IATSS Research 39 (2016) 156–163

Contents lists available at ScienceDirect

IATSS Research

# The spatial relationship between pedestrian flows and street characteristics around multiple destinations

Kazuki Nakamura *

*Kagawa University, Faculty of Engineering, 2217-20 Hayashi-cho, Takamatsu, Kagawa 761-0396, Japan*

ARTICLE INFO

Available online 3 September 2015

*Keywords:*
Pedestrian flow
Street characteristic
Pedestrian link
Accessibility
Pedestrianisation

ABSTRACT

Accessibility improvement for pedestrians has received increasing attention in planning. However, pedestrian space is more likely to be designed only for individual streets to secure minimum easiness of walking, and little attention has been paid to developing a street network for pedestrians to walk around multiple destinations on a neighbourhood scale. There is also a lack of empirical analysis of how much pedestrian accessibility would vary depending on the characteristics of streets on routes to specific destinations. This paper is aimed at examining the spatial relationship between pedestrian flows by street type and various street characteristics around multiple destinations in a city centre. First, a literature review summarises what street characteristics should be considered in accessibility analysis for pedestrians. Then, a pedestrian flow model is developed in a way that measures accessibility with street characteristics of origins, destinations, and routes on multi-scales from on-street ones to neighbourhood-scale ones. A multiple regression model is made using data from the West End area in London, in which street characteristics are taken for routes from each street segment to nearby stations and attractions. As a result, this analysis found that the route characteristics to a single nearest station and attraction can account for pedestrian flows well, but route characteristics to multiple nearby stations and attractions do not improve the model fit. These results are more prominent for pedestrianised streets. Their implication may be that these destinations are currently not linked well for pedestrians, and pedestrianisation is required to contribute more to the linkage.



## 1. Introduction

Improvement of pedestrian accessibility is increasingly expected in transport planning for its contribution to sustainable development through economic, social, and environmental co-benefits. While transport planning has investigated pedestrian accessibility to propose a traffic-calming measure at the city level, urban design has paid more attention to specific design elements to propose pedestrian-friendly built environments at the neighbourhood level. Mixed-use and high-density developments are generally encouraged for the physical design, as in New Urbanism. However, these design elements have not been well-established through empirical analysis [1].

Street design is a critical element of a pedestrian-friendly environment. Many streets have been designed more for cars, as most were constructed during motorisation periods. As a result, the design of on-street pedestrian spaces is typically ignored, that is, sidewalks are set only to secure the necessary space for pedestrian access. Street design is thus increasingly required to improve spaces for pedestrians to move through and stay around [2].

However, these improvements are likely to be introduced only for individual streets. In city centres, increased effort has been made to improve streets to enhance the attractiveness of individual areas as shopping and sightseeing destinations. On the other hand, there is a lack of street improvements to link destinations segregated by heavy traffic despite their spatial advantage of being within walking distance in the city centre. Thus, to improve pedestrian access, strategic approaches to improving links to nearby multiple destinations at a large scale must be emphasised [3].

It is necessary to measure pedestrian accessibility in order to evaluate such street improvements for links around multiple destinations. In traditional transport planning, accessibility measures are established for citywide travel by car and public transport. They account for the ability to reach key destinations with accessibility factors that comprise the characteristics of the origins, destinations, and routes between them [4]. To analyse local accessibility for pedestrians, a similar approach has been discussed in urban design [5], [6].

Nevertheless, existing accessibility measures have limitations in their application to evaluating pedestrian links. Transport accessibility measures is made using origin/destination (OD) travel data, but such

* Tel.: +81 878642162; fax: +81 878642188.
*E-mail address:* knaka@eng.kagawa-u.ac.jp.

Peer review under responsibility of International Association of Traffic and Safety Sciences.

http://dx.doi.org/10.1016/j.iatssr.2015.08.001

data are less available for local pedestrian travel. Instead, urban design develops accessibility measures for pedestrians using pedestrian flow volume as an operational and interpretable indicator, in which good accessibility is reflected by higher pedestrian flow. In city centres, where the majority of pedestrians are shoppers, pedestrian accessibility improvement is expected to increase pedestrian flow volume [7].

However, accessibility measures in urban design are heavily focused on the morphological aspects of street networks [8]. In this context, street design would not affect pedestrian accessibility without extensive morphological change of the street network. For instance, the morphology may not be changed by traffic-calming measures, such as pedestrianisation, but the impact of traffic-calming measures on pedestrian accessibility may not be ignorable. It was reported that the observed impacts of traffic calming projects in European city centres contributed to 20%–40% increases in pedestrian flows depending on the spatial scale of the improved areas [9].

This paper conducts an empirical analysis to examine the spatial relationship between pedestrian flows by street type and various street characteristics around multiple destinations in a city centre to improve accessibility measures for pedestrians. The remainder of this paper consists of three parts: literature review, methodology and data collection, and pedestrian flow analysis. First, a literature review is conducted on accessibility measures for pedestrians in transport planning and urban design to summarise appropriate key accessibility factors of street characteristics. Then, a model of multiple regression analysis (MRA) is developed to account for the spatial patterns of pedestrian flow volume on non-pedestrianised and pedestrianised streets, respectively, with street characteristics around nearby stations and attractions in the West End area in London. Finally, the MRA is conducted to examine the contributions of multi-scale street characteristics to pedestrian flows.

## 2. Literature review

Considering the impact of street characteristics on pedestrian accessibility, we conduct a literature review to determine critical accessibility factors. Although many potential accessibility factors of street characteristics may affect pedestrian behaviour, the purpose of this study is not to develop a detailed pedestrian model and test all possible factors. Instead, this study focuses on extracting major indicators in accessibility measures for pedestrians. In addition, as the factors affecting pedestrian movement may differ depending on the context of an area, attention is paid to the travel of pedestrian shoppers in a city centre.

Conventional measures used to evaluate streets for pedestrians pay significant attention to on-street characteristics, represented by level of service (LOS). While LOS is developed for various road transport users, pedestrian LOS is measured using walking space, as proposed by Fruin [10]. In this measure, walking space is regarded as street capacity for pedestrian flow, in which insufficient capacity decreases LOS for pedestrians owing to crowding. In Fruin's LOS concept, more walking space is recommended for shoppers so they can move around more. Yet, it should be noted that pavement width is positively correlated with pedestrian flow volume [11], but this does not necessarily mean that pavement expansion alone can generate higher pedestrian flow through increased demand for walking.

Early attempts to estimate pedestrian flow volume paid attention to another on-street characteristic, land use. As pedestrian travel has less-specific origins and destinations than other types of transport, land use has been taken into account at a street level as a key variable accounting for pedestrian flow volume in a city centre [12], [13].

On the other hand, an accessibility analysis for pedestrians derived from transport studies considers neighbourhood-scale street characteristics to represent the spatial relationship between origins and destinations. Place-based accessibility measures consist of spatial characteristics of origins, destinations, and routes in pedestrian travel [14], [15], [16]. Talen [17], [18] points out five classes of factors affecting pedestrian accessibility: pedestrian attributes, spatial locations of origins, spatial locations of destinations, destination attributes, and routes attributes between origins and destinations. In these studies, street characteristics of routes are generally measured using the distance between residential origins and commercial destinations. As in traffic flow estimation, the accessibility measure can be applied to estimate pedestrian flow volume in a city centre with distance from individual houses to anchor shops [19]. Although this approach is suitable for a small neighbourhood area, it is too data-intensive for accommodating a large number of visitors from all over the city to a large city centre.

Studies in urban design have developed a simpler approach to pedestrian accessibility measurement, paying more attention to route street characteristics. They hypothesise that street configuration is the most important and sole contributing factor to pedestrian accessibility [20]. Street configuration includes the morphological connectivity of a street network, in which a well-connected street network (e.g. a grid pattern) is more likely to draw people than a less-connected one (e.g. a cul-de-sac pattern). This approach interprets complex street configuration with a simple behavioural principle of pedestrians' preference for more legible routes in a street network. Observation studies have consistently reported that distance is overestimated in complex network layouts [21], [22], [23]. By measuring the connectivity of a street network with the number of changes in direction between street segments, it was proven that street configuration is significantly related to pedestrian flow volume [24]. Configuration analysis has become ones of the most popular approaches to pedestrian accessibility. Pedestrian flow models have also been developed using street configuration indicators and applied to practical street improvement projects owing to their simplicity [25].

However, configurational accessibility analysis does not consider the quality attributes of routes. These route characteristics are accountable only for accessibility improvements from extensive street-network morphological changes. A traffic-calming measure, such as pedestrianisation, does not necessarily change the morphology of a street network. Particularly, the conflict between pedestrians and vehicles must be considered to reflect that route quality affects pedestrian accessibility [26], [27], [28]. Pedestrianisation was reported to increase traffic flows on surrounding streets owing to traffic shifts from the pedestrianised area [29]. This conflict is prominent at intersections with heavy cross-traffic flow caused by longer wait time and higher accident risks, and it may worsen pedestrian accessibility by segregating pedestrian links. Street configuration analyses can be applied to estimate neighbourhood-scale traffic flows on local streets [30], but the impact of the conflict on pedestrian flows have not been analysed with it.

Configuration analysis has another limitation in evaluating pedestrian-link development between multiple key destinations. This limitation is attributed to insufficient consideration to the impacts of specific key destinations for pedestrian accessibility. Although configurational analysis hypothesises that street connectivity to all other streets in the network can account for local land use, key destinations in a city centre are often exogenous and context-dependent. Therefore, explicit consideration to these locations is needed to evaluate potential accessibility improvements in pedestrian links among them.

## 3. Methodology and data collection

### 3.1. Pedestrian flow model

In this study, a pedestrian flow model is developed with MRA to capture the contribution of each accessibility factor to overall place-based accessibility for pedestrians on a street segment. The model measures overall pedestrian accessibility using a unit of pedestrian flow volume as an interpretable indicator. In a city centre, accessibility