing and create a confidence interval based on the calculated Z-statistic. Units are in micrograms per cubic meter.

95% Confidence Interval of Mean	(26.219 , 29.235)

Testing the null hypothesis that the mean of our data is equal to 35 micrograms per cubic meter, we clearly reject the null with a p-value of 2.432 e-18. We safely conclude that the mean value of $PM_{2.5}$ concentrations at the Hazard Street bridge is below the 24-hour standard.

5.3.3 Comparison to Other Sites

Regardless, we have a significant number of data points above this standard. We now compare our $PM_{2.5}$ data from the Hazard Street Bridge site to data taken from two other major pollution hotspots in Houston, namely Clinton Drive and Park Place. The data from these two other sites were taken on the same days and at the same times as our data, so we can assume that most external conditions (i.e.,weather-related factors) were roughly the same.

Figure 14 compares all of our $PM_{2.5}$ data to all of the data from the other two sites. The horizontal red line represents the 35 micrograms per cubic meter 24-hour standard.

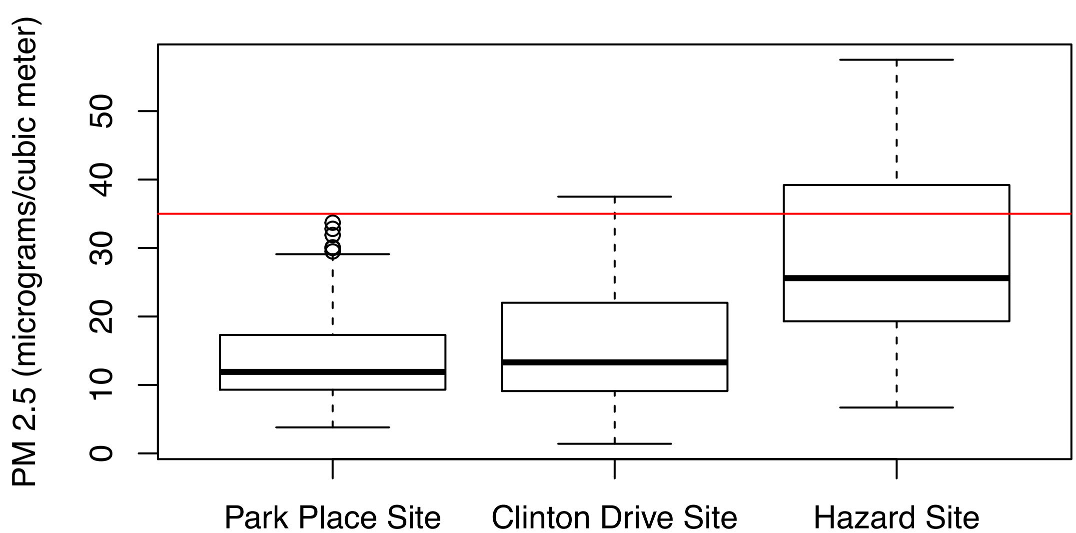

Figure 14: $PM_{2.5}$ Concentrations by Site

Clearly, our $PM_{2.5}$ data from the Hazard Street Bridge site is in substantially higher concentrations than the data from the two other sites. This raises concern, given that the Park Place site and the Clinton Drive site are well-established as having some of the highest levels of air pollution in the Houston metropolitan area. We will return to a discussion of these sites after examining the relationships between $PM_{2.5}$ concentrations at the Hazard Street Bridge site and our other collected variables.

5.3.4 $PM_{2.5}$ and Wind

Comparing $PM_{2.5}$ concentrations to the wind speed at the time of data collection, we see that wind speed does not have a discernible effect on $PM_{2.5}$ concentrations (Figure 15). Note that the data points are slightly jittered to improve readability.

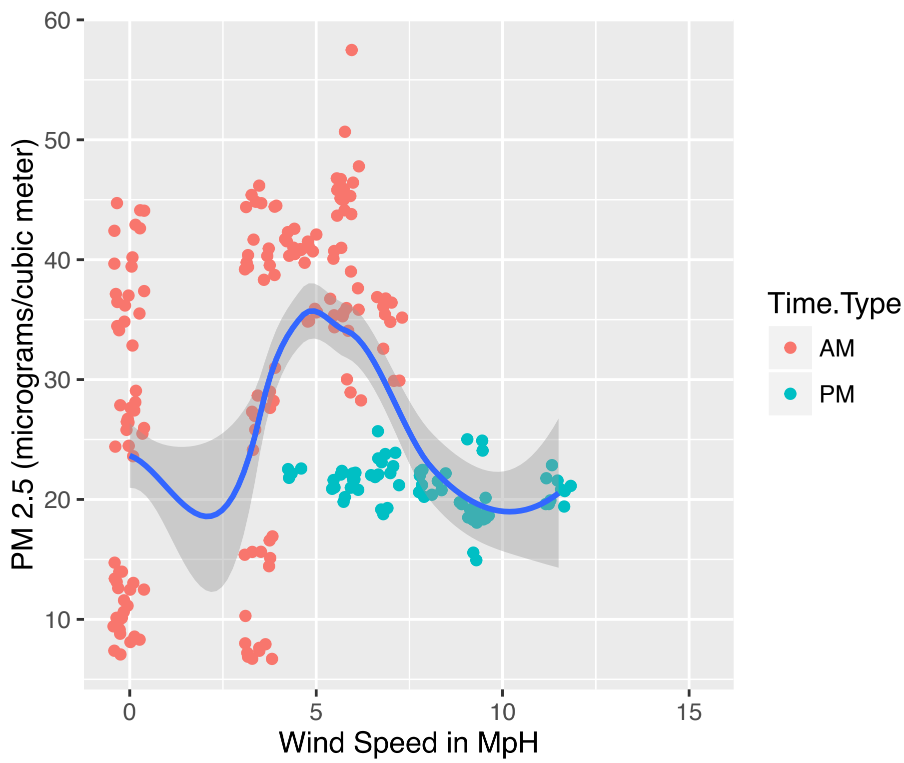

Figure 15: $PM_{2.5}$ Concentrations by Wind Speed

5.3.5 $PM_{2.5}$ and Traffic

We turn next to the relationship between traffic congestion and $PM_{2.5}$ levels. Recall from Figure 10 that we see significantly higher levels of traffic congestion in the afternoon than in the morning. However, it turns out that increased traffic congestion does not appear to be associated with higher levels of $PM_{2.5}$. In fact, observing Figure 16, there would even appear to be a correlation between high $PM_{2.5}$ concentrations and lower traffic congestion.

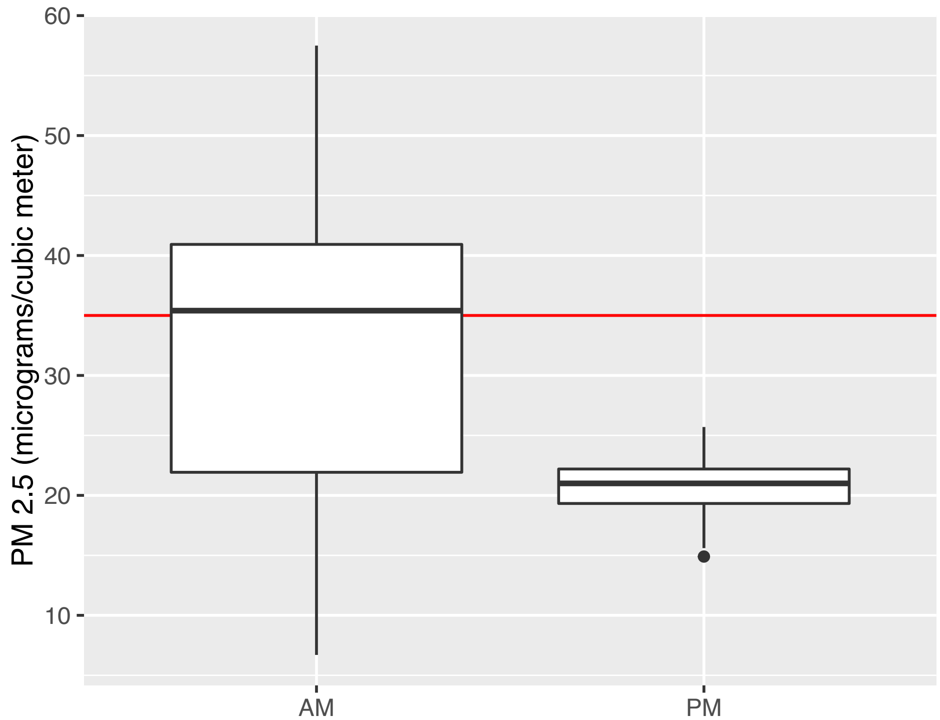

Figure 16: $PM_{2.5}$ Concentrations by Time of Day

The median concentration of the morning $PM_{2.5}$ data is actually above the 24-hour standard. However, when traffic congestion was higher, in the afternoon, even the maximum value of our $PM_{2.5}$ data is below the standard. Interestingly, the spread and variability of the morning data is significantly greater than that of the afternoon data; we will return to this observation later. It seems counterintuitive that lighter traffic congestion in the morning would cause the effects we see, so we need to take into consideration other factors at play. We turn next to temperature.

5.3.6 $PM_{2.5}$ and Temperature

We begin by comparing $PM_{2.5}$ concentrations to temperature at the time the data was collected. Figure 17 shows $PM_{2.5}$ concentrations by time of day (am and pm measurements are colored red and blue, respectively) along with their corresponding temperatures.

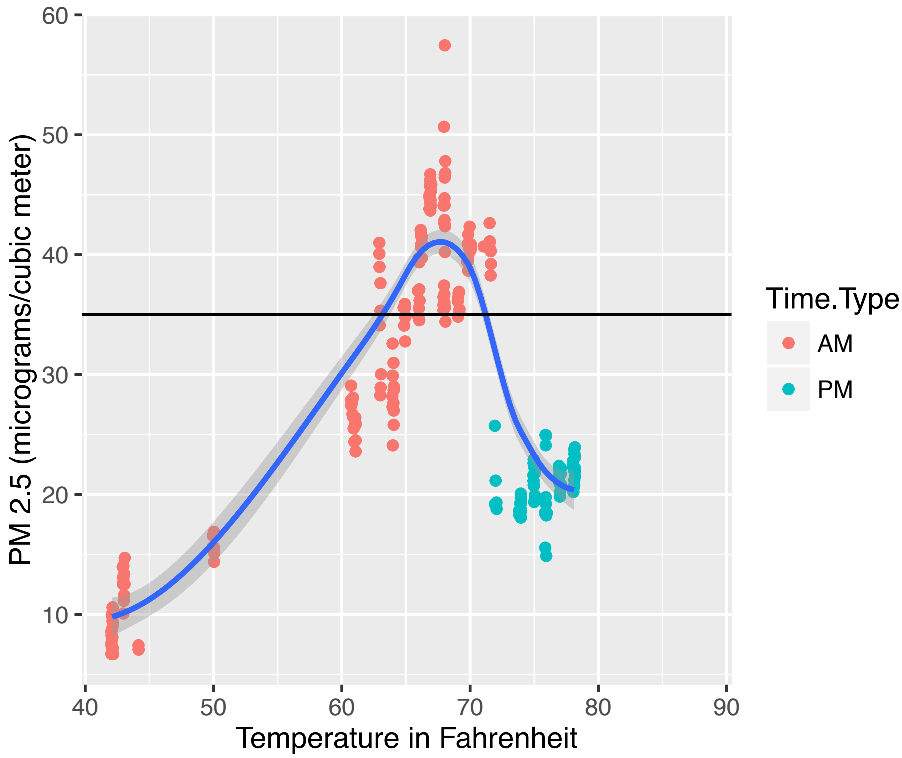

Figure 17: $PM_{2.5}$ Concentrations by Temperature

Given the shape of the regression line, it initially seems uncertain that temperature is correlated to $PM_{2.5}$ concentration. However, the crucial context of this plot is that the data points which make the curve slope downwards at the end were all collected in the afternoon. Recall that the only data points we collected which were higher than the 24-hour standard were taken in the morning. Given that the afternoon concentrations are all below the standard, we can narrow our focus to the morning data points. If we exclude the samples taken in the afternoon and focus solely on the morning concentrations, we see that $PM_{2.5}$ concentrations tend to rise as temperatures rise throughout the morning. This relationship between morning temperatures and $PM_{2.5}$ concentrations can be seen in Figure 18.

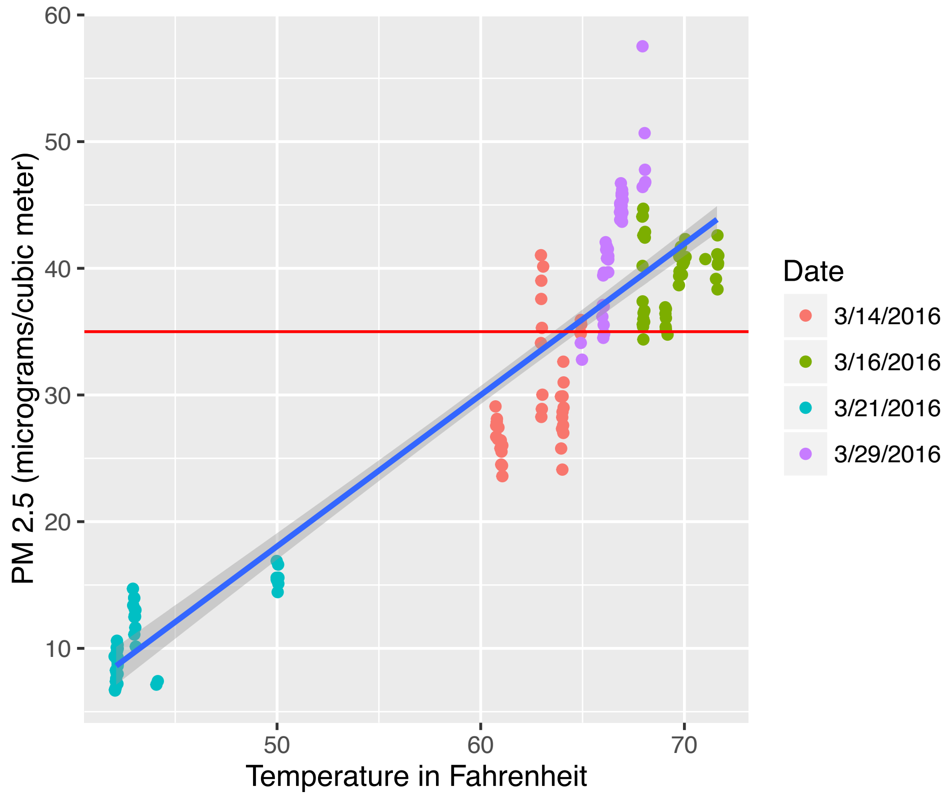

Figure 18: Morning $PM_{2.5}$ Concentrations by Temperature

Unfortunately, we were only able to sample air on one day (March 21st) that significantly differed in temperature from the others. Nonetheless, this plot would seem to imply that in the morning, higher temperatures are associated with higher concentrations of $PM_{2.5}$.

We now return to the data taken from the Park Place and Clinton Drive sites, again comparing the morning $PM_{2.5}$ concentrations to the temperatures at the time of collection. Since these samples were taken hourly rather than every five minutes, there are fewer data points. In addition, we have included data from three additional mornings (February 8th, February 10th, March 15th), two cold and one warm. These dates were selected solely on the basis of their temperatures in order to make sure that the one cold morning (March 21st) on which we sampled is in fact indicative of a trend. As it turns out, observing Figures 19 and 20, we see that the same trend (higher morning temperatures associated with higher $PM_{2.5}$ levels) is prevalent.

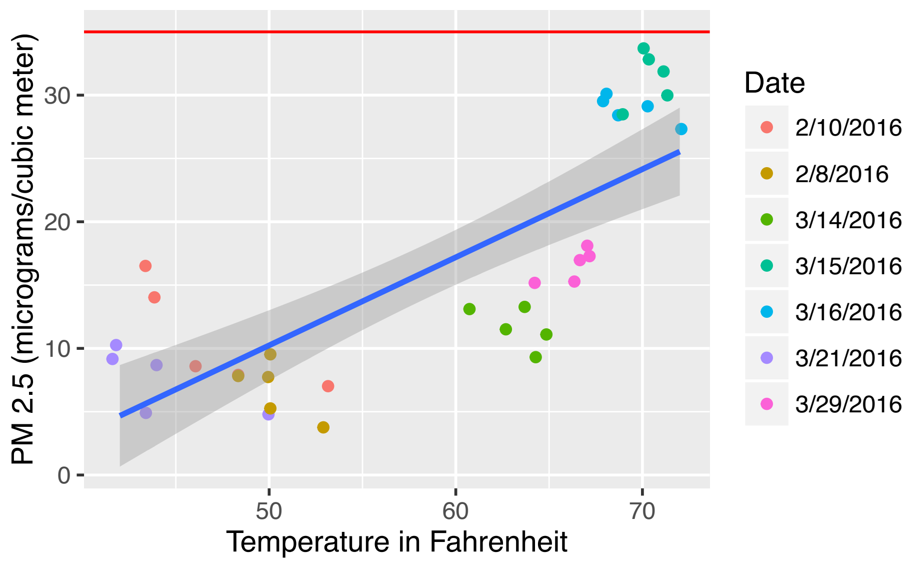

Figure 19: Park Place Morning Data

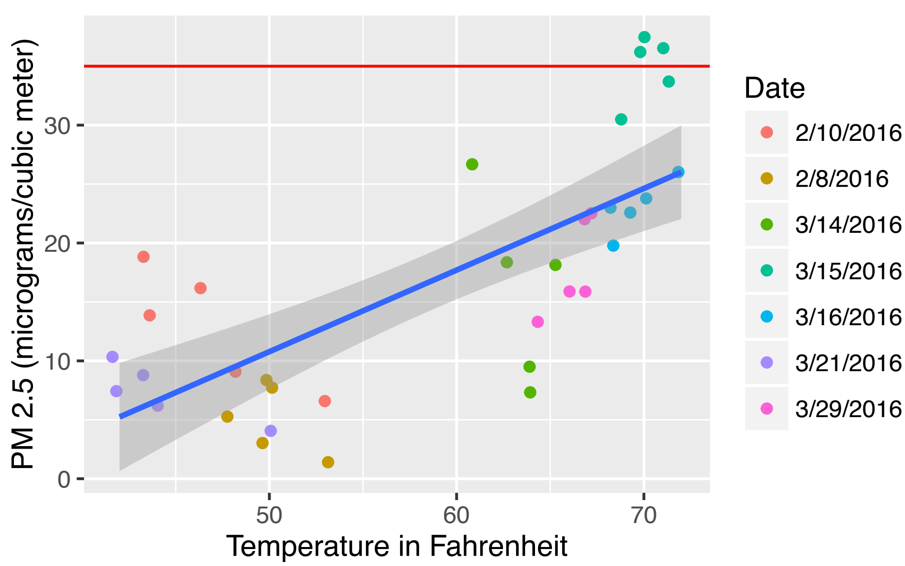

Figure 20: Clinton Drive Morning Data

These findings support our conclusion that higher morning temperatures are correlated with higher concentrations of $PM_{2.5}$.

5.3.7 $PM_{2.5}$ Variability and Trend Analysis

As we have seen, the variability of the $PM_{2.5}$ data at the Hazard Street Bridge is significantly greater in the morning than in the afternoon. It turns out that we see this exact same trend in the data at the other two sites.

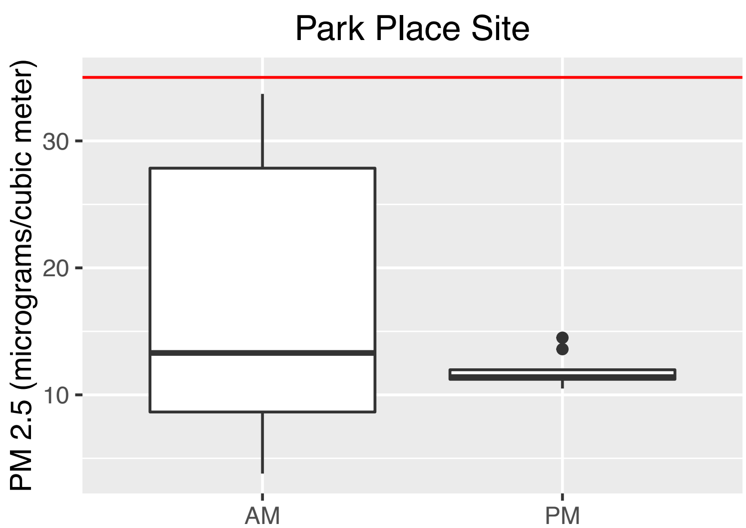

Figure 21: Park Place Concentrations by Time of Day

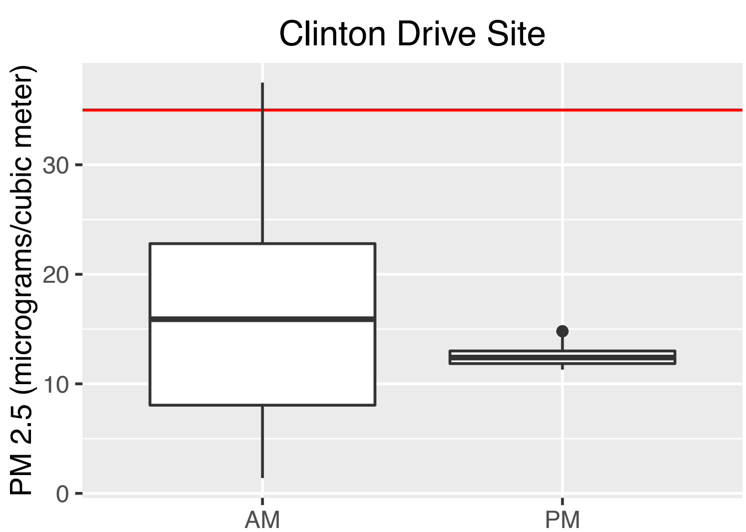

Figure 22: Clinton Drive Concentrations by Time of Day

5.3.8 $PM_{2.5}$ Takeaways

Although almost all the $PM_{2.5}$ data from these two other sites is below the 24-hour standard of 35 micrograms per cubic meter, two immediate observations agree with the data from the Hazard Street Bridge site:

- The mean and median concentrations of $PM_{2.5}$ are higher in the morning than they are in the afternoon. In addition, this is the only time we see concentrations approach (or even breach, in the case of the Hazard Street Bridge site) the 24-hour standard.

- The spread and variability of $PM_{2.5}$ concentrations at these three sites is quite high in the morning, but in the afternoon, concentrations seem to stay in a very narrow interval.

Thus, our data suggests that we should be most concerned about $PM_{2.5}$ levels on warm mornings.

6 Overcoming Challenges

A project with as many stakeholders as ours was bound to encounter some challenges, and indeed it did, the majority of which related to scheduling and equipment procurement.

Most of the initial challenges we encountered centered around which aspects of the project were necessary, and which were preferable, but optional, in order to complete the project succcessfully. An example of such an aspect was the expectation that the HART students be fully trained to operate the sampling equipment before they began sampling work. Originally, the Houston Health Departments Bureau of Pollution Control and Prevention communicated that they wished the student team to be fully versed in all aspects of the sampling process, including being able to upload the data from the equipment and learning various system functions of the equipment. However, the training required for this level of expertise was delayed due to schedule conflicts, which, in turn, delayed the start data of data collection. At this point, stakeholders reconsidered this training and decided that it was not necessary for data collection. Instead, it was determined that the student team needed only to know the rudimentary functions of the equipment (i.e., how to turn the equipment on and off) in order to successfully collect air samples at the site. Because our research timeline was relatively short, we determined that, although full training on how to operate the air sampling equipment would have provided a broader perspective and new skills for our research team, receiving such training before air sampling began would have made it difficult to complete the project within the designated time frame.

In similar fashion, our team was originally informed that we would need to arrange for the shoulder of US-59 to be closed in order to ensure the safety of the equipment. Therefore, we communicated with TxDOT repeatedly to secure an approved traffic control plan, and secured the shoulder for a three week span. More so, we reached out to numerous traffic control contractors to get a quote for the closure of the shoulder. After receiving the quotes – all of which were at a minimum of 1,000 dollars per day – it became evident that closing the shoulder would not be economically feasible. Fortunately, it also came to our attention that the sampling equipment would not be as large as we originally anticipated, so the closure of the shoulder was no longer integral. In addition, we realized that closing a shoulder would potentially impact traffic patterns and thus affect the representativeness of the data we collected, so we were happy to proceed without closing the shoulder.

Another challenge that slowed the project was the procurement of a propane generator that could power the NO_2 sampling equipment for eight hours per day. This was essential for the execution of our project, which was designed to capture the air pollution emitted from rush hour traffic in both the morning and afternoon. Unfortunately, the Bureau of Pollution Control and Prevention (henceforth called Bureau) did not have such a generator, and was not able to secure one from inside the City of Houston. In the end, Bureau staff were able to locate one, but it had to be transferred to Houston from Connecticut. The transport of this generator took approximately two weeks. Therefore, it was not until mid-March that we were able to begin sampling.

Due to the aforementioned complications, we had to deviate from our original sampling plan, which consisted of two separate sampling periods: three days in January/February and three days in late March and early April. This original sampling schedule attempted to provide a range of pollution data under different seasonal conditions, such as air moisture and temperature. However, because we started sampling in mid to late March, sampling days were selected on more arbitrary basis: when weather conditions were fair. In the end, this resulted in five sampling days, two of which only captured one of the rush hour periods of the day.

The final challenge our team experienced was technical difficulties with the sampling equipment, the majority of which occurred near the end of our sampling schedule. We used two different monitors, an NO_2 monitor and a GRIMM $PM_{2.5}$ monitor, and experienced trouble with both. The NO_2 monitor had to be connected to a generator from a long extension cord for the entirety of the sampling period. There were two instances where the cord became unplugged from the generator, which jeopardized the data. Fortunately, this never occurred for more than 10 minutes. Moreover, at the end of March, the NO_2 monitor became kinked at the capture point. While we are unsure of how this would affect the results, we decommissioned the monitor for the final two sampling days. Finally, we attempted to sample $PM_{2.5}$ data in early April, but on the day of sampling, the GRIMM sampling device would not turn on unless plugged in for charging. Thus, we had to abandon our sampling plans for April. We experienced challenges, but they should not cause us to deem our findings inconclusive. Indeed, we were still able to sufficiently characterize the air pollution in a way that more than adequately builds a foundation for future air pollution research and intervention projects.

7 Recommendations

Our data shows that air pollution at the Hazard Street Bridge site is worse than or comparable to locations across Houston that are known for having poor air quality. As such, we believe that a stationary air remediation device would be beneficial at the Hazard Street bridge site. Based on our findings, such a device should target mornings, particularly those with higher temperatures, as these conditions are associated with the highest concentrations of $PM_{2.5}$ and NO_2. However, we suggest that more data be collected in order to ensure the accuracy of our results. Such additional research would also be useful in broadening the scope for the usage of the device in certain conditions.

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