6th International Symposium on High-Speed Rail Socioeconomic Impacts

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A Methodological Reassessment of High-Speed Rail Accessibility Impacts through the Transport Connectivity Metric: application to the Italian case study

Emanuela Montenegro[1], Arianna Naimo[2], Mario Tartaglia[2]
[1]University of Bari 'Aldo Moro'; [2]Ferrovie dello Stato Italiane – FS Research Centre

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Introduction and literature review



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Research context

Why rethinking accessibility measurement matters for High-Speed rail and transport policy

Accessibility is a multidimensional concept

Accessibility is the ability to reach opportunities, yet existing indicators often only partially capture this experience



People (origins) → **Transport system** (modes, services, networks, frequencies, transfer, etc.) → **Opportunities** (job, services, activities)

The High-Speed Rail (HSR) paradox

High speeds in HSR systems do not necessarily translate into high accessibility or equal access to opportunities



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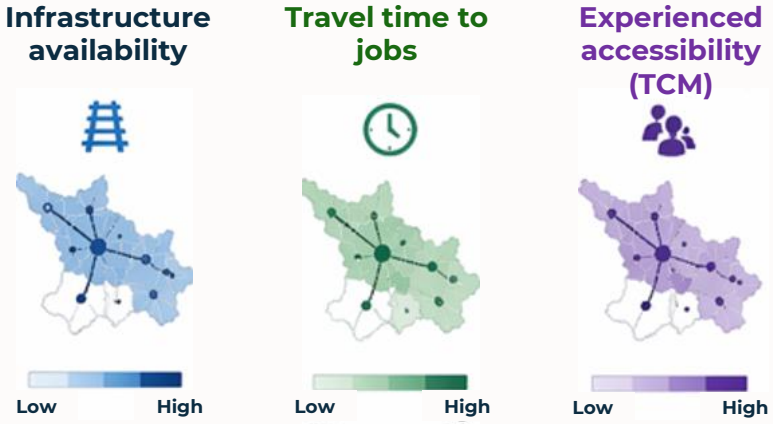


- Very fast travel times between major cities
- Poor first/last mile connections
- Low service frequency
- Uneven spatial distribution of opportunities

Accessibility indicators are not neutral

Metric choice matters: different indicators can produce different representations of accessibility and territorial impacts

Different metrics, different pictures of the same reality



Trends and Evolution in Mobility Planning

Evolution of accessibility thinking in Transport Planning: from movement-based planning to opportunity-based accessibility

Accessibility is a cornerstone concept in transport research, linking transport systems, opportunities and territorial outcomes, and has inspired a wide range of methodological approaches since Hansen (1959).

Mobility-oriented planning	Accessibility Theory	Activity-based and behavioural approaches	Triple Access Planning
Transport Planning Theory CATS, 1962	**Hansen, 1959; Geurs & van Wee, 2004**	**Hägerstrand, 1970; Ben-Akiva & Lerman, 1985**	**Lyons, 2018; Lyons et al., 2024**
First, forecast travel demand and then provide infrastructure capacity	Measure how transport and land-use systems enable access to opportunities	Account for time-space constraints, daily activities and travel choices	Integrate physical mobility, spatial proximity and digital access
			
Predict & Provide	**Access to opportunities**	**Activities & Choices**	**Decide & Provide**

Shift the focus from 'moving' to 'reaching' opportunities

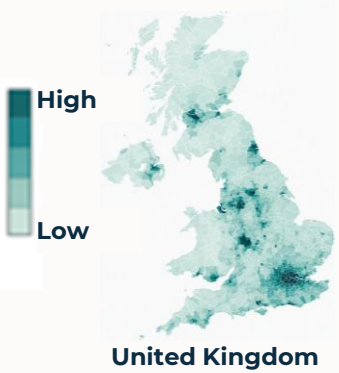
Transport Connectivity Metric (TCM) – UK DfT (2025)

Measuring people's ability to reach opportunities across modes under real service conditions

Multidimensional Inputs

Population-Weighted Origins	Destinations: Opportunities	Transport Networks	Travel Times	Service Frequency	Spatial Distribution	Observed Behaviour
Accessibility is measured from where people live, weighted by the number of residents in UK	TCM considers opportunities that people need to reach, across different types and locations	Multi-modal networks including rail, car and public transport (bus, metro, tram)	Door-to-door (or access/egress sensitive) travel times between origins and opportunities	Timetables and frequency of services reflect the real level of service available in a given time period	The geographic distribution of both population and opportunities in a given territory matters	TCM is grounded in observed choices and behaviour patterns (e.g. mode use, volume of time)

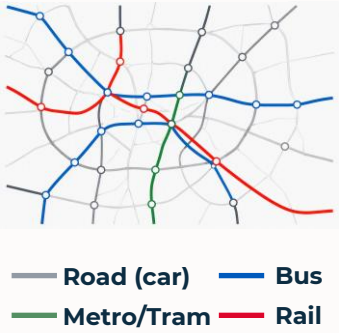
Resident Distribution



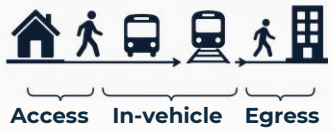
Opportunities Types



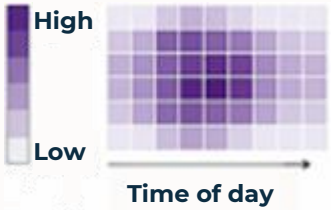
Network Structure



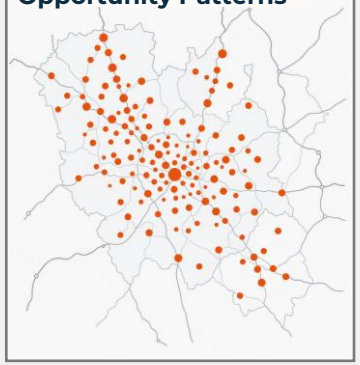
Door-to-Door Journey



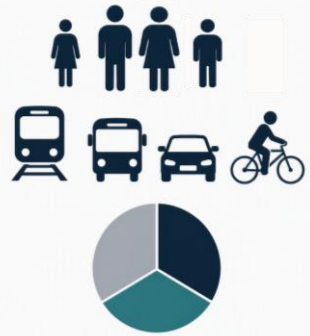
Service Frequency Patterns



Population & Opportunity Patterns



Observed Mobility Patterns

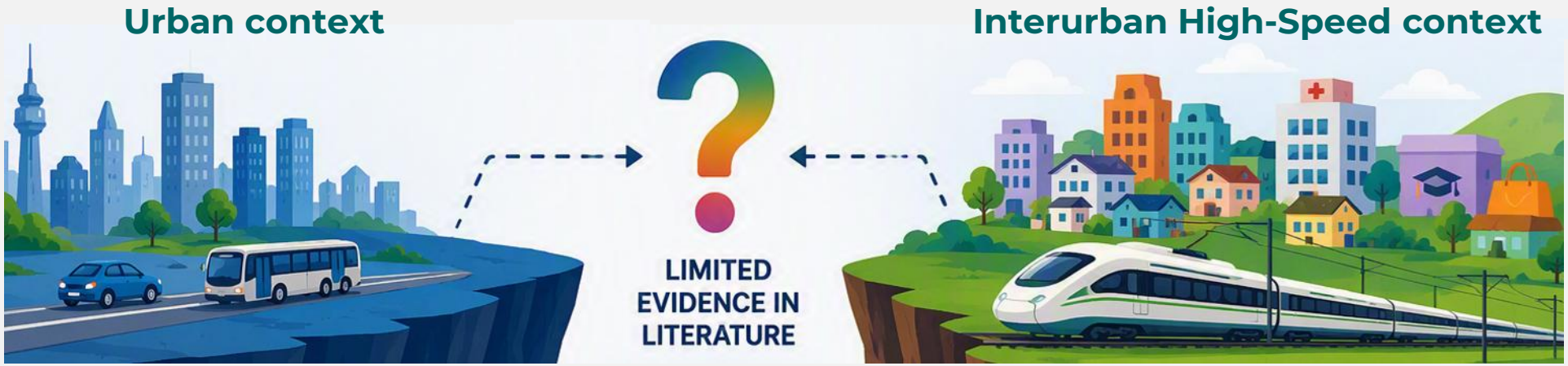


TCM Output & Purpose:

Higher TCM scores reflect greater access to opportunities, not simply greater mobility

Literature Gap and Research Objectives





Knowledge Gap ▶ **Holistic metrics such as the TCM** have not yet been applied to **interurban high-speed/long-distance** rail accessibility and existing indicators do not provide a complete view of how rail services translate into effective access to opportunities once service frequency, first/last-mile conditions, and the spatial distribution of destinations are considered.

Case Study ▶ **Italy HSR system** provides a particularly suitable case, with pronounced territorial disparities driven by service frequency, network structure, station accessibility, and the spatial distribution of opportunities.

Research Objective ▶ To **adapt the TCM** to interurban long-distance rail and assess how rail service, spatial position, opportunity distribution, and first/last-mile conditions jointly shape accessibility to opportunities across Italian cities.

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Research design



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Methodology

Study area

Cities were selected using two criteria:

at least 60,000 residents
→ capture cities with important administrative, economic, or transport roles

at least one station offering long-distance rail service
(Frecciarossa, Frecciargento, Frecciabianca, Intercity, Intercity Notte, EuroCity, EuroNight, or Italo)

The result is **54 cities**,
spanning Northern, Central, and Southern Italy

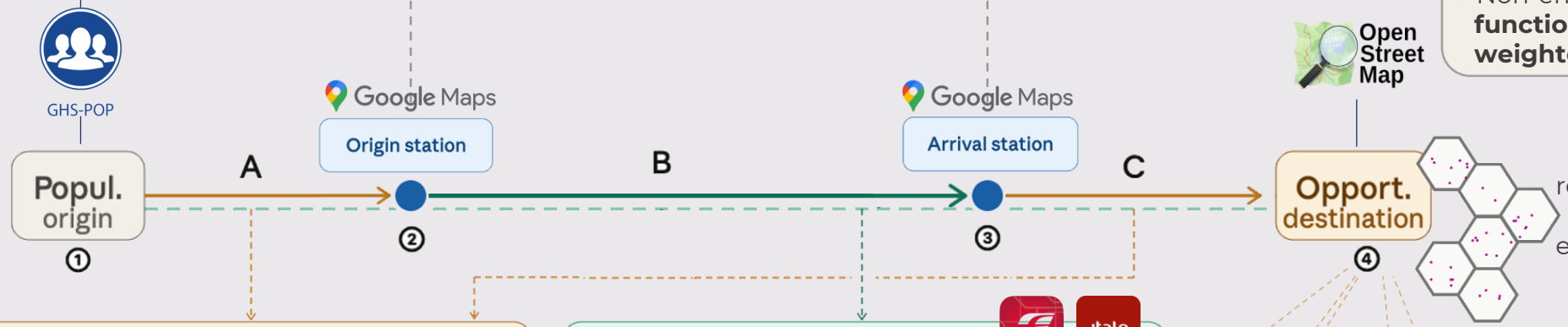
Methodology

Design of spatial reference points and journey components

✓A **single residential point per city** (100 m resolution).
✓The centroid of the **most populated** raster cell represents the likely trip origin.

Multi-station cities
For cities with multiple stations: travel times are computed for each station and then averaged, weighting each station by its proximity to the centroid (travel minutes) and the number of HS services to the destination (access) / from the origin (egress).

✓Opportunities are modeled as **hexagonal cells** (**H3**) containing OSM points of interest obtained through labels referring to each of the 5 opportunity categories.
✓Non-empty cells are **functional nodes weighted by POI count**.



A and C: First / last mile times
Google Maps APIs
→ Walking
→ Cycling
→ Car
→ Public transport
• Peak hour (average 6:30-7:30-8:30 am)
• Off-peak hour (average 2:30-3:30-4:30 pm)

B: Rail travel times
Including waiting times
+ Frequency as headway:
• Peak hour (6:00-9:00 am)
• Off-peak hour (2:00-5:00 pm)
✓March 2026 weekday
✓Only long-distance services with ≤1 transfer

Work*
Healthcare
University
Tourism
Leisure

* knowledge-intensive work

Door-to-door times

4 components are summed per mode and time (all expressed in minutes):

$$T_{ijh}^{m,s} = Access_i^{m,s} + \bar{R}_{ij}^{s} + F_{ij}^{S} + Egress_{jh}^{m,s}$$

Access and egress times | **Rail travel times** | **Frequency**

where:

- i = origin city
- j = destination city
- s = time window
- h = specific hexagon
- m = access/egress mode

(!) Unavailable services or routes mark the OD pair unreachable.

represented through the **average headway** among services in each time window divided by 2 (assuming random passenger arrivals at the departure station):

$$F_{ij}^{(s)} = \frac{120/N_{ij}^{(s)}}{2},$$

where N_{ij} are the available services in *s*.

Accessibility indicator: disaggregated level

- **Impedance:** without equivalent interurban behavioural data to TCM, a **negative exponential function** is used ($\beta = 0.02$ min^{-1}; sensitivity: 0.01, 0.03, 0.05).
- **Travel-time threshold:** the TCM considers destinations reachable within **60 min**; for interurban rail, the threshold is extended to **240 min**, consistent with potential same-day return trips (180 min also tested).

Node-level indicator

$$C_{ijh}^{(k,m,s)} = O_{jh}^{k}\, e^{-\beta T_{ijh}^{(m,s)}}\, 1\left(T_{ijh}^{(m,s)} \leq 240\right)$$

where:

O_{jh}^{k} =number of opportunities belonging to category k contained in destination node h;

$T_{ijh}^{(m,s)}$ = corresponding door-to-door travel time;

$1(\cdot)$ = is an indicator function equal to one when the travel time does not exceed the threshold and zero otherwise.

City-level indicator (by category-mode-window)

$$A_{i}^{k,m,s} = \sum_{j} \sum_{h \in H_j} C_{ijh}^{(k,m,s)}$$

where:

H_j is the set of opportunity nodes within destination city j.

The double ∑ aggregates node-level contributions (a) within each city j and (b) across all destination cities.

Methodology

Accessibility indicators

Five destination purposes assessed through one common modal framework

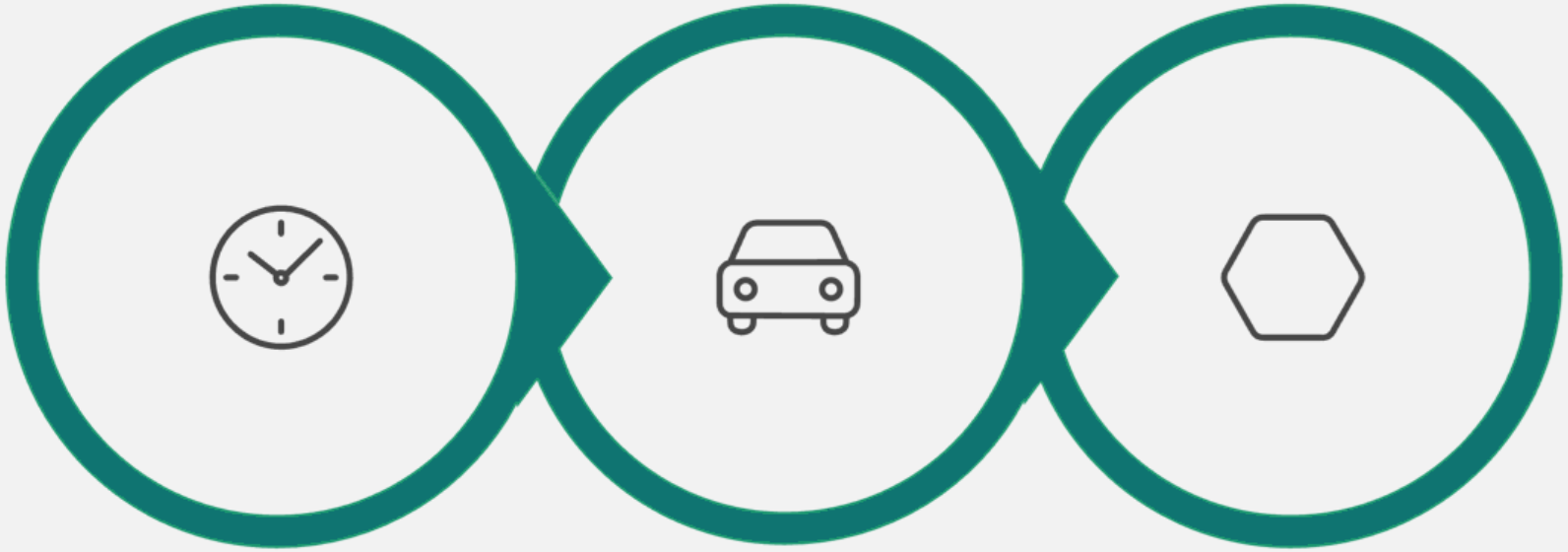
- **Work**
- **University and Research**
- **Healthcare**
- **Tourism**
- **Leisure**

Accessibility modes

	**Public Transport**	**Public Transport (Peak)**	**Public Transport (Peak-off)**
	**Car**	**Car (Peak)**	**Car (Peak-off)**
	**Bicycle**	**Bicycle (Peak)**	**Bicycle (Peak-off)**
	**Walking**	**Walking (Peak)**	**Walking (Peak-off)**

! In the case of **cycling** and **walking**, Peak and Off-peak refer only to the rail travel-time and service frequency windows, since first- and last-mile times are time-invariant.

Accessibility indicator: aggregated level



Average time-window values

Use of car as proxy of access/egress mode

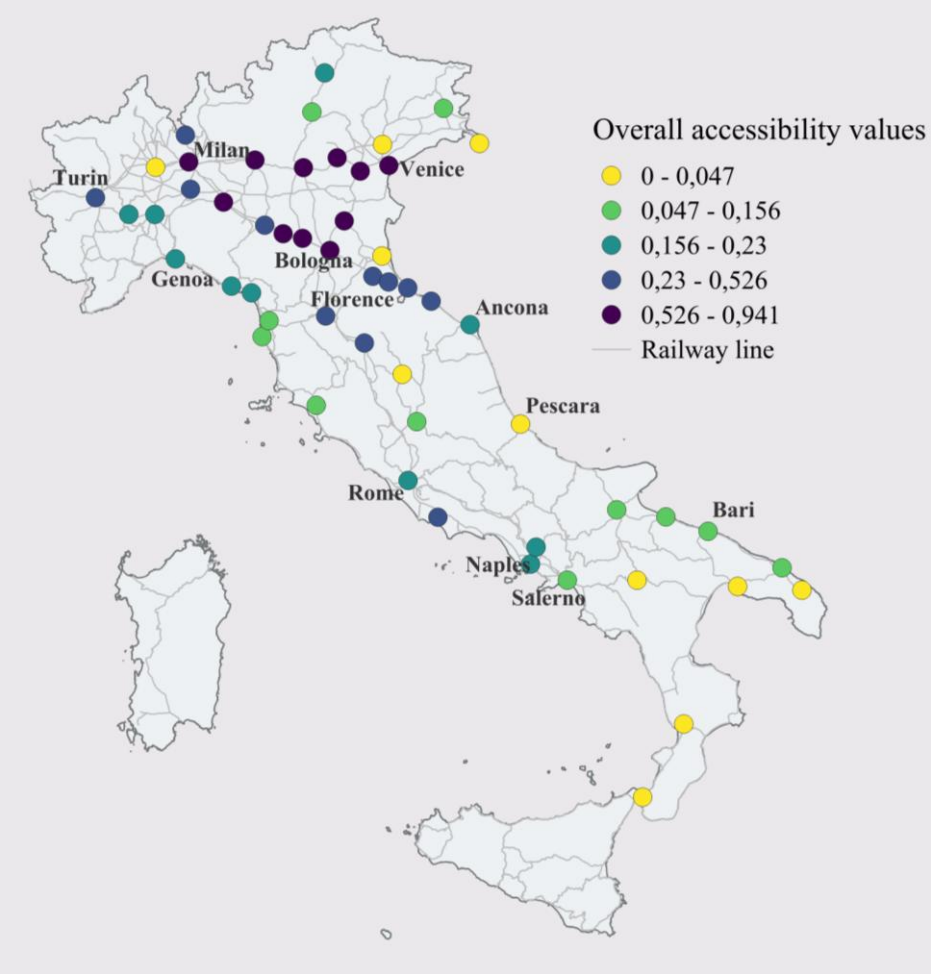
Normalisation for each category

Each category is min-max normalized, then combined with equal weights

The overall accessibility indicator is calculated as the **arithmetic mean** of the **five normalized category-specific indicators**:

$$A_i^{overall} = \frac{1}{5}\sum_{k=1}^{5} \tilde{A}_i^k$$

Overall accessibility and associated factors



Accessibility is a joint outcome of:

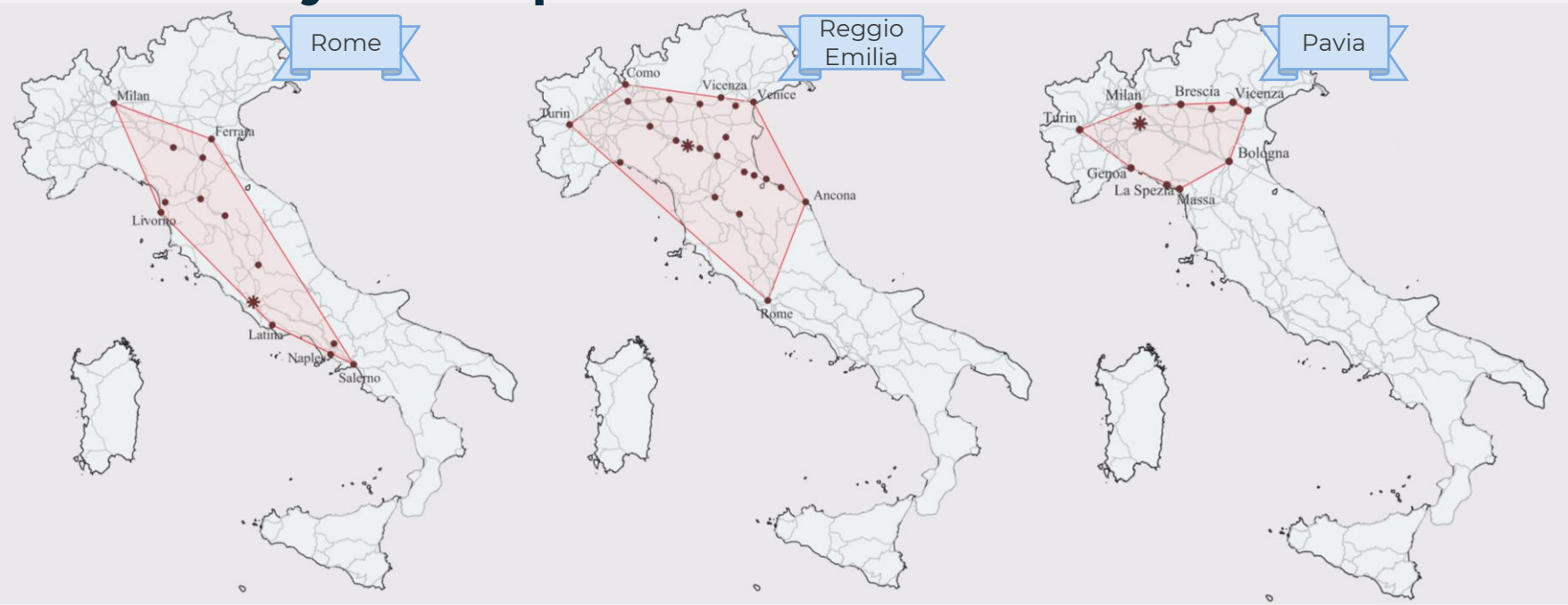
- ✓ **rail service quality**,
- ✓ **spatial position** within the urban system,
- ✓ **volume of opportunities** reachable in other cities,
- ✓ **time** required to access and leave the rail network.

Highest values cluster in **intermediate cities within dense, well-connected urban systems**, where many opportunity-rich destinations are reachable within 240 minutes.

Reference time period: first half of 2026

Results

Reachability envelopes



240-min reachability envelopes illustrate how the spatial configuration of reachable destinations shapes accessibility

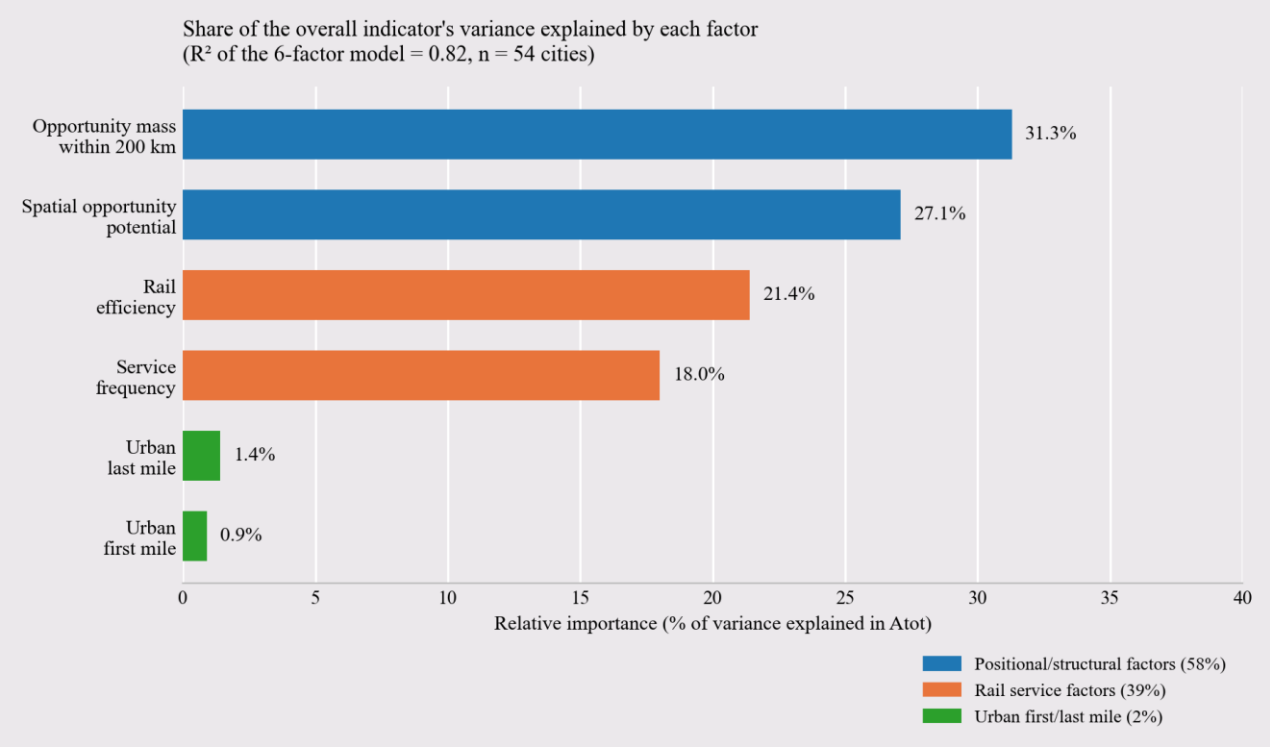
- **Reggio Emilia vs Rome:** similarly broad envelopes, but RE reaches more opportunity-rich cities at lower travel times.
- **Rome vs Pavia:** Pavia has a smaller envelope, but proximity to Milan (a single high-opportunity city generates much higher accessibility).

- Cities with reachable opportunities
- Origin
- 4h nodal envelope
- Railway line

	Reggio Emilia	Rome	Pavia
Cities within 240 min	22	13	10
Time-weighted opportunity mass	8.825	1.699	5.937
Main contribution	Milan (37%)	Naples (32%)	Milan (79%)

Accessibility cannot be inferred from reachability alone, but depends on which **destinations** are reached, their **opportunity mass**, and the **time** required to reach them.

Relative contribution of positional, rail and urban factors to accessibility

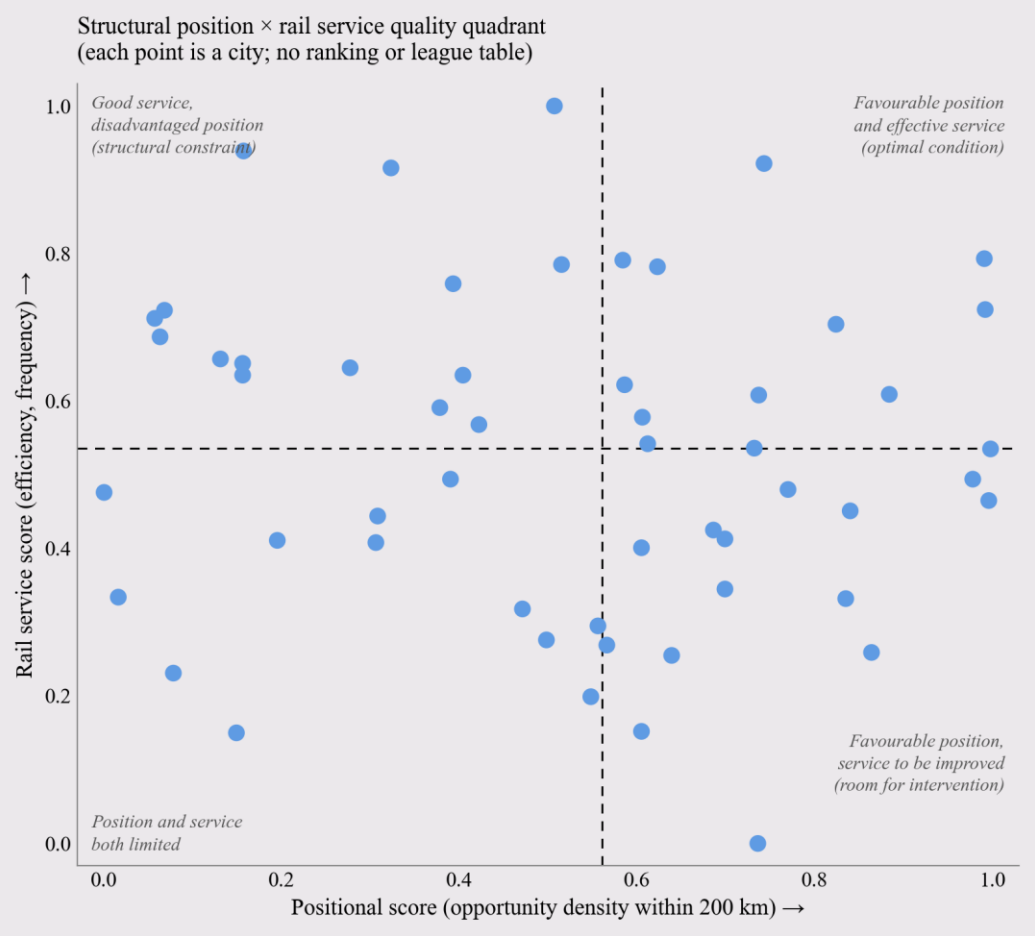


To identify the factors underlying **differences** in overall accessibility, A_{tot} is related to six diagnostic dimensions (that explain 82% of the variation across cities, $R^2 = 0.817$).

Spatial position has the largest relative contribution, while rail efficiency and frequency remain fundamental in converting territorial potential into effective accessibility.

Low aggregate first/last-mile shares do not imply limited relevance in specific cities or modal scenarios, but rather that they explain a smaller share of overall differences across cities.

Combination of spatial position and rail service across cities

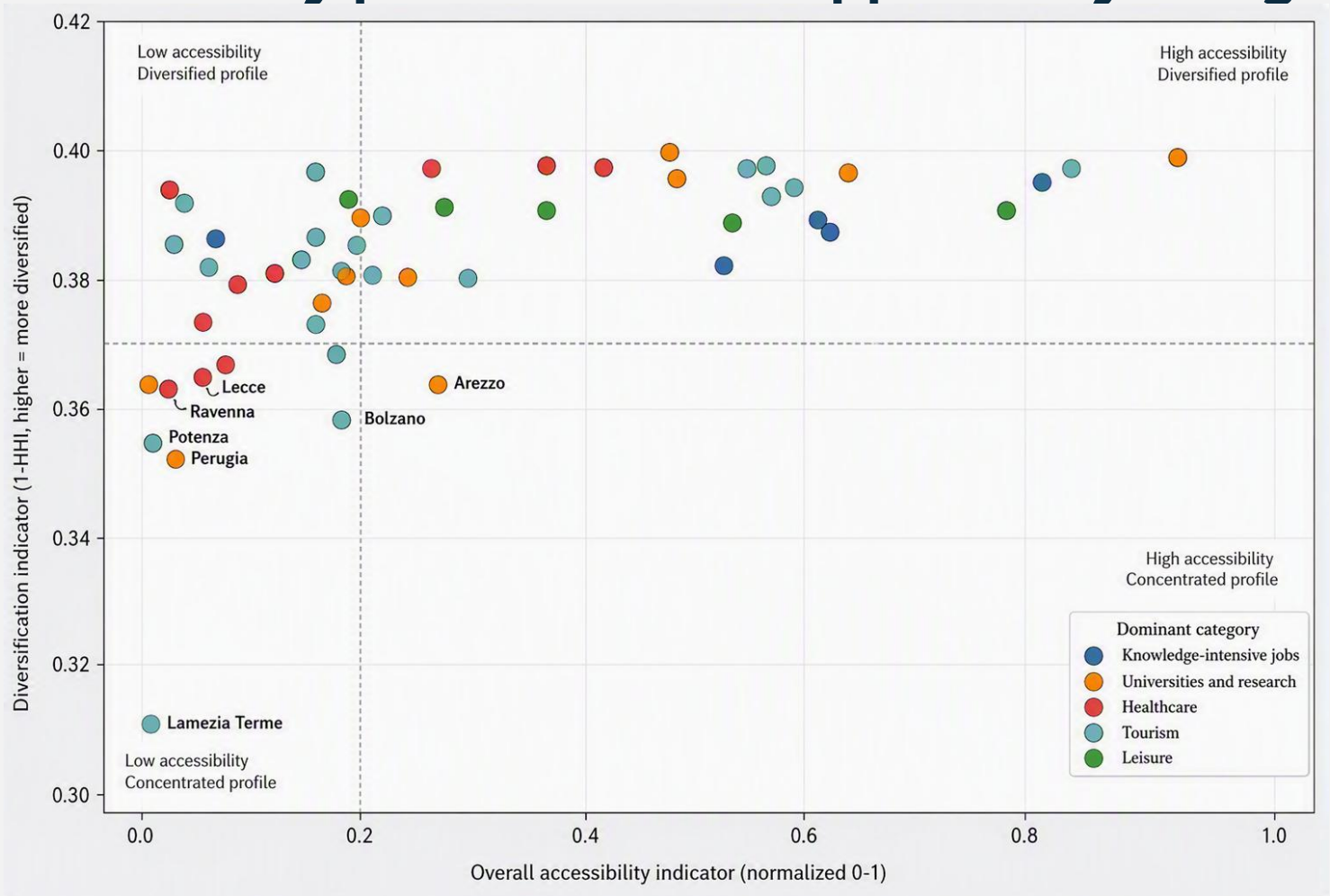


The six dimensions are then summarized into two key axes: proximity to opportunities and rail-service performance.

- Strong spatial position does not necessarily coincide with strong rail performance.
- Similar accessibility levels can result from different combinations of opportunity proximity and rail performance.

Results

Accessibility patterns across opportunity categories



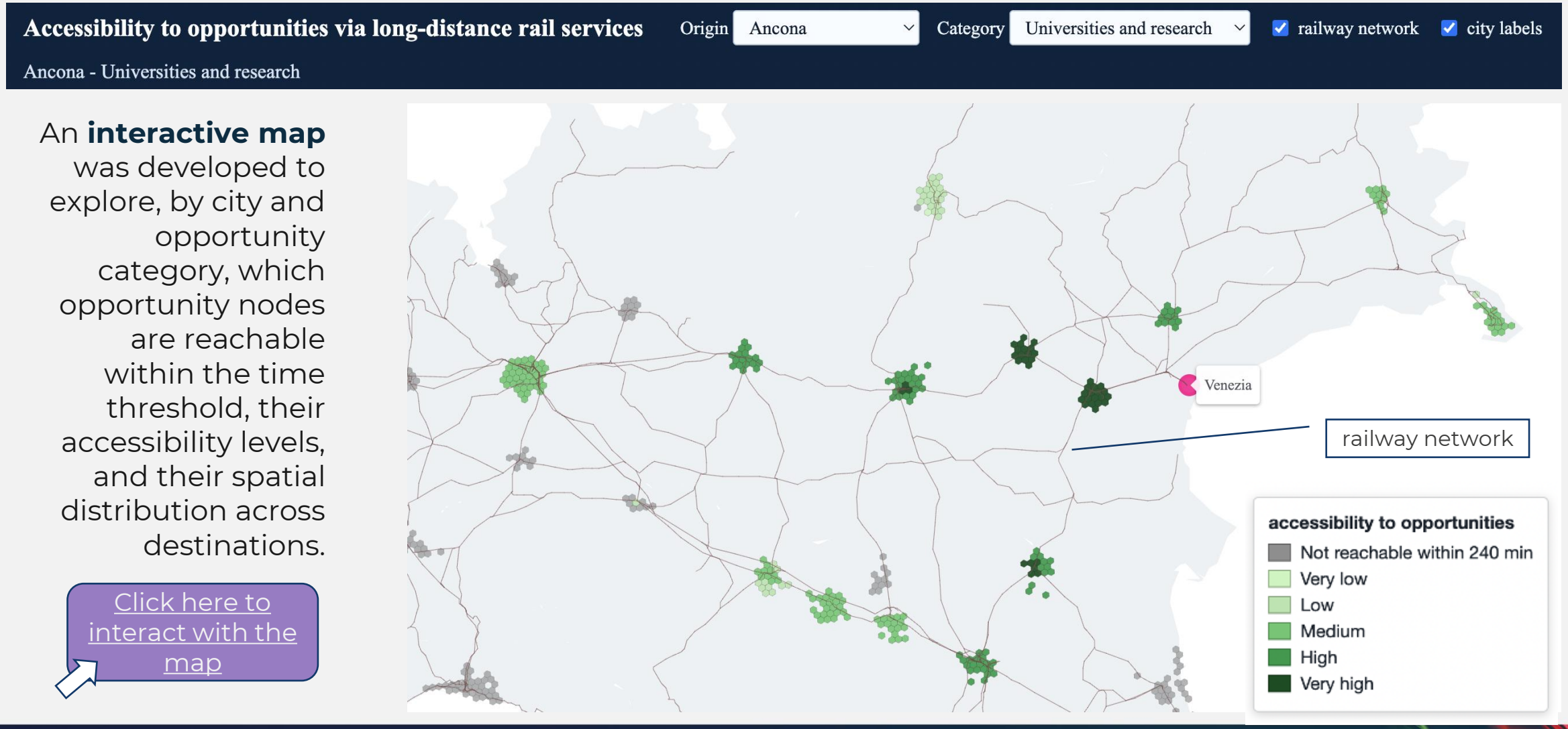
→ **Rankings** remain highly consistent across categories
Spearman ρ = 0.90–0.98

→ However, **city accessibility profiles** remain generally diversified
1–HHI = 0.707–0.800; max = 0.80
Higher accessibility is associated with greater diversification *(ρ = 0.660)*

→ **Differences** emerge mainly in the relative weight and spatial concentration of categories

- **Knowledge-intensive work**: most concentrated *(Gini = 0.547)*
- **Tourism**: most dispersed *(Gini = 0.473)*

Results

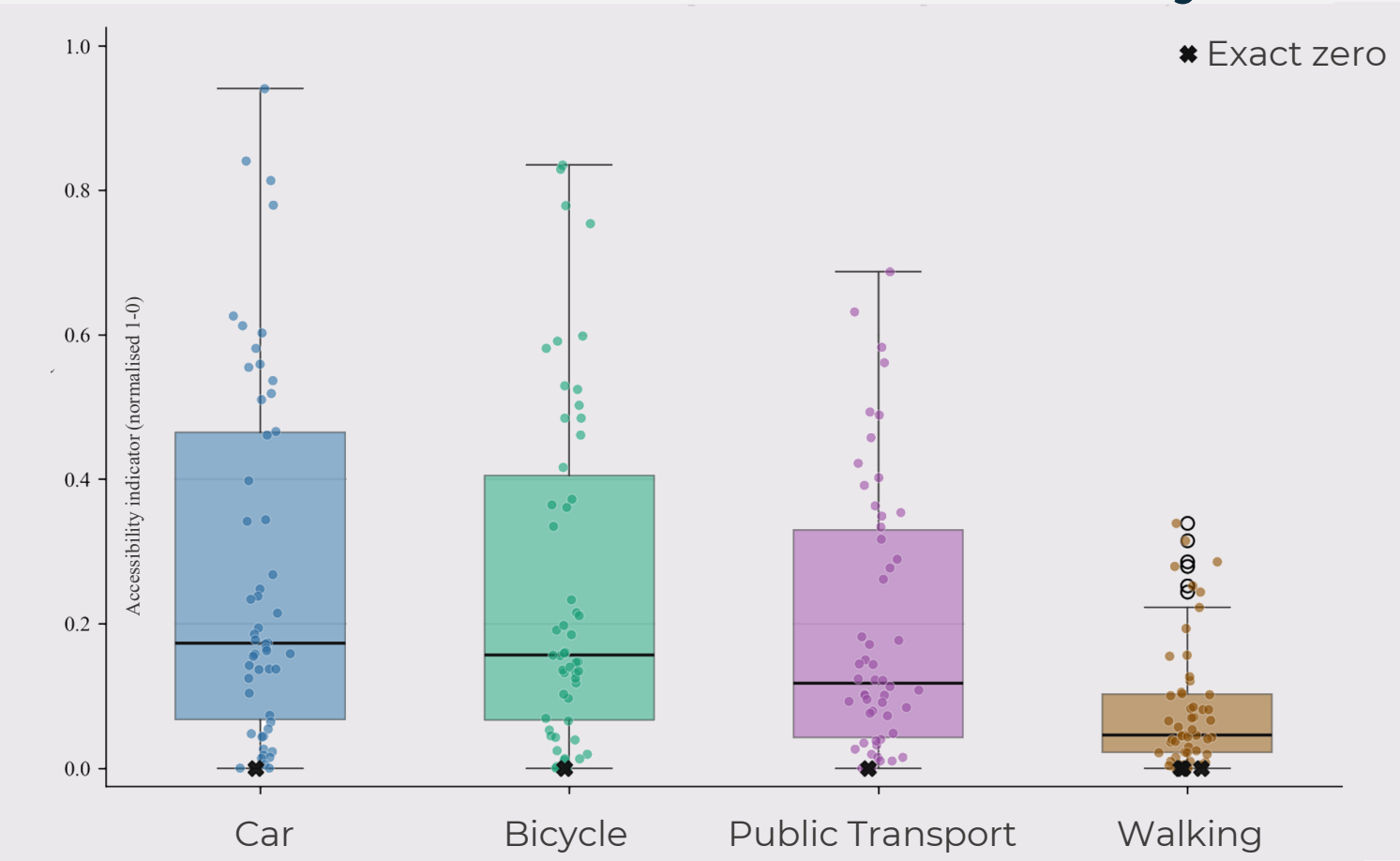


An **interactive map** was developed to explore, by city and opportunity category, which opportunity nodes are reachable within the time threshold, their accessibility levels, and their spatial distribution across destinations.

Click here to interact with the map

Results

First- and last-mile effects on accessibility



Car is the baseline; cycling, public transport and walking represent counterfactual first/last-mile scenarios on the same normalization scale.

Cycling remains closest to the car scenario, while **public transport** and especially **walking** progressively reduce accessible opportunities.
Median accessibility: car 0.173 | cycling 0.157 | PT 0.117 | walking 0.046

First/last mile can absorb a substantial share of the total travel-time budget, reshaping the set of destinations that remains reachable within 240 min.
Median first + last mile: 29.2 min car | 46.1 cycling | 58.7 PT | 148.5 walking

Public transport takes 14.2 min longer than cycling, due to (a) waiting/transfers (b) gaps in route availability.

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Final summary



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Final summary

Main contributions and future research directions

Contributions

- TCM extended to **interurban long-distance rail**, combining door-to-door travel with the mass, composition and spatial distribution of reachable opportunities.
- The **framework** allows accessibility to be diagnosed and disaggregated by spatial position, rail service, opportunity category and first/last-mile mode.

Key findings

- Accessibility is **cumulative**: it depends on the combination of spatial position, the mass and distribution of reachable opportunities, rail efficiency and frequency, and first- and last-mile conditions;
- **Spatial position** and **rail service** account for ~58% and ~39% of explained cross-city variation respectively;
- Accessibility patterns are highly **consistent across opportunity categories**, while city profiles remain diversified (knowledge-intensive work is the most concentrated category; tourism the most spatially dispersed).
- First/last mile impacts on the effective opportunity set: ***cycling*** remains close to the car scenario, while ***public transport*** and especially ***walking*** reduce accessibility.

Future developments

- Extend the analysis from **long-distance services to the full rail offer**, including regional services that may be crucial for nearby-city connections (the current scope may underestimate accessibility to nearby cities that are served mainly by regional rail).
- **Empirically calibrate impedance functions** using observed interurban travel behaviour.
- Expand temporal and spatial coverage and use the framework for **scenario analysis** of frequency, travel times and station–urban integration.

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