Measuring access to primary health care using two-step floating catchment areas and a public/private multi-modal transport model

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Abstract

Floating catchment area (FCA) models are widely promoted as a technique to measure potential accessibility in a range of health applications. Since their initial formulation in the early 2000s a number of enhancements have been proposed to better measure accessibility. Encouraged by the growing availability of road network data, and a realisation of the inherent limitations of straight line distances in such models, there has been an increasing adoption of network distances in such models. However, the majority of studies using FCA models are still predicated on the assumption that people access health care facilities using only private means of transport. This study describes how public transport availability and frequency can be incorporated into FCA models to provide a more realistic appraisal of accessibility for those population groups most likely to be reliant on public means of transport to access health care services. The potential advantages of this approach and its policy implications are illustrated with reference to a case study of access to primary health care facilities within South Wales, UK.

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Keywords

Potential accessibility, Floating catchment Area, Multi-modal network, GIS, Primary health care.

Introduction

An increasing number of studies are concerned with developing *place-based* accessibility measures based on spatial proximity between objects located in different geographic locations (Bissonnette *et al.*, 2012). Whilst acknowledging the ongoing efforts that are concerned with the development of alternative *person-based* space-time accessibility measures which account for variations in the activity-travel patterns of individuals (see Neutens *et al.*, 2012), the focus here is on area-based measures derived from a variant of the gravity model that provide intuitively interpretable scores and which has generated a great deal of academic interest in the last decade. The floating catchment area (FCA) approach to measuring the spatial variability of access to a variety of public and private services, first came to prominence in the academic literature in the early 2000s (Luo and Wang, 2003; Luo, 2004). Since then a number of extensions to the initial formulation have been proposed (Luo and Qi, 2009; Ngui and Apparicio, 2011). Drawing on the health geography literature, these include the use of more detailed population assignment and estimation models to finely locate and aggregate potential demand, the restriction of potential demand to population sub-groups most likely to use different types of facilities, the isolation of supply measures to those services offering a particular medical speciality or service, the adoption of network-based datasets such as those derived from national mapping agencies or volunteered data sources (e.g. Open Street Map) to overcome inherent flaws in straight-line calculations, and the promotion of sensitivity analysis by experimenting with modelling parameters such as catchment travel times and distance decay functions.

However, an area that has been relatively overlooked in such research studies relates to the inclusion of measures based on public transport availability and frequency (Langford *et al.*, 2012). To date, an inherent assumption in most studies concerns a restricted emphasis on the role of access via private transport (i.e. car). This could be problematic where people are either forced, or chose, to use public transport to access primary health care facilities. Findings from the National Survey of Wales, for example, suggest that only 62% of the sampled population used a car as their usual mode of transport to get to a General Practitioner (GP) or family doctor. Thus the incorporation of different measures of public transport service and quality within FCA measures is a potentially fruitful area of research, both from a public health and a social justice perspective. Whilst a number of studies have incorporated measures of public transport into accessibility calculations (e.g. Lovett *et al.*, 2002; Martin *et al.*, 2008) few to date have used FCA techniques to examine the differences in potential access measures using multi-modal approaches. In this paper we describe the development of bespoke software (an ArcGIS™ Add-in) to compute multi-travel mode FCA scores. By mapping the outputs and comparing trends to a 'traditional' single-mode FCA score based on the assumption that all travel is by car, we are able to highlight areas where very different access levels are reported depending on the actual travel mode. Potential policy implications of adopting such an approach are discussed and evaluated in the conclusions of the paper.

Enhancement to floating catchment area (FCA) techniques

Some of the earliest studies using floating catchment area (FCA) methods to measure accessibility were those of Radke and Mu (2000) and Luo and Wang (2003).

Their findings illustrated how the use of these techniques addresses two major shortcomings of the “container” approach for calculating supply and demand relationships (i.e. those measured within artificially contrived areas that seldom conform to natural geographic patterns of either health care delivery or patient utilisation). Specifically, container approaches ignore those patients who could potentially use services in neighbouring areas or those practitioners who service wider communities (i.e. health services outside the boundaries are deemed to be ‘inaccessible’). Secondly, it is unlikely that such services are uniformly available to all potential patients within these administrative areas supporting a preference for gravity-based approaches wherein the closer the health facility to the origin of population demand, the greater its contribution to the overall accessibility score. In essence floating catchment area techniques use principles derived from gravity models to take into account variations in supply/demand relationships with distance to provide an interpretable measure of the amount of supply units accessible per unit of demand. Since the original FCA approach was described several enhancements to the basic methodology have been proposed and demonstrated in a range of application areas. For example, the ‘*two-step*’ floating catchment area method (2SFCA) permits overlapping (‘floating’) catchments of predetermined catchment size to represent the service areas of such facilities It involves two stages; step 1 calculates a provider/population ratio within a service catchment area of each service location, while in Step 2 these ratios are summed by establishing which service points are located in the catchment area of population demand points to yield an access score allocated to the relevant population zone.

The models described in this paper build specifically on enhancements to the 2SFCA technique described by Mao and Nekorchuk (2013). Addressing the assumption that people travel to health care facilities via a single mode of transport (car) they proposed a solution to enable alternative modes of transport to be incorporated into the FCA model. This was accomplished by separating the demand-side population into those travelling by each travel mode so that travel time catchments associated with each subgroups are analysed separately and the computed availability equates to that proportion of the service available to those travelling to the facility by the particular transport mode. To implement the two transport modes used in their study (i.e. car and bus) a common network dataset was used but with different travel speeds assigned to its edge elements. In the absence of detailed bus routes/stops, in their study a bus was assumed to be able to travel along all the same roads as a car but at a slower speed (specifically, a constant 10 miles per hour). This study advances 2SFCA analysis by incorporating fully independent network datasets to model population mobility via each transport mode, thereby providing much more realistic estimates of the travel times experienced by public transit users which includes the time taken to walk and from to a bus stop as well as travel times between stops derived directly from detailed timetable information.

Methods of incorporating multi-modal approaches to measuring accessibility

To illustrate how multi-modal approaches can be incorporated into FCA calculations we use a case study of accessibility to General Practitioner surgeries in three local authority areas of South Wales (Figure 1); a study area of approximately 520,000 people with potential access to 355 doctors located at 88 Primary Care sites (as of May, 2015). Because both speed of travel and the actual network elements (i.e. the specific edge elements representing roads, bus routes and footpaths) associated with each mode are typically quite different, this has involved the use of dedicated public and private transport networks. This can be justified because, whilst we can expect car-drivers to utilise most roads for example, bus travel is clearly restricted to the subset along which bus routes operate. Furthermore, bus travel can only start and end at bus stops, thus a walking element is also required at either end of the journey. Finally, although walkers travel slowly they can use footpaths, alleyways and such-like that are unavailable to bus and car. Such differences mean travel catchments computed around supply and demand points can vary substantially according to travel mode.

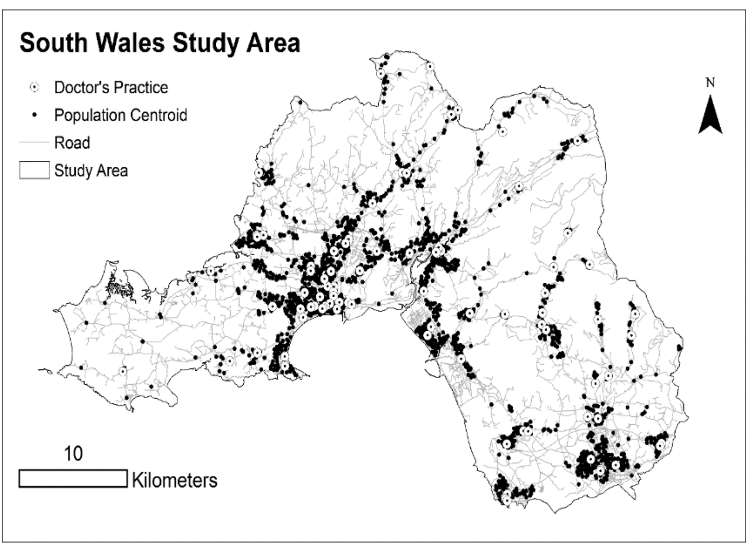

Figure 1 - Distribution of GP sites and population centres in the study area

For the private (car) transport network, speeds were assigned to a digital network provided by the Ordnance Survey using well-established guidelines regarding maximum speeds within urban and rural areas (with additional time penalties for crossing major road junctions, for turning right, and for left turns between minor and major road classes). To create the more complex bus network dataset, two key data sources were employed; a database containing geo-referenced information for every bus stop in the UK (National Public Transport Access Node dataset), and another that provides detailed UK-wide timetable information (Traveline National Dataset). For each journey leg (i.e. between bus stops along a route) a simple geometric edge element was constructed and a timetable-derived travel time attached. Finally, links were created between the footpath / road walking network and the bus travel network by using the bus stop locations. Demand populations were divided into two groups which are expected to use public and private transports modes respectively. Bespoke software in the form of an ArcGIS™ Add-in was written to facilitate the computation of 2SFCA scores using this multi-model framework to reflect the differential experiences of those electing to use public and private transport modes respectively. The outcomes of these experiments are described in detail in the next section.

Results

The implications of variations in bus provision can be made by comparing bus-travel FCA scores with those derived from a 'traditional' car-only FCA model (i.e. one that assumes all people seek healthcare facilities by car) for a range of threshold travel times and distance decay parameters. Thus we have computed the differences in the 2SFCA scores derived separately for Bus and Car travellers using multi-modal models with those of the single-mode distribution (in this instance adopting a 15 minute travel time threshold and assuming a linear distance decay function in all cases). Of particular interest are those areas where very different access levels are reported depending on the transport mode. Figure 2 shows the distribution of FCA accessibility scores for the study area with the major urban centre (Swansea) highlighted in greater detail.

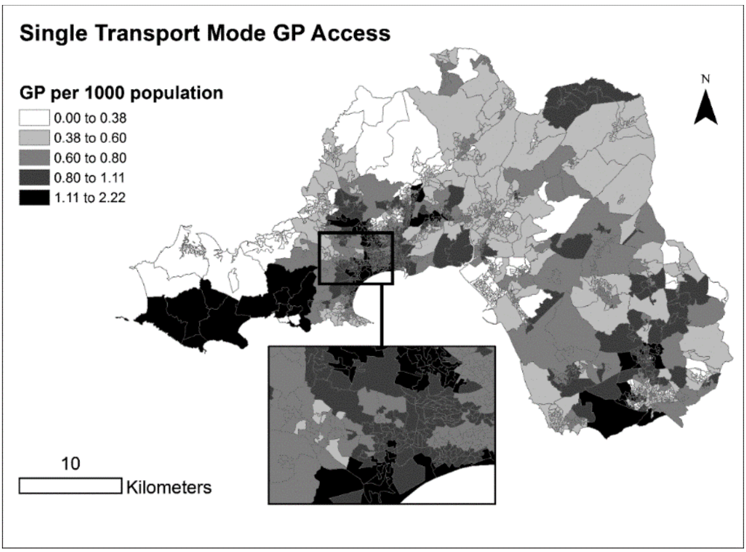

Figure 2 - Distribution of 2SFCA scores for the single travel mode model

This represents the output from a 'traditional' FCA analysis which includes the assumption that all the population accesses GP facilities via private means of transport. Figure 3 shows that, when modelled with independent networks, car users in the majority of census output areas are apparently much better off than that implied by the 'traditional' FCA approach. Counter-intuitively there are some instances where they experience lower access scores, but this can arise, for example, where the presence of a regular bus service increases the completion arising from bus-users or where car-ownership levels are lowest. Conversely a detailed analysis of bus users shows them to be, unsurprisingly, much worse off than the single-mode or undifferentiated model implied (Figure 4). Problems are exacerbated in areas with poor provision of bus services, but again counter-intuitively some areas do experience an improved service for the same reason as before (i.e. a smaller demand is placed upon their GP services due to the poor access for bus travellers in nearby census tracts).

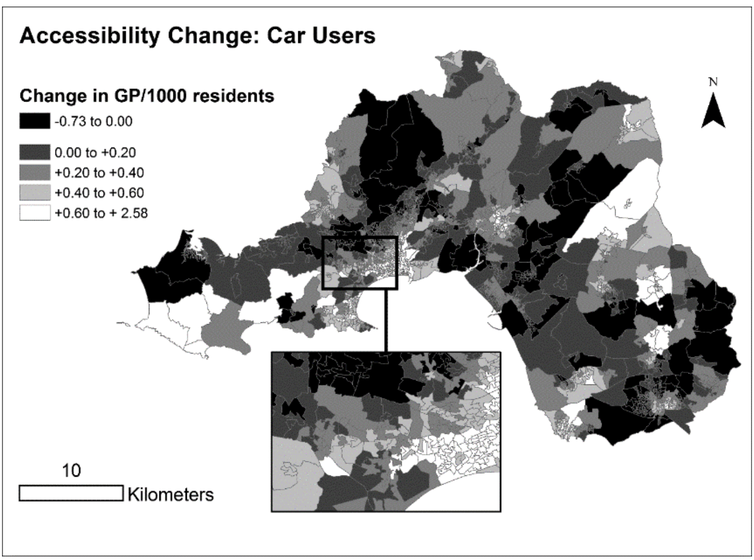

Figure 3 - Difference in 2SFCA scores between the users of a single mode (car only) transport network and the car users in a multi-modal car/bus transport network

A deeper interpretation of these spatial patterns forms part of our future research plans in the area, but it is evident that lower scores for bus travellers result from a more accurate representation of the transport options and capabilities so that the number of GP surgeries reachable within any threshold travel time is often severely curtailed.

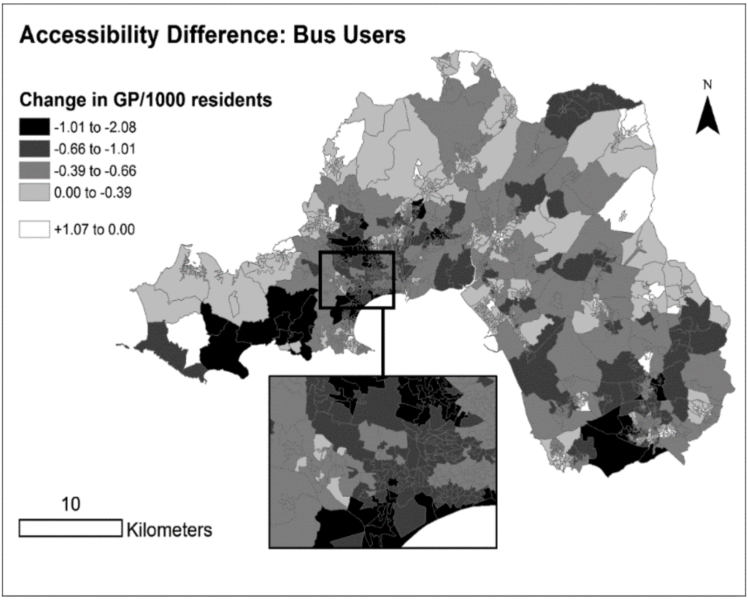

Figure 4 - Difference in 2SFCA scores between the users of a single mode (car only) transport network and the bus users in a multi-modal car/bus transport network

This, in turn, implies that the 'share' of the total GP service available to car users rises as a consequence of the poorer 'reach' of those travelling by bus and so increases FCA access scores recorded for the former. Crucially then, any FCA analysis which assumes a car-only travel mode is likely to greatly over-estimate the accessibility levels experienced by those who either choose to, or are forced to, utilise public transport.

Discussion/Conclusion

Previous studies have drawn attention to the importance of access to public transit for users of primary care services especially for those individuals living in low-supply areas (Ryvicker *et al.*, 2012). Despite this, the majority of studies of accessibility to health facilities, in particular, assume travel to access such services is accomplished through the use of a private car (Guagliardo, 2004). This study, which has built on previous research concerned with the use of floating catchment area techniques to measure potential access to services, has shown how dedicated independent travel networks can be built for alternative modes of transport, and then incorporated into FCA access measures to better reflect the travelling opportunities and travel times experienced amongst corresponding cohorts. Using a case study of access to primary care surgeries in South Wales, the inclusion of multi-modal models within a small area analysis of accessibility has highlighted the relative disadvantage of bus users compared to car users. In common with other studies that have adopted a similar approach to measuring potential accessibility, a number of potential limitations do have to be acknowledged. For example, no data is available for the study area on the actual modal split of patients for those attending patient appointments. The demand locations have been approximated by the centroids of the smallest census output for which denominator data in available in the UK, but we cannot rule out people attending surgeries for more routine appointments from their workplace. Similarly there may be problems in the representation of demand using residence-derived centroids for some of the larger census output areas. Future work will also consider the inclusion of data related to the quality of provision and supply-side data on health (such as opening times, the gender of the general practitioner within the practice, and so on). Finally assumptions have been made regarding the form of the distance-decay parameters (for different modes of transport) and travel time thresholds used in the models. Nevertheless, there is the ability to easily vary such parameters in the FCA model should empirical data become available in order to conduct sensitivity analysis under different policy scenarios. Further research is needed to seek evidence for associations with patterns of deprivation, ethnicity, age and other such socio-economic variables and to establish the potential implications on health outcomes in the study area. Such research can be used to examine the implications of future changes in service configurations and to inform policy interventions regarding the provision of health facilities and public transport opportunities and could be especially beneficial for those investigating disparities in health care visits for the elderly and those population groups most dependent on public transport.

References

Bissonnette L., Wilson K., Bell S., Shah T.I. (2012), Neighbourhoods and potential access to health care: The role of spatial and aspatial factors, *Health and Place*, 18(4), pp. 841-853.

Guagliardo M. (2004), Spatial accessibility of primary care: Concepts, methods and challenges, *International Journal of Health Geographics,* 3, 3.

Langford M., Fry R., Higgs G. (2012), Measuring transit system accessibility using a modified two-step floating catchment technique, *International Journal of Geographical Information Science*, 26(2), pp. 193-214.

Lovett A., Haynes R., Stunenberg G., Gale S (2002), Car travel time and accessibility by bus to general practitioner services: a study using patient registers and GIS, *Social Science and Medicine,* 55, pp. 97-111.

Luo W. (2004), Using a GIS-based floating catchment method to assess areas with shortage of physicians, *Health & Place,* 10, pp. 1-11.

Luo W., Qi Y. (2009), An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians, *Health and Place*, 15, pp. 1100-1107.

Luo W., Wang F. (2003), Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region, *Environment and Planning B: Planning and Design,* 30, pp. 865-884.

Mao L., Nekorchuk D. (2013), Measuring spatial accessibility to healthcare for populations with multiple transportation modes, *Health and Place*, 24, pp. 115−122.

Martin D., Jordan H., Roderick P. (2008), Taking the bus: Incorporating public transport timetable data into healthcare accessibility modelling, *Environment and Planning A*, 40, pp. 2510-2525.

Neutens T., Delafontaine M., Scott D., De Maeyer P. (2012), An analysis of day-to-day variations in individual space-time accessibility, *Journal of Transport Geography*, 23(1), pp. 81-91.

Ngui A.N., Apparicio P. (2011), Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal, *BMC Health Services Research*, 11, pp. 166.

Ryvicker M., Gallo W.T., Fahs M.C. (2012), Environmental factors associated with primary care access among urban older adults, *Social Science & Medicine*, 75(5), pp. 914-21.