AGILE: GIScience Series, 5, 48, 2024. https://doi.org/10.5194/agile-giss-5-48-2024
Proceedings of the 27th AGILE Conference on Geographic Information Science, 4–7 Sept. 2024.
Editors: Alison Heppenstall, Mingshu Wang, Urska Demsar, Rob Lemmens, and Jing Yao.
This contribution underwent peer review based on a full paper submission.

Assessment of bicycle accessibility to mobility hubs under different criteria for cycling network quality

Lucas van der Meer [1], Christian Werner [1], and Martin Loidl [1]

[1]Department of Geoinformatics, University of Salzburg, Salzburg, Austria

Correspondence: Lucas van der Meer (lucas.vandermeer@plus.ac.at)

Abstract. The criteria used to delineate the cycling network have large implications on computed levels of bicycle accessibility to mobility hubs. We present an approach to bicycle accessibility assessment that gives insights into these implications. First, we compute a bicycle suitability index for each street segment in the proximity of a hub. Then, we compute how many households have access to the hub using only streets with a bicycle suitability above a given index threshold, while not accepting a detour from the shortest path beyond a given detour threshold. We repeat this for different combinations of threshold values that reflect varying quality standards for the cycling network. The results are presented by means of graphs and maps that show how computed levels of bicycle accessibility vary under different criteria.

Keywords. bicycle accessibility, public transport, mobility hubs, bikeability, urban planning, sustainable mobility

1 Introduction

Multimodal mobility hubs are places where different sustainable transport modes are integrated seamlessly to help promote connectivity (Aono, 2019). In practice, a common role for such places is to facilitate a transfer between the bicycle for first and last mile travel, and public transport services for longer distance travel. Essential to this role is that the hubs are well accessible by bicycle for the people that live in their proximity.

We can quantitatively assess the level of bicycle accessibility in different ways. For a detailed review of these, we refer to Vale et al. (2015). A common approach is to replicate traditional accessibility metrics that have mostly been used for the analysis of car traffic, with the only difference being that travel costs are computed based on cycling speed (e.g. Nichols et al., 2023; Schneider et al., 2023). Such approaches neglect that the suitability of the infrastructure for cycling (i.e. how safe and comfortable streets are to ride a bicycle) is of significant importance for cyclists and therefore has a large influence on bicycle accessibility (Ehrgott et al., 2012). One simple but clear approach to integrate this influence is by computing travel costs on the cycling network only, and disregard streets that are not suitable for cycling. For example, Abad and Van der Meer (2018) assessed bicycle accessibility in Lisbon using a low-stress cycling network inferred from OpenStreetMap tags, while Cunha and Silva (2023) analyzed the same city by retrieving the delineation of implemented and planned cycling networks from the city council. This already shows that there is no common understanding of what defines "the cycling network". Many other definitions have been used, ranging from “only separated bike lanes” to “every street on which cycling is legally allowed” (Reggiani et al., 2023).

As Reggiani et al. (2023) pointed out, the type of cycling network that is analyzed and the quality standards on which the constitution of this network is based has large implications on analysis results. This also holds for the analysis of bicycle accessibility. In current approaches the data analyst has to decide what a reasonable quality is. In line with the critiques of Reggiani et al. (2022), we argue that it should be the task of the policymaker to make such choices, and that the data analyst should merely provide insights on how different choices lead to different outcomes.

Building on these ideas, we present an approach that shows how the adoption of different quality standards for the cycling network affect computed bicycle accessibility levels of a mobility hub from the perspective of people that live in the proximity of the hub.

2 Methods

Our methodology consists of two steps. First, we create a street graph with a computed bicycle suitability index for each street segment. This graph is then used to analyze bicycle accessibility from household locations in the proximity of a mobility hub to bicycle parking facilities at the hub itself. We repeat this for different scenarios that reflect varying definitions of what constitutes a good cycling network.

2.1 Computation of bicycle suitability

We use the open-source toolbox NetAScore (Werner et al., 2024) to extract street shapes from OpenStreetMap data, convert them into a routable graph structure, and compute a bicycle suitability index for each street segment in that graph. This is a composite index combining multiple indicators that each describe one aspect of bicycle suitability. Indicator values are mapped to a quantitative scale from 0 (lowest bicycle suitability) to 1 (highest bicycle suitability). The final index is then computed as a weighted average of the quantified indicators. For this paper we selected four different indicators, which are listed in Table 1.

Table 1. Indicators for the bicycle suitability index

Topic	Indicator	Description	Weight
Safety	Bicycle infrastructure	Type of bicycle infrastructure (separated bike lane, painted bike lane, etc.)	3
Safety	Road category	Type of street (primary, residential, etc.) serving as a proxy for traffic intensity	2
Comfort	Pavement	Type of pavement (asphalt, cobbles, etc.)	1
Comfort	Gradient	Severity of the incline of the street (steep up, flat, steep down, etc.)	1

Fig. 1 gives a visual impression of what different bicycle suitability index values mean, along with textual labels for the extreme values and the median. For a detailed description of the NetAScore workflow, we refer to the documentation: https://github.com/plus-mobilitylab/netascore.

2.2 Computation of bikeable access

We use the software package sfnetworks (van der Meer et al., 2023) within the software environment R (R Core Team, 2023) to represent and analyze the street graph that resulted from the NetAScore computations. The travel cost of an edge is set equal to its geographic length. We remove edges that are exclusively meant for pedestrians, such as footpaths, and subsequently select the largest connected component. This graph is the basis for the analysis. For each bicycle parking facility at the mobility hub, we find the nearest node. We call those the hub nodes, and they represent the locations where cyclists park their bicycle and enter the hub on foot. We then label each node in the graph that is within a network distance of 3 kilometers (or 15 minutes, assuming an average cycling speed of 12 km/h) from any of the hub nodes to be "in proximity" of the hub. This threshold is based on the idea that important destinations should be accessible within a 15 minute bicycle ride. It has been used before as the lower bound of threshold distances to delineate the potentially accessible area by bicycle (Schneider et al., 2023). Each household location is snapped to its nearest node. Only households for which the nearest node is labeled as being in proximity of the hub are kept in the analysis.

To assess which of those households have bikeable access to the hub we compute the shortest path from each household node to its closest hub node. We do this both on the complete street graph and on the largest subset of the street graph that contains only bikeable edges. We call that subset the "bikeable street graph". What makes an edge bikeable, depends on a given index threshold. Each edge that has a bicycle suitability index that is higher than or equal to the index threshold is considered bikeable. If a household has a connection to the hub on the bikeable street graph, we label it as having bikeable access if and only if the shortest path on the bikeable street graph is an acceptable detour from the shortest path on the complete street graph. What makes a detour acceptable, depends on a given detour threshold. If the detour is less than or equal to the detour threshold, the detour is considered acceptable. Finally, we compute the proportion of analyzed households that has bikeable access to the hub. This number serves as the quantification of bicycle accessibility towards the hub.

We repeat the analysis for all different combinations of index thresholds in the sequence $0, 0.05, 0.1, \ldots, 1$ and detour thresholds in the sequence $1, 1.1, 1.2, \ldots, 2$. The considered index thresholds cover the full range of possible bicycle suitability indices computed by NetAScore, while the considered detour thresholds cover the range of all reported values of cyclists' detour behavior in the literature reviewed by Reggiani et al. (2022).

2.3 Selection of an exemplary use-case

To show the described methodology in practice, we choose the central train station of Salzburg as an example of a mobility hub location. Salzburg is a middle-sized city in Austria, and its train station is a meeting point for urban, regional, national as well as international public transport connections. We select three locations around the train station where larger bicycle parking is available. Two of them are located at the western side of the station, while the other is at the eastern side. As data input to the NetAScore toolbox we provide an OpenStreetMap extract in osm.pbf format, which we downloaded from Geofabrik (Geofabrik, 2024) for the full extent of Austria and then clipped to the shape of the Salzburg province. In addition, we provide the Digital Elevation Model of Austria in 10m spatial resolution (Geoland.at, 2019), which NetAScore uses to infer the gradient indicator. We use the Austrian address database of 2021 (Bundesamt für Eich- und Vermessungswesen, 2023) as a proxy for household locations.

Figure 1. An impression of what different bicycle suitability indices mean. Each image shows a street segment in Salzburg that is typical for the corresponding index range. The textual labels at the bottom describe the hypothetical extremes of the index, as well as the median.

2.4 Data and software availability

All data and software used in our study are available under open licenses. This means the analysis can be fully reproduced without the need to acquire any proprietary data or closed-source software. The supplementary materials needed to reproduce the analysis, including data, code, and associated documentation, are available on Zenodo: https://doi.org/10.5281/zenodo.10949524.

3 Results

The analyzed mobility hub location at the central train station in Salzburg is shown on the map in Fig. 2, along with the street network and household locations in its proximity. Each street segment is colored by its bicycle suitability index. This provides a first view on the spatial characteristics of the bicycle infrastructure quality and its connectivity. It indicates that the majority of the streets have a bicycle suitability index of approximately 0.5. This is because many streets in this area of Salzburg are flat residential streets without any dedicated bicycle infrastructure. Most of the households are located in proximity of such streets. Segments with high bicycle suitability can be found at both sides of the Salzach river, and along some main axes perpendicular to the river. However, they do not continue all the way to the location of the mobility hub.

Fig. 3 shows the computed bicycle accessibility levels for all considered combinations of index thresholds and detour thresholds. This allows to assess the influence of these thresholds in one overview. The left end of the curves represents bicycle accessibility when considering all streets on which cycling is legally allowed to be bikeable. If this value is not 100%, it means that for some of the analyzed households the hub is not reachable using only those streets on which it is allowed to cycle, without making a detour that exceeds the detour threshold. The right end of the curves represents bicycle accessibility when considering only those streets with the highest possible bicycle suitability to be bikeable. If this value is not 0%, it means that there are people for which the hub is reachable even if they do not accept anything worse than the highest possible bicycle suitability, nor a detour that exceeds the detour threshold.

We see that for our exemplary use-case in Salzburg the curves do not show a linear decrease in accessibility between these two extremes, but drop steeply from very high accessibility to very low accessibility when the index threshold is in the second quartile of the index range. The more detour you find acceptable, the later the curve drops. However, for the higher detour thresholds, there is almost no difference to be seen anymore. They all reach an accessibility of approximately zero when the index threshold is set to any value above 0.5. This means that street segments with higher bicycle suitability do not connect households to the hub at all, not even when people would accept a large detour.

Combining the insights from Fig. 2 and Fig. 3, we can infer a probable explanation for this shape. Most of the households are located along one of the many residential streets without dedicated bicycle infrastructure, which have a bicycle suitability index of 0.5. Even if there is a well-connected and highly suitable cycling network along some main axes, those people would first have to use some less suitable streets before reaching it. Similarly, if the hub nodes are not connected to those axes directly, they will become isolated nodes in bikeable graphs for higher index thresholds, and only be reachable for those people that have a hub node as the the nearest node to their household. If an adopted quality standard requires bicycle suitability higher than an index value of 0.5, policy should focus on improving the first and last stretches of routes.

Fig. 4 shows the locations of households that have bikeable access to the hub for specific combinations of index and detour thresholds. The displayed information is similar to Fig. 3, but integrates the spatial perspective of Fig. 2. This clearly shows the large influence that varying criteria for cycling infrastructure quality have on the computed levels of bicycle accessibility.

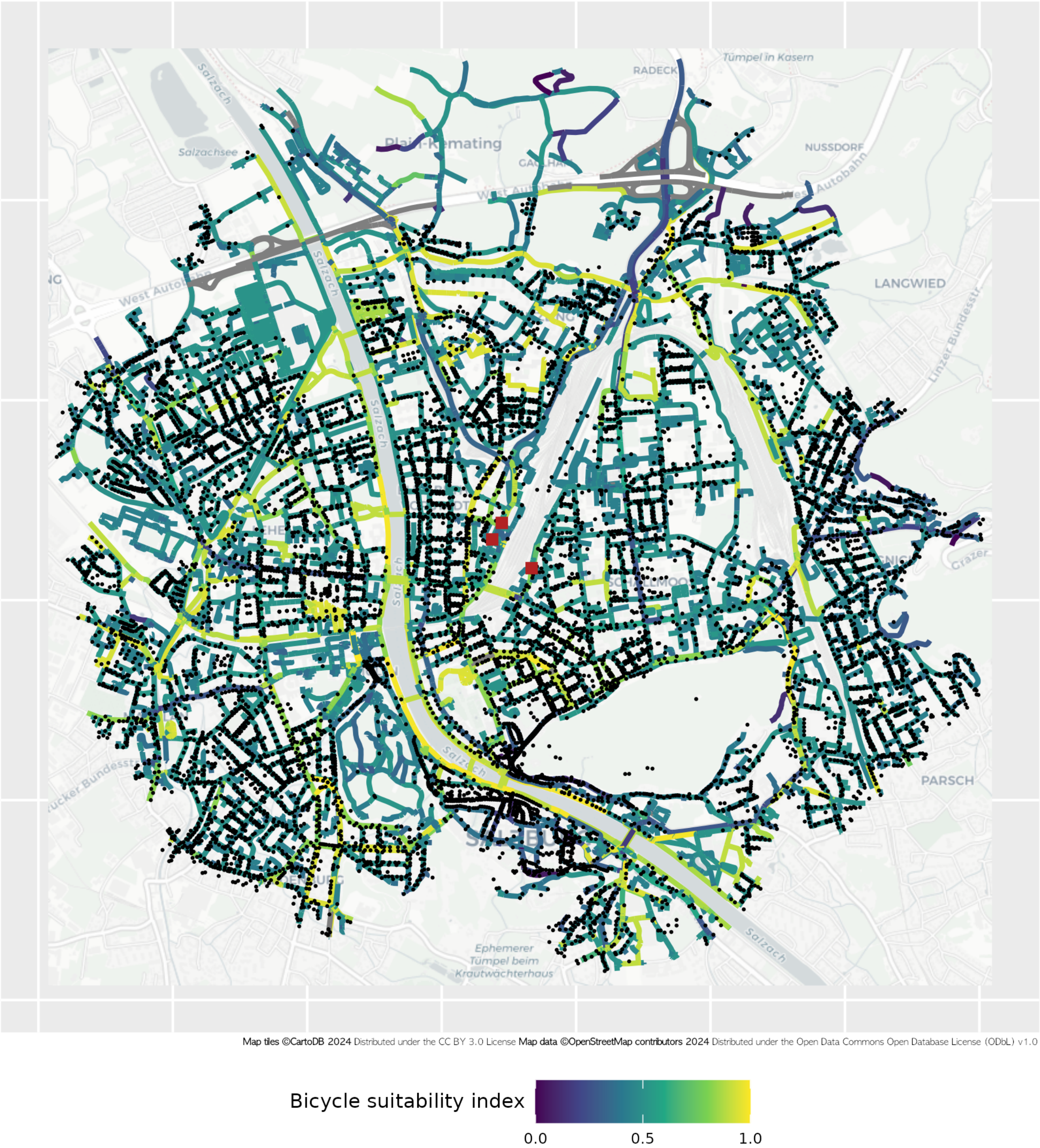

Figure 2. The street network (lines colored by bicycle suitability index) and household locations (black dots) around the bicycle parking stations of the exemplary mobility hub location in Salzburg (red squares).

4 Discussion

We presented an approach that provides a different view on the assessment of bicycle accessibility to a central location. While we looked specifically at potential trips from households to a mobility hub, the same ideas can be used to assess bicycle accessibility from mobility hubs to workplaces and amenities, and in other application cases outside of the mobility hub context. The added value of the approach is that it shows how different definitions of suitable cycling infrastructure influence the computed bicycle accessibility, in a way that is meant to be simple and intuitive to understand. Future research should include workshops to evaluate if the approach is indeed received as being useful and intuitive by potential users, such as policymakers.

The shown analysis is strongly simplified in some aspects. Bicycle suitability is computed by four basic indicators. Other influential factors, for example those related to the attractiveness of the environment, are neglected. Furthermore, the index is only computed for individual street segments, and not for the intersections of streets. Neither does it consider characteristics of the hub itself, most importantly the quality and size of the bicycle parking facilities. While including additional factors could result in a more realistic index, it may increase complexity and limit ex-

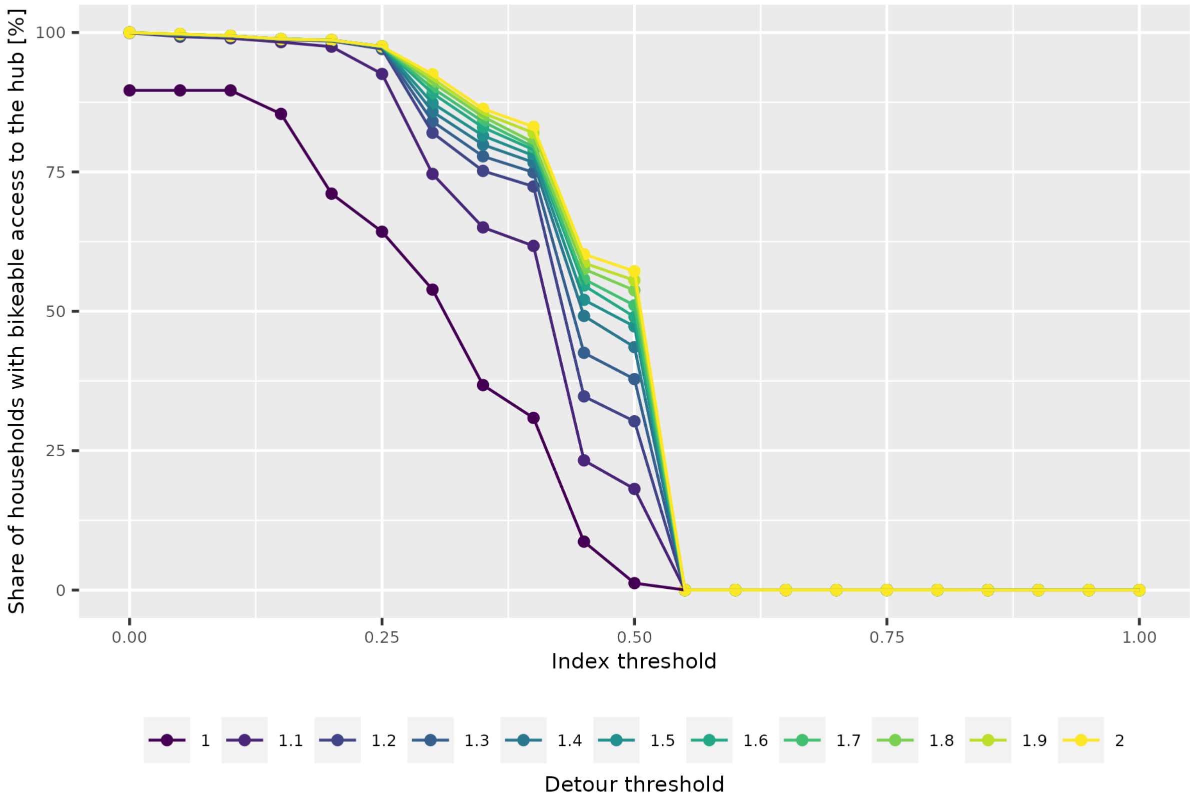

Figure 3. Computed accessibility from households to the hub for different combinations of index and detour thresholds.

plainability. Note, however, that the approach itself is independent from the method used to compute a bicycle suitability index. Even if such an index has an ordinal scale, bar charts could be used for visualization instead of continuous curves.

Ideally, data on the number of residents would be available for each household. Compared to our approach of counting the number of households, this would give a more accurate insight in how many people actually have bikeable access to the hub. Another important simplification is that we do not analyze differences in accessibility between socio-demographic groups. Future research should extent the approach to account for equity issues.

The technical implementation of the graph analysis could be more sophisticated. Households are now simply snapped to their nearest node. If the edges that connect this node are part of a street with low bicycle suitability, the household will not have bikeable access to the hub for most of the index thresholds, even if directly next to this street there is a high-quality separated bikelane. Also, the distance between the household location and its nearest node is not considered. The same simplifications apply to the locations of the bicycle parking facilities at the hub. In further developments of the software that move beyond the proof-of-concept stage, these issues should be addressed.

Inherent to our presented approach is that given a certain index threshold, a street segment is either considered bikeable or not bikeable. This is independent from the length of the street segment. Hence, it is not possible to model a short segment with low bicycle suitability as being acceptable, even though a longer segment with equally low bicycle suitability is not acceptable. Although in practice many cyclists use such a way of thought in their route choice, we argue that in the context of bicycle accessibility our approach is justified. The fact that there are cyclists who still choose to ride a route even though it has short sections of low bicycle suitability, does not mean that such a route should by definition be considered as providing good bicycle accessibility to the destination. This holds for cyclists who are less confident, like children or senior citizens, but equally for those that choose to ride the route nevertheless.

On the other hand, the binary distinction between bikeable and not bikeable also means that the margin by which the bicycle suitability index exceeds the given index threshold has no influence on the computed bicycle accessibility levels. A street segment with a bicycle suitability index that exceeds the index threshold by a large margin does not contribute more to a good bicycle accessibility than a street segment with a bicycle suitability index equal to the index threshold.

Considering these implications, it should be stressed that our approach essentially computes edge weights by a generalized cost function of distance and bicycle suitability, returning an infinite weight if the bicycle suitability is lower than a threshold value, and weights equal to

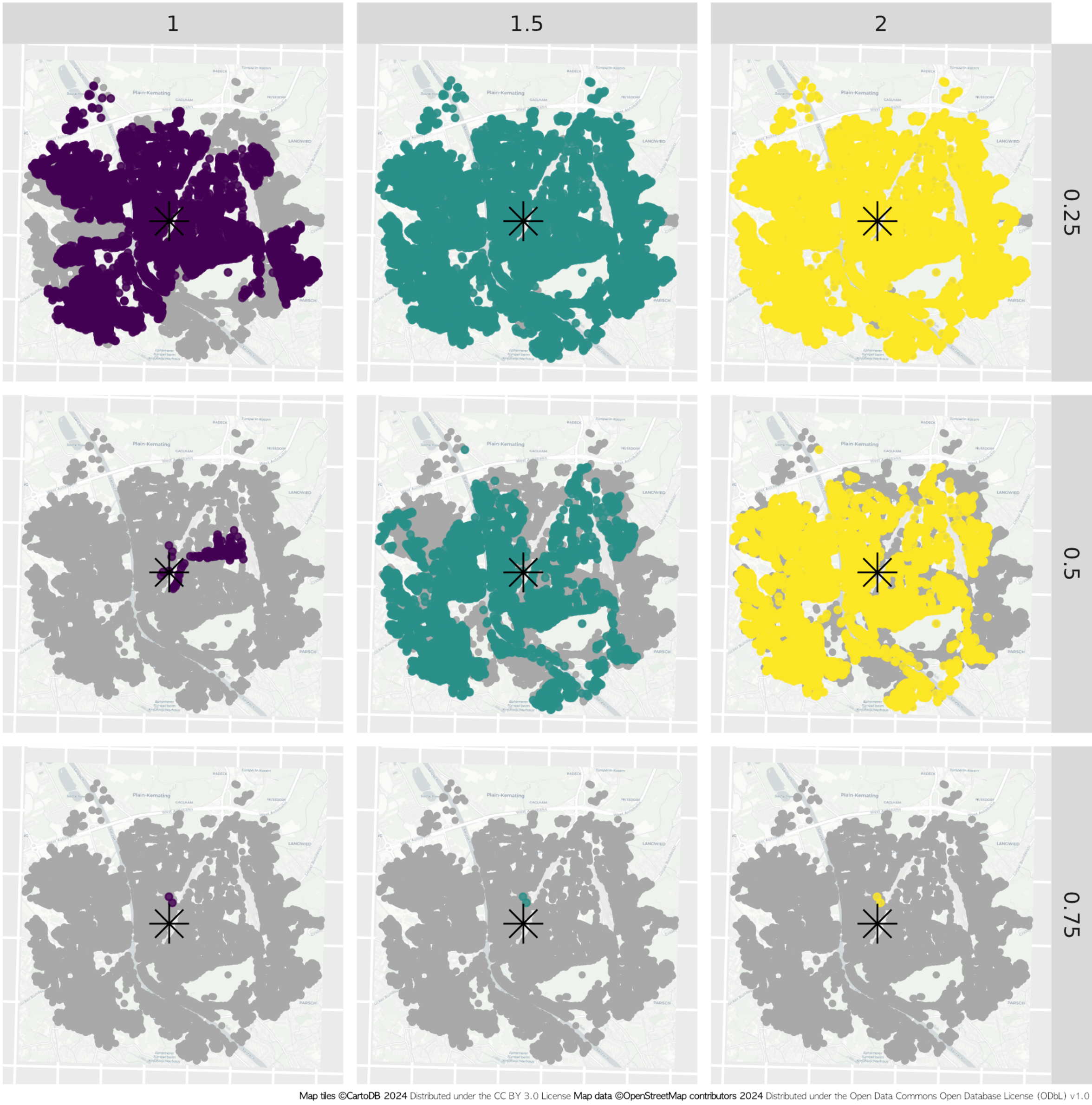

Figure 4. Locations of households with bikeable access to the hub for different combinations of index thresholds (rows) and detour thresholds (columns). For comparison, all households in the proximity of the hub are mapped by grey dots in the background. The asterisk is the centroid of the hub nodes.

geographic distance otherwise. This cost function could easily be adapted to show a more gradual decrease of edge weights as bicycle suitability increases, be it linearly, exponentially, or any other shape. We could show how computed bicycle accessibility is influenced by different weighting parameters in the cost function, and by different acceptance thresholds for the total route cost. We could also integrate distance decay functions that give more importance to households closer to the hub. Defining if such adaptations provide more valuable insights comes down to the same question we have asked before, and that is inherent to any modeling task: how to find a good balance between complexity and explainability?

5 Conclusion

In this paper we presented a new approach to assess and communicate bicycle accessibility to mobility hubs. It shows how computed levels of bicycle accessibility vary under different criteria for cycling network quality. In comparison to aggregated metrics, this provides richer information to potential users that can help them to make decisions within the specific context they are working in.

Author contributions. Lucas van der Meer: Conceptualization, Methodology, Formal analysis, Data curation, Software, Writing - Original Draft, Writing - Review & Editing, Visualization; Christian Werner: Methodology, Data curation, Writing - Review

& Editing; Martin Loidl: Methodology, Supervision, Funding acquisition, Writing - Review & Editing.

Competing interests. The authors declare no competing interests.

Acknowledgements. The authors thank Research Studios Austria - Studio iSPACE for contributing to the funding of this research.

References

Abad, L. and Van der Meer, L.: Quantifying Bicycle Network Connectivity in Lisbon Using Open Data, Information, 9, https://doi.org/10.3390/info9110287, 2018.

Aono, S.: Identifying Best Practices for Mobility Hubs, Tech. rep., UBC Sustainability Scholars, https://www.sustain.ubc.ca/about/resources/identifying-best-practices-mobility-hubs, 2019.

Bundesamt für Eich- und Vermessungswesen: Adresse Relationale Tabellen Stichtagsdaten 01102021, https://www.data.gv.at/katalog/dataset/adressen-relationale-tabellen-stichtagsdaten#resources, accessed on 23.01.2024, licensed under Creative Commons Attribution License 3.0, 2023.

Cunha, I. and Silva, C.: Equity impacts of cycling: examining the spatial-social distribution of bicycle-related benefits, International Journal of Sustainable Transportation, 17, 573–591, https://doi.org/https://doi.org/10.1080/15568318.2022.2082343, 2023.

Ehrgott, M., Wang, J. Y., Raith, A., and van Houtte, C.: A bi-objective cyclist route choice model, Transportation Research Part A: Policy and Practice, 46, 652–663, https://doi.org/https://doi.org/10.1016/j.tra.2011.11.015, 2012.

Geofabrik: austria-latest.osm.pbf, http://download.geofabrik.de/europe/austria.html, accessed on 23.01.2024, licensed under Open Data Commons Open Database License, 2024.

Geoland.at: Digitales 10m - Geländemodell aus Airborne Laserscan Daten in der Projektion EPSG:31287, https://www.data.gv.at/katalog/dataset/land-ktn_digitales-gelandemodell-dgm-osterreich#resources, accessed on 23.01.2024, licensed under Creative Commons Attribution License 4.0, 2019.

Nichols, A., Duran, D., and Büttner, B.: SmartHubs Accessibility Tool, Tech. rep., SmartHubs, https://www.smartmobilityhubs.eu/_files/ugd/c54b12_2ecb4e9b488d45f8818c524f51f9b3a9.pdf, 2023.

R Core Team: R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/, 2023.

Reggiani, G., van Ooijen, T., Hamedmoghadam, H., Daamen, W., Vu, H. L., and Hoogendoorn, S.: Understanding bikeability: a methodology to assess urban networks, Transportation, 49, 1572–9435, https://doi.org/10.1007/s11116-021-10198-0, 2022.

Reggiani, G., Verma, T., Daamen, W., and Hoogendoorn, S.: A multi-city study on structural characteristics of bicycle networks, Environment and Planning B: Urban Analytics and City Science, 50, 2017–2037, https://doi.org/10.1177/23998083231170637, 2023.

Schneider, F., Jensen, A. F., Daamen, W., and Hoogendoorn, S.: Empirical analysis of cycling distances in three of Europe's most bicycle-friendly regions within an accessibility framework, International Journal of Sustainable Transportation, 17, 775–789, https://doi.org/10.1080/15568318.2022.2095945, 2023.

Vale, D. S., Saraiva, M., and Pereira, M.: Active accessibility: A review of operational measures of walking and cycling accessibility, Journal of Transport and Land Use, 9, https://doi.org/10.5198/jtlu.2015.593, 2015.

van der Meer, L., Abad, L., Gilardi, A., and Lovelace, R.: sfnetworks: Tidy Geospatial Networks in R, https://luukvdmeer.github.io/sfnetworks/, version v0.6.3, 2023.

Werner, C., Wendel, R., Kaziyeva, D., Stutz, P., van der Meer, L., Zagel, B., and Loidl, M.: plus-mobilitylab/netascore: v1.0.1-fix, https://doi.org/10.5281/zenodo.10666445, version v1.0.1-fix, 2024.