A MATSim-based Framework for Modelling the Influence of the Built Environment on Walkability and Cyclability

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Introduction

The built environment (BE) influences active travel perceptions, behaviours, and accessibilities. High-quality infrastructure such as dedicated cycle lanes reduces the perceived stress of active travel. Ambience-related features such as green visibility and streetlighting can make active travel more pleasant and comfortable. The availability of low-stress and pleasant routes impacts the perceived impedance of active travel, thereby influencing people's behaviour and health.

Accessibility is a core indicator in research relating the BE to active travel (Cervero et al., 2009). Definitions vary and are evolving, but it broadly refers to the ease of reaching destinations (Boisjoly & El-Geneidy, 2017). Accessibility can be mode-specific, with walkability and cyclability referring to accessibility on foot and by bicycle respectively. Some BE studies have estimated walkability and/or cyclability empirically. However, due to computational and data limitations, they typically rely on aggregate area-level BE indicators. These are vulnerable to the modifiable aerial unit problem which can negatively impact model sensitivities, especially as route quality can vary substantially within a small area. Recent studies have argued for micro-environmental (e.g., link-level) attributes which can be more effective at capturing active travel behaviour and produce models that are more behaviourally realistic and policy-relevant (De Vos et al., 2023).

Some walkability and cyclability studies have estimated accessibility empirically using two-component models which consider land use (i.e. destinations) together with the impedance of reaching them. The dominant approach is cumulative opportunities (i.e., counts of destinations within a specified time or distance threshold). This method is simple to formulate and explain to policymakers, but from a behavioural perspective it has well-known limitations. First, hard cut-offs are not as theoretically robust as smooth decay functions such as the gravity-based approach in Hansen (1959). Second, existing methods generally do not consider how the BE influences perceptions of impedance and therefore accessibility (Van Wee, 2016). Some recent studies have addressed these issues individually (e.g., Krenz et al. (2023) regarding the decay function or Rhoads et al. (2023) regarding BE). However, due to limitations in data acquisition, computation, and lack of methodological guidance, they have not been addressed together through a holistic approach.

We present an impedance and accessibility tool that builds from the MATSim framework to support micro-environmental modelling of walkability and cyclability. First, we describe a custom walking and cycling impedance function which includes perceptions of BE. Next, we introduce a flexible and compute-optimised MATSim-based accessibility tool which aims to help researchers overcome common limitations of two-component accessibility models when evaluating active travel. This work has been developed through the JIBE[1] project and is open source available at https://github.com/jibeproject/matsim-jibe.

Study Area

We use a detailed pedestrian and cycle MATSim network for Greater Manchester that has been enriched with 61 link-level BE attributes from multiple sources including OSM, satellite imagery, British Ordnance Survey, and local authority data. Network creation is described in further detail in Labib et al. (2022).

Method

We first build from the MATSim bicycle extension developed by Ziemke et al. (2019) to create custom travel time and disutility functions for walking and cycling. Link stress is modelled as a function of traffic speeds, volumes, infrastructure quality, and the number of freight loading points on each link. Junction stress is a function of signal type and the speeds and volumes of crossing traffic. These stress models were estimated from guidance in the UK Cycle Infrastructure Design (2020) handbook. In

[1] Joining Impact models of transport with spatial measures of the Built Environment (https://jibeproject.com).

addition, we estimate link ambience as a function of the number and diversity of points of interest along each link, green visibility (in daytime), and presence of streetlights (at night).

Next, we developed a compute-optimised MATSim-based accessibility tool that can efficiently calculate accessibilities using any impedance function, any decay function, and at any level of disaggregation. To achieve this, we adapt the SpeedyGraph and LeastCostPathTree data structures which were originally developed by SBB for skim matrix calculations (Rieser & Scherr, 2019). Within the tool, impedance is defined through the existing TravelDisutility interface and is precalculated into the SpeedyGraph-based data structure. The decay function is defined using a new DecayFunction interface and can take any form including cumulative, exponential, gaussian, or a combination. The algorithm calculates accessibly by routing to the coordinate of every given destination and can account for destinations with multiple access points. Accessibilities are initially calculated for every network node but can be aggregated to grid cells or zones as needed. Accessibilities can also be calculated for exact addresses, making use of connector links and segments to ensure fully disaggregate results.

As a demonstration, we present address-level walkability results to food stores, making use of a walk-specific impedance function and cumulative-gaussian decay function as recommended by Vale and Pereira (2017). The calculation for a network of 418638 nodes and 5375 destinations took 3 hours on a desktop PC with an 8-core 3.7GHz processor. A sample of the results are given in figure 1 below.

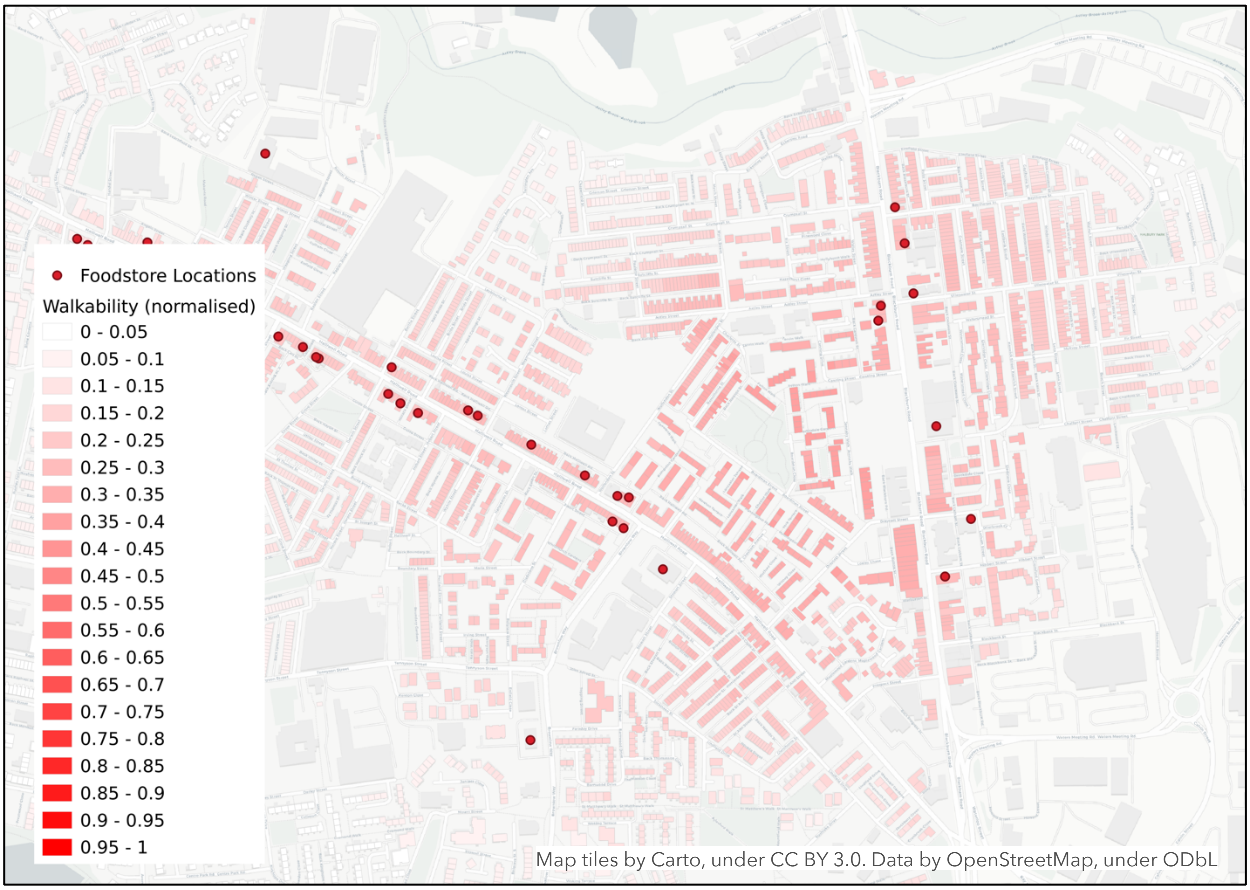

Figure 1: Address-level food store walkability results using a cumulative-gaussian decay function

Conclusions

MATSim offers a powerful framework for the modelling and analysis of active travel perceptions and accessibilities. The highly optimised data structures available within MATSim make it possible to explore the impacts of micro-environmental BE on active travel using a spatially precise and theoretically robust methodology. The tools and methods presented here are therefore not only designed for MATSim developers, but also geographers, urban planners, and epidemiological researchers aiming to evaluate the impacts of BE policy on active travel.

References

Boisjoly, G., & El-Geneidy, A. M. (2017). How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transportation plans. *Transport Policy*, *55*, 38–50. https://doi.org/10.1016/j.tranpol.2016.12.011

Cervero, R., Sarmiento, O. L., Jacoby, E., Gomez, L. F., & Neiman, A. (2009). Influences of Built Environments on Walking and Cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation*, *3*(4), 203–226. https://doi.org/10.1080/15568310802178314

Cycle Infrastructure Design. (2020). TSO (The Stationery Office). https://www.gov.uk/government/publications/cycle-infrastructure-design-ltn-120

De Vos, J., Lättman, K., Van Der Vlugt, A.-L., Welsch, J., & Otsuka, N. (2023). Determinants and effects of perceived walkability: A literature review, conceptual model and research agenda. *Transport Reviews*, *43*(2), 303–324. https://doi.org/10.1080/01441647.2022.2101072

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

Krenz, K., Dhanani, A., McEachan, R. R. C., Sohal, K., Wright, J., & Vaughan, L. (2023). Linking the Urban Environment and Health: An Innovative Methodology for Measuring Individual-Level Environmental Exposures. *International Journal of Environmental Research and Public Health*, *20*(3), 1953. https://doi.org/10.3390/ijerph20031953

Labib, S. M., Itova, I., Staves, C., Zapata-Diomedi, B., Both, A., Gunn, L., Khreis, H., Abbas, A., Sivakumar, A., Panter, J., Giles-Corti, B., & Woodcock, J. (2022, March 28). *Integrating spatially detailed micro-environmental attributes to a routable transport network for active travel modelling: A pilot study in Greater Manchester*. 30th Annual Geographical Information Science Research UK (GISRUK), Liverpool, United Kingdom. https://doi.org/10.5281/zenodo.6411626

Rhoads, D., Solé-Ribalta, A., & Borge-Holthoefer, J. (2023). The inclusive 15-minute city: Walkability analysis with sidewalk networks. *Computers, Environment and Urban Systems*, *100*, 101936. https://doi.org/10.1016/j.compenvurbsys.2022.101936

Rieser, M., & Scherr, W. (2019, April 29). *Calculation of Skim Matrices Based on MATSim Data*. MATSim User Meeting, Leuven, Belgium. https://svn.vsp.tu-berlin.de/repos/public-svn/matsim/meetings/usermeetings/2019/Rieser_SkimMatrices.pdf

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

Van Wee, B. (2016). Accessible accessibility research challenges. *Journal of Transport Geography*, *51*, 9–16. https://doi.org/10.1016/j.jtrangeo.2015.10.018

Ziemke, D., Metzler, S., & Nagel, K. (2019). Bicycle traffic and its interaction with motorized traffic in an agent-based transport simulation framework. *Future Generation Computer Systems*, *97*, 30–40. https://doi.org/10.1016/j.future.2018.11.005