Journal of Transport Geography 67 (2018) 61–72

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

A new procedure using network analysis and kernel density estimations to evaluate the effect of urban configurations on pedestrian mobility. The case study of Vitoria –Gasteiz

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A R T I C L E I N F O

Keywords:
Pedestrian
GIS
Network KDE
Sustainable mobility
Walking
Built environment

A B S T R A C T

Walking as a stand-alone transport mode has recently been the focus of attention by researchers, urban planners and the public. The reasons are multiple and involve health, economic, social and environmental issues. City planners are implementing new urban configurations aimed at providing global solutions for environmental and mobility challenges by improving the availability and quality of the public space for walking. The aim of this paper is to provide a procedure to evaluate the impact of obstacles to pedestrian mobility and walkability —understanding obstacles as street crossings where pedestrians must wait to continue their route. The procedure combines the calculation of travel time on minimum cost routes and network kernel density estimations. The implementation of a new urban configuration in a medium sized city in northern Spain —the superblocks model in Vitoria-Gasteiz city— serves as a case study. The main results show that the implementation of the superblocks reduces pedestrian travel times by approximately 4–5%, and that the greatest improvements in pedestrian mobility due to the reduction of obstacles are found in areas in the city centre or in streets linking important residential areas with the centre. The procedure has been demonstrated to be useful for urban and transport planners to identify priority areas of action and to evaluate pedestrian movements and walkability under new urban configurations.

1. Introduction

Non-motorized transport has recently received considerable attention from academics, urban planners, and civil communities. The reasons are multiple and involve health, economic, social and environmental issues (Arranz-López et al., 2017). This paper focuses on walking, as the fundamental, cheapest and most sustainable means of transportation. Walking is included in intermodal travel chains, since every trip begins and ends with walking, and is also an important form of access in itself (ITF, 2012; Litman, 2003). From a health standpoint, walking is a means of enhancing people's physical activity regardless of age, education or income (Brownson et al., 2000). Non-motorized transport is an opportunity to correct inactive lifestyles, which have profound impacts on physical and mental health and wellbeing. It also increases the opportunities for social interaction, and leads to engagement with the place and sense of community (Gatrell, 2013; Wang et al., 2016; Wood et al., 2010). From the environmental point of view, increasing the share of walking among transportation modes reduces motor vehicle use and its negative impacts (Joh et al., 2015).

The term “walkability” refers to the spatial characteristics of urban environments, such as urban density and sprawl, land-use mix distribution, connectivity and the spatial configuration of streets, among other aspects (Foltete and Piombini, 2007; García-Palomares, 2010; Peponis et al., 2008; Yu, 2015). All these spatial characteristics affect pedestrian route distances (and in consequence travel time), which is one of the main factors influencing pedestrian mobility (Seneviratne and Morrall, 1985; Noland, 1996; Guo and Loo, 2013). Walkability is also used in the literature to reflect how the built environment facilitates or hinders walking (Victoria Transport Policy Institute, 2017; Wang et al., 2016). Different approaches have been used to evaluate the main built environment characteristics that affect walking conditions: discrete choice models (Broach and Dill, 2015; Guo and Loo, 2013), interviews and focus groups (Ferrer and Ruiz, 2017; Lockett et al., 2005), and street audits (Craig et al., 2002; Cunningham et al., 2005; Day et al., 2006). Some of these studies identify obstacles as street crossings (they are considered barriers where the pedestrian have to

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https://doi.org/10.1016/j.jtrangeo.2018.02.001
Received 22 August 2017; Received in revised form 25 January 2018; Accepted 5 February 2018

stop and wait, with or without traffic lights) and physical obstacles on the pavements, such as bollards, stairs, trees, etc., as important aspects that could influence the travel mode choice (Cain et al., 2014; Ferrer and Ruiz, 2017; Guo and Loo, 2013; Moniruzzaman and Páez, 2016). The combination of impedances and negative factors caused by these micro-elements in the built environment (crossings and physical obstacles) could have an influence on support for walking in the neighbourhood at the macro level (Cain et al., 2014; Cervero and Kockelman, 1997; Saelens and Handy, 2008), and micro level improvements have been shown to have a possible positive effect on the walkability of an area (Boarnet et al., 2005).

Traditionally, one of the approaches followed to improve the quality of the urban environment has been to pedestrianize certain areas that were originally designed for motorized modes. These new pedestrian zones have been implemented in the centre and old town areas of the city. The pedestrianization of the city centre can be found in cities all over the world, including Copenhagen, where the process was initiated in the early 1960s (Gemzoe, 2001), several cities in Germany and the UK (Hass-Klau, 1993), and Seville, which initiated the pedestrianization of its city centre in the last decade (Castillo-Manzano et al., 2014). In recent years city planners and researchers have also incorporated the need to integrate sustainable transport modes and walkability into the urban design of wider parts of the city. The "Réinventons nos places!" ("Let's reinvent our squares") project in Paris (Paris City Council, 2016), the urban regeneration strategy and the implementation of priority residential areas in Madrid (Madrid City Council, 2017) and the superblocks model currently being implemented in Vitoria-Gasteiz and Barcelona (Barcelona City Council, 2016) are examples of the new urban configurations designed to give global solutions to environmental and mobility challenges while increasing the opportunities for improving the availability and quality of the public space. All these new urban design proposals incorporate ideas from the shared spaces approach, where pedestrians have priority and the street is treated as a continuous surface without differentiating between vehicular and pedestrian zones (Hamilton-Baillie, 2008; Karndacharuka et al., 2014). In particular, superblocks are urban cells in which motorized mobility is transferred to streets on the outer perimeter, leaving the inner streets as shared spaces in which access by non-resident vehicles is restricted. In consequence, obstacles (traffic lights, pedestrian crossings and physical obstacles) can be removed from the inner streets giving maximum preference to non-motorized modes inside the superblock (Barcelona City Council, 2016).

Researchers are aware that sustainability in cities is dependent on promoting walking. The scientific literature has recently featured a number of studies that relate street network configurations with pedestrian mobility (Kang, 2016; Kang, 2017; Peiravian et al., 2014; Rychlewski, 2016). Audit tools have been developed to identify street features that influence walking at neighbourhood scale (Cunningham et al., 2005; Day et al., 2006). Pedestrian travel time in the urban network has also been used to evaluate pedestrian mobility (Lei and Church, 2010; Noland, 1996; Ortega et al., 2014), in addition to the spatial analysis of the density of particular events across the city (Mejia-Dorantes et al., 2012; Mejia-Dorantes and Martin-Ramos, 2013; Tri Do et al., 2015). Combined methods such as the calculation of least cost pedestrian routes and linear planar kernel density measures were useful to define urban designs with priority pedestrian corridors (Delso et al., 2017). However, to our knowledge there is lack of procedures to evaluate the spatial distribution of pedestrian obstacles in different areas of the city.

Pedestrian obstacles can be mapped in GIS to evaluate their spatial distribution. However, a simple map of the obstacles would not accurately reflect the intensity and negative synergies of the presence of obstacles in certain areas of the city. Kernel density estimation has been used to represent the intensity of events across space (Smith et al., 2015). The common approach to density estimation in urban environments is to use planar kernel density estimation (PKDE) (Gibin et al., 2007; Kloog et al., 2009; Leslie, 2010). PKDE is a non-parametric method to produce homogeneous density surfaces of linear or point events over a 2-D planar space based on Euclidean distances. However, the distribution of many events in urban environments is constrained by road networks which could be considered 1-D configurations. In these situations the consideration of a uniform 2-D space would be incorrect (Miller, 1999). Thus, efforts have been made in recent decades to develop network kernel density estimation (NKDE) algorithms to be used to analyse point events over road networks. Xie and Yan (2008) developed a NKDE approach for point events to estimate the density of traffic collisions over a road network and investigate different factors influencing the density outputs, and compared their results with PKDE. Okabe et al. (2009) analysed the bias of three NKDE functions and proposed computational implementations for two of them that proved to be unbiased (the class of equal-split continuous and discontinuous kernel functions). Pedestrian obstacles are usually grouped in certain parts of the city such as intersections between major roads and roundabouts, which are generally regulated with more traffic lights, pedestrian crossings, barriers and other elements than other parts of the network. The continuity of the kernel function was therefore considered an important property, and the continuous equal-split kernel function (Okabe et al., 2009) is proposed for this study. This function has higher computational requirements than discontinuous equal-split kernel functions (Okabe et al., 2009), but the computational times are affordable due to the low bandwidths required to evaluate pedestrian mobility (commonly 100–300 m (Porta et al., 2009)). NKDE has been widely used to identify hotspots, especially in the field of road accident analyses (Harirforoush and Bellalite, 2016; Xie and Yan, 2013; Young and Park, 2014); to our knowledge, however, this is the first study to use NKDE to evaluate pedestrian mobility.

In view of the above concerns, we set out to measure the possible negative synergies caused by the presence of a high proportion of pedestrian obstacles —in particular pedestrian crossings— on the overall walkability of an area. The impact of an obstacle on the overall walkability of the city also varies according to the rates of pedestrian movement in the place where it is situated. The aim of this work is to provide a procedure to measure the impact of pedestrian obstacles across the city and to apply this procedure to evaluate different urban configuration scenarios. We will address two research questions. How do different urban configurations affect pedestrian movements across a city? How can we measure the impact of the urban configuration on the walkability across a city? In the developed procedure, GIS network analysis is applied to obtain pedestrian routes for different scenarios from the same set of origins and destinations. The importance of pedestrian obstacles across the city is measured using NKDE. In consequence, rather than evaluating the increase in walking trips after the implementation of a new urban configuration, this procedure allows comparing the difference in the walking experience between different urban configurations. Vitoria-Gasteiz, a medium-sized city in the north of Spain, serves as a case study. It is a compact city which has seen the gradual implementation of the superblocks urban configuration, and a sustained increase in walking in recent years.

This paper is structured as follows: after this introduction, Section 2 below explains the methodological approach of the procedure, which combines kernel density methodologies with GIS network analysis tools. In Section 3, the methodology is tested in a case study, Vitoria-Gasteiz, and the results of implementing the superblocks model in the city are analysed. Finally, Sections 4 and 5 contain the discussion of the results and conclusions respectively.

2. Methods

The proposed procedure uses origins and destinations of pedestrian trips to obtain minimum-cost routes that will serve as input data to measure the impact of pedestrian obstacles. Therefore, the first step involves calculating the optimal routes in terms of pedestrian travel