A MATSim-based framework to Incorporate High Resolution Built Environment Data for Modelling Walkability and Cyclability

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MATSim User Meeting
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Contents

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Built Environment Influences Active Travel

Pedestrian and Cycling Infrastructure

- Width
- Surface quality
- Separation from traffic
- Traffic speed / volume

Junctions and Crossings

- Signal type
- Crossing speed / volume

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Images from UK Department for Transport Cycle Infrastructure Design Book: https://www.gov.uk/government/publications/cycle-infrastructure-design-ltn-120

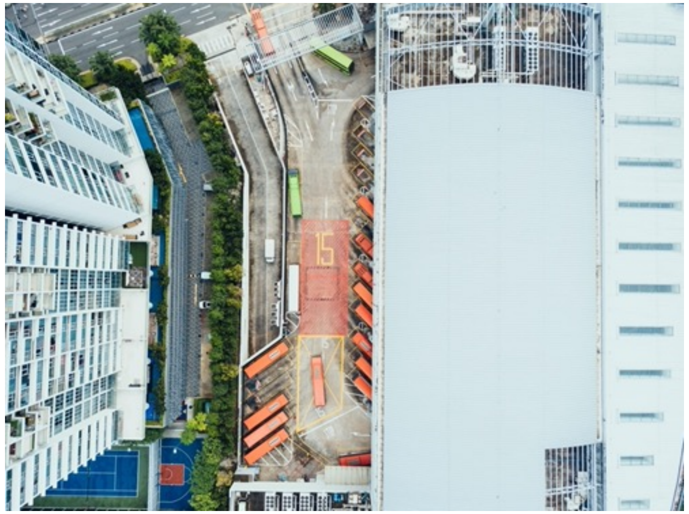
Built Environment Influences Active Travel

Vehicle Infrastructure

- Traffic filters
- Freight loading zones

Ambience

- Tree cover
- Green visibility
- Points of interest
- Streetlighting



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Influences on Travel Behavior

- Route Choice
- Mode Choice
- Trip Generation
- Public transport subscription
- Bicycle ownership
- Car ownership
- Choice of residence / workplace

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Lots of research on this topic…

- Examples in **Public Health research**…
  - Cain, K. L., Millstein, R. A., Sallis, J. F., Conway, T. L., Gavand, K. A., Frank, L. D., Saelens, B. E., Geremia, C. M., Chapman, J., Adams, M. A., Glanz, K., & King, A. C. (2014). Contribution of streetscape audits to explanation of physical activity in four age groups based on the Microscale Audit of Pedestrian Streetscapes (MAPS). Social Science & Medicine, 116, 82–92. https://doi.org/10.1016/j.socscimed.2014.06.042
  - Zapata-Diomedi, B., Herrera, A. M. M., & Veerman, J. L. (2016). The effects of built environment attributes on physical activity-related health and health care costs outcomes in Australia. *Health & Place*, *42*, 19–29. https://doi.org/10.1016/j.healthplace.2016.08.010
- Examples in **Transport modelling**…
  - Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. Transportation Research Part D: Transport and Environment, 2(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6
  - Thao, V. T., & Ohnmacht, T. (2020). The impact of the built environment on travel behavior: The Swiss experience based on two National Travel Surveys. Research in Transportation Business & Management, 36, 100386. https://doi.org/10.1016/j.rtbm.2019.100386
- Examples in **MATSim**…
  - Ziemke, Dominik et al. *Modeling bicycle traffic in an agent-based transport simulation.* Procedia Computer Science, 2017 (https://doi.org/10.1016/j.procs.2017.05.424)
  - Antoniou, Eleni et al. *Simulation of e-bike and e-scooter trips using MATSim. Presented at MUM2022 (https://ethz.ch/content/dam/ethz/special-interest/baug/ivt/ivt-dam/events/2022/05/31/presentations/Antoniou_EtAl_MUM_2022_Presentation.pdf)*

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Walkability and Cyclability as an Accessibility indicator

- **Describes a location** (e.g., household or workplace)
- Indicator of **travel behavior** and **social equity**
- Typically use **aggregate**, **area-level** measurements of land use and/or the transport network
- Examples:
  - *Density of pedestrian or cycle paths in an area*
  - *Network connectivity*
  - *Land use diversity*
  - *Number of shops within 800m (10-minute) walk*
  - *Some aggregation of the above*

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Walkability and Cyclability: Common Limitations

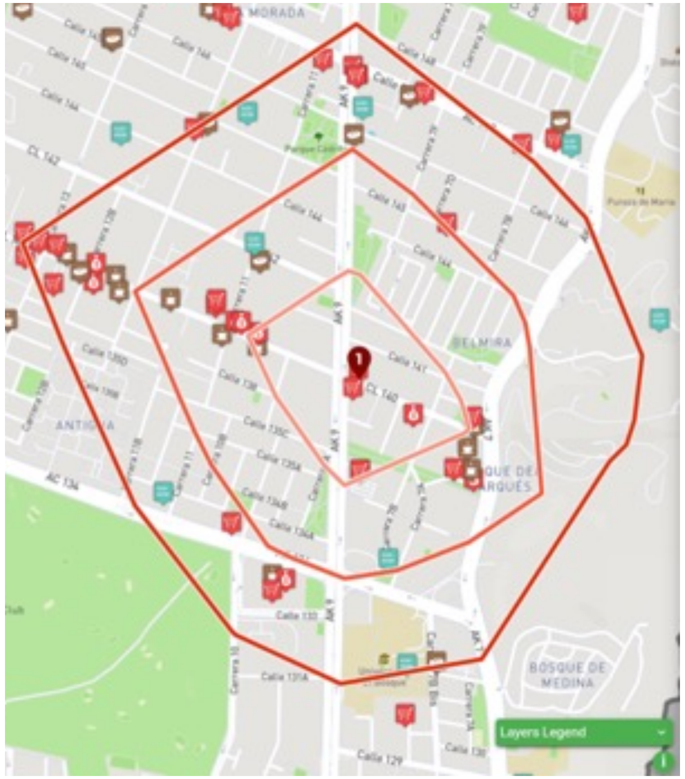
- **Spatial aggregation**
  - ➢ Modifiable Aerial Unit Problem (MAUP)

- **Hard cutoffs**
  - ➢ Smooth decay functions are more behaviorally realistic

- **Assumption of independence** between built environment, network, and land use
  - ➢ People perceive the built environment as they use the network to get places
  - ➢ Assuming independence distorts modelled relationship and assessments

<u>**Why?**</u>

- *Simple to develop and describe*
- *Challenging to integrating built environment, network, and land use*
- *Computational feasibility*



https://www.open-accessibility.org

Research Overview and Methods

Developing a fully disaggregate walkability and cyclability assessment tool

Main Research Goals (Overview):

1. Incorporate built environment characteristics into a MATSim network at the street segment (link) resolution

2. Specify an active mode accessibility model incorporating the **built environment, transport network,** and **land use** through a two-component approach

3. Efficiently estimate accessibilities at any level of disaggregation, e.g.:
   - Zones
   - Grid cells
   - Exact households

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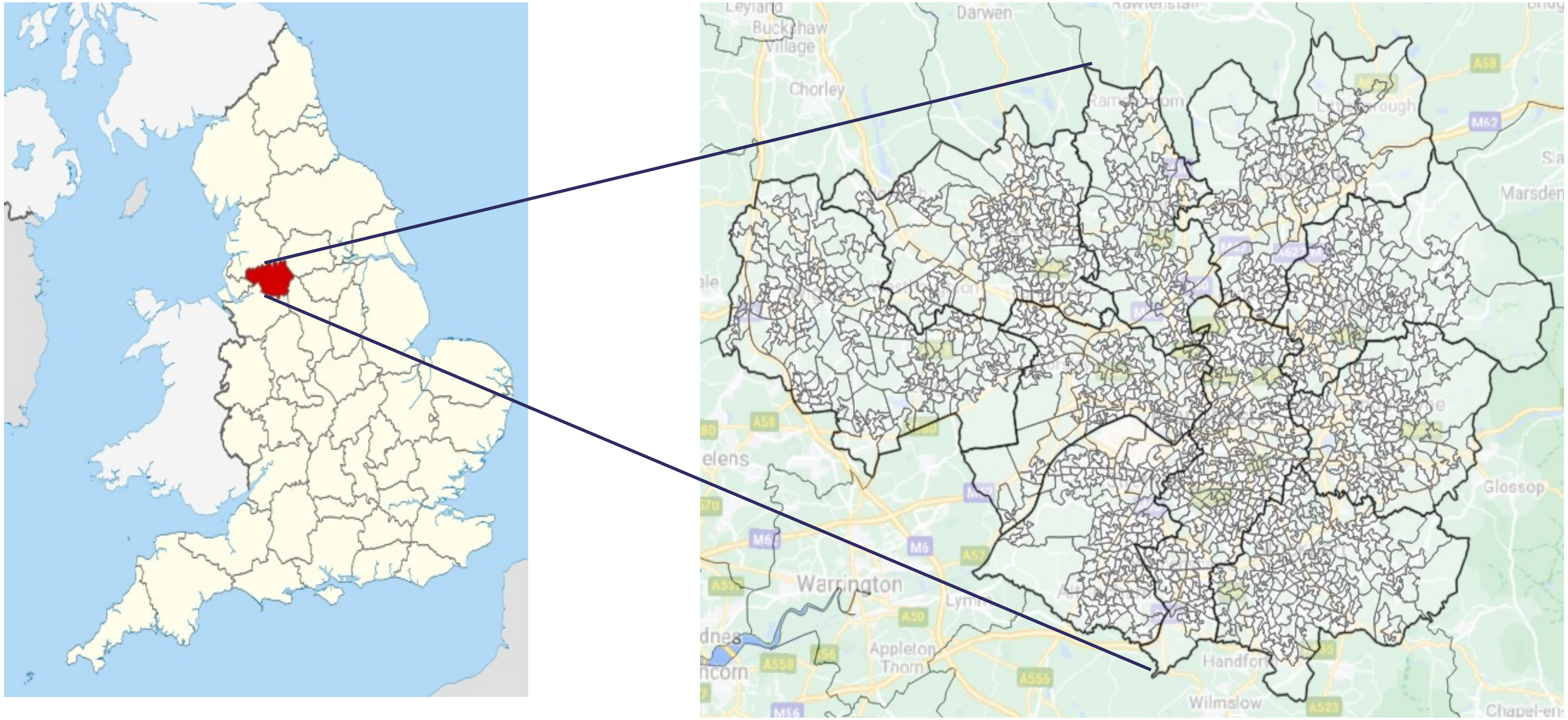
Study Area: Greater Manchester



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Research Goals:

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Goal 1: Incorporating Built Environment Attributes into MATSim

- Road infrastructure information
- Posted speed
- Sidewalk, Cycleway

- Road width
- Traffic calming features
- Digital Surface Model
- Digital Terrain Model
- Points of Interest

- Observed 85th % speed
- Crossings, signals
- Cycle infrastructure (Bee Network)
- Streetlights (Bee Network)
- Canopy data (City of Trees)

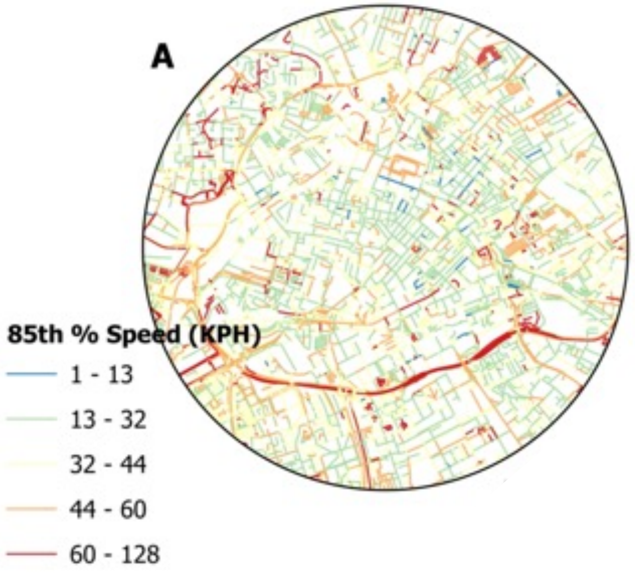
- Normalized Difference Vegetation index (Sentinel-2)

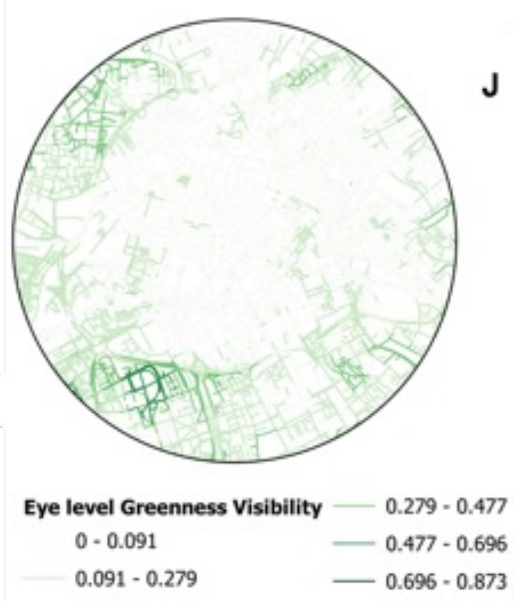
- Modal filters
- Quietness index

- Crime locations

Total of 65 link attributes

Examples:





Result (network.xml):


```xml
<link id="404423rtn" from="210689" to="344813" length="7.834059578968688" freespeed="13.4112" capacity="600.0" permlanes="1.0" oneway="1" modes="ca
    <attributes>
        <attribute name="POIs" class="java.lang.Double">0.0</attribute>
        <attribute name="aadt" class="java.lang.Double">1226.4529</attribute>
        <attribute name="aadt2" class="java.lang.Double">0.0</attribute>
        <attribute name="aadtFwd" class="java.lang.Double">613.22645</attribute>
        <attribute name="allowsCar" class="java.lang.Boolean">true</attribute>
        <attribute name="allowsCarFwd" class="java.lang.Boolean">true</attribute>
        <attribute name="crime" class="java.lang.Double">0.0</attribute>
        <attribute name="cross85PercSpeed" class="java.lang.Double">NaN</attribute>
        <attribute name="crossAadt" class="java.lang.Double">NaN</attribute>
        <attribute name="crossLanes" class="java.lang.Double">NaN</attribute>
        <attribute name="crossSpeedLimitMPH" class="java.lang.Double">NaN</attribute>
        <attribute name="crossVehicles" class="java.lang.Boolean">false</attribute>
        <attribute name="crossWidth" class="java.lang.Double">NaN</attribute>
        <attribute name="cycleosm" class="java.lang.String">null</attribute>
        <attribute name="cycleway" class="java.lang.String">no</attribute>
        <attribute name="disconnected_bike" class="java.lang.Boolean">false</attribute>
        <attribute name="disconnected_car" class="java.lang.Boolean">false</attribute>
        <attribute name="disconnected_walk" class="java.lang.Boolean">false</attribute>
        <attribute name="dismount" class="java.lang.Boolean">false</attribute>
        <attribute name="edgeID" class="java.lang.Integer">404423</attribute>
        <attribute name="endsAtJct" class="java.lang.Boolean">false</attribute>
        <attribute name="fwd" class="java.lang.Boolean">false</attribute>
        <attribute name="hgvPOIs" class="java.lang.Double">0.0</attribute>
        <attribute name="junction" class="java.lang.String">no</attribute>
        <attribute name="motorway" class="java.lang.Boolean">false</attribute>
        <attribute name="name" class="java.lang.String">New Drake Green</attribute>
        <attribute name="ndvi" class="java.lang.Double">0.390443881352742</attribute>
        <attribute name="negPOIs" class="java.lang.Double">0.0</attribute>
        <attribute name="osmID" class="java.lang.Integer">699773100</attribute>
        <attribute name="quietness" class="java.lang.Integer">80</attribute>
        <attribute name="shannon" class="java.lang.Double">0.0</attribute>
        <attribute name="speedLimitMPH" class="java.lang.Integer">30</attribute>
```

Research Goals:

1. *Incorporate built environment characteristics into a MATSim network at the street segment (link) resolution*

2. Specify an active mode accessibility model incorporating the **built environment, transport network,** and **land use** through a two-component approach

3. *Estimate accessibilities at any level of disaggregation, e.g.:*
   - *Zones*
   - *Grid cells*
   - *Exact households*

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Two-component Accessibility Model

Function of **destination locations** and the **impedance of reaching them**:

$$A_i = \sum_j f(W_j, c_{ij})$$

Where:

- W_j *is the weight of destinations*
- c_{ij} *is the cost of reaching them (potential to incorporate built environment)*
- $f()$ *is some decreasing function (usually exponential)*

Background:

- *Hansen, W. G. (1959). How Accessibility Shapes Land Use. Journal of the American Institute of Planners, 25(2), 73–76. https://doi.org/10.1080/01944365908978307*
- *Used predominantly in* ***transport modelling*** *to evaluate* ***car*** *and* ***public transport*** *accessibility*
- *Research gap w.r.t. using this for* ***active modes*** *and* ***built environment***

Composite Link Cost

Included Elements	Origin
Distance	**Dominant in existing tools**
Travel time	**MATSim Bicycle Extension** (Ziemke et al. 2019)
Gradient	
Surface type (e.g., asphalt, gravel, sand, …)	
Ambience (e.g., greenness, POIs, lighting, …)	**New**
Link Stress (e.g., vehicle traffic, cycle infrastructure, …)	**From guidance in UK Cycle Infrastructure Design Handbook (https://www.gov.uk/government/publications/cycle-infrastructure-design-ltn-120)**
Intersection Stress (e.g., crossing type, crossing traffic/speed, …)	

Costs are aggregated from the link to the route level, along the **least-cost** path

Composite Link stress (s_l)

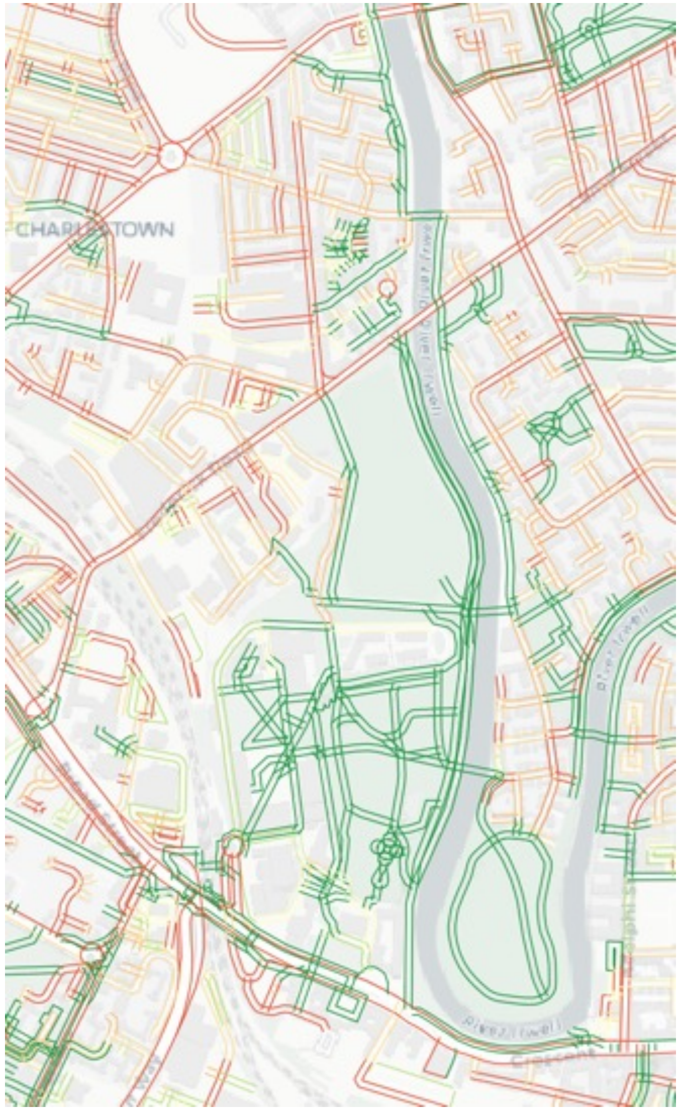
For each link, we score its **stress** based on guidance from the UK Department for Transport.

Function of **infrastructure type & separation** and **traffic speed & volume**

- <u>Example for cycling:</u>

Speed Limit[1]	Motor Traffic Flow (pcu/24 hour)[2]	Protected Space for Cycling			Cycle Lane (mandatory/ advisory)	Mixed Traffic
		Fully Kerbed Cycle Track	Stepped Cycle Track	Light Segregation		
20 mph[3]	0 2000 4000 6000+					
30 mph	0 2000 4000 6000+					
40 mph	Any					
50+ mph	Any					

https://www.gov.uk/government/publications/cycle-infrastructure-design-ltn-120



Composite Junction stress (s_j)

We score stress for each intersection based on the **signalization**, **crossing type**, and **crossing traffic speed & volume**

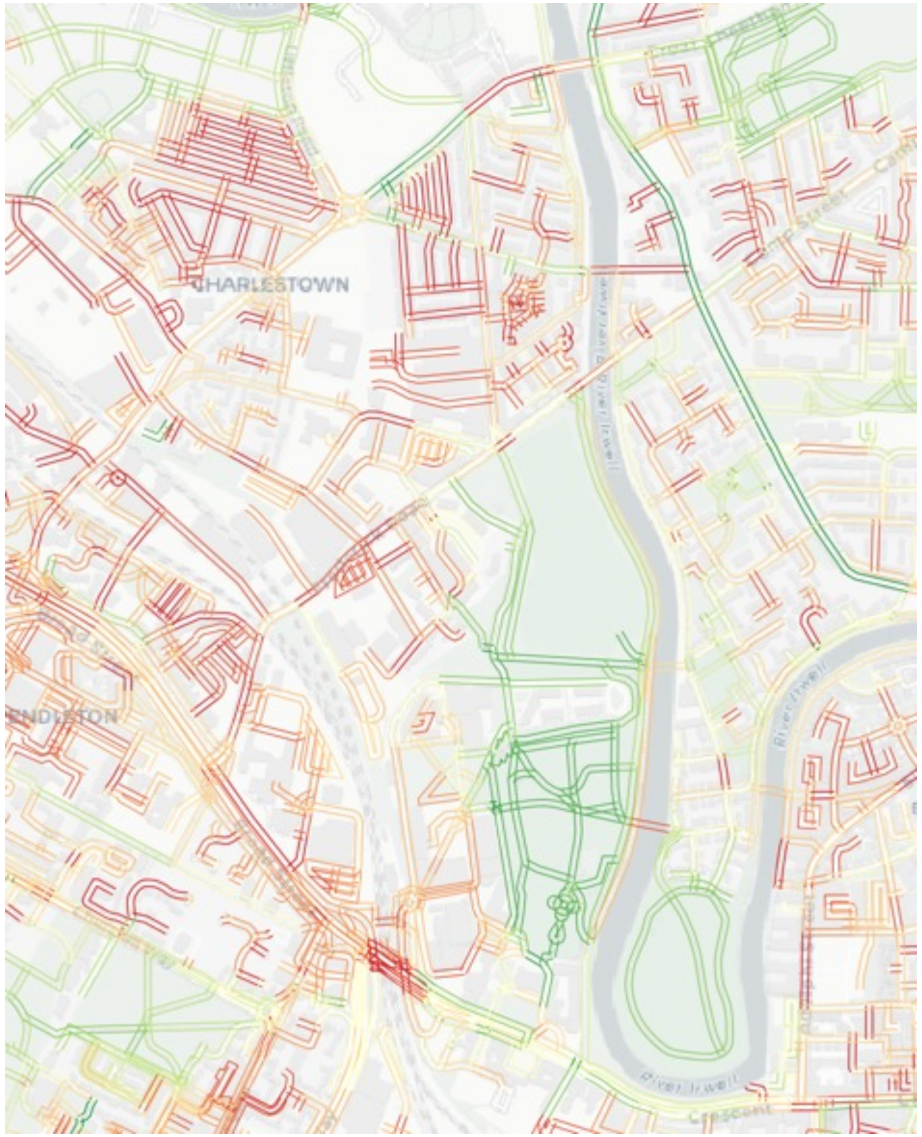
Speed Limit	Total traffic flow to be crossed (pcu)	Maximum number of lanes to be crossed in one movement	Uncontrolled	Cycle Priority	Parallel	Signal	Grade separated
≥ 60mph	Any	Any					
40 mph and 50 mph	> 10000	Any					
	6000 to 10000	2 or more					
	0-6000	2					
	0-10000	1					
≤ 30mph	> 8000	> 2					
	> 8000	2					
	4000-8000	2					
	0-4000	2					
	0-4000	1					

https://www.gov.uk/government/publications/cycle-infrastructure-design-ltn-120

Composite Link Ambience

We score the **ambience** (or “attractiveness”) for each link based on:

- Shannon diversity index
- Points of interest
- Green visibility (daytime)
- Street lighting (at nighttime)
- Crime rates



Cost Function

$$c_l = m_{tt}tt_l + m_{\nabla}\nabla_l x_l + m_c c_l x_l + m_a a_l x_l + m_s s_l x_l + m_s s_j x_j$$

- $m_{tt}tt_l$: time (s)
- $m_{\nabla}\nabla_l x_l$: gradient
- $m_c c_l x_l$: surface comfort

(time, gradient and surface comfort) From MATSim Bicycle Extension (Ziemke et al., 2019)

- $m_a a_l x_l$: link ambience
  - eye level green
  - shannon index
  - POIs
  - street lighting
  - “negative” POIs
  - crime
- $m_s s_l x_l$: link stress
  - bike/pedestrian infrastructure
  - traffic volumes
  - traffic speed
- $m_s s_j x_j$: intersection stress
  - crossing type
  - crossing volume
  - crossing speed

(link stress and intersection stress) Based on UK DfT Cycle Design Handbook

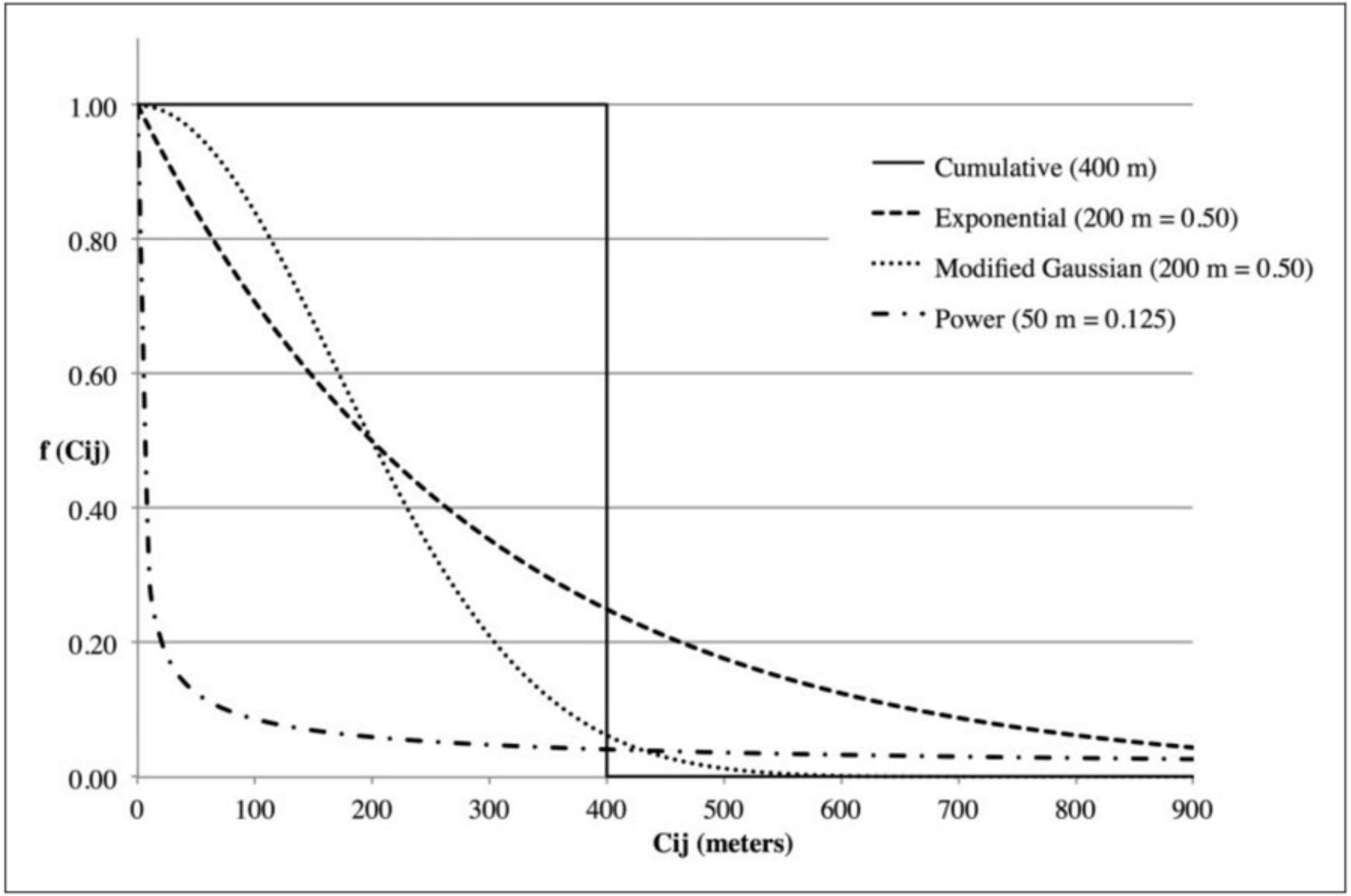
Where

x_l is the length of link l, x_j is the width of intersection j at the to-node of link l

m is the marginal cost of each link attribute,

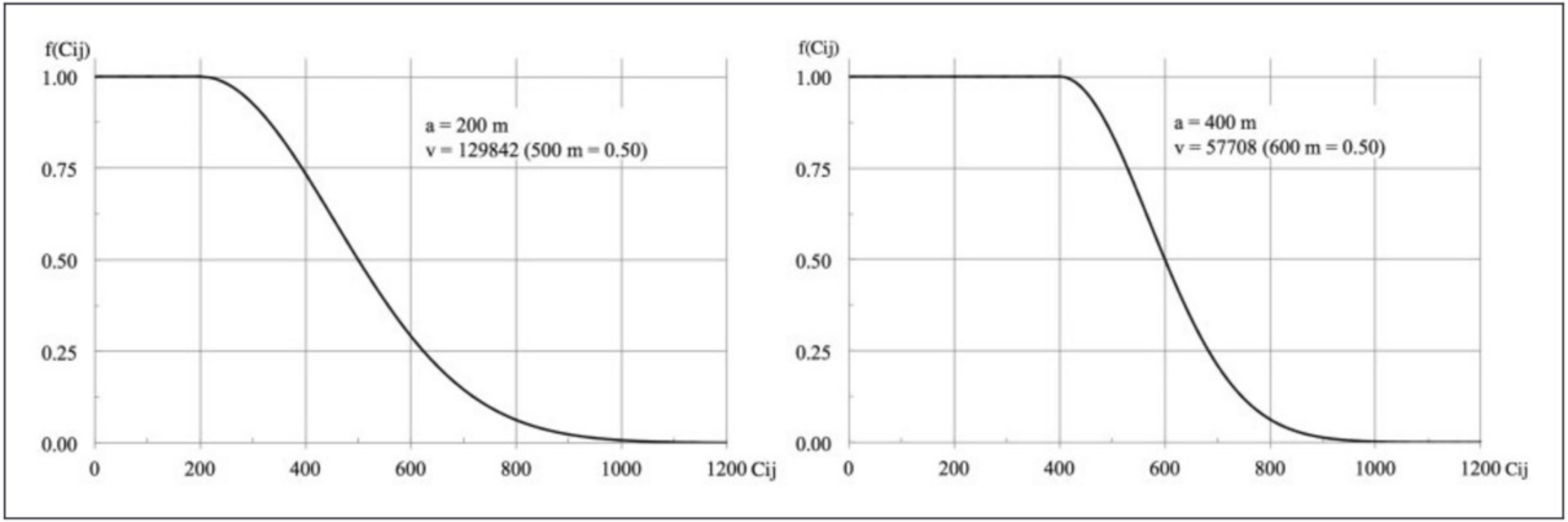
attributes tt_l, ∇_l, c_l, a_l, s_l, and s_j as defined above. c_l, a_l, s_l, and s_j are restricted to the range 0–1.

Decay function



Vale, D. S., & Pereira, M. (2017). The influence of the impedance function on gravity-based pedestrian accessibility measures: A comparative analysis. *Environment and Planning B: Urban Analytics and City Science*, *44*(4), 740–763. https://doi.org/10.1177/0265813516641685

"Cumulative gaussian" decay function



Vale, D. S., & Pereira, M. (2017). The influence of the impedance function on gravity-based pedestrian accessibility measures: A comparative analysis. *Environment and Planning B: Urban Analytics and City Science*, *44*(4), 740–763. https://doi.org/10.1177/0265813516641685

Decay function: Implementation in MATSim

```
public class CumulativeGaussian extends DecayFunction {
    5 usages
    final private double a;
    3 usages
    final private double v;
    1 usage   Corin Staves
    public CumulativeGaussian(double a, double v, Double cutoffDist, Double cutoffTime) {
        super(cutoffTime, cutoffDist);
        this.a = a;
        this.v = v;
    }
    1 usage   Corin Staves
    public CumulativeGaussian(double a, double v) {
        super(Double.NaN, Double.NaN);
        this.a = a;
        this.v = v;
    }
    4 usages   Corin Staves
    public double getDecay(double cost) { return cost <= a ? 1. : Math.exp(-1 * (cost - a) * (cost - a) / v); }

}
```

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MATSim tools & data structures

SpeedyGraph

- A “highly optimized data structure” for representing a MATSim network”
- Originally developed by SBB to efficiently calculate skim matrices
- https://github.com/SchweizerischeBundesbahnen/matsim-sbb-extensions
- *Enhanced to include pre-calculated link disutilies*

LeastCostPathTree

- Efficiently calculates least cost path trees to *all* nodes using the *SpeedyGraph* structure
- Specifying cutoffs reduces computation time further
- Also developed for MATSim SBB extensions

Steps

1. Convert network to a *SpeedyGraph*

2. Snap destinations to nodes

3. For every analysis point
   - Build a *LeastCostPathTree*
   - Loop over every destination node and calculate two-component accessibility based on cost, destination weight, and chosen decay function

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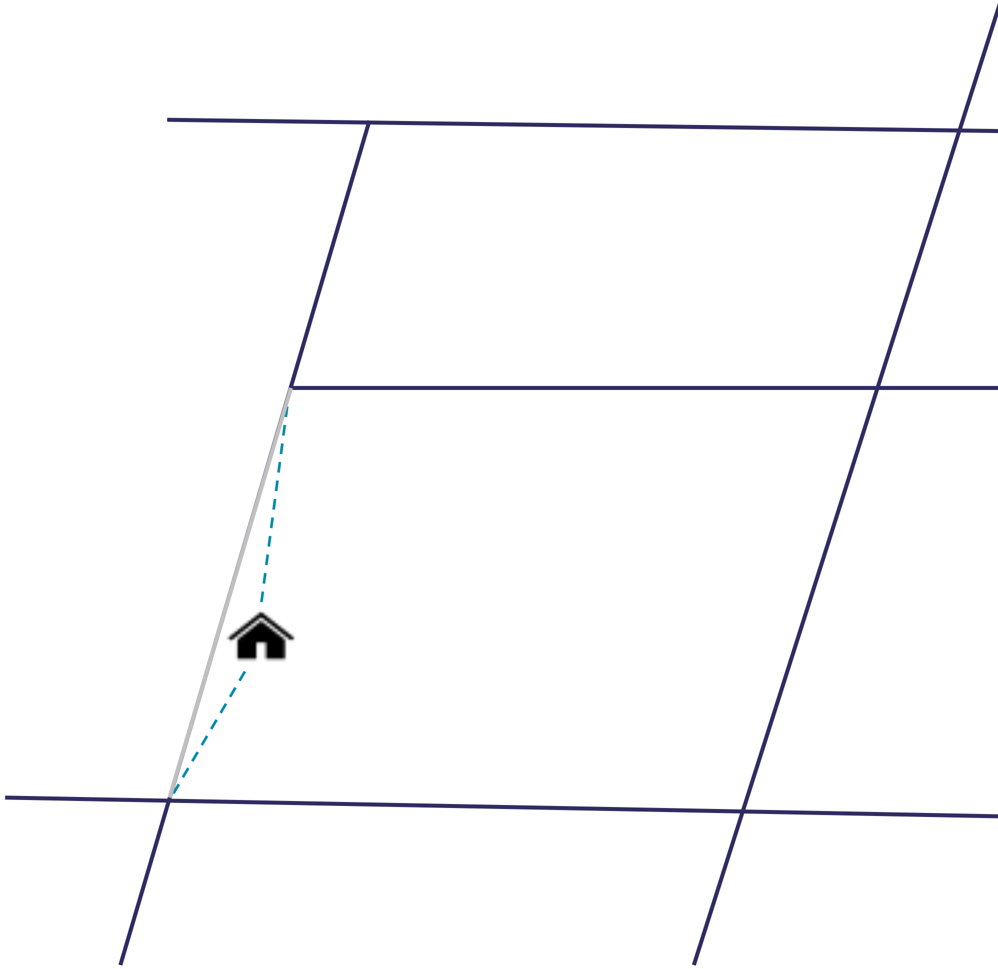
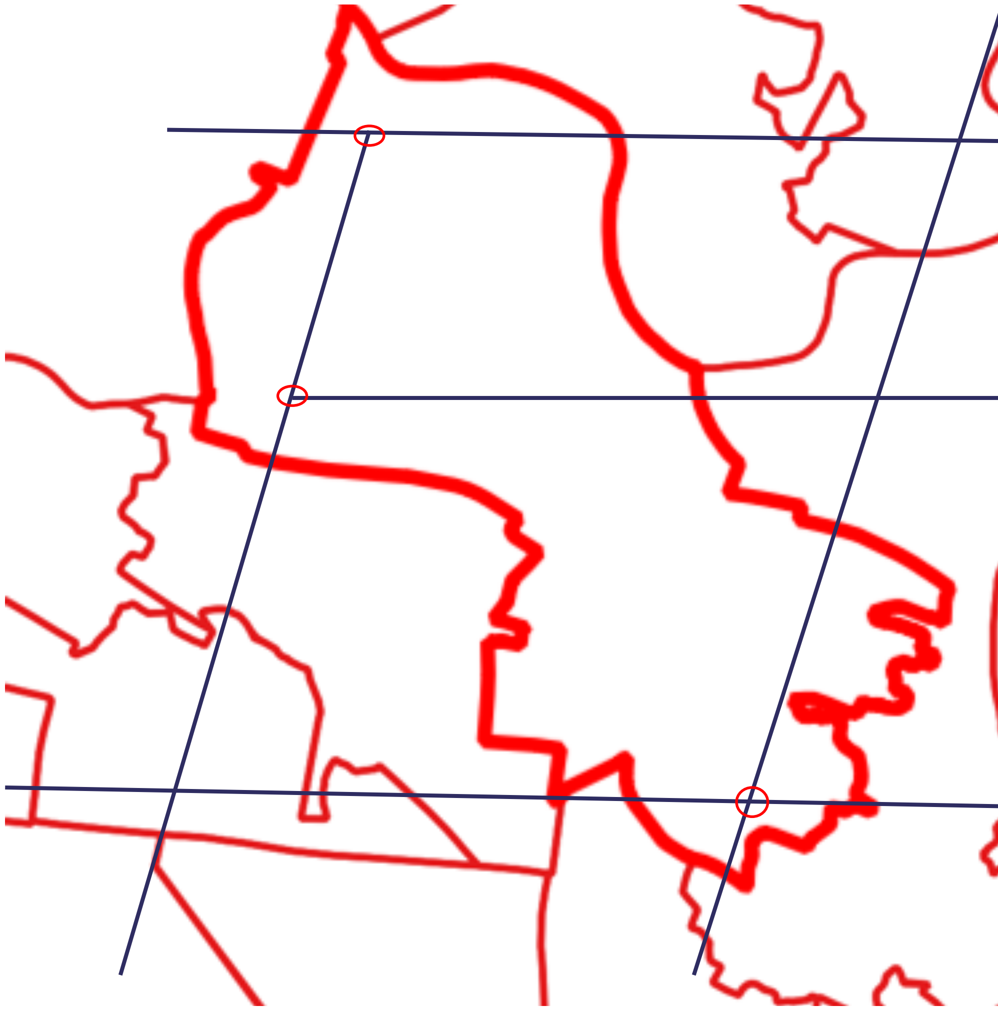
Calculating Accessibility of Points

- Identify closest network link
- Define “pseudo-node” at point
- Define two “pseudo-links” between point and to/from node of closest link
- Calculate accessibility at new “pseudo-node”



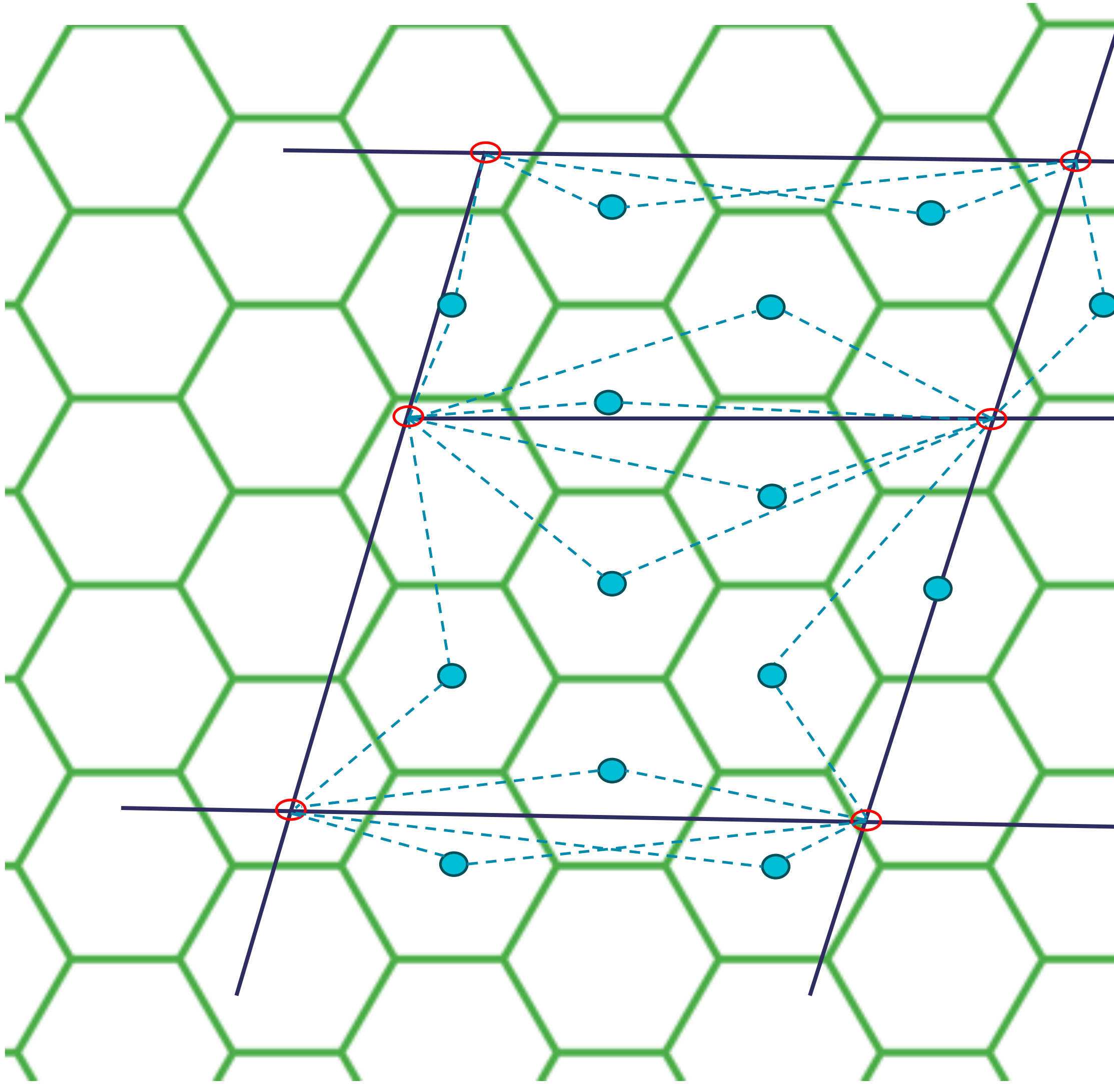
Calculating Accessibility of Polygons

- If polygon contains at least one node, use the average accessibility of the nodes in the polygon



Calculating Accessibility for Polygons

- If polygon contains at least one node, use the average accessibility of the nodes in the polygon
- If polygon contains no nodes, calculate polygon centroid and use point method



Example: Walking accessibility to Foodstores

Analysis units: Households
Destinations: Food stores
Impedance: Distance only
Decay: Cumulative Gaussian

$$A_i = \sum_j O_j \delta_{ij}, \qquad \text{for } C_{ij} \le a$$

$$A_i = \sum_j O_j e^{-\frac{(C_{ij}-a)^2}{v}} \qquad \text{for } C_{ij} > a$$

with a = 200, v = 57700

(decay function specification from Vale and Pereira, 2017)

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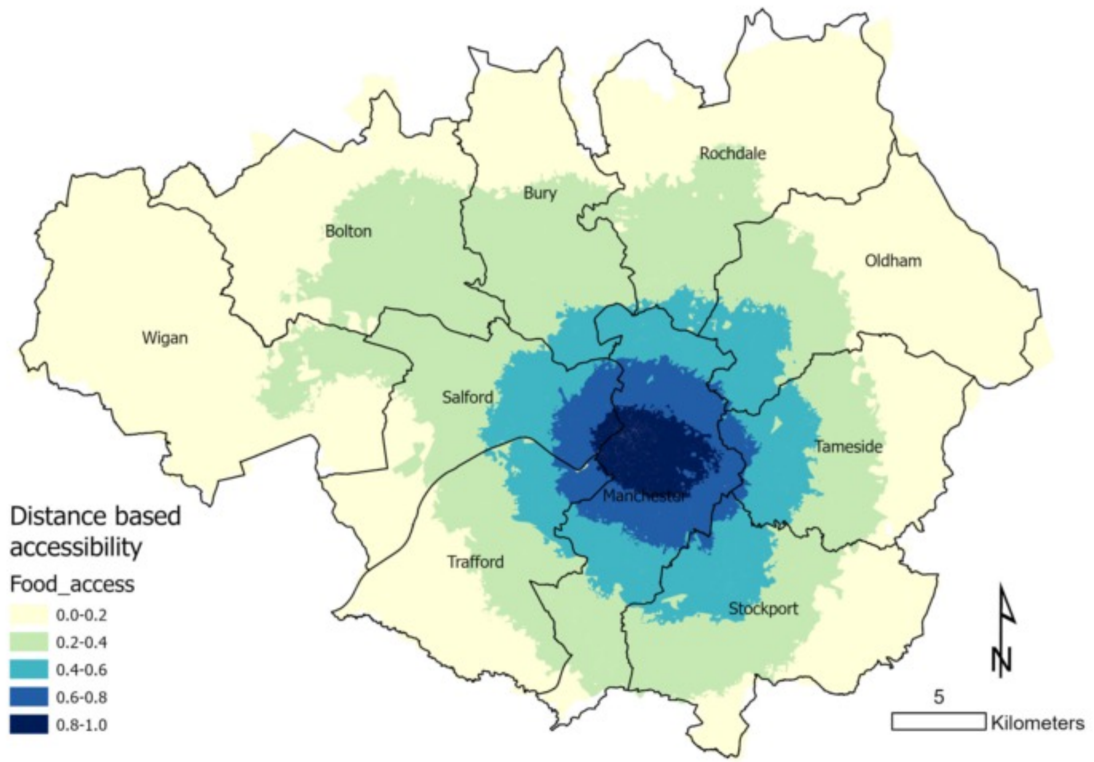
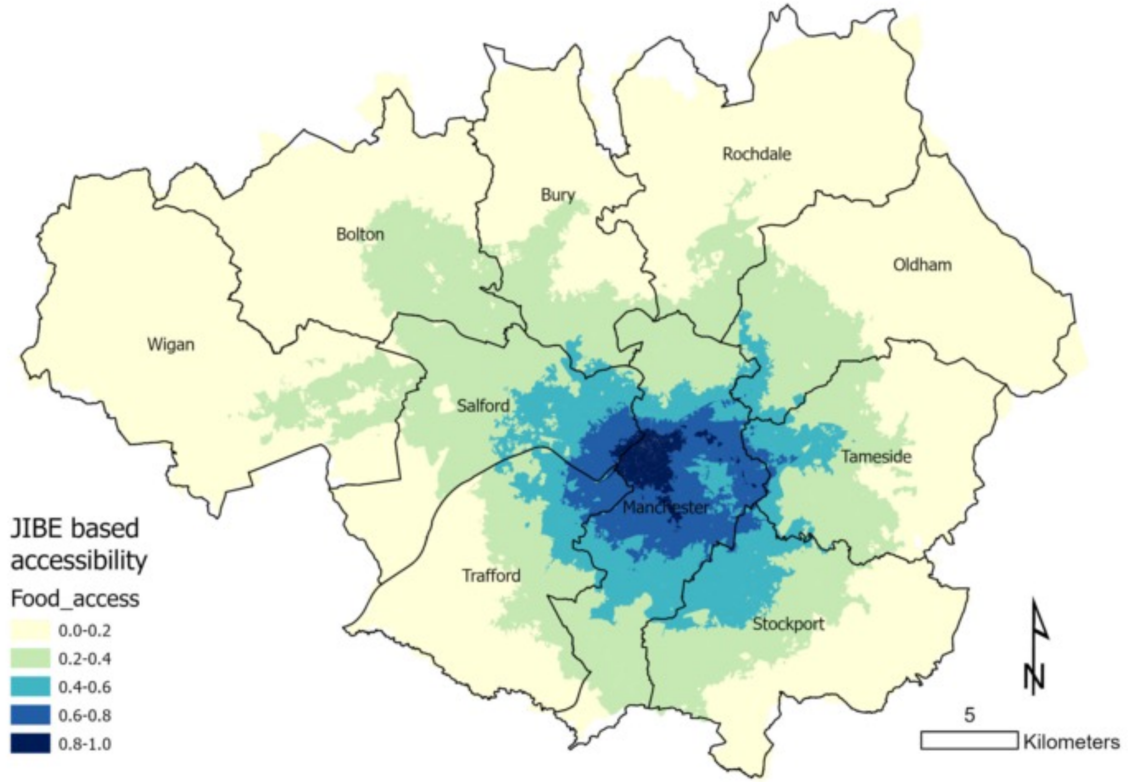
Example: Cycling accessibility to foodstores

Analysis units: Hexagonal Grid cells (50m radius)
Destinations: Food stores
Decay function: Exponential (α parameter based on observed trips)
Impedance: Distance only | Composite (incorporating ambience/stress)





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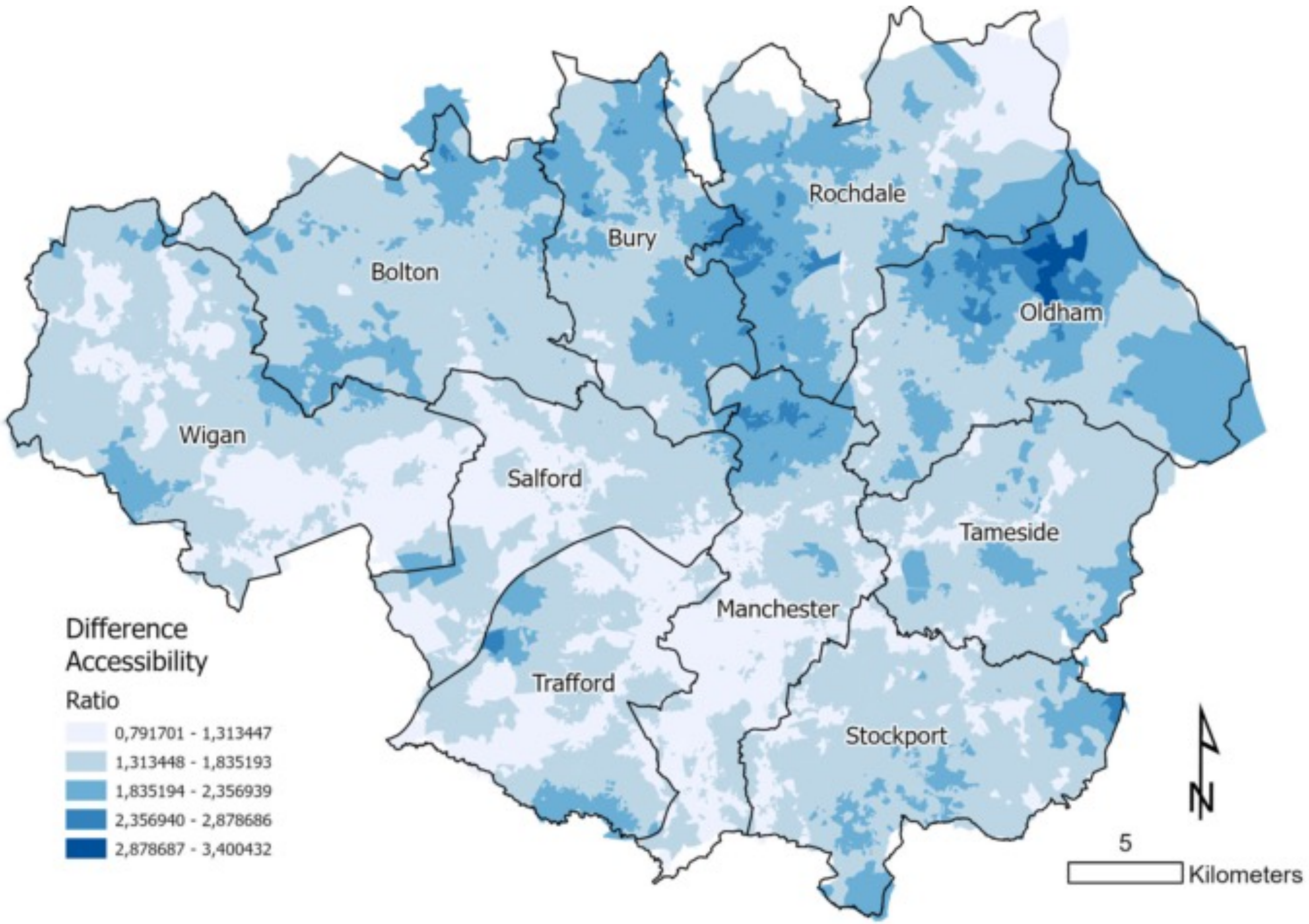
Ratio: Composite vs. Distance-based Accessibility



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Capabilities

- Forward/active and backward/passive accessibility (or a combination)
- Variation in fine-grained zones/polygons
- Destinations with Multiple access points
- Non-contiguous polygons
- Any impedance (cost) function
- Any decay function
- Can specify cutoff distances/times to improve runtime
- Open source: https://github.com/jibeproject/matsim-jibe/tree/master/src/main/java/accessibility

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Summary

- Evaluating impacts of the built environment on walkability and cyclability is a **research focus** across geographic, urban, social, transport, and health sciences
- Simple, one-dimensional indicators dominate, despite their theoretical and behavioral limitations
- Tools and frameworks developed for MATSim facilitate computationally feasible **high-resolution evaluation** of walkability and cyclability which incorporates the built environment, network, and land use

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jibe

"Joining Impact Models of Transport with Spatial Measures of the Built Environment"

https://jibeproject.com

Professor James Woodcock

University of Cambridge

Dr Belen Zapata-Diomedi

RMIT University

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