Measuring Exposure of Urban Cyclists to PM2.5 Using an Instrumented Bike

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PRINCIPIA
TCF

Seeing Like a Bike (SLaB)

Road

GPS
3D Accelerometer
3D Gyroscope
3D Magnetometer
Microphone array

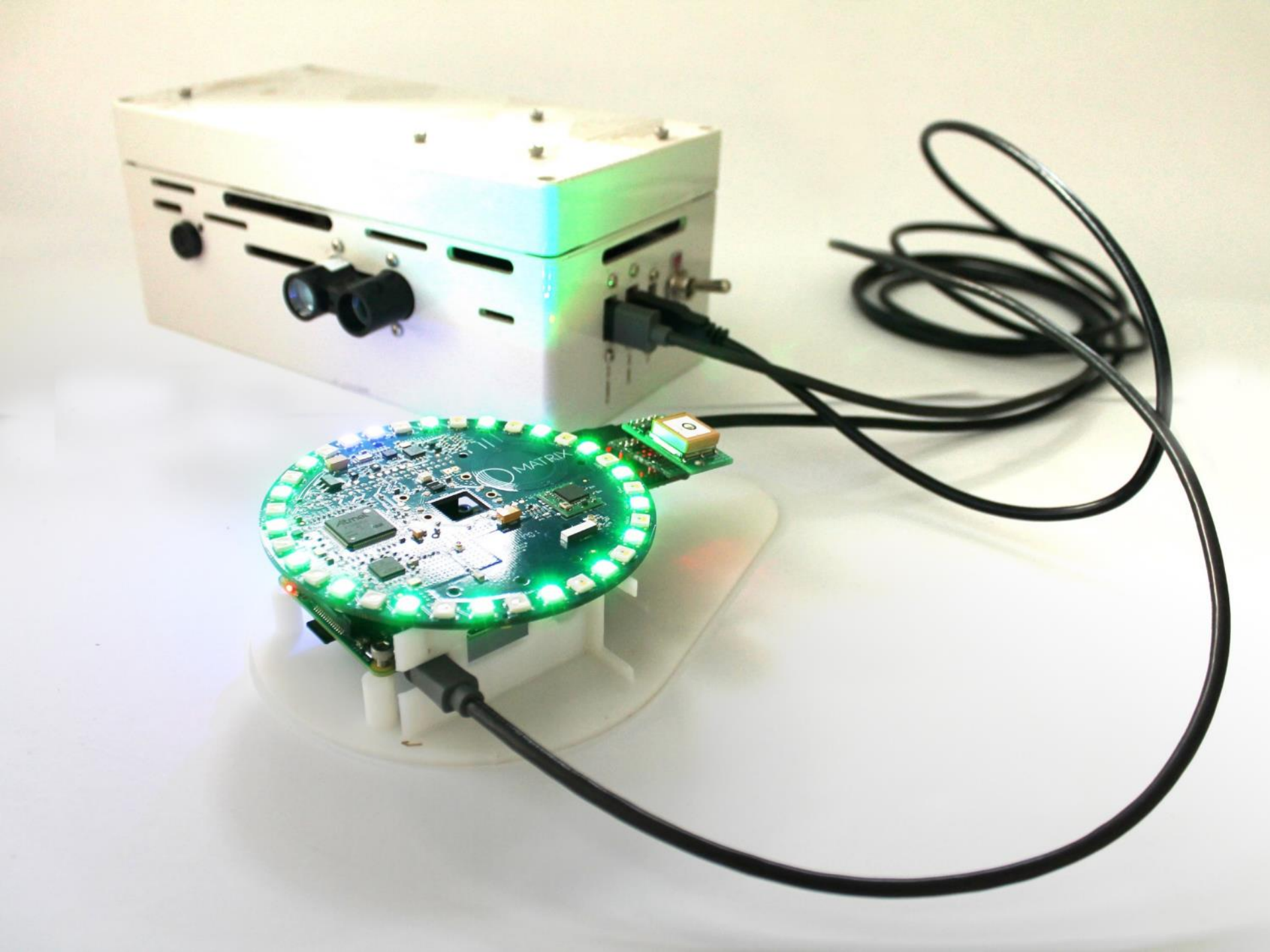
Environmental

Temperature
Humidity
Barometer
UV

Ozone
Nitrogen Dioxide
Sulfur Dioxide
Carbon Monoxide
Particulate Matter

Traffic

2x Lidar Rangefinders
3x Ultrasonic Rangefinders


MATRIX

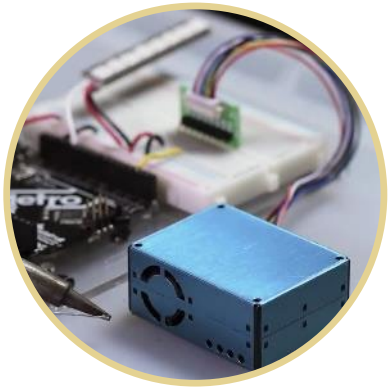
Motivation for Air Quality Project

- Pollutant exposure can be vary significantly depending on mode and route
- Cyclists are vulnerable to particulate matter
- Prolonged or repetitive PM exposure has many adverse health impacts
  - Reduced lung function, asthma, heart attack, and stroke
- Limited research to understand which types of cycling infrastructure may be better or worse for cyclists' health based on PM exposure

Objective for Air Quality Project

To assess the feasibility of
using an instrumented bicycle
equipped with low-cost air quality sensors
to monitor the $PM_{2.5}$ exposure
of cyclists in Atlanta, Georgia

Air Quality Sensors



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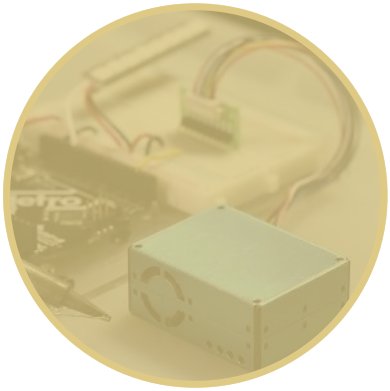
Air Quality Sensors

SLaB Box
Custom collection of environmental sensors



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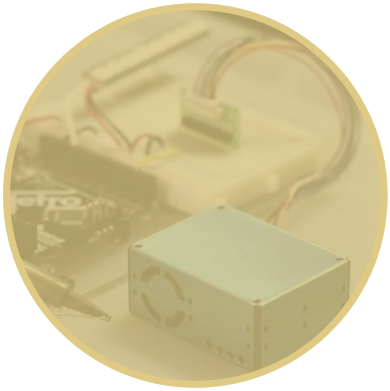
Air Quality Sensors

SLaB Box
Custom collection of environmental sensors

GRIMM
High Quality, Research Grade Air Quality Sensor



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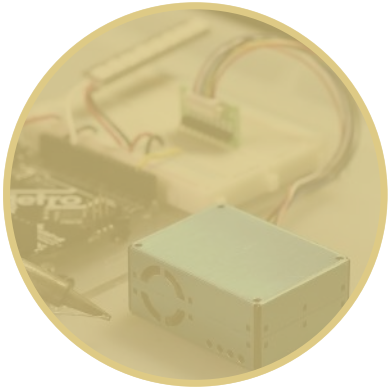
Purple Air
Creating an Air Quality Network using the IoT



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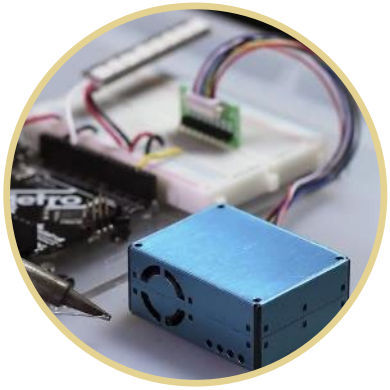

PMS5003
Off the shelf, hobbyist Air Quality sensor

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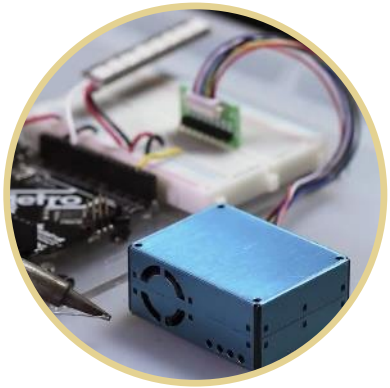
Sensor Selection

- Selected for low-cost and small size
- Facilitated data collection with bicycle
- Had the highest correlation with the expensive commercial-grade sensors used by the EPA



PMS5003
Off the shelf, hobbyist Air Quality sensor

Sensor Calibration

- Stationary comparison of GRIMM 1.109 aerosol spectrometer and Plantower PMS5003 sensors
- Mobile comparison of GRIMM 1.109 aerosol spectrometer and Plantower PMS5003 sensors

Sensor Testing Instrumented Bicycle

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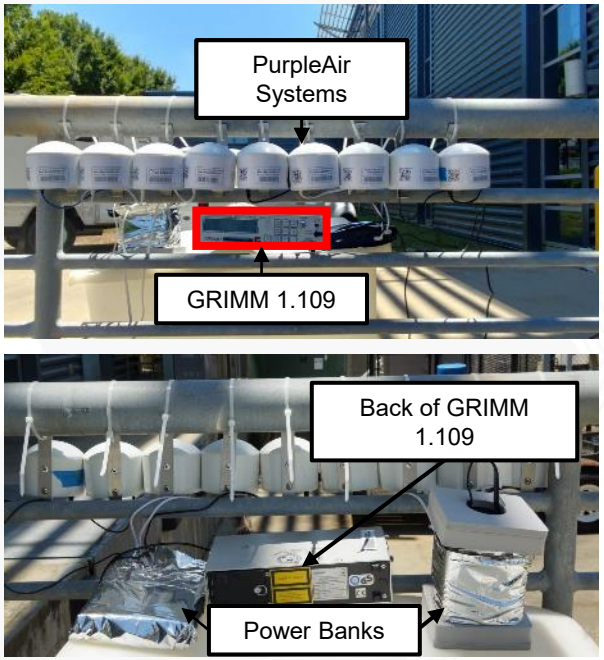
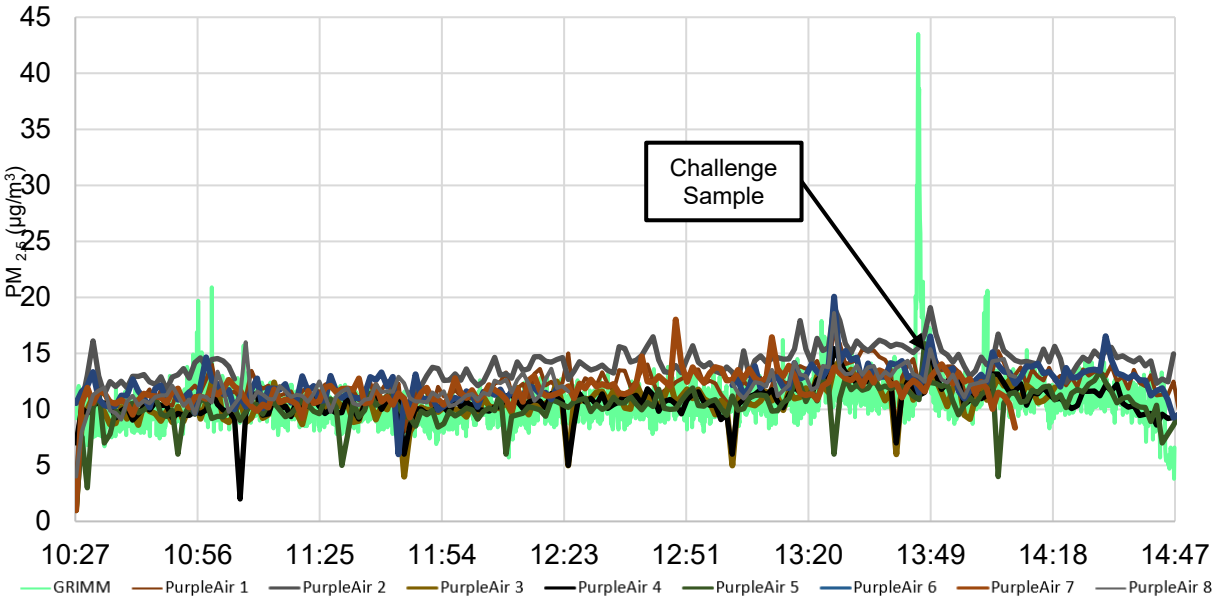
Stationary Comparison



Stationary comparison test configuration



PM2.5 concentrations recorded by GRIMM 1.109 and PMS5003 sensors

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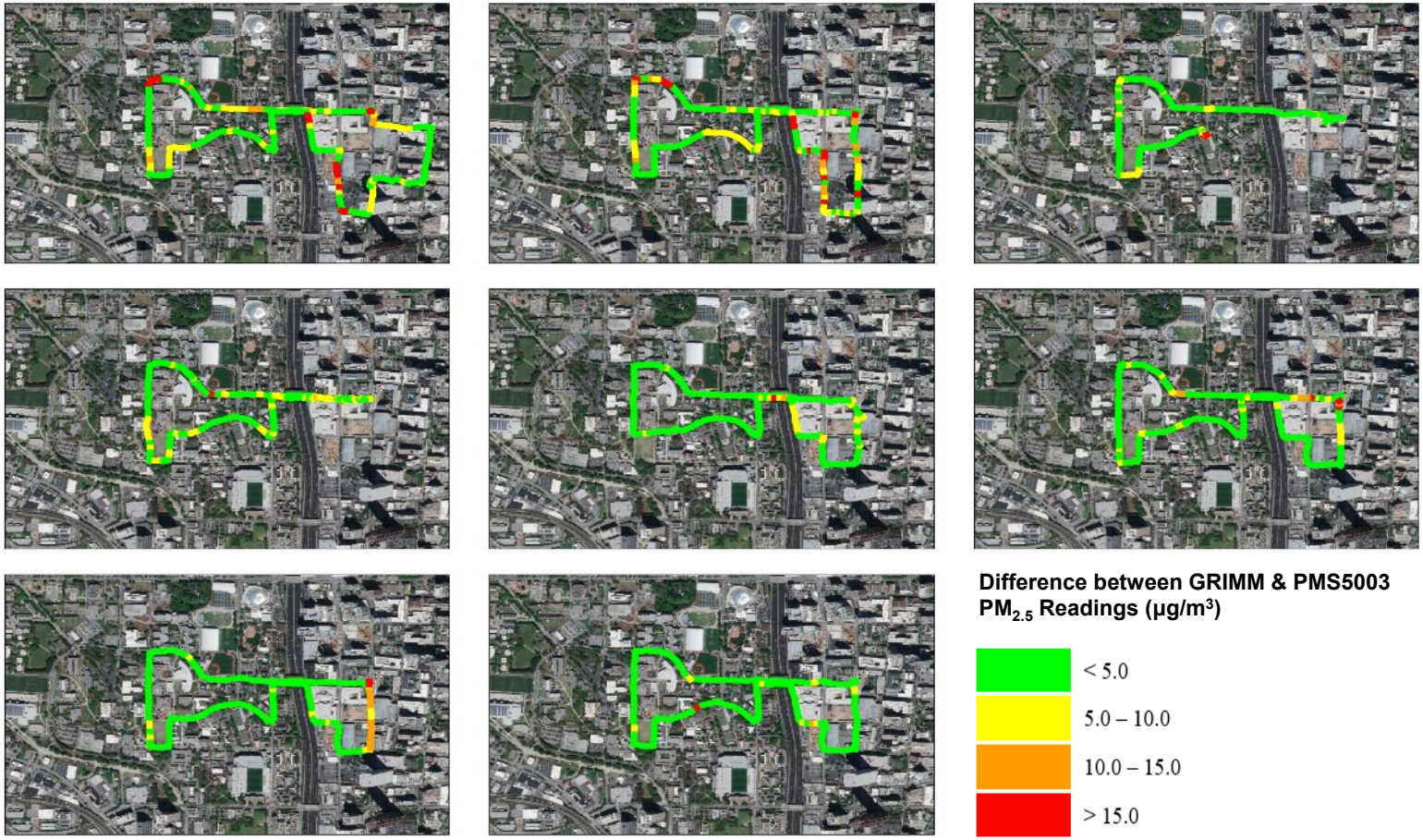
Mobile Comparison



Difference between GRIMM 1.109 and PMS5003 sensor readings during mobile monitoring

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Sensor Calibration Findings

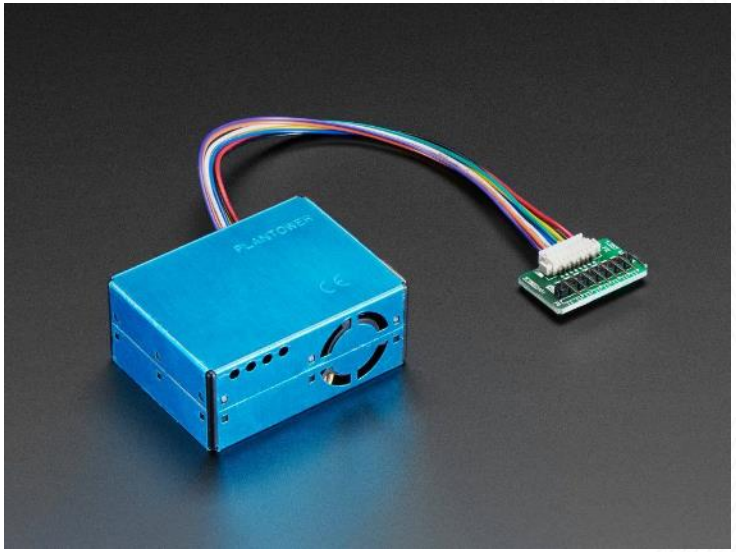
- Stationary comparison
  - Produced similar trends
  - Differed in magnitude of readings and quickness of response
- Mobile comparison
  - Agreed for most distances with some short distances of large variations
  - Low-cost sensors were concluded to be representative of observed patterns

Data Collection Instrumented Bicycle

Front Component
Compute
Functions
Arduino Uno

Rear Component
Sensors
Raspberry Pi

Instrumented bicycle with identified front and rear components



Plantower PMS5003 Digital universal particle concentration sensor

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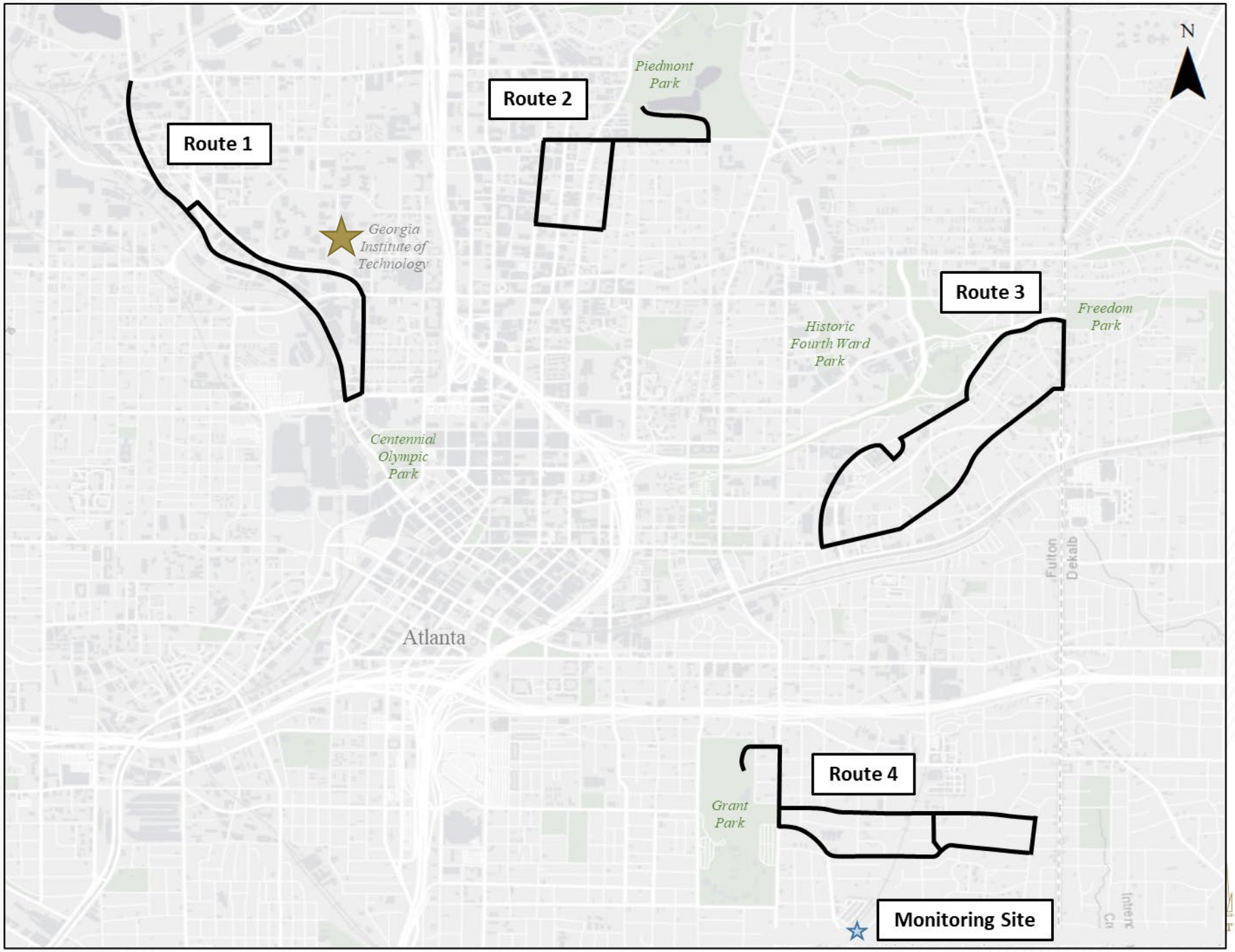
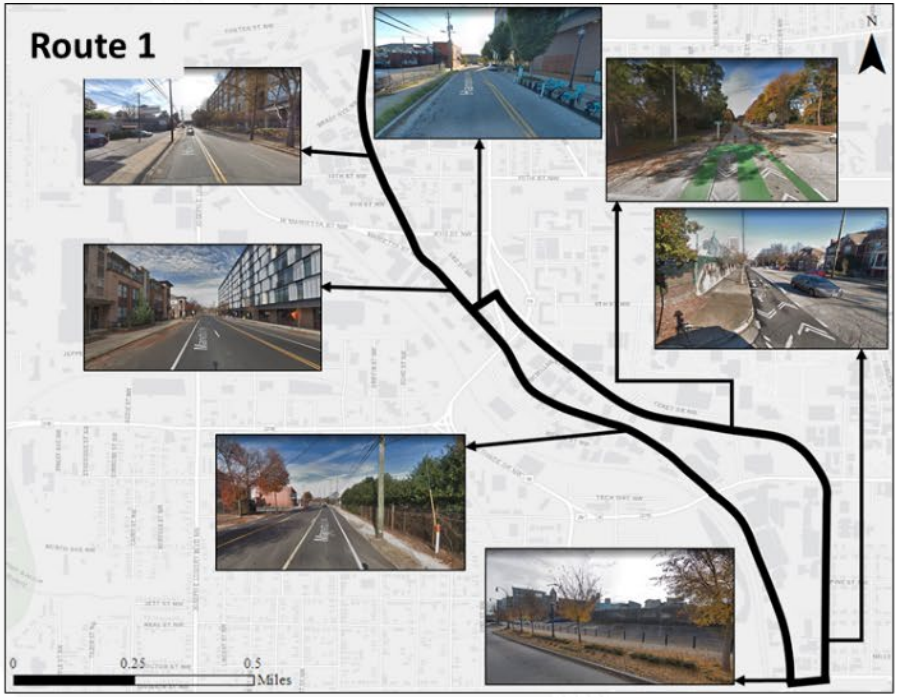
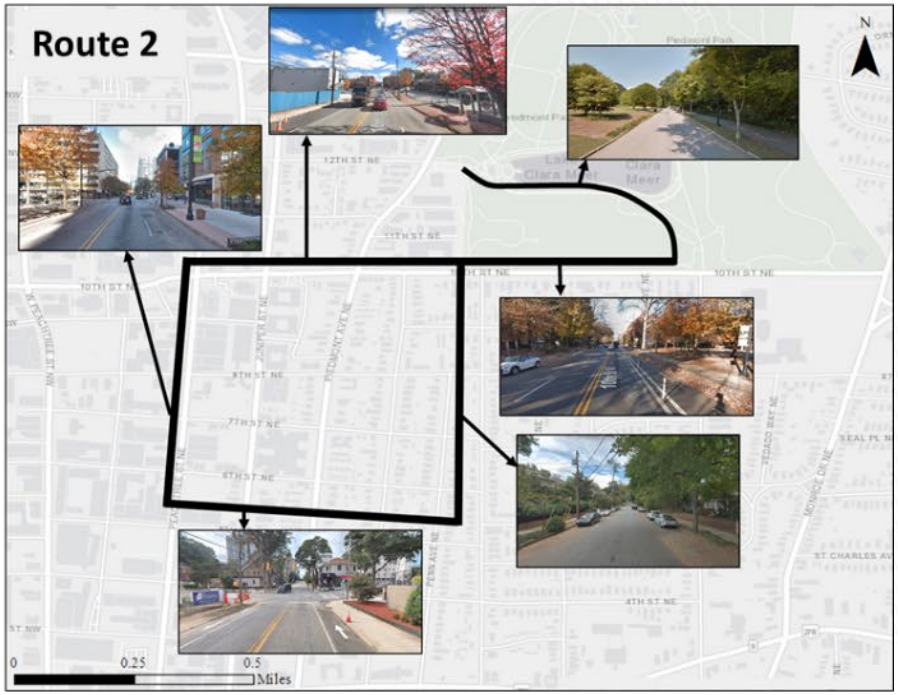
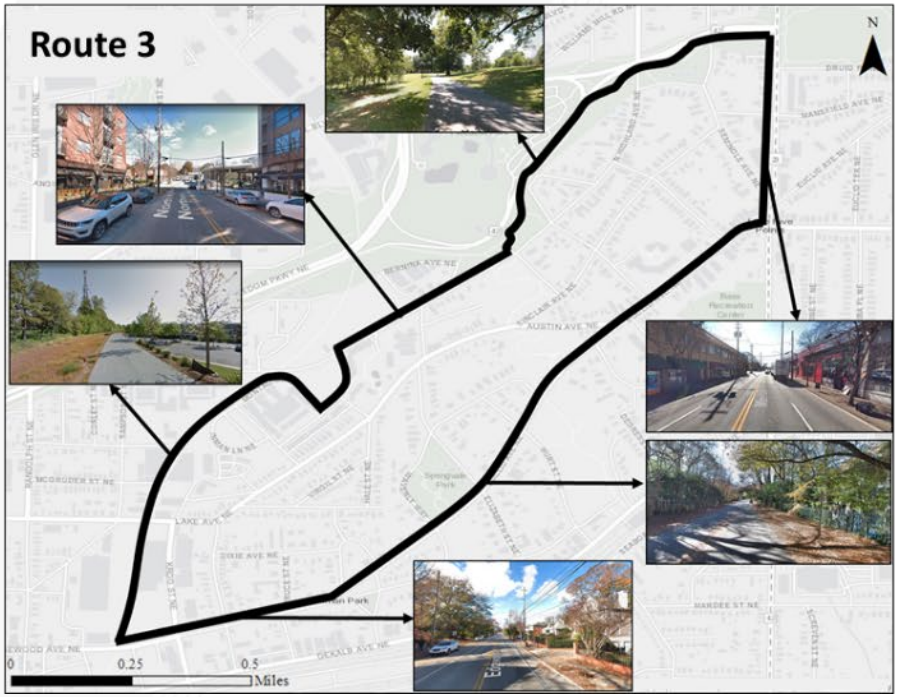
Data Collection

- Monitor PM2.5 along routes composed of different types of cycling infrastructure with an instrumented bicycle
- Map PM2.5 exposure of the different routes to compare types of cycling infrastructure


N
Route 1
Route 2
Route 3
Route 4
Monitoring Site
Piedmont Park
Georgia Institute of Technology
Centennial Olympic Park
Historic Fourth Ward Park
Freedom Park
Grant Park
Atlanta
Fulton
Dekalb

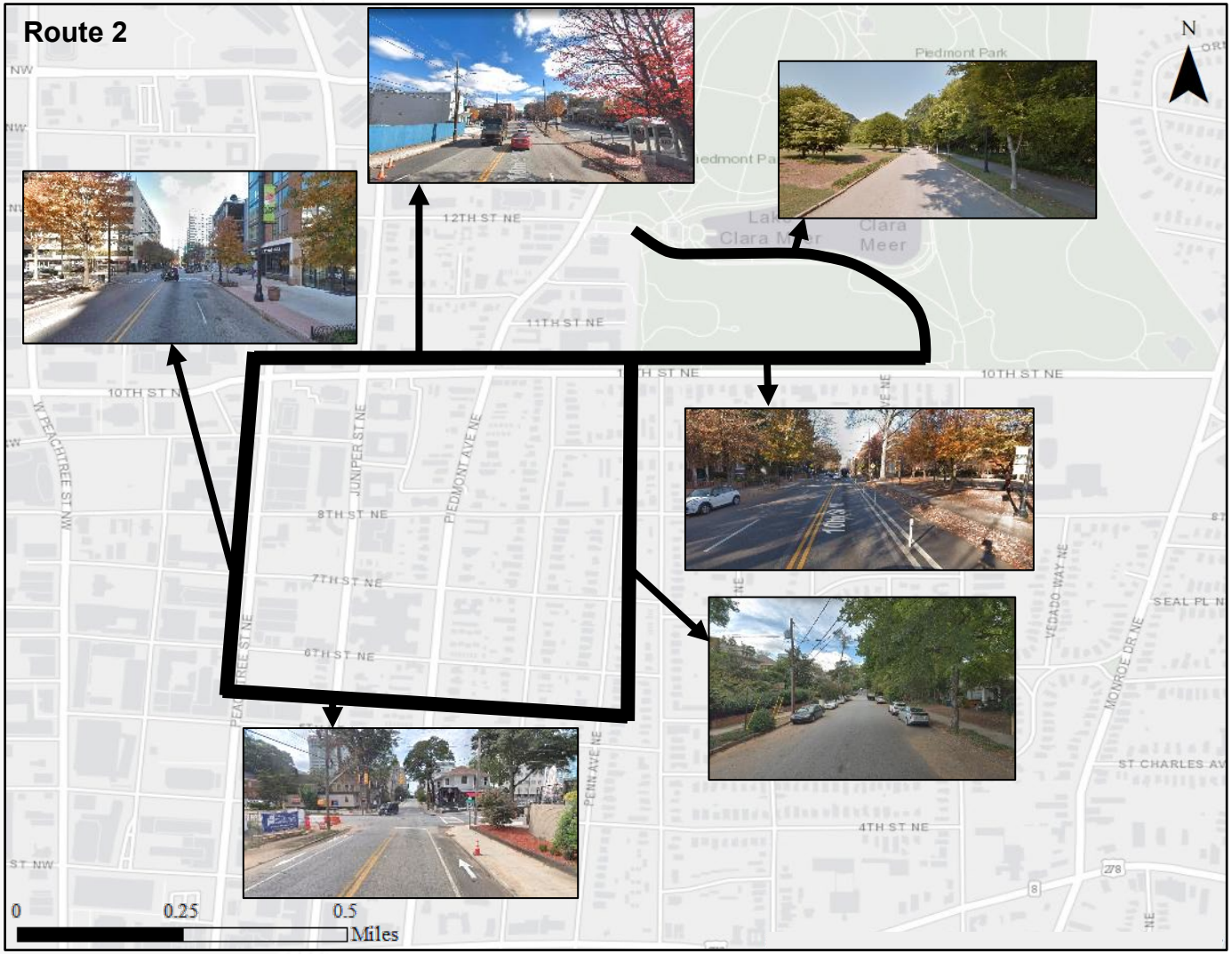

Route 1
N
0
0.25
0.5
Miles


Route 2
N
0
0.25
0.5
Miles


Route 3
N
0
0.25
0.5
Miles


Route 4
N
0
0.25
0.5
Miles

Route 2



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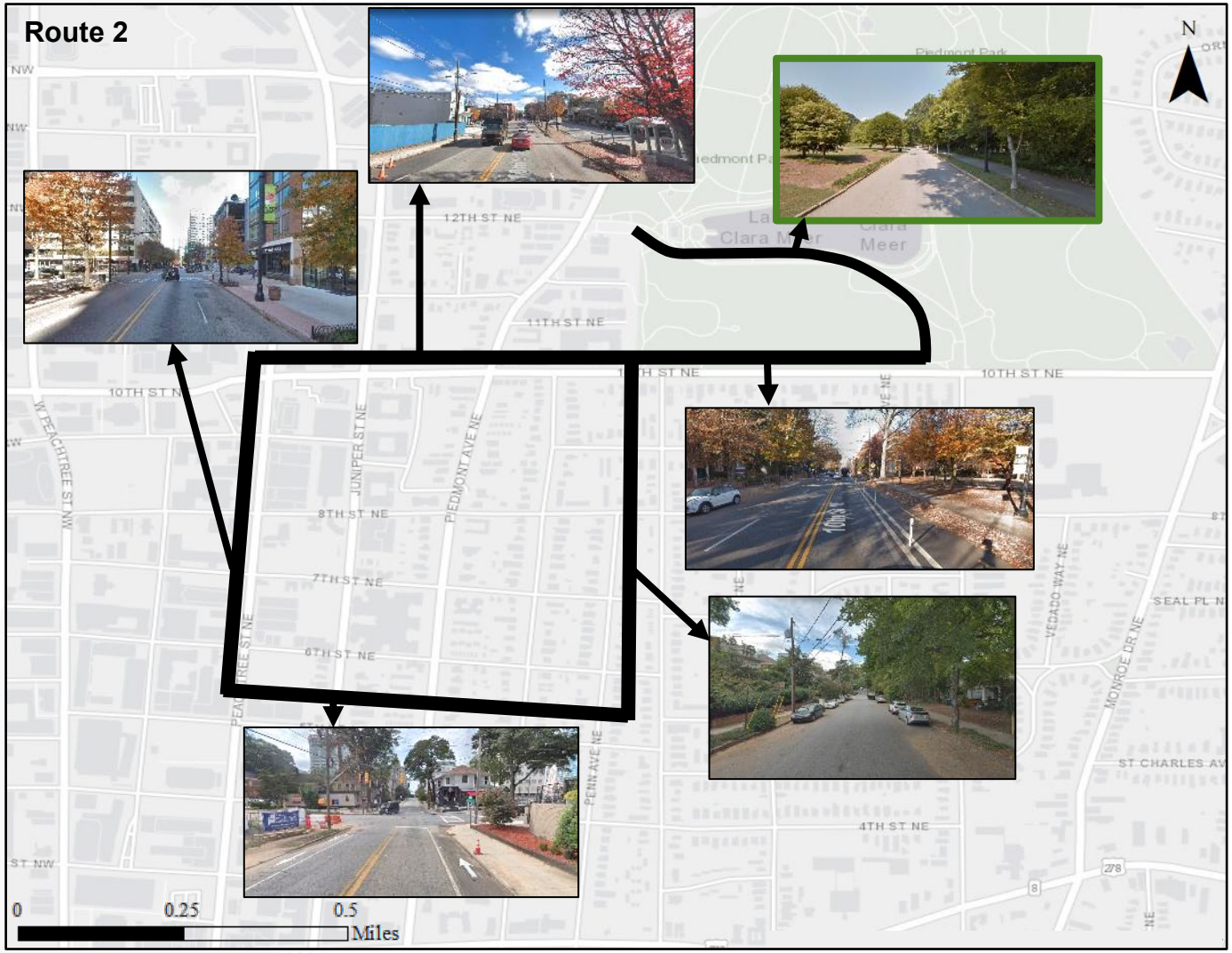

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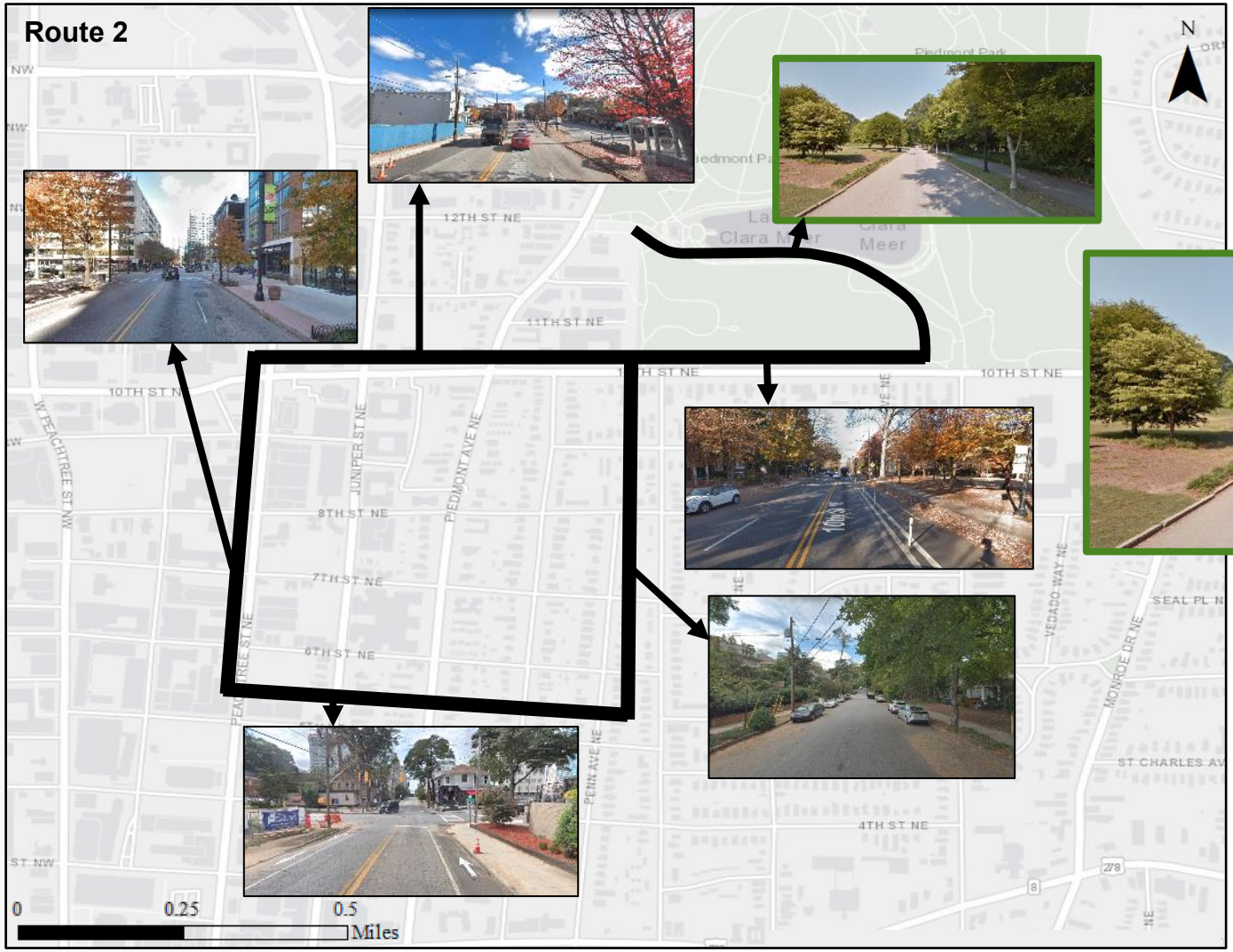

Piedmont Park

Route 2

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10th Street Cycle Track

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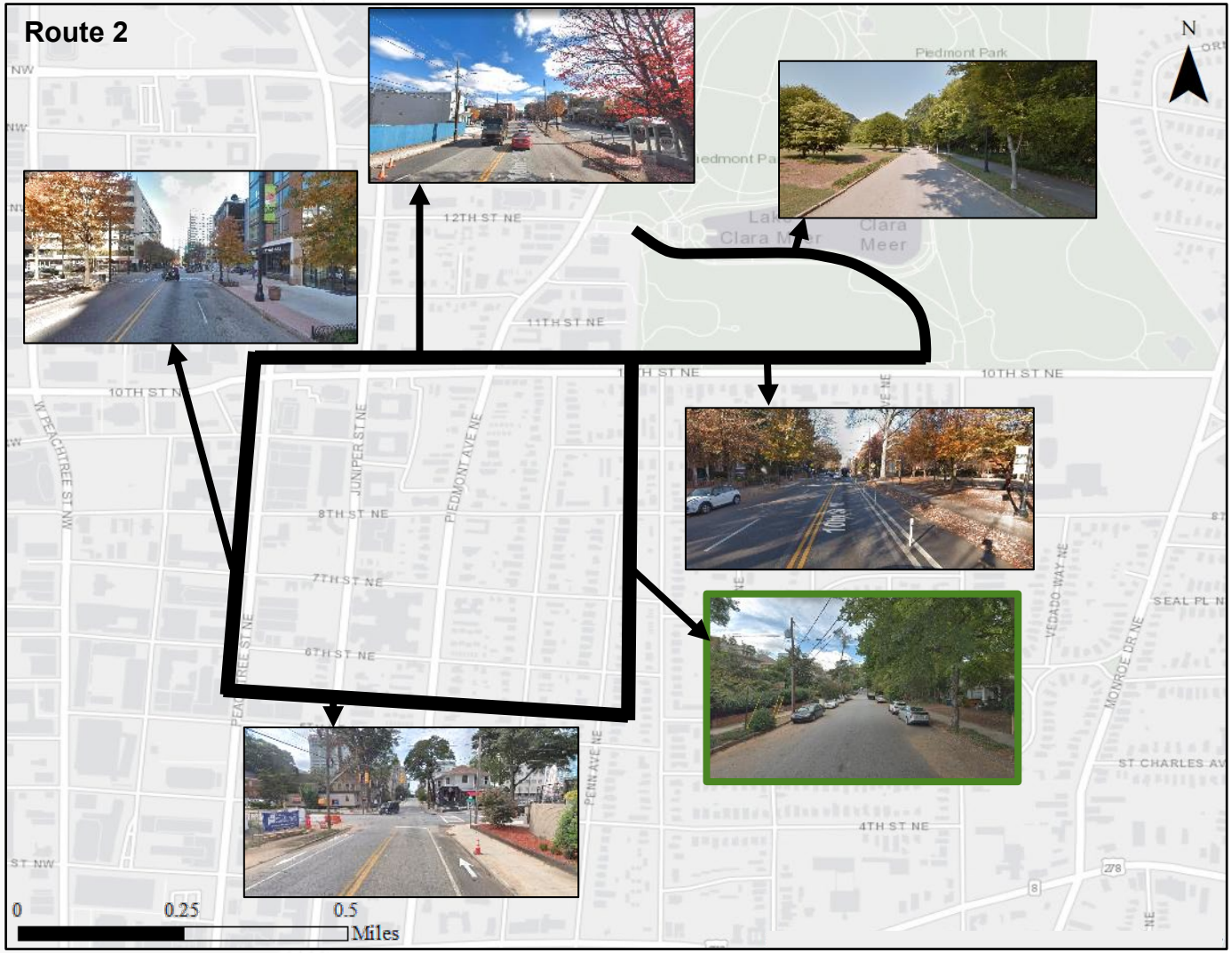

Route 2

Myrtle Street

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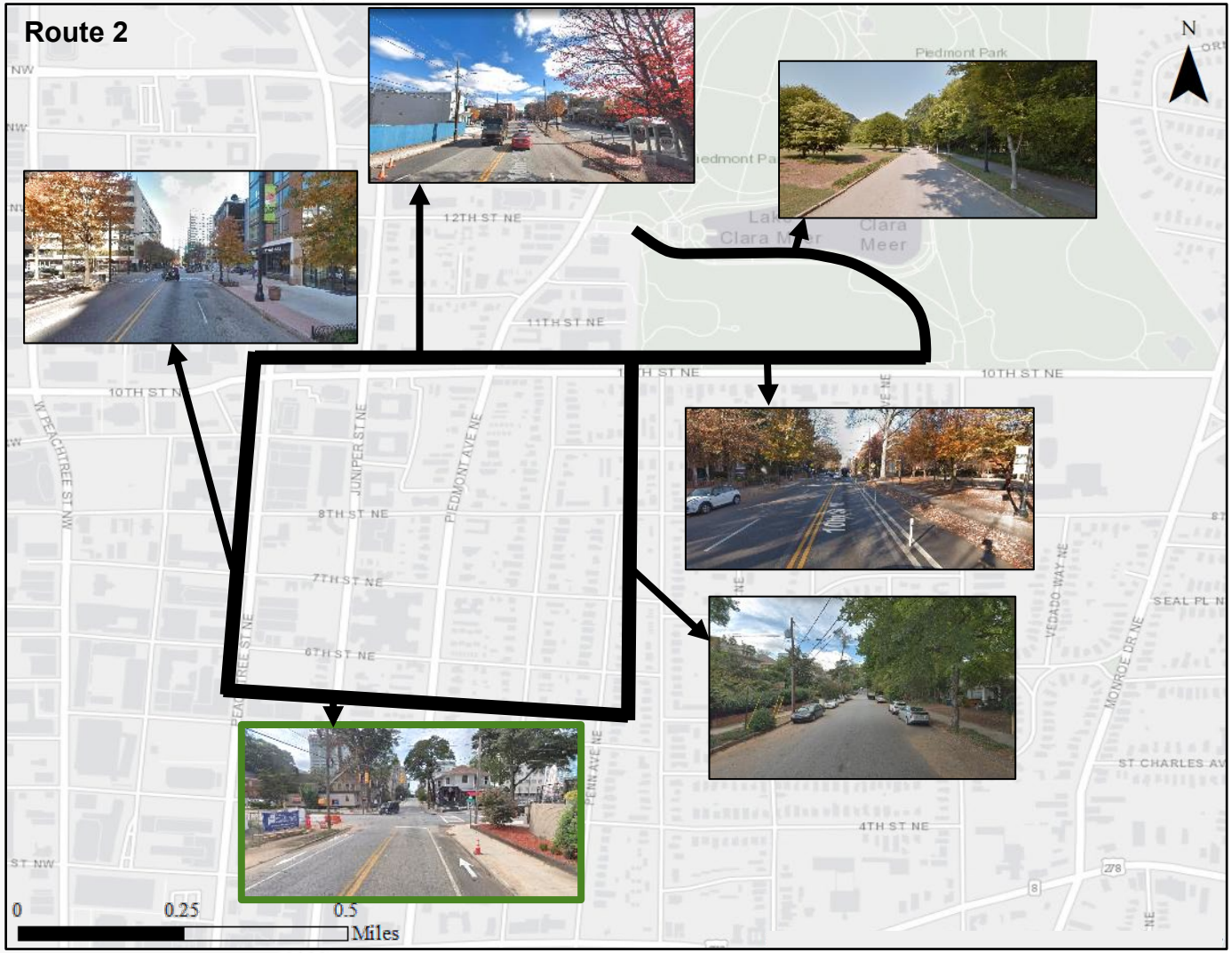

Route 2

5th Street

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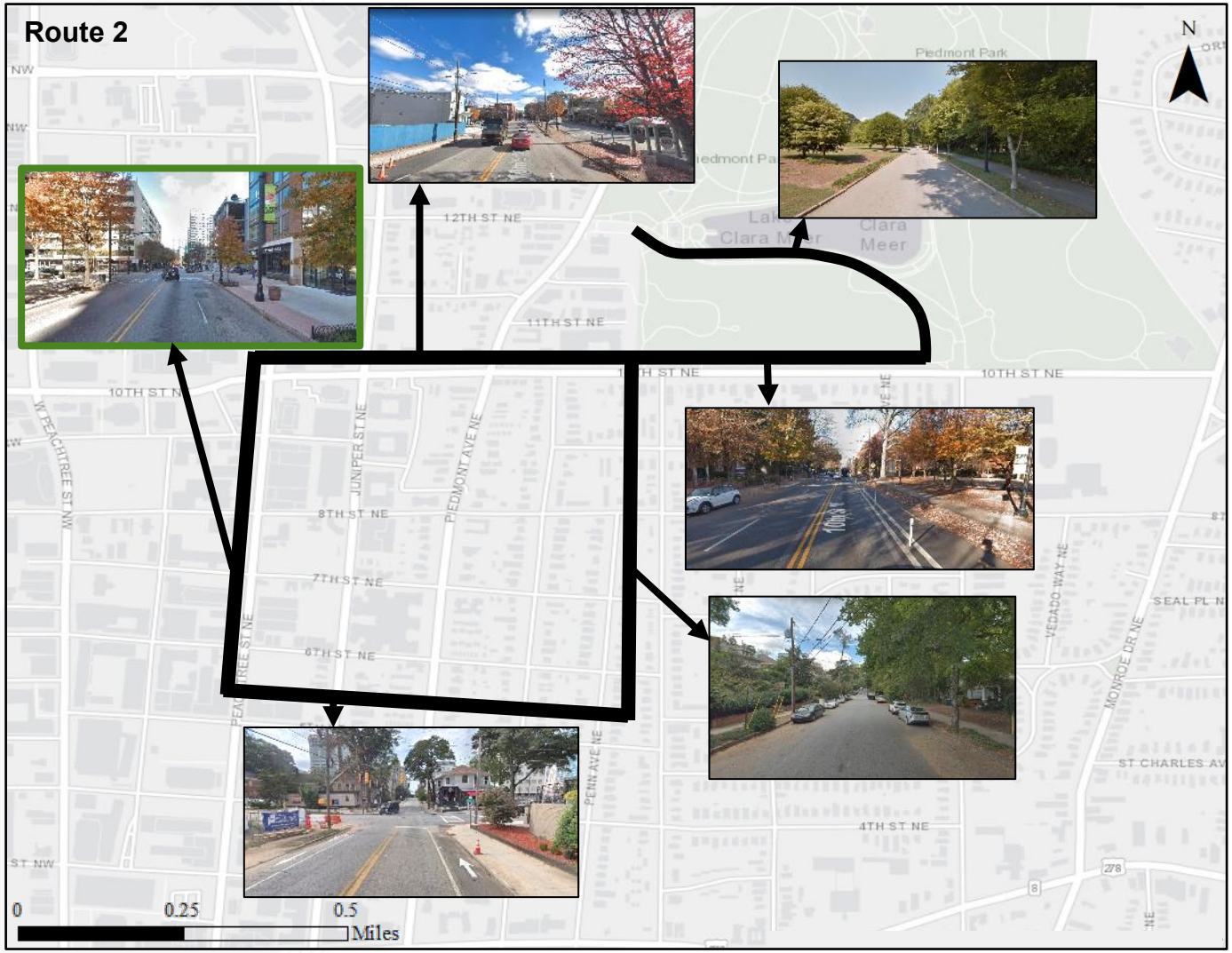
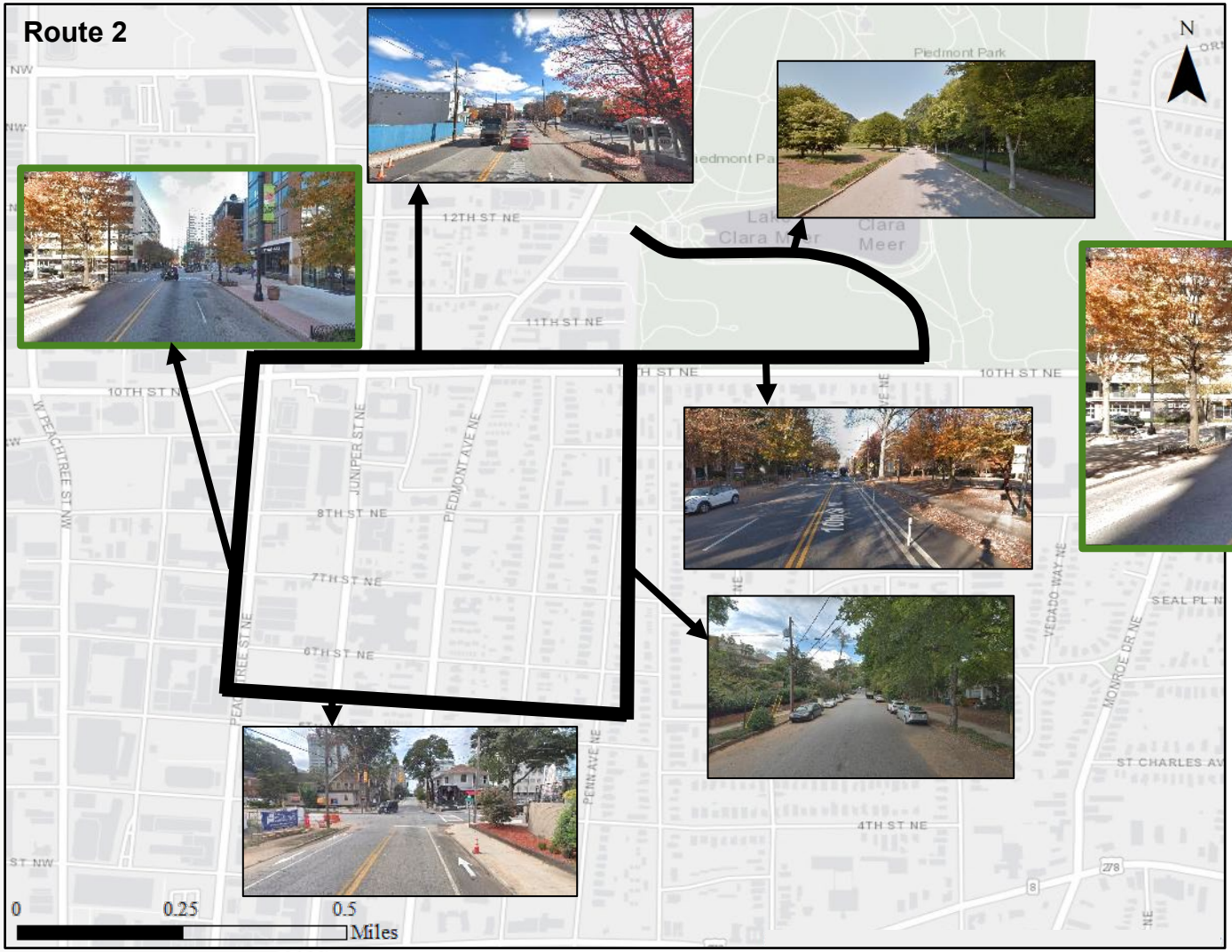
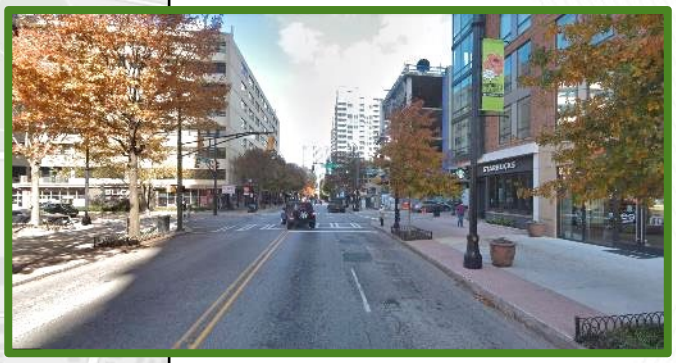


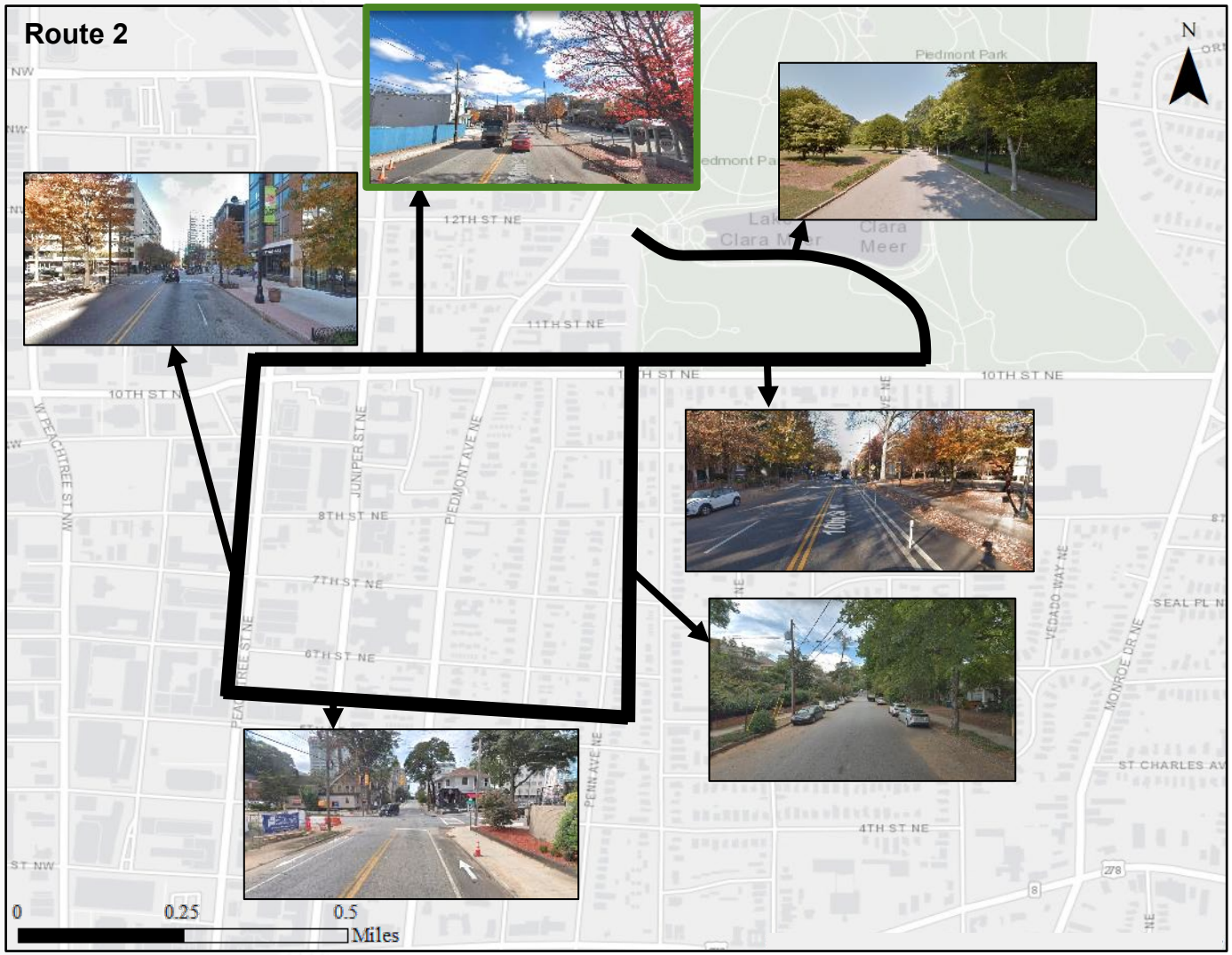
Route 2





Peachtree Street

Route 2



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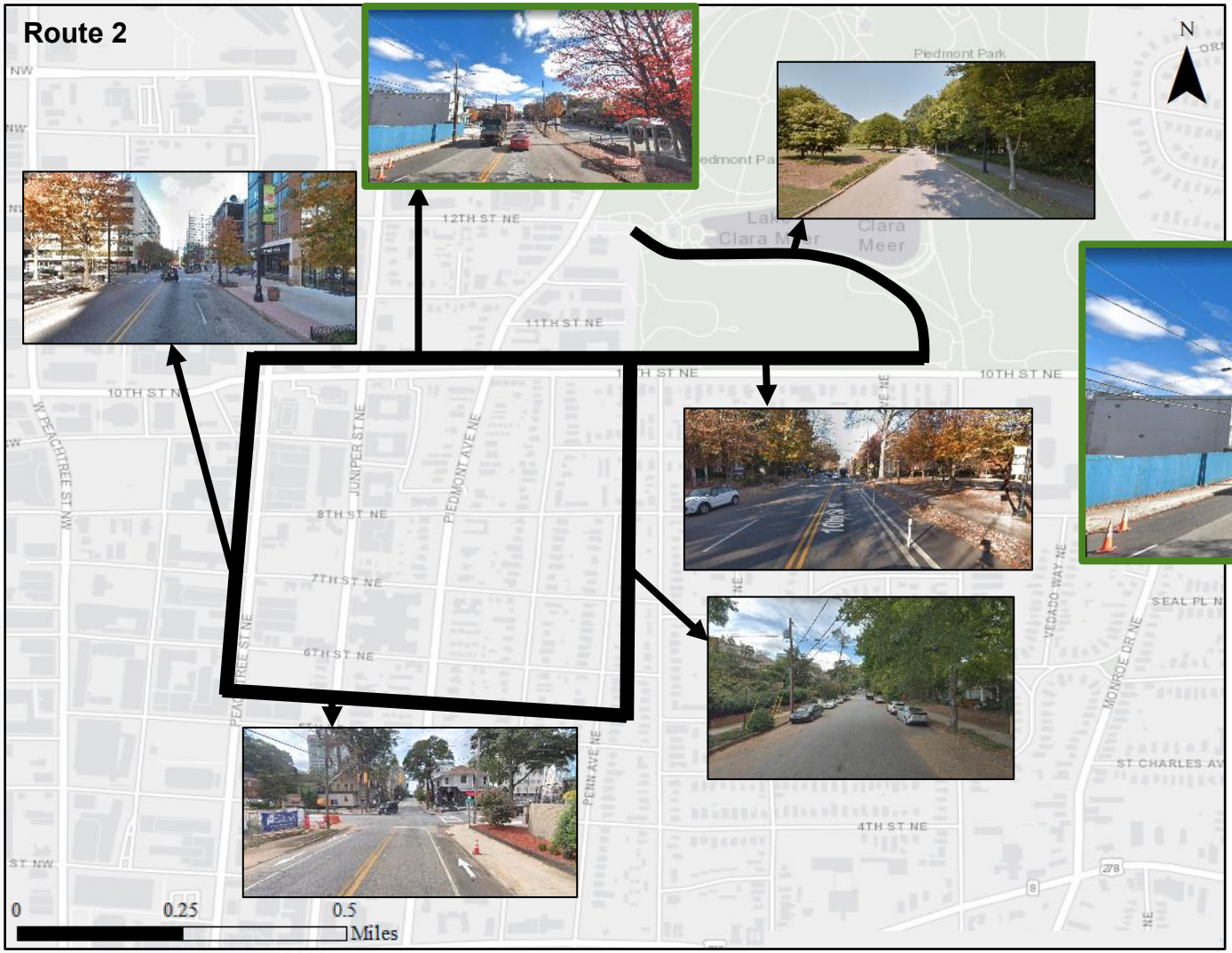
Route 2



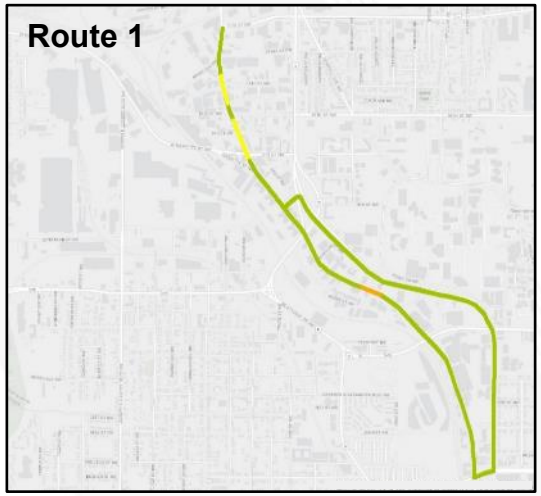
10th Street

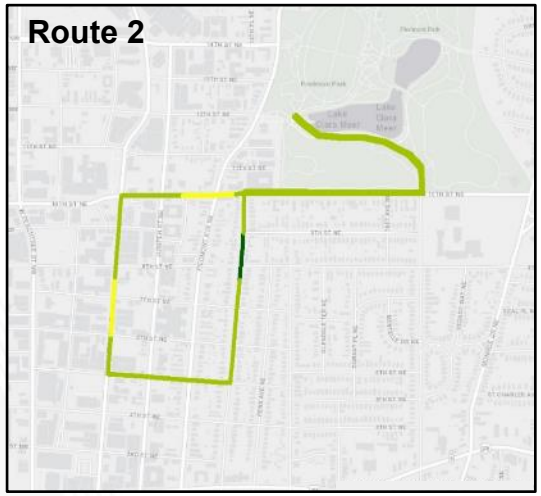
Methodology

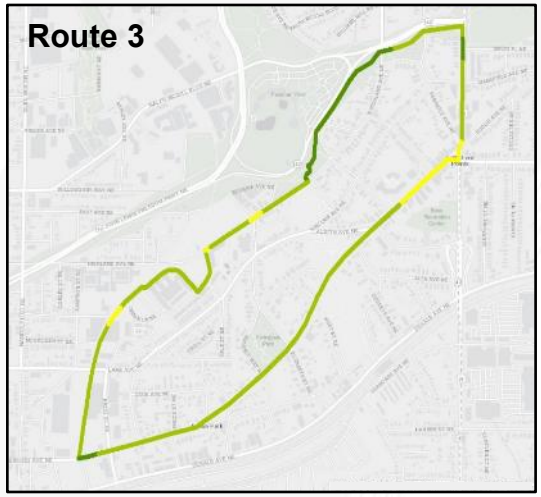
- Participants elected to ride instrumented bicycle on one of four routes
- Each route was completed by at least 5 participants
- 27 runs → 24,000 data points
- Recorded start time, background PM2.5, temperature, wind speed, wind direction, relative humidity

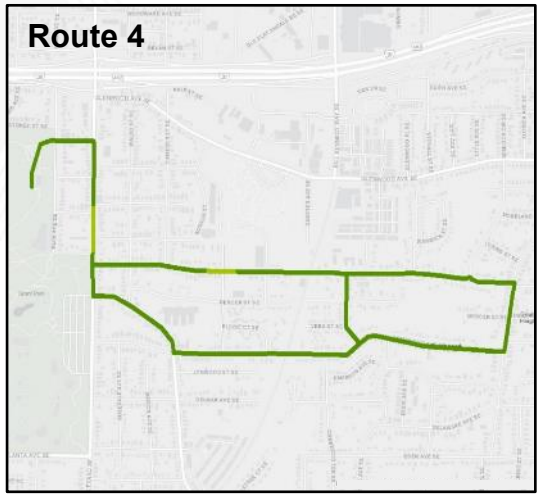
Methodology

- Corrected for background PM2.5 concentrations
- Segmented routes
- Assigned cycling infrastructure type, GDOT roadway functional classification, and land use type to each segment



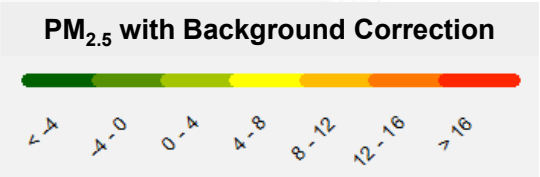






Descriptive Statistics for Routes

Route	Average $PM_{2.5}$ ($\mu g/m^3$)	Minimum $PM_{2.5}$ ($\mu g/m^3$)	Maximum $PM_{2.5}$ ($\mu g/m^3$)	Standard Deviation
With Background Correction				
1	1.82	-5.48	18.96	4.18
2	2.42	-5.22	25.75	3.83
3	2.17	-6.56	13.72	5.17
4	-1.26	-5.79	11.78	3.52
Without Background Correction				
1	7.60	-1.13	25.57	4.02
2	9.45	1.00	32.95	4.55
3	8.53	1.24	22.86	5.67
4	3.80	-1.19	16.88	3.24



Linear Regression for $PM_{2.5}$

Variable	Units	Coefficient		P
Intercept	N/A	-0.17		0.898
Weekday or Weekend	Dummy	3.33	***	<0.001
Time of Day	Dummy	-0.23		0.215
Temperature	°F	0.04	*	0.012
Wind Speed	mph	-0.12	***	<0.001
Relative Humidity	%	0.12	***	<0.001
Cycling Infrastructure	Dummy	-0.58	•	0.056
Minor or Major Road	Dummy	-1.36	***	<0.001
Commercial Land Use	Dummy	2.72	***	<0.001

N=900, R_2 = 0.259

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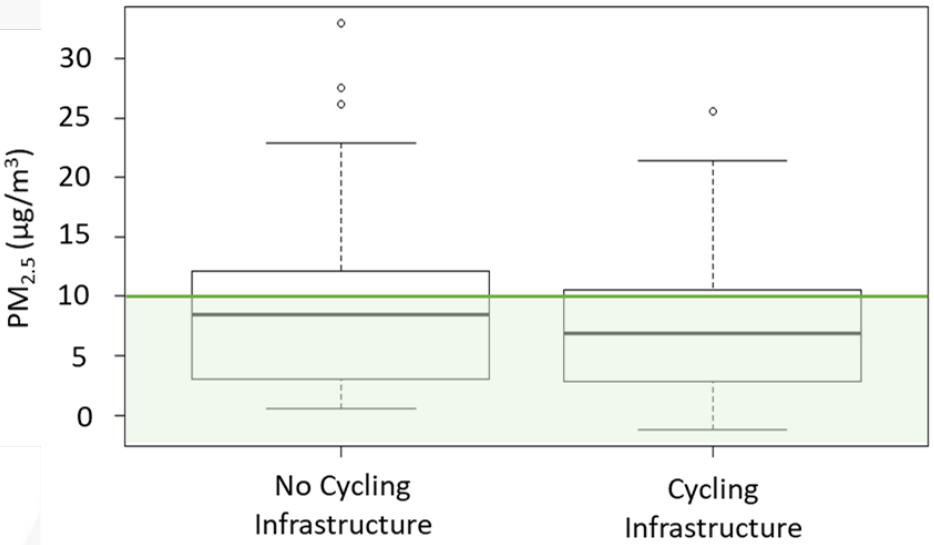
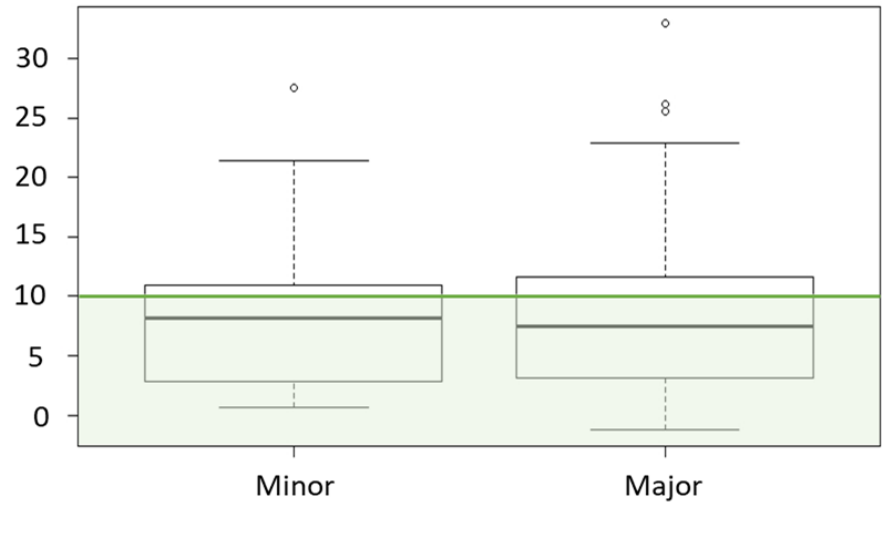
Segmented $PM_{2.5}$ Concentrations

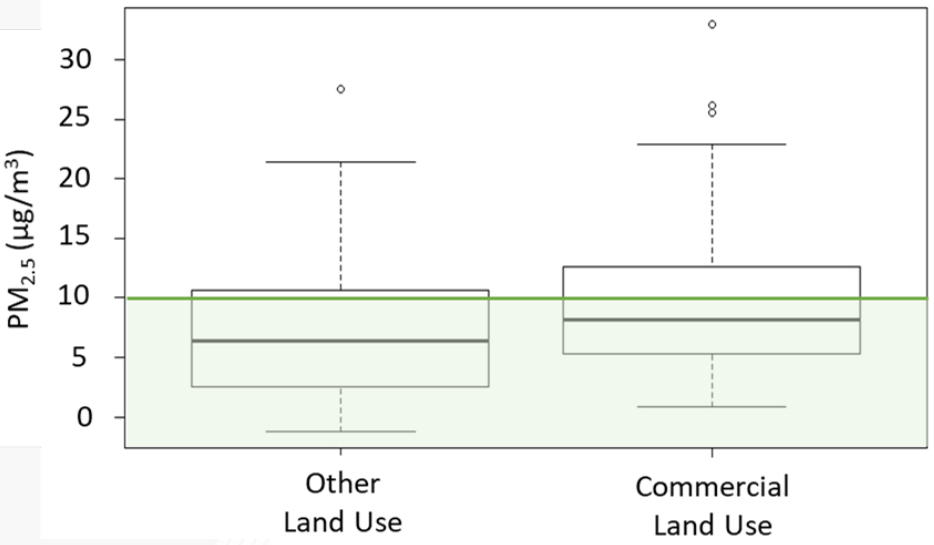
Cycling Infrastructure



Functional Classification



Land Use



Prolonged or repetitive exposure to $PM_{2.5}$ concentrations exceeding 10 $\mu g/m^3$ has negative long-term health effects including reduced lung function, asthma, heart attack, and stroke.

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Conclusions

- Lower $PM_{2.5}$ exposure observed on designated cycling infrastructure and roadways with lower traffic volumes
- Land use, specifically commercial areas, one of the most significant indicators of cyclists' $PM_{2.5}$ exposure
  - Demand for bicycle infrastructure in cities is greatest in commercial areas, where desirable restaurants and businesses are present
- Cyclists' $PM_{2.5}$ exposure more impacted by meteorological variables that lead the background concentration to be higher along the entire route than roadway/traffic characteristics along the route
- Findings in alignment with previous instrumented bicycle studies and pollutant exposure studies of other modes of transportation

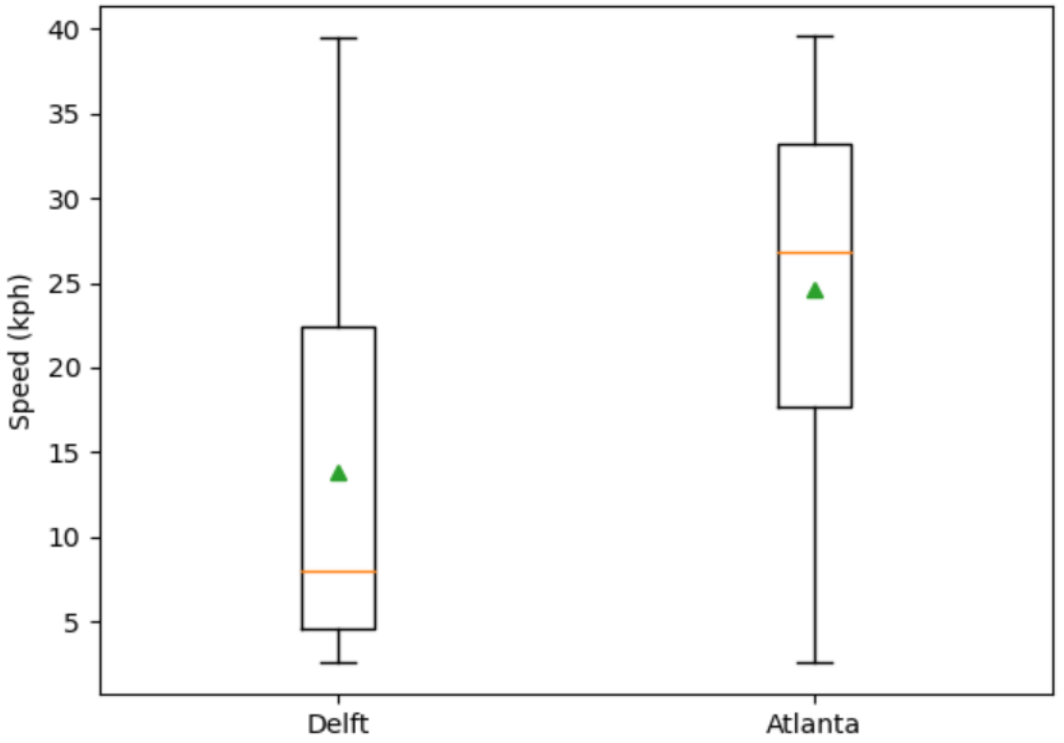
Continuing SLaB Research - Stress and Speed (using GPS)

Causes of Stress

- Speed Differential
  - Delft = 18%
  - Atlanta = 34%

Stress Reducers

- Speed Differential
  - Delft = 29%
  - Atlanta = 41%



Continuing SLaB Research - Close-pass Events (using LIDAR)

Delft	Bus	Distance	Rider Type	"Most drivers don't seem to notice cyclists"	Stress Rating
1	No	850 mm	Strong & Fearless	Disagree	Low
2	No	720 mm	Enthused & Confident	Disagree	Low
3	Yes	580 mm	Comfortable, but Cautious	Strongly Disagree	Moderately Low
4	No	670 mm	Comfortable, but Cautious	Strongly Disagree	Moderately Low
5	Yes	620 mm	Enthused & Confident	Disagree	Low
6	Yes	610 mm	Comfortable, but Cautious	Strongly Disagree	Low
7	Yes	600 mm	Enthused & Confident	Strongly Disagree	Moderately high
Atlanta					
1	No	710 mm	Comfortable, but Cautious	Strongly agree	Moderately high
2	No	900 mm	Enthused & Confident	Agree	High
3	No	710 mm	Strong & Fearless	Agree	Moderately low
4	No	700 mm	Enthused & Confident	Strongly agree	Moderately low

Specific Infrastructure Stressors = Narrow (Delft), No Bicycle Facility (Atlanta)

Continuing SLaB Research - Eye Tracking

Thank You!

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