Where are the centers of a city? A method to analyze centrality and modal equity of transport in comparable manner across city regions

Henrikki Tenkanen[*1,2], Jeison Londoño Espinosa[†2] and Tuuli Toivonen[‡2]

[1] Department of Geography, University College London
[2] Digital Geography Lab, Department of Geosciences and Geography, University of Helsinki

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Summary

Accessibility is a widely used conceptual tool to understand the abilities of people to move in cities by different travel modes at different times of the day. In this paper, we introduce multi-modal centrality assessment, which is a methodology to understand centrality of city regions in a comparative manner by different travel modes based on accessibility modelling. With case studies from Helsinki and Tallinn, we demonstrate how this approach can provide new insights about urban morphology and modal equity in urban regions.

KEYWORDS: accessibility, multimodality, centrality, transportation, equity

1. Introduction

One of the most important and widely used conceptual and analytical tools to understand the functioning of cities and the wealth of issues related to developing our urban environments is the concept of *accessibility*. Accessibility binds together issues of land use, transportation and socio-economic aspects which all constitute factors that can either enable or hamper (planning of) a good and sustainable future (Hickman, Hall & Banister, 2013). Accessibility has been widely used as a tool to understand the abilities of people to move in cities by different travel modes at different times of the day, and assess how equitable our urban environments are for different groups of people (Lucas, van Wee & Maat, 2016; Pereira, Schwanen & Banister, 2017). Hence, the notion of accessibility has long been an important tool for planning.

Accessibility can be analyzed and measured in various ways, but currently the most widely used measure is travel time since it is an intuitive and comprehensive measure of distance between locations. Using time as a measure of distance is also useful because it is uniform between different travel modes. From the analytical perspective, network analysis is a crucial part of understanding the travel times between locations. In network science, understanding the centrality of a network has been widely studied in the past decades for example in social sciences. Centrality indices are widely used also in urban morphology studies that aim at describing and understanding the spatial structure and characteristics of city regions. Various studies aim at understanding the central locations of cities e.g. based on the topological features of a network, or based on different travel modes such as public transport (Curtis & Scheurer, 2017) or private car (Rubulotta *et al.*, 2013). However, analyzing and comparing the centrality of a city between different travel modes has not been conducted before, to our best knowledge.

In this paper, we introduce *multi-modal centrality assessment* (MMCA), which is a methodology to understand centrality of city regions in a comparative manner by different travel modes. MMCA extends the previous approach introduced by Porta, Crucitti & Latora (2006) for conducting multiple

[*] h.tenkanen@ucl.ac.uk
[†] jeison.londonoespinosa@helsinki.fi
[‡] tuuli.toivonen@helsinki.fi

centrality assessment. Furthermore, we demonstrate how this approach can provide new insights about urban morphology and modal equity in urban regions.

2. Multi-modal centrality assessment

2.1. Comparative accessibility measures form the basis for the analysis

Calculating multi-modal centrality is based on travel time calculations that follow a so called door-to-door approach (Salonen & Toivonen, 2013). In door-to-door approach all steps of a journey are considered, which makes it possible to more realistically compare different travel modes to each other (Figure 1).

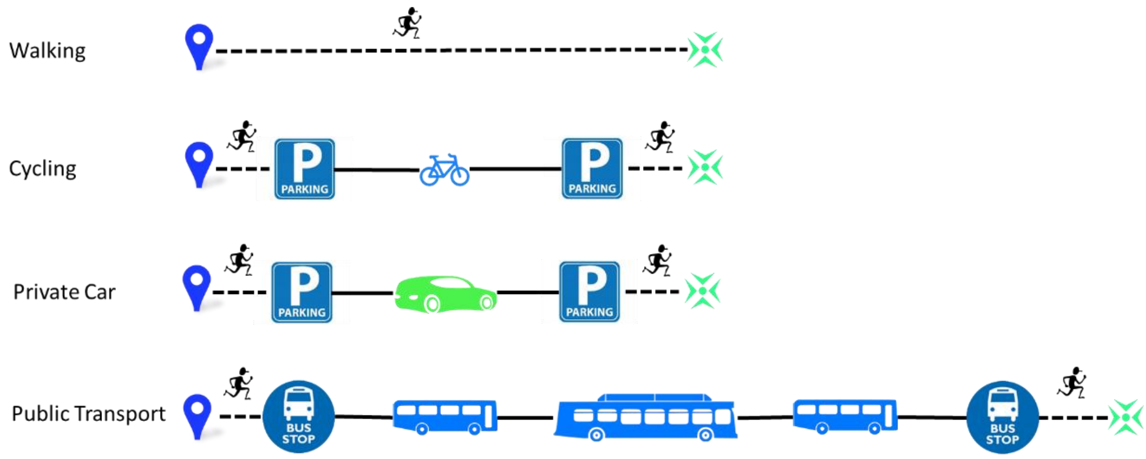

Figure 1. In door-to-door approach, all legs of the journey are considered that allows more realistic comparisons between different travel modes.

2.2. Data and tools for travel time calculations

Calculating the multi-modal centrality in the city region is based on travel time estimates are calculated between predefined locations in the region. For the calculations, we use open data mainly from two different sources: OpenStreetMap for street network and speed limits, General Transit Feed Specification (GTFS) data for public transport schedules, locations of the stops, and the available transit routes in the region. The dynamics in car travel times are based on an intersection delay model (Toivonen *et al.*, 2014) that uses GPS-based floating car measurements as an input. The actual travel time are calculated using OpenTripPlanner (www.opentripplanner.org/) for public transport and a Python package called NetworkX (https://networkx.github.io/) for car.

2.3. Calculation of multimodal centrality

To calculate the centrality indices for different travel modes, we first conduct all-to-all calculations between all possible origin and destination points that in our case consider centroids of a systematic statistical grid. For making computing intensive calculations more feasible timewise, we conduct one-to-many routings using Dijkstra's algorithm and utilize supercomputing resources to distribute the calculations. As a result, we get a 3-dimensional dataset having a separate travel time layer for each location in the study region (Figure 2a).

In the second stage, we compute the actual centrality indices for each grid cell by calculating vertical cross-section median travel time for each location in the region. This produces a layer where each grid cell gets an index based on how central it is compared to other locations in the region (Figure 2b). By utilizing the door-to-door approach described earlier, these indices are comparable between different travel modes.

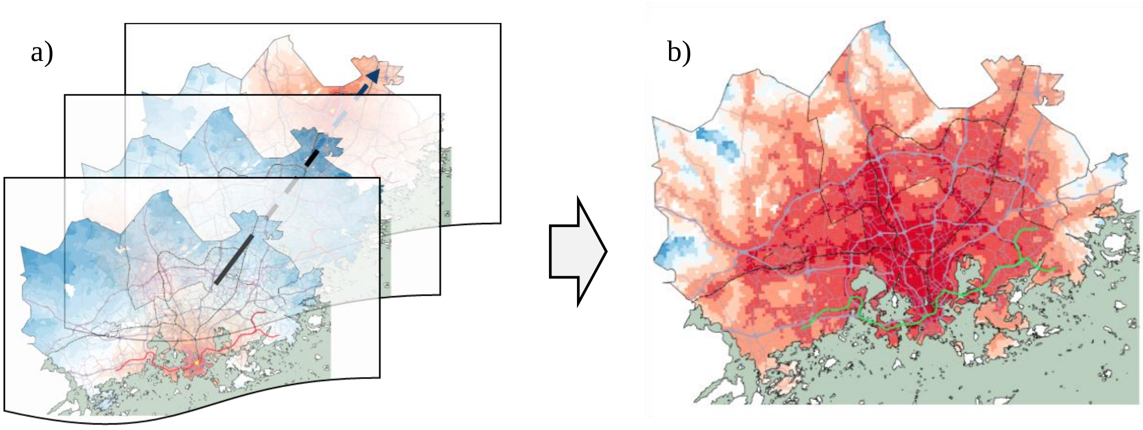

Figure 2. A stack of travel time matrices (a) for each location in the region is used to calculate the centrality layer for the region which is a product of cross-sectional (vertical) median travel times.

3. Results

To demonstrate the proposed approach, we assess and compare the multimodal centralities of two city regions: Helsinki in Finland and Tallinn in Estonia. Figure 3 shows the most central grid cells (the most central 10% of the grid cells) by public transport and private car. Discrepancy between the distribution of the most central areas in the regions reveal that the accessibility realities varies considerably depending on the travel mode. Hence, as our results suggest, the proposed approach is able to detect the differences in the orientation of the transport system.

Figure 4 demonstrates how the population in the city regions are distributed in relation to the centrality indices. In Helsinki Region, the discrepancy between transport modes is evident: population is more centralized into areas with high accessibility by public transport (blue line) compared to private car. In Tallinn, the situation is more equal, as the lines of cumulative accessibility are closer to each other.

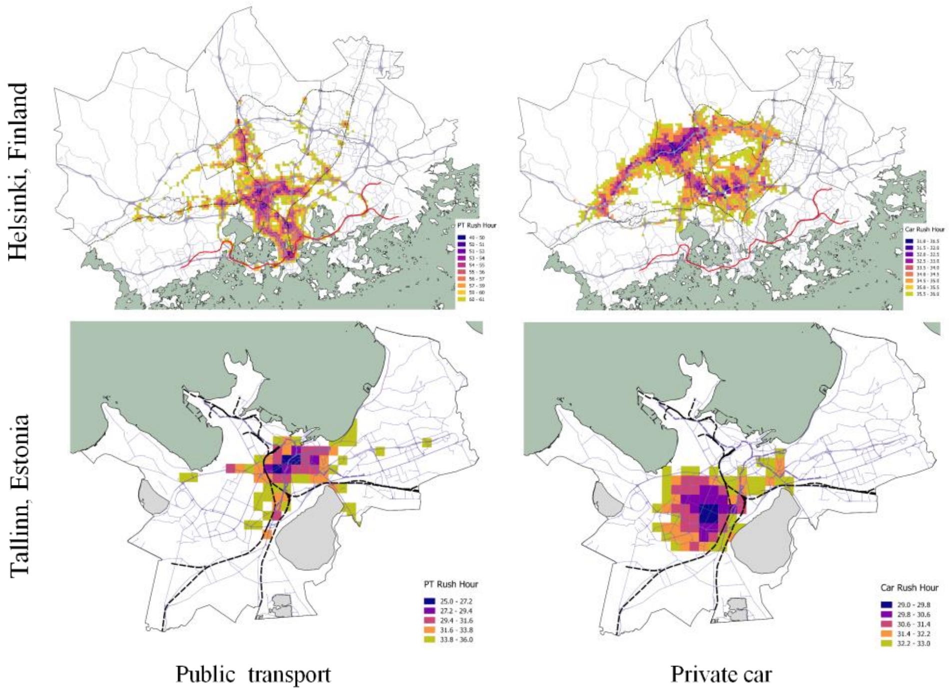

Figure 3. The most accessible areas (best 10 %) in Helsinki and Tallinn by public transport and car reveal discrepancies in centrality between travel modes and city regions.

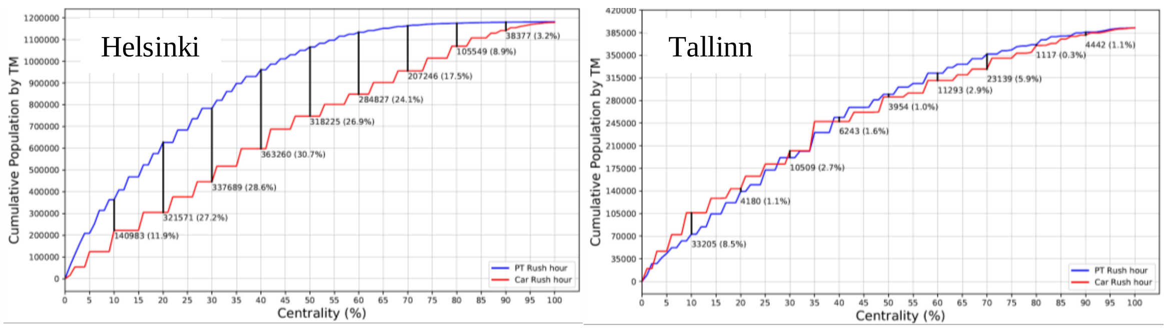

Figure 4. Cumulative population curves show the number of citizens living under specific centrality index (0-100 %) by public transport (blue line) and private car (red line).

4. Discussion & conclusions

In this paper, we have introduced a new approach to assess the centrality of city regions by different travel modes in a comparable manner. With the approach it is possible to understand how the accessibility realities in cities differ based on if you use a car or travel by public transport. By combining the multimodal centralities to different datasets (such as socio-demographic data) it is possible to retrieve valuable information about the performance of a city, or to estimate how equitable the city is from the transportation perspective.

Although the proposed approach can provide comprehensive insights about the functioning of cities from the transportation perspective, the drawback of the approach is, that it is computationally intensive. For instance, in Helsinki Region there were altogether 13000 origin-destination points that resulted altogether 169 million connections for public transport and car. It is also possible to integrate the "human component" better into the analyses by using e.g. more advanced centrality measures such as *place time rank* (Rubulotta *et al.*, 2013) to incorporate also individuals into the centrality measures themselves.

To conclude, the proposed multi-modal centrality assessment provides a novel systematic approach that can be used to compare different city regions to each other, and to reflect the centrality measurement with different datasets. Hence, the approach can provide fruitful ground to study various socio-spatial phenomena and provide new insights about urban morphology.

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Biographies

Henrikki Tenkanen is a postdoctoral researcher specialized in accessibility and mobility analytics. He currently works on his own research project and is based at the University College London, and is also a member of Digital Geography Lab, Uni. Helsinki.

Jeison Londoño Espinosa is software engineer and a GIScientist who conducted his MSc thesis about multimodal centrality analyses as a visiting student at Digital Geography Lab, University of Helsinki. Jeison got his MSc from geoinformatics at University of Münster.

Tuuli Toivonen is an Associate Professor in geoinformatics at the Department of Geosciences and Geography, University of Helsinki, and the leader of Digital Geography Lab.