Harvard John A. Paulson School of Engineering and Applied Sciences

Northeastern University

Rethinking Quality Metrics for Equitable Low-Cost Urban Sensor Networks

Alex Cabral, Harvard University, acabral@g.harvard.edu

Jim Waldo, Harvard University

Amy Mueller, Northeastern University

WBEZCHICAGO

Little Village residents install air sensors to monitor neighborhood pollution

Residents say the city isn't doing enough to protect them from nonstop t
and industry, so they're taking matters into their own

Air quality monitoring program advances environmental justice for Latinos in east Las Vegas

KTNV LAS VEGAS

Monday, May 16, 2022 | The Hardest-Working Paper in America | 75°/49° Forecast, Page 24

CHICAGO SUN-TIMES

CHICAGO'S BAD AIR HOTSPOTS

New sensors reveal gulfs in pollution between neighborhoods PAGES 8-11

Colorado pursues better air pollution monitoring in 'disproportionately impacted communities'

DENVER abc

Grist

Low-cost sensors are helping communities find gaps in air quality data

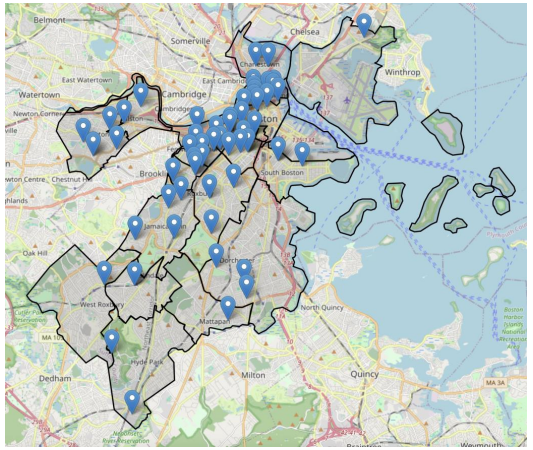
From Ohio's fracking fields to California's oil refineries, residents are tracking pollution missed by the EPA.

Hyoung Chang/MediaNews Group/The Denver Post via Getty Images

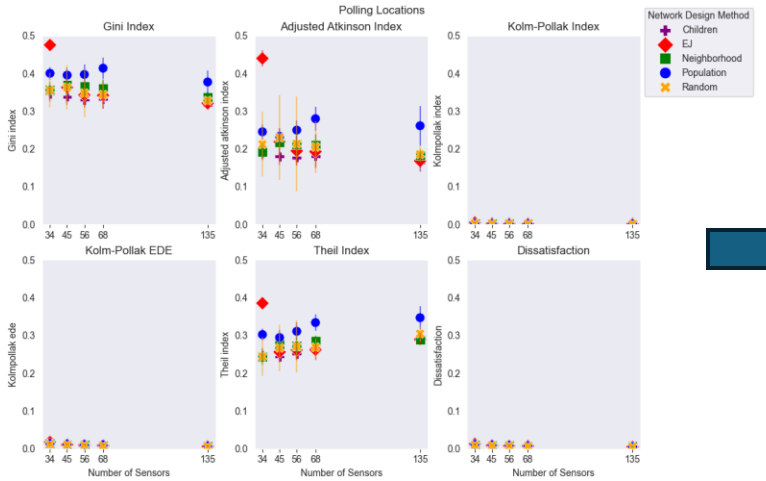
Can we measure equity?

- *Equity* does not have a clear definition (Levy, et al., 2006)
- Inequality is often used as a proxy metric to identify and measure equity or inequity (Logan, et al., 2021; Sheriff & Maguire, 2020)
- Recommendations on how to choose metrics for environmental health applications (Levy, et al., 2006; Sheriff & Maguire, 2020)
- Unclear how the different inequality metrics perform in practice

Approach

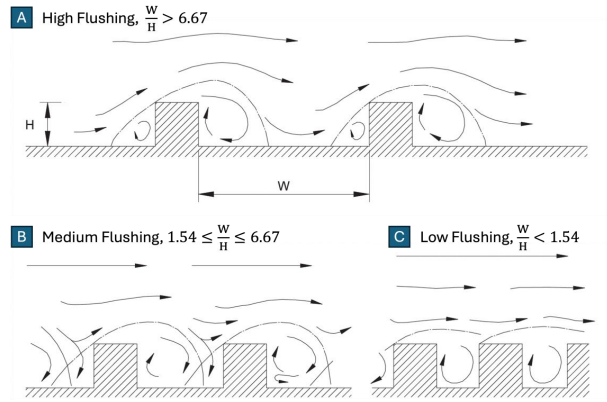


Simulate sensor network placements



Explore quantifiable differences in inequality metrics

- How does the design process affect metrics?
- How does the metric choice affect perception of network design quality

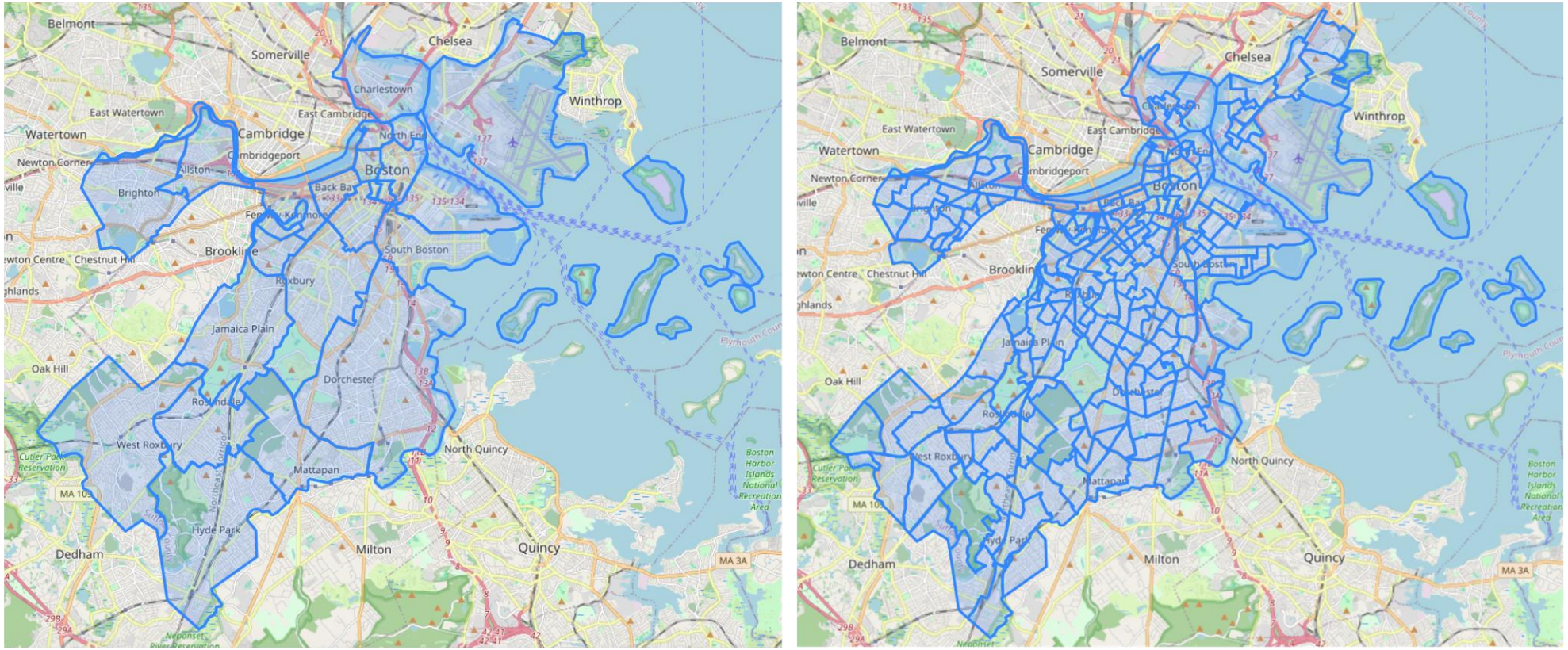


Reflect on which additional urban factors can help drive equitable sensor network design

Current Sensor Placement Strategies

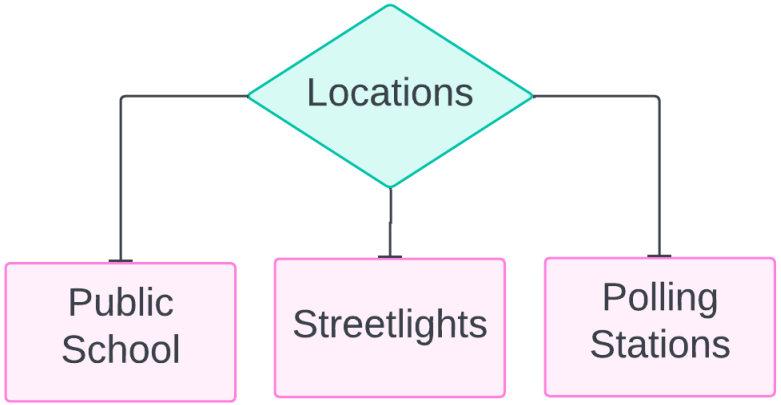
- Permissions are a major constraint
  - Work with a single organization
- Common goal to have a sensor in every neighborhood
- Optimize sensor placement based on demographics
  - Gathered from US Census data

Boston Neighborhoods and Census Tracts



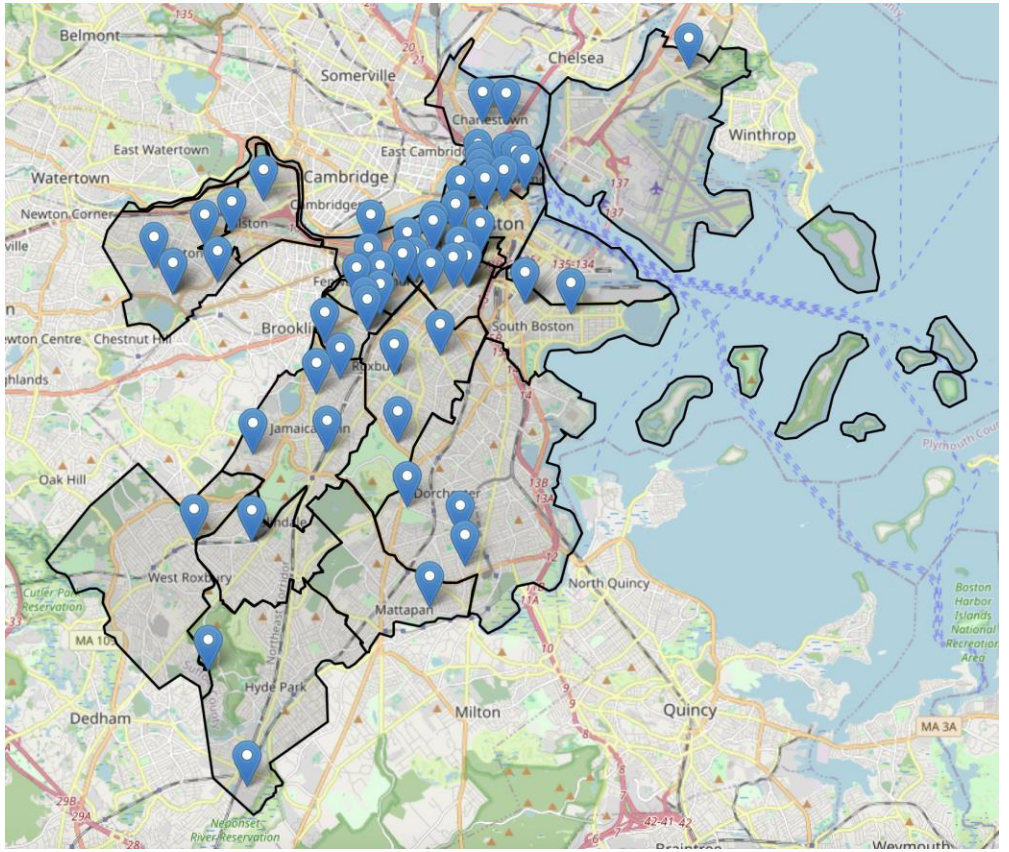
Based on data from Analyze Boston

Simulated Sensor Placements



Example of Simulated Design Output

- 68 sensors
- At polling stations
- Placed based on population density



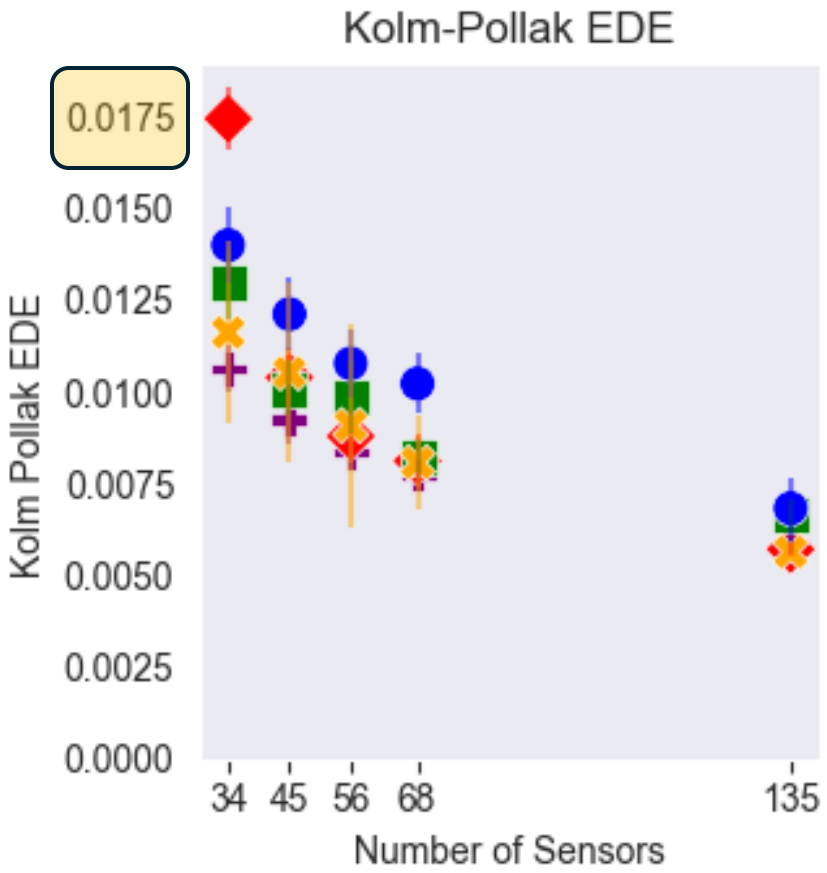
Inequality Metrics Analyzed

- Gini Index:
- Atkinson Index:
- Kolm-Pollak Index
- Kolm-Pollak Equally Distributed Equivalent (EDE)
- Theil Index:
- Citizen Dissatisfaction (Sun, et al., 2018)

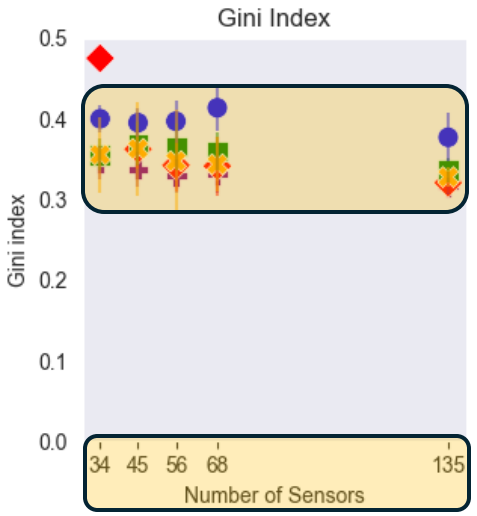
- 0: the most equal distribution
- 1: most unequal distribution

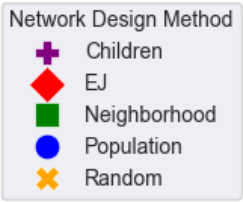
- Minimum distance to a sensor
- Weighted per census tract
  - Population
  - Race

Results


Kolm-Pollak EDE
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
Kolm Pollak EDE
34
45
56
68
135
Number of Sensors

Results

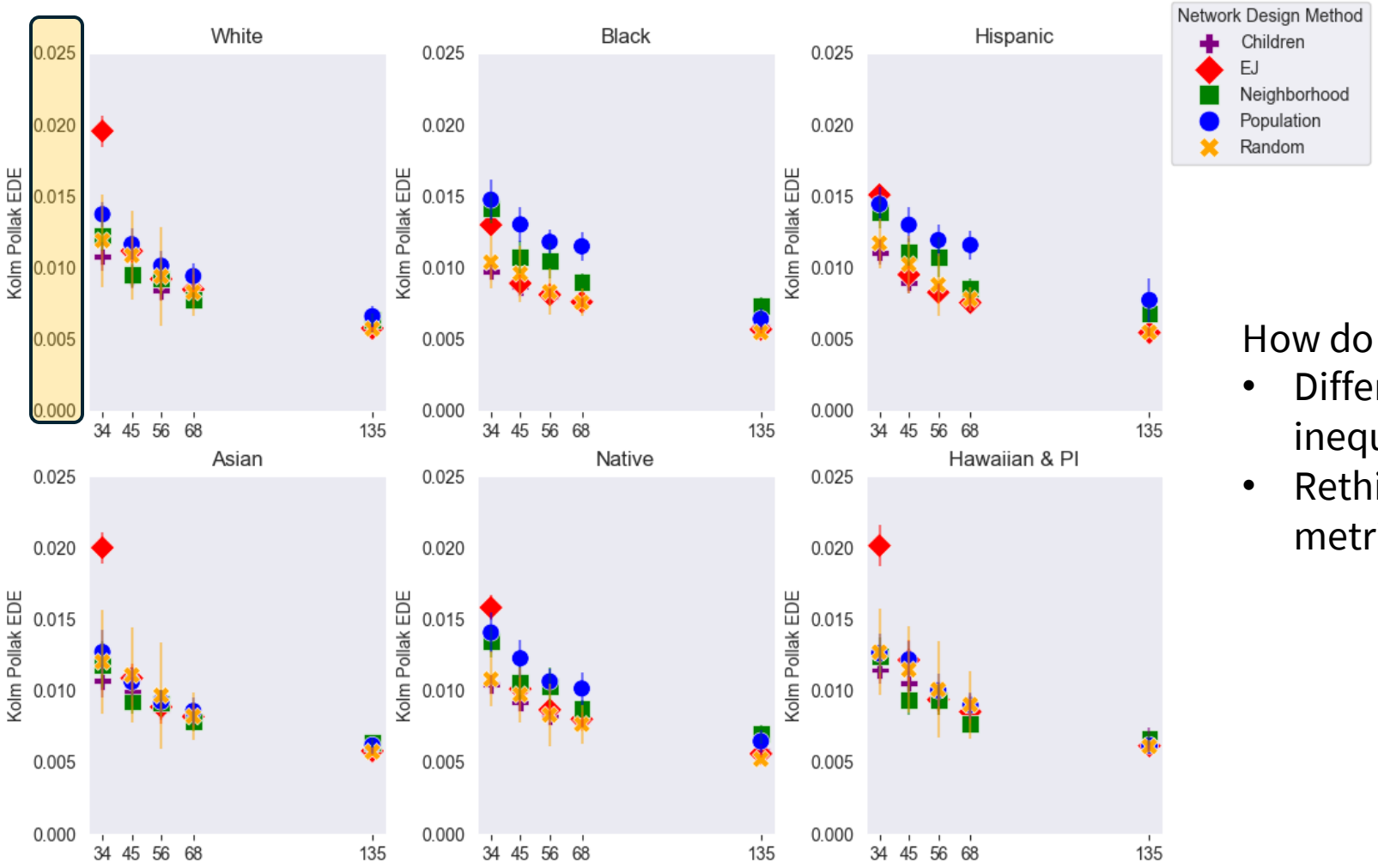




More equal

Results by Race

More equal

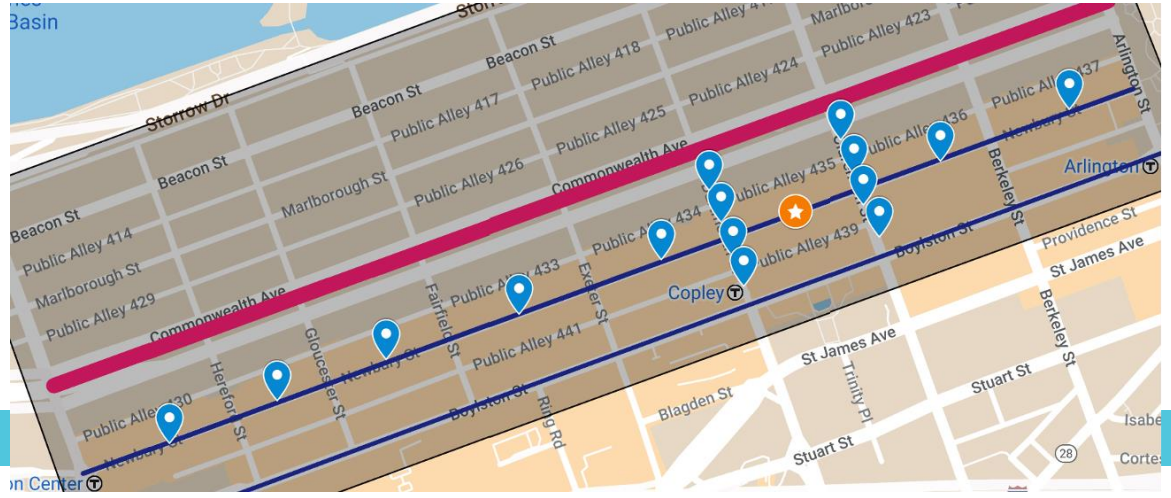


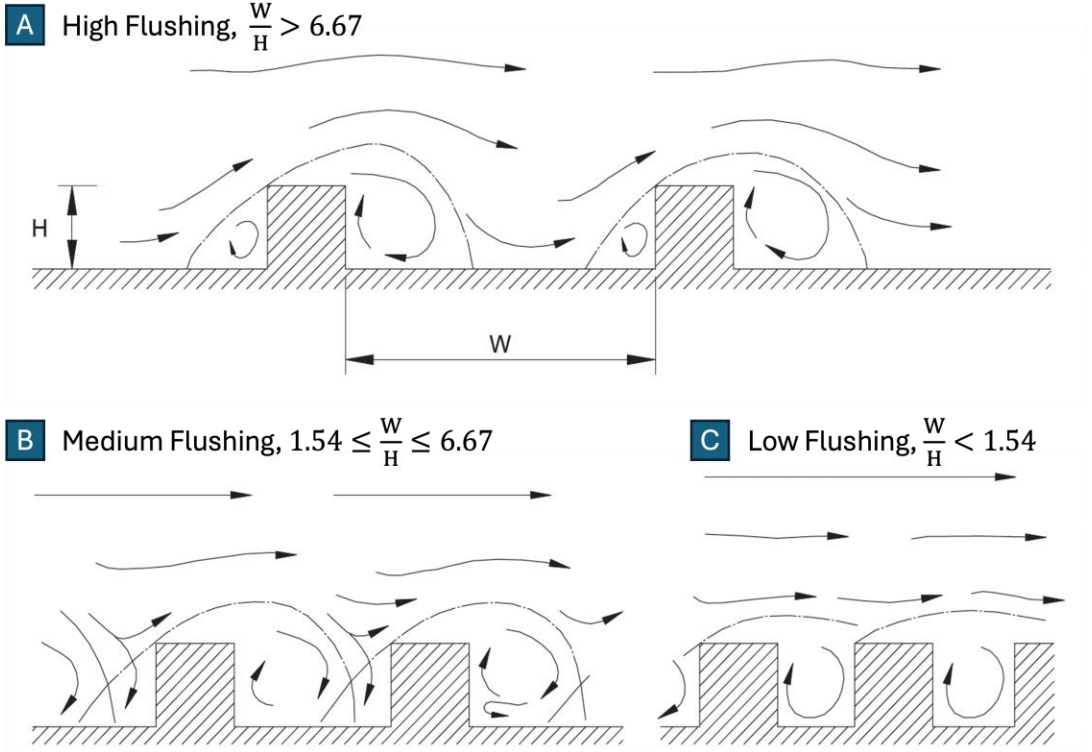
How do we move forward?

- Different inequality or inequity metrics
- Rethink parameters for the metrics we are using

What can we learn from urban form?

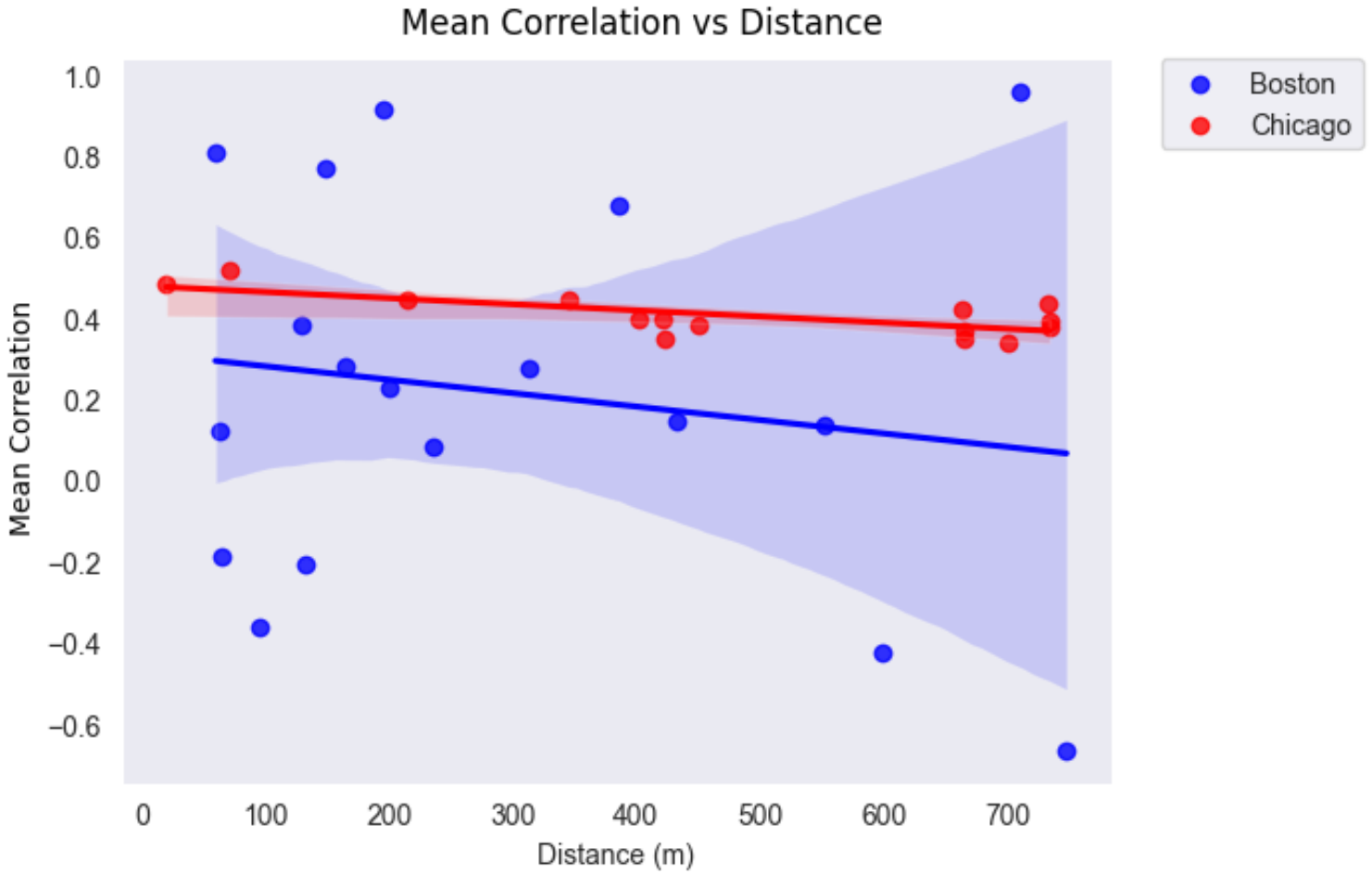
- Examine correlation between $PM_{2.5}$ readings at multiple locations as function of urban form
- Dylos DC1700 laser particle counters
- 3 study areas with mix of canyon ratios and grid layout





Adapted from Yoo, et al., 2006

The Role of Urban Form in Designing for Equity



- Need more sensors on low canyon ratio streets to capture heterogeneity?
- Less about distance, more about what is between person and sensor
- Dependent on how the streets are used

Towards Quality Metrics for Social Equity

- Equity must be defined for the local context *before* a network is designed
  - Might not have a mathematical model stakeholders agree on
  - Are these income-based metrics serving our needs?

- Knowledge about a city and its people is necessary to:
  - Design networks that achieve equity goals
  - Compare different designs and tradeoffs

Email: acabral@g.harvard.edu