Open Data and Air Quality Data for Personalized Route Planning in Smart Cities

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Who we are

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AIQS AI-enhanced air quality sensor for optimizing green routes [2024-2025]

Funded by ECOSISTER internal call

- **Goal**: Improve low-cost PM sensor data accuracy and integrate into urban routing to reduce exposure.

Partner

UNIMORE UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

CINECA

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Stakeholder / Sponsor

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https://ecosister.it/

ECOSISTER *Ecosistema Territoriale di Innovazione dell'Emilia-Romagna [2022-2025]*

AIQS project

Artificial Intelligence for Improving Low-Cost Air Quality Data

10 international datasets

Machine learning, Neural Networks, Fuzzy Logic, Foundational models comparison

Open Framework (TRL 7)

Optimizing Sensor Hardware Design to Reduce Environmental Noise

Optimize air sampling of sensors through fluid dynamics

Pre-treatment modules to eliminate hygroscopic effects

Intelligent Routing Systems to Minimize Pedestrian Exposure to Air Pollution

Open-source algorithm to suggest green routes for pedestrians and cyclists, minimizing pollution exposure – GRAFMOVE (on GitHub)

Tested in Modena with synthetic AQ data and in Ferrara with real PM2.5 data

Tutorial Outline

- **Session 1: Foundations of Smart Mobility Data**
  - Graph Modelling of Urban Data, The role of open data
- **Session 2: Multi-objective Routing for Smart Cities**
  - Multi-Objective Optimization, Personalization Frameworks
  - Case Studies in Modena and Ferrara
- **Session 3: Hands-on Implementation**
- **Session 4: Q&A and Discussion**

Mobility Survey

Wooclap code: PQFKFE

https://app.wooclap.com/PQFKFE

Slides and code

http://bit.ly/3JHliCh

Session 1: Foundations of Smart Mobility Data

The Urban Mobility Challenge

- Multimodal
- Multidimensional
- Complex

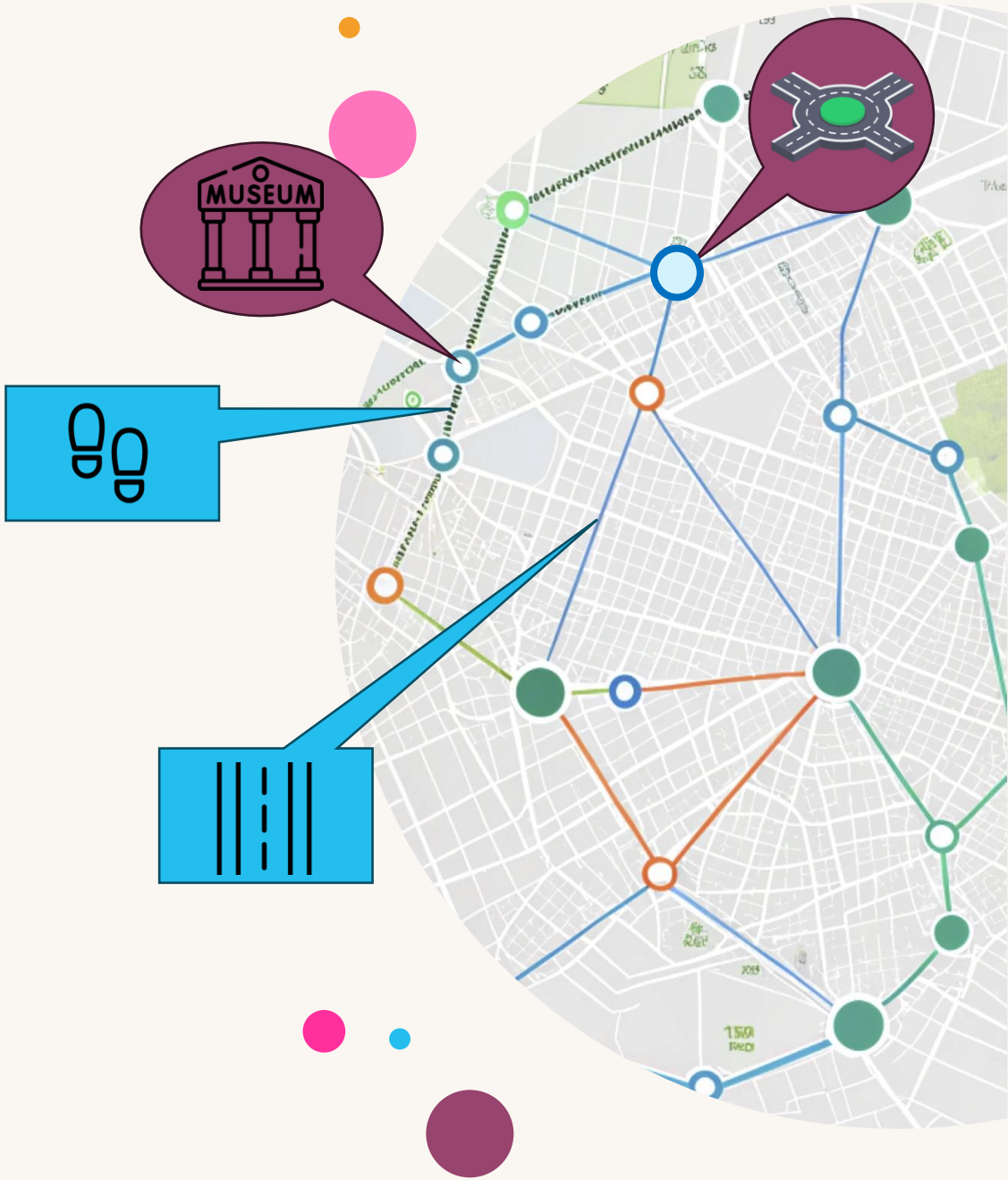
The Open Data Ecosystem

OpenStreetMap (The Physical Network) - A rich, detailed source of geospatial data.

GTFS (Static Public Transport): global standard for transit data (schedules, routes, stops).

Open Data Portals & Sensors (The Context): sources for dynamic and contextual data (air quality, traffic counts, accident data).

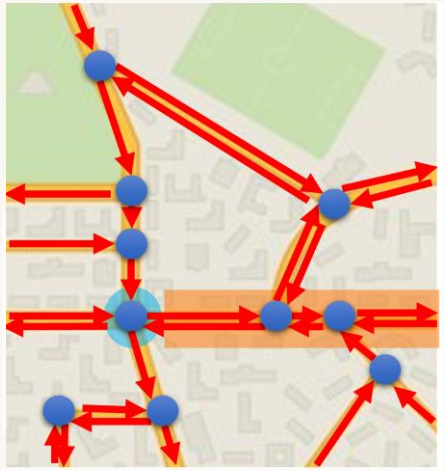
The Model: Representing the City as a Graph



- **Nodes**: intersections, bus stops, POIs
- **Edges:** connections (roads, paths) with a **weight** (e.g., length, time to traverse).
- *This graph abstraction is powerful!*
- It allows us to use well-known algorithms (like Dijkstra's or A*) to find the **shortest path** between any two points.

Graphs in the context of urban mobility - A real scenario

Primal and Dual Graph – A Perspective Shift

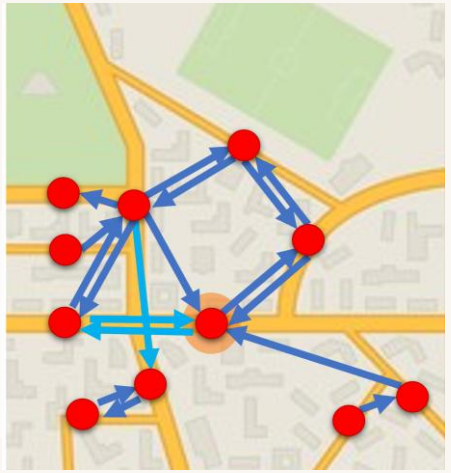


Primal Graph

Standard Representation

Nodes (●): Intersections (junctions, crossroads).

Edges (—): Street segments (the road between two intersections).



Dual Graph

Spatial Representation

Nodes (●): Street Segments

Edges (—): Adjacency (two streets that intersects on a junction/that share junction).

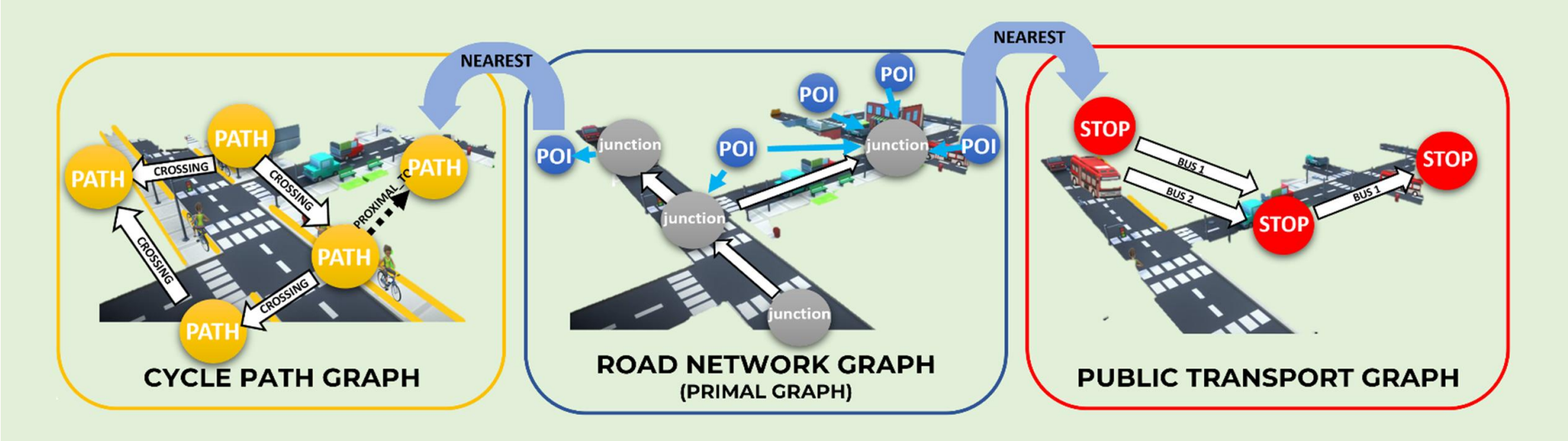
Primal and Dual Graph

What Analyses Do They Enable?

Primal Graph (Flow)	Dual Graph (Space)
• **Routing** (shortest, greenest path). • **Centrality** (identifying critical junctions). • **Accessibility analysis** (how reachable a node is). • **Traffic simulation**.	• **Analysis of the urban connectivity** of blocks. • **Identification of communities** of similar areas (e.g., neighborhoods). • **Land-use planning** (analysis of services per zone).

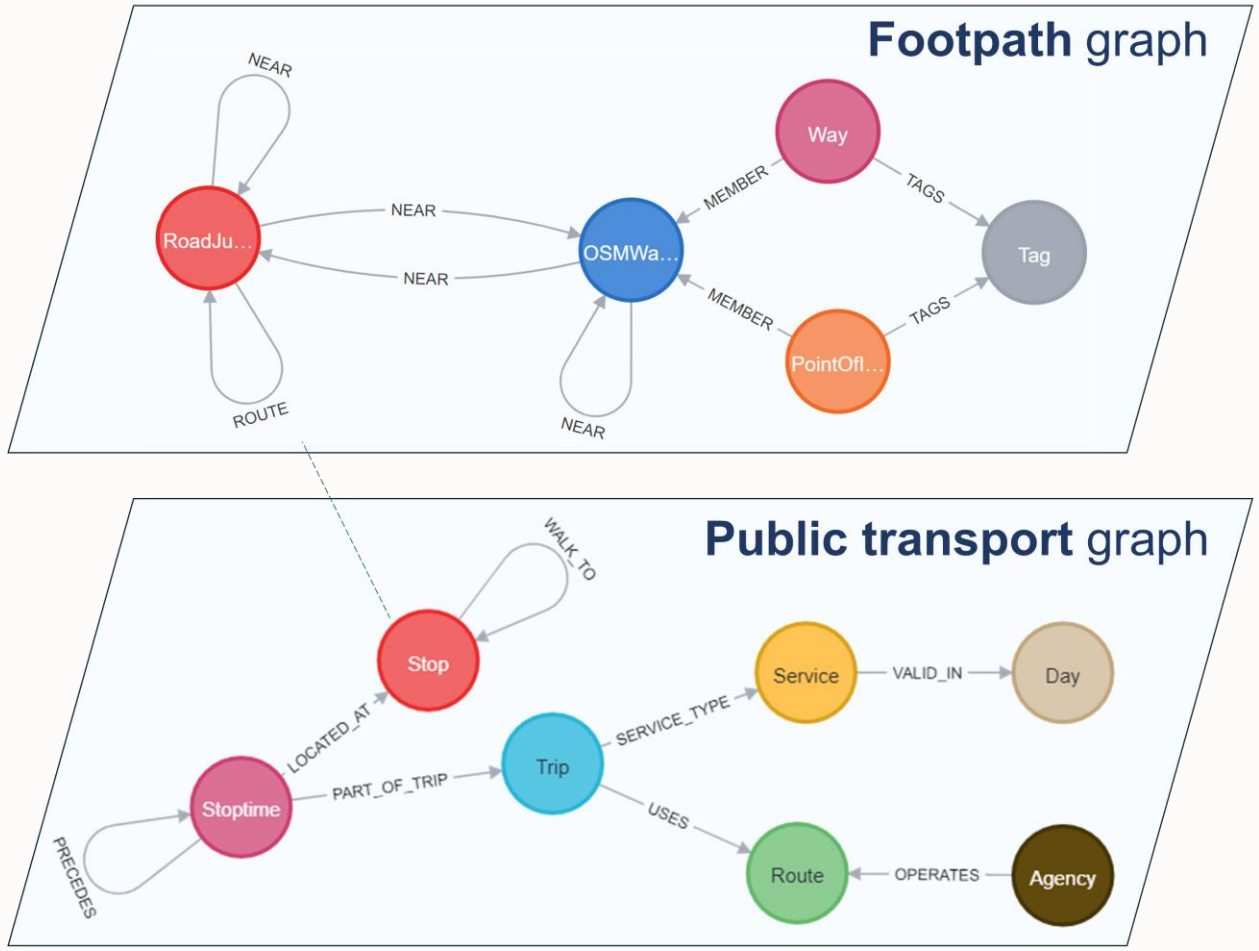
Beyond the Car: Modeling Multimodal Networks

A urban smart mobility graph isn't one network; it's several **interconnected layers**. A multi-modal journey is a path that moves across these layers.



- **Layer 1:** Pedestrian Network (footpaths, crossings). Weight = walking time.
- **Layer 2:** Cycling Network (bike lanes, shared roads). Weight = cycling effort/safety.
- **Layer 3:** Road Network (for cars/buses). Weight = travel time.

Use case in Modena



Use case in the city of **Modena**

- 37994 junctions
- 86128 routes
- 10335 amenities

- 82 routes
- 7545 trips
- 3972 stops

Making it Smart: Dynamic Weighting with Real-Time Data

- The graph structure is static, but the **edge weights are dynamic** and computed from real-time or contextual data (e.g., current PM2.5 levels).

PERSONALIZATION

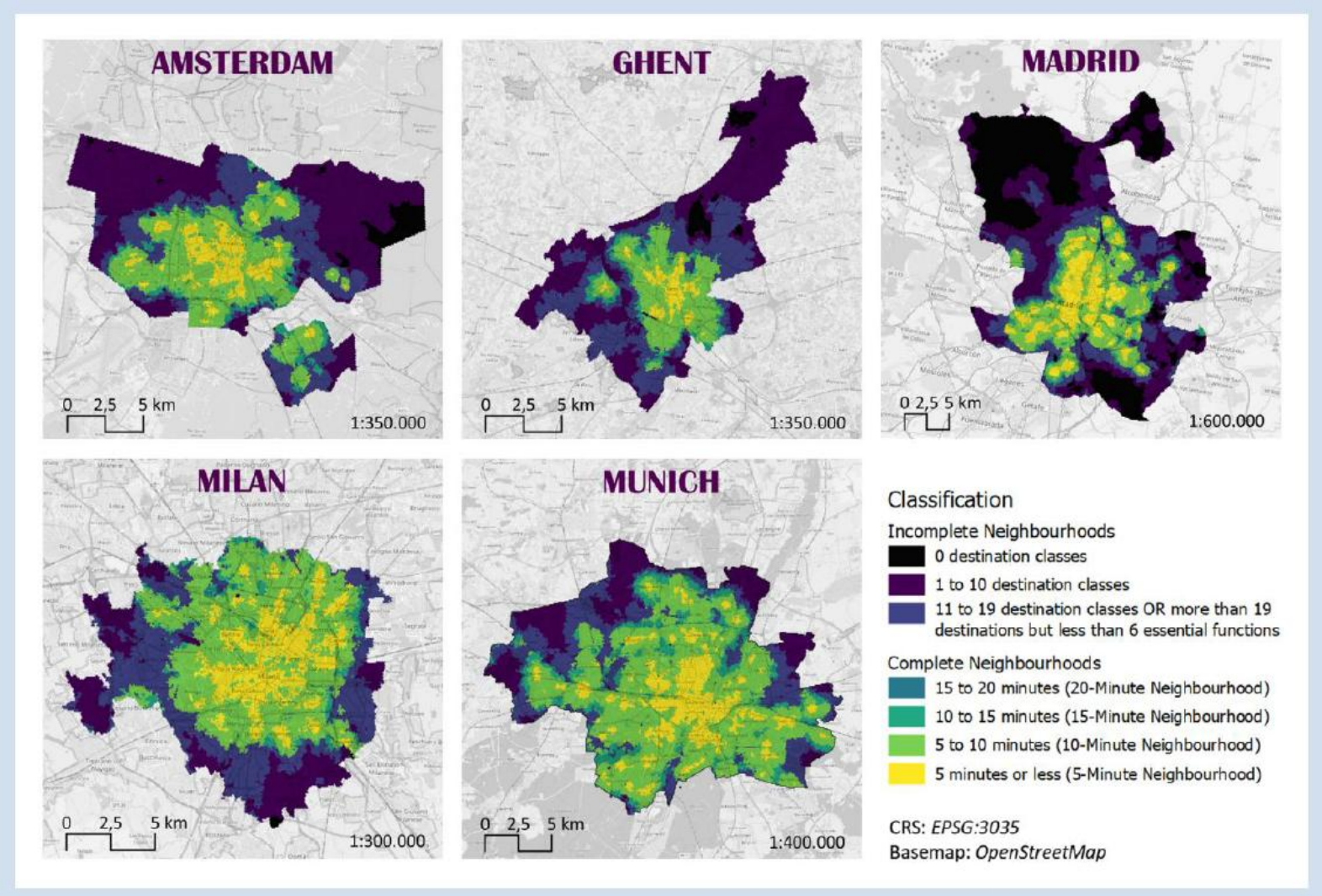
Weight= (α * time) + (β * air_quality) + (γ * risk)

- α, β, γ coefficients are the **personalization knobs** -a commuter might set α (time) high, while a tourist might set β (air_quality) high.

The 15-Minute City: Rethinking Urban Mobility

Proximity
Sustainability

- Cities designed so that daily needs are accessible within 15 minutes
- Promotes active mobility (walking, cycling)
- Relies on efficient, sustainable public transport
- Reduces congestion and pollution



Challenges of the 15-Minute City

Multimodal Routing

- Integration of walking, cycling, micro-mobility, and public transport
- Need for seamless connections and real-time data
- Balancing speed, accessibility, and sustainability

Challenges of the 15-Minute City

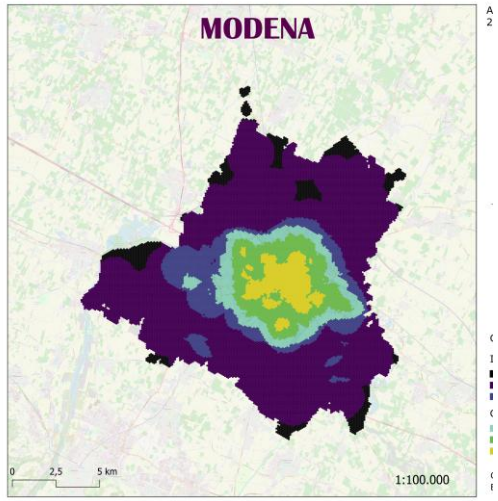
Personalization

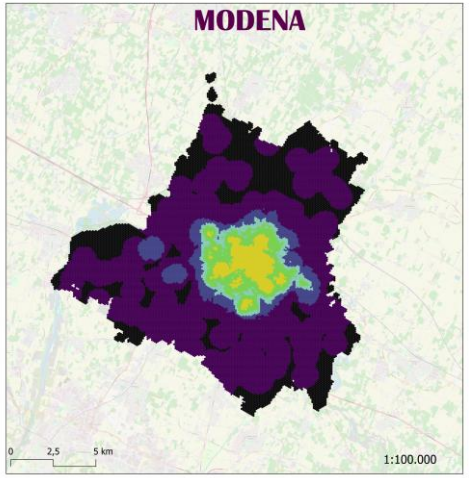
- Different walking speeds and mobility needs
- Diverse priorities: healthcare, education, work, leisure
- Adapting routes and services to individual preferences

Challenges of the 15-Minute City

Accessibility

- Ensure all residents, including the elderly and wheelchair users, can reach essential services within 15 minutes.
- Physical barriers (uneven sidewalks, lack of ramps, inaccessible transport) limit mobility and inclusivity.


MODENA
0
2,5
5 km
1:100.000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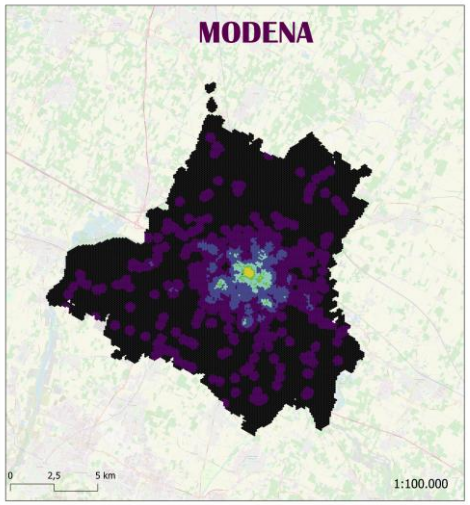

MODENA
0
2,5
5 km
1:100.000

Mobility Survey

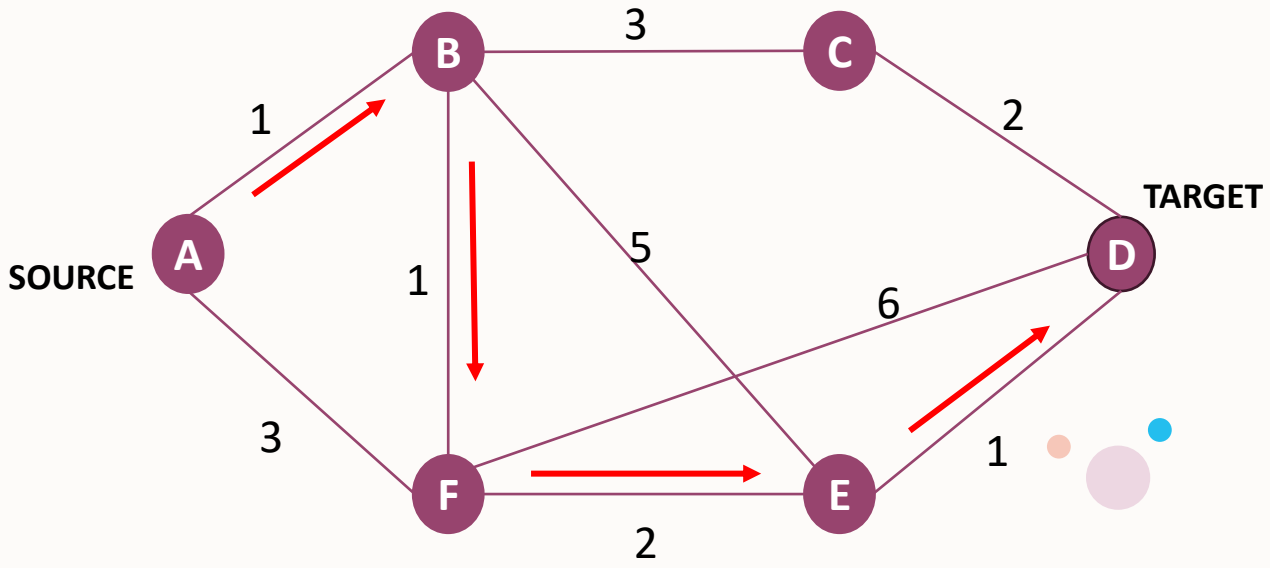
Wooclap code: PQFKFE

https://app.wooclap.com/PQFKFE

Session 2: Multi-objective Routing for Smart Cities

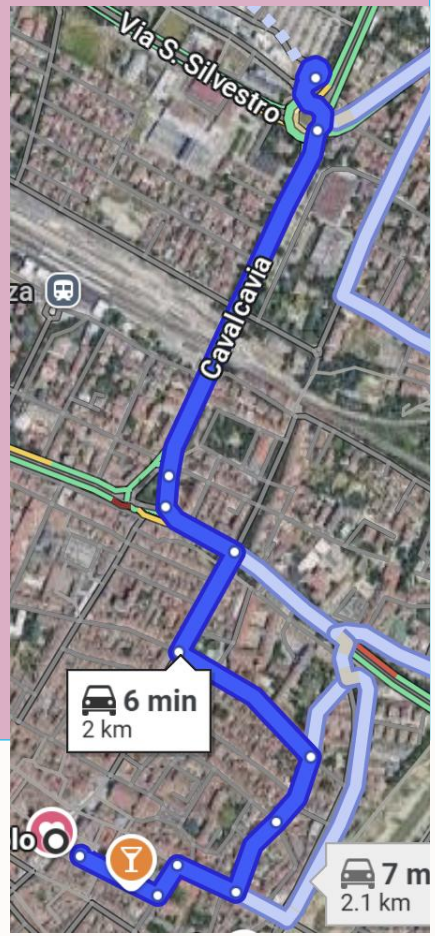
Shortest path

- A shortest path is the path with the **minimum total weight** (or distance) between two nodes (or vertices) in a weighted graph.
- Common algorithms for finding shortest paths:
  - **Breadth-First Search (BFS)**: For unweighted graphs.
  - **Dijkstra's Algorithm**: For graphs with non-negative edge weights.
  - **Bellman-Ford Algorithm**: For graphs that can have negative edge weights (but no negative cycles).
  - **A***: Used for single-pair problems and employs heuristics to speed up the search.

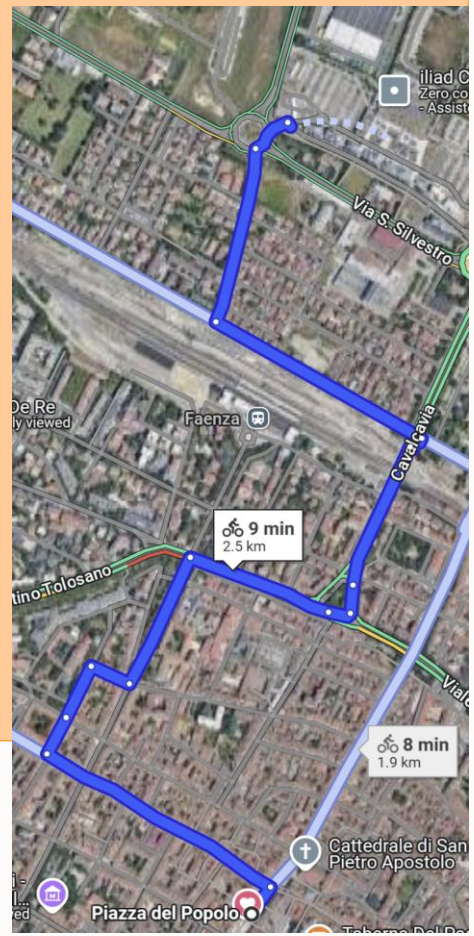


Different transport modes, different shortest paths

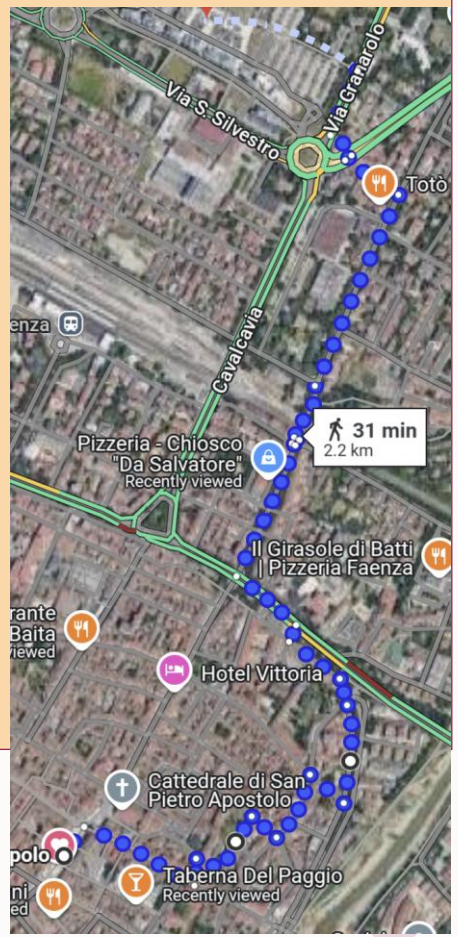
CAR



CYCLISTS



PEDESTRIANS



Some existing routing systems

	Target	Shortest path	Green area	Air pollution	Safety	Road slope	POI
Google Maps		✓	✗	✗	✗	✓	✓
OsmAnd		✓	✗	✗	✗	✗	✓
Vroom		✓	✗	✗	✗	✗	✗
OpenRoute Service		✓	✗	✗	✗	✗	✗
Brouter		✓	✗	✗	✗	✓	✗
AIQS		✓	✓	✓	✓	✓	✓

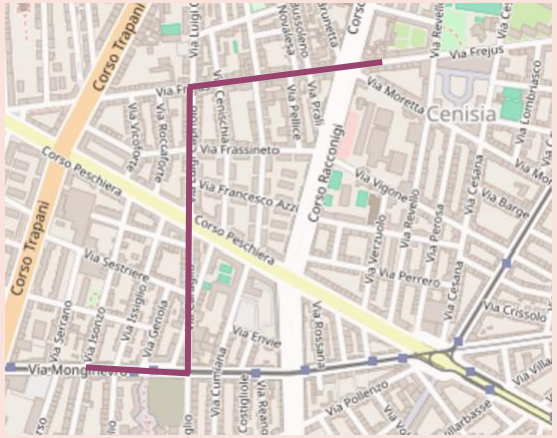
Multi-Objective Optimization

- This approach to route planning aims at **simultaneously** optimizing two or more (often conflicting) objectives when determining optimal routes

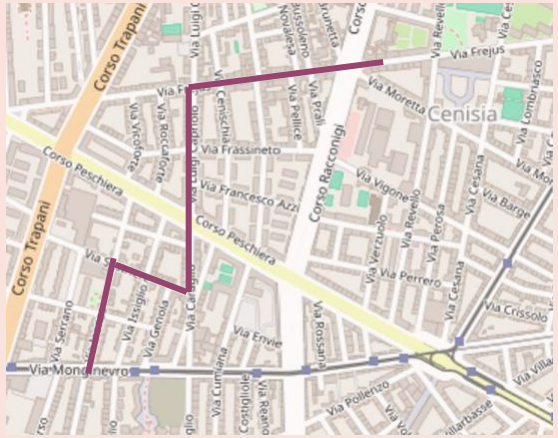
- Examples: *minimizing travel time,*
  reducing energy consumption,
  improving safety, …

Multi-Objective Optimization

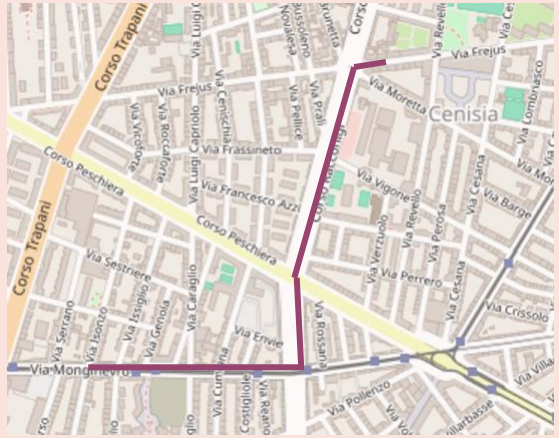
One objective



Shortest path

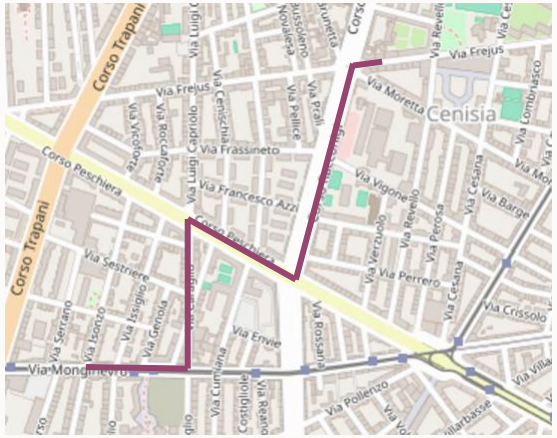


Safest path



Most fuel-efficient path

OPTIMAL TRADE-OFF

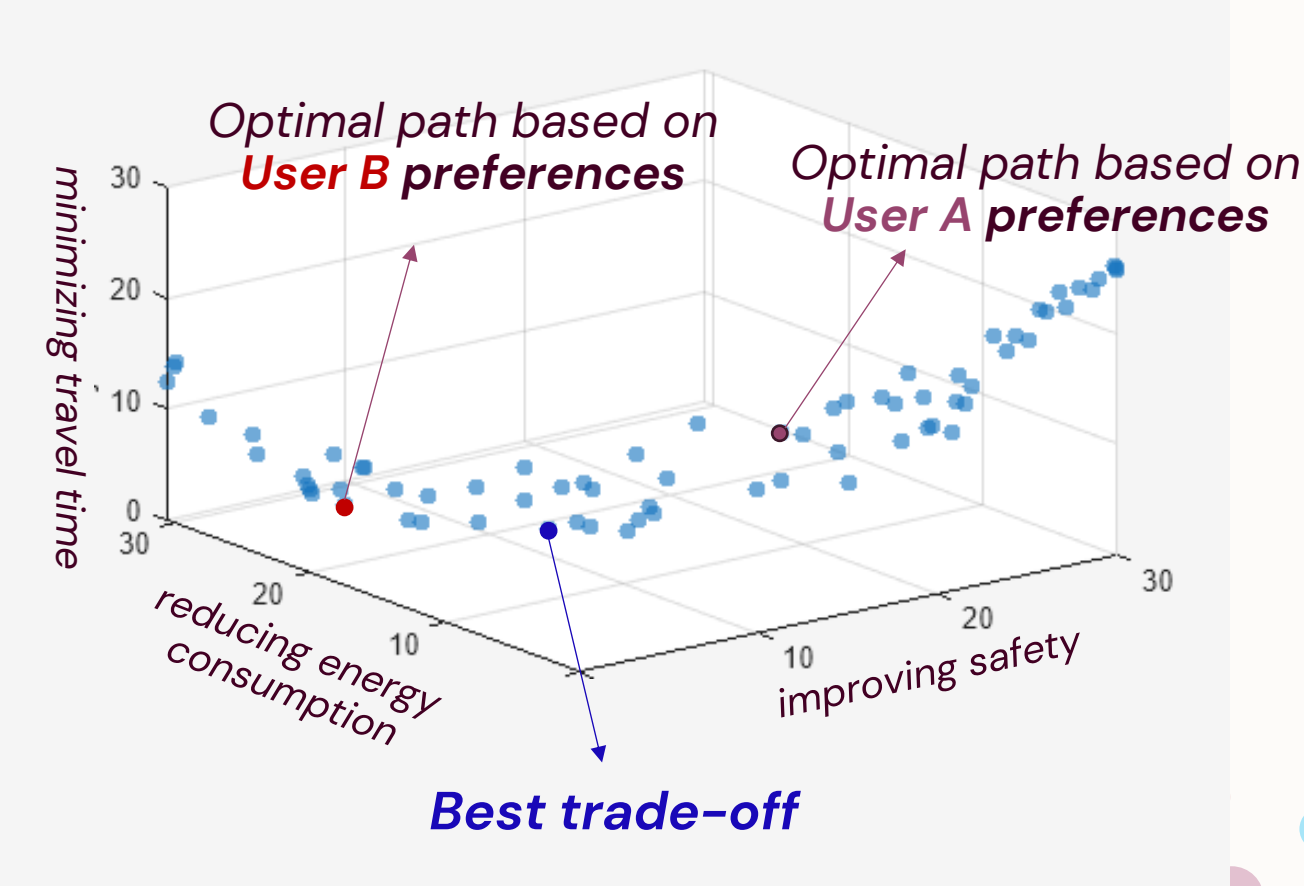


USER PREFERENCES

Most important criteria: travel distance and safety

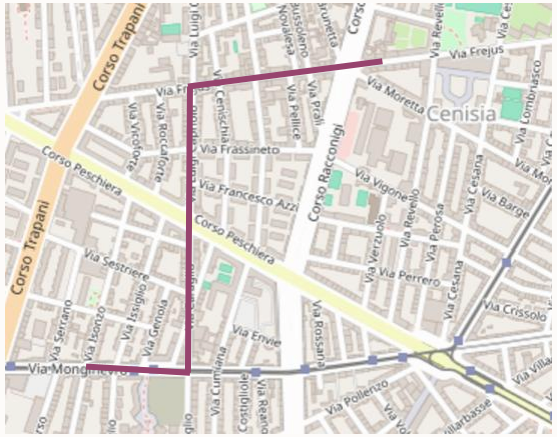
Multi-Objective Optimization

- Objective: identifying a set of **Pareto-optimal solutions** that are **non-dominated** solutions, **well-distributed** in the objective space to approximate the Pareto front as closely as possible
- This allows to find **trade-offs** among competing objectives and select routes that best align with user preferences, policy goals, or contextual constraints



Personalized routing

- Objective: identifying the optimal path according to **personalized user preferences**

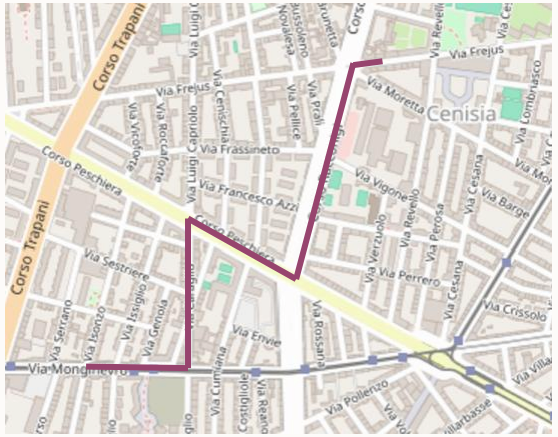


USER A

Priority: travel distance

USER B

Priorities: travel distance and fuel consumption



USER C

Priorities: travel distance and safety

Focusing on pedestrians and cyclists

- Factors influencing the **route choices** of cyclists and pedestrians may include:
  - Total route length
  - Presence and accessibility of green spaces
  - Road typology (e.g., dedicated bike lanes, sidewalks, paved roads)
  - Sidewalk conditions
  - Ambient air quality
  - Volume of motorized traffic
  - Perceived or actual safety

- *Nandita Basu, Oscar Oviedo-Trespalacios, Mark King, Md. Kamruzzaman, andMd. Mazharul Haque. 2023. What do pedestrians consider when choosing aroute? The role of safety, security, and attractiveness perceptions and the builtenvironment during day and night walking. Cities 143 (2023), 104551. doi:10.1016/j.cities.2023.104551*
- *M. Eugenia López-Lambas, J. Manuel Sánchez, and Andrea Alonso. 2021. Thewalking health: A route choice model to analyze the street factors enhancingactive mobility. Journal of Transport & Health 22 (2021), 101133. doi:10.1016/j.jth.2021.101133*
- *National Association of City Transportation Officials (NACTO). 2016. GlobalStreet Design Guide. NACTO. https://nacto.org/publication/global-street-design-guide/*

Two real-world case-studies, different objectives to optimize

- **Modena**:
  - Travel distance
  - Road classification
  - Green areas proximity
  - *Road safety*
- **Ferrara**:
  - Travel distance
  - Road classification
  - Green areas proximity
  - *Air pollution*

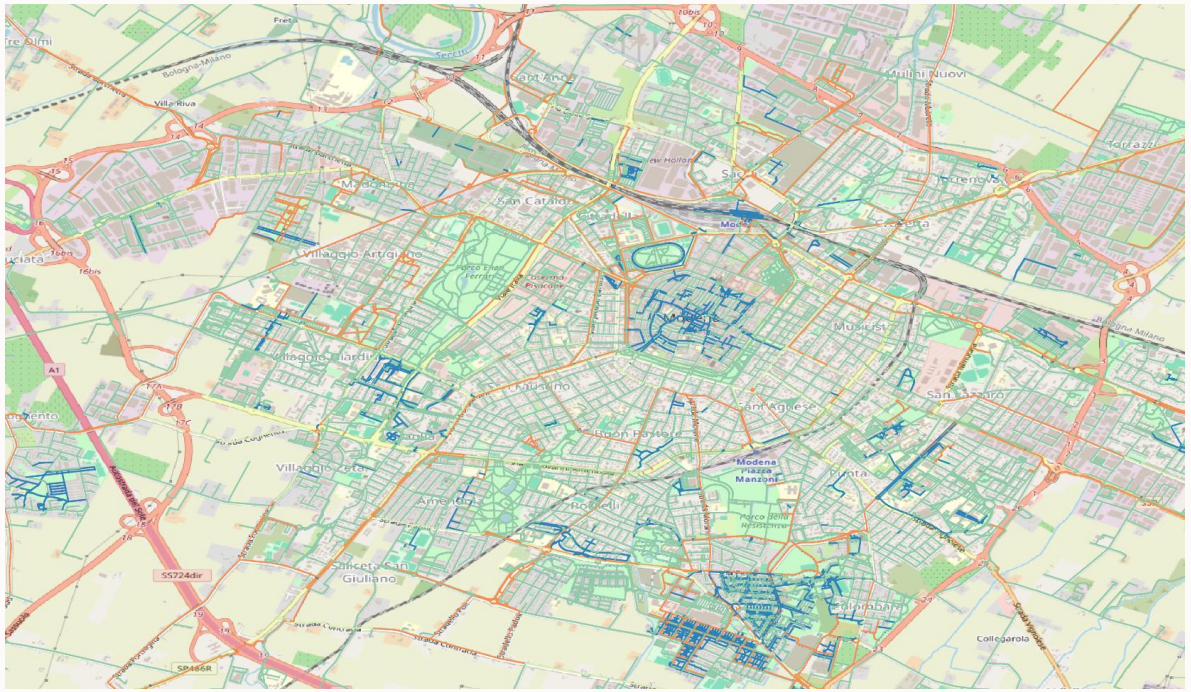
Modena - road classification

Priority class

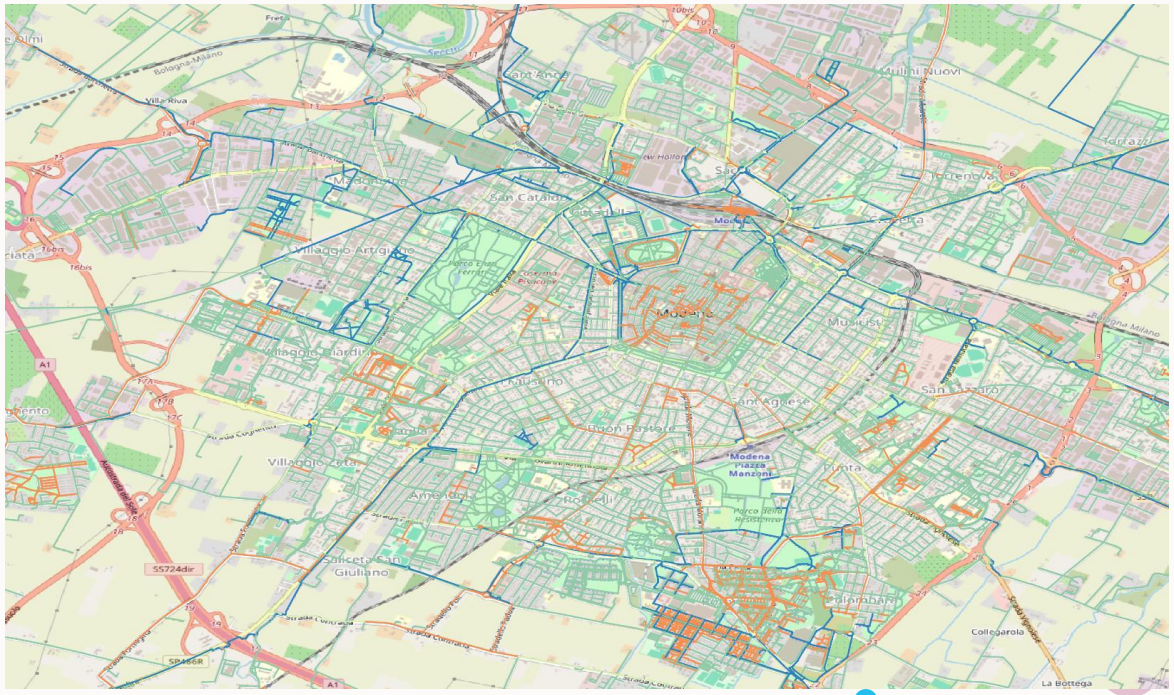
- 1
- 2
- 3
- 4
- 5

- Based on the OpenStreetMap ***highway*** attribute

https://wiki.openstreetmap.org/wiki/Key:highway



PEDESTRIANS



CYCLISTS

Modena - green areas proximity

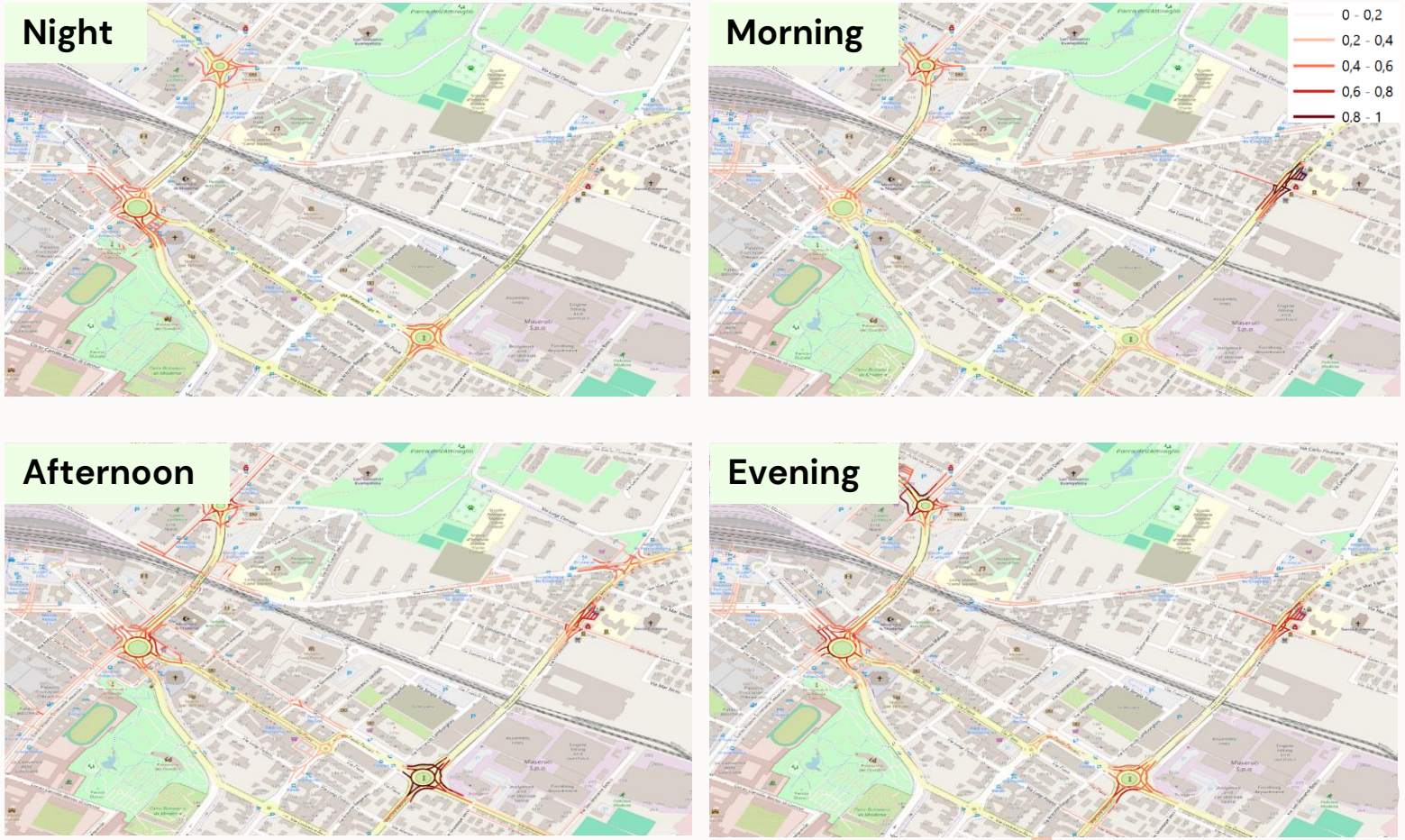
For each edge:

$$green_area_weight = \frac{road_length}{1 + green_area_percentage}$$

green_area_percentage indicates the percentage of green area of the road, e.g., 100% if the road is inside a park, 30% if it is close to a row of trees, …

Modena - road safety

Geolocated road accidents
(2013-2023)



Modena - optimal path identification

From ***Scuola d'Infanzia San Paolo*** to ***Fontana dei due fiumi***

Shortest path

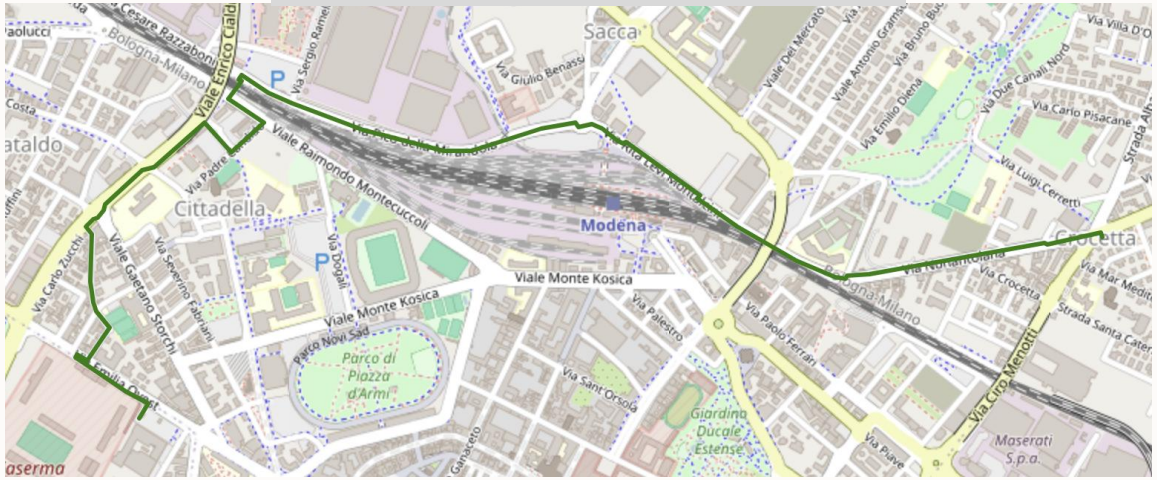
Green path

Modena - optimal path identification

SHORTEST PATH

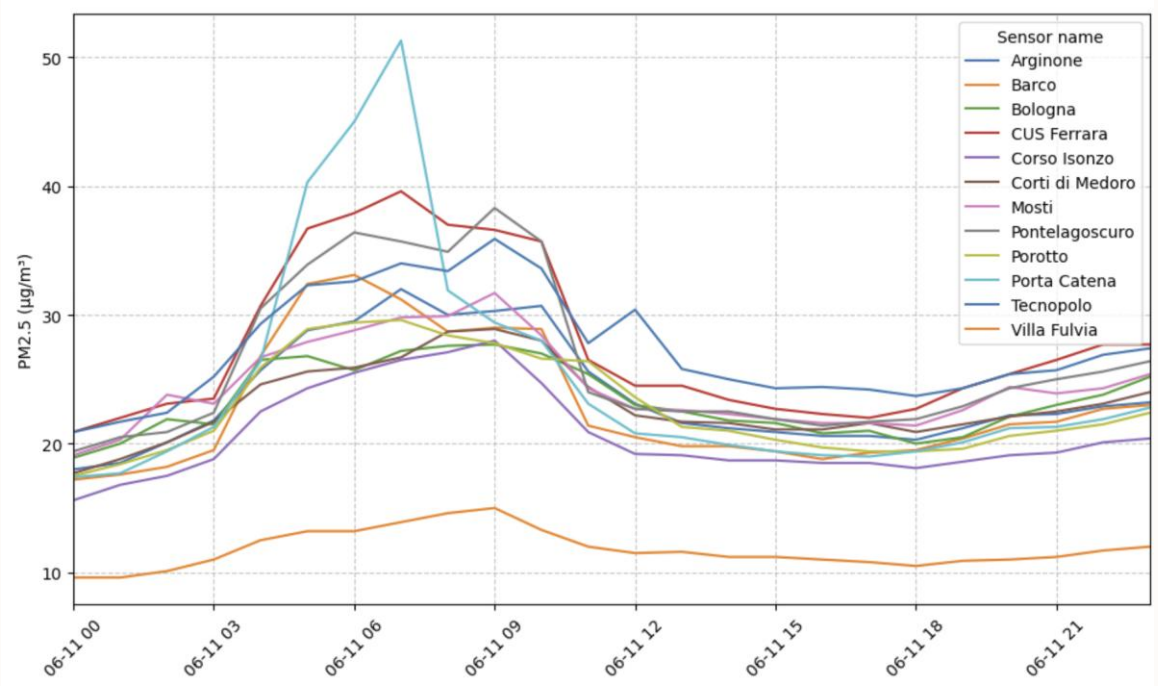
PATH WITH THE BEST *TRADE-OFF*

SAFEST PATH

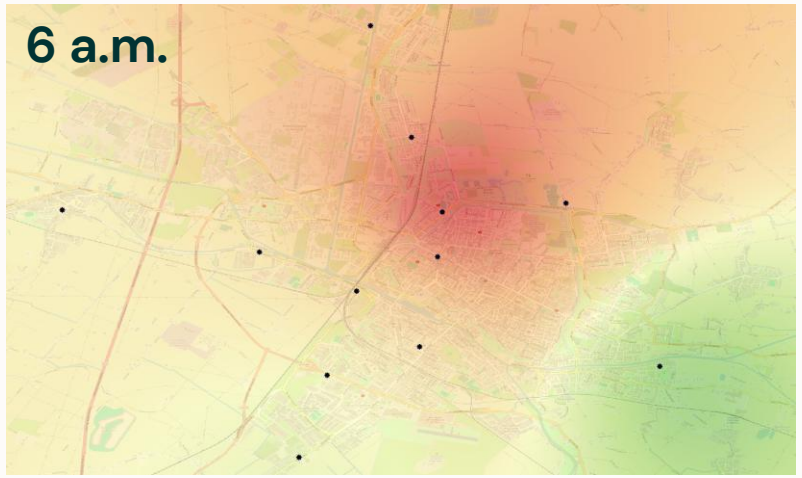


Ferrara - air pollution

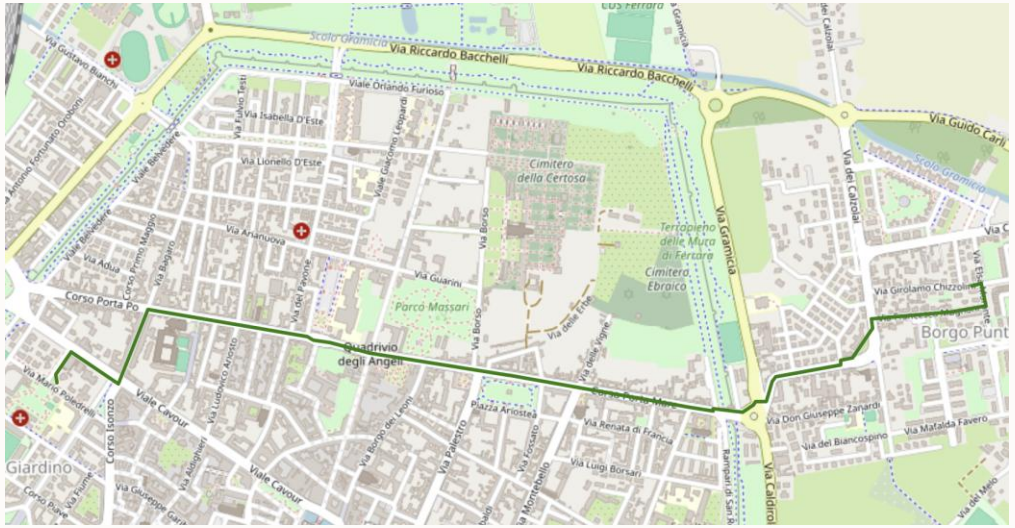
- Air pollution has a high **daily variability**

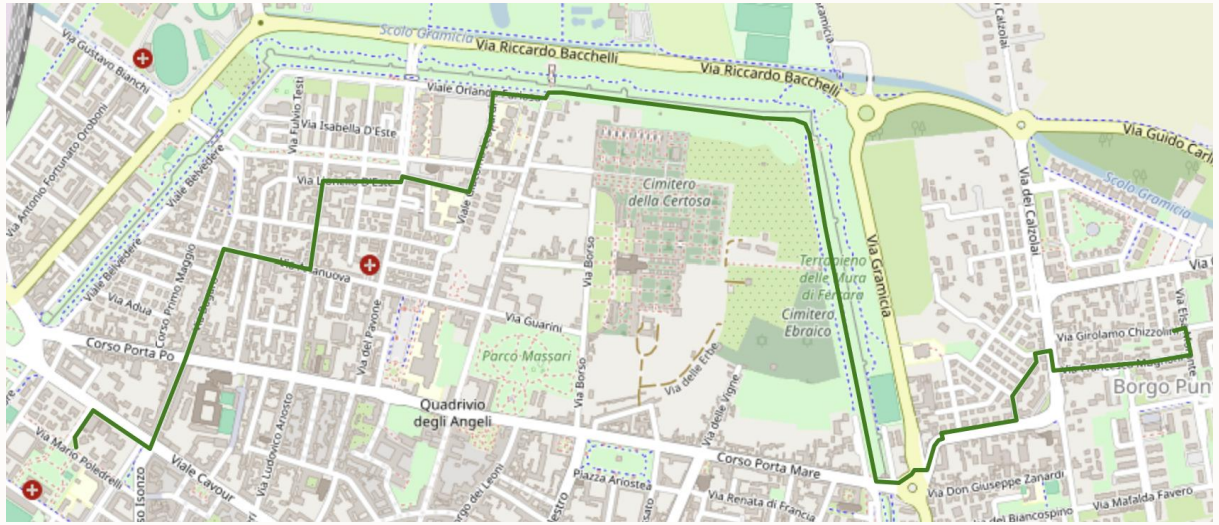


PM2.5 Ferrara – June 11, 2025
12 sensors



Ferrara - optimal path identification





Shortest and least polluted path

Path optimizing road priority

Mobility Survey

Wooclap code: PQFKFE

https://app.wooclap.com/PQFKFE

Session 3: Hands-on Implementation

Tasks

- **Step 1 – Graph Import**
  - Import and explore graphs generated from OpenStreetMap using Neo4j where contextual data (e.g., air pollution, road accidents) have been integrated
- **Step 2 – Path Generation**
  - Define a start point and an end point (from a set of suggested points)
  - Generate a sufficiently large set of candidate paths between the two points for multi-criteria analysis
- **Step 3 – Pareto Front Identification**
  - Identify the Pareto-optimal set (non-dominated solutions) among candidate paths
- **Step 4 – Optimal Path Selection and Interactive Exploration**
  - Select the most suitable path from the Pareto front based on user preferences
  - Visualize the selected path on the map
  - Modify the user preferences and explore how they affect the optimal solution

Tools

- Python code
- Google Colab (or Jupyter notebook)
- Python libraries: pandas, matplotlib, networkx, pymoo, folium

http://bit.ly/3JHliCh

Session 4: Q&A and Discussion

Mobility Survey

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