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A flow-based statistical model integrating spatial and nonspatial dimensions to measure healthcare access

Jia-Hong Tang[a], Yen-Hui Chiu[b], Po-Huang Chiang[c], Ming-Daw Su[d], Ta-Chien Chan[e,*]

[a] Research Center for Humanities and Social Sciences, Academia Sinica, Taipei 115, Taiwan
[b] Department of Education and Research, Taipei City Hospital, Taipei 106, Taiwan
[c] Institute of Population Health Sciences, National Health Research Institutes, Zhunan 350, Taiwan
[d] Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei 106, Taiwan
[e] Research Center for Humanities and Social Sciences, Academia Sinica, 128 Academia Road, Section 2, Taipei 115, Taiwan

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ABSTRACT

Assessing access to healthcare for an entire healthcare system involves accounting for demand, supply, and geographic variation. In order to capture the interaction between healthcare services and populations, various measures of healthcare access have been utilized, including the popular two-step floating catchment area (2SFCA) method. However, despite the many advantages of 2SFCA, the problems, such as inappropriate assumption of healthcare demand and failure to capture cascading effects across the system have not been satisfactorily addressed. In this paper, a statistical model for evaluating flows of individuals was added to the 2SFCA method (hereafter we refer to it as F2SFCA) in order to overcome limitations associated with its current restriction. The proposed F2SFCA model can incorporate both spatial and nonspatial dimensions and thus synthesizes them into one framework. Moreover, the proposed F2SFCA model can be easily adapted to measure access for different types of individuals, over different service provider types, or with capacity constraints in a healthcare system. We implemented the proposed model in a case study assessing access to healthcare for the elderly in Taipei City, Taiwan, and compared the weaknesses and strengths to the 2SFCA method and its variations.

1. Introduction

Good access to healthcare that enables people to benefit fully from a healthcare system is widely recognized as an important facilitator of overall population health. Access to healthcare is influenced by many factors, e.g., the supply of healthcare services, demand for healthcare, the population's health status, demographic characteristics, socioeconomic status, and geographical impedance between a population and healthcare services.

The concept of access to healthcare is complex and thus difficult to define and measure. The seminal paper by Penchansky and Thomas (1981) proposed a useful definition by accounting for each of the following dimensions: accessibility, availability, affordability, accommodation, and acceptability. Recently, some published literatures have introduced a conceptualization of access to healthcare by describing broad dimensions (Levesque et al., 2013; Saurman, 2016). Joseph and Phillips (1984) classified access according to two categories, potential and revealed access. Potential access refers to a person's ease of accessing these services based on existing conditions but does not warrant the utilization of the service. Revealed access, based on potential access, focuses on the actual use of services. Both types of access can be further classified into spatial and nonspatial access based on how the healthcare access is influenced by spatial factors (e.g. spatial location and travel distance) and nonspatial factors (e.g. socio-economic status, or cultural background) (Luo and Wang, 2003; Wang and Luo, 2005; Wan et al., 2012; Bissonnette et al., 2012; Wang, 2012).

Healthcare access is a multidimensional concept and needs to account for both spatial and nonspatial dimensions simultaneously (Khan, 1992). Spatial access varies across space because neither healthcare providers nor populations are evenly distributed (Luo and Wang, 2003). A widely accepted measure to assess spatial accessibility, the two-step floating catchment area (2SFCA) method, has been developed by Luo and Wang (2003). A key feature of the 2SFCA method is its use of catchments that are specific to population and service locations rather than relying on artificially pre-defined regions.

With regard to nonspatial access, it is influenced by a wider

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[*] Corresponding author.
E-mail addresses: jhtang.cw@gmail.com (J.-H. Tang), A3360@tpech.gov.tw (Y.-H. Chiu), chiangp@nhri.org.tw (P.-H. Chiang), sumd@ntu.edu.tw (M.-D. Su), dachianpig@gmail.com (T.-C. Chan).

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selection of demographic and socioeconomic variables that affect healthcare access, and thus it is difficult to identify the needs for every socioeconomic group, since there are potentially hundreds of combinations. The healthcare needs incorporate the wider socioeconomic and environmental determinants of health, such as culture, religion, deprivation, housing, diet, education and employment, so that we can say that the healthcare needs of a population are constantly changing according to demographic and socioeconomic factors. Whilst direct measures of mortality and morbidity are generally preferred measures of healthcare needs (Morrissey et al., 2008; McGrail and Humphreys, 2009a), they are not readily available for small geographic areas. Despite the difficulty of quantifying healthcare needs in a single measure, doing so is central to any assessment of healthcare access which is focused on minimizing inequities. Although researchers are aware of the importance of both spatial and nonspatial dimensions in assessing healthcare access, often the two are studied separately among the limited literature (Wang and Luo, 2005; McGrail and Humphreys, 2009a; Field, 2000; Wang and Tormala, 2014).

Healthcare access may be conceived as the interface between potential users and healthcare resources, and is influenced by characteristics of those who supply as well as those who utilize the services. Measurement of spatial access over a healthcare network involves accounting for demand, supply, and network structure. Popular approaches are based on floating catchment areas (Guagliardo, 2004; Luo, 2004; Comber et al., 2011; Ngui and Apparicio, 2011); however, the methods may estimate demand inaccurately over the system because they were initially developed simply to overcome the regional boundary issue. Spatial interactions, known as spatial flows, refer to economic or demographic flows between different locations, and imply a complementarity between two places engaged in a supply–demand relationship which is subject to certain costs (Hayes and Wilson, 1971; Bennett et al., 1985). Spatial interaction models (Wilson, 1967, 1971; Boltzmann, 2008) (SIMs) are thus especially suited to study the spatial interaction between providers and population locations in a healthcare network.

According to the principle of equity in healthcare access, people should have equal access to health services, which in practice is not achieved, due to inequalities in the distribution of medical resources such as healthcare facilities and physicians. This paper thus focuses on the methodology for measuring potential access with integration of spatial and nonspatial dimensions to provide a summary measure of access to healthcare from the individual's perspective, and aims at identifying areas that are underserved or at risk of being underserved by healthcare services. Towards that goal, a flow-based statistical model was proposed in this study to estimate spatial flows to improve the 2SFCA method by capturing individuals' decision-making and cascading effects across the system, and to thus estimate healthcare demand much more accurately. A key feature of the proposed model, besides the simultaneous modelling of multiple spatial factors by the SIM, is the accounting of the nonspatial factor effect, as well as the interactions between spatial and nonspatial effects. The variations of the 2SFCA method have not yet incorporated information from spatial flows that represent a realistic pattern of behavior in terms of how individuals choose to access healthcare services. The accuracy of the proposed model compared to the 2SFCA method and its variations is analytically demonstrated, and a case study of healthcare access for the elderly in Taipei City, Taiwan is used to compare these approaches.

2. A statistical model in measuring healthcare access

2.1. Review of the 2SFCA method

The original 2SFCA method is closely related to the simple provider-to-population ratios (PPRs) method (Wang, 2012). PPRs provide a crude measure of access as a supply-to-demand match ratio in an area. However, PPRs are restricted to differentiating access using fixed geographical or administrative boundaries, and they ignore both cross-border movement between boundaries and distance decay within boundaries (Luo and Wang, 2003; Wang, 2012). The 2SFCA method builds upon the framework of PPRs, but instead uses floating catchments that originate from provider and population locations to allow the catchment of each provider and population to float based on the distances between each pair (Luo and Wang, 2003). The size of the catchment is determined by a choice of maximum travel time (or distance), where all services (or populations) within that catchment are considered accessible and equally proximate to that particular population (or service provider), whilst all locations outside of the catchment are not accessible. As the name suggests, the final 2SFCA score is calculated using two connected steps:

Step 1: For each service (j), find all populations that fall within a threshold distance (d_0) and calculate the provider-to-population ratio, R_j.

$$R_j = S_j / \sum_{k\in\{d_{kj}<d_0\}} P_k \tag{1}$$

where S_j is the capacity of healthcare provider j and P_k is the population of area k.

Step 2: For each population (i), find all services that fall within a threshold distance (d_0) and the accessibility of area i, A_i, is to sum the PPRs from step 1.

$$A_i = \sum_{j\in\{d_{ij}<d_0\}} R_j = \sum_{j\in\{d_{ij}<d_0\}} \left(S_j / \sum_{k\in\{d_{kj}<d_0\}} P_k\right) \tag{2}$$

Step 1 of the 2SFCA method determines what population k of size P_k are located within the catchment border, d_0, of each service provider j of volume S_j, thus defining the provider-to-population ratio R_j within a service catchment. Step 2 then assigns these service ratios to the population by determining which services are located within the catchment border, d_0, of each population i, and aggregating the Step 1 scores to calculate an area's access. The only decision required in applying the 2SFCA method is the catchment size, d_0, which is then applied at both Steps 1 and 2.

Despite its relatively straightforward nature and popularity, the method's major limitation is its dichotomous approach that defines a service provider inside a catchment as accessible and one outside the catchment as inaccessible, and several studies have attempted to improve it (Ngui and Apparicio, 2011; McGrail and Humphreys, 2009b, 2014; McGrail, 2012).

The enhanced 2SFCA (E2SFCA) is a variation that applies an impedance function to create weights for opportunities within the catchment area to account for decay of the willingness to travel as distance increases (Luo and Qi, 2009). By generalizing the distance decay effect as a term $f(d)$ (Wang, 2012), all measures in the 2SFCA method can be synthesized as follows.

$$A_i = \sum_{j\in\{d_{ij}<d_0\}} R_j \cdot f(d_{ij}) = \sum_{j\in\{d_{ij}<d_0\}} \left(S_j \cdot f(d_{ij}) / \sum_{k\in\{d_{kj}<d_0\}} P_k \cdot f(d_{kj})\right), \tag{3}$$

where the distance decay function, $f(d)$, across a catchment can be treated as a continuous function, a piecewise-defined function, or a hybrid of the two across a single zone.

2.2. Modelling framework

Since equity in healthcare is widely accepted as an important goal of public policy, minimizing inequality in healthcare access can help to close the gap. For improving access or service over the healthcare system, most work uses measures of the accessibility of healthcare service to maximize service coverage, minimize travel needs of individuals, limit the number of facilities, maximize health, or combine some of these goals (Wang, 2012). There is a need to consider how cost-benefit analysis fits with considerations for equitable access to