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Measuring the effects of street network configurations on walking in Seoul, Korea

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ABSTRACT

Many scholars have confirmed the close correlation between street network configurations and pedestrian behavior. To elaborate on this discussion and to analyze the connection between street layout and walking using sophisticated methods, we attempt to capture the links and surrounding network features of urban street patterns. To this end, we employ the following four elements: *closeness*, *betweenness*, *severance*, and *efficiency*. Our empirical study examines street network configurations via a multi-scale network radius. The results show that locations with closer destinations and areas where people pass more frequently throughout a given network are associated with higher walking volume. Furthermore, a greater resemblance between straight-line and path distances from origins to destinations tend to encourage walking mobility. A longer convex hull, with a maximum radius that covers a wider shape and structure of links, is the most favorable setting for walking within a radius of up to 500 m. We confirm that a higher convex hull-shape index reveals more deviation from the circularity of a street network's convex hull. This negatively affects walking within a radius of 1–2 km. We conclude that link and network radius-based attributes of street formations have significant effects on the spatial variations of walking within multi-scale walkable neighborhoods. The framework and results are intended to help with the design of pedestrian-friendly street patterns and to create sustainable and livable cities.

1. Introduction

Walkable cities and neighborhoods are the core paradigm in urban planning, urban design, and transport policy. A significant amount of literature has addressed the advantages of walkable cities in terms of urban economics, urban environments, health, and social cohesion (Talen & Koschinsky, 2013). The central questions for urban planners and designers are which settings benefit pedestrians, and how to improve walkable cities. Street networks are the leading characteristics of pedestrian-friendly cities. As many studies have confirmed, street attributes such as density, connectivity, and proximity have a significant effect on walking behaviors and on choosing whether to walk (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009; Lamíquiz & López-Domínguez, 2015).

Previous studies on walkable urban settings have identified various factors, such as socioeconomic elements, the built environments, and street configurations that affect walking activities and walking volume in urban areas (Peiravian, Derrible, & Ijaz, 2014). A number of studies have found that a greater density of residents and mixed high-rise development, along with public transit, create substantially better conditions for pedestrians (Agrawal & Schimek, 2007; Cervero & Kockelman, 1997; Holtzclaw, 1994; Lopez-Zetina, Lee, & Friis, 2005). Other studies highlight the blended growth of residential and neighborhood retail properties as the main drivers of increased walking activities (Cervero, 1996; Ewing, 1995; Frank & Pivo, 1994). Prior empirical models have controlled for street features, and have commonly noted the power of street patterns, which serve as channels to help people reach their destinations.

Many studies on street configuration have found that diverse street attributes generate higher walking volume. While early investigations emphasized the physical features of street networks in relation to walking behavior, later research confirmed the significance of street density and link structures for walking activities (Cervero & Kockelman, 1997; Crane & Crepeau, 1998; Ewing & Cervero, 2010; Lee & Moudon, 2006; Song & Knaap, 2004). As analytic methods have advanced toward catchment area concepts and the space syntax methodology, recent research has discovered that pedestrians tend to be concentrated around their main destinations and adjacent streets with higher integration and choice, as measured by space syntax tools (Handy, Paterson, & Butler, 2003; Hess, Moudon, Snyder, & Stanilov, 1999; Hillier, 1996; Peponis & Wineman, 2002; Rodríguez, Khattak, & Evenson, 2006). Since local contexts produce spatial connections between street designs and walking volume, many scholars have controlled for other relevant aspects of walking environments,

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such as the street density in given areas, connectivity, and block size (Baran, Rodriguez, & Khattak, 2008).

A few recent studies have attempted to test the validity of newly measured street patterns in terms of property prices, social cohesion, and walking access to green spaces. Local and global accessibility along thoroughfares substantially explain the spatial variations of residential property prices. Specifically, a longer convex hull, with a maximum radius that covers a wider shape and structure of links, tends to enhance social interactions and cohesion in neighborhoods (Chiaradia, Hillier, Schwander, & Barnes, 2013; Cooper, Fone, & Chiaradia, 2014). Furthermore, a higher *betweenness* of streets indicates better network connectivity and, combined with green spaces, encourages people to walk (Sarkar et al., 2015).

While many scholars have tried to confirm that demographic traits, land development features, and street configurations affect the spatial patterns of pedestrian volume, few tests have used a sophisticated approach to show how heterogeneous attributes of urban layouts are linked to walking volume. Our hypothesis is testable in that walking volume and the choice to walk are associated with numerous traits of street designs, as verified in prior research (Lee & Moudon, 2006; Song & Knaap, 2004). Empirical tests result in specific policy implications and detailed guidance, which will enable improved pedestrian-friendly street designs and urban environments.

Existing studies emphasizing the importance of street features have made several significant contributions to urban studies and policy. First, these previous studies have attempted to understand the effects of fine-grained street layout on walking. Theories on central business district-focused spatial economies have failed to explain polycentric urban structure. As a result, small-scale layout analyses have increased as an alternative perspective to capture local features of street configuration (Cuthbert, 2007). Second, analyzing spatial street layout suggests rigorous knowledge of unexplored micro-level streets beyond the level of over-simplified accessibility and centrality at the macro-level (Chiaradia et al., 2013). In particular, individual walkers tend to respond to the conditions and features of their nearest streets. Thus, delving into street layout in small-scale neighborhoods effectively explains and predicts spatial variation in walking volume. Third, previous studies have found a local connection between socioeconomic activities and street networks. Because urban spatial structures consist of human settlement and movement, these sophisticated studies have strengthened our understanding of the dynamic connection between land use and urban mobility. Fourth, the diverse approaches of previous studies, such as accessibility analyses, graph theories, space syntax, and morphological measures, suggest that they provide valuable insights and relevant policies on multiple features of street configurations (Sevtsuk, 2010). The accumulated findings have led to follow-up advanced studies and more effective policy and design for livable and sustainable cities. Finally, empirical studies have suggested specific and detailed policy implications for urban planning, land use planning, transportation policy, and urban design (Rashid, 2016). Specifically, diverse empirical studies have emphasized the importance of fitting relevant policies within local contexts, such as land use, street configuration, and walking behaviors.

Notwithstanding the intense interest and aforementioned existing empirical studies, we still need clear evidence of the multifaceted relation between street configuration and walking behaviors. This arises primarily because various features of street layout affect the spatial variation of walking volume. This study expands the perspectives on various street attributes by setting hypothetical notions, such as destination density and distribution, cognitive difficulty of street navigation, ease of walking (flow), and navigability through network connections and covered areas. These notions are conceptualized in four metrics and quantified using seven sub-measurements.

This study applies a newly developed network analysis containing multiple metrics (*closeness, betweenness, severance*, and *efficiency*) in the continuum of the discussion of previous approaches. We expect that these link-centered approaches will capture the multi-dimensional spatial features of street network arrangements (Cooper et al., 2014). Street layouts are not simple, homogenous features of urban areas. Thus, we need a fine-grained, micro-level analysis of street designs to discover the links and surrounding network features of street layouts (Chiaradia et al., 2013). The section titled "Measuring link-focused, spatial network configurations" discusses the need for new methods in further detail.

Thus, we aim to elaborate on the discussion of prior studies by testing how various characteristics of street patterns change walking activities in Seoul, Korea. Furthermore, we attempt to assess the effects of the links and surrounding network features on street configurations. In order to better understand the impacts of the new metrics of street network layouts on walking volume, we measure *closeness*, *betweenness*, *severance*, and *efficiency*, using the link as a basic unit. We use the concept of a network radius to capture the surrounding networks. A network radius is a type of pedestrian catchment area in which the radius is set as the walkable distance. The noteworthy difference between the two concepts of network radius and pedestrian catchment area is that we use the radius to measure the diverse metrics of street configuration, rather than using the radius per se.

We theorize that the diverse attributes of built street patterns will be correlated with spatial variations in walking volume. Thus, we test how the four metrics of street configurations affect walking volume, while controlling for other street attributes, location attributes, neighborhood attributes, and population and employment density.

In summary, our contributions to the relevant studies and policies are as follows. First, we measure street configurations in terms of *closeness*, *betweenness*, *severance*, and *efficiency* at a local level of analysis in order to capture various features of street networks. Second, we test core hypotheses on the multifaceted effects of measured street configurations on walking, controlling for other explanatory variables. Third, we compare the various effects among the metrics of street configuration within several neighborhood scales in order to provide specific ideas on urban policy and design. Fourth, we interpret key findings of previous studies and within local contexts to aid our understanding of the micro-level street configuration associated with walking behaviors.

This paper consists of four sections. The first section discusses the study area and data sources that enabled us to determine how the multiple elements of street layouts influence spatial variations in walking. The second section describes the motivation behind measuring link-focused spatial network configurations, the street metrics (and relevant hypotheses), other variables, and the analytic methods used. The third section describes and discusses the key findings of our empirical analysis. Then, the final section summarizes the findings and suggests relevant implications for urban policy and design.

2. Study context and data sources

With > 10 million residents, Seoul contains a high proportion of mixed land use and dense street systems. In 2010, the population density was 17,466 people per km^2 (Urban Information Network, 2010). The large number of sidewalks and the high-quality public transit system have created a favorable urban environment for pedestrians. The total volume of sidewalks in 2009 amounted to 2523 km^2. The public transit system comprises nine subway lines and > 290 stations, with routes that collectively span 316.8 km. The bus transit system provides > 11,000 bus stops and several bus rapid transit (BRT) lanes (Seoul Institute, 2015).

Since 2004, the Seoul Metropolitan Government (SMG) has established key policy goals and taken steps to make the metropolis more sustainable and pedestrian friendly. In 2013, the SMG announced its plan "Pedestrian-Friendly City, Seoul." The SMG is constantly enhancing urban settings by creating pedestrian-friendly streets with wider sidewalks, implementing lower speed limits for vehicles, and creating connections between formerly separated streets (Seoul Metropolitan