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Research Paper

Re-conceptualizing accessibility to parks in multi-modal cities: A Variable-width Floating Catchment Area (VFCA) method

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HIGHLIGHTS

- Proposed spatial access model takes into account aspects of urban planning.
- Model supports scenario analysis and evaluates access for different transport modes.
- Access inequality in Mecklenburg County and related social injustice are discussed.
- Sensitivity of model demonstrated by comparison with more commonly used 2SFCA model.
- Choice of spatial access model greatly impacts study outcomes.

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ABSTRACT

An increasing number of studies have sought to identify disparities or inequalities in the distribution of urban parks and green spaces. Results of these analyses have diverged considerably depending on the method used to assess accessibility. In this article, we revisit an increasingly popular technique, the two-step floating catchment area (2SFCA) method, and modify it to better align with the ways in which parks are planned and intended to be used. In this respect, we develop a Variable-width Floating Catchment Area (VFCA) method that models park attractiveness as a function of its size and number of amenities. We further compare accessibility according to four modes of transportation: bicycling, driving, public transit, and walking. A case study on access to public parks in Mecklenburg County, North Carolina, the U.S. is performed. In general, walking access to parks is found to be low throughout the county, access to larger regional parks is greatest for outlying suburban areas, and center city residents have access to a greater number of park amenities. Study results are compared to those obtained when using the original 2SFCA and indicate important differences in spatial accessibility patterns. Consequently, caution must be adopted when choosing a spatial access model and interpreting the resulting spatial patterns of accessibility. The parameters of the VFCA can easily be set to different values, making it a tool for scenario analyses. This study further improves our understanding regarding accessibility to public parks, which can help develop effective planning strategies.

1. Introduction

Access to public spaces such as parks, green spaces or green infrastructure, has been associated with improved levels of physical activity (Bedimo-Rung, Mowen, & Cohen, 2005; Chiesura, 2004; Cohen et al., 2006, 2007; Tzoulas et al., 2007). This finding holds the potential to alleviate persistent and global decreases in physical activity – a problem that is particularly acute in urban areas across the United States (Parks, Housemann, & Brownson, 2003) and is one of the primary causes of worldwide increases in noncommunicable diseases (NCDs) such as chronic and heart disease. In addition to increased physical activity, Bedimo-Rung et al. (2005) assert that living in proximity to these spaces contributes to lower levels of stress and fewer mental health problems. Given these benefits, it is in the best interest of urban leaders to strive toward providing their residents with adequate access to parks and open space, in a manner that is equitable across its population.

A growing body of literature has emerged to evaluate whether or not access to public open spaces is equitable across

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socioeconomic (Crawford et al., 2008; Timperio, Ball, Salmon, Roberts, & Crawford, 2007), racial (Boone, Buckley, Grove, & Sister, 2009; Dai, 2011; Miyake, Maroko, Grady, Maantay, & Arno, 2010; Moore, Diez Roux, Evenson, McGinn, & Brines, 2008; Sister, Wolch, & Wilson, 2010), or religious groups (Comber, Brunsdon, & Green, 2008), as well as between rural and urban areas (e.g., Dai, 2011; Parks et al., 2003; Wolch, Byrne, & Newell, 2014). The resulting empirical evidence is mixed, but often tends to be reflective of the socioeconomic or racial sorting of the city. Central city locations naturally contain less room for large open spaces than surrounding suburban areas and therefore, those living in the urban core presumably reside farther from larger parks than their suburban counterparts; a finding reached by a number of papers (e.g. Boone et al., 2009).

A variety of spatial accessibility methods have been used in the literature to measure access to services; they are reviewed in Section 2 of this article. Although many authors have contributed to the conceptual improvement of access models, there is still no consensus as to which method is most appropriate to use for strategic and/or planning purposes. Nonetheless, the selection of a method has a direct impact on the results (Talen & Anselin, 1998).

One increasingly popular technique employed in the accessibility literature is the two-step floating catchment area (2SFCA) method (Luo & Wang, 2003). This method evaluates access to a commodity (e.g. hospitals, parks), considering both the supply and demand for that service. Its strength lies in its ability to pinpoint underserved areas and/or supply points that are close to reaching their carrying capacity. Its major limitation however, rests on its assumption that the demand for a particular service is based on distance alone, without taking into account additional characteristics of that facility (e.g. level of service, amenities). In the case of public parks, local park and recreation departments plan and design their parks and facilities with a certain target in mind (e.g. neighborhood vs. regional park); also referred to as “normative standards” (Páez, Scott, & Morency, 2012). The public’s utilization of parks is therefore shaped by their access to both local and regional parks. Additionally, this accessibility landscape may vary considerably depending on the mode of transport available to individuals – those with a car will have a larger number of available facilities than those traveling by foot, for example.

With this conceptualization in mind, we propose a modification to the 2SFCA method, namely the Variable-width Floating Catchment Area (VFCA) method, which is explained in detail in Section 3. In this proposed method, park attraction is modeled as a function of distance to the demand and as a function of a set of park characteristics, namely its size and the number of available amenities. We further compare the resulting park accessibility landscapes for four different modes of transportation: bicycling, driving, public transit, and walking. This study contributes to the literature on spatial accessibility modeling, and more specifically to the conceptualization of access to public parks, which to date has either narrowly focused on size, or has treated all parks equally. The methodology is illustrated on a case study of park access in Mecklenburg County, North Carolina, U.S. (see Fig. 2). Results of the new model are compared with the traditional 2SFCA method (Section 4), followed by a discussion on the strengths, limitations, and implications of the model and results of the case study in Section 5. The paper concludes in Section 6.

2. Literature review

Access to facilities and public environments that support physical activity (e.g.: sidewalks, bike lanes, trails and parks) has shown to have a positive relationship with levels of physical activity (U.S. Department of Health and Human Services, 2010; Lopez & Hynes, 2006). Given a key link between physical inactivity and the risk for noncommunicable diseases (NCDs), these public facilities and environments can play a crucial role in the development of effective health prevention strategies. Assessing the equality of access to public services – including public parks, is a building block toward planning for these prevention strategies. Therefore, it is important to evaluate the effectiveness of current measures of spatial access.

2.1. Healthy Parks, Healthy People: the equity of park access

In 2010, NCDs accounted for 2 out of every 3 (34.5 million) deaths globally, representing a 30% increase since 1990, making it today’s leading cause of death worldwide (Lozano et al., 2013). This increase is often attributed to a global decrease in physical activity, which prompted the World Health General Assembly – in 2004, to develop a global strategy that promotes a healthy diet and regular physical activity (Bauman & Craig, 2005; see resolution WHA 57.17). Unfortunately, trends show that the daily level of activity of the U.S. population is still decreasing (Brownson, Boehmer, & Luke, 2005; Hallal et al., 2012). Less than half the population of adults meets the national guidelines for physical activity (Haskell et al., 2007). So far, prevention strategies to reduce NCDs have focused on “individual-based” approaches that strive to change people’s behavior (Koohsari, Kaczynski, Giles-Corti, & Karakiewicz, 2013). In these approaches, the trusted relationship between a health professional and its clients or patients is used to raise awareness regarding dietary and physical activity recommendations, eventually leading to the establishment of healthier habits. Other strategies – used more commonly in planning, employ the public environment as a behavior changing mechanism. These “place-based” approaches to health prevention (Koohsari et al., 2013) have an advantage in that they can – in theory, reach more people without the direct intervention of health professionals, potentially contributing to a more cost effective strategy.

Coordinated by the National Park Services since 2011, the U.S. Healthy Parks Healthy People program aspires to reframe the role of public open space to become a health prevention strategy. This program was established in response to the first congress organized by the Healthy Parks Healthy People international movement, held in Melbourne, Australia in 2010. Research on such “place-based” approaches generally use spatial planning tools (e.g. Geographical Information Systems, GIS) to evaluate the quality and equity of an environmental service or intervention (e.g. Koohsari et al., 2013; Talen & Anselin, 1998; Veitch, Salmon, Ball, Crawford, & Timperio, 2013).

From a social justice perspective, every citizen should be able to enjoy the benefits of a public good or service equally (Talen & Anselin, 1998). A number of researchers have evaluated this in the context of public parks, particularly in urban settings (Veitch et al., 2013). For example, Dai (2011) quantified spatial access to urban green spaces and evaluated disparities among racial/ethnic and socio-economic groups in Atlanta (GA), suggesting that access was worse in neighborhoods with a higher concentration of African Americans and in socioeconomically disadvantaged areas. Other findings from studies evaluating the spatial access to open, green and recreational space tend to be mixed. These differences can often be attributed to the method that was used to estimate “spatial access”. To this date, no consensus has been reached as to which measure of spatial access is most appropriate to use. In addition, several studies fail to indicate their inclusion criteria or definition for “parks”, “open spaces” and/or “green spaces”. As a consequence, it is often difficult to validate or compare findings from different studies.

2.2. Modeling spatial accessibility

Spatial access to a good or service (i.e. commodity) is defined as a function of the availability (supply) of this commodity and the associated impedance (e.g. distance, price) faced by the demand to access or acquire this commodity. Several spatial accessibility metrics are derived from so-called "container" approaches. The original container method identifies whether a commodity (e.g. a park) is located within some geographic unit (e.g. census block, block group, or tract). This binary way of evaluating accessibility is very limited given that administrative boundaries are artificial barriers to access; in reality, individuals are often able to access parks in adjoining units. Moreover, administrative boundaries often divide a study area into subunits of varying sizes, which can significantly impact results. For example, if an area is split into two sub-units – one large and one small unit, there is a higher probability that the larger unit contains more supply points. Therefore – solely based on its size, there is a higher likelihood that the larger unit will exhibit a higher access score. Despite these shortcomings, this approach is still used in neighborhood-scale environmental justice and social equity-based analyses (e.g. Vaughan et al., 2013), primarily because of its simplicity and ease of implementation.

Buffer analysis (Nicholls, 2001), kernel density estimation (Moore et al., 2008), and network constrained service area methods (Miyake et al., 2010) have all been proposed as alternatives to container methods (Cromley & McLafferty, 2012). These latter methods fall under the classification of "coverage" models (Talen, 2003) as they determine the population that falls within a specified distance from a supply point. The population that resides within this pre-defined distance is considered "covered" by that supply point; results of these models are often driven by the definition of this distance. Because it is often difficult to set an appropriate distance at which a service is no longer considered "accessible", results of such coverage models can be considered to be somewhat arbitrary.

The distance-threshold limitation of coverage models motivated the use of Thiessen polygons (Boone et al., 2009; Sister et al., 2010), which generates polygons (often asymmetric in shape) delimiting the area of influence or so-called "service area" of each commodity. None of the polygons overlap each other, so that each population center (demand point) always falls within exactly one service area. Summing the number of demand points (and associated population) that fall within each Thiessen polygon gives an estimate of the total demand for each commodity. This technique makes it possible to estimate potential crowding at certain locations and can pinpoint underserved areas. However, it assumes that all residents of a demand point will use the facility that is closest to their residence, an assumption that may not be realistic in the case of public parks, given that individuals may choose to interact with larger regional parks located further away (Boone et al., 2009; Sister et al., 2010).

Gravity-based models overcome this closest park assumption by incorporating notions of attraction and friction to estimate the propensity to travel to a particular location. These models offer some conceptual improvement upon the simpler, aforementioned metrics given that the literature has found empirical support for the idea that park amenities play a role in attracting visitors willing to travel a greater distance beyond their neighborhood park (McCormack, Rock, Toohey, & Hignell, 2010). On the other hand, gravity-based models are continuous measures that incorporate the full range of destination options but tend to produce an overly smoothed accessibility landscape (Luo & Wang, 2003; McGrail & Humphreys, 2009).

Floating catchment area (FCA) methods represent another category of accessibility measures, initially conceived in a healthcare context. In FCA approaches, a catchment area is drawn around a supply point based on the maximum distance individuals are expected to travel; any demand point within that catchment area is deemed to have access to that supply point, while all others do not. It is a dichotomous technique in contrast to the continuous, gravity measures (Luo & Wang, 2003; McGrail & Humphreys, 2009). Combined measures such as the two-step floating catchment area (2SFCA) method with a distance decay function have been proposed as a superior alternative for identifying potential disparities in accessibility (Dai, 2011). This latter measure specifies a given catchment area around a facility and estimates both supply and demand (i.e. attraction and crowding) within that region. Its major limitation is that each catchment area is set at a fixed distance, regardless of the type of facility, which does not adhere to the way that some commodities are planned.

The limitations of the original 2SFCA method have prompted a number of improvements including the incorporation of a distance decay parameter within each catchment – toward either the population or supply side (Dai, 2011; Luo & Qi, 2009) and the use of variable-width catchments (Luo & Whippo, 2012). Luo and Whippo (2012) suggested the use of variable catchment sizes in a healthcare-specific context where catchment sizes are expanded incrementally until a minimum, specified provider-to-population ratio is reached. While this may make conceptual sense in assessing healthcare access, determining an optimal population-to-park ratio is much less intuitive.

Two recent methodologies have been proposed as theoretically superior toward evaluating park access. These include the population-weighted distance (PWD) method developed by Zhang, Lu, & Holt (2011) and an "accessibility in the context of spatial disparity" measure (ASD) put forth by Lee and Hong (2013). Both of these measures are based on gravity-based spatial interaction considerations whereby larger, more attractive parks are expected to attract a larger share of the population. Zhang et al.'s (2011) national study and Vaughan et al.'s (2013) local study (in Kansas City, MS) on park accessibility both incorporated notions of choice sets; modeling supply and demand as a probability function (based on Huff's (1964) market area segmentation model). Lee and Hong's (2013) ASD approach involves discretizing the urban area into a continuous grid and computing a gravity-model inspired service-to-population ratio. The distance decay parameter helps to distinguish the intended usage and expected demand for various types of parks: neighborhood parks have a service coverage area of 250 m, medium sized parks have a service area of 1000 m, and parks of a larger size do not have a coverage limit.

All these methods require a certain measure of distance, which is another element that can significantly impact analyses. Although network-constrained distances are widely recognized as superior approximations of travel as compared to their Euclidean counterpart (Gutiérrez & García-Palomares, 2008), the ease of computing Euclidean distances has contributed to their persistent use. The inclusion of alternative modes of transportation in accessibility studies is a burgeoning field of study. Assessment of accessibility by public transit has been implemented by Delmelle and Casas (2012) and Mavoa, Witten, McCreanor, and O'Sullivan (2012), while Reyes, Páez, and Morency (2014) examined pedestrian access based on revealed walking trip lengths. Mao and Nekorchuk (2013) proposed a multi-modal 2SFCA method where the specified catchment area is modified according to a designated transport mode.

2.3. Modeling park access for policy and planning purposes

With a specific set of functions in mind for each park, local park and recreation departments plan and anticipate a certain level of demand. Neighborhood parks are intended to serve residents living in their immediate vicinity, are typically of smaller size and often provide limited parking accommodations. Regional parks on the other hand, are larger, offer more or distinct amenities and are planned to attract residents from further away. In planning, differences in service levels are also referred to as "normative standards". Páez et al. (2012) define "normative accessibility" as a level of accessibility considered to be acceptable from the vantage point of a planner or policy maker. The authors distinguish this from the notion of "positive accessibility", which they define as the level of impedance perceived acceptable and reasonable by individuals themselves (Páez et al., 2012, p. 142). For modeling purposes, a critical differentiation must be made with regards to the type of accessibility being measured. If the specified distance is intended to reflect actual travel behavior, then a positive approach must be apprehended, which often requires surveying the public. On the other hand, in a normative approach, a certain level of access is set and reflects the distance at which planners and policy-makers have agreed all individuals *should* have an acceptable access to a particular facility (Páez et al., 2012). These notions – normative and positive accessibility, are similar to the ideas of potential and revealed accessibility that have been formulated by Khan and Bhardwaj (1994) in the context of access to healthcare. They refer to "potential access" as the prescribed level of access provided by the supply and refer to "revealed access" as the level of access actually experience by the demand. In this study, we evaluate the potential (or normative) accessibility to public parks. To this end, we propose a modification to the 2SFCA method that incorporates catchment areas of varying sizes to better reflect how parks are planned and their intended use. In addition our proposed model allows the estimation of spatial access for different modes of transportation (car, public transit, bike and walking). We refer to this modified version as the Variable-width Floating Catchment Area (VFCA) method.

3. The Variable-width Floating Catchment Area (VFCA) method

The VFCA method can be applied to commodities other than public parks. Thus, we introduce the VFCA method in a more generic form within this section but will explain each parameter in the context of access to parks. We introduce the following notation:

I = set of geographic units (e.g. census block groups)
J = set of public facilities (e.g. public parks)
K = set of amenities at each public facility (e.g. baseball field, tennis court)
i = index of the geographic unit
j = index of the public facility
k = index of the amenity available at the public facility
m = index of transport mode (e.g. car, public transit, walking, cycling)

The travel time t_{ijm} is estimated from each geographic unit i to each public facility j, using a road network and by means of a particular transport mode m. For each geographic unit i, the total population g_i, is provided.

3.1. The catchment area of a park as a function of its attractiveness

Following the 2SFCA method (Luo & Wang, 2003), spatial accessibility is estimated by summing the attraction coefficient of a set of parks available within a certain travel budget. This travel budget can be defined as a cut-off value beyond which people are unlikely to travel to a particular destination. In this paper, we suggest that the attractiveness of a park be a function of its size and number of amenities. The attraction coefficient, S_j, of the supply at node j is estimated using a weighted sum approach (Eq. (1)), where the weights γ_A and γ_K reflect the importance of park acreage (S_j^A), and on-site amenities (S_j^K), respectively and where $\gamma_A + \gamma_K$ equals 1.

$$S_j = \left[\gamma_A \frac{S_j^A}{\max_{j\in J} S_j^A}\right] + \left[\gamma_K \frac{S_j^K}{\max_{j\in J} S_j^K}\right] \quad \forall j \in J \qquad (1)$$

Note that S_j^A and S_j^K can be changed to any other set of characteristics when spatial access to commodity other than parks is being assessed. The normalized attraction coefficient, $\bar{S}_j$, redistributes all the attraction values between 0 and 1 (Eq. (2)):

$$\bar{S}_j = \frac{S_j - \min_{j\in J} S_j}{\max_{j\in J} S_j - -\min_{j\in J} S_j} \quad \forall j \in J \qquad (2)$$

Based on this attraction value, each park is assigned a catchment area of a certain size depending on the travel mode. The higher the attraction value of a park (e.g. large park with multiple amenities), the larger the extent of its catchment. The catchment area of each park, T_{jm}^{crit}, is defined using the normalized attraction coefficient, $\bar{S}_j$, and is dependent on the travel mode m that is used.

This definition of catchments in the VFCA method is illustrated in Fig. 1. Three parks (A, B and C) of varying sizes and number of amenities ($|K_A| = 2$, $|K_B| = 3$, $|K_C| = 1$) are distributed across a hypothetical study region (Fig. 1, left). After computing the attraction coefficient of each park (see Eqs. (1) and (2)), the extents of their catchment are calculated (Fig. 1, right). In this study, we will compare spatial accessibility of each demand point between four modes of transport: (1) driving, (2) public transit, (3) bicycling and (4) walking. The travel mode coefficient, ζ_m (where $\zeta_{car} = 1$; $\zeta_{transit} = 4/3$; $\zeta_{cycling} = 6/5$ and $\zeta_{walking} = 8/7$), translates each normalized attraction coefficient into a catchment area expressed in minutes (Eq. (3)).

$$T_{jm}^{crit} = \begin{cases} \zeta_m * 5\,\text{min}, & \bar{S}_j < 0.1 \\ \zeta_m * 15\,\text{min}, & 0.1 \le \bar{S}_j < 0.3 \\ \zeta_m * 30\,\text{min}, & 0.3 \le \bar{S}_j < 0.7 \\ \zeta_m * 45\,\text{min}, & 0.7 \le \bar{S}_j < 0.9 \\ \zeta_m * \max(t_{ijm}), & 0.9 \le \bar{S}_j \end{cases} \qquad (3)$$

In this paper, we consulted with staff from the Mecklenburg County Department of Park and Recreation in order to determine appropriate travel mode coefficients, ζ_m and maximum travel budgets (in minutes) per transportation mode. In this respect, we are adhering to a normative accessibility assessment (Páez et al., 2012).

3.2. Crowding at a park as a function of the park-to-population ratio and distance decay

Crowding at a park can discourage one's willingness to travel to a park, and as a consequence, it can reduce its attractiveness. This latter consideration is in the same spirit as Lee and Hong's (2013) ASD metric. The park's acreage is divided by the total population within its catchment and gives a sense of potential crowding (park-to-population ratio). A low park-to-population ratio (e.g. small park surrounded by large population) indicates there is a higher likelihood for crowding. Based on the catchment area of each public facility, T_{jm}^{crit}, the set of geographic units that fall within this catchment is selected ($N_{im} = \{j : t_{ijm} < T_{im}^{crit}\}$). The total demand, V_j for each public facility j is computed by summing up the respective populations, g_i in this set (N_{im}) and using a distance decay

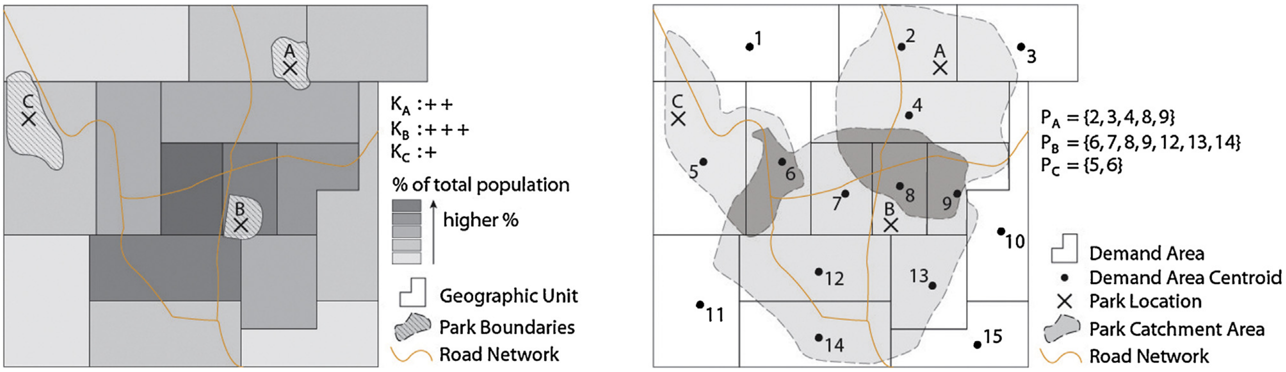

Fig. 1. Illustration of the concept of the variable-width floating catchment area (VFCA) method.

coefficient, β, to give a higher importance to populations living in geographic units located closer to public facility j (Eq. (4)).

$$V_j = \sum\nolimits_{i \in N_{jm}} \frac{g_i}{t_{ijm}^{\beta}} \quad \forall j \in J \tag{4}$$

The distance decay coefficient, β, governs the shape of the decay function; when β is high (>1), the demand for parks will decrease faster with increasing distance. For instance, a higher distance decay coefficient might be used for the elderly, as they would be expected to travel shorter distances to visit parks (see Schwanen & Páez, 2010).

The park-to-population ratio, R_j (crowding index) of park j is then computed by dividing the acreage by the total population within the catchment area, V_j (Eq. (5)).

$$R_j = \frac{S_j}{\sum_j V_j} \quad \forall j \in J \tag{5}$$

When studying commodities other than public parks, this ratio can be re-defined using alternative parameters.

3.3. Spatial accessibility to parks

When estimating the spatial accessibility, the park-to-population ratios, R_j, are summed and weighted by the distance that separates the geographic unit from the park. A distance decay function gives a higher weight to the park-to-population ratio of a park when they are located closer to the geographic unit's centroid. The spatial accessibility at geographic unit i is then defined as:

$$A_i = \sum\nolimits_{j \in N_{im}} \frac{R_j}{t_{ijm}^{\beta}} \quad \forall i \in \mathrm{I} \tag{6}$$

The spatial accessibility score of each block group is estimated four times; once for each mode of transport. The higher the accessibility score, the greater the accessibility of that geographic unit to parks, compared to all other geographic units in the study area.

The VFCA method is not intended to replace other methods such as the two- or three-step floating catchment area methods, however our approach provides an alternative model to capture facility attraction. Moreover, since all parameters are designed to be flexible, this approach has the capability to support scenario analysis, which can be extremely useful for planners (Xiang & Clarke, 2003).

4. Case study: access to public parks in Mecklenburg County

We illustrate the VFCA method to assess spatial access to public parks in Mecklenburg County, North Carolina (see Fig. 2). Mecklenburg County (encompassing the City of Charlotte) has experienced rapid population growth and geographic expansion in recent years. In the 2000s, its Metropolitain Statistical Area had the fourth largest population growth in the nation. While suburbanization has pushed greenfield developments toward the outer extents of the county and surrounding areas, Charlotte's center city has simultaneously undergone significant gentrification and vertical residential development (Delmelle, Thill, Furuseth, & Ludden, 2012). Given these rapid transformations, the case of Mecklenburg County presents a particulary interesting case study to assess park service provision and evaluate equity to help determine where new services might be necessary.

Fig. 2. Locator map for Mecklenburg County (encompassing the City of Charlotte) in North Carolina, U.S.A.

4.1. Data

The Mecklenburg County Department of Park and Recreation oversees a total of 210 parks and recreation facilities located on more than 17,600 acres of parkland. From the total number of parks and recreation facilities, 161 public parks were included in our study. It is important to note that our study does not include private parks, yards or any green infrastrucutre or open space that was not labeled as a public park by the Mecklenburg County Department of Park and Recreation.

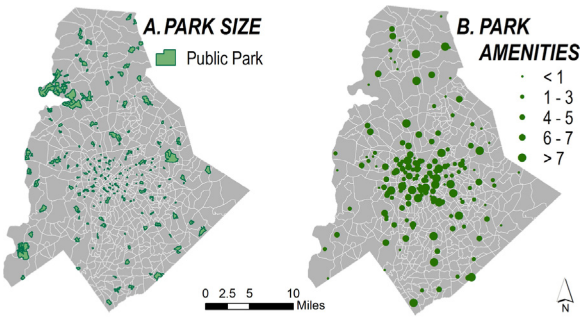

Fig. 3. Spatial distribution of public parks in Mecklenburg County. In (A) the size (polygon size reflects the acreage) and in (B) the number of amenities available (the larger the symbol the higher the number of amenities).

Following Nicholls' (2001) approach, the entrance of each public park was geocoded. Fig. 3A shows the location and approximate size of each public park while the number of amenities at each public park is shown in Fig. 3B using a proportional symbol; the larger the dot, the higher the number of amenities available at that park.

The available amenities were provided by the Mecklenburg County Department of Park and Recreation and were then visually inspected using satellite imagery. Following consultations with regional planners, the following nine amenities were listed as desirable attractions: baseball/softball fields, tennis courts, basketball courts, children's playground equipment, disc golf, soccer fields, family shelter (picnic area) and water/boat access. The presence of an amenity was recorded in binary terms (1, if the amenity is available at a park and 0, otherwise).

The spatial accessibility to public parks was assessed at the block group level using 2010 census data. The centroid of each census block group was used as a point of origin to measure the distance to each public park. Using the Google Maps^{TM} Library for the Python programming language, travel distance was computed between each census block group and each public park for each mode of transport considered (driving, public transit, bicycling and walking). The best-path algorithm used by Google Maps^{TM} attempts to find the optimal (fastest) route between an origin and a destination, while also guaranteeing a certain level of safety when traveling by bicycle or by foot. This translates in a tendency to route cyclists along greenways or existing bicycle lanes on paved roads, while the availability of sidewalks is an important element when walking. The VFCA method is also written in the Python programming language while the results are visualized using a GIS platform.

4.2. *Scenarios*

One of the advantages of the VFCA method is its ability to create different scenarios by letting the parameter values vary. Moreover, the current set of parks and associated amenities can be changed (e.g. adding a new park location), providing the capability to analyze the impact of additions and/or changes. We illustrate the VFCA method under different scenarios to gain insight on the sensitivity and the spatial structure of the model. First, park size and corresponding amenities determine the catchment area of each park. Different weighting scenarios can be implemented to assess the sensitivity – and robustness – of spatial accessibility scores. For example, giving more weight to the size of the park than to the number of amenities might result in different accessibility scores. Second, the travel mode coefficients, ζ_m, can be adapted as well. A Department of Park and Recreation usually has particular standards they need to reach (normative standards). As an example, a county might strive to give everyone access to a neighborhood park within a 10-min walk and to a regional park within a 20-min drive. These objectives can be implemented using the VFCA approach. Results for three different scenarios will be presented. For each scenario, the same distance decay coefficient ($\beta = 1.2$) was used.

4.2.1. *Scenario I: two-step floating catchment area (2SFCA)*

In the first scenario, we evaluate accessibility using the original 2SFCA method by Luo and Wang (2003). The catchment of each park is fixed and set using a 15-min catchment area. Thus, all catchments are uniform regardless of each park's size and number of amenities.

4.2.2. *Scenario II: VFCA, attraction based on park size only ($\gamma_A = 1; \gamma_K = 0$)*

In the second scenario, park size is the only factor used to compute the attraction of a park and its catchment area. Thus, compared to Scenario I (2SFCA), we now explicitly incorporate the concept of variable-width catchments. Consequently, comparing scenarios I and II will show the effect of using variable widths on accessibility results.

4.2.3. *Scenario III: VFCA, equal weighting ($\gamma_A = \gamma_K$)*

In the third scenario we look at accessibility outcomes when park size and number of on-site amenities are equally weighted. Comparing scenarios II and III will illustrate the effect on accessibility results when using an additional variable (namely, park amenities) to estimate park attraction.

5. Results

The results of each scenario are mapped in Figs. 4 and 6; these maps represent relative accessibility scores according to each mode of transportation (Páez, Mercado, Farber, Morency, & Roorda (2010) introduce relative accessibility maps to compare positive accessibility values based on observed travel behaviors). Each map is illustrated using the same classification and color scheme (quintile classification and sequential colors). As the resulting accessibility value is a ranked score between 0 and 1, this classification scheme makes it possible to compare patterns for different modes of transport. The dark, red color shades reflect block groups experiencing higher accessibility to public parks using a particular mode of transport. The light, gray shades reflect block groups with low levels of spatial accessibility, compared to all other block groups in the study area.

Fig. 4A shows the results of scenario I (2SFCA) for each mode of transport (driving, transit, bicycling and walking). For this method, higher accessibility scores are found chiefly in the western and northern portions of the county. When traveling by car, the highest accessibility scores are found in block groups located in the western part of the county, but when traveling by transit, bicycle or foot, a more spatially dispersed pattern is observed. These results demonstrate that block groups located between multiple public parks possess higher accessibility scores (see Fig. 3 for a map of park locations). It is noteworthy that the pattern for each respective mode of transportation largely follows the underlying transport infrastructure.

Fig. 4B shows the results for each mode of transport when implementing scenario II (VFCA, based on park size only). When comparing Fig. 4A and B (scenario's I and II), clear differences are revealed. Accessibility results by car in Fig. 4B demonstrate a more dispersed pattern; block groups that are well connected to several public parks or parks of larger sizes result in higher accessibility scores. We also note that the higher density of high-speed roads in the western portion of the county helps give rise to the accessibility patterns observed in Fig. 4A. Results by public transit (Fig. 4B) show higher scores for block groups connected to larger parks through transit express routes.

The distribution of accessibility scores among block groups in Mecklenburg County are illustrated in Fig. 5 under scenario I

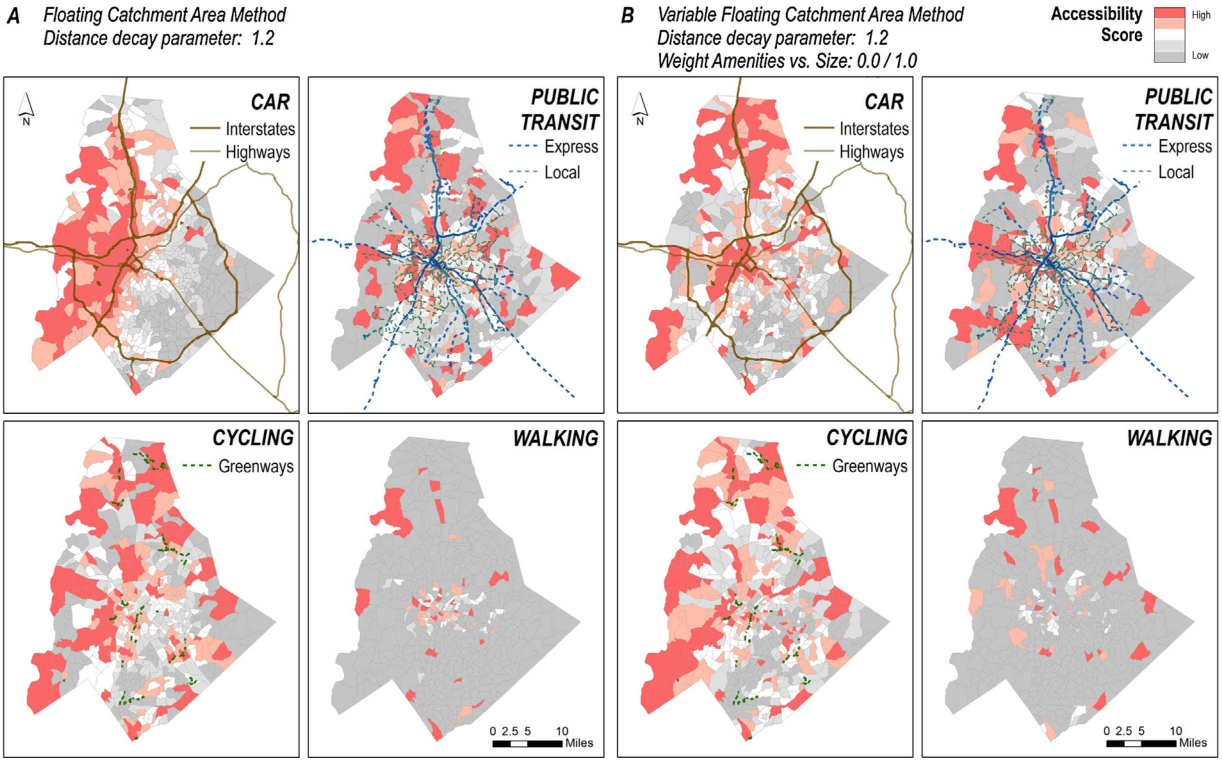

Fig. 4. Spatial accessibility for scenarios I and II, for four different modes of transportation.

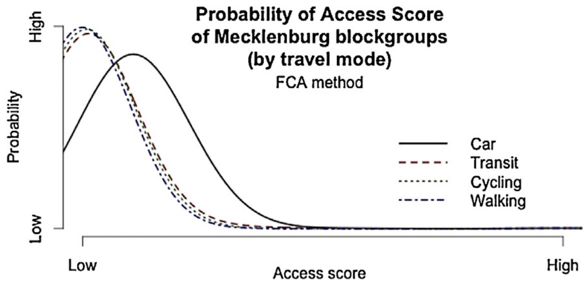

Fig. 5. Distribution of spatial accessibility scores for scenario I for four different modes of transportation.

(2SFCA). This graph suggests that most block groups experience very low accessibility scores, regardless of the transport mode. When traveling by car, the probability that a block group has a higher accessibility score is slightly greater compared to the three remaining modes of transport.

Fig. 6 illustrates the variation in accessibility scores using scenario III (VFCA based on park size and number of amenities). For each mode of transport, there is now a bias toward block groups located nearby the center of the county (Charlotte Uptown area or city center). Since a greater number of amenities is found in public parks located closer to the city center, the pattern reveals higher accessibility values for block groups located near or in-between parks with multiple amenities. When traveling by car, the city center and neighborhoods located along interstates have a much higher level of access. When traveling by public transit, high levels of accessibility are observed in the city center and along bus route corridors (Fig. 6 – public transit). A few block groups located at the periphery of the county consistently experience high levels of accessibility. This is partly due to the close proximity of the block group's centroid either to a park's entrance, a well-connected road or a bus stop. Accessibility levels for pedestrians appear relatively low and patchy in all scenarios.

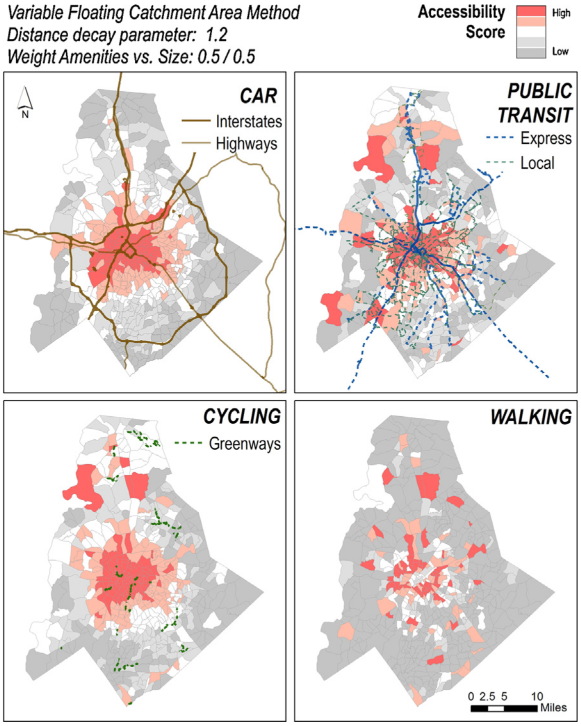

Fig. 6. Spatial accessibility for scenario III, for four different modes of transportation.

The accessibility patterns in Fig. 4 (scenarios I and II) drastically contrast with those in Fig. 6 (scenario III), and this holds true for all modes of transportation. When comparing the results for car travel, we observe a near mirror image between Fig. 4A and Fig. 6. As larger parks tend to be located in the northern and western edge of Mecklenburg County (see Fig. 3), block groups in these areas

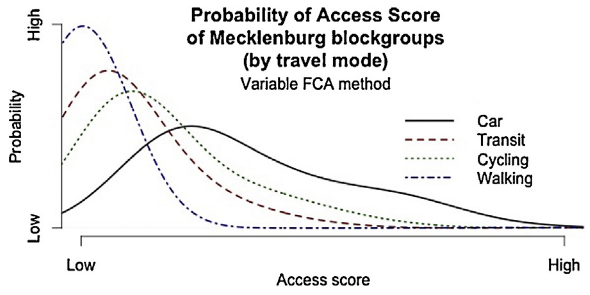

Fig. 7. Distribution of spatial accessibility scores for scenario III for four different modes of transportation.

experience higher levels of accessibility when more weight is given to park size.

The distribution of accessibility scores among block groups in Mecklenburg County, under scenario III is represented in Fig. 7. The VFCA model is deemed to create outcomes that better reflect the barriers faced by residents when accessing public parks. Compared to the graph in Fig. 5, accessibility scores shows a more broad distribution when using the VFCA method, particularly when traveling by car. Given Mecklenburg County's car-dominated development patterns, as well as its expansive supply of parks in the periphery of the city and of larger parks in the suburbs, this result fits with our initial conceptualization of park access. Those with a car enjoy a wide range of park options. Access options are also increased for cycling and transit in this method; notably, access via bicycle is greater than access via transit, given the long travel times by public transportation. Finally, as would be expected, walking results do not differ much between the two methods, as those traveling by foot are restricted to nearby parks.

6. Discussions

In this article, we have argued that the existing models of spatial accessibility employed in the academic literature to evaluate the equitable provision of parks across an urban landscape have been largely disjoint from the ways in which planners intend for parks to be utilized. After consultations with park planners of Mecklenburg County, we have re-conceptualized the two-step floating catchment area (2SFCA) method – a popular accessibility model initially developed for healthcare applications, to more closely approximate the normative standards enacted by planners when deciding on the placement of parks. Our modified model, a Variable-width Floating Catchment Area (VFCA) method, addresses the following two shortcomings inherent in the 2SFCA method: (1) modeling a park's intended use with catchment sizes of variable widths and (2) modeling spatial access for different modes of transportation. In respect to the first point, parks throughout a metropolitan area are not intended to be treated equivalently. Our model addresses this by allowing park catchment sizes to vary based on their characteristics or attractiveness, in this case according to size and number of available amenities. The technique provides flexibility in weighting the importance of size versus number amenities when estimating attractiveness, allowing planners and decision makers to compare accessibility under various scenarios. Second, we recognize that the accessibility landscape across a metropolitan region may vary drastically depending on the mode of transportation under consideration. To address this, we estimated travel time and computed the relative accessibility according to four modes of transport: car, public transit, bicycling, and walking.

A case study illustrated the VFCA method on public parks for Mecklenburg County, NC. Overall, our results revealed important distinctions according to how the parameters of the model were specified. For instance, when park size was the sole factor dictating the attractiveness of a public park (scenario II) and when traveling by car, northern, outlying suburban areas of Mecklenburg County enjoy much higher levels of accessibility. This result was expected, given the significant proportion of larger parks located in the northern periphery of the county. On the other hand, when size and amenities were weighted equally (scenario III), populations living closer to the center of Mecklenburg County (Charlotte Uptown) and along the main road arteries experienced higher accessibility values. All scenarios resulted in very low accessibility scores when walking. This finding is important from a social equity perspective; those without a personal car are at a greater disadvantage than those with cars, in all parts of the city. Such a result may imply the need for an increase in the number of neighborhood parks rather than an emphasis on larger regional parks, which chiefly serve residents with a personal car. Future research could employ a more comprehensive analysis of the demographic profile of neighborhoods and their corresponding accessibility to various modes of transportation.

From the three different scenarios we have illustrated in this paper, we find that different accessibility models (2SFCA vs. VFCA) can generate very contrasting outcomes. Consequently, caution must be adopted (1) when choosing a spatial access model, (2) when interpreting spatial patterns of accessibility and (3) when providing policy advice based on the results of the study. Clearly, there is no "one size fits all" model; the circumstances of the modeling effort should help dictate the parameters being used and ideally, more than one model should be run to ascertain a more complete image of the accessibility landscape of an urban area. The robustness of the results can be supported when several accessibility measures generate similar outcomes.

While our proposed approach makes some conceptualization advancements for landscape planning, it does rely on a number of assumptions, which are likely to affect our results. First, accessibility was estimated using block group centroids as a point of origin for all travel and assumes that subsequent accessibility values are uniform across individuals residing within the boundaries of that block group. In reality of course, some segments of the population face lower levels of mobility, such as seniors (Schwanen & Páez, 2010) or those with disabilities (Casas, 2007). In order to capture this population heterogeneity, the more prescriptive, or normative modeling exercise undertaken in this study could be complemented with an investigation on actual travel behaviors of these population groups. Second, for public transit, we used travel time estimates during a typical workday, and as such did not explore the change in accessibility at different times of day, nor during the weekend. Third, similarly to Nicholls (2001), we used the park's main entrance to model accessibility. This may underestimate accessibility values as larger parks may have more than one entrance. Fourth, we used nine types of recreational amenities, which is not an exhaustive list, nor does it reflect the quantity or quality of each amenity. However, our model can easily be modified to incorporate more amenities or account for other factors such as the presence of trails. Moreover, it is possible to adjust weights to each of the amenities. For example, unique amenities that attract users from a greater distance may be assigned higher weights. As an example, Grayson Park is an average sized neighborhood park (12 acres) in the southern part of Mecklenburg County. However, it is the only park in the county with a skate park, making it unique and an incredibly popular destination for skateboarders all over the county and beyond. It is also important to note that not all groups of the population use or seek amenities in a similar manner. For instance, adolescents may prefer active sports (e.g. soccer, baseball, tennis) while the elderly may favor parks with walking trails and more passive recreation. Similarly, preferences may vary based on cultural differences. These considerations can be best apprehended by more in-depth qualitative interviews with the public, which could inform the development of relative accessibility scores for various user groups – thus better bridging the more technical modeling exercises with actual public experience.

Despite these limitations, the VFCA model has several strengths. First, the concept of attraction (Delmelle, Li & Murray, 2012; Farhan & Murray, 2006; Roy & Thill, 2004) is explicitly modeled by a weighted objective. The catchment area of each public park contracts or expands based on the level of attraction and the preferred mode of transportation. Second, the methodology is deployable to other commodities such as transportation infrastructure, schools, farmers markets and medical centers. It would also be pertinent to implement in cities in other parts of the world where urbanization and transportation issues vary dramatically from the southern U.S. city featured in this study. Finally, since all parameters are designed to be flexible, this approach has the capability to support scenario analysis, a key exercise for sparking critical and strategic thinking in the planning process (Xiang & Clarke, 2003). As scenario planning generates plausible outcomes under various circumstances, alternative decisions can be evaluated in light of feedback from the public on the importance of amenities versus size, or in comparing resulting landscapes from the placement of a new neighborhood versus a regional park, for example.

7. Conclusions

The accessibility model introduced in this article, along with the accompanying case study is beneficial for planners and policy makers looking to improve access to parks and recreational facilities in their area. This work has underscored the importance of planning for equity from a holistic perspective; transportation infrastructure, facility locations and associated level of service are all critically important in shaping the accessibility landscape of an urban area. Increasing the total number or acreage of public parks may not always be the best outcome for some neighborhoods. The improvement of public transport connections, for example, may be a more cost effective and logical way to link low income residents to green space, rather than expanding existing parks or constructing new ones. However, this would require effective communication among different administrations. Further, public parks may offer several recreational amenities, but those may be in disrepair or located in high crime areas, reducing their attractiveness. Previous studies have found that there is a lost potential at parks that do not meet the needs of certain population groups and/or where there is a presence of crime, vagrancy, and vandalism (Loukaitou-Sideris, 1995). Collecting qualitative data is crucial and will help improve our understanding of park access while enhancing the specification of access models. Ultimately, access models that are sound have the potential to become an effective planning and policy tool to develop and communicate place-based prevention strategies. As discussed in this article, the assessment and improvement of access to public parks holds great potential in the worldwide battle against noncommunicable diseases.

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