Incorporating Network-based Built Environmental Attributes of Walkability and Cyclability into Accessibility Modelling: A Pilot Study for Greater Manchester

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Summary

Accessibility is a key instrument for assessing active mobility. However, accessibility measures often suffer from biases due to spatial aggregation, isochrones with arbitrary cut-offs, and distance-based cost functions that ignore the route conditions. Previous literature has addressed these issues individually, but not holistically. This study applies the MATSim framework to efficiently route between billions of origin-destination pairs to calculate fully disaggregate Hansen accessibilities using cost functions sensitive to network quality. With examples of greenspace and foodstore accessibility, we demonstrate the potential of this method for providing policy-relevant insight into the suitability of the built environment for active travel.

KEYWORDS: Accessibility, Built Environment, Active travel

1. Introduction

There is growing interest in assessing walkability and cyclability in urban areas. Common indicators for understanding walkability and cyclability are of two types. The first is street network-based including indicators of network spatial structure such as intersection density and connectivity (Randall and Baetz, 2001). The second is spatial interactions-based indicators such as the Hansen (1959) accessibility. Network-based indicators are useful for evaluating street network quality but ignore the types and distances of the destinations people are trying to reach. On the other hand, accessibility-based measures are useful from a destination perspective but often ignore the quality of the street network one must use for reaching those destinations. This is because most of these methods commonly use distances for impedance, which ignore the suitability of the transport infrastructure one must use to reach destinations.

Additionally, accessibility calculations commonly rely on spatial zone systems, which can bias results due to the modifiable areal unit problem. This problem is exacerbated for analyses into walk behaviour as walk trips can be small in relation to zone sizes. Imani et al (2019) incorporated network quality into disaggregate measures of cycle accessibility. However, this methodology categorised links into discrete categories and generated isochrones, which can cause results to be heavily sensitive to arbitrary cut-off values. In contrast, using continuous approaches via Hansen accessibilities would enable a stronger theoretical foundation, but computational limitations of traditional routing algorithms generally make this unfeasible.

Considering the aforementioned issues, this study presents a comprehensive methodological framework for calculating fully disaggregate walking and cycling Hansen accessibilities that considers street network quality. The MATSim framework (Horni et al., 2016) is applied to calculate routes and route disutility as a function of network-based built environment attributes (Labib et al., 2022). As MATSim can efficiently route between billions of origin-destination pairs, it becomes possible to use continuous impedance functions and avoid zone-based analysis by routing between any desired analysis unit (e.g. points, polygons, grids cells) and every possible destination. We provide some examples of this process for the Greater Manchester (GM) area.

The overall process and reproducible code is available on GitHub at
https://github.com/jibeproject/matsim-jibe/tree/master/src/main/java/accessibility

2. Method

We calculate the Hansen accessibility A_i of locations i using

$$A_i = \sum_j {W_j}^{\alpha} e^{-\beta c_{ij}} \tag{1}$$

where W_j is the weight of destination j, α and β are positive parameters, and c_{ij} is the 'cost' of reaching destination j from origin i, defined by

$$c_{ij} = \sum_{l \in P_{ij}} c_l \tag{2}$$

where c_l is the 'cost' of link l on the least-cost path P_{ij} between i and j. Link cost c_l is commonly equal to link length (i.e., distance), which would make c_{ij} equal to the shortest distance. However, it could also be a function of other aspects of disutility such as perceived safety, gradient, and attractiveness. By including these other attributes in c_l it becomes possible to include the street quality and suitability of the network's design (e.g. width or segregation of bike lanes and footpaths) into the accessibility calculations.

2.1. Input Data

Network
A spatial dataset of nodes and links. Link attributes should include the start node, end node, length, and any additional attributes to be used for calculating link costs.

Destinations
A set of destination locations with IDs and weights. Destinations such as parks or fields may have multiple access points. If this is the case, the algorithm routes to all possible access points of a destination from a given origin but chooses only the destination with the smallest c_{ij}.

Origins
A set of locations to calculate accessibility for. This could be a set of points, polygons, or a grid.

2.2. Calculation

The calculation is performed in Java. GIS data are processed using the GeoTools library for Java (geotools.org). Network data are stored and processed using MATSim. The routing and accessibility calculations adapt code by Rieser and Scherr (2019).

1. Read and process all input data. Convert network into MATSim (.xml) format.

2. Define the link cost function $f(l)$ and parameters α and β
3. Pre-calculate link costs c_l for all links on the network
4. Calculate accessibilities for every node in the network. For each node n:
    - Calculate a least-cost path tree for the node i
    - Loop through all destinations to calculate the node's accessibility A_i using equation 1, identifying c_{ij} using the least-cost path tree.
5. Calculate accessibilities for every analysis unit p by looping through each:
    1. Identify the closest network node i and closest link
    2. Define a straight-line connector link k to the closest node.
    3. Calculate c_k for the connector link based on attributes from the closest link.
    4. Calculate the accessibility A_p for location p by adjusting A_i for the additional cost c_k

$$A_p = e^{-\beta c_k} A_i \tag{3}$$

6. As accessibilities are unitless, normalise results to values between 0 and 1 for comparability.

This process gives us normalised accessibility values for each origin point or polygon, which can be used for accessibility mapping or for further transport analysis.

3. Example

3.1. Study Area and Input Data

Input Data

We present an analysis of walking and cycling accessibility to foodstores and greenspaces for GM. Our input network consists of 529178 links and 418638 nodes and was harmonised from various data sources to include link attributes relevant to walkability and cyclability, as described in Labib et al. (2022). Accessibility was calculated at the UK postcode unit for all 113485 postcodes in GM.

Destination data for green space and foodstores were obtained from Ordnance Survey (OS). For both destination types, areas were used as destination weights. Accessibilities were calculated for postcodes within GM. To avoid boundary effects, destinations within a 10 km buffer area were included, leading to a total of 15902 greenspace access points and 5374 foodstores.

Link Costs and Parameters

To incorporate the suitability of the network for walking and cycling into this accessibility measure, we develop a composite cost function that considers various link-based built environment walkability and cyclability indicators:

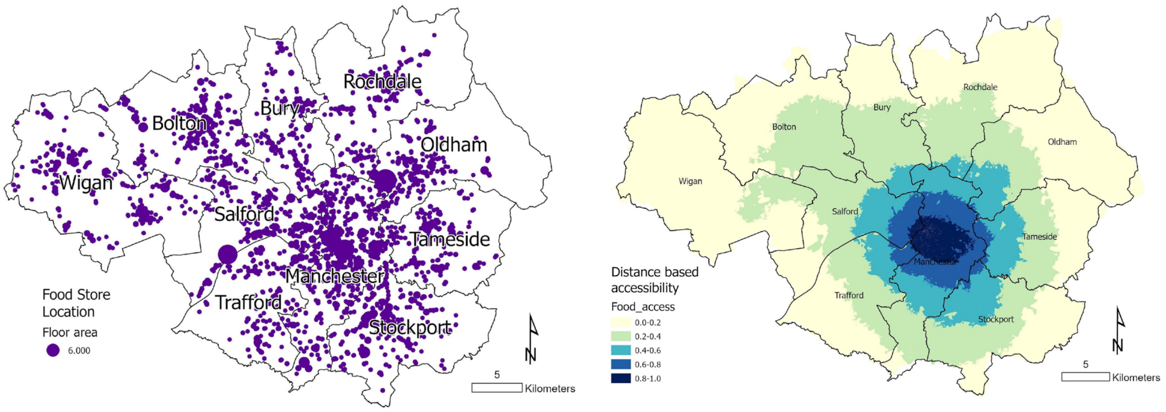
$$c_l = x_l\left(\frac{m_{tt}}{v_l} + m_{\nabla}\nabla_l + m_c c_l + m_a a_l + m_s s_l\right) + m_s s_j \tag{4}$$

where x_l is the length of link l, v_l is the travel speed along link l, ∇_l is its gradient, c_l is a surface comfort score, a_l is an attractiveness score, s_l is a link stress score, s_j is a junction stress score, and the m values are marginal costs associated with each cost component. This cost function was based on existing walk and cycle routing algorithms from Ziemke et al (2017), guidance from the UK department for transport (*Cycle Infrastructure Design*, 2020), expert opinion from travel behaviour and built environment researchers, and consultation with the local authority on route plausibility for walkers and cyclists. For comparison, this study also considers a distance-only based cost function ($c_l = x_l$).

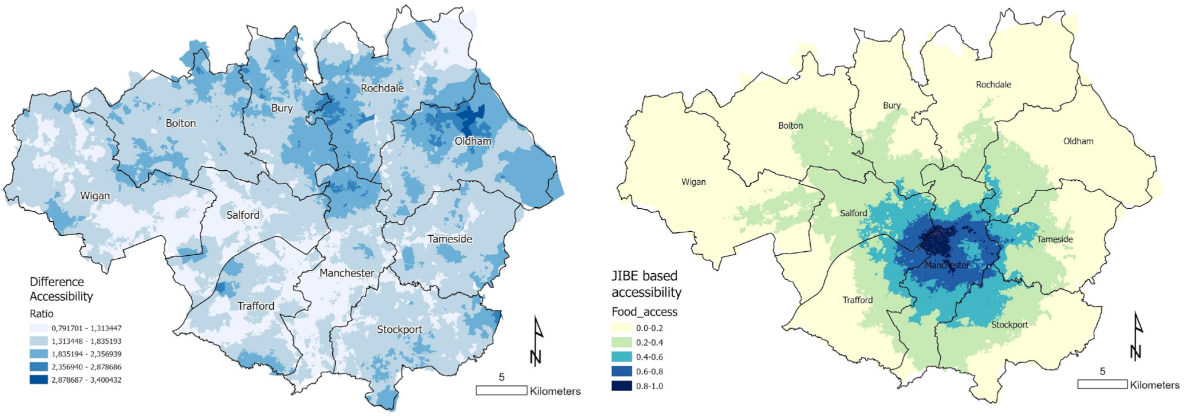
For this study we set $\alpha = 1$, and we define β by fitting an exponential distribution to observed travel in a local travel diary survey.

3.2. Results

Figure 1 presents results for cycling accessibility to foodstores. The calculation (which involved calculating for around 2 billion OD pairs) took about 2 hours on an 8 core 3.2GHz Intel Xeon. Figure 1(a) shows the locations and weights of all possible destinations used for calculating accessibility. Figure 1(b) shows accessibility results based on a purely distance-based cost function ($c_l = x_l$). This is the most common approach to assessing walkability and cyclability and ignores the quality and suitability of the street for reaching destinations. On the other hand, figure 1(c) shows accessibility results using the composite cyclability cost function shown in equation 4. It can be observed here that certain areas (for example north of the centre) have substantially lower foodstore accessibility relative to a purely distance-based measure. These discrepancies can be observed more clearly in figure 1(d) which presents the ratio of the distance-based cost accessibility versus the composite cost accessibility. In this figure, the darker areas indicate locations where cyclability to foodstores is poor with respect to distance only accessibility, indicating potential for improvement to cycling provision.



(a) Locations and Weights of Foodstores **(b)** Distance-based Accessibility



(d) Distance / Composite Ratio **(c)** Composite Cost-based Accessibility

Figure 1 Accessibility Results for Cyclability to Foodstores

4. Discussion

The efficiency of the MATSim framework enables new potential for accessibility analysis beyond what has traditionally been computationally feasible. Using this framework, we evaluated active travel accessibility not just based on distance to destinations, but rather based on the extent to which pedestrians and cyclists can reach those destinations via attractive and low-stress routes. Our example analysis revealed how considering infrastructure provision substantially influenced the map of cycle accessibility to GM food stores.

This framework also allows for a more theoretically robust basis for accessibility. Rather than using categorical values for route quality which impose hard restrictions on the accessibility calculation, we used a continuous measure of link impedance which considers the full network. In addition, rather than using isochrones with arbitrary cut-off values, it became possible to use a continuous impedance decay function incorporating all destinations into the accessibility calculation.

Looking beyond accessibility mapping, future research can investigate the relationship between calculated accessibilities and observed active travel behaviour, similar to Cruise et al. (2017), to investigate which approaches give the strongest indicators of walking and cycling, and to develop statistical models suitable for estimating active travel demand.

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7. Biographies

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