A Community-Engaged Process Toward Cost-Effective Solution-Centered AQ Sensor Network Design and Operations

Amy Mueller, Associate Professor, Northeastern University
Mars Keesey, iSUPER Research Technician, Northeastern University
Yasser Aponte, iSUPER Community Partnerships Manager, Northeastern University
John Balaguer, Undergraduate Research Assistant, Northeastern University
Nicolas Minutillo, iSUPER Principal Software Engineer, Northeastern University
Dan O'Brien, Professor, Northeastern University

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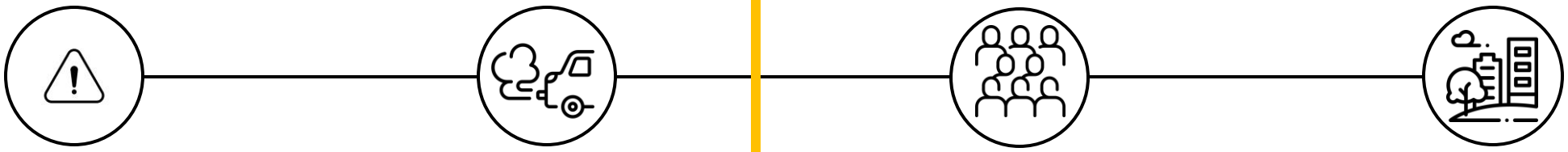
What is the (real) problem?

AIR IS A SHARED RESOURCE

AIR POLLUTION IS AN URBAN HAZARD



Air pollution is the world's LARGEST ENVIRONMENTAL HEALTH RISK

Air quality can vary BLOCK-TO-BLOCK

Communities deserve NEIGHBORHOOD SCALE AIR QUALITY to be a DECISION METRIC

City-level planning could benefit from TOOLS

Individuals could benefit from DATA to support HEALTH PROTECTIVE DECISIONS

What is the (meta) problem?

- **Simple community questions do not have simple answers** (even if we had perfect measurements)
- Sensor data are only **a starting peek into a complex story** about a heterogenous and changing environment
- Academic incentive, timeline structures, funding structures misaligned with realities of **community engagement** and **municipal projects**

What is the (meta) problem?

- **Simple community questions do not have simple answers** (even if we had perfect measurements)
- Sensor data are only **a starting peek into a complex story** about a heterogenous and changing environment

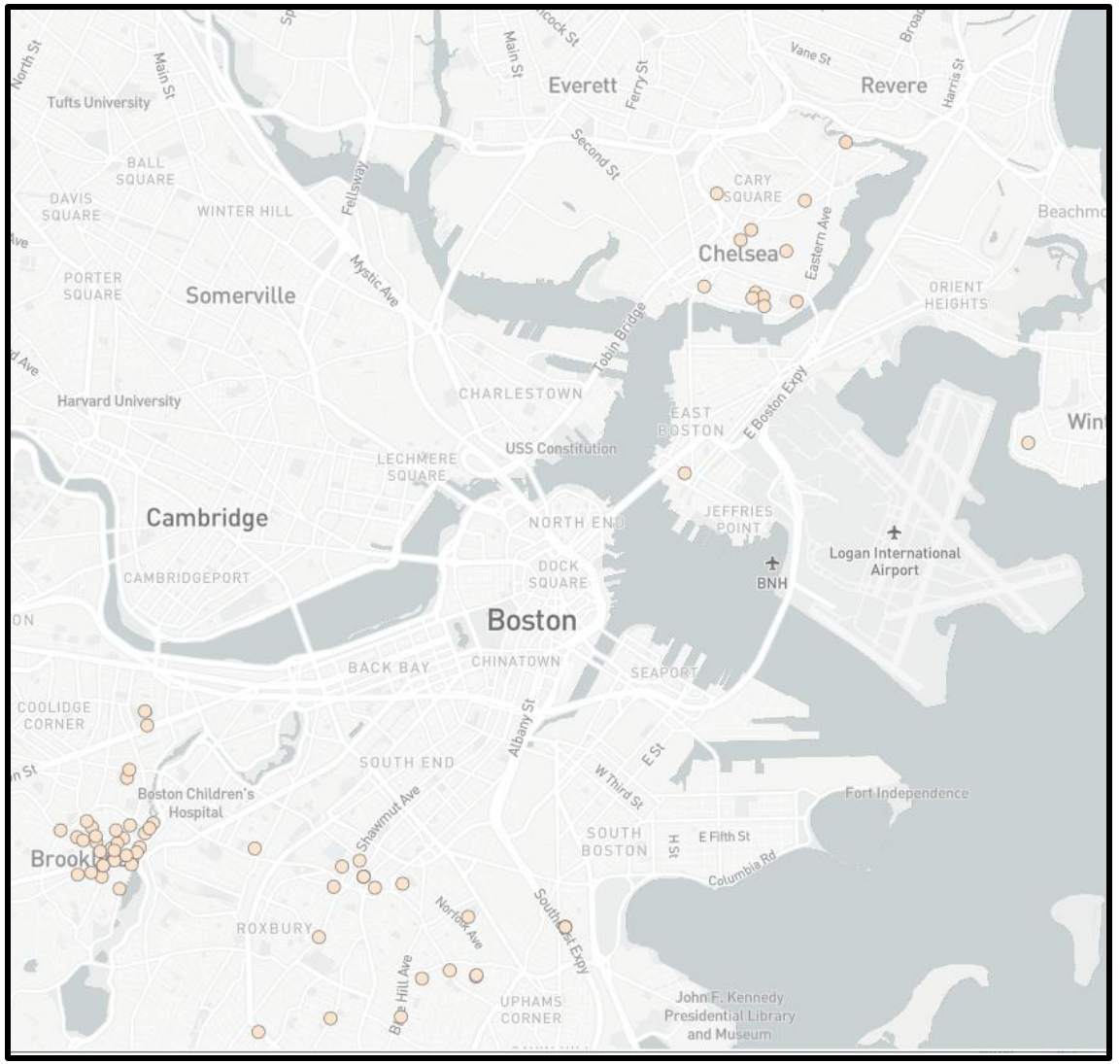
There is not enough expert person-time to provide technical assistance to communities/municipalities individually.

We need standards, guidelines, automation to scale.

“It’s simple, right?”

Sensors

Data



But: sensors go where? to do what?

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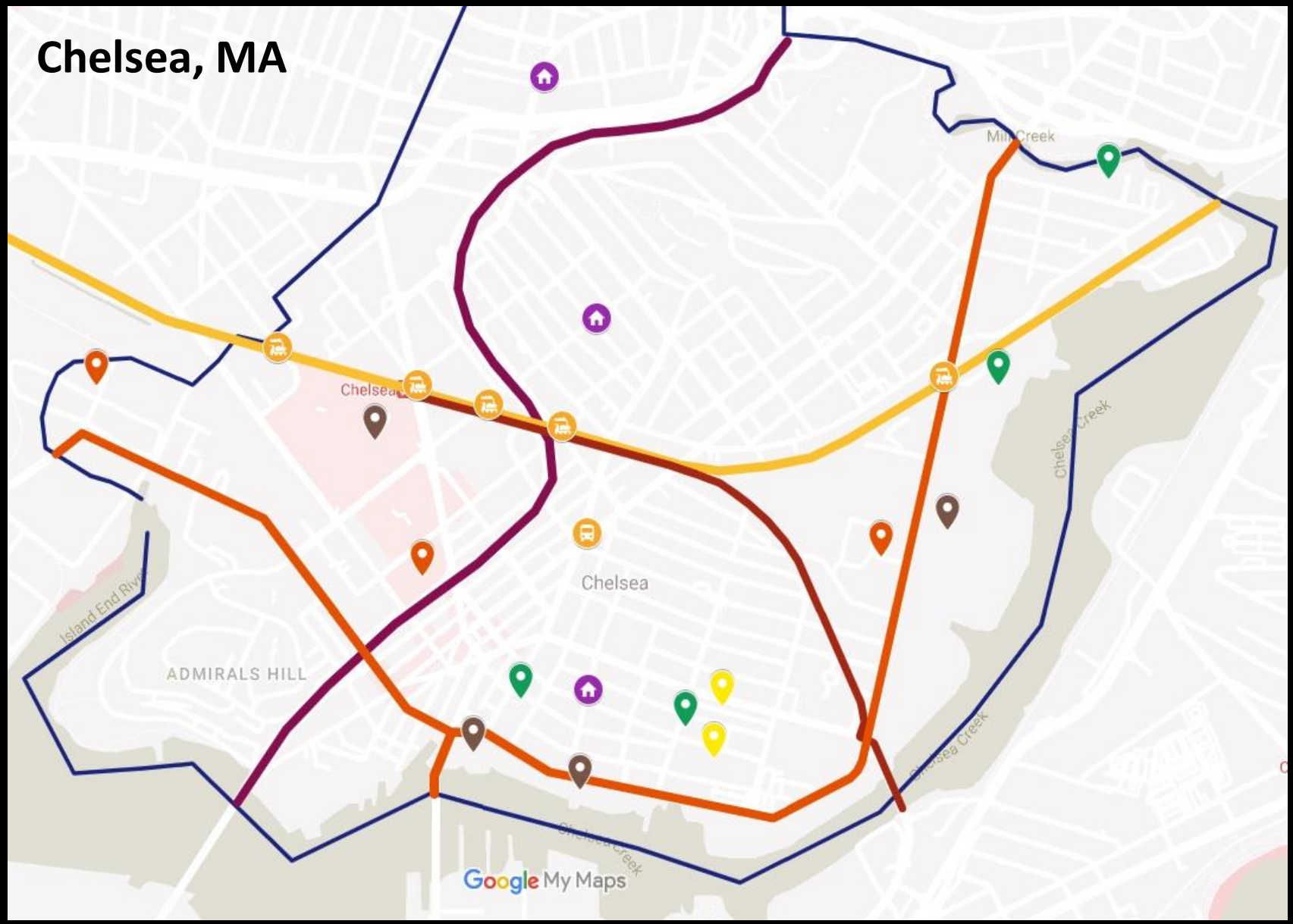

- Freight trucking (diesel)
- Public transit (diesel)
- Major highway
- Point sources
- Upcoming construction
- Upcoming green infrastructure
- Neighborhoods

Example driving questions

Stakeholders

- What is the impact of greenspace? (Is park/near-park air quality better than in other areas?)
- What is the impact of traffic light or pedestrian crosswalk timing settings?
- What is the impact of separated bus or bike lanes?
- Is my air dangerous? When? Why?

Example driving questions

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Academic

- What sensor placement (how many, where) will support answering these questions?
- What data quality is needed?
- How can we interpolate between sensors keeping in mind hyperlocal emissions and events + urban form?
- Are there prototypical question types we can build tools around?

Example driving questions

Stakeholders

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How do we build something so useful that I engineer myself out of a job?

Next: sensors go on what?

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Permissions…

But also just existence of appropriate infrastructure at the right place

Partnerships make it possible

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The Neighborhood Developers

CHELSEA • SETTLED 1624 • A TOWN 1739 • A CITY 1857 • WINNISIMMET

dcr Massachusetts

GreenRoots 30 Years

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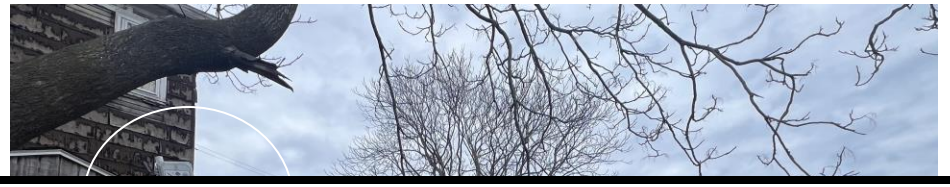

Requirements:

~10’ (3m) height, ambient air flow, southern view (solar)

Current & expanding sensor installs

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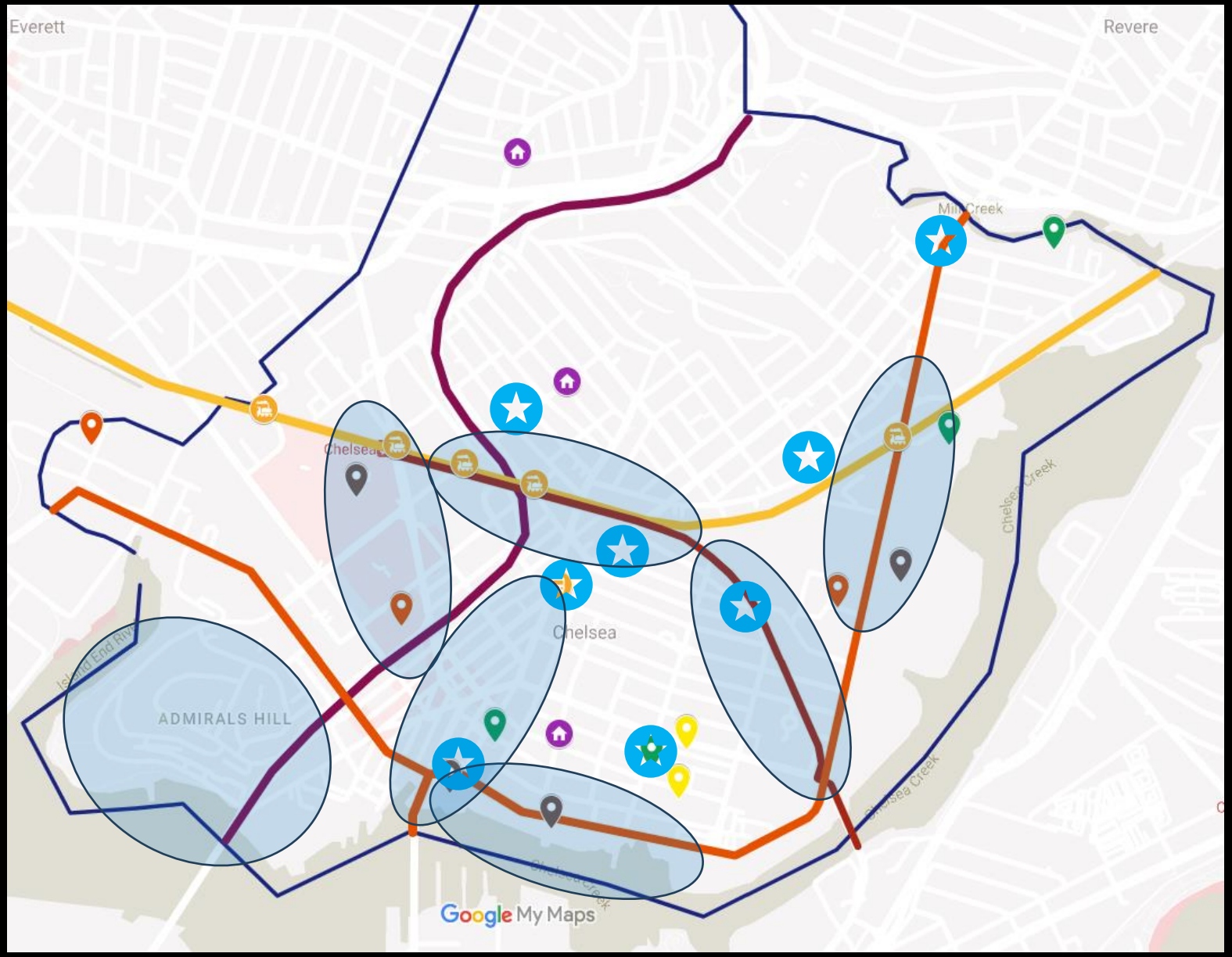

- Freight trucking (diesel)
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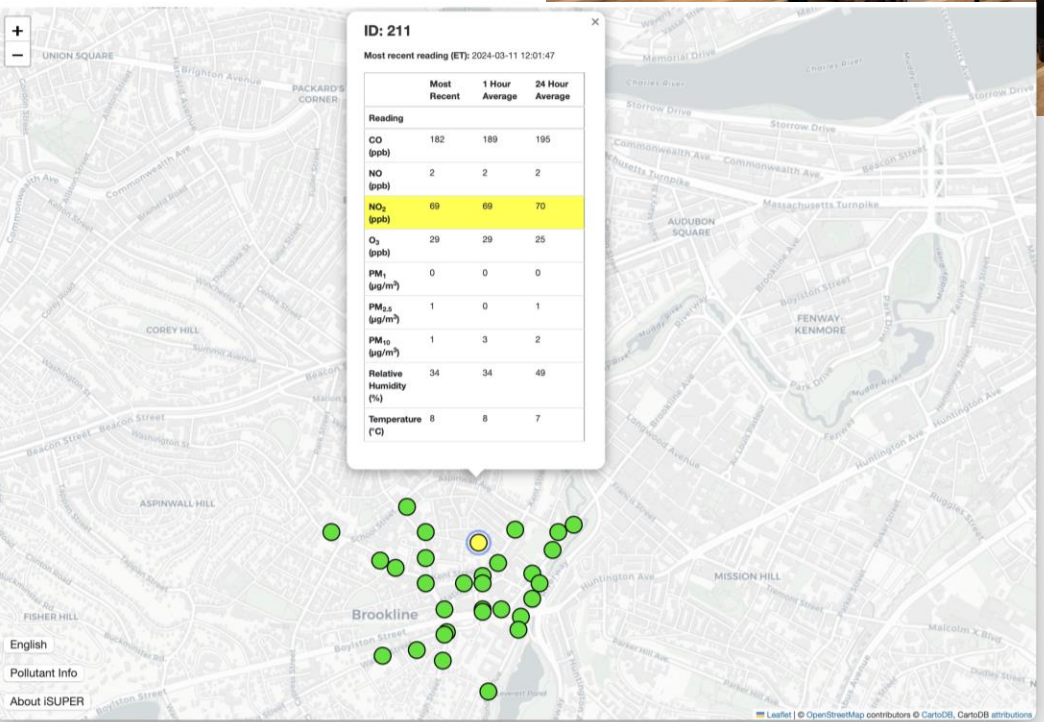
Meeting “data” needs



Community suggestions:

- Show all sensors + EPA data
- Show pollution sources
- Overlay weather (e.g., wind)
- Use AQI colors to show risk – but convert to health-related context

- Continuous spatial maps
- Confidence in numbers

- Decision support tools (health-protective, change advocacy)

Meeting “data” needs

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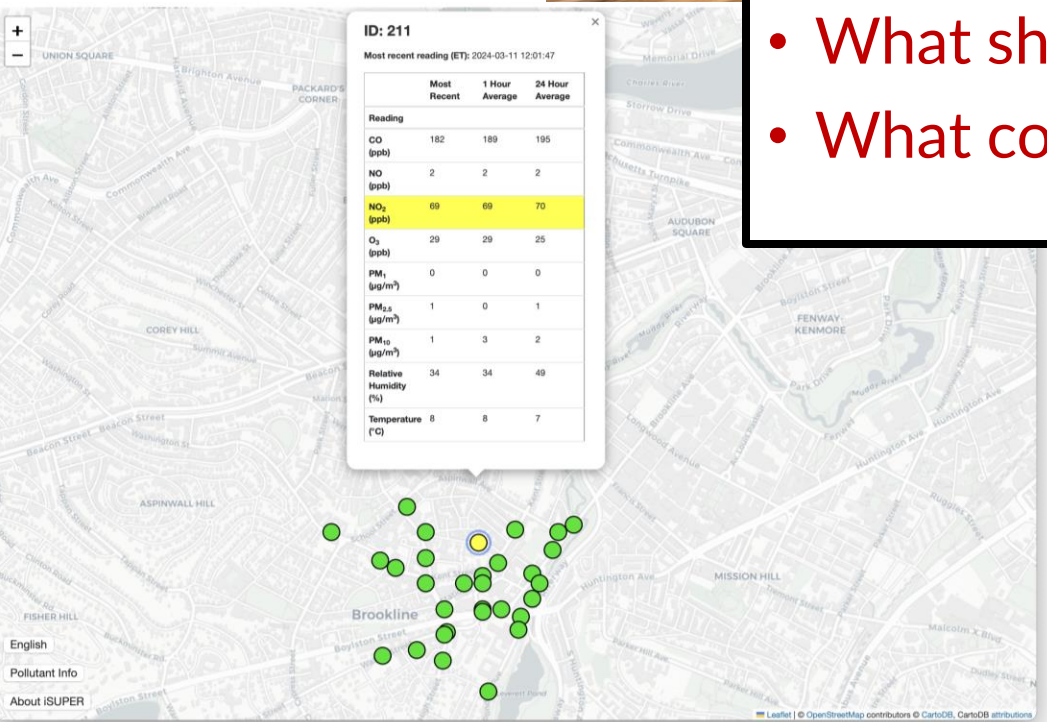
- Explain what I see
- How much should I trust it?
- What should I do now?
- What could improve the future?



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Community cxns beyond “research”

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Goals:

- **Listen** to community perspectives and observations
- **Inform** residents on sensor technologies, air pollution science, and where to find data
- **Engage** in the spaces & activities the community already values

La Colaborativa

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Our (5yr) project "product" goals

- **Leverage limited high resolution studies to**
  - Understand true urban heterogeneity
  - **Rationalize sensor network design** to **support stakeholder actions/interventions** at a scale **that can be realistically maintained over time**
  - Build/leverage (physics & ML) models to minimize # sensors needed

- **Tools to make data useful ("data to insight")**
  - **Layers of related information & tools to correlate with AQ**
  - Tools tuned to stakeholder needs (alerts, what-if scenarios)
  - **Prototypical types of questions with automated analyses**
  - **Communicate uncertainty / data quality**

- **Minimize overhead of sensor network management**
  - Automated fleet health checks and alerts
  - Decision support tools: symptom → response

On my mind

- Intercomparability of data demands some consistency in installation – **standardized height + no hyper local anomalies**

- All tools need to be **open-source** & **useable by communities**
  - Sensor fleet management
  - Data portals with layers, tools, insights
  - How to ingest "on the ground" knowledge from community members?

- What are the "prototypical" types of questions?
  - Near term (personal decision support?) & Long term (infrastructure design, advocacy)

- **Communicating uncertainty**

On my mind

- Intercomparability of data demands some consistency in installation – **standardized height + no hyper local anomalies**

- All tools need **mmunities**
  - Sensor fleet
  - Data portals
  - How to inge **unity members?**

How do we work together to get here?

Where do such tools live in perpetuity?

- What are the
  - Near term (personal decision support?) & Long term (infrastructure design, advocacy)

- **Communicating uncertainty**

Others here this week!

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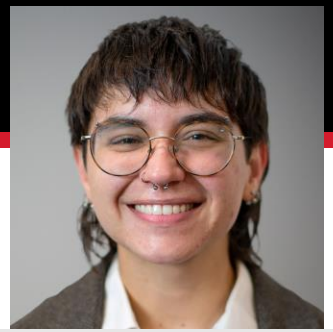

Mars Keesey

Dr. Alex Cabral

Efficient Fleet Management of a Network of Air Quality Sensors

Mars L. Keesey[1], Nicolas Minutillo[1], and Amy V. Mueller[1,2]
[1]Department of Civil & Environmental Engineering and [2]Department of Marine & Environmental Sciences
Northeastern University, Boston, MA

Project Background & the iSUPER Pilot Sensor Networks

Background
- Air pollution is a major environmental health risk
- In urban areas, measuring air quality (AQ) gradients requires a high-resolution sensor network, but...
- The cost, labor, and lack of guidance for AQ networks is prohibitive for communities and policymakers.
- iSUPER is building end-to-end tools to support
  (1) easy sensor network management
  (2) stakeholder-driven sense-making from data
  (3) advanced decision support tools
- Piloted with networks of QuantAQ MODULAIR AQ monitors (Fig. 1).

Fig. 1: MODULAIR™ air quality monitor solar-powered assembly

Community Sensor Networks
Pilot sensor networks with partnering communities of Brookline and Chelsea, MA – 50+ sensors of 160+ available installed so far (Fig. 2). Sensors mounted to poles (streetlamps, utility poles), fences, garden sheds, etc.

Fig. 2: Air quality monitor network in Brookline (left) and Chelsea (right) as of 4/10/2024.

Challenges for Urban Sensors
- Insufficient solar input: Shadowing from nearby buildings/trees, especially due to low winter sun angle
- Extreme cold: Li-Ion batteries cannot charge below 0 °C (safety limit)
- True south: Difference between magnetic and true north can be significant (e.g., 14° in Boston) – requires precise compass & careful installation to optimize solar charging

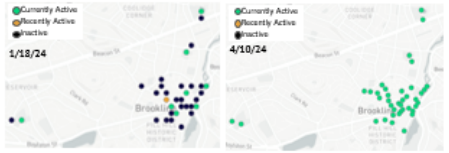

Fig. 3: Brookline AQ sensor network status on 1/18/24 and 4/10/24 [illegible] 1/18/24 caused by

Quality Assurance (Ops & Maintenance)

Understanding **symptoms** and how they link to **root causes** is critical for building **decision support tools** for **effective and efficient O&M.**

Known symptoms, cause, and solutions (Table 1) have been determined based on nearly 7 months of data collection and fleet operator experience. As an example, the decision tree in Figure 5 shows a root cause analysis for **when a sensor has been offline for > 3 days.**

Deployment C

Comparable & consistent
require installation consi
- Height: Air inlet at 10
- Orientation: Solar pan
  194° (true south in Bo
- Cell signal: Access to
- Light: No obstacles blocking sun

Asset management is also critical in operations pre- and post-deployment:

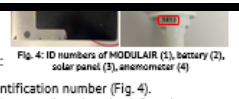

Fig. 4: ID numbers of MODULAIR (1), battery (2), solar panel (3), anemometer (4)

- Each component is assigned an identification number (Fig. 4).
- All parts tracked individually – deployment (location, date) & maintenance

Sensor offset	Expected uncertainty (if in range) / Calibration error or drift / Instrument failure / Sensor degradation or expiration / Poor-performing data models

■ Requires maintenance visit to resolve ■ May resolve without intervention
■ May resolve without intervention. If not, requires relocating sensor ■ May be resolved remotely

Table 1: Known abnormal sensor symptoms and associated potential causes.

Sensor Network & Data Ma

As network size increases, automation tools are
data management includes:
- Separate public & operator portal functions
  they need in the form they prefer
- Public - map of sensors with current/past rea
  to simultaneously view other urban datasets
- Operator – automate anomaly detection, tra
  create maintenance tickets (see below for de

Anomaly Detection
Rules based on operator-identified sensor symptoms & solutions (Table 1)
- Error flags - sensor offline, broken, etc.
- Warning flags - data loss, abnormal readings, etc.

Device State
- Recent state – based on % data lost within the last hour
- Device health – based on % data lost within a week
- Prior issues and operator notes for each sensor

Fig. 6: Ticket creati

Ticketing for Tracking O&M
Create tickets to plan sensor interactions– ins
- Group into "trips" – easy use as in-field che
- In-progress and completed interactions sto
- Support identification of recurring problem

The iSUPER portal can be used with any AQ se
Goal is supporting sensor network managemer

Next Steps & Ongoing Proj

unctionality to ensure
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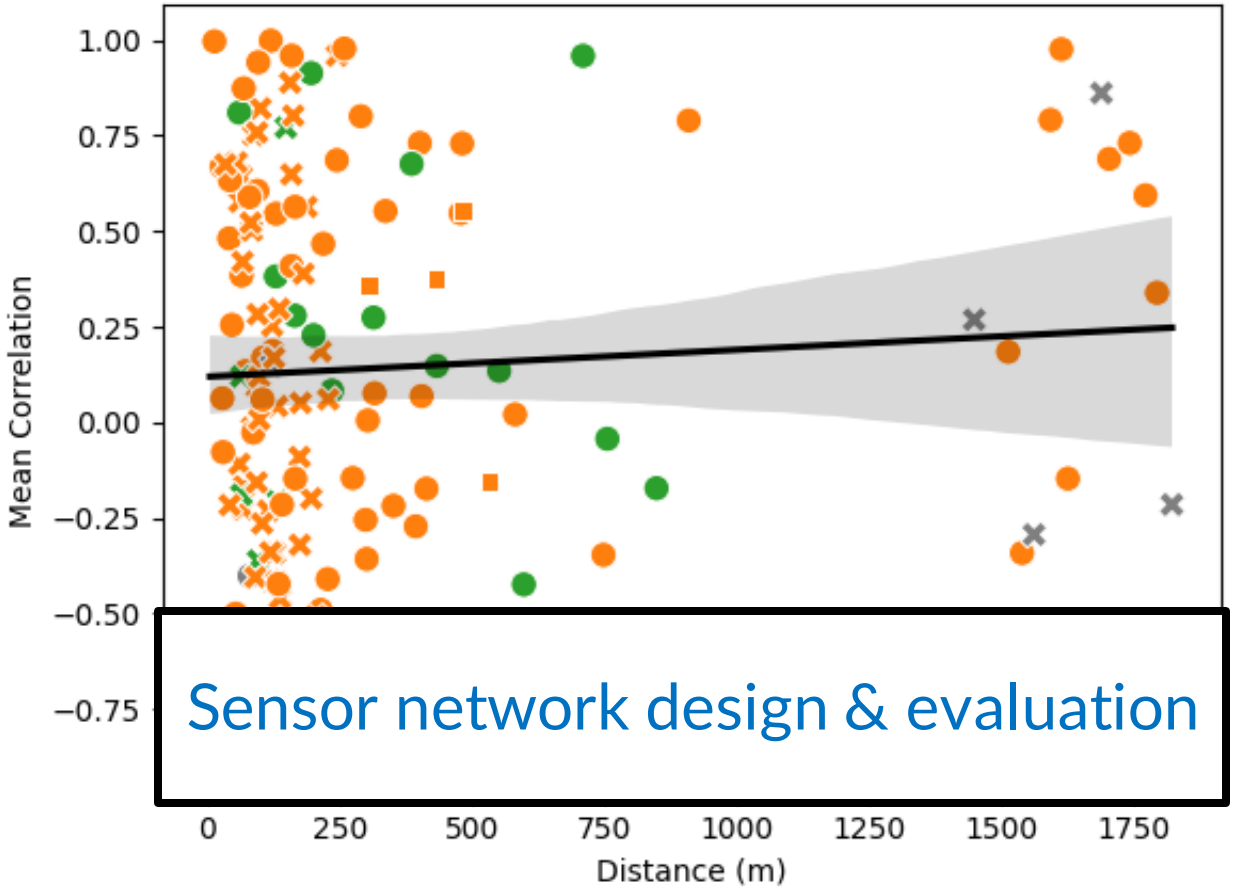
e & data accuracy by

nal fleet managemen
d decision support
to other types of air
erlocal data with part

ments

This work is supported by the Northeastern Uni
- Collaborators: Jack Balaguer, Yasser Aponte, S
  Nail Bashan, Pushkar Rajesh Patil, and all iSU
- Community Partners: The Town of Brookline,
  The City of Chelsea, GreenRoots, The Neighb



Sensor network management

Sensor network design & evaluation

Acknowledgements – Questions?

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Thanks to:

- All collaborators on this project:
  - Interdisciplinary NU faculty, staff, and student team
  - Municipal and community partners
- Funding from the Northeastern University Impact Engine program
- iSUPER Community Advisory Board

Scan me to see air quality data!

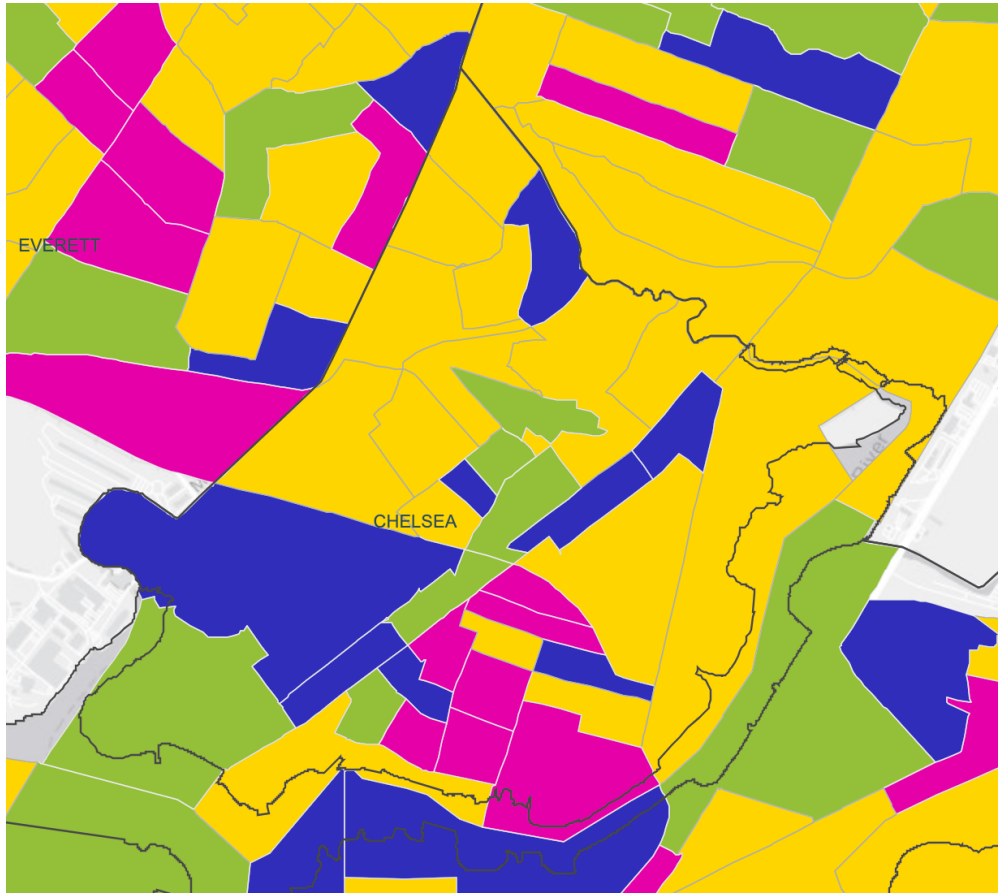
For more info:

Amy Mueller – a.mueller@northeastern.edu

iSUPER: https://impactengines.northeastern.edu/ie/isuper/

Extra Slides

Chelsea's population



- Minority: the block group minority population is >= 40%, or the block group minority population is >= 25% and the median household income of the municipality the block group is in is < 150% of the Massachusetts median household income
- Income: at least 25% of households have a median household income 65% or less than the state median household income
- Language isolation: 25% or more of households do not include anyone older than 14 who speaks English very well
- Minority and Income
- Minority and English isolation
- Income and English isolation
- Minority, Income and English isolation

How do we learn what "data access" means to diverse groups of people?

- Information, MassGIS (Bureau of Geographic. "Massgis Data: 2020 Environmental Justice Populations." *Mass.Gov*, www.mass.gov/info-details/massgis-data-2020-environmental-justice-populations. Accessed 28 Mar. 2024.

QuantAQ air quality sensors

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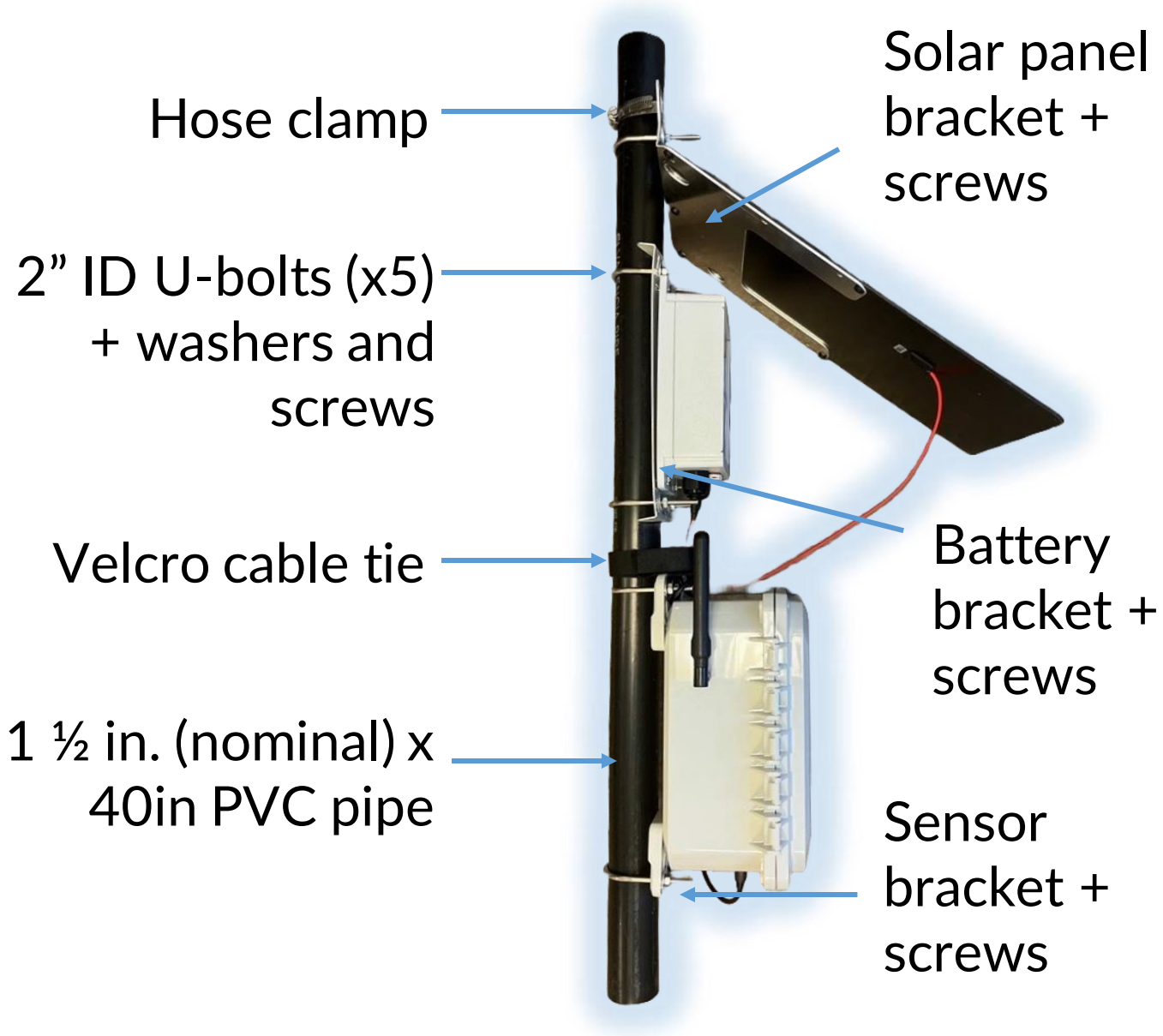

Pre-assembly:

- MODULAIR bracket attachment
- Solar panel bracket attachment
- Battery charging (~5-10 hours)
- Battery bracket attachment
- Anemometer attachment assembly
- Attach MODULAIR and battery to PVC

In-field assembly:

- Attach solar panel to PVC
- Attach anemometer to PVC
- Add antenna to MODULAIR
- Plug in all cables and secure