Quantifying Air Pollution at the Stamford Transportation Center

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Quantifying Air Pollution at the Stamford Transportation Center

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Table of Contents

Abstract ................................................................................................................................. 3

1. Introduction ..................................................................................................................... 3

2. Objective .......................................................................................................................... 5

3. Theory ............................................................................................................................... 5

4. Equipment ........................................................................................................................ 6

5. Experimental Methods .................................................................................................... 11
   A. Calibration of Monitor .................................................................................................. 11
   B. Deployment Location .................................................................................................. 14

6. Results and Discussion ..................................................................................................... 16
   A. Spring Run .................................................................................................................. 16
   B. Fall Run ...................................................................................................................... 20
   C. Winter Run .................................................................................................................. 21
   D. Seasonal Comparison .................................................................................................. 23
   E. Comparison to Surrounding Area ................................................................................. 26

7. Future Work and Recommendations ................................................................................ 27

8. References ........................................................................................................................ 29

9. Acknowledgements .......................................................................................................... 30

10. Appendix:
    
    A. Calibration Curve MATLAB Code
    B. Spring Run MATLAB Code
    C. Fall Run MATLAB Code
    D. Winter Run MATLAB Code
Abstract

There is a need to analyze particulate matter concentrations at the Stamford Transportation Center according to the Western Connecticut Coalition of Governments. Stamford has recently undergone rapid urbanization and large scale construction resulting in traffic congestion. Congested traffic areas in urban centers are key contributors to poor air quality. Therefore, there is a need to analyze the pollution concentrations at the bus stops near the station. Every day, hundreds of shuttles and cars idle around the Transportation Center. Thousands of passengers wait at nearby bus stops every day and can potentially be exposed to high amounts of vehicle produced pollution due to their close proximity to the road. In order to collect data, the monitor will be deployed for a two week period each season and then retrieved to analyze its data. The objective of this study is to determine the relative airborne particulate matter concentrations at the Stamford Transportation Center and compare this data to the surrounding area. It was found that the winter run had the highest particulate matter concentration readings, but overall, the average readings at the Stamford Transportation Center are lower than or very close to the surrounding area.

1. Introduction

Passenger trains are becoming a more appealing way for employees to commute to work every day. As a result, train stations are bringing in thousands of people every day. There are many benefits to public transportation such as the reduction of environmental pollution from automobiles and traffic congestion. The station is located near Downtown Stamford and the South End bringing in about 3,000 people during the morning rush each day, according to Jamie
Bastian, Associate Planner with the Western Council of Governments [14]. Annual ridership in 2016 reached 8.4 million on Metro North [1]. This makes the Stamford Train station the second busiest station after Grand Central in the entire MetroNorth system [1]. The station is close to dozens of bus stops where Greyhound, Peter Pan, CTtransit, UConn Stamford buses, and private shuttles pickup and drop off passengers every day [1]. Most current design guidelines for bus shelters do not consider the possibility of pollutant exposure [2].

Drivers inside their cars with their windows up are estimated to have low exposure to these outdoor pollutants. However, a cyclist would be exposed to the pollutants even though he is not directly contributing to this pollution. Similarly, when commuters wait at bus stops, they are not shielded by a barrier to protect them against pollutants. It is estimated that the average commuter in the United States spends about 45 minutes per day traveling to and from work [2]. A study was done examining how much air pollution passengers are exposed to at bus shelters that either faced the roadway traffic or faced away from the roadway traffic [2]. The bus shelter orientation was found to have significant impacts on the concentration readings of the four particulate matter sizes [2]. As expected, the shelters towards the roadway were observed to have higher concentrations inside the shelter than outside the shelter [2]. On the other hand, shelters that faced away from the roadway were found to have lower concentrations inside the shelters than outside of them [2]. The bus shelters at the Transportation Center face the roadway. Therefore, passengers are at risk of being exposed to high particulate matter concentrations.
2. Objective

The overall objective of the study is to conclude what time of year passengers are exposed to the highest particulate matter concentrations and how these concentrations compare to the surrounding area. The monitor must first be calibrated against another calibrated monitor to ensure similar readings. Then, the monitor will be placed at the site for three two-week periods at different times of the year. The particulate matter concentrations will be recorded and the data will be analyzed. The particulate matter concentrations from the surrounding area during the same time period will be compared. Then conclusions can be drawn. Recommendations will be made with a goal to ultimately reduce passengers’ exposure to vehicle pollution.

3. Theory

Particulate matter, also called aerosols, are fine particles that pose a severe threat to both the environment and humans when their concentrations are too high for a period of time [5]. Particulate matter is composed of a mixture of solid particles and liquid droplets that can contain molecules of carbon, hydrocarbons, and other various materials [2]. Particulate matter is one of the six common air pollutants that are regulated by the National Ambient Air Quality Standards as part of the Clean Air Act of 1990 [4]. There are generally three classifications of particulate matter based on the aerodynamic diameter of each particle: PM$_{10}$, PM$_{2.5}$, and PM$_{1.0}$ [5]. The first type of particulate matter have particles with diameters about 10 micrometers wide, the second have diameters about 2.5 micrometers, and the last have particles with smaller diameters [5]. These small particles are easily inhaled into the lungs and can occasionally travel into the bloodstream [5]. Since 2.5 micrometer particles are so small, they bypass many of the body’s
natural defense mechanisms. Some aerosols are carcinogenic and can lead to many long term health effects such as heart and lung disease [5]. The fine particles also lead to reduced visibility. The EPA currently regulates particles smaller than 10 micrometers. According to the EPA, fine particle concentrations are highest in the Eastern United States from July to September when sulfur dioxide emissions readily turn into sulfates [9]. On the other hand, fine particle concentrations are highest from October through December in the Western United States due to nitrates formed in colder weather [9]. This observation will be tested in this study which takes place in the Eastern United States.

Passenger trucks, cars, and shuttles are major sources of air pollution. Soot produced from vehicle exhaust is a type of particulate matter. Exhaust from diesel vehicles also contributes to the particulate matter pollution. According to the Union of Concerned Scientists, trucks and buses make up only about five percent of all vehicles, however, they generate more than twenty-five percent of global warming emissions from the transportation section [6]. Volatile organic compounds (VOCs) are also emitted from tailpipes and eventually get converted into particulate matter through chemical reactions [6]. Robinson, an engineer at Carnegie Mellon University, measured the amount of PM that is produced from VOCs and found that it is ten times as great as what was originally released from the tailpipe itself [8].

4. Equipment

The equipment used in this study include the TSI DustTrak II Aerosol Monitor Model 8530 and the TSI Environmental Enclosure 8535. The current DustTrak monitor is the desktop version and is a Class I laser-based instrument. The main accessories used in this study include
the zero filter, the USB cable, conductive tubing, the external pump kit, the external pump power cable, the external pump flow tube, and the exhaust adapter. The inlet allows the monitor to be connected to the water bottle trap in the Environmental Enclosure by the conductive tubing. The On/Off button is located right above the touchscreen on the device. On the right side of the monitor is the power inlet and on the left side is the USB inlet. On the back of the monitor is where the filter can be accessed and the internal batteries can be inserted. The aerosol monitor is always placed within the Environmental Enclosure during testing to ensure the monitor is protected from the elements.

The DustTrak can be supplied power by either batteries or by an external AC power source. The batteries have a short life span and only last about six hours. Therefore, an external power source is used in this study and the monitor is plugged into a power outlet to ensure that it can run continuously for two weeks. The external pump needs to be connected to the monitor or the monitor cannot take samples. The pump is designed to run continuously for a long period of time. To connect the external pump to the DustTrak, there are two connections that are made. The first is the power connection and the second is the external pump connection to the exhaust adapter. Inside the external pump are HEPA filters and the pump. The power connector must be securely attached as it can easily be disconnected due to vibrational movement during sampling. The exhaust pump is powered off of the DustTrak monitor and does not need to be powered itself. The additional port on the external pump is where the pump exhaust exits.
Figure 1: DustTrak monitor front view

Figure 2: Environmental Enclosure exterior
Figure 3: Internal view of Environmental Enclosure with DustTrak Monitor

Figure 4: Internal view of Environmental Enclosure with DustTrak monitor connected to the water bottle trap
An impactor of $PM_{2.5}$ was installed in the inlet of the DustTrak. This is used to create a size range of particles that can enter the instrument. Therefore, small aerosols with diameters of about 2.5 microns or smaller can enter the monitor. The instrument runs at 3.0 L/min, the factory default settings, for the impactors to achieve the most accurate particulate matter size. 2.0 L/min of the total flow of 3.0 L/min is used to measure aerosol flow. The remaining 1.0 L/min is used for sheath flow. The internal flowmeter controls the flow rate to ± 5% of the factory setpoint. The monitor can be connected to a computer by USB to download the sampling data. The data can be imported to the computer for analysis. The TSI TrakPro software was used to create graphs, generate reports, and analyze data.

Figure 5: TSI TrakPro Software interface
The instrument needs to be calibrated to zero every time it is used. The Zero Cal filter mechanism is attached to the inlet at the beginning of each run. To access the zero calibration setting, “Setup” is selected from the bottom menu of the monitor. Then, “Zero Cal” is selected. The zeroing process takes about thirty seconds and the monitor states “Zero Cal Complete” when done. The instrument is zeroed before every run.

![Image of calibration process](image)

Figure 6: The screen showing the zero calibration process

5. Experimental Methods

A. Calibration of Monitor

The monitor has not been factory calibrated since June 2016 as displayed in Figure 7. Therefore, it is essential to verify that the data the monitor collects is still valid. In order to calibrate the monitor, the device was placed at the McAuliffe Park CT DEEP center in East Hartford from January 8th, 2019 to January 22nd, 2019. The DustTrak ran for fifteen days alongside the TAPI 640X monitor also measuring particulate matter 2.5 concentrations. A recording was taken every minute for a total of 20,784 data points. The results from both monitors were then compared. The data was plotted against each other in a one-to-one plot. If both monitors read the same concentrations, a straight line of $y=1 \times x$ would result. However, the
resulting equation of the line was \( y = 0.3018x + 1.5904 \). In this equation, the \( x \)-variable represents the raw DustTrak data where the \( y \)-variable represents the calibrated particulate matter concentration based on the readings of the TAPI 640X monitor. This equation can now be used to find the calibrated value of the DustTrak monitor’s readings.

![Monitor setup screen](image)

Figure 7: The monitor has not been calibrated since 2016 so manual calibration is necessary.

![Monitor on roof](image)

Figure 8: The DustTrak monitor on the roof of the DEEP center in East Hartford
The data was compared in two ways. The first was a minute-by-minute comparison between the DustTrak data and the DEEP center data. A linear regression line was plotted and is displayed below. This resulted in an $R^2$ value of 0.9155.

![Figure 9: A one-to-one plot of the DustTrak data versus DEEP Center data on a minute basis](image)

Then an hourly comparison was done and this resulted in a linear regression with an $R^2$ value of 0.9293. This regression line has an equation equal to $y=0.3018x + 1.5904$ and will be used to calibrate the data that the DustTrak monitor collects.
B. Deployment Location

After calibration of the monitor, the next step was determining the deployment location of the monitor. Deployment location of the monitor was essential to the project. An initial site assessment was conducted on February 25th, 2019. The goal was to place the monitor in an area that was close enough to traffic, but far enough away so that it was not in plain sight. Another concern was locking the monitor in place so it could not be stolen or damaged. The monitor has to be deployed in an accessible place so that it could be left and retrieved after a two-week period. The Environmental Enclosure also needs to be plugged into a power source to run continuously for two weeks. These conditions limited the potential locations for the placement of the enclosure at the Stamford Train Station.
It was decided that the monitor would be placed on top of a bus shelter under the I-95 overpass directly adjacent to the train station. This shuttle area is between North and South State Streets and next to Washington Boulevard. In this area, buses frequently idle potentially exposing passengers to particulate matter. The monitor was connected with a bike lock and two Master Locks onto a beam on top of the shelter. The monitor can be plugged into the outlet on top of the shelter. The top of the bus shelter can only be reached from an 8-foot ladder. Therefore, this location is ideal as it provides a power supply and is not easily accessible to the average passenger.

Figure 11: Monitor Placement under the I-95 overpass
6. Results and Discussion

A. Spring Run

The first deployment of the monitor was from April 25th, 2019 to May 10th, 2019, and the monitor began running at 8:59 am. It logged a concentration reading every minute for two
weeks for a total of 21,600 data points. The DustTrak records in units of \( mg/m^3 \) but the data was converted to \( \mu g/m^3 \). Data was retrieved from the monitor using the TrakPro software. Raw data was converted using the equation of the calibration line. The average reading was 5.00 \( \mu g/m^3 \).

There were several unexplained, high readings recorded in this run. For example, the maximum reading was 955.28 \( \mu g/m^3 \) on 05/01/19 at 21:01:46. This high reading could be accurate or the monitor could have made an error logging the data point; therefore, this anomaly will be compared to other runs. Literature reports similar situations when using the DustTrak where there are “sudden artefact jumps in PM concentration” [12]. When the raw data jumps to a large value, it does not generally increase gradually. Rather, it increases suddenly in only a few minutes. When the monitor jumped to the calibrated value of 955.28 \( \mu g/m^3 \), or the raw data value of 3160 \( \mu g/m^3 \), it increased substantially in only 2 minutes and then returned down to normal levels. It is hard to conclude if there was a reason for the sudden increase or if this was an error in data logging by the monitor.

Table 1: Sudden jump in PM concentration, bolded font used to indicate abnormal data collected.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Raw Data (( \mu g/m^3 ))</th>
<th>Calibrated Data (( \mu g/m^3 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/1/19</td>
<td>20:58:46</td>
<td>8</td>
<td>4.0048</td>
</tr>
<tr>
<td>5/1/19</td>
<td>20:59:46</td>
<td>7</td>
<td>3.703</td>
</tr>
<tr>
<td>5/1/19</td>
<td>21:00:46</td>
<td>1150</td>
<td>348.66</td>
</tr>
<tr>
<td>5/1/19</td>
<td>21:01:46</td>
<td><strong>3160</strong></td>
<td><strong>955.28</strong></td>
</tr>
<tr>
<td>5/1/19</td>
<td>21:02:46</td>
<td>99</td>
<td>31.47</td>
</tr>
<tr>
<td>5/1/19</td>
<td>21:03:46</td>
<td>48</td>
<td>16.08</td>
</tr>
<tr>
<td>5/1/19</td>
<td>21:04:46</td>
<td>12</td>
<td>5.21</td>
</tr>
</tbody>
</table>
To make the data more accurate, statistical outliers will be removed. In this study, an outlier is defined as a value three standard deviations from the mean. First, the overall mean and standard deviation were calculated in MATLAB. Then, it was determined which points fell outside the range of three standard deviations from the mean and these points were removed from the data set. There are 135 outliers that were removed from the first data set. The graph on the left displays the calibrated data collected over time in minutes. The graph on the right is the calibrated data without the statistical outliers. Note that the y-axis bounds are decreased once these points are removed.

![Graph](image)

Figure 14: Comparison of particulate matter plots with and without outliers for Spring Run

Another error was several negative raw data points were recorded from the DustTrak. This is impossible as particulate matter concentration cannot drop below zero. Literature also cites this error and recommends having the monitor be sent for a factory reset [12]. After calibration, all values are positive, solving the negative concentration issue.
A MATLAB code was written to identify the trends during the first run. The morning rush hour for this study is from 7 am to 9 am. The evening rush hour is from 4:30 pm to 7 pm. The average weekend and weekday values were also examined. In this run, there are two weekends that occur within the time period. The first weekend had an average concentration of 2.43 $\mu g/m^3$, while the second weekend had an average concentration of 5.41 $\mu g/m^3$. It is noted that the second weekend had much higher concentrations than the first weekend. This could be because a minor holiday occurs during the second weekend and more passengers could be traveling during this time. A comparison between day and night was also done. Day is defined as 7am to 7pm and night is defined as 7pm to 7am. The overall average of the entire two week period was also calculated. The results are displayed in Table 2 below.

Table 2: Spring Run average concentrations

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Concentration ($\mu g/m^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Morning Rush Hour (7-9am)</td>
<td>4.49</td>
</tr>
<tr>
<td>Avg. Evening Rush Hour (4:30-7pm)</td>
<td>3.56</td>
</tr>
<tr>
<td>Avg. Weekend (Sat-Sun)</td>
<td>3.90</td>
</tr>
<tr>
<td>Avg. Weekday (Mon-Fri)</td>
<td>4.56</td>
</tr>
<tr>
<td>Avg. Day (7am-7pm)</td>
<td>4.28</td>
</tr>
<tr>
<td>Avg. Night (7pm-7am)</td>
<td>4.48</td>
</tr>
<tr>
<td>Overall Average</td>
<td>4.38</td>
</tr>
</tbody>
</table>

Weekday concentrations are higher than the weekend concentrations since less commuters are traveling on the weekend than during the week. The data in this set is relatively close to one another; there is not a large range of values once the outliers are removed.
B. Fall Run

Unfortunately, due to construction work on the bus shelters over the summer, a summer test could not be completed. The next test was run from November 11th, 2019 to November 25th, 2019. Similarly for this dataset, there are large spikes before the outliers are removed. These jumps were removed as done previously. There are 63 outliers in the Fall Run which is fewer than the Spring Run. The overall average is higher than the spring run. The average trends were found using MATLAB code and are displayed in Table 3 below. As in the previous run, the weekend reported lower concentrations than the weekday. However in this run, there is a larger difference between the weekend and weekday. There is also a large difference between the average morning evening rush hours with the morning being higher.

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Concentration (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Morning Rush Hour (7-9am)</td>
<td>6.32</td>
</tr>
<tr>
<td>Avg Evening Rush Hour (430-7pm)</td>
<td>4.84</td>
</tr>
<tr>
<td>Avg Weekend</td>
<td>3.30</td>
</tr>
<tr>
<td>Avg Weekday</td>
<td>6.38</td>
</tr>
<tr>
<td>Avg Day (7am-7pm)</td>
<td>5.30</td>
</tr>
<tr>
<td>Avg Night (7pm to 7am)</td>
<td>5.81</td>
</tr>
<tr>
<td>Overall Average</td>
<td>5.55</td>
</tr>
</tbody>
</table>
C. Winter Run

The next test was run from January 6th, 2020 to January 19th, 2020. This dataset has significantly more outliers than the previous runs, with 373 outliers removed. The average trends were calculated from the MATLAB code and are displayed in Table 4 below. Similarly, the average weekday concentrations are higher than the average weekend concentrations. In the same trend, the morning rush hour is higher than the evening rush hour.
Table 4: Winter run average concentrations

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Concentration (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Morning Rush Hour (7-9am)</td>
<td>7.97</td>
</tr>
<tr>
<td>Avg Evening Rush Hour (4:30-7pm)</td>
<td>6.63</td>
</tr>
<tr>
<td>Avg Weekend</td>
<td>6.17</td>
</tr>
<tr>
<td>Avg Weekday</td>
<td>7.46</td>
</tr>
<tr>
<td>Avg Day (7am-7pm)</td>
<td>6.45</td>
</tr>
<tr>
<td>Avg Night (7pm to 7am)</td>
<td>7.78</td>
</tr>
<tr>
<td>Overall Average</td>
<td>7.11</td>
</tr>
</tbody>
</table>

Figure 16: Particulate matter concentrations over time in minutes with statistical outliers removed for Winter Run
### Seasonal Comparison

Table 5: Comparison of Seasonal Runs

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Spring Concentration (μg/m³)</th>
<th>Fall Concentration (μg/m³)</th>
<th>Winter Concentration (μg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Morning Rush Hour (7-9am)</td>
<td>4.49</td>
<td>6.32</td>
<td>7.97</td>
</tr>
<tr>
<td>Avg. Evening Rush Hour (4:30-7pm)</td>
<td>3.56</td>
<td>4.84</td>
<td>6.63</td>
</tr>
<tr>
<td>Avg. Weekend (Sat-Sun)</td>
<td>3.90</td>
<td>3.30</td>
<td>6.17</td>
</tr>
<tr>
<td>Avg. Weekday (Mon-Fri)</td>
<td>4.56</td>
<td>6.38</td>
<td>7.46</td>
</tr>
<tr>
<td>Avg. Day (7am-7pm)</td>
<td>4.28</td>
<td>5.30</td>
<td>6.45</td>
</tr>
<tr>
<td>Avg. Night (7pm-7am)</td>
<td>4.48</td>
<td>5.81</td>
<td>7.78</td>
</tr>
<tr>
<td>Overall Average</td>
<td>4.38</td>
<td>5.55</td>
<td>7.11</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>12.76</td>
<td>5.70</td>
<td>4.27</td>
</tr>
<tr>
<td>Number of Statistical Outliers Removed</td>
<td>135</td>
<td>63</td>
<td>373</td>
</tr>
<tr>
<td>Total Number of Data Points</td>
<td>21,600</td>
<td>21,600</td>
<td>18,674</td>
</tr>
</tbody>
</table>

As shown by the data, it can be concluded that the winter run had the highest particulate matter concentrations. The data consistently follows this trend in all categories analyzed, except for the average weekend in the fall. Fall is a windy season which can also contribute to this discrepancy. In all runs, the morning hours had a higher concentration than the evening hours. The weekday concentrations were always higher than the weekend concentrations. Lastly, the day concentrations were lower than the night concentrations. This trend is expected as generally cold air settles to the ground with the lack of sun at night [15]. Particulate matter can accumulate on the ground and cause an increase in concentrations [15]. The standard deviation in the first run was significantly higher than the other two. There is no clear reason for this. Box and whisker plots were created to compare the runs in the different time categories. The horizontal
The red line indicates the median. The bottom and top edges of the box represent the 25th and 75th percentiles. The whiskers are about 99.3 percent coverage if the data are normally distributed.

Figure 17: Box and whisker plot comparing spring, fall, and winter morning rush hour data

Figure 18: Box and whisker plot comparing spring, fall, and winter evening rush hour data
Figure 19: Box and whisker plot comparing spring, fall, and winter day time data

Figure 20: Box and whisker plot comparing spring, fall, and winter night time data
E. Comparison to Surrounding Areas

Concentrations from the surrounding area are compared to conclude if those recorded at the Stamford Transportation Center are abnormally high. Air Quality System (AQS) daily particulate matter data is available from the EPA. The comparison monitor is located at the Roosevelt School in Bridgeport, Connecticut which is about 22 miles northeast from the train station. One value is reported per day at the site. The average concentration during the same time periods was found from the AQS data and is reported in the fourth column of Table 6 below. The average DustTrak data is also reported in column three for comparison. The DustTrak reported lower concentrations for the spring and fall runs, but similar results for the winter run.

Figure 21: Box and whisker plot comparing spring, fall, and winter overall data
Table 6: Comparison of AQS data and DustTrak data during the same time periods

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Date Range</th>
<th>Avg Conc from DustTrak (μg/m³)</th>
<th>Avg Conc from AQS (μg/m³) [16]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>04/25/19 - 05/10/19</td>
<td>4.38</td>
<td>6.3</td>
</tr>
<tr>
<td>2</td>
<td>11/11/19 - 11/25/19</td>
<td>5.55</td>
<td>8.0</td>
</tr>
<tr>
<td>3</td>
<td>01/06/19 - 01/19/19</td>
<td>7.11</td>
<td>7.7</td>
</tr>
</tbody>
</table>

The EPA has established categories for “good”, “moderate”, “unhealthy for sensitive groups”, “unhealthy”, and “very unhealthy” particulate matter 2.5 concentrations. The “good” range is from 0.0 to 15.4 μg/m³ [3]. Therefore, all averages fall within this range. This area can be deemed as good on average. Not all individual data points fall in this range, however, all the averages do.

7. Future Work and Recommendations

A private shuttle study was completed in 2016 by the Western Connecticut Council of Governments to assess various aspects of the Transportation Center. The first part of the study included outreach to employers and shuttle riders. A similar effort should be completed again in order to educate both the riders and the businesses about the potential exposure to particulate matter at the bus stops. Although riding the bus is more environmentally friendly than driving oneself, pollutant awareness is needed. Privately funded shuttles allow a competitive advantage to employees and customers, but come with added risks. According to the study, most shuttle trips are two miles or less [14]. The main recommendations that the 2016 study proposed were shuttle consolidation scenarios, North State Street transit prioritization, improved passenger amenities, and CTTransit optimization. Passengers should be encouraged to ride on CTTransit.
buses to reduce private shuttles, even though this can add time delays. Screens should be added to the area announcing the arrival of these shuttles as many are not familiar with the CTTransit routes and options. This feature may encourage passengers to ride an earlier shuttle, reducing the amount of time they spend outside. A private shuttle provides direct service whereas the CTTransit buses have more stops creating slower travel times with less frequent service to the Transportation Center. Additionally, CTTransit rides come at a cost where private shuttles are paid for by the employers. One recommendation is for companies to pay for public bus passes instead of providing their own private shuttle. On a different note, safety is a large factor at the bus stops. Many riders “frequently dart in front of shuttles to board” [14]. By reducing the number of shuttles, less buses will be present at a given time, decreasing feelings of chaos. Multiple shuttles can also be consolidated and can make two or more stops instead of a direct service as most private shuttles are never full. Despite the average particulate matter concentrations falling within the “good” range by EPA Guidelines [3], measures should be taken to reduce potential passenger exposure.
8. References


9. Acknowledgements

I would like to thank Kristina Wagstrom for her advice and guidance throughout this project. I would also like to thank Jamie Bastian and Francis Pickering from the Western Council of Governments, Michele Chaffee from Connecticut Department of Energy and Environmental Protection, and Jason Falcetta from Fusco Property Management at the Stamford Transportation Center.
function DustTrakvsDeep()

DEEPdata = 'DEEPdata.csv';
deepe = dlmread(DEEPdata, ',', [1, 1, 20784, 1]);
%x=length(deepe);

dusttrak = 'DustTrakdata.csv';
DT = dlmread(dusttrak, ',', [1, 4, 20784, 4]);
%y=length(DT);

deep2=zeros(346,1);
DT2=zeros(346,1);
sum=0;
sum2=0;

for i=1:346 %deep/60 = 346 hrs
    j=60*i; %mins
    for k=(j-59):j %mins in the i hour
        sum=sum+deep(k);
    end
    av=sum/60;
    deep2(i)=av;
    av=0;
    sum=0;
end

for i=1:(346) %DT/60 = 346
    j=60*i;
    for k=(j-59):j
        sum2=sum2+DT(k);
    end
    av2=sum2/60;
    DT2(i)=av2;
    av2=0;
    sum2=0;
end

p = polyfit(DT2,deep2,1);
disp(p)
%f=polyval(p,DT2);
%Bbar=mean(deep2);
%SStot= sum((deep2-Bbar).^2);
%SSreg= sum((f-Bbar).^2);
%SSres= sum((deep2-f).^2);
%R2= 1 - SSres/SStot
%R=corrcoef(DT2,deep2);
%Rsq=R(1,2).^2

a = zeros(346,1);

for i = 1:346
a(i) = 0.3018*DT2(i)+1.5904; %line of best fit
end

figure(1)
scatter(DT, deep)
xlabel('DustTrak Monitor Data')
ylabel('DEEP Center Data')
title('1:1 Plot of DEEP Center vs. DustTrak Monitor (per minute) in ug/m3')

figure(2)
scatter(DT2, deep2)
hold on
plot(DT2,a)
hold off
xlabel('DustTrak Monitor Data')
xlim([0 90])
ylabel('DEEP Center Data')
title('1:1 Plot of DEEP Center vs. DustTrak Monitor (per hour average) ug/m3')
legend({'data points', 'linear regression'},'Location','northwest')
end

0.3018    1.5904
function DustTrak4_25()

Run4_25='DustTrakRun425.csv';
Concentrations = dlmread(Run4_25, ',', [1,3,21600,3]);
Date = dlmread(Run4_25, ',', [1,5,21600,5]);
Time = dlmread(Run4_25, ',', [1,4,21600,4]);
CalibratedVal= zeros(1,21600);
MorningRush=zeros(1,21600);
EveningRush=zeros(1,21600);
Day=zeros(1,21600);
Night=zeros(1,21600);
averageMorningRush=0;
averageEveningRush=0;
averageWeekend=0;
averageWeekday=0;
averageNight=0;
averageOverall=0;
newAverage=0;
k=0;

for i = 1:21600
    CalibratedVal(i) = .3018*(Concentrations(i))+1.5904;
end

figure(1)
plot(CalibratedVal)
xlabel('Time')
ylabel('Concentration ug/m3')
ylim([0 400])
title('Run 1 Spring DustTrak Data')

for q=1:21600
    averageOverall=averageOverall+CalibratedVal(q);
end
averageOverall = averageOverall/21600;
display(averageOverall);

B=std(CalibratedVal);
newCalibratedVal = zeros(1,21465); %this removes 135 outliers
newtime=zeros(1,21465);
newdate=zeros(1,21465);
count = 1;
for m=1:21600
    if CalibratedVal(m) < (averageOverall+3*B) &
    & CalibratedVal(m) > (averageOverall-3*B)
        newCalibratedVal(count)=CalibratedVal(m);
        newtime(count) = Time(m);
        newdate(count) = Date(m);
        count=count+1;
    end
end
%len=0; used to calculate the length that newCal value should be
%for r=1:21465
%    if newCalibratedVal(r) ~= 0
%        len=len+1;
%    end
%end
%disp(len)

for j=1:21465
    if newtime(j) > 070000 && newtime(j) < 090000
        k=k+1;
        MorningRush(k)=newCalibratedVal(j);
    end
end
averageMorningRush = sum(MorningRush)/k;
MorningRush2=MorningRush(1:k);
display(averageMorningRush);

k=0;
for h=1:21465
    if newtime(h) > 163000 && newtime(h) < 190000
        k=k+1;
        EveningRush(k)=newCalibratedVal(h);
    end
end
averageEveningRush = sum(EveningRush)/k;
EveningRush2=EveningRush(1:k);
display(averageEveningRush);

k=0;
Weekend=zeros(1,21465);
for l=1:21465
    if newdate(l)==42719 || newdate(l)==42819 || newdate(l)==50419 ||
        newdate(l)==50519
        k=k+1;
        Weekend(k)=newCalibratedVal(l);
    end
end
averageWeekend=sum(Weekend)/k;
Weekend2=Weekend(1:k);
display(averageWeekend);

Weekday=zeros(1,21465);
k=0;
for m=1:21465
    if newdate(m)==42719 && newdate(m)==42819 && newdate(m)==50419 &&
        newdate(m)==50519
        k=k+1;
        Weekday(k)=newCalibratedVal(m);
    end
end
averageWeekday=sum(Weekday)/k;
Weekday2=Weekday(1:k);
display(averageWeekday);

k=0;
for n=1:21465
    if newtime(n) > 070000 && newtime(n) < 190000
        k=k+1;
        Day(k)=newCalibratedVal(n);
    end
end

averageDay = sum(Day)/k;
Day2=Day(1:k);
display(averageDay);

k=0;
for p=1:21465
    if newtime(p) < 070000 || newtime(p) > 190000
        k=k+1;
        Night(k)=newCalibratedVal(p);
    end
end

averageNight = sum(Night)/k;
Night2=Night(1:k);
display(averageNight);

newAverage=mean(newCalibratedVal);
display(newAverage);

figure(2)
plot(newCalibratedVal)
ylim([0 60])
title('Run 1 without Stastical Outliers')
xlabel('Time')
ylabel('Concentration ug/m3')

g = [ones(size(MorningRush2)), 2*ones(size(EveningRush2)),
     3*ones(size(Day2)), 4*ones(size(Night2)),
     5*ones(size(newCalibratedVal))];
figure(3)
boxplot([MorningRush2, EveningRush2, Day2, Night2,
       newCalibratedVal],g,'Notch', 'on', 'Labels',
       {'MorningRush', 'EveningRush', 'Day', 'Night', 'Overall'})
xlabel('Time Period')
ylabel('Concentration ug/m3')
title('Box and Whisker Plot for Spring Run 1')
end

averageOverall =

    5.0021
averageMorningRush =
  4.4886

averageEveningRush =
  3.5572

averageWeekend =
  3.9021

averageWeekday =
  4.5560

averageDay =
  4.2818

averageNight =
  4.4806

newAverage =
  4.3806
function DustTrak11_11()
Run11_11='DustTrakRun1111.csv';
Concentrations = dlmread(Run11_11,',,',[1,3,21600,3]);
Date= dlmread(Run11_11,',,',[1,8,21600,8]);
Time = dlmread(Run11_11,',,',[1,7,21600,7]);
CalibratedVal= zeros(1,21600);
MorningRush=zeros(1,21600);
EveningRush=zeros(1,21600);
Day=zeros(1,21600);
Night=zeros(1,21600);
averageMorningRush=0;
averageEveningRush=0;
averageWeekend=0;
averageWeekday=0;
averageDay=0;
averageNight=0;
averageOverall=0;
newAverage=0;
k=0;

for i = 1:21600
    CalibratedVal(i) = 0.3018*(Concentrations(i))+1.5904;
end

figure(4)
plot(CalibratedVal)
xlabel('Time')
ylabel('Concentration ug/m3')
ylim([0 400])
title('Run 2 Fall DustTrak Data')

averageOverall=mean(CalibratedVal);
display(averageOverall);

B=std(CalibratedVal);
display(B)
newCalibratedVal = zeros(1,21537);
newtime=zeros(1,21537);
newdate=zeros(1,21537);
count = 1;
for m=1:21600 %this removes 63 outliers
    if CalibratedVal(m) < (averageOverall+3*B) && CalibratedVal(m) > (averageOverall-3*B)
        newCalibratedVal(count)=CalibratedVal(m);
        newtime(count) = Time(m);
        newdate(count) = Date(m);
        count=count+1;
    end
end

%len=0; used to calculate the length that newCal value should be
%for r=1:21600
%    if newCalibratedVal(r)~=0
%        len=len+1;
%    end
%end
%disp(len)

for j=1:21537
    if newtime(j) > 70000 && newtime(j) < 90000
        k=k+1;
        MorningRush(k)=newCalibratedVal(j);
    end
end
averageMorningRush = sum(MorningRush)/k;
MorningRush2=MorningRush(1:k);
display(averageMorningRush);
%display(MorningRush(1:15))
%display(MorningRush2)

k=0;
for h=1:21537
    if newtime(h) > 163000 && newtime(h) < 190000
        k=k+1;
        EveningRush(k)=newCalibratedVal(h);
    end
end
averageEveningRush = sum(EveningRush)/k;
EveningRush2=EveningRush(1:k);
display(averageEveningRush);

Weekend=zeros(1,21537);
for l=1:21537
    if newdate(l)==111619 || newdate(l)==111719 || newdate(l)==112319
        k=k+1;
        Weekend(k)=newCalibratedVal(l);
    end
end
averageWeekend=sum(Weekend)/k;
Weekend2=Weekend(1:k);
display(averageWeekend);

Weekday=zeros(1,21537);
k=0;
for m=1:21537
    if newdate(m)==111619 && newdate(m)==111719 && newdate(m)==112319
        k=k+1;
        Weekday(k)=newCalibratedVal(m);
    end
end
averageWeekday=sum(Weekday)/k;
Weekday2=Weekday(1:k);
display(averageWeekday);

k=0;
for n=1:21537
    if newtime(n) > 070000 && newtime(n) < 190000
        k=k+1;
        Day(k)=newCalibratedVal(n);
    end
end
averageDay = sum(Day)/k;
Day2=Day(1:k);
display(averageDay);

k=0;
for p=1:21537
    if newtime(p) < 070000 || newtime(p) > 190000
        k=k+1;
        Night(k)=newCalibratedVal(p);
    end
end
averageNight = sum(Night)/k;
Night2=Night(1:k);
display(averageNight);

newAverage = mean(newCalibratedVal);
display(newAverage);

figure(5)
plot(newCalibratedVal)
ylim([0 60])
title('Run 2 without Stastical Outliers')
xlabel('Time')
ylabel('Concentration ug/m3')

% g = [ones(size(MorningRush2)), 2*ones(size(EveningRush2)),
%      3*ones(size(Day2)), 4*ones(size(Night2)),
%      5*ones(size(newCalibratedVal))];
figure(6)
boxplot([MorningRush2, EveningRush2, Day2, Night2,
        newCalibratedVal],g,'Notch', 'on', 'Labels',
        {'MorningRush', 'EveningRush', 'Day', 'Night', 'Overall'})
xlabel('Time Period')
ylabel('Concentration ug/m3')
title('Box and Whisker Plot for Fall Run 2')
end

averageOverall =

5.6741
\[ B = 5.7025 \]

\[ \text{averageMorningRush} = 6.3151 \]

\[ \text{averageEveningRush} = 4.8413 \]

\[ \text{averageWeekend} = 3.2993 \]

\[ \text{averageWeekday} = 6.3772 \]

\[ \text{averageDay} = 5.3020 \]

\[ \text{averageNight} = 5.8060 \]

\[ \text{newAverage} = 5.5543 \]
function DustTrak0106()
Run01_06='010620Run.csv';
Concentrations = dlmread(Run01_06, '','',[1,3,18674,3]);
Date= dlmread(Run01_06, '','',[1,8,18674,8]);
Time = dlmread(Run01_06, '','',[1,7,18674,7]);
CalibratedVal= zeros(1,18674);
MorningRush=zeros(1,18674);
EveningRush=zeros(1,18674);
Day=zeros(1,18674);
Night=zeros(1,18674);
averageMorningRush=0;
averageEveningRush=0;
averageWeekend=0;
averageWeekday=0;
averageDay=0;
averageNight=0;
averageOverall=0;
newAverage=0;
k=0;

for i = 1:18674
    CalibratedVal(i) = 0.3018*(Concentrations(i))+1.5904;
end

figure(7)
plot(CalibratedVal)
xlabel( 'Time' )
ylabel( 'Concentration ug/m3' )
ylim([0 400])
title( 'Run 3 Winter DustTrak Data' )

averageOverall=mean(CalibratedVal);
display(averageOverall);

B=std(CalibratedVal);
display(B)
newCalibratedVal=zeros(1,18301); %this removes 373 outliers
newtime=zeros(1,18301);
newdate=zeros(1,18301);
count=1;
for m=1:18674
    if CalibratedVal(m) < (averageOverall+3*B) && CalibratedVal(m) > (averageOverall-3*B)
        newCalibratedVal(count)=CalibratedVal(m);
        newtime(count) = Time(m);
        newdate(count) = Date(m);
        count=count+1;
    end
end

%len=0;  used to calculate the length that newCal value should be 
%for r=1:18675
if newCalibratedVal(r)~=0
    len=len+1;
end
end

disp(len)

for  j=1:18301
    if  newtime(j) > 070000 & newtime(j) < 090000
        k=k+1;
        MorningRush(k)=newCalibratedVal(j);
    end
end
averageMorningRush = sum(MorningRush)/k;
MorningRush2=MorningRush(1:k);
display(averageMorningRush);

k=0;
for  h=1:18301
    if  newtime(h) > 163000 & newtime(h) < 190000
        k=k+1;
        EveningRush(k)=newCalibratedVal(h);
    end
end
averageEveningRush = sum(EveningRush)/k;
EveningRush2=EveningRush(1:k);
display(averageEveningRush);

k=0;
Weekend=zeros(1,18301);
for  l=1:18301
    if  newdate(l)==11120 | newdate(l)==11220 | newdate(l)==11820 | 
        newdate(l)==11920
        k=k+1;
        Weekend(k)=newCalibratedVal(l);
    end
end
averageWeekend=sum(Weekend)/k;
Weekend2=Weekend(1:k);
display(averageWeekend);

Weekday=zeros(1,18301);
k=0;
for  m=1:18301
    if  newdate(m)==11120 & newdate(m)==11220 & newdate(m)==11820 & 
        newdate(m)==11920
        k=k+1;
        Weekday(k)=newCalibratedVal(m);
    end
end
averageWeekday=sum(Weekday)/k;
Weekday2=Weekday(1:k);
display(averageWeekday);
for n=1:18301
    if newtime(n) > 070000 & newtime(n) < 190000
        k=k+1;
        Day(k)=newCalibratedVal(n);
    end
end
averageDay = sum(Day)/k;
Day2=Day(1:k);
display(averageDay);

k=0;
for p=1:18301
    if newtime(p) < 070000 | newtime(p) > 190000
        k=k+1;
        Night(k)=newCalibratedVal(p);
    end
end
averageNight = sum(Night)/k;
Night2=Night(1:k);
display(averageNight);

newAverage = mean(newCalibratedVal);
display(newAverage);

figure(8)
plot(newCalibratedVal)
ylim([0 60])
title('Run 3 without Statistical Outliers')
xlabel('Time')
ylabel('Concentration ug/m3')
g = [ones(size(MorningRush2)), 2*ones(size(EveningRush2)),
     3*ones(size(Day2)), 4*ones(size(Night2)),
     5*ones(size(newCalibratedVal))];
figure(9)
boxplot([MorningRush2, EveningRush2, Day2, Night2,
        newCalibratedVal],g,'Notch', 'on', 'Labels',
        {'MorningRush', 'EveningRush', 'Day', 'Night', 'Overall'})
xlabel('Time Period')
ylabel('Concentration ug/m3')
title('Box and Whisker Plot for Winter Run 3')
end

averageOverall =

7.4299

B =

4.2662
averageMorningRush =
    7.9716

averageEveningRush =
    6.6340

averageWeekend =
    6.1727

averageWeekday =
    7.4616

averageDay =
    6.4539

averageNight =
    7.7796

newAverage =
    7.1119
Box and Whisker Plot for Winter Run 3

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