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Dynamic cities: Location-based accessibility modelling as a function of time

Olle Järv[a,*,1], Henrikki Tenkanen[a,1], Maria Salonen[a], Rein Ahas[b,2], Tuuli Toivonen[a,*]

[a] Digital Geography Lab, Department of Geosciences and Geography, University of Helsinki, FI-00014 Helsinki, Finland
[b] Mobility Lab, Department of Geography, University of Tartu, EE-51014 Tartu, Estonia

A R T I C L E I N F O

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A B S T R A C T

The concept of *accessibility* – the potential of opportunities for interaction – binds together the key physical components of urban structure: people, transport and social activity locations. Most often these components are dynamic in nature and hence the accessibility landscape changes in space and time based on people's mobilities and the temporality of the transport network and activity locations (e.g. services). Person-based accessibility approaches have been successful in incorporating time and space in the analyses and models. Still, the more broadly applied location-based accessibility modelling approaches have, on the other hand, often been static/atemporal in their nature. Here, we present a conceptual framework of dynamic location-based accessibility modelling that captures the dynamic temporality of all three accessibility components. Furthermore, we empirically test the proposed framework using novel data sources and tools. We demonstrate the impact of temporal aspects in accessibility modelling with two examples: by investigating food accessibility and its spatial equity. Our case study demonstrates how the conventional static location-based accessibility models tend to overestimate the access of people to potential opportunities. The proposed framework is universally applicable beyond the urban context, from local to global scale and on different temporal scales and multimodal transport systems. It also bridges the gap between location-based accessibility and person-based accessibility research.

1. Introduction

The UN has projected that the amount of people living in urban areas will rise from the 54% at present to 66% by 2050 (UN, 2014, 2015). Our cities are forming an ever more complex global network society (Castells, 2000) that is steered by the flows of people, products, waste, money and data (Urry, 2007). This reshaping of mobile urban societies is influencing not only the daily lives of citizens (Cresswell & Merriman, 2011) and the dynamic structures of cities (Batty, 1971), but also the global economy and urban hierarchies (Sassen, 1991). The rapidly urbanizing world is challenged by a myriad of environmental and social problems. A comprehensive understanding of the dynamics of cities from spatial, temporal and social perspectives is needed to be able to plan sustainable and liveable cities, and to mitigate social challenges such as socio-spatial inequality, public health, segregation and aging.

Spatial accessibility is one of the key conceptual and methodological tools for examining and modelling urban patterns and processes (Bertolini, le Clercq, & Kapoen, 2005; Geurs, Krizek, & Reggiani, 2012). The concept of accessibility binds together the key components of an urban structure: people, mobility and social activities, and makes it possible to have a functional view of urban structures and processes. In general, spatial accessibility describes “the potential of opportunities for interaction” (Hansen, 1959). However, the concepts of access and accessibility are slippery notions that have many definitions (Gould, 1969; Penchansky & Thomas, 1981). The conceptualization and operationalization varies substantially depending on whether accessibility is examined from a location-based (also referred to as place-based) or a person-based perspective. Also, the applied approach for measuring accessibility (constraint-, attraction-, or benefit-oriented), the complexity of modelling (e.g. social, economic, and environmental components), the measure of network distance (time, distance, CO_2 load or trip quality, e.g. Banister, 2011) as well as the broader research context influences how (and what) accessibility is examined (Geurs & van Wee, 2004; Miller, 2005). Overall, defining accessibility and developing methods to measure accessibility has improved over time and continues to be an ongoing effort (van Wee, 2016).

Accessibility has become an important analytical approach and the

* Corresponding authors.
E-mail addresses: olle.jarv@helsinki.fi (O. Järv), henrikki.tenkanen@helsinki.fi (H. Tenkanen), maria.salonen@helsinki.fi (M. Salonen), rein.ahas@ut.ee (R. Ahas), tuuli.toivonen@helsinki.fi (T. Toivonen).
[1] Contributed equally.
[2] Deceased 18 February 2018.

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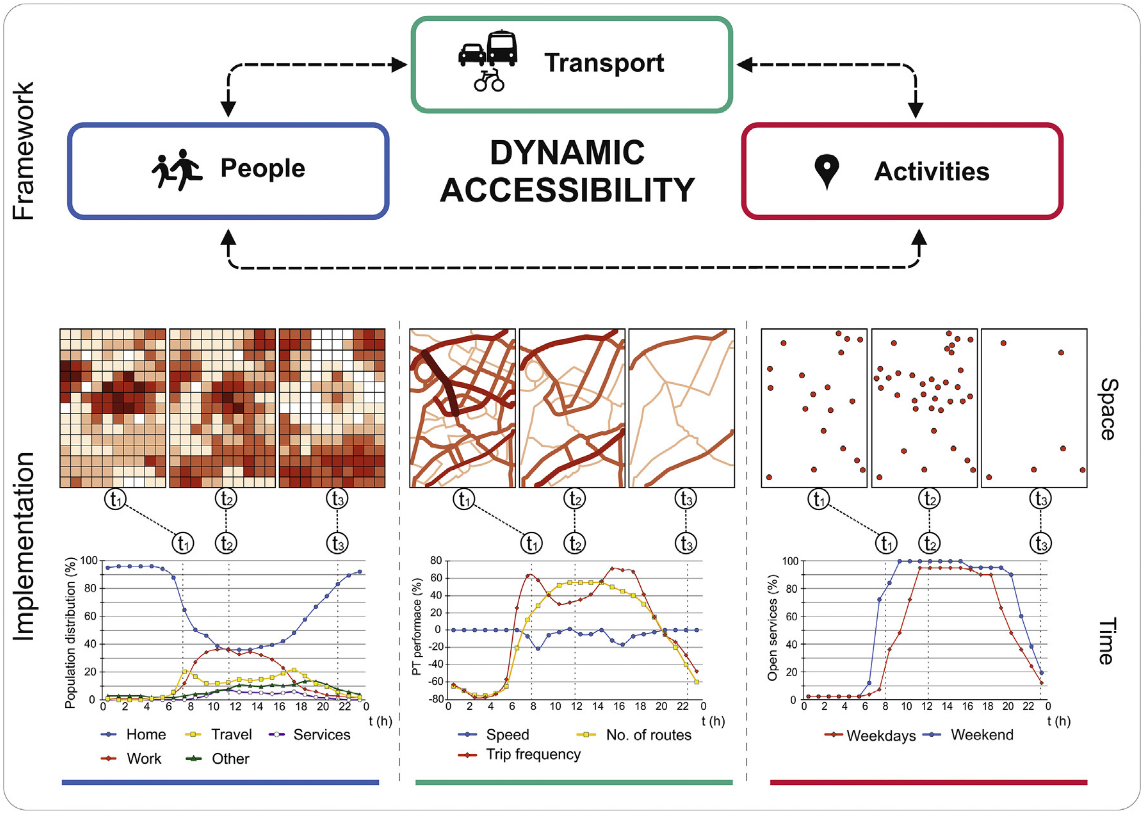

Fig. 1. The conceptual framework for a dynamic location-based accessibility modelling (top), where all three basic components of spatial accessibility (people, transport and activities) vary as a function of time. The implementation of the framework (bottom) is an illustration of our case study, exemplifying the variation of accessibility in space and time to grocery stores in Helsinki, taking into account all the three accessibility components within a 24-h timeframe. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

existing literature is rich in applications (van Wee, 2016). From a location-based modelling perspective, accessibility has been used as a tool to understand the compactness, functioning, sustainability and equity of the urban form and to identify likely centres of social interaction. Examples range from analysing transport network efficiency and land use strategies (Benenson, Martens, Rofé, & Kwartler, 2011; Geurs & van Eck, 2003; Gutiérrez & García-Palomares, 2008; Kujala, Weckström, Mladenović, & Saramäki, 2018; Vandenbulcke, Steenberghen, & Thomas, 2009) to the economic performance of a city (Chin & Foong, 2006; Salas-Olmedo, García-Alonso, & Gutiérrez, 2016). Accessibility has also been applied to understand the social and environmental justice (Farrington & Farrington, 2005; Laatikainen, Tenkanen, Kyttä, & Toivonen, 2015; Wolch, Byrne, & Newell, 2014) and the spatial equity in urban areas (Dai & Wang, 2011; Lucas, van Wee, & Maat, 2016; Talen & Anselin, 1998; Van Wee & Geurs, 2011). Recently, more applications are being linked to public health (Neutens, 2015; Tenkanen, Saarsalmi, Järv, Salonen, & Toivonen, 2016; Widener, Farber, Neutens, & Horner, 2015), wellbeing and the quality of life of urban dwellers (Casas, 2007; Lowe & Mosby, 2016; Serag El Din, Shalaby, Farouh, & Elariane, 2013).

While the concept of spatial accessibility is inherently related to time, as it determines access to, and the use of desired social opportunities, the time dimension has to date been poorly incorporated into spatial accessibility modelling (Kwan, 2013). Despite advances in time-dependent person-based accessibility modelling (see, e.g. Neutens, Delafontaine, Schwanen, & Weghe, 2012; Widener et al., 2015), still most of the location-based accessibility models rely entirely or partially on an atemporal view of access (Chen et al., 2017; Lucas et al., 2016). Such “sedentary” models presume that people are at home, and that both transport supply and the opportunities for activities of social practices are fixed in time. However, neglecting the temporal dynamics of cities and the mobility of inhabitants (Schönfelder & Axhausen, 2010) may lead to biased or even misleading conclusions in accessibility models (Neutens et al., 2012; Tenkanen et al., 2016).

One factor limiting the full incorporation of the time dimension into a location-based accessibility modelling has been the lack of temporally sensitive spatial data. In recent years, however, suitable data sources for modelling have gradually emerged. For example, General Transit Feed Specification (GTFS) data is providing temporal data on public transport, and platforms like Foursquare or Yelp on the activity locations of people (Dewulf et al., 2015; Tenkanen et al., 2016; Widener et al., 2015). Still, even in the case of partially dynamic location-based accessibility studies, there is often a lack of information on the actual whereabouts of people in time (see, e.g. Widener et al., 2017). Such information would be needed to facilitate dynamic accessibility modelling instead of using static census data. However, the widespread use of mobile communication technologies and the emerging big data revolution are providing additional data sources (e.g. mobile phone or social media data) to reveal dynamic locations of people (Chen et al., 2018; Kitchin, 2014; Moya-Gómez, Salas-Olmedo, García-Palomares, & Gutiérrez, 2017). The latter is needed for applying fully dynamic accessibility modelling.

In this paper, we aim to contribute to the conceptual development of location-based accessibility research by proposing a generic conceptual framework of dynamic location-based accessibility modelling, where all three of the core components of accessibility (people, transport, and activity locations) are considered as a function of time. Furthermore, we exemplify the proposed framework by investigating urban food accessibility. This example was chosen because food is one of the basic physiological needs for everyone, and because the social inequality of accessing food stores from the spatial accessibility perspective often depends on time (Fransen et al., 2015; Stępniak & Goliszek, 2017). We take advantage of novel data sources (GTFS, mobile phone data,