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Measuring spatial accessibility to healthcare for populations with multiple transportation modes

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ABSTRACT

Few measures of healthcare accessibility have considered multiple transportation modes when people seek healthcare. Based on the framework of the 2 Step Floating Catchment Area Method (2SFCAM), we proposed an innovative method to incorporate transportation modes into the accessibility estimation. Taking Florida, USA, as a study area, we illustrated the implementation of the multi-mode 2SFCAM, and compared the accessibility estimates with those from the traditional single-mode 2SFCAM. The results suggest that the multi-modal method, by accounting for heterogeneity in populations, provides more realistic accessibility estimations, and thus offers a better guidance for policy makers to mitigate health inequity issues.

1. Introduction

Inequitable access to healthcare has long been recognized as a problem in the United States. For example, Rosenblatt and Lishner (1991) had estimated a tenfold difference in the physician supply between urban and rural populations in the US. Meade and Emch (2010) had revealed a shortage of general practitioners in Midwestern and southern counties, but a surplus in northern and eastern counties. Lovett et al. (2002) reported extremely low accessibility to general practitioners in remote rural areas due to a lack of public transportation services. Many of these health inequity issues can be attributed to uneven distributions of populations, health facilities, and transportation networks between them, all of which pose a critical challenge to regional health planning and interventions (Rosenblatt and Lishner, 1991; Todd et al., 1991; Wang, 2012). For those health planners, measuring healthcare accessibility of populations are often the essential first step toward any meaningful and effective government intervention programs (Guagliardo, 2004; Luo, 2004).

Spatial accessibility to healthcare refers to the ease with which residents of a given area can reach medical services and facilities (Hewko et al., 2002). Different from its aspatial counterpart, the spatial accessibility emphasizes the role of geographic distance in the interactions between health services and population demands (Joseph and Bantock, 1982; Luo and Wang, 2003). In recent years, measurements of spatial accessibility to healthcare have received increasing attention, due to their capability of describing geographic variations within large regions, for example, within counties or states (Guagliardo, 2004; Wang, 2012). Since the spatial accessibility is primarily calculated by geographic information systems (GIS), it has also been referred to as the GIS-based accessibility (Langford and Higgs, 2006; Luo, 2004). Simple measures of spatial accessibility could be travel distance or travel time of a population to the nearest health service (Brabyn and Skelly, 2002; Dutt et al., 1986). More sophisticated methods include: the gravity model (Joseph and Bantock, 1982), the Two Step Floating Catchment Area Method (2SFCAM) (Luo and Wang, 2003), and the kernel density method (Guagliardo et al., 2004), as well as their variants (Luo and Qi, 2009; McLafferty and Grady, 2004; Wang and Roisman, 2010). In general, these methods attempt to formulate distance-dependent interactions between health services and population demands, while representing competition among populations for limited resources. A service-to-population ratio is finally calculated for each population of interest to gauge its healthcare accessibility (Yang et al., 2006). These accessibility measures, then, help identify under-served areas and suggest optimal allocation of health resources (Ayeni et al., 1987; Oppong and Hodgson, 1994; Rosero-Bixby, 2004).

Of these traditional methods, an intrinsic assumption is that all people are traveling to health facilities by a single (or uniform) transportation mode, in most cases, traveling by car. This uniform assumption is unrealistic in many populations, such as low-income populations which lack means for car ownership, or metropolitan populations which favor public transportation due

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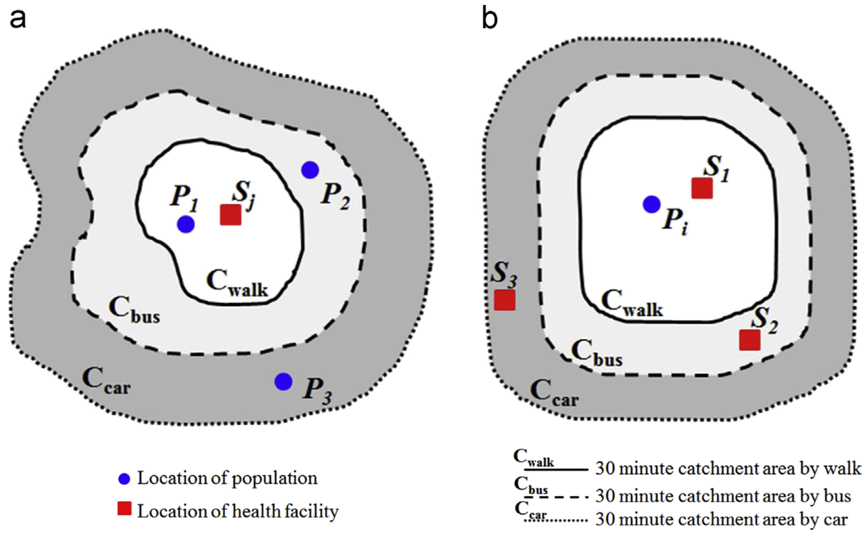

Fig. 1. A sketch map of multi-mode 2SFCAM for healthcare accessibility. (a) Step 1: create multiple catchment areas by mode around a facility and estimate service-to-population ratio for the facility. (b) Step 2: draw multiple catchment areas by mode around a population, and calculate the overall accessibility of the population.

to traffic and parking issues. Neglecting various transportation modes of the populations, these methods would inevitably introduce errors into the accessibility estimation. To date, little attention has been paid to incorporating multiple transportation modes into accessibility measures. Without such an improved measure, health planners may unintentionally misidentify underserved areas, and design less-effective mitigation programs.

To fill this knowledge deficit, we propose a multi-mode accessibility measure based on the framework of 2SFCAM. We applied our multi-mode measure to estimate the spatial accessibility of residents to hospitals in the state of Florida, United States, and compared the results to those from a traditional single-mode method. The remaining of this article is organized as follows: the next section reviews the traditional 2SFCAM and describes the principles of multi-mode accessibility measure. The third section illustrates the data preparation and implementation of multi-mode method. The fourth section presents the results and discussion. The last section summarizes findings and concludes the article.

2. Multi-mode measure for spatial accessibility to healthcare

2.1. Review of traditional 2SFCAM

The traditional 2SFCAM is based on a threshold effect of travel time and implemented in two steps (Luo and Wang, 2003). First, for each health facility j, search for all populations that fall within a threshold travel time (d_0) from j (that is, catchment area j), and compute a service-to-population ratio V_j within the catchment area .

$$V_j = \frac{S_j}{\sum_{k \in d_{kj} \le d_0} P_k} \tag{1}$$

where d_{kj} is the travel time between k and j, P_k is the population at location k that falls within the catchment area j (that is, $d_{kj} \le d_0$), and S_j is the capacity of service at health facility j.

Secondly, for each population at location i, search for all health facilities (j) that fall within the threshold travel time (d_0) from i (that is, catchment area i), and sum all service-to-population ratios, V_js, included in the catchment area (Eq. (2)). The outcome A_i indicates the healthcare accessibility of population at location i.

$$A_i = \sum_{j \in d_{ij} \le d_0} V_j \tag{2}$$

The 2SFCA method has been widely used in recent studies that evaluate healthcare accessibility to physicians, cancer care facilities, pediatric providers, etc. (Albert and Butar, 2005; Wang et al., 2008; Wang and Roisman, 2011). It has also received criticisms in the literature due to its equal access assumption, i.e., all populations within the same catchment area have equal access to healthcare (Guagliardo, 2004; Wang, 2012). This assumption is not always true, particularly when people take a variety of transportation modes to seek healthcare. An improved measure is called for to address this shortcoming.

2.2. Design of multi-mode 2SFCAM

Following the framework of 2SFCAM, we propose a multiple transportation mode method called the multi-mode 2SFCAM. To incorporate n ($n \ge 1$) transportation modes $\{M_1, M_2, M_3, \ldots, M_n\}$, each population P_k at location k is divided into n subpopulations by mode, denoted as $P_k = \{P_{k,M1}, P_{k,M2}, \ldots, P_{k,Mn}\}$. This information on transportation modes could be derived from regional travel surveys or census data, such as the census transportation planning products (CTPP). Our multi-model method is implemented in following two steps.

Step 1: we added the subpopulation structure into Eq. (1) of the traditional 2SFCAM, and formulated it into

$$V_j = \frac{S_j}{\sum_{k \in d_{kj}(M_1) \le d_0(M_1)} P_{k,M_1} + \sum_{k \in d_{kj}(M_2) \le d_0(M_2)} P_{k,M_2} + \cdots + \sum_{k \in d_{kj}(M_n) \le d_0(M_n)} P_{k,M_n}} \tag{3}$$

where $d_{kj}(M_n)$ is the travel time by the mode M_n between location k and facility j. $d_0(M_n)$ is a predefined threshold travel time from j by mode M_n. To build a working model, these threshold travel times (by mode) can be empirically estimated from statistics of regional travel surveys. In this way, a number of catchment areas by mode could be drawn around facility j, and the subpopulations of corresponding modes are included as the demands for health services S_j (Fig. 1a). For example, all people in Population 1 (in Fig. 1a) have access to facility j, because the population falls within all three catchment areas (of different modes) around facility j. However in Population 3,