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A Literature Review of the Use of GIS-Based Measures of Access to Health Care Services

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Abstract. The increasing availability of Geographical Information Systems (GIS) in health organisations, together with the proliferation of spatially disaggregate data, has led to a number of studies that have been concerned with developing measures of access to health care services. The main aim of this paper is to review the use of GIS-based measures in exploring the relationship between geographic access, utilisation, quality and health outcomes. The varieties of approaches taken by researchers concerned with teasing out the relative importance of geographical factors that may influence access are examined. To date, in the absence of detailed data on health utilisation patterns, much of this research has focused on developing measures of potential accessibility. This paper then critically evaluates the situation with regard to the use of such measures in a broad range of accessibility studies. In particular, there has been less research to date that examines the relationship between such measures and health outcomes. In the final sections of the paper, I draw on the review to outline areas where a broader research agenda is needed, particularly in relation to more recent innovations in health care delivery.

Keywords: geographical information systems (GIS), potential accessibility, utilisation rates, health outcomes

1. Introduction

One of the key priories in meeting the UK Governments' social inclusion and social justice policy agenda is the requirement for equal access to a range of both primary and secondary healthcare services for disadvantaged groups [18]. In response to this policy agenda, some health organisations are collaborating with local transport authorities in monitoring, evaluating and assessing existing accessibility problems through mapping audits of National Health Service (NHS) facilities and transport provision. As evidenced in the literature reviewed below, medical geographers have had a long-standing interest in the measurement of health care accessibility (see for example [47]). The principal aim of this paper is to review recent research that has examined the use of relatively new software tools in measuring accessibility to health services; namely Geographical Information Systems (GIS). GIS are software tools that enable researchers to input, store, manipulate, analyse and visualise spatial information. The integration of geographically referenced data from a variety of agencies concerned with health issues is enabling researchers to visualise trends and relationships over space and time in order to monitor the influence of government policies such as those aimed at reducing health inequalities. Examples of the use of GIS in public health include those concerned with examining spatial patterns of disease, analysing the potential impacts of noxious facilities on trends in morbidity and mortality in local neighbourhoods and the

use of such tools in emergency planning and ambulance routing. Recently web-based GIS tools have been developed that enable the integration of spatial data, together with analytical and visualisation tools in order to address health concerns in real-time and encourage public participation in public health decision-making. As highlighted below, such tools also have the potential to help residents locate their nearest health facility or one that meets their requirements. Further applications of the use of GIS in the health sector are included in the chapter by Gatrell and Senior [24] and the book by Cromley and McLafferty [17].

Despite a relative large literature on the use of GIS in health applications in general, few have provided an overview of the current state of play with regard to the application of GIS-based measures of access in the health arena and identified potential avenues for further research. It is the aim of this paper to redress this gap by drawing on the existing literature base (using bibliographic health databases such as MEDLINE, EMBASE and CINAHL and by reviewing ongoing and recently completed research papers funded by the NHS and included on the National Research Register) in order to critically evaluate the use of such measures in primary and secondary health care. The paper is concerned with reviewing the current status of techniques to examine and measure accessibility. Whilst recognising the importance of qualitative approaches to analysing access to health care, which take into account non-quantifiable factors such as beliefs and culture, the focus here is on quantitative techniques and, in particular, the use of GIS in such studies. This review has drawn attention to the need for a combination of approaches to fully identify the types of factors influencing the take-up of health care. The majority of studies conducted to date have used GIS-based techniques in order to develop potential accessibility measures. In contrast, there has been much less research concerned with examining utilisation of services using GIS approaches and even fewer studies that have looked at the relationship between such measures and overall health outcomes. The paper outlines factors which may have influenced such trends but also highlights the importance of new developments in data and spatial technologies which offer significant potential in this area. The survey of previous studies that have used GIS to measure access to health services has revealed that the use of such techniques are not confined to developed countries but increasingly, as more detailed data sets become available and the use of technologies such as Global Positioning Systems (GPS) become more widespread, are being used in developing countries. The literature is drawn therefore from many countries with different health care systems and populations such that any inferences about access may not be comparable. The primary concern in this paper has been with the methodologies used to examine access through GIS approaches rather than the context within which individual studies have been directed.

The rest of the paper is structured as follows. In the next section, alternative definitions of accessibility are considered and previous research studies that have focused on measuring accessibility are reviewed. This has revealed that, in the absence of detailed patient level surveys of health service utilisation patterns, much of this research has been concerned with measuring potential barriers to access. Section 3 summarises previous research studies that have specifically developed GIS-based measures of accessibility. Most current commercial GIS packages have networking capabilities that permit an analysis of distance and travel-time based measures; in addition other studies have been concerned with adding accessibility functionality to existing packages (see for example [66]). In this paper, however, the review

is confined to the application of such measures in a health context. In Section 4, based on studies conducted to date, gaps in our current knowledge with regard to the relationships between such measures and health outcomes are highlighted and examples provided on how such research could be taken forward particularly in relation to new developments in healthcare service delivery. Such a review is particularly timely given new IT initiatives in the health sector and exciting new developments in geographic information handling technologies. Finally conclusions from the review are provided in section five of the paper.

2. Accessibility

2.1. Definitions

There have been a number of different definitions of accessibility proposed in the health services research literature (see for example [28]). Penchansky and Thomas ([74]; p. 128), for example, 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 [1] also consider wider definitions of accessibility that go beyond geographical or spatial accessibility to consider, for example, financial, informational and behavioural influences. There have been a number of critiques of their 'framework for the study of access' (see [20] for a fuller discussion). Gulliford et al. [29] draw a distinction between "having access" to health care and "gaining access", the former may result from the availability of services, the latter refers to whether individuals have the resources to overcome financial, organisational and socio-cultural barriers and utilise that service. Thus any study that investigates variations in accessibility needs to examine issues surrounding 'affordability', 'physical accessibility', and 'acceptability'. They further suggest that "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" ([29]; p 186). Beliefs and expectations of different groups in different geographical and cultural settings will also influence such trends [3].

In the rest of this paper, I am concerned with exploring the most relevant definition of geographic access for GIS-based analysis which focuses on the interaction between the individual and the health care system. For example, Joseph and Phillips [47], building on previous studies, distinguish between potential accessibility and revealed accessibility (or utilisation). The former assess the nature and pattern over space of physical access to service facilities. Joseph and Bantock [46], for example, derived measures of 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 [47]. Andersen ([2]; p. 4) drawing on a conceptual framework defines potential access as simply "the presence of enabling resources". Khan ([49]; 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" [46]. This could be represented as travel time, road or map distance. Other studies have been concerned with looking at the actual use of services (*'revealed accessibility'* or *'realised access'*). As Khan ([49]; 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 in particular on the role of geographical factors.

2.2. Previous approaches to measuring accessibility

Previous studies on the role of spatial factors have examined the impacts of 3 broad sets of factors on overall accessibility; (a) the spatial configuration and characteristics of the health delivery system along with a broad range of quality measures associated with particular services; (b) the role of the transport system in getting individuals to these destinations, including the respective importance of private and public transport in different socio-cultural contexts and (c) the characteristics of individuals utilising health services or, more commonly, the characteristics of the areas in which they reside based on relevant census data. There have been a number of studies that have been concerned with presenting quantitative approaches to measuring accessibility to services (see for example [30–32, 54, 97]). Previous studies in the health sector have been concerned with examining variations in the locations of, for example, doctor's surgeries at a variety of spatial scales in order to examine potential inequalities in relative accessibility of such services (e.g. [52, 53]). It is not the aim of this paper to revisit such literature—rather, I focus on those studies that appear to be relevant to those researchers interested in applying GIS-based techniques in the health arena. In so doing I draw attention to the particular methodological and data concerns that would appear most relevant for such applications. Talen [91] has described a number of approaches to measuring accessibility (Table 1). Using this framework, Talen and Anselin [92] highlight, through a comparison of different access measures of local populations to the spatial distribution of playgrounds in Tulsa, Oklahoma, the sensitivity of results to the precise definitions and measurement of accessibility employed. Often such measures are based on the simple count of facilities in census tracts or the number of services and facilities available within a certain physical or drive-time distance of a demand point within an area. In the absence of detailed locational data for individuals accessing such services, population demand is usually summarised at the population-weighted or, more commonly geographic centroids, of such areas. Fortney et al. [21] have compared the accuracy of methods of calculating availability and accessibility of services using a range of alternative measures using a sample of patients and medical providers and mental health specialists in Arkansas. Their findings suggest that the "measurement accuracy can be substantially improved by using a GIS" ([21]; p. 181).

Khan [49] has reviewed the approaches taken to calculating potential access measures in a health context and provides a useful typology which acknowledges the dichotomy between potential and realised (revealed) and spatial and aspatial measures. The most basic measures compare the supply of facilities (e.g., numbers of general practitioners, dentists,

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 10 km 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).

pharmacists, etc.) with the potential demand for such services (based on aggregates of population) in a defined area (e.g. [51, 90]). This corresponds to Joseph and Phillips [47] 'regional availability' approach and has been used to examine spatial patterns of health services in relation to demand for a particular geographical unit of analysis (often presented as ratios of population to practitioners). However, such measures are limited because they assume that there is no cross boundary flow of people accessing facilities in adjoining areas. The sensitivity of these measures to the spatial resolution of the census unit under consideration, and the implications of varying such service area boundaries when examining the potential availability of health care, has long been recognised [67]. Another limitation of physician-to-population measures is that they assume all consumers have equal access to such facilities independent of where they live in the census tract or their personal circumstances. Thus they do not account for the role of distance for example or of a 'distance-decay' effect on utilisation patterns. This has led others to propose measures that use probabilistic techniques which take into account overlapping areal units in order to 'allocate' the supply of health services in relation to the time patients spend travelling to access such services (e.g. [102]). GIS can be used to measure travel times under different transport or network scenarios and are therefore increasingly being used in more advanced applications, where suitable data sources are available, in order to examine spatial and temporal variations in accessibility (see Section 3).

A number of recent studies have proposed alternatives to area-based physician-to- population measures to try to overcome these limitations. One set of techniques, for example, uses circles of varying radii (calculated by using GIS to buffer an arbitrary distance or travel time based on assumed utilisation behaviour) placed at the (population-weighted) centroid of a census tract and counts the number of physicians within the circles in order to calculate a physician-to-population ratio for each tract [63]. These floating catchment area

(FCA) methods, it is argued, overcome the assumption regarding cross-boundary flows by extending the radius of the circle outside the immediate census zone but, in the absence of detailed information on individual addresses (or the socio-economic characteristics of people accessing such services), are still limited by assuming equal access within the catchment. In the absence of individual household locations and population counts, the demand for such services is often estimated either by calculating the number of people at a census centroid, or by the proportion of the census area pro-rated for population, that intersects with this circle. Either method introduces errors; for example summarising a population of a zone by assuming all live at the centroid may provide a crude estimate of accessibility [36], whilst the second method assumes an equal distribution of a population across that tract. Both, therefore, have limitations but often researchers do not have access to finer resolution data required for more accurate assessments of the spatial distribution of individuals living within census tracts and have to assume that services will be equally available to all people living in the catchment area. There are also questions regarding the sensitivity of the physician to population ratios to the size of the radius of the circle used in the floating catchment methodology.

An important enhancement of this methodology is the two-step FCA approach described by [80]. This is a relatively sophisticated technique that accounts for the interactions between patients and physicians across administrative boundaries by evaluating accessibility as the ratio between supply and demand, both of which are determined within travel-time catchments. In the first step, a travel-time catchment is computed around each supply point (e.g., a primary healthcare practice) and its estimated population count utilised to calculate a physician to population ratio (Rj). In the second step, travel-time catchments are computed around every demand centre (e.g., a population-weighted centroid) and accessibility to service provision is measured by summing all Rj values contained within this zone [64]. The final accessibility measure reports the balance between doctor availability (i.e., physician to population ratio) and service accessibility (sum of all supply points lying within a given travel-time of the demand centres), returning higher values as accessibility increases. [99] illustrate the application this two-step FCA methodology in a study of healthcare access within the State of Illinois. Non-spatial factors can then be combined with these techniques in order to highlight for example inner city areas that have poor spatial measures of access on the FCA approach. In the absence of detailed utilisation data such measures are calculated from demand points based on where patients reside and not where they work for example. This may be particularly problematic for access to non-urgent services where patients may attend such facilities during the working day. The radius can be defined on the basis of a pre-defined hypothesis (e.g., the average walking distance a person is prepared/able to travel to access a particular facility) or can be based on actual empirical evidence from those utilising the service. Often however, such data does not exist at a sufficient level of detail so the circle radius tends to be calculated at specified increments (e.g., 10, 15, 20 min travel time).

In summary, the choice of measure selected to examine spatial patterns in accessibility has to be considered in the light of the particular service under consideration and differing assumptions concerning travel behaviour to that service [31]. Thus for a local service (e.g., playgrounds in Talen and Anselin's research) a measure based on minimum distance to

the nearest facility may be appropriate; but for services with a potentially wider demand catchment, alternative measures may need to be developed. Khan [49] has suggested that a combination of approaches be taken in order to calculate potential accessibility measures based on the regional availability and accessibility approaches advocated by [47]. The use of GIS in such applications is reviewed in the next section of the paper.

3. Use of GIS in measuring access to health services

3.1. Introduction

GIS has been used extensively in the health sector for a couple of decades [37]. In particular, there is a relatively large literature showing how GIS has been used to examine spatial patterns of disease and in environmental correlation studies through techniques such as spatial clustering. GIS has also been used to examine spatial patterns of health services and in planning the location of new health facilities (see Gatrell and Senior [24]) for a wider review). Typically these studies involve the use of standard GIS functionality such as buffering (e.g., generating catchments at physical or travel time distances away from doctors surgeries or hospitals), overlay analysis (e.g., examining the location of patients in relation to such areas) and network analysis (using characteristics of a network such as travel speeds or public transport availability to gauge how long it takes patients to access a facility). Increasingly, however, researchers are incorporating more sophisticated spatial analytical techniques not currently available within proprietary packages in order to examine different aspects of accessibility. For example, a limitation of such studies is that measures tend to be calculated from demand points based on where patients reside (typically derived from their residential postcode) and not from where they work. Thus important research strands relate to how appropriate the place of residence is as a representation of human activity patterns as it relates to the use of health services. There have been a number of studies that have incorporated a temporal component in relation to, for example, individual-level accessibility and time-space budgets and activity patterns based on travel diary data (e.g. [56, 100, 101]). In the near future, this is likely to be a particularly fruitful area of research in the health arena given recent developments in location-based services but in this paper I am primarily concerned with reviewing those studies that have used GIS to examine spatial patterns in access to, and utilisation of, health facilities.

As Cromley and McLafferty ([17]; p. 234) highlight "GIS necessarily emphasize accessibility, the geographical dimension of access." The majority of studies to date have used GIS to measure potential accessibility to both primary and secondary health services in order to examine spatial inequalities in health care delivery [65, 76, 82]. There have also been a number of studies that have taken an area-based approach to measuring accessibility using GIS including some that have incorporated access to health services as a key domain in an overall index summarised for areas, usually census or administrative tracts (e.g. [38, 103]). In the latter study, for example, the researchers developed the Community Resources Accessibility Index for urban areas of New Zealand that used a distance-based approach to accessibility with a constraint representing the distance an individual or group would be prepared to travel to access a particular type of publicly available community resource. This,

in turn, can be compared for different areas of a city to identify areas with poor access to health promoting resources. As the authors acknowledge the index measures physical and not social access, with some facilities/services not being available to certain sections of the community. Area based measures are also dependent on the exact nature of the areal unit which, in the case of relatively coarse administrative areas, may hide significant intra-zonal variations in accessibility. Nevertheless, such measures can provide a useful exploratory tool to identify areas where there are gaps in provision prior to more detailed qualitative studies. In the United States, for example, GIS has been used to identify primary care shortage areas in relation to federally funded programs (e.g. [48]). McLafferty ([65]; p. 31) also suggests that "there is great potential for using GIS to identify vulnerable populations and examine geographical access to quality services and treatments" before drawing attention to the relative lack of published studies that take service quality into account.

3.2. GIS and potential access to health facilities

Recent studies have used spatially disaggregate data sets in order to calculate accessibility measures based on the postcodes/zip codes of patients that are converted to grid references and inputted into a GIS in order to examine straight-line or travel-time distances to, for example, the nearest health facility for different road network states (e.g. [5, 8, 9, 15, 21, 55, 73, 75, 81, 87]). Some studies, recognising the need to also consider aspatial factors when describing utilisation behaviour, have provided accessibility measures for those with different health needs or by population sub-group [39]. [97], for example, have shown how the existing networking capabilities of GIS can be used to estimate travel times to health services, using the case studies of hospitals serving 2 million people in North Carolina and illustrate the potential of GIS in 'what-if' modelling in different policy scenarios. They demonstrate how location-allocation methodologies, available in a number of commercial GIS packages, can be used to assign patients to their nearest hospital and to identify areas that are 'under-served' in terms of health facilities. However, as the authors themselves acknowledge, their models assume that the decision to allocate patients to hospital services is based on travel times from patient residence when clearly other factors need to be considered (see below). [61] used a GIS to calculate potential access for the elderly to 214 hospitals in Illinois. During the course of their research they developed alternative measures of accessibility based on straight-line distances to the closest five hospitals for each census block group in order to establish if there were variations in accessibility between those living in Metropolitan and rural areas.

In our previous research we have developed an index of potential physical accessibility to a range of services, including health care facilities, for communities within Wales (see [38]). These measures, adapted from the methodology used to examine potential accessibility to general practitioners in rural areas of Canada [46], have used demand points based on population-weighted centroids and supply points as the service facilities, in order to calculate accessibility scores at two service ranges, namely 5 and 10 km, which represent the maximum assumed walking distance and driving distance range respectively. Again, in the absence of detailed patient level utilisation data, assumptions have had to be made in relation to the use of such services, but the research has highlighted regions of poor

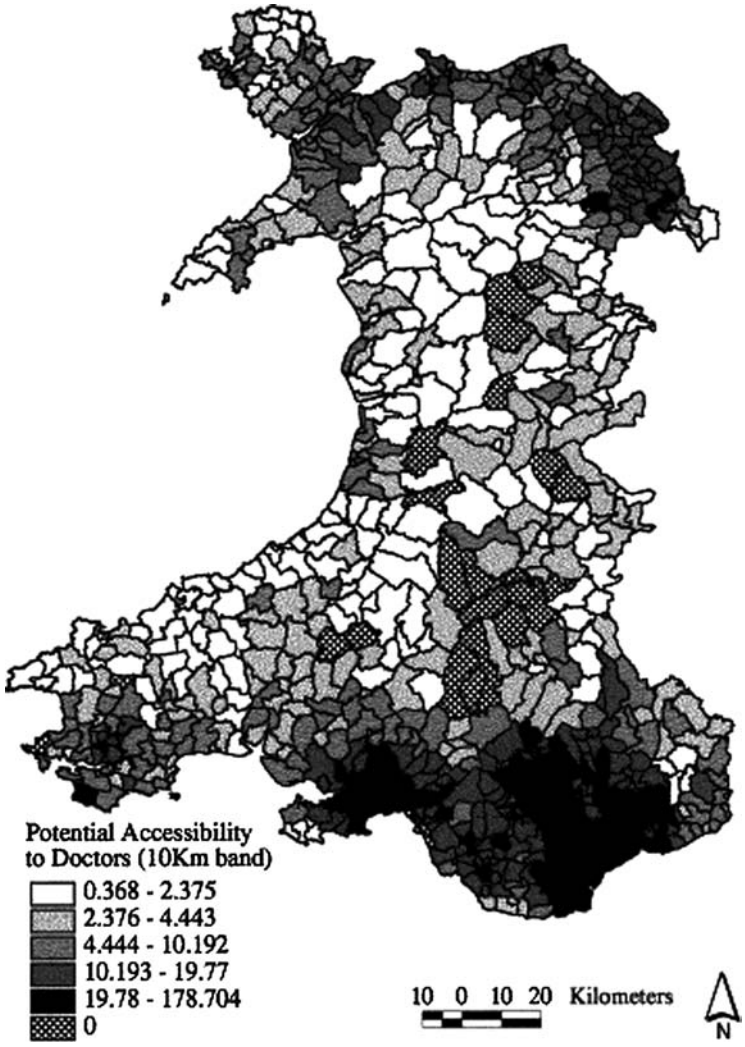

Figure 1. Potential accessibility to GP practices in Wales (community level).

potential access to healthcare services in Wales which could provide the basis for more detailed localised studies in particular areas (figure 1). We are currently in the process of updating these measures, and examining potential relationships with health outcomes in Wales using the 2001 Census of Population.

A major assumption in many of these studies is that patients will use their nearest health facility; some studies have found that this may not necessarily be the case (e.g. [69]) but, in the absence of detailed utilisation data, researchers have often had to make such assumptions. [35], for example, found using postcoded patient registers and estimated

travel times from residential postcodes to GP surgeries, that only 56% of the population of 3 counties in Eastern England were registered with their nearest general medical practice and that the proportion registered with their nearest practice varied between urban and rural areas. As expected there was a decline in registrations with increases in travel time.

However, in rural areas proportionally more patients attend the nearest practice reflecting the lack of alternative options. Their study also demonstrated the importance of travel time on choice of GP surgery attended and highlighted the need to incorporate consumer behaviour as well as travel times into potential accessibility models. [30] demonstrate the use of alternative measures in order to illustrate methods by which access to proposed sites of the New Royal Infirmary in Edinburgh can be examined both for those with and without means of private transport. Using GIS such measures can be used to examine the implications of proposed changes in service delivery or transport networks (such as improvements to walking and cycling routes, improved bus services and car parking charges). GIS can be used to target such improvements in those parts of the city that have the greatest health needs or for particular population sub-groups. [25], for example, used GIS to create a continuous density surface of primary care providers for children in Washington DC which, when examined in relation to underlying child population density, revealed variations in spatial accessibility across the city and disparities amongst different ethnic and socio-economic neighbourhoods. Changes in GIS-based accessibility measures can also be used to monitor the impacts of health sector reforms; Rosero-Bixby [81], for example, used GIS to find improvements in access to outpatient care following health care reforms in regions of Costa Rica in the mid 1990s and concludes by suggesting that GIS has great potential to identify those communities that have inadequate access to health care and where such interventions could be targeted to improve access.

GIS also permits analysts to examine the impacts of access in relation to compounding factors such as patient characteristics (including deprivation) and rurality. Lin [58], for example, used GIS to examine rates of hospitalisation in an area of British Columbia, Canada, and found an inverse relationship between such rates for census enumeration areas and physical (as opposed to travel-time) distance to hospitals, a trend that remained after controlling for income. The use of GIS also permitted the incorporation of topographical barriers into the analysis deemed to have an impact on hospitalisation [59]. Wood and Gatrell [104] have used GIS in order to examine access to hospice care in North West England and calculated measures of potential accessibility in relation to deprivation scores. They used a combination of distance and travel time techniques in order to highlight gaps in provision and demonstrate the use of such tools in planning hospice service provision. As recognised by researchers a limitation of such measures is that, in the absence of detailed demand data, they consider supply-side characteristics only. A further assumption is that all groups have equal access to (private) transport opportunities. Recent research in the UK has drawn attention to the need to consider the intricacies of the transport system in an analysis of accessibility measures based on both car driving times and public transport timetables (e.g. [19, 62, 70]). Certain socio-economic groups may be dependent on public transport to access health facilities and a number of studies have investigated the potential of incorporating detailed public transport timetables into GIS-based access measures in order to develop a

fuller picture of public access in relation to, for example, opening hours for health services. Lovett et al. [62], for example, analysed patterns of community transport, as well as detailed bus timetables, with GP patient register information in order to identify areas that had poor access to GP services in Eastern England. GIS was used to compare areas poorly served by public or community transport opportunities with their socio-economic characteristics in order to examine overall patterns of accessibility. Such studies also demonstrate the potential of GIS to monitor the implications of, for example, Government policies towards public transport provision, on access to health services for those without access to private transport opportunities.

GIS is increasingly being used in developing countries in order to examine potential access to health facilities and to plan the location of new treatment centres, for example, in relation to treating malaria [71, 83], tuberculosis [95] , access to HIV treatment [94], planning public mental health and cancer resources [7, 72, 84] and to examine attendance patterns at rural clinics [91]. [84] drew attention to the limitations of existing data sources in such contexts but also provided evidence that accessibility to cancer treatment centres in South Africa was dependent on the level of development with poorer areas having fewer such centres. The potential use of GPS in such regards is also a fruitful area for further research. GIS can be used to investigate spatial patterns of diseases in relation to such accessibility measures. [85] have used GIS to find out how many patients have potential access to hospitals that provide specialised services for stroke victims in order to identify gaps in provision both geographically and by social groups.

3.3. GIS and health care utilisation

In contrast to research using GIS to derive potential accessibility measures, there have been fewer studies that have examined the spatial relationship between the location of potential clients and detailed patterns of service utilization [65]. Often such patterns are examined at an aggregate level for health authority areas for population sub-groups in order to examine variations in utilisation rates in relation to distance. In other instances more detailed and up-to-date patient level data may be available (see Table 2 for a cross-section of such studies). The importance of such utilisation-based measures stems from the fact that they are often used to assess need for, and planning of, health care in resource allocation mechanisms (see Asthana et al. [4] for a wider critique of the use of such measures). Although there have been attempts to compute utilisation rates, often through the use of proxy measures, the use of GIS has often been confined to visualising spatial patterns. Carriere et al. [14], for example, investigated spatial and temporal patterns in hospital utilisation in relation to patterns of deprivation in Winnipeg, Manitoba (1989–1996). GIS was used by Fortney et al. [22], to measure the impacts of travel times to providers of treatment for depression and to highlight the importance of such barriers for patients in rural areas of Arkansas. Distance may also have an impact in urban contexts. For example, in the absence of individual patient level data, Jones et al. [45] used the distance between GP practices and tertiary centres in the East of London to examine the relative importance of distance (together with factors such as ethnicity and deprivation at the practice level) on access to angiography and noted

Table 2. Examples of previous studies using GIS to investigate utilisation patterns.

Authors	Area	Health issue	Methodology	Findings
Gatrell et al. [23]	South Lancashire, England	Uptake of screening for breast cancer	Regression analysis of social class and census-derived variables as well as distance to a GP surgery, and the practice characteristics to predict uptake	Uptake rates for screening were related to practice deprivation scores and the number of female doctors.
Jones et al. [43]	Norfolk, England	Utilisation of asthma services	Logistic regression of sample of 9764 adults aged between 20–44	Utilisation behaviours associated with smoking status and levels of care ownership in census area in which they residence; likelihood of consultation declined with distance from a surgery.
Martin et al. [68]	Modelling at national (UK) level	Uptake of Renal Replacement Therapy (RRT)	Multi-level modelling of those factors predicted to be influential on acceptance onto RRT. GIS used to calculate catchment areas and travel distances	Deprivation, access and supply significant influences on acceptance rates but also important regional influences. Distance found to be important after particular threshold is reached—travel times more useful than crow-fly distances.
Haynes et al. [34]	Cambridgeshire, Norfolk and Suffolk, England	Age and sex adjusted inpatient episode ratios for acute, psychiatric and geriatric specialities.	Regression analysis of episode ratios at a ward level and census data, health service provision and straight-line distance to nearest GP and hospital	Measures of health needs, service provision and distance significant predictors of ward level variations in inpatient episodes. Importance of confounding factors, e.g., urban areas with health facilities had worse health status; Impact of distance seen to vary with nature of inpatient episode.
Hyndman et al. [40]	Perth, Western Australia	Response to invitations to attend mammography screening	GIS used to monitor response to attend 6 fixed site screening clinics	Woman more likely to respond positively to invites if they lived closer to existing clinics.
Maheswaran et al. [66]	Trent Region UK	Utilisation of renal replacement therapy rates	Rates examined in relation to socio-economic deprivation, age, ethnicity, gender and travel distances	After adjustment for confounding variables, rates for haemodialysis decrease with increasing distance from renal units but no evidence of a similar decrease for peritoneal dialysis.

an inverse relationship between such rates and the distance of the study practices from such centres. Other researchers, with access to more detailed datasets, have been able to use GIS to examine the relative influence of distance on utilisation rates after controlling for other potential confounding factors (e.g., Maheswaran et al. [66] study of renal replacement therapy rates in the Trent region of the UK which noted a slight decrease in the prevalence of therapy with increasing distance from a renal unit).

There have also been a number of studies concerned with using GIS in conjunction with accessibility measures to assess the effectiveness of screening and to examine the influence of travel distance to the facility on screening rates and to identify potential 'gaps' in coverage [6, 86]. Gatrell et al. [23], for example, investigated the uptake of screening for breast cancer in South Lancashire using postcoded GP information. Specifically, they used social class and a range of census-derived variables as well as distance to a GP surgery, and the practice characteristics, to identify the factors that are the most useful predictors of uptake rates. In their study, regression analysis revealed that uptake rates for screening were related to practice deprivation scores and the number of female doctors. In addition, residuals from these models could be used to identify practices performing well or poorly after controlling for deprivation and the availability of female doctors.

A number of recent studies in the UK have explored the importance of service delivery factors on patient access in relation to factors such as catchment characteristics (e.g., deprivation levels) and individual patient-level variables. Examples include access to out-of-hours primary care services [79] and NHS Direct [11]. In the former study, for example, it was found that "most of the variation between locations can be explained not by spatial variables, but differences in the ways in which services are organised" ([79]; p. 29). Thus the role of distance has been questioned in relation to that particular health care provision service. However, a study of health utilisation patterns in Belgium, found that the socio-economic characteristics (as measured by educational attainment and household income) of the patients were more important than supply characteristics in explaining the use of health services although the exact relationship varied according to the type of health service [96].

In summary, a review of the literature has revealed that there is significant interest in the use of spatial technologies in measuring geographical access to healthcare services. As Cromley and McLafferty assert (2002, p. 258) "by documenting changes in service availability in their geographical and social contexts, and analysing differential impacts on population groups and places, GIS can play an important role in understanding evolving patterns of accessibility and their consequences." A logical extension to such work is to explore the relationship between access factors and health outcomes and to examine the impacts of changes in service delivery (e.g., the centralisation of some health services) on such outcomes; Gulliford [27], for example, has explored the potential relationships between the supply of doctors at the health authority level and health measures such as infant mortality rates and hospital admissions. Variations in access to oncology centres have been studied as a potential explanatory factor for inequalities in patient survival from lung cancer in the South East of England [41]. More research is needed however in order to demonstrate the use of GIS techniques in monitoring spatial trends in access to specialist care following service re-organisation [78]. Ideas for further research in this area are discussed in the next section.

4. Measuring relationships with health outcomes

In contrast to the breadth of literature concerning the development of access measures and their use in analysing potential access to facilities, there has been relatively less research (certainly in the published domain) on the potential influence of geographical access on spatial patterns in health service treatment and outcomes. Guagliardo [25] suggests that "the body of work will be greatly advanced when we begin to precisely quantify how the spatial accessibility of primary care actually impacts population health'. This is reinforced by McLafferty ([65]; p. 34) who suggests that "we know little about how the spatial organisation of health services and treatments influences the outcomes of those treatments". This is despite concerns expressed in the media certainly in the UK, for example, regarding the so-called "postcode lottery"; namely, that where you happen to live may determine the types of treatment you receive and may influence overall health outcomes. Whilst previous studies have found an *association* between under-served areas and higher than average morbidity rates (e.g. [52]), there has been a relative lack of research that has looked at the potential *impact* of differential access to either primary or secondary health care services on patterns of outcomes (see [70] for an example of the exception to this in their research in the South-West of England). More research is needed on referral and treatment patterns for patients from more inaccessible areas. The increased public scrutiny of issues surrounding rural health as a result of, for example, the foot and mouth crisis in the UK in 2001 has also drawn attention to the impacts of (the lack of) access to health services in such contexts and the potential consequences for health outcomes (e.g., in relation to access to mental health services; [77]). Similar concerns have been expressed with regard to the provision of oncology services in remote rural areas (e.g., [88]).

Evidence of the impacts of distance (or travel times) on health outcomes has been contradictory but GIS has a potential useful role to play here in providing more precise measures of the impacts of such factors in order to update those studies that have used alternative measures of urban/rural residence which Fortney et al. ([22]; p. 891) describe as a "poor proxy for geographic accessibility." There have been a number of papers concerned with investigating the potential impacts of ambulance response times in attending road traffic accidents on fatality (see [35] for a summary of such research). Jones and Bentham [42], for example, found no relationship between outcome and expected time taken to reach victims and to convey them to hospital, either before or after adjustment for other factors; i.e. no evidence that survival is related to ambulance journey times but that more severe accidents on fast stretches of roads in rural areas may account for higher mortality rates from accidents. However, they suggest that more research is needed to see how applicable this is to more remote rural areas.

Research concerned with examining such trends in relation to health services at fixed points is more difficult given the unavailability or limitations of existing health datasets and the need to account for confounding variables with which to isolate the potential influence of accessibility to health services. Kim et al. [50] explored the survival rates following surgery for cancer in relation to distance from specialist centres controlling for factors such as the age of the patient. Jones et al. [43, 44] have examined the relationship between asthma deaths and distance to the nearest large acute hospital and found a tendency for the

number of deaths from asthma to increase with travel times to hospital for an area of Eastern England. Jack et al. [41] used a multi-level modelling approach in order to investigate the potential impact of geographical variations in the treatment administered to patients with lung cancer and patient survival for 26 health authorities in the South East of England. Their findings suggest that, after adjusting for case mix, there was evidence of wide variations in treatment patterns between the health authorities. The researchers found some evidence that the geographical inequality in treatment given to these patients and variations in patient survival "might be explained by variations in access to oncology centres" ([41]; p. 1025). Again the importance of compounding variables needs to be evaluated in such studies; outcome for some cancers, for example, are worse for those who live in deprived areas. Coleman et al. [16] for example found survival rates lower for patients living in poor areas (based on the Carstairs deprivation score), although the extent of disparity varied by cancer type and was less for those less amenable to treatment. Researchers need to assess the relative importance of access to treatments in relation to other factors that may account for these patterns (for example, are these outcomes the result of worse health conditions in deprived areas or less use of preventive services such as screening in such groups or does the quality of care differ?).

More research is needed to gauge the extent to which different treatments are provided according to where patients live and attend health services and the influence of distance on, for example, doctors' referral practices. Are doctors more reluctant to refer patients who live further from a specialist centre? There have been a number of studies that have explored the uptake of health screening (e.g., for breast cancer) and a potential relationship with morbidity and mortality but more research is needed in order to examine the impacts of distance in relation to other potentially impacting factors. The relationship between uptake of screening and disease rates has been disputed but the possibility of delayed diagnosis as a result of poor access to specialist centres particularly in rural areas has been the subject of a number of studies (e.g. [12, 13, 57]). Other socio-economic factors will need to be taken into account to provide a fuller understanding of patterns of health take-up [9] but GIS provides us with a set of tools with which to disentangle the influence of geographical factors. Another potentially interesting research thread could concern the impacts of new technological developments such as telemedicine on access to services and associated health outcomes. Much of the research summarised above has been concerned with the physical availability and/or utilisation of services at a fixed point in space or time. Recent innovations that aim to overcome problems of geographic accessibility of patients to healthcare such as the availability of information over the Internet and advice lines such as through NHS Direct service in the UK may call into question "traditional" indices of accessibility as patients explore other pathways to healthcare. More research is needed to investigate the impacts of such developments on health outcomes/treatments using GIS approaches.

5. Conclusions

The aim of this paper has been to compare and contrast previous approaches to measuring accessibility with new methods built around the use of Geographical Information Systems (GIS). The principal message from the review is that we have barely scratched the surface

with regard to the use of GIS methods in accessibility studies but that new technologies such as the combination of GIS and Global Positioning Systems (GPS) have significant potential to address policy concerns regarding health inequalities that may partly arise through a lack of access to primary and secondary healthcare facilities. Recent developments in geographically disaggregate data will enable the implementation of analytical techniques in a range of health contexts and at a variety of spatial scales. GIS has the potential to provide an improved evidence base with which to identify and target groups and areas with lower levels of accessibility and to monitor the impacts of any service re-locations or changes in delivery on accessibility. This should build on a relatively large literature base that describes the use of GIS in examining the most suitable locations for health facilities using increasingly sophisticated techniques that take into account actual travel times in relation to, for example, opening times of health facilities. Whilst a number of studies have demonstrated the potential of incorporating detailed public transport timetables in the calculation of such indices, for example, these tend presently to be limited to prototype systems for particular health regions. Health geographers have been to the fore in developing such measures but, in common with the use of GIS in other health applications [37], there is less evidence in the literature of such research being conducted in the profession. In addition, whilst there has been some research in other sectors into how the quality of services can be incorporated into accessibility analysis (e.g. [89]), few studies have investigated the impacts of spatial variations in the quality of healthcare provision. A review of the literature has also drawn attention to the importance of controlling for other factors that influence accessibility such as socio-cultural variables and health supply characteristics and has revealed more complex inter-relationships between such factors and, for example, service utilisation.

However, this review of the existing published literature has also drawn attention to the different definitions attached to the term accessibility in health contexts, highlighted some conceptual issues which provide an important context for further research in this area before examining the current state of play with regard the application of GIS. Through a review of the approaches taken, I have tried to identify some common strands for researchers in this area, highlighted current limitations of the use of GIS and outlined some areas for further research. The introduction of new technologies such as GPS and detailed satellite imagery, for example, have the potential to create more accurate spatial data sets in order to estimate access measures at local scales (see for example [75]). These exciting developments, together with the more widespread use of GIS in health organisations, should lead to an increase in such studies in response to current policy concerns.

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