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The use of GIS-derived accessibility measures in mixed methods research: A research agenda

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Abstract

This paper aims to review the state of play of GIS use in measuring accessibility to services drawing on work in areas such as health, public services, transport and environmental justice. The first section describes what is meant by 'accessibility' in the context of our research. To date this has predominantly been concerned with measures of geographical accessibility whilst recognising that this forms but one component of a wider notion of access which includes financial, socio-economic and physical measures. We then focus on geographical accessibility to outline some of the key methodological issues that continue to form the basis of numerous studies in this area – including scale of aggregation, distance metrics used, and the implications of different population assignment techniques. Such issues are illustrated using the floating catchment technique, one of the most popular methods for measuring accessibility in the social science literature over the last decade. We demonstrate its application using the case study of access to public transit in the Head of the Valleys area of South Wales. The paper goes on to describe a research agenda aimed at improving such measures by: incorporating public transport timetables, analysing services of varying quality and characteristics, and measuring access for differing socio-economic groups and alternative (population) demand points. The final section outlines preliminary thoughts on how modelled accessibility measures could be combined with qualitative data to provide a more complete picture of the factors influencing accessibility and how this relates to resident perceptions of access to key public services. In so-doing we highlight the importance of contextualising measures with the daily experiences of residents through Qualitative GIS, and explore new ways in which such data can be integrated through mixed method approaches.

Keywords: Accessibility; Public Services; Qualitative GIS; Wales; Heads of the Valleys

1. Introduction

The ‘convergence’ of Geographical Information Systems (GIS) and Computer-Aided Qualitative Data Analysis (CAQDAS) through mixed method approaches in geographical and sociological applications is currently a topic receiving much interest (see for example Fielding and Cisneros-Puebla, 2009; Jung and Elwood, 2010). A recent text on Qualitative GIS has presented a number of case studies that illustrate how GIS can be integrated with qualitative techniques such as ethnography in social and economic applications (Cope and Elwood, 2009). This article is broadly concerned with adding to this field of knowledge by showing the benefits of an integrated approach to combine GIS-derived quantitative measures with data derived from survey and interview-based methodologies. Our specific objective is to assess the application of modelled accessibility measures using a database of public services in Wales and to suggest a research agenda whereby this work could be integrated with qualitative data to provide a more comprehensive picture of spatial variations in access. The importance of measuring accessibility in terms of evidence-based policy frameworks, implementation and evaluation, is widely acknowledged. In particular, the use of GIS to examine fairness in the spatial distribution of services such as schools, hospitals and jobs by analysing patterns of accessibility is now well established.

Whereas a significant amount of research has been conducted relating to the derivation of quantitative accessibility measures and their potential refinement, comparatively few studies have attempted to link such measures with qualitative data related to, for example, a population’s experiences or perceptions of access for local areas. This study explores the integration of such techniques using mixed methods approaches specifically for an area of South Wales (although outcomes should have wider relevance in other contexts). The first part of the paper describes an empirical investigation of the calculation of accessibility measures for the study area. The second part presents preliminary ideas on how these measures can be integrated within a GIS environment with resident’s accounts of access to services. Whilst a number of Government Surveys (such as *Living in Wales*) include questions on respondents opinions of local services, including perceived ease of access, to date little research has attempted to combine these two strands. Here we present a case study where such a task could be attempted and propose a methodology that will form the basis for our future work programme.

2. Accessibility: Definitions

Many definitions of accessibility have been proposed in the transport and health services literature (e.g. see Gulliford and Morgan, 2003), but there continues to be an on-going debate over exact definitions and the best method of calculating such scores (Pirie, 1979; Song, 1996; Vandenbulcke et, 2009). Working from a healthcare perspective Penchansky and Thomas (1981; p. 128) argue that "...access is most frequently viewed as a concept that somehow relates to consumers ability or willingness to enter into the health care system" and define access as "...a concept representing the degree of 'fit' between the clients and the system". They proceed to break down access into a series of dimensions – availability, accessibility, accommodation, affordability and acceptability. Aday and Andersen (1974) also consider wider definitions of accessibility beyond geographical or spatial factors, such as financial, informational and behavioural influences, although there have been a number of critiques of their 'framework for the study of access' (see Field and Briggs, 2001 for a fuller discussion). Gulliford et al (2002) draw a distinction between "having access" to health care and "gaining access"; the former results from the availability of services, whilst the latter refers to whether individuals have the necessary resources to overcome financial, organisational and socio-cultural barriers and thereby utilise the service. They suggest "...the availability of services, and barriers to access, have to be considered in the context of the differing perspectives, health needs and material and cultural settings of diverse groups in society" (Gulliford et al., 2002; p 186). Beliefs and expectations of different groups in different geographical and cultural settings will also influence such trends (Andersen and Aday, 1978).

In this paper we are concerned with investigating the most relevant definition of geographic access for a GIS-based analysis, focussing on the interaction between individuals and destination locations using characteristics of the intervening transport network (Handy and Niemeier, 1997). Joseph and Phillips (1984), building on previous studies, distinguish between potential accessibility and revealed accessibility. The former assesses the nature and pattern over space of physical access to service facilities. Joseph and Bantock (1982), for example, compute potential accessibility to general practitioners in rural areas of Canada. The measure adopts the term '*potential'* accessibility because no actual interaction between the two sides of the demand-supply equation is implied (Joseph and Phillips, 1984). Andersen (1995; p. 4) drawing on a conceptual framework defines potential accessibility as simply "the presence of enabling resources", while Khan (1992; p. 275) refers to the "availability of that service moderated by space, or the distance variable". The measure generally assumes that "...given a maximum range for the service being offered at a facility and assuming that every member of the population is a potential user of the service, the pattern of physical accessibility will depend only on the relative location of the population and the service facilities" (Joseph and Bantock, 1982). This could be represented as travel time, road or Euclidean distance. Other studies have considered actual utilisation of services (or '*revealed accessibility'*). As Khan (1992; p. 275) recognises "Utilisation of services, or the actual entry into the system, is dependent on *barriers* and *facilitators* of both the service system and the potential users." In the following section, we describe measures of these aspects of accessibility in more detail, focusing particularly on the role of geographical factors in deriving potential measures of accessibility.

3. Calculating accessibility measures and their application

Whilst an increasing number of studies have attempted to measure access to public services in fields as diverse as land-use planning, travel demand forecasting and employment opportunities for different socio-economic groups, there remains no general consensus on the most appropriate methodology. Whilst much of the impetus for this research continues to come from the transport literature, recent studies have also considered accessibility to a wider range of public (and private) services (Halden, 2002). In this paper we do not intend to review the relative strengths and limitations of different accessibility measures (see for example, Song (1996), Talen (2003) or Rushton (1999) for a wider discussion). Increasingly research is being conducted within the sphere of health geography where access to facilities is important when gauging the relative impacts of geography on health outcomes. Early work in this area was often concerned with the distance effects of potentially health-damaging or noxious facilities (Higgs, 2004; 2009). More recently attention has turned to examining the role of 'health-promoting' environments such as green space and public parks (Nicholls, 2001; Pearce et al., 2006; Comber et al., 2008; Coutts, 2008; Hillsdon et al., 2006; Witten et al., 2008; Jones et al., 2009), playing fields (Talen and Anselin, 1998; Smoyer-Tomic et al., 2004), sports facilities (Witten et al., 2003; Diez Roux et al., 2007; Macintyre et al., 2008a; Panter et al., 2008), forestry and healthy food opportunities (Apparicio et al., 2007; Larsen and Gilliland, 2008; Sharkey and Horel, 2008).

Building on the reviews by Handy and Niemeier (1997) and Talen (2003), Table 1 (below p. 29) shows some of the methods by which accessibility has traditionally been measured. In the absence of data on service utilisation (*revealed accessibility*) it has often been calculated as a count of services lying within a census tract in relation to demand estimated by the total population count or some other particular target group (i.e. a *population-to-provider ratio*). Alternatively, GIS have also been used to calculate *coverage* measures reporting the number of services within a given Euclidean distance/time of demand points such as population-weighted centroids (e.g. Brabyn and Barnett, 2004; Lin, 2004; Langford et al, 2008) or individual residences (McEntee and Agyeman, 2010), or to derive *proximity* measures based on the population within specified drive-times of health services (e.g. Christie and Fone, 2003; Apparicio et al., 2008; Klein et al., 2009). A number of recent studies have conducted sensitivity analyses on the results of accessibility studies when using different modes of *geographic placement* (e.g. centroid versus individual addresses) and *measurement* technique (e.g. drive-time versus Euclidean distance) with varying outcomes. Hewko et al. (2002) note the importance of aggregation errors, while Jones et al. (2010) found relatively small differences in the impact of geographic placement. Research has also been conducted on the efficacy of using network distance over straight line distance, both in the UK (Jordan et al., 2004) and the United States (Phibbs and Luft, 1995). In practice the use of different techniques is often a trade-off between the availability of appropriate datasets and software and the aims/objectives and resources of the particular project.

Each of these measures has its limitations. Population-to-provider ratios are problematic for small areas in particular, since there is likely to be movement of people across boundaries to access services (Fortney et al., 2000; Guagliardo, 2004). Meanwhile, proximity measures assume people always use their *nearest* facility to access a particular service. Such problems have led to a recent body of research concerned with extending such measures particularly in respect to health services. Luo (2004), for example, used simple circles of varying radii centred at census tract centroids. These ‘float’ from one residential area to another computing a physician-to-population ratio using the number of facilities found within each buffer (Wang, 2000). This so-called *floating catchment area* (FCA) method still makes assumptions regarding service availability within the circular area; namely that services are equally available to all residents regardless of actual distance from the facility. It overcomes assumptions regarding cross-boundary flows by extending a circular catchment beyond the immediate census zone, but is still limited by the use of a single point with which to represent population demand.

An enhancement of this methodology is the two-step FCA (2SFCA) introduced by Luo and Wang (2003), building on earlier work by Radke and Mu (2000). Essentially a special case of the gravity model, it better accounts for interaction between patients and physicians across administrative boundaries. It evaluates accessibility as the ratio between supply and demand, both determined within travel-time catchments. In step one, catchments are computed around each supply point j (e.g. GP practice) and using service volume (e.g. number of doctors) and estimated catchment population (typically based on centroids falling inside the area) a population-to-provider ratio (Rj) is established. In step two, travel-time catchments are computed around demand centres (e.g. census tract centroids) and service accessibility measured by summing all *Rj* values (derived in step 1) contained in this zone. The final accessibility measure reports the balance between availability (e.g. physician-to-population ratio) and service accessibility (the sum of all supply points within a given travel-time of the demand centre), returning higher values as accessibility increases. This technique has found use in both health geography and beyond. For example, estimating access to pediatric services (Guagliardo, et al., 2004; Cervigni et al., 2008), to physicians amongst Chinese immigrants (Wang, 2007), to employment centres (Wang, 2000), and to other urban services (Langford et al., 2008).

Wang and Luo (2005) report a practical application of 2SFCA for the State of Illinois. Physicians were located by zip code, and demand centres represented by (population-weighted) census tract centroids. Travel-time catchments (30-minutes) were computed via a vector road network with speeds determined by road classification and urban/suburban/rural differentiation. Parameters contained within the model inevitably affect outcomes. For example, specific road speeds adopted influence catchment size, as too does the threshold travel time chosen (Luo, 2004; Yang et al., 2006). Any variation in parameters (e.g. specifying different road speeds for different times of day) requires model recalibration. Furthermore, Langford and Higgs (2006) demonstrated that differing spatial representations of population within the 2SFCA model also affects accessibility estimates. In their study of access to GPs in three Unitary Authority areas in Wales they showed that a more accurate model of population based on 'dasymetric mapping' can cause significant spatially variations in final accessibility scores.

More recently Luo and Qi (2009) note two limitations of 2SFCA. First, the assumption of equal access within a catchment, and second that locations outside a catchment have no access at all. They introduce an enhanced two-step floating catchment area (E2SFCA) technique by adding a distance-decay parameter into the model. This assigns geographical weights in both steps of the process. Both the magnitude of weightings and the position of break points used in their discrete (stepped) function can be varied according to the nature of the service being considered. They also note that catchment size might be varied in step 1 or step 2 of the methodology. Deciding how these parameters should be set introduces new dilemmas and, as the researchers suggest, "...to properly address these issues, detailed surveys of actual utilization of health services would be necessary" (Luo and Qi, 2004; p. 1105).

The same shortcomings of 2SFCA were identified by McGrail and Humphreys (2009a) who, whilst recognising its strengths over simple population-to-provider ratios, caution against its use in rural areas. Examining primary care provision in rural Victoria, Australia, they demonstrate problems arising when catchment areas are set too small, and suggest step 2 catchments could be made larger to account for the fact that rural populations often accept the need to travel further to access services. Similarly, they make a case for some catchments in step 1 to be larger given that facilities in towns in rural regions provide services to larger, more isolated, hinterlands. However, increasing catchment size exacerbates the assumption of equal access within catchments such that "...using a large catchment size, the 2SFCA method measures 'choice' rather than accessibility in these sparsely populated areas" (McGrail and Humphreys, 2009a; p. 537). Like Luo and Qi (2009) they advocate a distance-decay function to account for within catchment impedance, and dynamic catchment sizes to reflect 'expected' service and population catchments (p. 539). Once again detailed empirical data on service utilisation is needed to justify the setting of such parameters. As this is rarely available, the "decision points" used in improving the method remain based on local or anecdotal evidence (McGrail and Humphreys, 2009b). Despite these concerns, McGrail and Humphreys (2009a; p. 540) suggest "...the 2SFCA method provides the best available framework upon which an improved measure of spatial accessibility can be developed".

One under-researched area in accessibility studies is that of incorporating public transport timetables into the analysis. Research to date using 2SFCA, as with most of the accessibility measures highlighted above, has tended to assume travel by private car and not public transport. Models tend to use travel times based on road length with average speeds allocated according to road type. Hence the main impedance in the model is the nature of the road network. Recent research in the UK has demonstrated how public transport timetables could be incorporated into measures of health services accessibility (e.g., Martin et al., 2002, 2008; Lovett et al. 2002; Haynes et al., 2003). Martin et al (2008) demonstrate the complexity of analysis involved in translating digital timetable data structures into the formats needed to conduct analysis within a GIS. Despite these difficulties they show how bus timetables used in real-time journey planning could be used by accessibility analysts to study social and spatial variations in public access to a hospital in Devon. In the absence of detailed passenger information on change of service and waiting times information these calculations remain only approximations. Nevertheless those sections of the community with the greatest health needs are more likely to use public transport and a full analysis of access to health services needs to take such factors into account. As Martin et al., (2008; p. 2513) state "...it is important that the current state of accessibility modelling be developed so as to better incorporate the reality of travel by public transport". Incorporating public transport travel into FCA-based access measures would seem a fruitful area for further research. Our preliminary ideas on how this could be accomplished within a GIS package are developed in the following sections.

4. Implementing accessibility analysis within ArcGIS

Despite the widespread popularity of 2SFCA accessibility measures in recent research literature they are not yet readily available as an analytical tool within GIS packages such as ArcGIS. To meet the research objective of extending the current FCA based literature it was first necessary for us to develop a bespoke capability to compute 2SFCA (and E2SFCA) metrics. Wang and Luo (2005) demonstrate that 2SFCA can be implemented as a sequence of relational joins inside a GIS, but we elected to utilize the VBA programming language embedded within ArcGIS. The chief advantage of this approach is the power and flexibility that a full programming environment provides for rapid modification and development of FCA methodology. Furthermore VBAs event-driven environment offers rapid windows interface prototyping giving the potential to develop a fully integrated user-friendly FCA tool within ArcGIS. However, at this point in the research cycle we need maximum flexibility in developing FCA methodology and therefore currently use a combination of menu-driven ArcMap tools together with the bespoke VBA code. In future the network analysis operations could be combined to create a fully stand-alone FCA accessibility tool for ArcGIS.

To conduct 2SFCA (or E2SFCA) using our VBA macros requires the user to:

1. Load appropriate datasets into the OD (Origin-Destination) matrix analysis tool in Network Analyst Extension. This uses a supplied road network and user-specified parameters to compute the shortest network route between each origin and destination point, subject to a specified maximum distance threshold.

   OS MasterMap™ Integrated Transport Network (ITN) layer is used to create the network topology dataset. *Origins* consist of points representing population demand centres (e.g. Output Area population-weighted centroids) and *Destinations* are points representing service provision centres together with appropriate attributes (e.g. NapTAN Bus Stops with total number of visits per week).

2. Configure and solve the OD matrix. In particular FCA catchment size is specified at this stage using the ‘default cutoff value’ parameter. Its value will depend on the analysis undertaken. So, for example, 400m might be used to analyse accessibility to bus stops, whilst 5000m might be more appropriate if studying Hospital A&E facilities. Whether spatial impedance will be based on distance or time is also specified here.

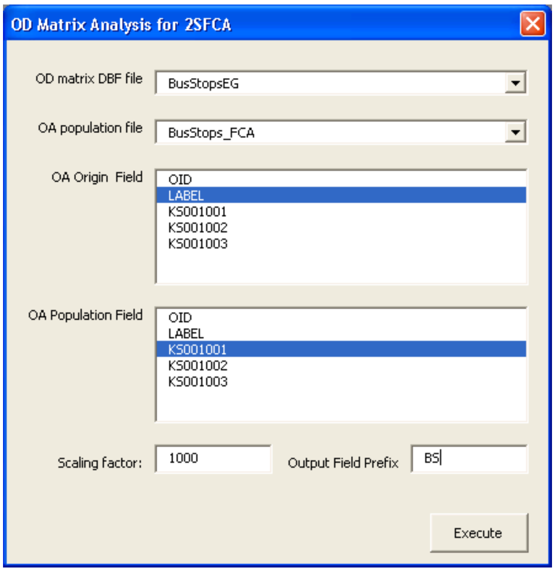
In other words network routing can minimise travel distance or time when traversing between points. Whichever is selected, computed routes can still report both their length and their travel time in the final output.

3. Access our bespoke VBA routines via a simple button on the ArcMap toolbar to compute various accessibility metrics (documented below) from the OD matrix. Results are appended to a demand centre attribute table.

At the time of writing, the VBA tool computes the following accessibility metrics:

2SFCA accessibility score
E2SFCA accessibility score
Distance to nearest facility
Travel time to nearest facility
Number of facilities within specified catchment size
Average distance to facilities within specified catchment size

Figure 1 illustrates the VBA tool's simple interface and shows an example of the output.



Attributes of BusStops_FCA

OID	LABEL	KS001001	KS001002	KS001003	BSTwoStep	BSNearest	BSQuickest	BSChoice	BSAverage
0	00PFRM0002	311	155	156	3.920866	57.75108	0.097872	5	487.4389
1	00NZMW000	332	163	169	6.00343	121.88221	0.219827	7	311.08749
2	00NNTD0006	172	91	81	0	0	0	0	0
3	00PFQT0003	307	151	156	0	0	0	0	0
4	00NZMT0004	317	153	164	25.236593	198.25473	0.335988	8	561.31219
5	00PBPQ0004	331	167	164	5.559166	266.75974	0.439398	13	640.64069
6	00PFRA0002	280	141	139	2.803134	491.18076	1.119275	14	700.19885
7	00PBNJ0002	351	187	164	3.27425	579.73993	1.493722	6	743.20111
8	00NZNA0004	330	161	169	11.815925	81.106865	0.137454	13	500.21149
9	00NZNA0002	277	140	137	9.411847	337.54306	0.768159	13	642.87317
10	00PFQM0002	404	191	213	2.651643	301.10757	0.510295	14	678.74469
11	00PFQH0008	335	171	164	4.456415	243.4493	0.41258	11	491.52405
12	00PFQH0001	278	137	141	4.456415	119.71545	0.202885	11	470.69608
13	00PHME0012	284	141	143	23.353806	88.802505	0.058086	11	491.09393
14	00PFPK0004	366	180	186	4.67306	867.66888	1.048887	3	926.87335

Record: 0 Show: All Selected Records (0 out of 1495 Selected) Options

Figure 1: Implementing 2SFCA analysis within ArcGIS

Enhanced two-step floating catchment area (E2SFCA) scores are a recent development of the 2SFCA methodology and require further explanation. Suppose there are *n* service points and *m* population demand points, and that d_{ij} is the distance between demand point *i* and supply point *j*. We can construct, via a function to be discussed shortly, a matrix ***W*** containing a geographical weighting w_{ij} between each demand point *i* and supply point *j*.

Let the population count at a demand point be $\mathbf{p}_i$, and the quantity of provision (e.g. number of GPs at a surgery; number of buses visiting a bus stop each weekday) at a supply point be $\mathbf{s}_j$

Step one computes the population-to-provider ratio, R_j, for each supply point:

$$R_j = \frac{s_i}{\sum_{i=1}^{n} p_i \bullet w_{ij}} \qquad \text{for } j = 1 \text{ to } n$$

Step two computes the accessibility score, A_i, for each demand point:

$$A_i = \sum_{j=1}^{m} R_j \bullet w_{ij} \qquad \text{for } i = 1 \text{ to } m$$

The difference between 2SFCA and E2SFCA is the nature of the geographical weights in matrix ***W.*** In 2SFCA these are specified as:

$$w_{ij} = 1 \qquad \text{if } d_{ij} <= d^t$$
$$w_{ij} = 0 \qquad \text{otherwise}$$

where d^t is the user-specified catchment size (distance or time), and d_{ij} the actual distance (or time) between demand point *i* and supply point *j*. This dichotomous weighting model can also be described as a 'brickwall' filter. All locations inside the floating catchment area are counted with equal weight (i.e. without spatial impedance). Which implies people are equally willing to travel to a supply point irrespective of distance provided it is within the threshold, but are totally unwilling to access it beyond the threshold. Such a sharp differentiation of behaviour is probably unreasonable − consider the case of a point *just inside* versus one *just outside*. Similarly, 2SFCA treats a supply point very close to a population demand centre as equally attractive and thus equally likely to be utilized as one lying just inside the threshold distance.

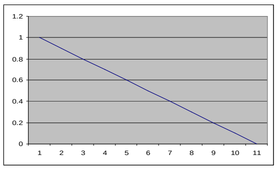
E2SFCA modifies geographical weightings in ***W*** to provide spatial impedance. This imparts a number of attractive properties to the accessibility estimation: Nearby service points are deemed more attractive than distant ones; the sharp dichotomous cut-off at the threshold distance is eliminated; and unlike a classic gravity model there remains a spatial limit of influence. However, it also raises the issue of what form the distance decay function should take, and how it should be implemented.

Luo and Qi (2009) used a discrete stepped function consisting of three zones with weights based on the Gaussian decay curve. McGrail and Humphreys (2009a) proposed a similar stepped approach with two-zones consisting of an initial period of zero decay followed by a linear decline to zero at threshold distance. We prefer to use a continuous decay function, but its precise form remains a matter of choice; some possible candidates are:

Simple linear decay

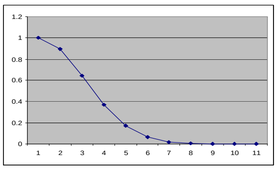
$$w_{ij} = (d^t - d_{ij}) / d^t \qquad \text{if } d_{ij} <= d^t$$

$$w_{ij} = 0 \qquad \text{otherwise}$$



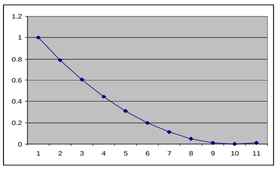
Gaussian decay

$$\mathrm{Exp}(-d_{ij}^2/d_t^2)$$



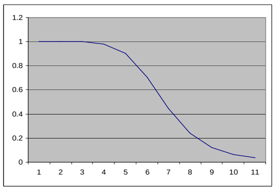
The Bi-square function

$$[1 - (d_{ij}/d_t)^2)]^2$$



The Butterworth filter

$$1 / [1 + \varepsilon\, (d_{ij}/d_t)^n]$$

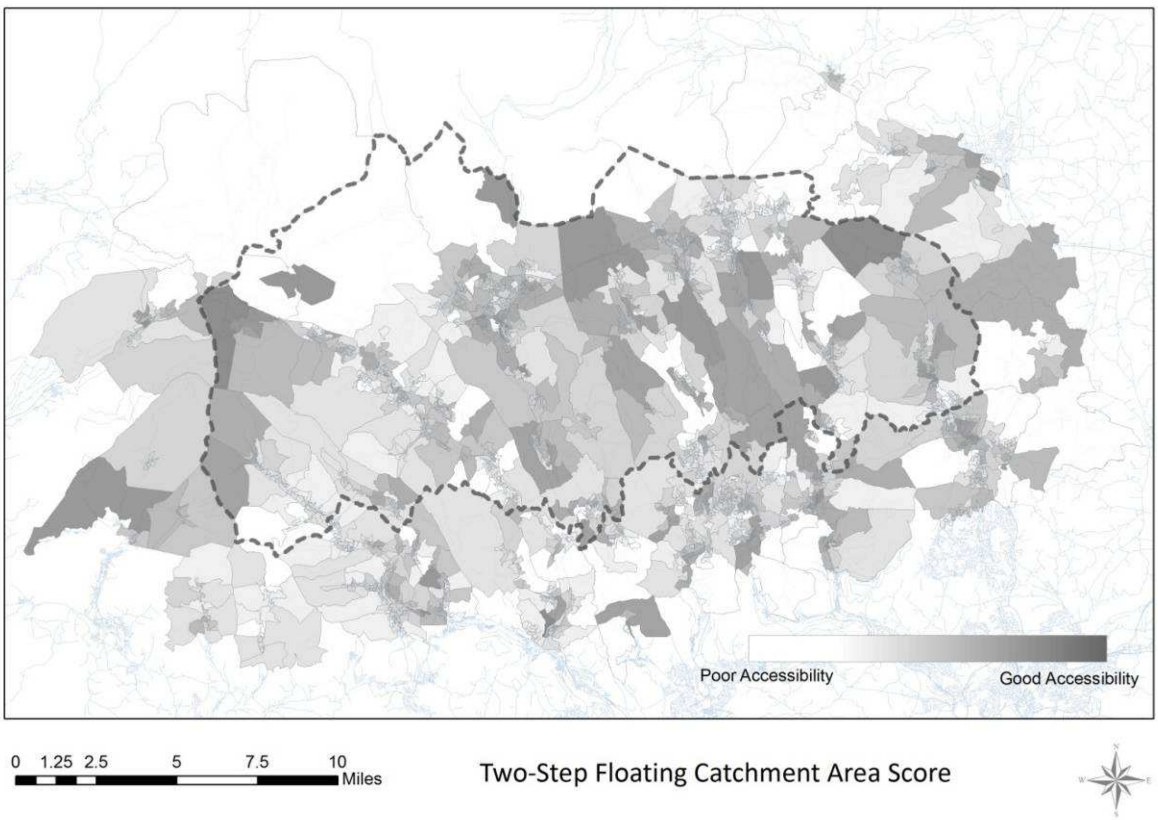


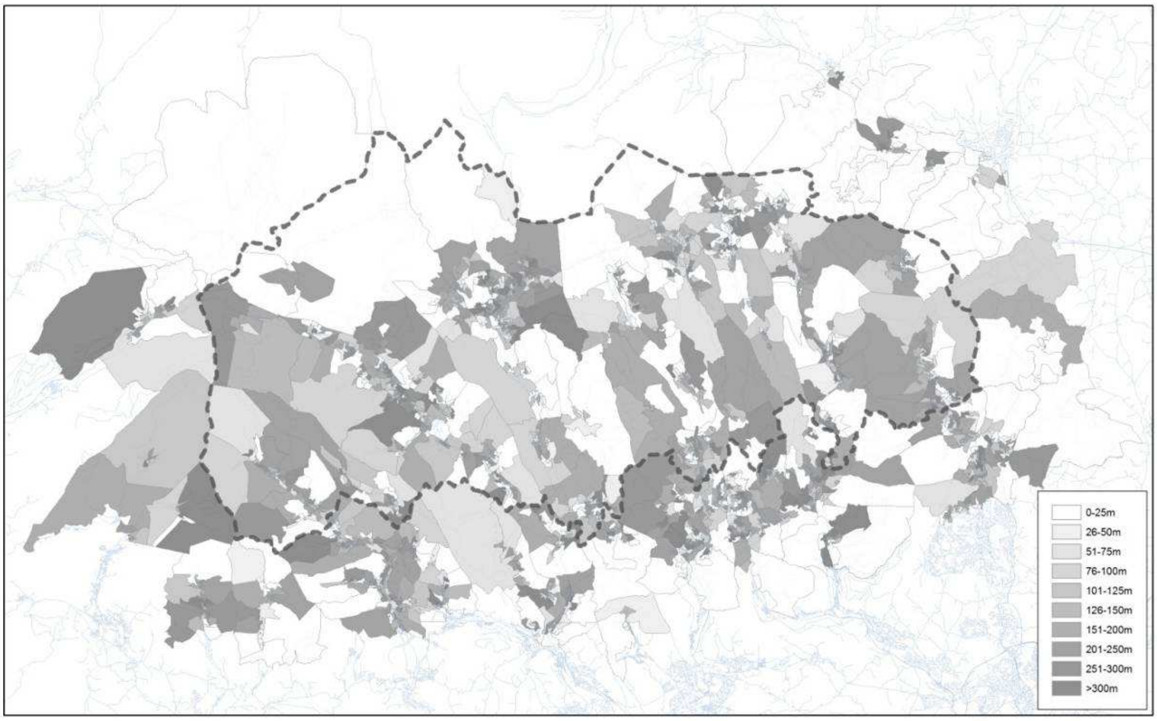
Currently our VBA macro implements all these decay functions. The Butterworth filter is a continuous function that mimics the two-zone model proposed by McGrail and Humphreys. It consists of a flat ‘pass-band’ region with no spatial impedance, followed by a smooth decay in a transition zone such that zero is reached at the threshold distance.

5. Calculating Accessibility Measures for the Heads of the Valleys

To demonstrate the potential for FCA-based accessibility scores in locality areas being studied under the WISERD research initiative we applied them to the Heads of the Valleys region. Datasets assembled in ArcMap include the OS MasterMap™ Integrated Transport Network (ITN) layer with network topology built in ArcCatalog; 2001 UK Census population data (Output Area population weighted centroids); and a National Public Transport Accessibility Network (NapTAN) database of bus stops and other public transport access nodes maintained by Thales Information Systems for the Department for Transport. Using a floating catchment size of 800m, accessibility scores for bus stops in the Heads of the Valleys locality are shown in Figure 2.

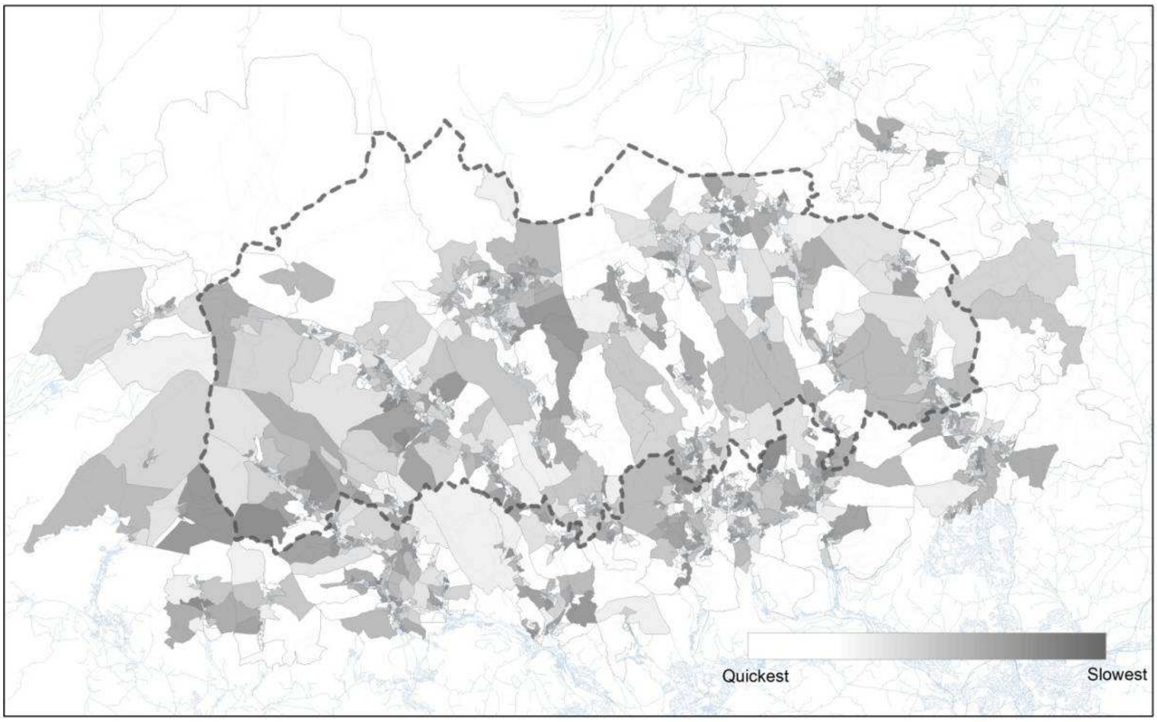
Figure 2: Outputs from FCA analysis for the Heads of Valleys (access to bus stops)





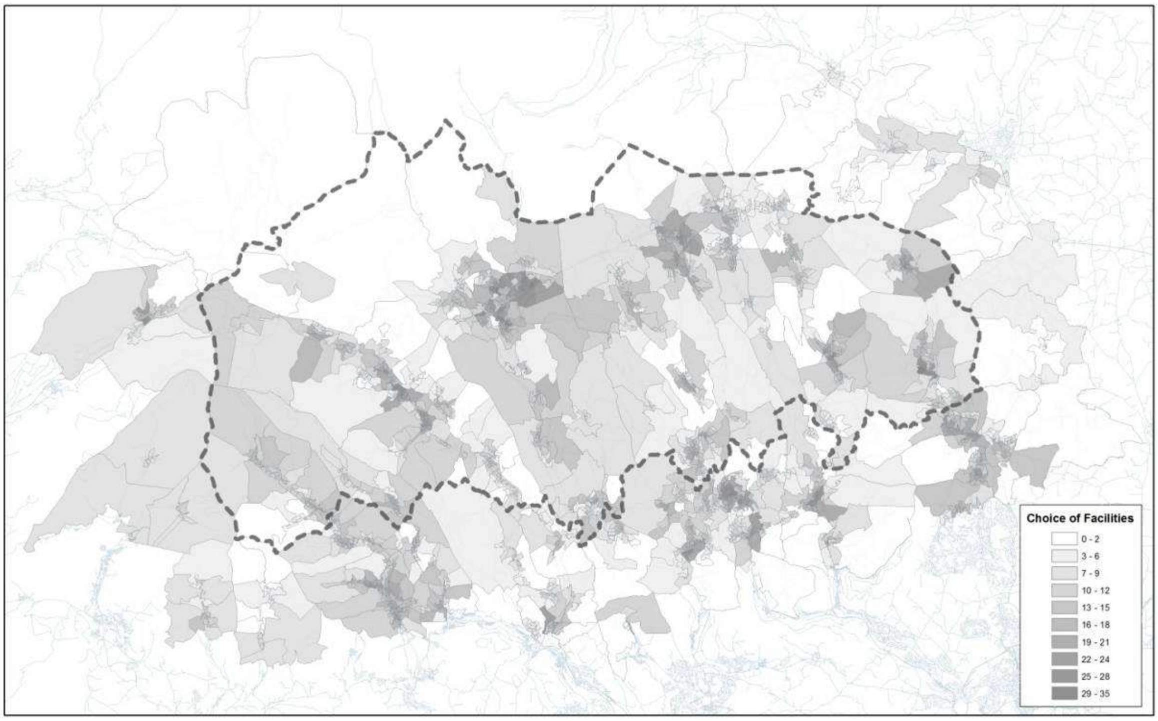
0 1.25 2.5 5 7.5 10 Miles

Distance to Nearest Facility

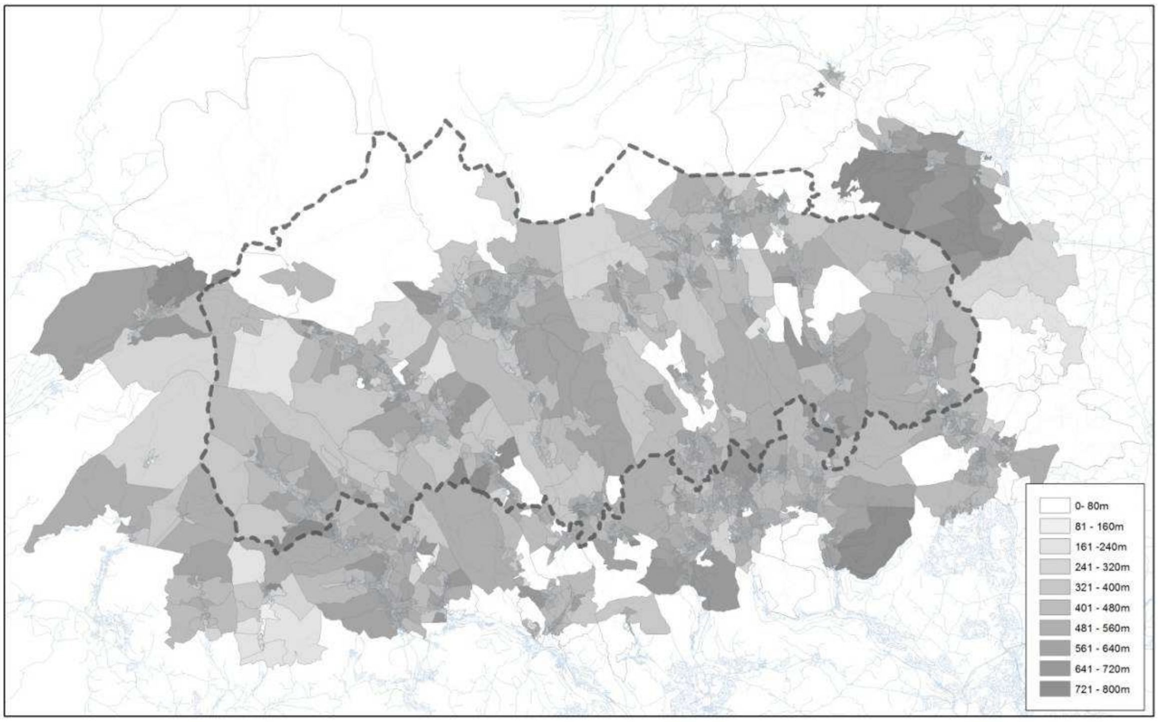


0 1.25 2.5 5 7.5 10 Miles

Quickest Access to Facilites



Choice of Facilities



Average Distance to Facilites

The ‘standard’ distance used in many transport accessibility studies is 400m (see Hsiao et al., 1997; Murray, 2001; Horner and Murray, 2004) which is assumed to be the maximum distance people are prepared to walk to a bus service. Clearly we can experiment with different walking distances using this tool. These maps clearly demonstrate that ‘accessibility’ is a difficult concept to precisely define and measure, even inside a GIS, as discussed in Sections 2 and 3 above. Whilst broad spatial patterns may be consistent between maps notable differences arise locally depending on which metric is adopted. Important research questions remain. For example, in terms of access to the public transport system will potential users be more concerned with distance to their nearest bus stop, or just how quickly they can reach it? Do residents feel they have greater accessibility if given a wider choice of bus stops to travel to? Do they take account of the average distance to all nearby bus stops or only the distance to the closest? The 2SFCA score calculated here incorporates an estimate of the demand side input (i.e. how many people a bus stop potentially serves), but do residents consider such nuances in their perceptions of accessibility? Do the patterns and spatial variations in these accessibility scores relate to wider socio-economic characteristics of the populations or locations being served? These and other questions are considered in our exploration of a research agenda that follows.

6. Potential advancements to FCA methodology

Accessibility to services is a function of a combination of factors related to the supply characteristics of the service under consideration (including availability, quality, etc), the demand or need for that service from a population located at geographically defined locations, the impedance of the transport network in facilitating access and the ability of people to reach such services within constraints imposed by, for example, finances and time. A full consideration of such issues is not easy to measure within a GIS – collating such a cross-sectional database to investigate all aspects is far from trivial. This is compounded by the changing nature of each of these factors, not least changes in demand/supply relationships over time. Here we are concerned with proposing a research agenda which we suggest could form the basis of a more comprehensive study of accessibility to services in Wales and beyond. In section 3 of the paper we drew attention to recent research which suggested improvements to FCA methodology. In this section we also suggest avenues of research which may be more widely applied to the use of such measures in analysing access to public services.

6.1 Incorporating public transport timetables

Although there is an increasing research interest in the development of non-motorised accessibility measures (Talen, 2003; Iacono et al., 2010), most studies to date have developed measures based on travel by private transport. Relatively few researchers have attempted to extend these measures to take into account the routes and frequencies of public transport. In order to consider the importance of public transport on accessibility we need information on the frequency of service and proximity to access points such as bus stops and railway stations. Such route and timetable information is increasingly available in digital form to support national travel enquiry systems such as Traveline Cymru (http://www.traveline-cymru.info/).

They are also being used by the Department of Transport to develop core accessibility indicators in England to calculate public transport travel times from each census output area to selected destinations and to calculate accessibility indicators at LSOA level describing travel times to services (Department for Transport, 2009). Service types include primary schools, secondary schools, further education, GPs, hospitals, food stores and employment centres.
http://www.dft.gov.uk/pgr/statistics/datatablespublications/ltp/coreaccessindicators2008).
Population characteristics of the output area are also taken into account for access to several of the services for certain 'target groups'. Public transport data is also used by local authorities to create accessibility profiles/strategies for their areas using software tools such as Accession as part of their Local Transport Plans. Martin et al (2008) suggest that the advantage of using such data is that they take into account probable congestion levels at certain times of day and are therefore likely to give a more realistic picture of actual transport opportunities.

Research currently being undertaken within WISERD is examining the potential to include public transport information into the FCA methodology. Traveline Cymru have provided data for Merthyr in Association of Transport Co-ordinating Officers (ATCO) Common Interchange Format (CIF). These files contain the geo-coding for each segment of a bus's route and the ID and geo-coding for each bus stop the route serves. There is a separate file for each service and the file is structured as data on stops, journeys and times. Martin et al (2008) showed how ATCO files could be restructured for use in accessibility analysis using Microsoft Visual Basic. Converting such data into useful maps related to for example service frequencies within ArcGIS, is far from trivial however. Figure 3 illustrates one such route with bus stops for Merthyr. Our current research is incorporating such data into the FCA calculations.

Figure 3: Example of public transport route for Merthyr Unitary Authority area

6.2 Population Assignment Model

In the absence of individually georeferenced residential addresses, traditional approaches to measuring accessibility use census area centroids as population demand points; especially those studies conducted at national or regional levels (see Vandenbulcke et al., 2009). Others have used postcode/zipcode point references which offer a finer spatial resolution. However, in both methodological approaches there remains the basic problem of the inherent assumption that all individual households in a census area (or postcode) have the same level of accessibility since trips are assumed to originate from a single point. The recent emergence of detailed geo-locational data for addresses, such as OS MasterMap ADDRESS-LAYER2 in the UK, which provides a spatial coordinate to a resolution of 0.1 m for each address, means that locations of individual residences can potentially be used for accessibility calculation. However, socio-economic characteristics of individual members of that household are typically not available so measuring potential implications of inequalities of accessibility by need remains problematic. Some studies have considered the importance of population assignment technique on the estimation of total population with access to public transport (e.g. Horner and Murray, 2004) but more work is needed to explore the use of disaggregate population representations in FCA and this will be one focus of our future research.

6.3 Aspatial characteristics of demand points

The limitations of physician to population ratios have been long recognised (e.g. Makuc et al., 1991). Some studies suggest the need for a wider consideration of non-spatial factors in refining measures of access (Wang and Luo, 2005; McGrail and Humphreys, 2009b). One criticism of 2SFCA is that it does not incorporate measures of health needs for different population sub-groups, or how such needs vary spatially. McGrail and Humphreys have suggested variations in such needs can be incorporated into step 1 of 2SFCA by increasing/decreasing the denominator in deriving R_j. More research is needed to incorporate such socio-economic characteristics particularly tailored to the service in question rather than the total population. Similarly the mobility of populations could also be incorporated into 2SFCA methodology (Yang et al., 2006). One aspect of this is car ownership or household car availability, and McGrail and Humphreys (2009b) suggest varying catchment sizes used in step 2 according to car ownership levels so as to reflect population mobility. In this way 2SFCA can include the implications of mobility disadvantage on access through decreased catchment size. Once again, however, the emphasis is on the requirement for empirical data to justify decisions on parameter settings. This becomes a significant problem when a range of services is considered and, as McGrail and Humphreys

(2009b; p. 9) suggest "...currently there is little empirical evidence to guide definitive decisions". In our future research we will be exploring the use of denominators which take such factors into account.

6.4 Characteristics (including temporal) of supply points

A number of studies have explored methods for incorporating time-space methods into accessibility analysis. Weber and Kwan (2002) examined how variations in commuting times and opening hours of services could be modelled in a GIS. This provided more realistic estimates of accessibility using an activity-travel diary dataset for Portland, Oregon and included factors such as commuter congestion. In relation to the examples presented in this paper of accessibility to public transport facilities, bus-stops might be weighted according to the frequency of service; a basic measure of attractiveness of each stop. This in turn could be used to address queries such as *Will residents choose a more distant bus stop with a higher bus frequency than a closer stop with a lower level of service?* Clearly areas could be close to a bus stop (in terms of network distance) but retain poor accessibility due to low bus frequency. This may not just be a rural phenomenon but may also be the case in some peripheral sub-urban estates exacerbating problems of social exclusion and deprivation. Similarly, another aspect often neglected is the quality of service offered at a destination – most models assume facilities are equally desirable. In the absence of data on the quality of provision, researchers assume individuals will access their closest facility when in reality this may be overlooked for a service perceived to be of a better quality or one where more services are provided. This may relate, for example, to the opening times of a facility or to characteristics of the service provided (e.g. number of doctors at a practice, health services offered at a practice). We will be exploring the influence of supply side characteristics in relation to public transport accessibility in our future research.

6.5 Distance decay parameters

Luo and Qi (2009) and McGrail and Humphreys (2009a) have both suggested enhancements to 2SFCA methodology by incorporating a distance decay function. As suggested by Vandenbulcke et al (2009; p. 52) "...the distance decay functions used in potential measures have the advantage of incorporating assumptions on individual's perceptions of transport." The exact nature of the distance decay function can only be estimated empirically with data derived from specific surveys. However, in practice most studies assume equal access or a linear weighted decline in the decay function when, in reality, the situation may be more complex. Our VBA macros described in Section 4 already have the capacity to utilise a number of continuous decay functions as described earlier.

One avenue for more research is to examine how sensitive any results from FCA techniques are to the exact form of decay function used.

7. Integrating modelled accessibility measures with qualitative data: A mixed methods approach?

Measures like 2SFCA are primarily concerned with geographical or physical accessibility to services. Whilst spatial patterns in demand and supply, and the existing transport network, lends themselves to such an approach researchers such as Penchansky and Thomas (1981) have drawn attention to the importance of other factors in providing a fuller picture of accessibility. Barriers imposed, for example, by an individual's acceptability, attitudes and affordability to different services are likely to influence resultant utilisation patterns and need to be seen in the light of wider socio-political processes. A consideration of such factors could lend itself to a combination of quantitative and qualitative approaches and could be guided by and benefit from both the GIS-based measures derived in this study and an input from survey and ethnographic data sources. One under-researched dimension relates to user perceptions of service. These reflect factors such as the quality of provision but are likely to be influenced by geography too if services are perceived to be distant or unattainable (for example through poor transport links or limited opening times) or to offer limited choice of goods or competition. A person's perception of accessibility to (nearest) services, based on their previous experiences could therefore lend itself to a qualitative analysis that could provide an interesting comparison to the quantitative methods highlighted above.

Some studies have already looked at modelled access in relation to perceived access; Jones et al (2009) considered green-space provision in Bristol and found a discrepancy between modelled and perceived access for residents in more deprived areas, suggesting distance alone was not the only consideration in predicting usage levels by those residents. This led the researchers to suggest "...interventions may be most effective if they target the perceptions and needs of residents of deprived neighbourhoods" (Jones et al., 2009; p. 500). Others have investigated whether perceptions of access to healthy food opportunities relates to actual provision for racial and ethnic minorities (Freedman and Bell, 2009). A standard methodological technique involves the analysis of the provision of services and/or health-promoting opportunities in relation to area level characteristics derived from census data. These studies, as with many ecological investigations of this nature, have the drawback that results can be influenced by the location of census boundaries, although others have examined the sensitivity of findings to perceived and neighbourhood-derived boundaries (e.g. Cho and Choi, 2005). Thus qualitative methods can be used together with GIS to create boundaries which take into account local knowledge and experiences.

Other studies have drawn attention to the importance of resident behavioural patterns and beliefs when comparing perceived versus GIS-generated accessibility measures. They suggest public self-reports of proximity to environmental resources may be questioned and that such judgements may be "...shaped by their social and personal significance" (Macintyre et al., 2008b; p. 1). Where perceived accessibility is poor, for example, this could either confirm or contradict a modelled estimate based on GIS approaches and thus lead to further investigation. Reasons might include inaccuracies in residents' estimation of distance (McCormack et al., 2008), their local knowledge or residential history, or may reflect user experiences or beliefs regarding services or their characteristics (Lackey and Kaczynski, 2009). Macintyre et al (2008a) were able to investigate this further as part of their wider *West of Scotland Twenty-07 Study: Health in the Community* study which used three cohorts to explore social differences in health. Data was collected for respondents which aimed to explain reasons for differences in perceived and actual access derived from GIS-based analysis of green parks in Glasgow. Where questions on perceptions of services form a component of cross sectional surveys, such as the *Living in Wales* survey (see below), quantitative techniques can be used to examine spatial variations in the relationship of perceived to modelled access. This may include investigating this relationship by urban/rural status or by socio-demographic variables and could be further investigated in ethnographic face-to-face interviews with residents in locality studies. Both approaches are considered in the following sections.

7.1 Cross-sectional analyses of modelled accessibility with survey data (the example of Living in Wales)

Living in Wales (LiW) is an annual survey carried out by Ipsos-MORI for the Welsh Assembly Government. It is described as the "main source of information on households and the condition of homes in Wales" (Welsh Assembly Government website). Household surveys were undertaken annually from 2004 to 2008 and property surveys conducted in 2004 and 2008. Topics in the household survey vary from year to year. The survey is made up of an interview with the Household Reference Person (HRP) or another adult in the household, and for some respondents, a follow-up visit is made by a qualified surveyor to undertake a statistical property assessment of their home. Results have been published by the NAW in Findings and Technical reports on, for example, *Citizens Views on Public Services* based on sub-samples of respondents. For example, the 2007 Citizen Survey conducted as part of the

Living in Wales survey has been used to gauge public opinion on their interaction with eight publicly available services. More generally findings from the household surveys are published as Statistical Releases (Welsh Assembly Government, 2008a) and summary data for Wales provided as Excel spreadsheets on the Assembly web-site with responses weighted to represent Wales.

The LiW surveys of 2006, 2007 and 2008 included questions which inquire as to actual usage and satisfaction with local bus services, GP surgeries, hospitals, all health services, recycling, sport and leisure and all Local Government services. These tend to be classified on a Likeart scale and cross tabulated with service user characteristics at the all-Wales level (see Table 2). For example a recent report drew on findings from the 2008 LiW survey to address which kinds of service users found it most difficult to get to and from a GP surgery (Welsh Assembly Government 2008b). This study found that varied significantly by various service user characteristics. Binary Logistic Regression was adopted in order to explore which service user characteristics remained significantly associated with satisfaction once other characteristics included in the model were held constant. Thus, for example, those who reported a limiting long term illness and were not working, those living in mid Wales, those with a relatively low socio-economic status experience greater difficulties in access. Of immediate relevance to the modelled surfaces included in section 5 of this paper, a question in both the 2006 and 2008 survey asks "*How easy or difficult is it to get to and from your nearest local bus stop?*". The findings from this part of the survey were used to gauge user experiences of public transport in Wales (Welsh Assembly Government 2008b). Thus it is possible to gauge actual use and perceptions of access for different socio-economic groups and to establish those users who find it most difficult, for example, to access a local bus stop.

However, a potential problem for in-depth local analysis with LiW is the spatial scale at which survey responses can be investigated. The only published spatial identifier is the Lower Super Output Area (LSOA) with inevitably some LSOA's having no respondent counts. In addition, the LiW survey has been replaced from 2009-10 by the National Survey for Wales. However, if access to the original data was possible, one potential avenue for research could involve generating modelled access scores for all unit postcodes in Wales to a particular service using the FCA methodology described in section 4 and matching this with the respondent's postcode in the LiW survey. This could subsequently be used to examine whether the perceived to modelled access relationship varies with, for example, rural/urban classification or census deprivation scores. GIS and statistical approaches could thus be used to analyse relationships between perceived and modelled accessibility and to study spatial distribution in perceived access across Wales.

7.2 Combining ethnographic data from locality studies

The modelled analysis of accessibility scores documented above has the potential to both inform, and benefit from, locality-based studies. Firstly such analysis can provide context (or baseline audits) for detailed household interview schedules, highlighting areas of particularly poor (or good) access to specific services guiding further in-depth investigation to see if modelled access values match individual experiences. As Farrington and Farrington (2005; p. 2) suggest

"the empirical measurement of accessibility does offer an informative background to discussion. Quantification of accessibility levels by measuring the opportunities available to defined people living in defined locations, and their ability to reach them by transport or other means …highlights at least the broad tapestry".

Secondly, more research is needed to combine quantitative accessibility measures with ethnographic information collected in locality-based studies and analysed in qualitative packages, and in particular to compare such measures with references to place extracted from field notes and transcripts. Matthews et al. (2005), for example, explored the use of geo-ethnography which examines actual or realised activity patterns, particularly in the context of low-income families. An area where such research has real potential is in the calculation of space-time accessibility measures where, using individual or household activity travel surveys, barriers to accessing services can be explored to examine change in measures over time. There have been a number of studies that have investigated the use of exploratory spatial analytical and visualisation techniques such as standard deviational ellipses in conjunction with such micro-data to study behavioural processes especially in urban contexts (Buliung and Kanaroglu, 2006, 2007; Kwan, 2000). Such techniques measure an individuals' access at a particular time and space and have been used to estimate, for example, daily activity spaces for different individuals within a family in relation to their employment, shopping patterns or health service utilisation patterns (Matthews, forthcoming).

Traditionally more resources and data have been needed in order to measure activity spaces; however, the use of mobile technologies, particularly Global Positioning Systems (GPS) to collect longitudinal data, in conjunction with network analysis within GIS, has led to renewed interest in measuring individual level accessibility measures building on the work of Kwan (1998, 1999, 2000, 2004), Kim and Kwan (2003) and Miller (1999). A recent example of this type of application is the Urban Diary project (Neuhaus, 2009) and such techniques are increasingly being used in health studies to examine activity spaces in relation to various aspects of urban design or health-promoting opportunities (Sherman et al., 2005). Whilst the need to examine ties to non-residential places have a solid theoretical grounding based on the inadequacies of census tracts as spatial “containers”, they are more difficult to measure given the need for individual level data. Ethnographic techniques have the potential to provide locational information which can link with GIS. Kwan and Ding (2008) provide an example of how GIS-based narrative analysis (‘geo-narrative’) can be used in combination with qualitative 3D GIS and time-space techniques to study the lives of Muslim women in Columbus, Ohio. They demonstrate how biographies, family history and daily activities as analysed in qualitative packages such as NVivo and Atlas-ti can be combined with GIS to provide a more comprehensive analysis of accessibility patterns. Another focus of recent research has been on the integration of qualitative techniques and GIS to examine space-time variations using travel diary surveys in order to explore ideas of ‘personal accessibility’ (Elgethun et al 2007; Kwan and Weber, 2008).

8. Conclusions

Accessibility measures provide decision-makers and planners with an important tool with which to investigate spatial inequalities in public and private service provision and to monitor the impact over time of policies designed to improve access. The primary aim of this paper is to draw attention to the potential of integrating GIS-modelled accessibility with qualitative data relating to perceptions and actual use of services in a locality. Clearly many aspects of accessibility may not necessarily have a geographical dimension. For example, previous studies have drawn attention to the importance of financial and cultural barriers to accessing health services (Jatrana and Crampton, 2009). Here we have been primarily concerned with measures based on potential interaction between supply and demand locations, illustrated with reference to one technique which is increasingly used in health applications in particular (the floating catchment area (FCA) technique). This is just one of many accessibility measures, each of which has its advantages and limitations. In this study, FCA methods have been applied to analyse access to public services in one of the locality areas being studied in the WISERD research initiative (the Heads of the Valleys) and we discuss how basic FCA methodology can be modified and improved on (for example through innovative methods of integrating public transport timetables).

We then present our preliminary ideas on how such metrics can be integrated with qualitative sources and methodologies to generate a fuller picture of the types of factors influencing the utilisation of services. In particular, we highlight the potential for linking with the results from surveys conducted at the all-Wales level which ask respondents about perceptions of services. We suggest that the comparison of residents' perceptions with modelled access is very much an under-researched theme, and one which would benefit from a mixed methods approach based on qualitative GIS methodologies. We further draw attention to the potential to link such findings to those of the ethnographic surveys currently being conducted with stakeholders and households across localities in Wales as part of the WISERD initiative.

Table 1: Measurement of Accessibility (with examples from health sector)

Approach	Definition	Health Example
Container	The number of facilities contained within a given unit	Number of GP surgeries in census ward
Coverage	The number of facilities within a given distance from a point of origin	The number of hospitals 10km from a population centroid
Minimum Distance	The distance between a point of origin and the nearest facility	Distance between village centre and nearest pharmacy
Travel Cost	The average distance between a point of origin and all facilities	Average distance between centroid of census tract and all GP surgeries
Gravity	An index in which the sum of all facilities (weighted by size or supply side characteristics) is divided by the 'frictional effect' of distance	All GP surgeries (weighted by list size) or those with, for example, specialised services or female GPs, divided by distance

Adapted from Talen (2003)

Table 2: Living in Wales (LiW): questions asked in each survey which have an accessibility dimension

2006 LiW questionnaire:

MTCG7	How easy or difficult is it to get to and from your nearest local bus stop? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
TP1	About how long would it take you to walk from here to the NEAREST bus stop? I am interested in the nearest one even if it isn't the main one you use. *3 minutes or less; 4-6 minutes; 7-13 minutes; 14-26 minutes; 27-43 minutes; 44 minutes or longer; Don't know*
MTCA9	How easy or difficult was it to get to and from your GP surgery? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
MTCB2	How easy or difficult was it to get to and from the hospital in which you/they received treatment? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
MTCE4	Overall, how easy or difficult is it for <u>YOU</u> to get to and from {child's} primary school? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
MTCF4	How easy or difficult is it for YOU to get to and from {child's} secondary school? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
MTCI7	Overall, how easy or difficult is it to get to and from local sports and leisure facilities? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*

2007 LiW questionnaire:

MTCM12	How easy or difficult was it to get to and from the dental practice? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
TP1	About how long would it take you to walk from here to the NEAREST bus stop? I am interested in the nearest one even if it isn't the main one you use. *3 minutes or less; 4-6 minutes; 7-13 minutes; 14-26 minutes; 27-43 minutes; 44 minutes or longer; Don't know*
MTCP7	How easy or difficult is it to get to and from your nearest train station in Wales? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion; Don't know*
MTCQ9	Overall, how easy or difficult is it to get to and from your nearest library? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion; Don't know*

2008 LiW questionnaire:

MTCG7	How easy or difficult is it to get to and from your nearest local bus stop? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
MTCA9	How easy or difficult was it to get to and from your GP surgery? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*
MTCI7	Overall, how easy or difficult is it to get to and from local sports and leisure facilities? *Very Easy, Fairly Easy, Fairly Difficult, Very difficult, no opinion*

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