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Effect of Reducing Maximum Cycle Length on Roadside Air Quality and Travel Times on a Corridor in Portland, OR

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ABSTRACT

The Sydney Coordinated Adaptive Traffic System (SCATS), an adaptive signal system designed to reduce congestion, has been installed on a heavily trafficked roadway in Portland, OR. In addition to traffic performance metrics, we are investigating how this system affects roadway emissions of air pollutants. A twenty-second reduction to maximum cycle length was proposed for the SCATS system to address pedestrian delay concerns. A two-week trial period with this reduced cycle length was implemented. Travel times and roadside air pollution concentrations were monitored throughout this study period and compared to before and after periods with the current maximum cycle length. Average travel times were found to be significantly higher during the reduced maximum cycle length, but with a mean difference of only 4-5 seconds for travel time. Assessment of travel time for this roadway suggests that a twenty second decrease in maximum cycle length to help shorten pedestrian delay can be made without significant consequences to travel time. Total traffic volumes were consistent for all four weeks of the study. Meteorological conditions were similar for the first two weeks comparing maximum cycle lengths. A shift in ambient temperature led the second two weeks of the cycle length comparison to have more similar meteorological conditions versus the first two weeks. Average NO and NO_2 concentrations were not significantly different for the first half of the study. However, NO and NO_2 concentrations were significantly higher during the reduced maximum cycle length for the second half of the study. When there was a significant difference based on t-test statistics, the measurements did show an increase in roadside concentrations during the shorter maximum cycle length. Preliminary results are unclear if changes to air quality (as assessed by NO and NO_2 concentrations) occur or not due to the reduced maximum cycle length. Results require further comparative analysis in which meteorology and traffic conditions are controlled for so that any difference in air quality due to maximum cycle length alone can be quantified.

INTRODUCTION

The Sydney Coordinated Adaptive Traffic System (SCATS) was installed on a main urban arterial corridor (Powell Boulevard, Portland OR) to help decrease overall vehicle delay and to achieve other performance measure benefits such as reduced traffic emissions. The optimization of traffic flow with this system can lead to an unintended increase in pedestrian crossing delay resulting in increased jaywalking and complaints. To balance the transportation planning goals of reducing congestion and emissions along with meeting the needs of pedestrian road users, a twenty second reduction in maximum cycle length was tested over two-weeks with concurrent monitoring of roadside air quality and travel time measurements throughout the testing period. This study assesses the changes in travel time and roadside air quality during the two-week testing period compared to before and after the change in maximum cycle length.

Adaptive signal systems can help reduce traffic congestion and vehicle delay by improved coordination shown by shorter travel times for vehicle users. Research has shown that results from SCATS implementation on a 3.1 mile arterial corridor in Oakland County, Michigan decreased travel times as much as 8% during peak travel periods and 30% during off-peak periods (*1*). Kothuri et al. (2012) through measurements and calculations has shown a larger cycle length will increase total maximum pedestrian delay and maximum average delay (*2*). Pedestrian time on the side streets for the Powell Blvd corridor are a constraint for this roadway and a reduction in maximum cycle length may reduce capacity for the through movements making it important to assess travel time changes. The improvement of reduced delay for pedestrians to cross SE Powell Blvd must be balanced with possible trade-offs for travel times, fuel consumption, and air quality.

Primarily through a reduction in stops and decreased vehicle delays, coordinated and adaptive signal systems have been shown to reduce fuel consumption and transportation related emissions. In reviewing several studies showing such reductions, Reynolds and Broderick (2000) noted changes in traffic variables are typically derived from emissions calculation models and simulations (*3*). The majority of these findings for adaptive signal systems have been made through modeling and simulation. In a specific study addressing changes in vehicular emission from SCATS, Stevanovic et al. (2012) found SCATS to outperform Time-Of-Day plans in terms of fuel consumption and related vehicular emissions through a VISSIM microsimulation model (*4*). Field evaluation of changes to transportation related air pollutants is rare. Additionally, reduced fuel consumption or altered emissions factors simulated must also be integrated into roadside dispersion modeling to help further understanding of how changes in fuel consumption and reduced tailpipe emissions translate to changes in concentrations of pollutants in and around the roadway. Air quality as a performance measure has been a strong research interest of the City of Portland and has led to the agency developing a relatively unique roadside air pollution monitoring station located in the Powell Blvd corridor. The objective of this paper is to quantify the effect on air quality and travel times of reducing the maximum cycle length.

BACKGROUND

Transportation is a major source of air pollution for urban environments. Acceleration events are tied to higher emissions compared to free flow conditions and have been measured with portable emissions measurements systems (*5*). Stevanovic et al. (2012) specifically found for SCATS that the largest cause of reduced fuel consumption and emissions was a reduction in number of stops (*4*). An evaluation study assessing the effectiveness of SCATS compared to a pre-timed system in Oakland County, Michigan used field collected travel times and travel speeds to estimate nitrogen oxide and other traffic pollutant emissions, finding SCATS to typically show lower emissions but results could depend on day of the week or peak period (*6*).

The SCATS adaptive system in Portland, OR is located on Powell Blvd between 6th Avenue and 77th Avenue. The 3.7 mile stretch of road has main street traffic volumes up to 2,800 vehicles per hour during peak period. The corridor is a five lane undivided arterial with two vehicle through lanes in each direction, with left turn bays and auxiliary right turn lanes at select intersections. Powell Blvd runs a high frequency service bus route, serving downtown Portland and Gresham, making transfers to other major routes at cross streets. Powell Blvd also has a high mix of other road users, including freight, public transit and pedestrians. No bike lanes are provided on the facility.

SCATS was implemented in October 2011. The system evaluates traffic demand at the intersections within its system every cycle and selects a cycle time that meets the needs of the overall corridor. Offset values are assigned dynamically as the cycle times are changed based on the traffic demand throughout the corridor.

With the change to this adaptive signal system, there were increases in pedestrian delay. Feedback from city residents to the Portland Bureau of Transportation (PBOT) about these increased delays led the City of Portland to propose a twenty second decrease in maximum cycle length, making the total cycle length 120 seconds, while the current maximum cycle length is 140 seconds.

The roadside continuous air quality monitoring station is located at an intersection that includes a high school, city park, and a cross street that includes bike lanes. Continuous monitoring of roadside air quality is rarely implemented for an extended time period. As changes and adjustments are made to the SCATS system, this station provides a unique opportunity to study the impact on roadside concentrations of traffic-related pollutants.

STUDY QUESTIONS

During the two-week trial period of the proposed change in cycle time, pedestrian delay was expected to decrease. With a shorter maximum cycle length, travel times for vehicles were expected to increase due to a possible increase in stops at intersections during congested periods. This study will present the travel time results for four weeks, including the two-week trial period and two weeks (including one before and one after) with the current cycle time. Comparisons of travel times among these four weeks will be presented and any changes discussed.

The next step of our research was to see if this change in cycle length was reflected in changes to air quality. There was a possibility that certain transportation related air pollutant concentrations may increase due to more acceleration and idling if frequency of stops increased and queues were longer due to the reduction in maximum cycle length. Comparisons of transportation related pollutant concentrations from the monitoring station will be presented for the same four weeks described above.

METHODS

Travel Time Data

Travel time of the motorists was collected based on a method established developed by Quayle et al. (2010) that utilizes Bluetooth technology (*7*). Cellphones, MP3 players, laptops, or in-car Bluetooth systems contain unique numeric identifiers known as MAC addresses. These addresses can be read by readers with Bluetooth technology. These readers can be deployed along the road to detect and read the MAC addresses from the devices located in the vehicle passing along. There are six readers placed at intersections along Powell Blvd. The MAC addresses detected by the readers are transmitted wirelessly to a Data Collection Unit (DCU), which is located in the signal controller cabinet. The data was then downloaded and processed using custom software developed by Kittelson & Associates and Digiwest. The MAC addresses recorded at different readers are matched in order to give a travel time. The travel time data are uploaded to the Portland Oregon Regional Transportation Archive Listing (PORTAL-at www.portal.its.pdx.edu), an archive of transportation data from the Portland-Vancouver metropolitan region and is available to other researchers.

For this project, we are looking at travel times between 21st Avenue and 33rd Avenue along Powell Blvd, highlighted by points A to B within the larger Powell corridor in Figure 1. The data was analyzed using R, a language for statistical computing and graphics, to see if there was a significant difference in travel times before and after the maximum cycle time change. The data was analyzed in different periods of the day to see the affect on peak travel periods.

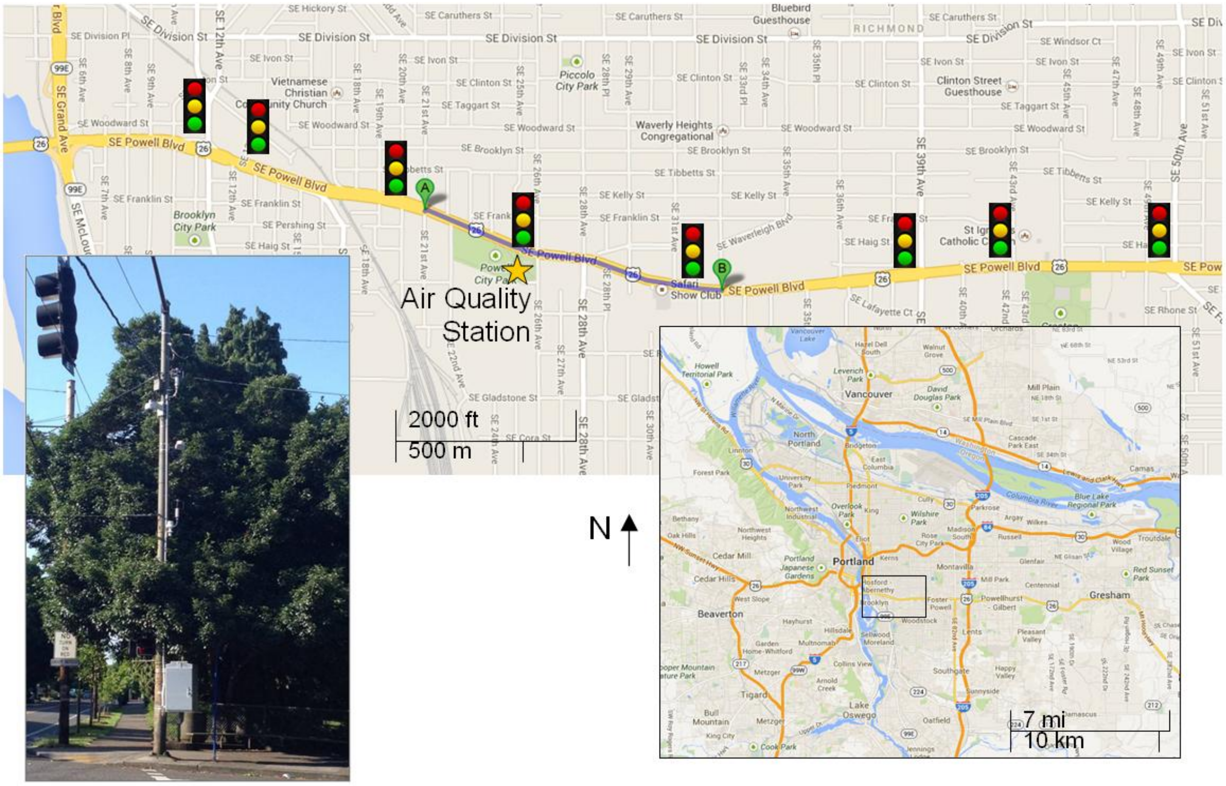

FIGURE 1 SE Powell corridor showing traffic signals and location of air quality station. Points A and B mark the route for which travel time data were collected (21st to 33rd). Air quality station and pole mounted meteorological equipment pictured on the left. Powell corridor related to the greater Portland area on right.

Air Quality Data

Air quality instruments were installed in a pole mounted traffic signal cabinet on the SW corner of the intersection of Powell Blvd and SE 26th Ave (Figure 1). The monitoring station is equipped to collect continuous measurements of nitrogen oxides (NO_x) (Teledyne T200 Chemiluminescence NO/ NO_2/ NO_x Analyzer) as well as particulate matter mass concentrations PM_{10} (particles with a diameter $\leq 10\mu m$) and $PM_{2.5}$ (particles with a diameter $\leq 2.5\mu m$) using a TSI DustTrak DRX Aerosol Monitor 8533. Wind speed and direction were collected using RM Young 3D Sonic Anemometers Model 81000 and temperature and relative humidity with an RM Young probe Model 41382VC. Meteorological instruments are an important piece of roadside monitoring to understand how pollutants transport and transform from tailpipe emissions to roadside ambient concentrations. Non-reactive sampling lines for the monitoring equipment were passed through to the top of the signal cabinet ensuring that the intakes are out of reach of disturbance from the street but still capturing road emissions at street level (3m above roadway). DustTrak was factory calibrated. The NO_x instrument was calibrated in the laboratory with certified gas standards. In addition, ambient sampling artifacts were assessed by passing calibration gases through the sampling system at the signal cabinet to confirm minimal loss.

Nitric oxide (NO) and nitrogen dioxide (NO_2) are the foci of this paper as they show a direct relationship to traffic volumes in the Powell corridor. PM_{10} and $PM_{2.5}$ typically show diurnal pollutants indicating traffic as a source for low wind conditions only and show more sensitivity to high emitting vehicles such as trucks or buses so are not the appropriate parameters to use for the purpose of this study. NO and NO_2 are primary traffic pollutants (together known as NO_x) and directly produced by combustion. NO makes up the majority of NO_x emissions released from vehicles and is elevated in roadside environments. NO combines with oxygen and other oxidants in vehicular combustion systems and ambient air to form NO_2, making NO_2 both a primary and secondary pollutant. NO_2 is a criteria pollutant regulated by the Environmental Protection Agency (EPA). Increased concentrations of NO_2 around roadways and associated health risks were recognized by the EPA 2010 Final Rule requiring the establishment of near-road NO_2 monitoring and changes to the one hour NO_2 National Ambient Air Quality Standard (NAAQS) (*8*). The data collected thus far at the Powell roadside monitoring station has consistently shown NO and NO_2 as responsive parameters to traffic; showing diurnal relationships and different patterns for weekends and weekdays. NO and NO_2 will be the foci for investigating the relationship between air quality, traffic, and the proposed change in maximum cycle length in the SE Powell corridor.

RESULTS AND DISCUSSION

Cycle Length

Reducing the maximum cycle length to 120s from the current maximum of 140s resulted in changes to the real-time cycle lengths used in the Powell corridor primarily during congested time periods (Figures 2-4). Cycle times used in SCATS are changed based on the traffic demand throughout the corridor. As congestion increases, maximum cycle lengths are used. With the reduced maximum cycle length, the time periods within each day in which the maximum cycle length was used in the signal system were different compared to the weeks with the current maximum cycle length. Figures 2-4 highlight the changes in these patterns of cycle length signal timing for the intersection at which the air quality monitoring station is located. These figures show the cycle lengths (in seconds) reported from SCATS over one full day from each week of the study period (before, during 1, during 2, and after). The gray dotted line shows the current 140s maximum cycle length and the black dotted line shows the reduced 120s cycle length. The colored boxes show a time period in which the maximum cycle length was implemented by the signal system. Figure 2 shows the Monday of each week in the 4 week study period (representing weekday patterns), Figure 3 shows the Friday of each week (different traffic than other weekdays), and Figure 4 shows the Sunday of each week (represents weekend patterns).

The time periods where maximum cycle length was realized in the before and after weeks (Figures 2a, 2d, 3a, 3d, 4a, 4d) are different than the two-weeks with the reduced cycle length (Figures 2b, 2c, 3b, 3c, 4b, 4c). Fifteen minute traffic volumes from SCATS were similar over the four weeks showing traffic intensity was consistent (Figure 5), ranging from 10 to 800 vehicles at peak periods. The study period was designed to fall after spring break holidays so traffic volumes would be consistent. The time periods showing differences in signal timing allowed us to focus our investigation of air quality concentrations on time periods where we knew traffic volumes were the same but there were known differences in the signal timing. NO, and NO_2 concentrations were assessed for the following distinct time periods based on the cycle length data from SCATs:

- Monday– Friday Morning Periods 6:35- 10:55am
- Monday- Thursday Afternoon Periods 12- 12:55pm
- Monday- Thursday Evening Periods 3-6:45pm
- Friday Afternoon/Evening Periods 11:15am- 7:00pm
- Weekends 11:25am to 6pm

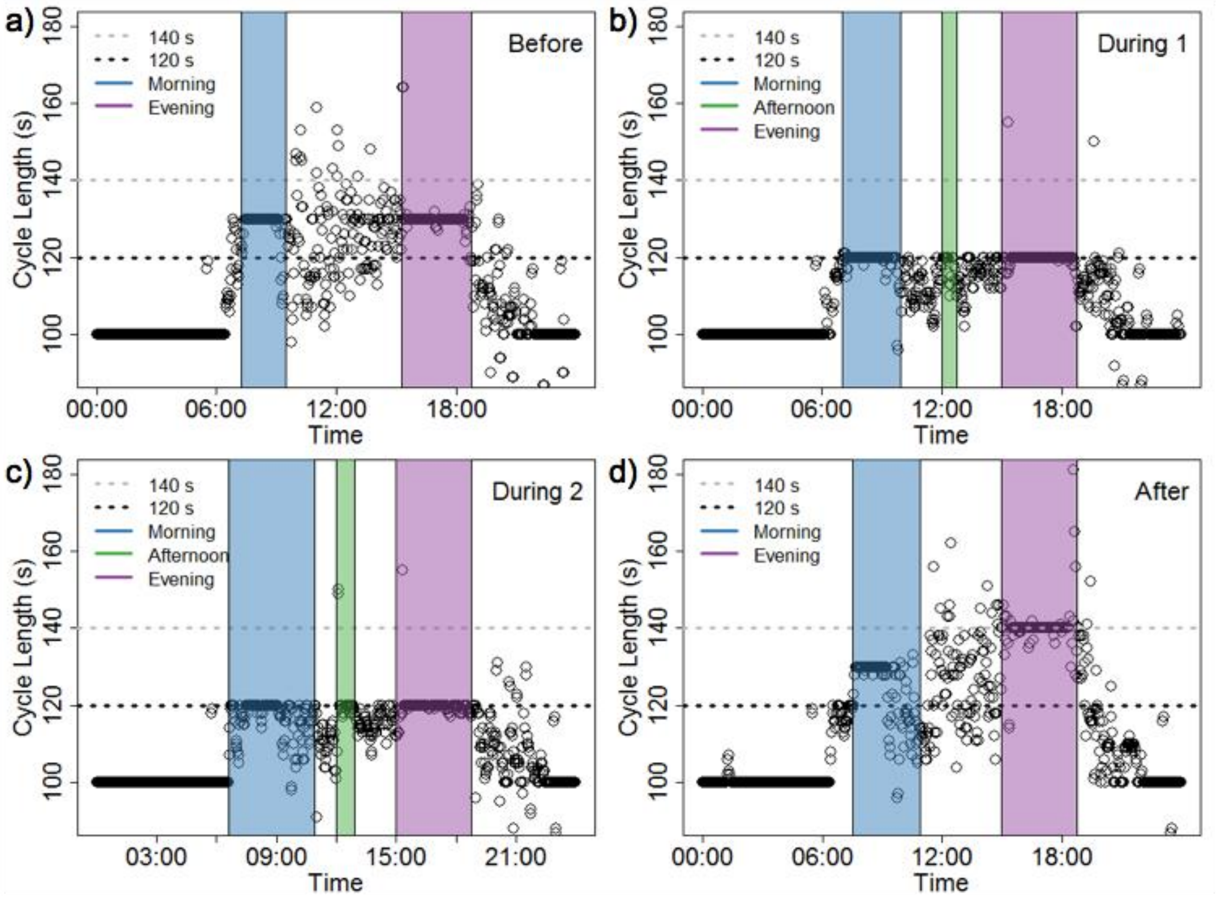

FIGURE 2 Cycle length versus time of day for the Monday of each week in the study. Horizontal lines show current and reduced maximum cycle length. Colored boxes highlight time periods when maximum cycle length is reached. a) Before week, b) During first week with reduced cycle length, c) During second week with reduced cycle length, d) After the two-week trial period.

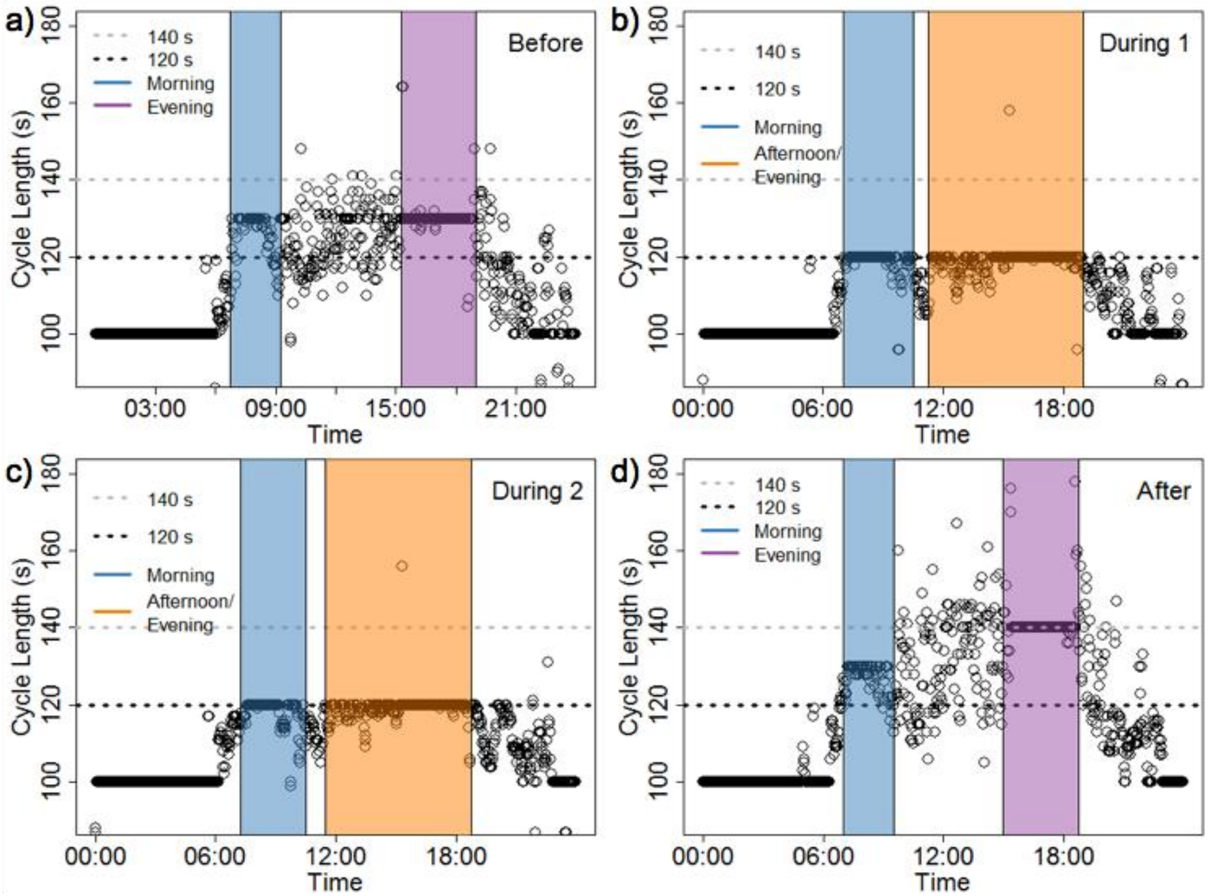

FIGURE 3 Cycle length versus time of day for the Friday of each week in the study. Horizontal lines show current and reduced maximum cycle length. Colored boxes highlight time periods when maximum cycle length is reached. a) Before week, b) During first week with reduced cycle length, c) During second week with reduced cycle length, d) After the two-week trial period.

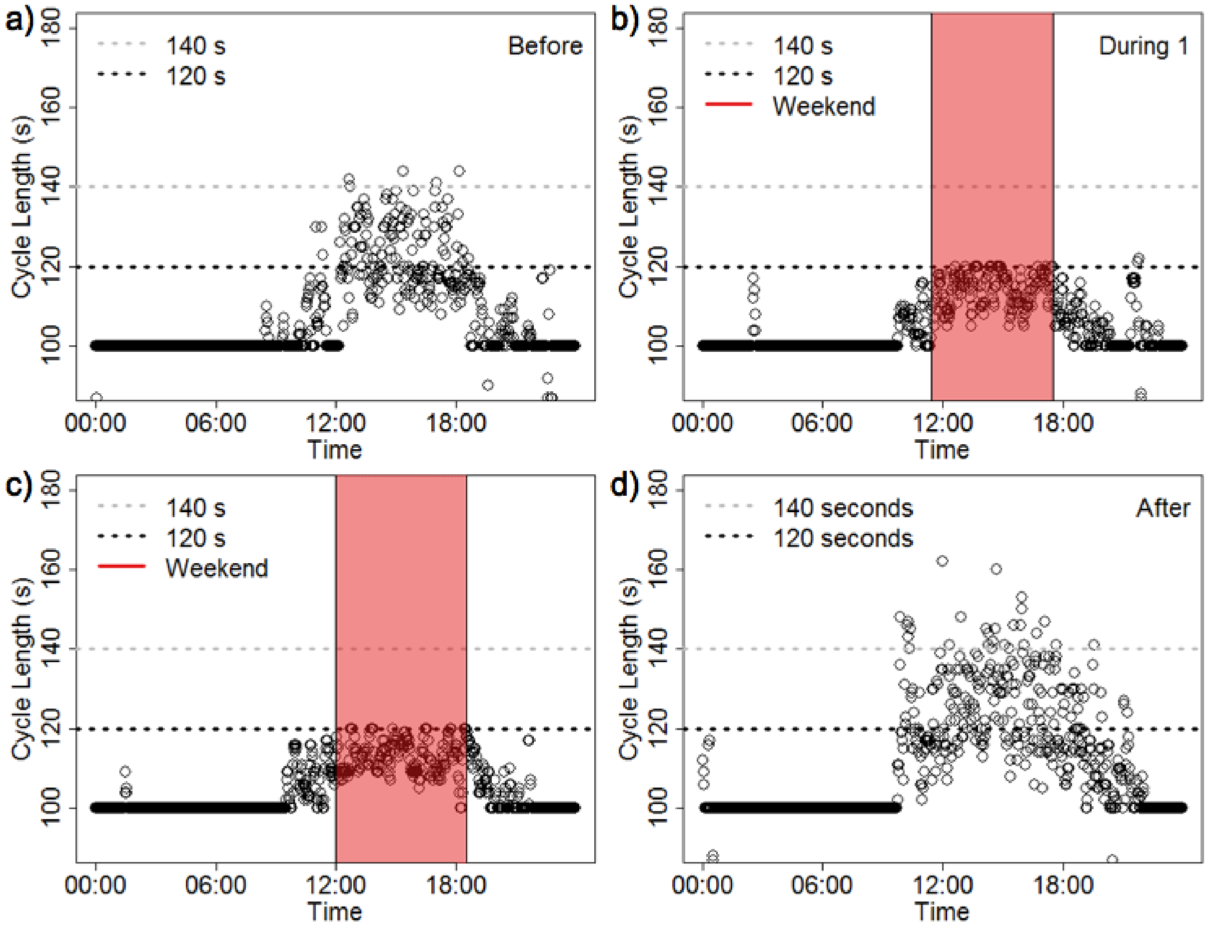

FIGURE 4 Cycle length versus time of day for the Sunday of each week in the study. Horizontal lines show current and reduced maximum cycle length. Colored boxes highlight time periods when maximum cycle length is reached. a) Before week, b) During first week with reduced cycle length, c) During second week with reduced cycle length, d) After the two-week trial period.

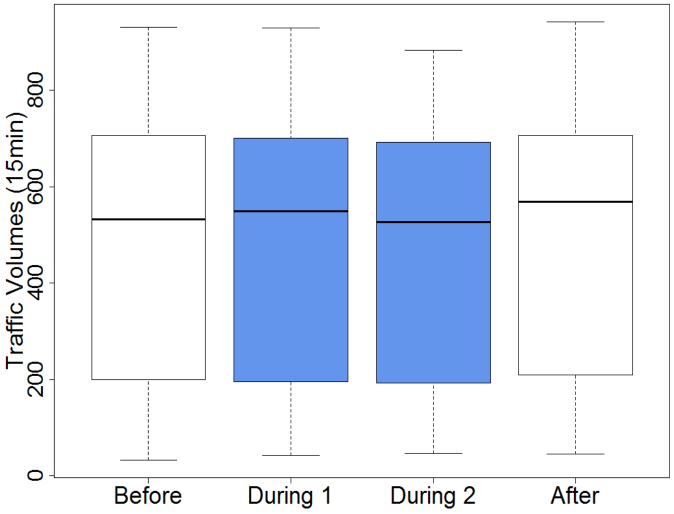

FIGURE 5 Average 15 min bin traffic volumes for each week of the study period.

Travel Time Effects

Comparisons of average travel times for the different maximum cycle lengths did show statistically significant differences (p-value<.05) (Figure 6). Eastbound travel times were significantly higher during the 120s maximum cycle length compared to the 140s maximum (t-value=2.638, p-value=.008). The mean difference in these cycle lengths was equal to 4.3 seconds. Westbound travel times were also significantly higher for the proposed cycle length (t-value=2.771, p-value=.005) with a mean difference of 5.4 seconds from the current maximum cycle length.

To investigate the time of day effects on SCATS cycle lengths that were highlighted by Figures 2-4, travel times were also compared for periods when SCATS was operating on maximum cycle lengths. Average travel times were factored out according to the actual cycle length data from SCATS and then compared for the two maximum cycle length periods (Figure 7). Eastbound travel times for these maximum cycle length periods did not show a significant difference between the two maximum cycle lengths settings (t-value=-1.004, p-value=2.732). Westbound travel times during congested periods did show a significant difference (t-value=2.825, p=.005) with a mean difference of 11.3 seconds, showing the highest increase in travel time with the reduced maximum cycle length. The median travel time for these congested periods in 7a and 7b are about 100 and 125s. These travel times for the stretch of road studied still indicate speeds around 30mph which would not be considered actual congestion. However, SCATS is operating these intersections using the maximum cycle length typically reserved for congested periods because of coordination to other, larger intersections. For the intersections within the study though, these results show a higher than needed cycle length is applied by SCATS.

Overall, statistical significant differences were found between the two maximum cycle length periods, except for eastbound congested periods. However, average differences of 4-5 seconds are acceptable changes for the corridor and can be evaluated as trade-offs with pedestrian delay concerns. The increased effect on travel times for congested westbound periods must also be taken into consideration and the limitations of SCATS tied to other intersections.

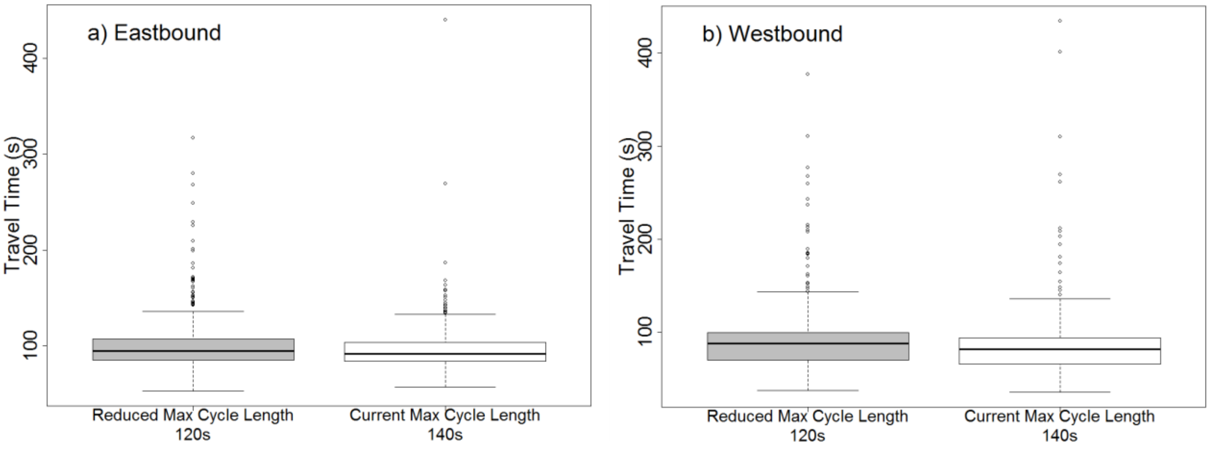

FIGURE 6 Boxplots of average travel times for the proposed and current maximum cycle length periods. a) Eastbound travel times (t-value=2.638, p-value=.008), b) Westbound travel times (t-value=2.771, p-value=.005)

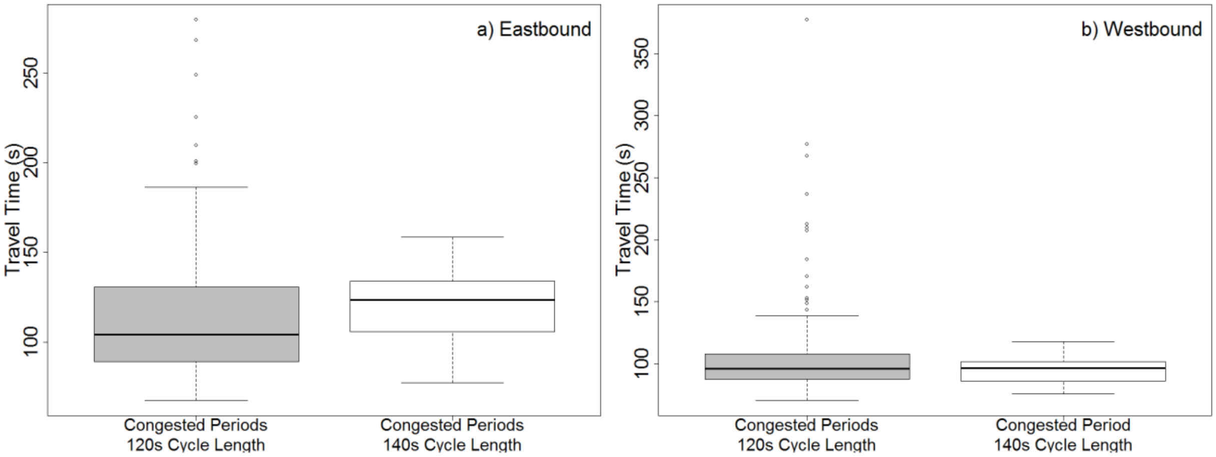

FIGURE 7 Boxplots of travel times during congested periods for the two maximum cycle length periods. a) Eastbound travel times for congested periods (t-value= -1.1004, p-value=2.732), b) Westbound travel times for congested periods (t-value=2.825, p=.005).

Air Quality Effects

Average NO and NO_2 (15min) concentrations for the four week study period are shown in Figure 8. Overall, these measurements do not show a significant difference during the two-weeks with decreased maximum cycle length for NO2 concentrations (t-value= -1.411, p-value= 0.158). However, NO concentrations were significantly higher during the reduced maximum cycle length period (t-value= -4.612, p-value= 4.178e-06) with a mean difference of 2.67ppb. Comparisons of weekdays only during the two maximum cycle length periods show a significant difference for both NO_2 (t-value= -4.842, p-value= 1.39e-06) and NO (t-value= -5.02, p-value= 5.67e-07). For weekdays only, NO_2 was higher during the 120s maximum cycle length with a mean difference of 1.6ppb and NO was higher with a mean difference of 3.6ppb. When there is a significant difference based on t-test statistics, the measurements do show an increase in roadside concentrations during the shorter maximum cycle length. These results suggest NOx may be sensitive to a reduction in maximum cycle length. The magnitude of concentration increase needs to be evaluated in terms of typical weekly and monthly concentration variations and bears further analysis to compare more narrow time periods that have similar meteorological and traffic conditions with the only difference in conditions being the actual maximum cycle length.

Meteorological measurements over the four-week study period are shown in Figure 9. The last two weeks of the study period had warmer, drier weather compared to the first two (Figure 9a). Average temperatures were higher with a positive trend for the last two weeks and relative humidity showed a decreasing trend towards the end of the four weeks. Wind speeds were low for the entire study period, ranging from 0- 4.2m/s with a median wind speed of 1.2m/s. Figure 9b does show some shifts in dominant wind direction among the four weeks. However, the low wind speeds would minimize dilution effects of wind on roadside NO_x. Due to the meteorological patterns shown in Figure 9, with more similar meteorology in the first half of the study and more similar meteorological conditions for the second half, NO and NO_2 concentrations were compared between week one and week two only and then also week three versus week four only. NO and NO_2 weekday concentrations did not show significant differences between the maximum cycle lengths for the first two weeks of the study (NO: t-value=-1.624, p-value= 0.105, $NO_{2:}$ t-value=-0.823, p-value=0.411). For the second half of the study, weekday

NO and NO_2 concentrations did show significantly higher concentrations during the reduced maximum cycle length. NO concentrations were higher during the second week of reduced maximum cycle length with a mean difference of 5.45ppb (t-value=-5.721,p-value-1.42e-08). NO_2 concentrations were also higher with a mean difference of 2.78ppb (t-value=-6.173, p-value=9.9e-10). NOx concentrations did not show a response to reduced maximum cycle length for the first two weeks of comparison but did show significantly higher concentrations with a reduced maximum cycle length based on statistical t-tests for the second two weeks of comparison. It appears unclear if there are differences or not for NO and NO_2 concentrations as a result of reduced maximum cycle length only and further statistical analyses are needed to compare and match time periods with similar traffic and meteorological conditions to quantify the effect of reduced maximum cycle length.

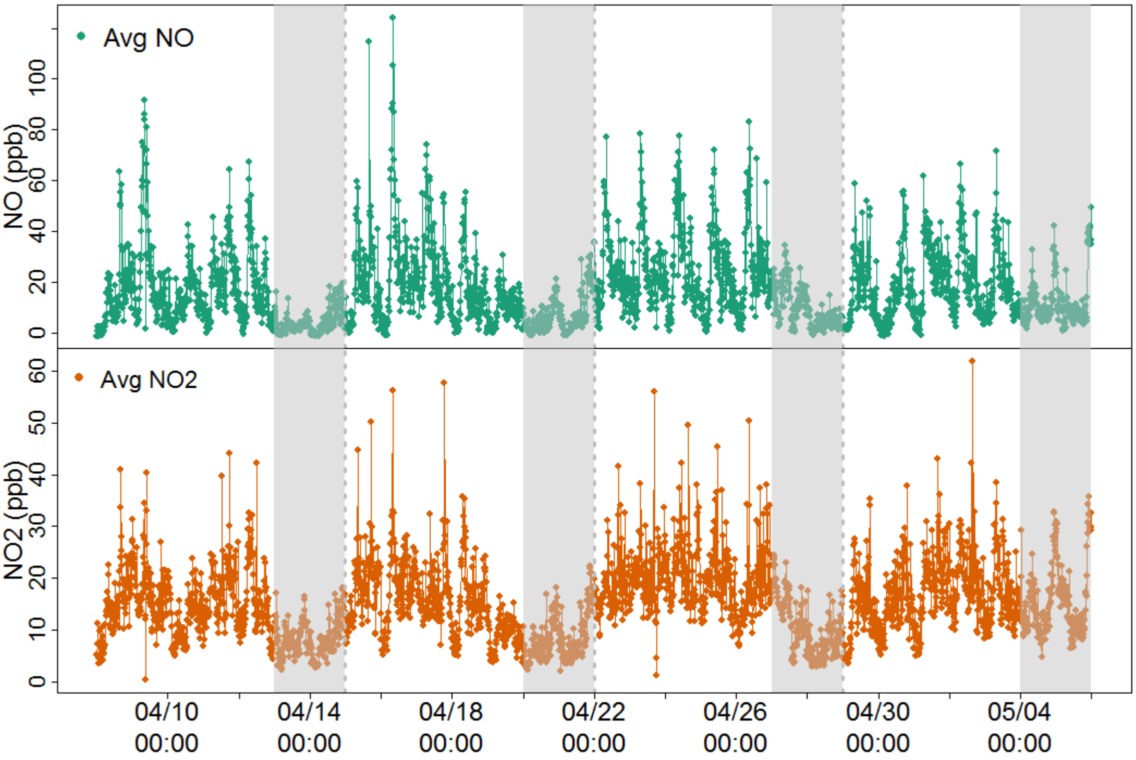

FIGURE 8 Average NO and NO_2 (15 min) over the four week study period. Gray shaded areas indicate weekends. Gray dotted line is the beginning of each week in study period.

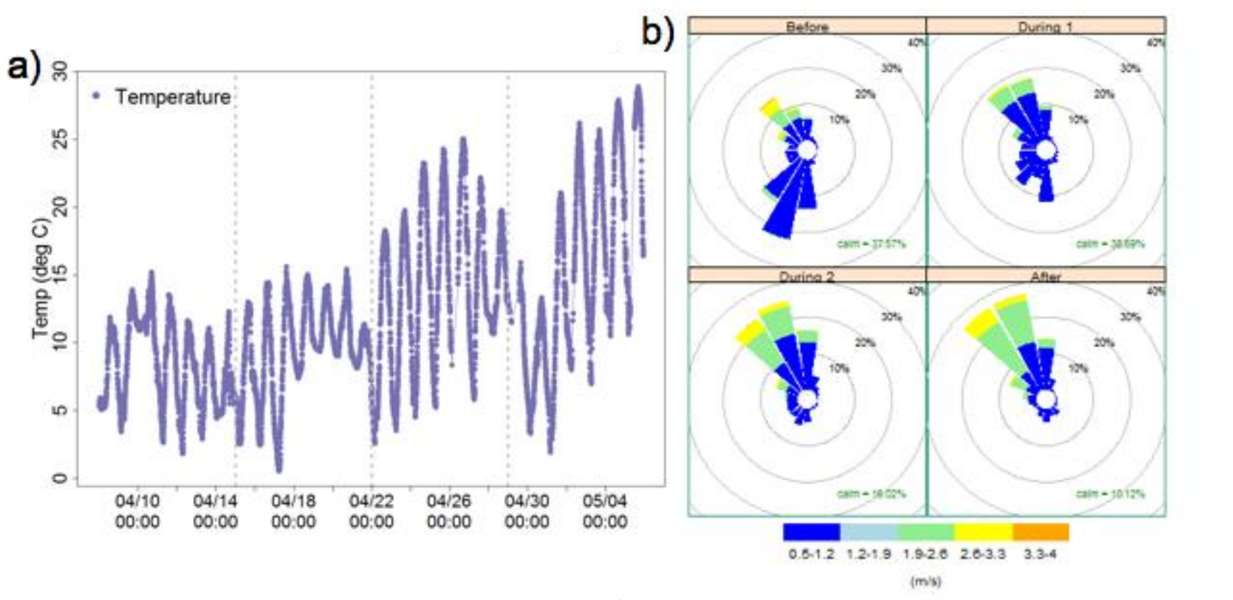

FIGURE 9 Meteorological measurements over the four week study period.
a) Temperature (Celsius), gray dotted lines show the beginning of a week, b) Wind roses

To further investigate any possible changes in air quality, data were disaggregated according to the time periods with known changes in cycle length patterns (Figures 2-4). For these five distinct time periods identified through the SCATS cycle length data, distributions of mean, median, maximum, and 97th percentile NO and NO_2 concentrations were compared for each week of the study period. Maximum and 97th percentile concentrations were assessed to explore the possibility that increased queuing and number of stops during congested times where the max cycle length was utilized may lead to higher peak spikes of traffic related pollutants. Differences in distributions of these NO and NO_2 summary statistics were explored at varying time aggregations of 30s, 1min, 5min, 10min, and 15min. However, no differences were found between the two-week trial period compared to the weeks with the current maximum cycle length for the varying time aggregations, NO or NO_2 variable. Examples of these comparisons are shown in Figures 10-13. Figure 10 shows the distributions of median NO concentrations (15 min bins) for each time period with known cycle length changes (Morning Mon-Fri, Afternoon Mon-Thurs, Evening Mon-Thurs, Friday Afternoon-Evening, and Weekend). Figure 11 follows the same format but shows distributions for maximum NO concentrations for 15 minute periods, Figure 12 shows median NO_2 concentrations, and Figure 13 shows maximum NO_2 concentrations.

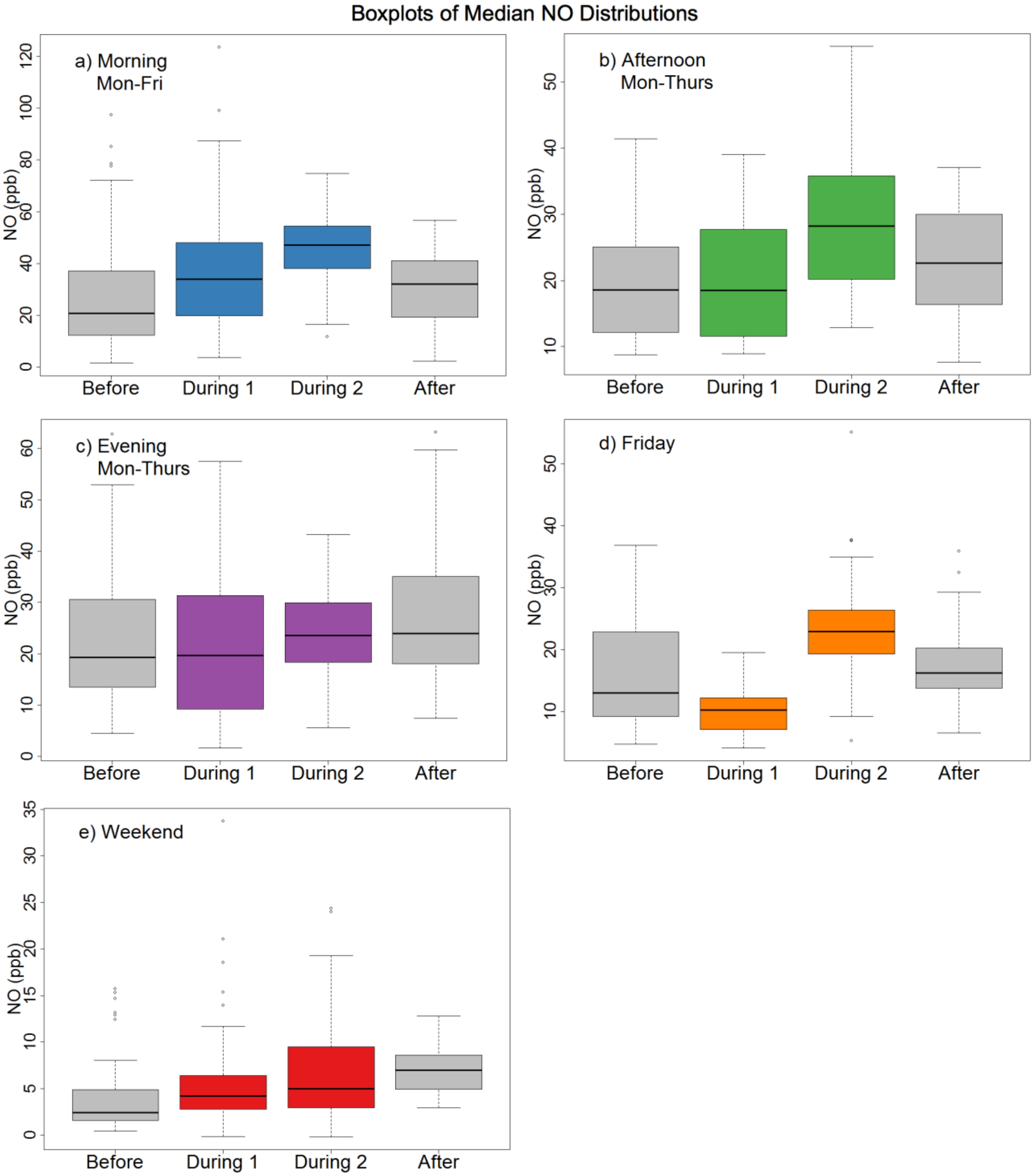

FIGURE 10 Boxplots of median NO distributions for each time period that a change in cycle length occurred (a-e).

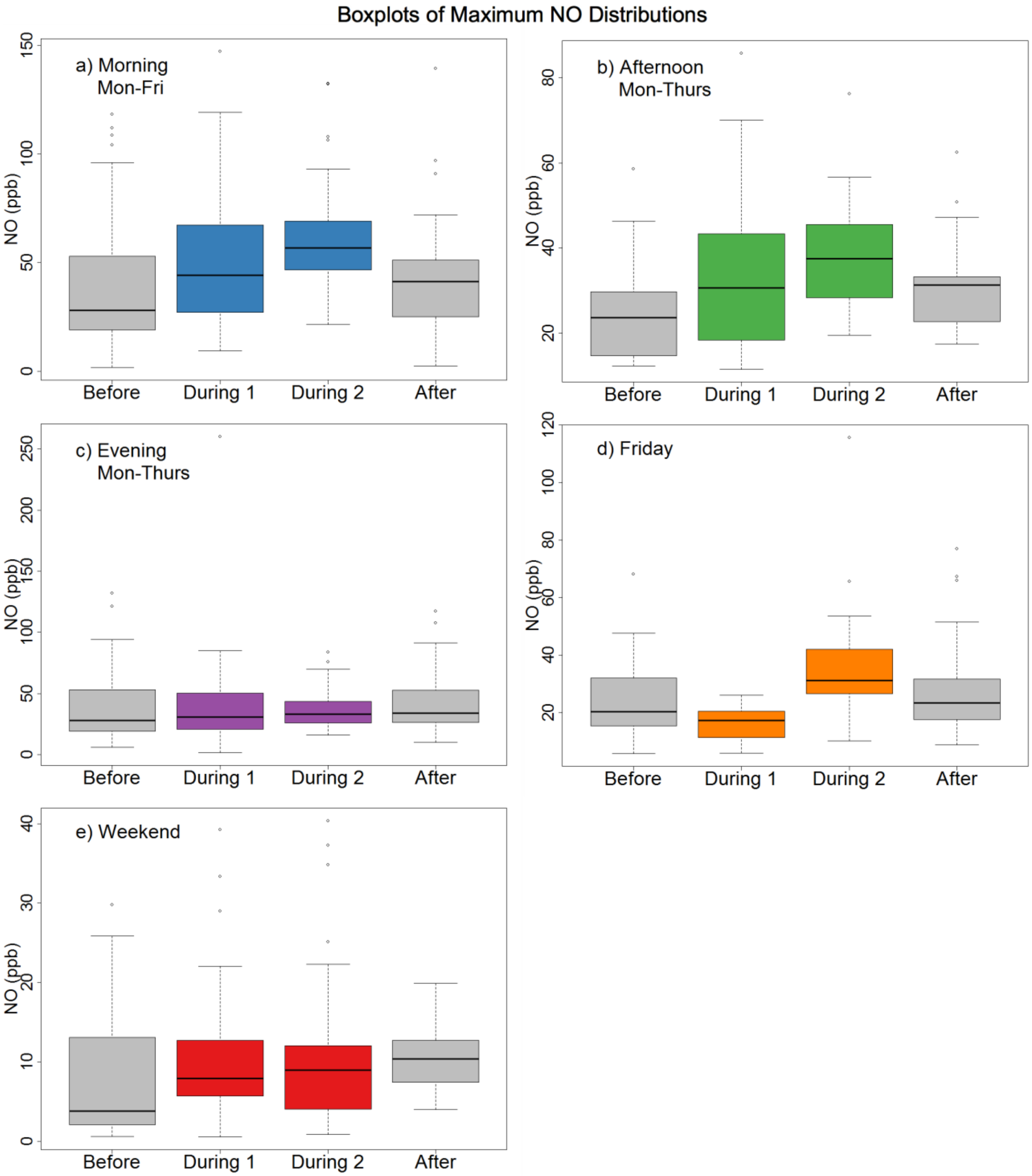

FIGURE 11 Boxplots of maximum NO distributions for each time period that a change in cycle length occurred (a-e).

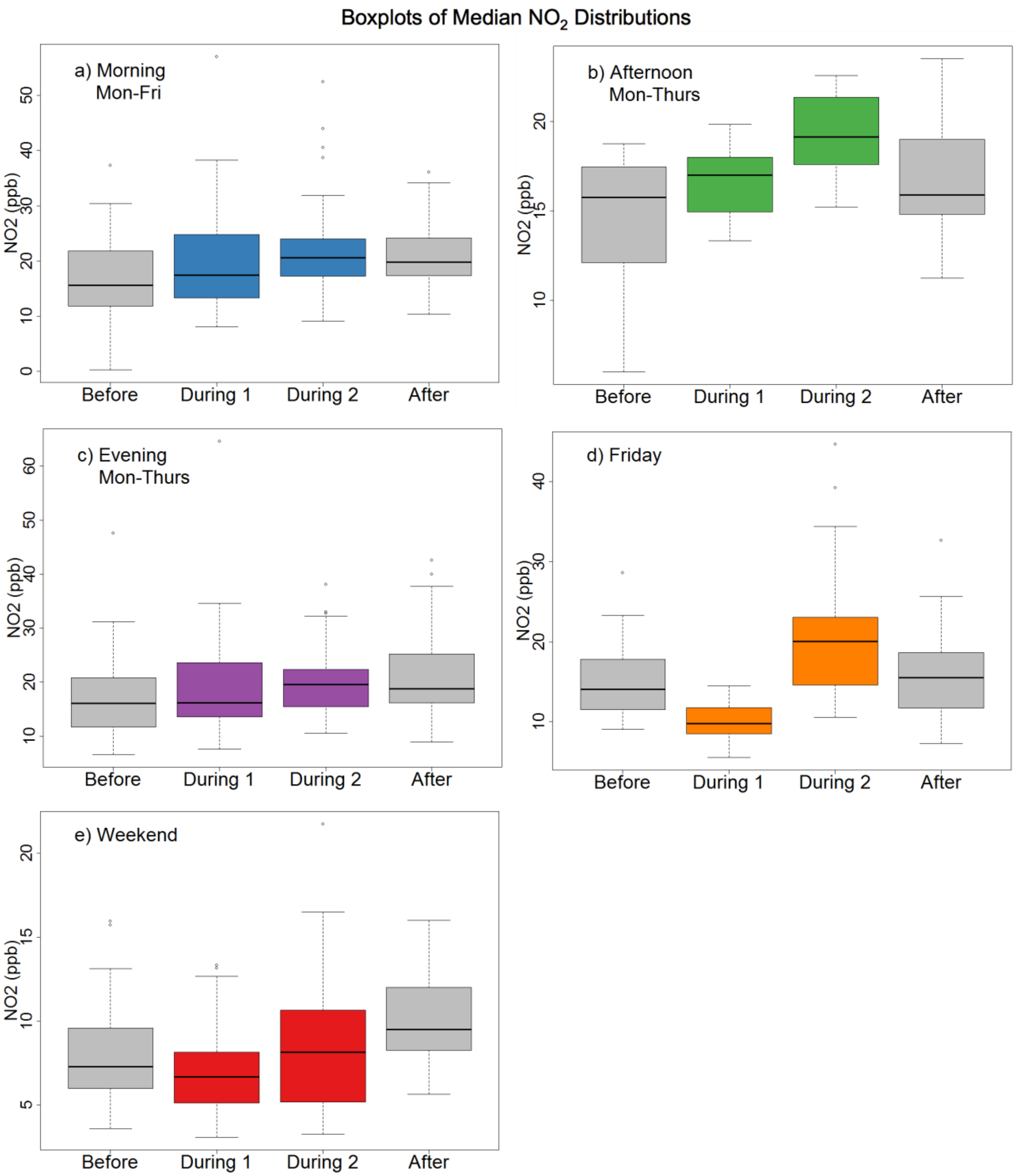

FIGURE 12 Boxplots of median NO2 distributions for each time period that a change in cycle length occurred (a-e).

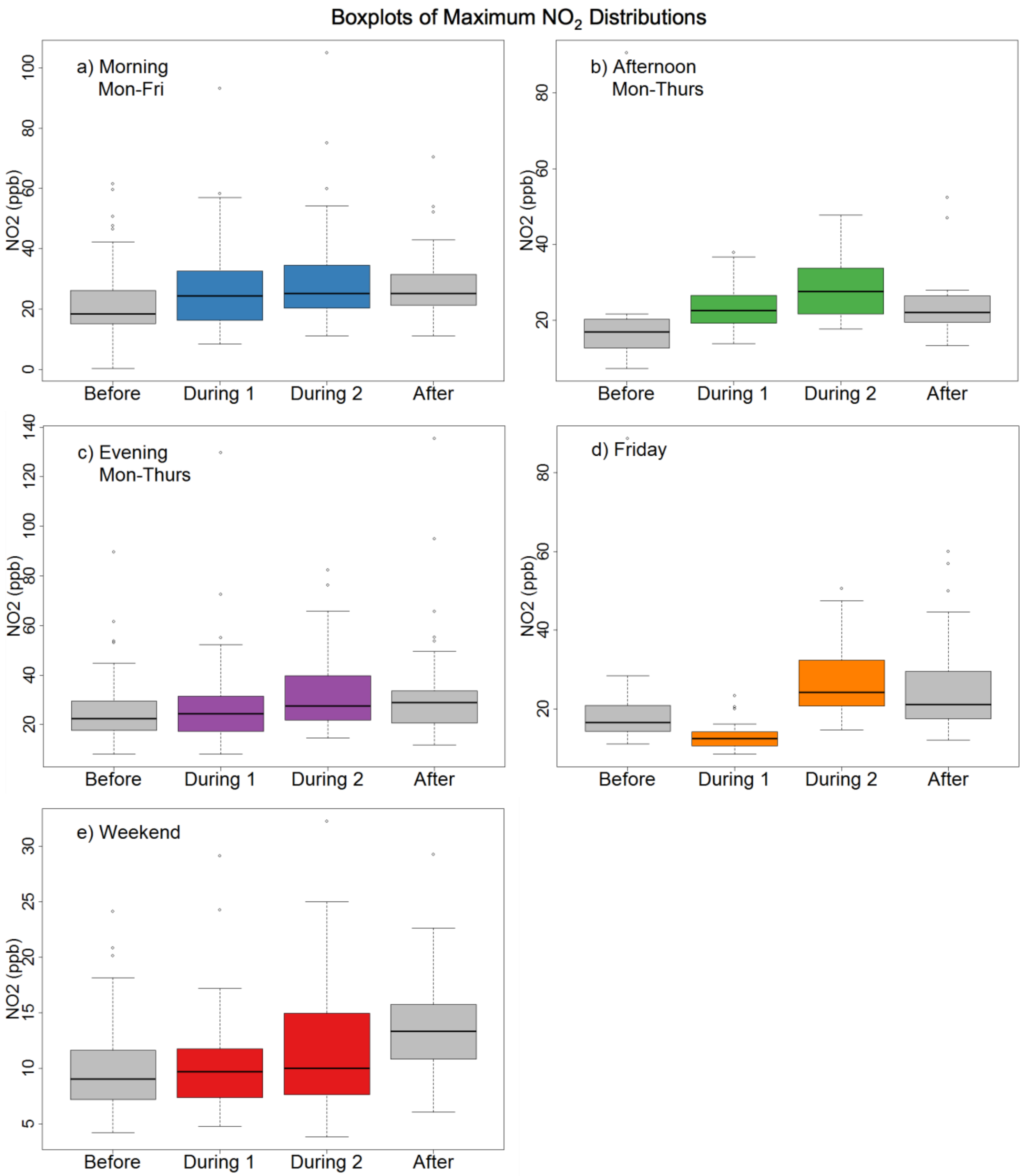

FIGURE 13 Boxplots of maximum NO_2 distributions for each time period that a change in cycle length occurred (a-e).

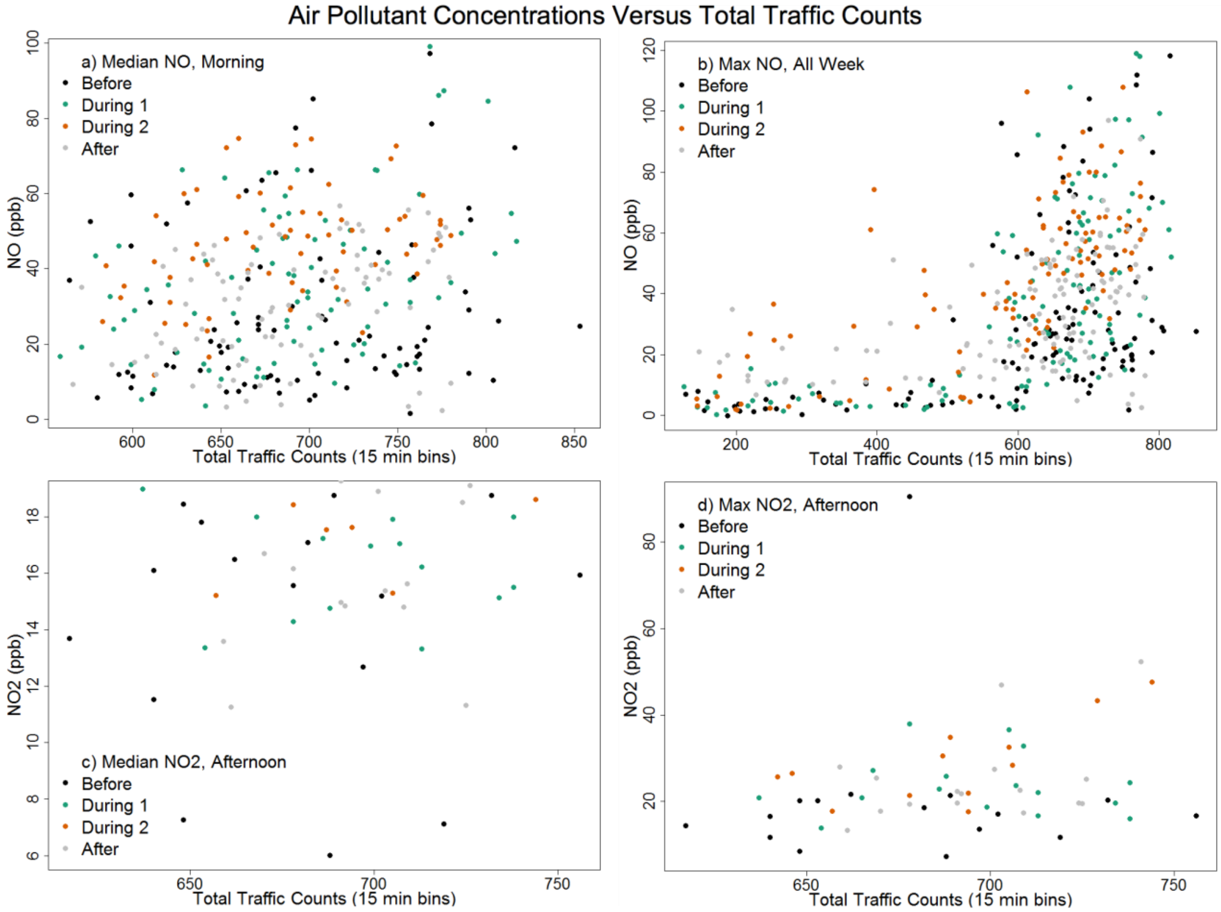

FIGURE 14 NO and NO_2 concentrations versus total traffic counts from SCATS a) Median NO (15min) for weekday morning periods, b) Maximum NO (15min) for morning periods for the whole week, c) Median NO_2 (15min) for Mon-Thurs afternoon periods, and d) Maximum NO_2 (15min) for Mon-Thur afternoon periods.

Figure 14 shows examples of the relationships of NO and NO_2 variables with total traffic counts from SCATS. Data from the two-weeks with reduced maximum cycle length are colored in green and orange and do not show a distinct pattern compared to the before and after weeks. Figure 14b shows the maximum NO concentrations versus total traffic counts for the morning periods of all four weeks. This plot shows an example of how NO and NO_2 changes in response to overall traffic counts. The background concentrations are relatively low overnight and then as the morning begins and traffic increases, NO concentrations rise. For this study, the total number of vehicles is a main contributor to elevated roadside concentrations, which is steady across the four weeks (Figure 5) and the effect from changes in traffic induced by the changes in maximum cycle length need to be quantified while controlling for meteorology and confounding factors across the four weeks of the study.

CONCLUSIONS AND FUTURE WORK

Our analysis shows that for the study corridor changes to the maximum cycle length in order to address problems of pedestrian delay could be made without large changes to travel time. There were statistically significant changes to travel times, but mean differences ranged from only 4-5 seconds. Changes to air quality (as assessed by NO and NO_2 concentrations) due to the reduced maximum cycle length are unclear and bear further analysis to compare specific time periods in which traffic and meteorological conditions are the same and the only difference affecting NOx would be due to the maximum cycle length. Statistical t-tests do show significantly higher NO concentrations with the reduced cycle length, but not for NO_2 concentrations. T-test results for weeks with similar meteorology show no significant difference for NO and NO_2 for the first half of the study, but do show significantly higher NO and NO_2 with the reduced maximum cycle length for the second half of the study. A more robust comparative analysis will be conducted to quantify the effect of a reduced maximum cycle length on NO and NO_2 while controlling for meteorology and traffic conditions as a result of time of day. There results will quantify any change in NOx due to the cycle length change only. Preliminary results based on travel times lend credence that this solution of reduced maximum cycle length to address pedestrian delay would not interfere with other goals for the corridor, and further analysis will be used to determine if air quality goals are also maintained with a reduced maximum cycle length.

In order to understand what amount of change in maximum cycle length would or would not result in changes to roadside air quality, emissions modeling must be combined with dispersion modeling. To take this work one step further, Synchro modeling will be combined with MOVES and NO and NO_2 emissions factor to generate emission factors for various scenarios including a twenty second decrease to max cycle length, a 40 second decrease, a 20 second increase, and other iterations. These emissions factors would then be used as inputs to roadway dispersion modeling. By combining our measured results here with modeling we can first compare how the models perform for the study period in this research providing us a framework to ground truth the models. If there is good agreement, then we can assess what type of changes to cycle length do results in changes for roadside air quality. This type of modeling and continued roadway monitoring for traffic and air quality parameters are important to understand how signal systems and traffic management can continue to be assessed and help accomplish goals for cities for transportation planning and management of the environmental effects of urban roadways.

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