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Rethinking urban green space accessibility: Evaluating and optimizing public transportation system through social network analysis in megacities

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HIGHLIGHTS

- Social network analysis is a valid approach to assess green spaces connectivity.
- Case studies suggest more green spaces not necessarily mean higher accessibility.
- Accessibility and connectivity can be improved through network optimization.

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1. Introduction

Urban green spaces or open spaces play a critical role in sustaining urban natural environments and the social systems that use these spaces. Urban green spaces are indispensable bridges between humans and nature as they are the primary preservers of biodiversity in cities (Jorgensen, Hitchmough, & Calvert, 2002). Urban green spaces help maintain the physical and mental health of city dwellers (Jackson, 2003; Takano, Nakamura, & Watanabe, 2002), improve the diversity of ethnic and religious groups (Comber, Brunsdon, & Green, 2008), and facilitate communication among communities by providing public meeting spaces (Martin, Warren, & Kinzig, 2004). Thus, urban green spaces play a significant role in supporting activities of various social groups (Barbosa et al., 2007). When cities lack urban green space, residents may choose to move out of the city, as was the case with Leuven, Belgium in 1998 (Van Herzele & Wiedemann, 2003). However, to achieve these benefits, urban green spaces must be accessible to the public, as accessibility is a key indicator used to evaluate the effective social and ecological functioning of cities (James et al., 2009). In megacities such as New York, Hong Kong, and Tokyo, urban green spaces are scarce resources compared to small cities or towns, and thus this scarcity presents a much more serious challenge for megacities.

As of 2013, there were 24 megacities in the world with inhabitants exceeding 20 million per city (PRB, 2013). Given that megacities are significant contributors to air pollution and population growth, ensuring that megacities have sufficient green space will help to slow environmental deterioration, improve the prosperity of cities, and enhance satisfaction of citizens. However, shortages of available space hinder cities from developing new green spaces and encourage the destruction of existing suburban natural environments to make room for the development of the built environment.

Even in cases where megacities have sufficient urban green space, traffic congestion often hinders citizens from accessing green spaces through private transportation. Therefore, enhancing the accessibility of public transportation systems to urban green space is one of the most cost effective approaches to enable connections between residents and natural environment. However, for decision makers to strategically facilitate access, it is necessary to have an effective, analytical tool to evaluate the performance of planned public transportation systems and guide the design process. Thus, the objective of this research is to provide decision-makers with a tool to analyze the efficacy of planned public transportation networks in providing access to urban green spaces.

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2. Background

2.1. Social network analysis and its application

Network modeling, which originated from graph theory, facilitates assessment of the structure and performance of complex geospatial systems. Within the network modeling approach, social network analysis (SNA) is a data processing scheme proposed in recent years (Knoke & Yang, 2008) that focuses on a system's structural features and the dynamic interactions among network vertices. For example, the "scale-free" property (Barabási & Albert, 1999) and "small world" property (Watts & Strogatz, 1998), of networks that facilitate distance and flow analysis were developed through SNA and were not possible with more traditional network modeling approaches. In the analysis of urban planning, traditional network approaches typically measure the length of roads, travel distances and cost. Although researchers have attempted to assess urban green space accessibility through traditional network approaches (Oh & Jeong, 2007), for large cities, due to traffic congestion and availability of convenient and economical public transportation facilities, accessibility must be measured with a different approach because the availability of transportation junctions as opposed to distance or cost is the primary consideration for city residents who seek to visit urban green spaces. Thus, to understand green space accessibility in megacities with modern public transportation systems, SNA is an appropriate analytical tool because it can capture the system's structural features such as junctions and routes.

Prior research in a variety of fields such as sociology (Wellman, 1997), organizational theory (Bott & Spillius, 2014; Tichy, Tushman, & Fombrun, 1979), epidemiology (Pastor-Satorras & Vespignani, 2002), computer science (Otte & Rousseau, 2002) and energy efficiency (Pisello, Castaldo, Poli, & Cotana, 2014; Xu, Taylor, Pisello, & Culligan, 2012) has contributed to the development of SNA as an analytical approach to studying the structural elements of systems with dynamic features. More specifically, SNA has been widely employed in many quantitative urban geographic studies. For example, Eubank et al. (2004) emulated the outbreak of disease in an urban network with a mathematical model based on SNA. Jiang and Claramunt (2004) adopted social network parameters to analyze urban road topology. Browning, Dietz, and Feinberg (2004) conducted research on urban neighborhood organizations and violent crime using SNA. Researchers have also used SNA to improve our understanding of street networks (Cardillo, Scellato, Latora, & Porta, 2006; Jiang, 2007; Porta, Crucitti, & Latora, 2006). Our research aims to develop a model, based on SNA, to quantify, evaluate and optimize the accessibility of urban green spaces through public transportation systems.

2.2. Using GIS geospatial analysis for green space accessibility assessment

As a geospatial data management platform, Geographic Information Systems (GIS) are the most widely used tools for geospatial analysis on green space accessibility. GIS facilitate the computation of distance, connectivity and directional relationships between points in a topographical network. Conventional network-based spatial analysis of GIS systems mainly focuses on routing, routine optimization, location and visualization. Some GIS tools, such as ArcGIS, provide researchers with network analytical packages to find the shortest routes and closest facilities, determine travel distance, optimize traffic flows, and estimate transportation costs. Although these tools are able to visualize existing networks, conduct fundamental analyses and translate scattered geospatial data into networks, they lack the ability to analyze the structural features of networks because they solely focus on length and path within networks. Even with these limitations, GIS has proven to be an effective approach to study certain aspects of accessibility to green space. For instance, Van Herzele and Wiedemann (2003) implemented a GIS system to analysis the accessibility and attractiveness of green spaces in an urban area by considering the physical distances and barriers to access (Van Herzele & Wiedemann, 2003). Zhang and Wang (2006) assessed a greenway augmentation plan using a series of landscape metrics and network systems (Zhang & Wang, 2006).

Although many of these studies have analyzed the road networks that connect residents to green spaces, all of the existing research assumes that distance and cost are the only drivers of a resident's motivation to visit green spaces (Schipperijn et al., 2010). Thus, existing research ignores that residents must also be able to conveniently access green spaces if they are to use them. Governments and service providers require a rational and reliable assessment approach to create development strategies based on evaluation of the efficiency of exiting systems in order to take actions that will create synergies between transportation facilities and city landscapes. Combining GIS and social network analysis can provide such an assessment approach.

2.3. Planning guidelines for green space accessibility

Based on the Accessible Natural Greenspace Standard (ANGSt) definition, *accessible green spaces* are vegetation zones that are available for the general public to use free of charge and without time restrictions (NE, 1995; Nearby-Nature, 2010). Since private green spaces only serve limited users, we focus our research on accessible green spaces to maximize the potential impact of our model. According to ANGSt's design principles, green spaces must provide connections to nature for residents, while ensuring that the connections are easily accessible. ANGSt recommends that any resident, regardless of where they live, should have an accessible green space that is: (1) at least 2 ha in size, and (2) no more than 300 m (or a 5 min walk) from their home. Moreover, ANGSt recommends that every resident have access to at least, (1) one accessible 20 ha site within 2 km of their home, (2) one accessible 100 ha site within 5 km of their home, (3) one accessible 500 ha site within 10 km of their home, and (4) a minimum of 1 ha of statutory Local Nature Reserve per thousand residents.

Although well-intentioned, these standards are difficult to apply to megacities because of the lack of appropriate space and the limitations imposed by existing urban infrastructure systems. In response to the challenges of implementing these standards in megacities, the Hong Kong Planning Department published a Hong Kong Planning Standards and Guidelines (HKPSG) to help developers determine the scale, location and site requirements of various land uses and facilities in Hong Kong (HKPD, 2014). The HKPSG recommends that open space and recreation facilities should be provided within an integrated recreation and open space framework, incorporating continuous pedestrian and/or cycle links. HKPSG suggests that local urban open spaces be located within short walking distance from the residents it intends to serve, preferably within a radius of not more than about 0.5 km and should be located close to major transport routes and interchanges. In sum, adaptation of the ANGSt to megacities can be achieved by integrating the public transportation system with pedestrian access. We take a synthesis of the ANGSt and HKPSG recommendations as assumptions that underlie the development of our combined social network analysis and GIS approach to study accessibility of public green spaces in megacities.