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Multi-modal two-step floating catchment area analysis of primary health care accessibility

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ABSTRACT

Two-step floating catchment area (2SFCA) techniques are popular for measuring potential geographical accessibility to health care services. This paper proposes methodological enhancements to increase the sophistication of the 2SFCA methodology by incorporating both public and private transport modes using dedicated network datasets. The proposed model yields separate accessibility scores for each modal group at each demand point to better reflect the differential accessibility levels experienced by each cohort. An empirical study of primary health care facilities in South Wales, UK, is used to illustrate the approach. Outcomes suggest the bus-riding cohort of each census tract experience much lower accessibility levels than those estimated by an undifferentiated (car-only) model. Car drivers' accessibility may also be misrepresented in an undifferentiated model because they potentially profit from the lower demand placed upon service provision points by bus riders. The ability to specify independent catchment sizes for each cohort in the multi-modal model allows aspects of preparedness to travel to be investigated.

1. Introduction

Geographical accessibility can be defined as the ease with which the residents in a given area can reach a particular service or facility and recent research literature has demonstrated that there is an on-going interest in measuring geographical accessibility to health care services (e.g. Martin et al., 2002; Wang and Luo, 2005; Wang et al., 2008; Wang and Roisman, 2011; Shi et al., 2012; Wang, 2012). Typically both the centres that supply primary health care services, and the people that place a demand upon them, are spatially unevenly distributed. This fact, together with the nature of the transport networks that are used to connect each to the other, ensures that some degree of inequality in geographical access is inevitable within any given study area. Because of this it becomes a useful exercise to determine the patterns of spatial accessibility to services across a region when evaluating opportunities for using health services. Potential accessibility measures should not be confused with revealed (or actual) service use, since many other factors may be influential on the uptake of service provision besides the impact of geographical friction, such as service affordability and awareness, demographic factors such as age, gender and ethnicity, and other social and cultural barriers (Higgs, 2009). Notwithstanding these concerns, there remain a number of reasons why calculating potential geographical access to primary health care facilities is of interest to service providers including the need:

- to monitor compliance with national guidelines concerning social equity (i.e. that there should be 'equal access to all'), and to ensure the maintenance of minimum standards of service level provision;
- to measure the efficiency and coverage of existing service provision and to assist in its operational management;
- to help develop policy and planning for future service provision, attempting to maximise access levels and minimise travel costs.

The purpose of this paper is to propose methodological enhancements to those studies conducted to date that have used so-called Two-Step Floating Catchment Area (2SFCA) methodologies to measure primary health care provision. Specifically, the aim is to provide greater sophistication in the 2SFCA modelling process by recognising that demand populations typically access health care facilities using both public and private modes of transport, and that these travel modes should be independently represented in order to accurately determine each sub-group's accessibility to the offered service. There have been few attempts to incorporate

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multiple modes of travel within 2SFCA models to date partly due to a lack of appropriate data sets relating to public transport provision in different settings. The findings presented here address gaps in the existing literature by drawing on open sources of data available in the UK that enable such networks to be created. Specifically by restricting the points at which bus services can be accessed to bus stops, and by adopting fully independent networks to represent car travel and detailed bus routes, 2SFCA models are developed that represent a more realistic approximation of actual travel behaviour. These enable comparisons to be made between the distributions of accessibility scores for different modes of transport to health services. This is illustrated with reference to potential access to General Practitioner (GP) surgeries in South Wales, UK.

The remainder of the paper is structured as follows. Section 2 provides a brief summary of pertinent past literature, focussing on methodological developments of the 2SFCA technique. In Section 3 we develop a multi-modal framework in which demand populations are divided into those expected to utilise public and private transports modes respectively. The mobility and travelling opportunities of each group are then independently modelled via dedicated topological networks to more accurately reflect the experiences each group encounters whilst attempting to access health care provision. To illustrate the model we present a case study in Section 4, describing how required datasets were assembled and explaining the tools used to compute the output metrics. Section 5 analyses the results, comparing outputs of the proposed methodology with previously adopted 2SFCA approaches and highlighting the analytical benefits that ensue. Finally, we present a summary of the work undertaken, prospects for its future development, and principal conclusions in the closing section of the paper.

2. Floating Catchment Area (FCA) analysis: Previous approaches

Many specific accessibility metrics have been proposed in the literature broadly classified into so-called ‘container-based’ and ‘distance-based’ approaches. The former consist of computing a supply-to-demand ratio within the boundaries of fixed areal partitions of geographic space. In the case of primary health care provision this is most likely to be a ratio between the number of general practitioners and the resident population count found inside the boundaries of a census tract. Such measures are simple to compute and to understand but have well-documented weaknesses, such as the inability to disclose spatial detail inside the area unit and an inherent assumption that no interaction occurs across area boundaries (Joseph and Phillips, 1984). Furthermore, container-based analysis is vulnerable to the effects of the Modifiable Areal Unit Problem (Openshaw and Taylor, 1981) whereby the results may be influenced by scale effects (i.e. size of container object) and zone effects (i.e. the exact location of tract boundaries, which are often arbitrarily defined). Distance-based metrics include the minimum cost (measured either as a geographical distance or a travel time) to reach a facility, the average cost to the *n* closest facilities, and the number of facilities reachable within a threshold cost. One criticism of these measures is that they take no account of the demand placed upon a service. This weakness is addressed by gravity models that explicitly analyse the interaction between supply and demand across space using a distance-decay function (Joseph and Bantock, 1982).

Much of the recent literature concerned with measuring access to health care provision has focussed on the use of 2SFCA approaches, which are essentially a specialised form of the gravity model (Luo and Wang, 2003). One of the earliest examples of the use of a GIS-based ‘floating catchment’ procedure is by Wang (2000) who used a simple circular zone centred over each administrative tract to compute a jobs-to-housing ratio in a study of job accessibility in Chicago. The action of a ‘floating’ zone overcame some of the issues associated with using census tracts as the container object because the circular catchment operated independently of zone boundaries. However, it retained the fallacious assumption that all services lying inside the catchment are fully available to the residents of that catchment, when most often they are shared with residents falling outside of the catchment boundary yet who still lie within a threshold distance of the service provision point. To address this weakness the floating catchment concept was further developed by Luo and Wang (2003) to incorporate ideas described as ‘spatial decomposition’ by Radke and Mu (2000). While the method of ‘spatial decomposition’ was based upon area units, the so-called two-step floating catchment area (2SFCA) method uses point features to represent the locations of service supply and demand.

In the first step a distance or travel time catchment is placed around each General Practice (GP) surgery (the primary health care service providers in the UK) and a physician-to-population ratio is computed using the number of doctors and estimated population falling within it. In the second step a similar floating catchment is placed over each demand centre (e.g. the population-weighted centroid of census tracts) and the service accessibility for this population rated by summing all physician-to-population ratios contained within the zone. The output metric is a familiar and easily understood physician-to-population ratio but, unlike the traditional container-based method, 2SFCA accessibility scores reflect spatial interaction between patients and physicians across administrative borders based upon computed travel times. FCA scores reflect capacity restrictions as well as local competition, allow for cross-border service-seeking activity, and provide a metric that is both easily interpreted and communicated (Fransen et al., 2015). The 2SFCA score is a relative measure in which the total service volume (e.g. number of physicians) within the study area, which still acts as a global container, is always preserved (Delamater, 2013). However, by using the 2SFCA technique service provision can be shown to be consumed spatially unevenly amongst the distributed population.

A number of criticisms of the original 2SFCA method have been identified, such as its reliance on a finite catchment size. One consequence of this feature is that locations falling outside of any catchment area are reported to have no access at all (Luo and Qi, 2009). It can also be responsible for producing artificially sharp boundaries in the accessibility scores returned for adjacent areas (McGrail and Humphreys, 2009). Furthermore, 2SFCA assumes that all population within a catchment have equal access to health care regardless of the actual distance/time between the demand and supply points (Wang, 2012); that is it does not account for distance impedance within the catchment limits (Luo and Qi, 2009). Seeking to address this latter concern, an Enhanced Two-Step Floating Catchment Area (E2SFCA) methodology was proposed by Luo and Qi (2009) incorporating a distance decay function into the floating catchments of both algorithmic steps. This may be implemented as a discrete stepped model approach (e.g. Luo and Qi, 2009, Wan et al., 2012), or via a continuous mathematical function (Langford et al., 2012), but in either case the question is raised as to the precise nature of the distance-decay function that should be adopted (McGrail and Humphreys, 2009).

A number of enhancements to these models have recently been proposed; of particular relevance to this study are the observations and subsequent methodological developments to the 2SFCA technique described by Mao and Nekorchuk (2013). They noted that in 2SFCA-based studies published to date an intrinsic assumption is made that people travel to health care facilities (or