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Measuring access to health services: deprivation and transport measures in urban and rural settings

By

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ABSTRACT

FACULTY OF MEDICINE, HEALTH AND LIFE SCIENCES

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MEASURING ACCESS TO HEALTH SERVICES: DEPRIVATION AND TRANSPORT MEASURES IN URBAN AND RURAL SETTINGS

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Three ideas are brought together in this thesis: that geographical access to health services may be unequal; that any such inequality is thought to disadvantage the residents of rural areas more than those of urban areas; and that within those areas which are most affected by poor geographical access to health services it is likely to be the poor who are most disadvantaged, resulting in inequity as well as inequality of access. A comprehensive and structured review of the literature found that there is limited reporting of the distances that people travel to health services; there is limited reporting of the differential impact of distance on different groups in the population; the assumption that poor geographical accessibility of health services is a feature of rural rather than urban or suburban areas has not been well tested; and there has been little comparison of different access measures. Little was known about the circumstances under which more complex measures would be worth calculating and those under which simple measures would give a representative view of geographical accessibility. In particular, very few studies had attempted to use public transport as a measure of geographical accessibility.

Empirical work based in the South West peninsular of England (an appropriate setting in which to examine differences in accessibility, as it combines scattered settlements, long travel distances and rurality with problems of low pay, unemployment and other aspects of deprivation) showed that, whilst access to primary care is generally good, rurality is not necessarily a feature of areas with poor access. Drive time appeared to be a more accurate measure of accessibility in peripheral and rural wards of the far South West than straight-line distances, and indications of lower levels of car ownership in the wards furthest from hospitals indicated that available measures were not giving a realistic picture of accessibility for people in these areas. Traditional measures of deprivation such as the Townsend score were not effective in identifying areas of health care need in rural areas, and whilst the Index of Multiple Deprivation 2000 was a better proxy for need, the 'access to services' domain of the index was not the underlying reason for this.

Accessibility measurements that use complex matrices of public transport information are rare. With the advent of powerful GIS they are, however, likely to become more usual. Electronic databases of transport timetable information (ATCO CIF files) have recently become available and provide a source of detailed data on public transport networks. In this thesis I describe the creation of a measure of geographical access to health services that is based on electronic public transport data, and use it to describe access to secondary health care in Cornwall. I discuss the potential and the limitations of the measure, and set out an agenda for future developments.

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Chapter 1: Themes and structure

1 Chapter overview

This chapter introduces the theme and aims of this research and sets out the structure of the thesis. It begins by introducing the central concept of geographical access to health services, drawing on relevant literature to describe the ways in which it has been defined and measured. The links between geographical isolation from health services and rurality are discussed and the concept of equity of access is examined. The role of public transport in developing an appropriate and useful measure of geographical access to health services is introduced.

1.1 Introduction

The theme of this research is the measurement and impact of variations in geographical access to health services. Geographical access describes the distance people have to travel and the time taken to make a journey to use health services. Understanding and measuring access to health services is important for two reasons. Firstly, barriers to the use of health services may result in unnecessary, avoidable, levels of ill health or premature death in the population, for example by delays in presentation or by under-referral. Secondly, even if no verifiable health impacts are associated with variations in access to health services, other burdens such as cost, time and worry may be disproportionately distributed if access is inequitable.

Geographical access is just one aspect of access to health services, but one that may be particularly significant within the United Kingdom (UK) National Health Service (NHS), where financial barriers to the use of services are strictly controlled. Within the NHS, fair access - independent of the ability to pay, of age, sex or area of residence - is a founding principle (NHS 1999). Equity of access to health services is also an important aspect of UK government policy (NHS 1997), one of the six elements of the NHS Performance Assessment Framework (NHS 1999) and an issue of special significance for rural areas (Department of Environment Transport and the Regions 2000b). Identifying areas of inequity in geographical access to health services may provide a useful tool for policy makers and help to inform decision making.

1.2 *What does 'access to health services' mean?*

'Access to health services' is a more complex concept than it first appears: subjects ranging from the cultural appropriateness of services, referral routes, clinical thresholds for admission, physical access to buildings to the provision of sufficient capacity to meet population need have all been described as studies of 'access' to health care[1], and a simple definition of access is yet to be agreed upon.

Access has been variously defined as:

- 'The habit or power of getting near or into contact with; entrance, admittance, admission (to the presence or use of)' (Oxford English Dictionary 2004)
- 'the geographical availability of key services' (Department of Environment Transport and the Regions 2000b), p166
- 'providing the right service at the right time in the right place' (Rogers, Flowers, & Pencheon 1999)
- 'the means through which the patient gains entry to the medical care system and continues the treatment process' (Andersen & Newman 1973), and
- 'those dimensions which describe the potential and actual entry of a given population group to the health care delivery system' (Aday & Anderson 1981)

A recent review of published work on access to health services described access as having four dimensions:

- 'service availability; utilisation and barriers to access; relevance and appropriateness of services; and both horizontal equity (equal care for equal needs) and vertical equity (appropriate care for different needs)' (Gulliford et al. 2002),

and Penchansky and Thomas identified five:

- 'affordability, acceptability, accommodation, availability and accessibility' (Penchansky & Thomas 1981)

Two concepts are apparent from these diverse definitions: firstly that access to health services incorporates the supply of health services ('the geographical availability…'; 'providing the right service…'); and secondly it includes factors which affect the use of services ('the habit or power…'; 'the means through which…'). The

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[1] In a structured literature search of a single year of MEDLINE (2000), the search term 'access' (in combination with terms defining need for and use of health services) produced concepts as diverse as geographical access (distance), availability (e.g. opening times and waiting times), cultural appropriateness (e.g. to disadvantaged or ethnic groups), referral routes (e.g. open access to outpatient clinics), clinical thresholds for admission, use of services, physical access to buildings and the provision of sufficient capacity to meet population need.

multi-dimensional nature of 'access' means that geographical access is just one part of a complex web of factors that influence the eventual use of health services, but it remains an important concept in the understanding of both equity of opportunity and equity of use of health services.

1.3 Why measure geographical access to health services?

Geographical access is one dimension of access which is often overlooked (Goddard & Smith 2001), yet geographical barriers such as travel time and distance may be an important determinant not only of the readiness with which people seek or are referred to health care, but also of the treatments which are offered, the degree to which patients are able to comply with long term programmes of treatment for chronic conditions and the speed with which acute treatment can be delivered in an emergency.

Furthermore, variations in geographical access influence the personal and financial costs of using health services for both patients and their carers, raising questions about the equity of health service provision. The impact of variations in geographical access to health services is likely to vary both between individuals and between areas. Barriers of time and distance and the associated costs of making journeys to health services may represent a largely unmeasured burden on already disadvantaged populations: the greatest disadvantage is likely to be experienced by individuals without access to a car (including members of one-car households without daytime access). Yet compared to issues such as social class, deprivation and ethnicity, all of which influence health and the use of health services, there has been relatively little attention paid to the measurement and understanding of variations in geographical access to health. There are no standard definitions of geographical accessibility, and no clear understanding of the meaning of good and poor geographical access. If policy makers are to address inequities of access, more research is needed both on appropriate methods for measuring access and on the relationship between access to health services, the use of health services and health (Goddard & Smith 2001;Gulliford, Figueroa-Munoz, Morgan, Hughes, Gibson, Beech, & Hudson 2002).

1.4 Measuring geographical access

Although distance decay in the use of health services (where rates of use of a facility decrease with increasing distance from its location) has been well documented, particularly in rural areas, geographical access remains peripheral to mainstream public health research. The techniques available for the measurement of geographical access may be one reason for this. Within health research, geographical access is usually measured using straight-line distances, road network distances or journey times (which assume private transport is used). These measures may mask poor geographical accessibility of health services to the most vulnerable populations. Appropriate measures of geographical access that reflect the experience of those in the most remote areas and those most in need of health services are needed.

There is no agreement on a standard measure of geographical access. The scattered nature of the literature on spatial access to health services may be one reason for the lack of a strong theoretical framework to draw together what work has been done, but several overviews of access measurement are available, including those by Vickerman (Vickerman 1974), Pirie (Pirie 1979), Guy (Guy 1983), Martin (Martin & Williams 1992), Connor (Connor, Kralewski, & Hillson 1994), Love (Love & Lindquist 1995) and Handy (Handy & Niemeier 1997). The concepts underlying models of geographical accessibility are considered in more detail in chapter 7, which deals with the design of a new measure of access, but the following section introduces some of the different measures of geographical accessibility: measures of interconnectedness; supply based measures; measures of distance and measures which combine distance and an estimate of attractiveness of services, and the ideas of potential and revealed measures of access.

1.4.1 Measures of interconnectedness

Early work on quantifying geographical access summarised accessibility through the interconnectedness of the points (nodes) within a network. Accessibility is expressed using the associated number (A.N.) of a node, the number of links to the most distant node on the network. A different form of the measure allows different networks to be compared, using an Aggregate Index (A.I.) of the average distance to all other nodes in the network. These measures have been described as 'topological' (Pirie 1979) or 'integral' accessibility, in contrast to the 'relative' accessibility described by the distance between two points (Ingram 1971).

1.4.2 Supply based measures

The second group of measures of geographical accessibility do not measure distance, but express geographical accessibility through the supply of services to a defined area or population. These measures have been summarised as 'supply-based contained-area' and 'supply-based partial-travel' studies (Connor, Kralewski, & Hillson 1994) and are often used in health services research. The most basic supply-based measure is whether there is a provider (such as a hospital or GP surgery) within an area or not. Slightly more complex is the ratio of providers to population, containing the additional information about the size as well as the presence of a service. The final supply-based measure is the 'cumulative opportunity' measure, or 'choice set', quantifying geographical access by counting the number of services available within a pre-defined area. Good access is associated with a higher number of services, poor access with fewer.

1.4.3 Distance measures

The distance between two points is one of the methods most commonly used in studies of geographical access to health services. Distance can be measured in many different ways, for example as a straight line between two points, as road distance, or as travel time. Few studies of geographical access to health services use more complex measurements than straight-line distance, although with the development of sophisticated Geographical Information Systems (GIS) and the increasing availability of computing power and data, it seems increasingly redundant to use a proxy measure such as straight-line distance when more realistic measures such as road distance or travel time are becoming readily available. Even fewer studies use anything other than private transport to estimate travel time, or use different measures for different population groups.

1.4.4 Measures of distance and attractiveness

Research on access to services such as retail opportunities has taken the measurement of geographical accessibility a step further, using measures which combine the attractiveness of services with the distance to it, collectively known as spatial interaction models. Modelling access this way makes more remote services less attractive and less likely to be used. This influence of distance is usually expressed as a negative exponential function, which assumes that the probability of using a service declines at a constant rate as distance (or travel time) increases, but a number of other functions have been suggested, including the normal (Gaussian) distribution and a reciprocal function (Ingram 1971). These measures are rarely used to predict geographical variations in use and demand for health services, possibly because they demand a substantial amount of data on the size of services and the degree to which increasing distance acts as a deterrent to travel.

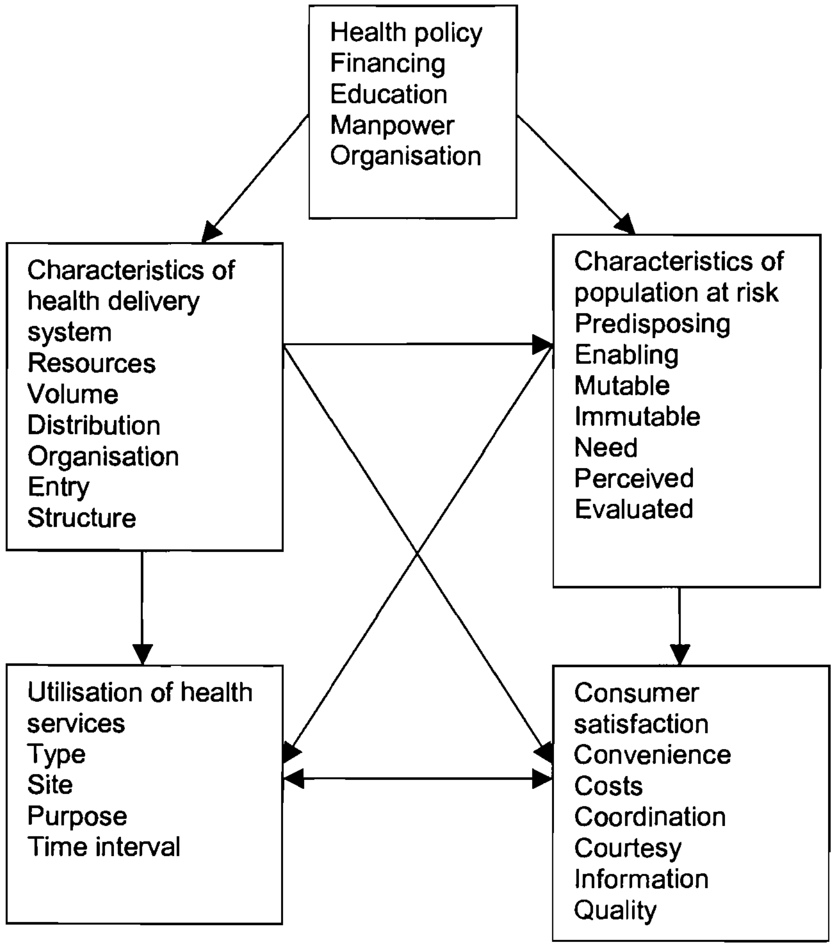
1.4.5 Revealed and potential access

The different definitions of access outlined in section 1.2 illustrate two clear ways of thinking about access: as the provision of services and as the use of services. These concepts correspond to the two main schools of thought in measuring geographical access: to concentrate on measuring and explaining patterns of utilisation (revealed access), or to concentrate on measuring the potential availability of services (potential access). Measures of access combining distance with a measure of the attractiveness of services – spatial interaction models – are designed to estimate use, or revealed access. Other measures describe the availability of services and, although they can be used in models that go on to explain variations in utilisation, are themselves measures of potential access.

It has been said that 'the proof of access is use of a service, not simply the presence of a facility' (Aday & Andersen 1974), but the measurement and modelling of revealed access suffers from a major drawback, namely the number of factors which can influence the use of health services. It is unlikely that all the influences on use could be accounted for, and any measure of revealed access is therefore likely to suffer from considerable amounts of residual confounding. Perhaps the strongest influence on utilisation is the level of need for health services. Need is difficult both to define and to measure, but is a vital component of fair access and is discussed in more detail in section 1.7.

The complexity of measuring revealed access to health services is demonstrated by early attempts to model accessibility. Anderson and Newman describe the interrelationship of the need for health services with individual level predisposing (for example health beliefs) and enabling (for example income and mobility) factors; the organisation of health services; and societal norms in health seeking behaviour (Andersen & Newman 1973), ideas which were refined into the 'behavioural model' of access to medical care (Aday & Andersen 1974). The interlinking of social and individual factors devised in this model can be seen in figure 1. Health policy is seen as the starting point for determining access, directly influencing the supply of medical care. The health care delivery system is then the means by which resources are organised and delivered to patients, and can directly affect patterns of utilisation. The characteristics of the population at risk include need; enabling factors such as income and community characteristics; and predisposing factors such as the values people hold act in combination with policy and the delivery of health care to result in realised (revealed) access, or the utilisation of health services. With a few exceptions (see, for example Rosenberg & Hanlon 1996) this model has been largely overlooked in quantitative health research. The use of health services has been measured and investigated in isolation from social patterns, and discussed in terms of personal financial and cultural barriers far more often than in terms of structural influences such as the spatial distribution of services.

Figure 1: 'Framework for the study of access' (reproduced from Aday and Anderson, 1974)



A more narrowly focused approach to the measurement of access is to measure potential accessibility. There is precedent for measuring dimensions of access separately. Barriers to using health services can be measured in terms of socio-economic factors (such as insurance status); the organisation of the health care system (such as opening hours or referral) or, as in this thesis, in terms of physical or spatial accessibility (such as the distance or travel time to health services). A model of potential physical accessibility of general practitioners presented by

Joseph (Joseph & Bantock 1982), simplifies access by concentrating solely on the physical pattern of resources and the potential to use them, should all other barriers be overcome. A similar model by Kahn emphasises the difference between 'spatial' and 'social' influences on the use of health resources. It includes terms for size of health care facilities, linear distance to health care, a distance decay component and a 'potential availability factor' for each physician, incorporating the population at risk (Khan 1992). This approach does not require measurement of the wide range of influences on utilisation detailed above, but can be used to answer the more limited question of 'to what extent is there equity of opportunity to use health services?'

1.5 How do the different measures of geographical access compare?

Selecting an appropriate measure of geographical access is not simple. Within both potential and revealed access measurement there is no 'gold standard', and the range of measures of geographical access in use can make it difficult to compare studies, as can the continual development of new and 'better' measures (Knickman 1998). Studies that explicitly compare different access measures, or use more than one measure in analysis, are rare but provide some basis for comparisons.

Assuming that geographical barriers to the use of health services are most accurately represented by the actual time taken to travel from home to the door of the hospital or health-centre (by a means and a route of the patient's choosing), it is clear that the majority of distance measures used are approximations of potential geographical accessibility. These different approximations are based on different underlying assumptions and are likely to give dissimilar pictures of accessibility.

Of the groups of access measures identified in section 1.4, it is the distance-based measures that are most often used in health research. Area based measures of supply, such as the number of providers per capita, or proxy measures such as urban or rural residence are a very poor reflection of distance-based measure of geographical access. A study in Arkansas, USA, showed that each of these measures explained less than 10% of the variance in travel time to health services (Fortney, Rost, & Warren 2000). Straight-line distance, cumulative opportunity measures (which sum the number of destinations or 'opportunities' within a given area) and gravity models can all give strikingly different pictures of accessibility to the same services (Guy 1983), underlining the importance of understanding the assumptions underlying each measure and of making an informed choice about the most appropriate measure to use.

1.5.1 Straight-line distance, road distance and travel time

Of all distance-based estimates of geographical access, straight-line distance will give the shortest measure of travel, systematically underestimating road distance by an estimated 20-25% (Williams et al. 1983) to 50% (Fortney, Rost, & Warren 2000). However, straight-line distances can give a close approximation of travel time, explaining between 60 and 95% of the variation in travel time (Fortney, Rost, & Warren 2000). The measurement of straight-line distances assumes that there are no major physical barriers impeding straight-line travel (for example areas of coastline or rivers), and that travel to and from the start and end points of the measured line is a relatively insignificant component of the entire journey. Correlations with road distance have been shown to be highest for long journeys, decreasing as journey length decreases, and are particularly unreliable in urban areas (where short travel distances combined with considerable choice of routes make straight-line an unreliable proxy for actual travel experience) (Phibbs & Luft 1995).

Road distance is a closer approximation to actual travel experience than straight-line distances, for example explaining over 96% of the variation in travel time to general medical services in Arkansas, USA (Fortney, Rost, & Warren 2000). Maps of population distribution by different measures of access to health services have been used to demonstrate that, in the densely populated areas of North West England, road distance is a more accurate reflection of travel time than straight-line distance (Martin et al. 1998). Road distance as a measure of geographical access does not differentiate between fast and slow roads, congested and free-flowing areas of traffic. Short distances do not necessarily indicate less of a geographical barrier to access. Using travel time as a measure of geographical access can overcome this problem.

Travel time has been used as the measure of geographical access in many studies of access to and the use of health services, and appears to be a precise and accurate measure of the impedance effect of distance. However, underlying the measurement of travel time as a measure of access is the assumption (either explicit or implicit) that a car is the means of transport. Travel time may therefore be a serious misrepresentation of access for groups without a car. Travel by public transport is almost certainly slower along most routes, with waits for connections and sub-optimal routes for a particular journey.

Travel time by public transport is rarely used as an indicator of geographical accessibility, a situation that may be more closely related to the difficulty of obtaining public transport timetable data in a usable form than to the measure's usefulness. Some authors have used the availability (rather than the journey time) of bus services as an indicator of public transport access (see, for example, Lovett et al. 2002), but this is not directly comparable with car-based journey times. Bus time has been modelled in the same way as car travel time for a limited geographical area of Cornwall, UK. Correlations between bus travel time, car travel time and straight-line distance were strong, but diverged in the more remote areas of the county, indicating a need for further investigation of the kinds of area where measures cannot be substituted for one another without misleading results (Martin et al. 2002).

1.5.2 The effects of estimating origin and destination points

The points between which access measures are calculated are an important influence on the comparability of geographical access measurements. These can be as precise as the postcode or grid reference, or as large as a zip-code area or administrative district, and the choice of scale may be imposed by regulations governing research and the use of data that could identify individuals. Where larger areas are used, centre points between which distance measurements are made must be chosen.

Variations in the type of distance measurement and the choice of origin and destination points all create very different measures of access, with different degrees of accuracy. The ratio of road distance to straight-line distance has been shown to be greater when straight-line distances are measured from area centroids than when they are measured between households, an effect which was most pronounced when geographical area centroids were used rather than population-weighted area centroids (Hyndman, Holman, & De Klerk 1999). The travel distance to general medical care has been estimated to be, on average, four miles greater when measured from zip-code centroids than when measured from the more precise 'street-segment' origins: an order of magnitude similar to the average travel distance. Straight-line distances measured between street level origin and destination points were shown to be a precise reflection of door-to-door travel time, accounting for almost 95% of the variation in travel time. Yet, when less accurate origin and destination points (zip-code centroids) were used, straight-line distance explained just under 63% of the variance. Straight line measurements between area centroids misrepresent 'true' geographical barriers (Fortney, Rost, & Warren 2000). Although areas where the correlations were lowest were not explored in the study, the correlation between door to door travel time and other measures is likely to be worse than expected for any journey which requires substantial travel to get to and from the 'start' and 'end' points of a straight-line or road distance measurement (Phibbs & Luft 1995). This draws into question the use of straight-line distances as a proxy for travel time in areas with unusual road networks or unexpectedly slow transport links, as well as for very short journeys.

It is unlikely that any of the measures of geographical access can be applied equally successfully to all areas and to all groups in the population. It has been suggested that, as the choice of access measure has a significant impact on the results, a greater awareness of the assumptions on which measures of accessibility are based is needed: for example, the use of different measures of accessibility for car owners and non car owners has been recommended (Guy 1983). The availability of new internet-based data sets, along with improvements in computer power, presents the opportunity to develop public transport access measures, and to compare them with other measures of geographical access. This has the potential to improve knowledge and understanding of the measurement and impact of variations in geographical access to health services.

1.6 Rurality and access to health services

One common assumption is that geographical inaccessibility of health services is essentially a rural problem. A 1994 review of the literature on rural health and health care (Watt, Franks, & Sheldon 1994) concluded that the 'impact of distance among the rural poor on health service utilisation [and] the effect of rurality on the outcome of common conditions for which agreed treatments exist...' needed to be addressed by further research, and rurality has often been used as a proxy indicator of geographical inaccessibility (Sommers 1989). In 2000 the UK Government White Paper 'Our Countryside: the future' (Department of Environment Transport and the Regions 2000b) emphasised the need both for equitable access to services and better rural transport, highlighting the need for the development of a robust method of measuring access and a better understanding of the relationships between access, health service use and health.

However, the assumption that (in the UK at least) poor access to health care is a rural problem has not been tested. Hospitals and tertiary services are increasingly located in large urban centres, meaning that travel distance to health services is likely to affect residents of smaller towns and villages as well as more traditionally rural areas. The consequences of this changing geography are not fully understood. If access is a problem outside of traditional rural areas, then rural policies are likely to exclude many in need.

1.6.1 What do we mean by rurality?

In order to evaluate geographical access for the residents of both rural and urban areas a definition of rurality is needed. Rural areas can seem easy to identify – they have different characteristics to urban areas. Population density tends to be lower; transport networks more sparse and services more thinly provided. Rural populations may have different characteristics to urban populations – populations may be older but, equally, they may be healthier and less in need of regular health services than equivalent groups in more urban areas and are often thought of as less deprived than urban populations. However, the measurement of rurality is not straightforward. It may be that a single, agreed measure of rurality is difficult to achieve, because of the multidimensional nature of the concept of rurality (Watt, Franks, & Sheldon 1994). Pragmatic judgements are often made, for example including all areas that are not physically urban or suburban.

Themes commonly found in the measurement of rurality are:

- Settlement size;
- Population density or sparsity;
- Population dispersion or 'nearest neighbour'[2];
- Accessibility to services;
- Peripherality[3] (distance from major service centres);
- Land use; and
- Multivariate classifications (Asthana et al. 2002).

[2] The nearest neighbour measures the average distance between a point and all other points in the area. It gives a measure of the scatter of the population.

[3] Peripherality is a measure of the distance between the location of interest and some central point, for example peripherality can be expressed as distance from London.

The choice of a measurement of rurality is largely dependent on data availability, and the different measures of rurality will identify different sets of 'rural' areas. Measures such as population density and the dispersion of the population can be applied and compared internationally, but it is important to recognise both the definition of rurality being used and the culture in which it is being employed. Personal perception of isolation combined with the means to travel may be a more important influence on rurality as a deterrent or an obstacle to accessing services than an empirical measure of population distribution. The most widely used measure of rurality is probably population density, but thresholds for a 'rural' population density vary and the measure cannot discriminate between a scattered population with no large settlements, and a population concentrated in a single area.

Multivariate or 'geodemographic' classifications of rurality recognise rurality as a complex, multivariate concept. Elements such as migration, population density and occupational structure (the percentage of the population defined as farmers or agricultural workers) combine to give the ingredients for a rural area, but are highly specific to the area in which they were developed (for example, see Cloke and Edwards, 1986, Regional Studies: 'Rurality in England and Wales 1981: a replication of the 1971 index). One commonly used UK classification of wards is based on a 'brainstorming' exercise, and the methods have never been written up fully (Wallace, Charlton, & Denham 1995). All the measures of rurality listed above have their shortcomings, which must be remembered when interpreting any analysis of research on rural areas.

In conclusion, the continuum from urban to rural is not smooth. The concept of rurality is complex, difficult to define and measure with precision. In examining the assumption that isolation from health services is a rural problem, this thesis uses the ONS multivariate classification of 1991 census wards to define rural areas, but in reviewing the literature it is not always clear what definition of rurality has been used.

1.7 Fair access

Once the distance from services has been established, equity of access to services (in both rural and urban areas) can be measured. It is important to establish that spatial, social, cultural and other variations in the availability and use of health services do not necessarily reflect inequitable access. Equity of access to health services is part of a wider framework of need, demand and supply of health services. Equity of access implies equal care for equal need, and definitions of access such as 'providing the right service at the right time in the right place' (Rogers, Flowers, & Pencheon 1999) imply something of the linkage between the provision of services, the knowledge and opportunity to use them, and the need for health care in an equitable system.

Facilities such as hospitals and health centres will always be further from some people than others. Although measures of geographical access will reflect this inequality, inferring inequity of access solely from differences in supply, such as variations in travel distance or the ratio of providers to population, has considerable limitations. The placing of hospitals, General Practitioners (GP) surgeries, clinics and specialist treatment facilities is not chosen to give a geographically uniform distribution of services, but to meet the need for the services they provide. However, the supply of health services is driven by historical patterns, public pressure (including pressure from doctors) and by political pressure as well as by need, making it unlikely that patterns of supply will be an effective reflection of patterns of the need for health care. Alternative measures of the need for health services are required.

1.7.1 Estimating need

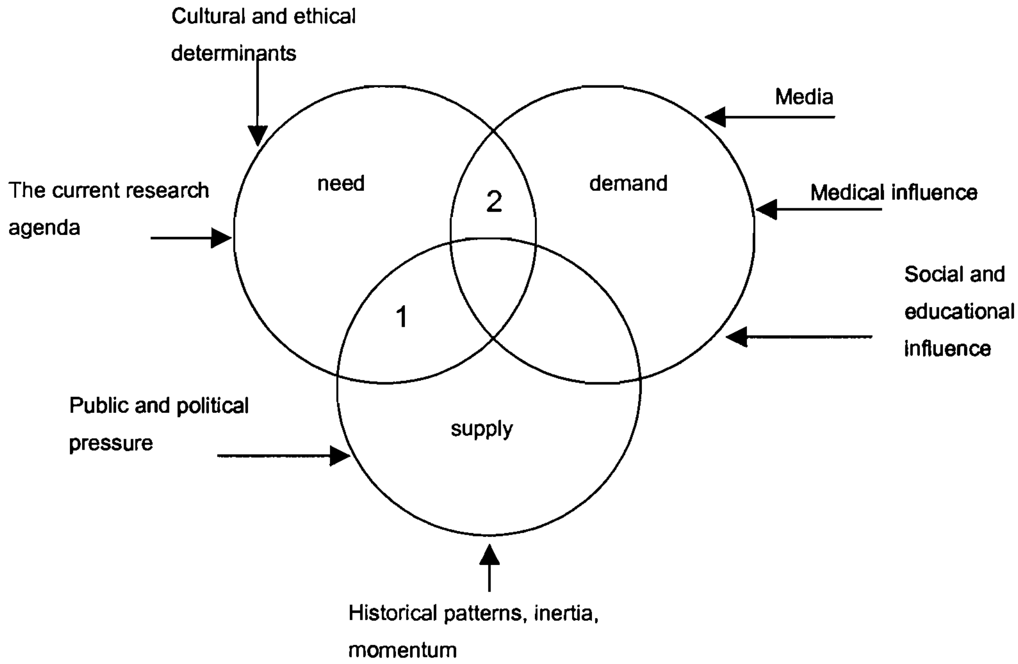
The need for health services can be defined in terms of ill health, or in terms of proxy measures that are related to ill health. Alternatively, the use of health services is often used as a measure of need. The use of health services is strongly related to the need for care, but is an unreliable proxy for need, firstly because use is to some extent a function of supply, and also because only those who both demand to use health services and succeed in doing so will become users. This depends on knowledge of available services and on a range of personal and social factors (such as health beliefs) which influence uptake. In the case of secondary services in the UK, demand is also related to referrals from primary care. Not all people who could benefit from health services demand to use them, and not all those who demand to use health services need them.

Stevens and Raftery provide a range of definitions of need including felt need (perceived by the individual), expressed need (felt need turned into the demand for a service), normative need (need agreed on by professionals such as clinicians) and comparative need (also professionally determined), but define the need for health services as 'the population's ability to benefit from health care', where 'health care' includes preventative and treatment services which are both available and effective. In other words, even where ill health exists, and there is demand for health services, if there is no effective preventative measure or treatment there is no need for health care (Stevens & Raftery 1994).

The relationship between need, demand and supply is illustrated in figure 2, reproduced from Stevens & Raftery 1994. Inequity in access to health services may exist where a service is both needed and supplied, but barriers to the use of the service inhibit demand and use (area 1 of figure 2), or where a service is both needed and demanded, but not supplied (area 2). These interrelationships between need, supply and demand have implications for the use of health services and for the measurement of access. If a service is needed and supplied, poor geographical access to that service may inhibit demand or create barriers to the use of the service despite need and supply existing, or may effectively restrict the supply of services, despite the presence of need and demand.

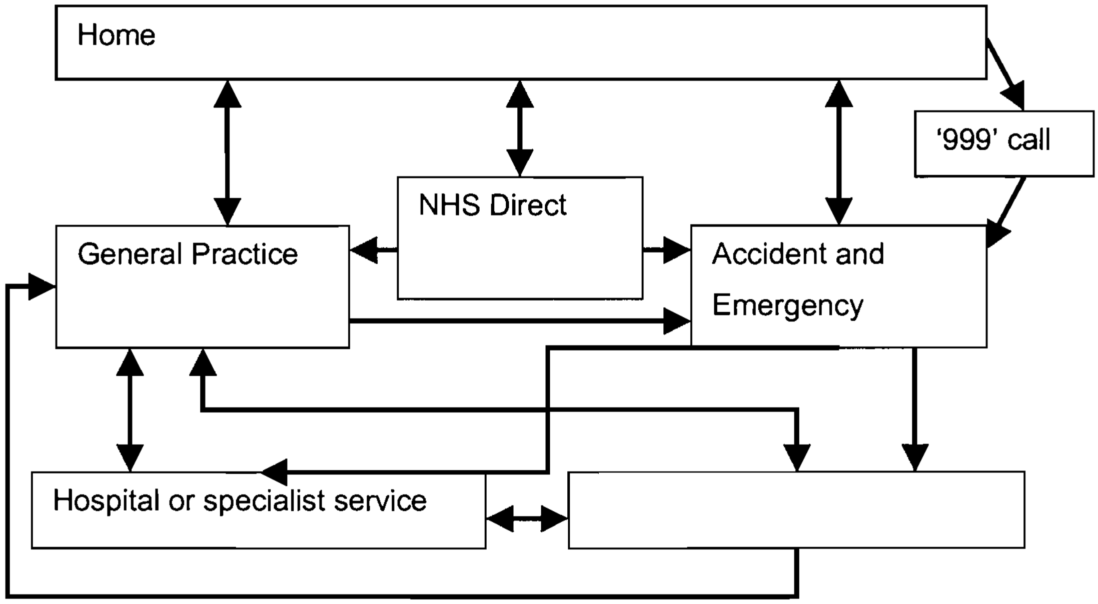
Figure 2: Need, demand and supply, influences and overlaps

(Reproduced from Stevens & Raftery 1994 with minor alterations)



Need and demand for health services from patients and the public are not the only influences on the demand for and use of health services. Demand for many health services is also influenced by health professionals, who act as gatekeepers to many more specialist forms of health care. The empirical work for this thesis is set in the UK, where entry to health care is through primary care, usually either a GP or a hospital A&E department (although the NHS Direct telephone service and NHS walk-in centres are now also part of primary care). If specialist care is required, patients are referred through the system by doctors in primary care settings. For the patient it is access to primary care services that may be vital in determining access to the wider health care system. Furthermore, the knowledge, understanding and health beliefs of gatekeepers in the system will influence the demand for specialist health services. Factors such as proximity do not necessarily imply accessibility to higher order services such as hospitals and specialist centres. In the USA it is possible to consult a specialist directly, but appropriate health insurance is necessary. Insurance companies and Health Maintenance Organisations (HMOs, organisers of packages of health care from a contracted group of suppliers) therefore act as highly effective gatekeepers in the USA, restricting the use of many health services, particularly for the estimated 33 million (Gatrell 2002) Americans without health insurance. Pathways through the UK health care system are illustrated in figure 3.

Figure 3: Pathways through the UK health care system



Defining need and measuring the need for health care is difficult, requiring either that the layman has a perfect recognition of illness (felt need) or that the judgement of clinicians is perfect, and that they assess all individuals with a potential need (normative and comparative need). Proxy measures of population need such as deprivation measures and rates of self reported illness are therefore often used to determine levels of need. A wide range of health problems have been associated with deprivation. The extent to which this relationship is due to the processes of deprivation itself (for example having insufficient resources to provide a healthy diet or adequate living accommodation); to psychological factors associated with relatively poor status, resources and amenities; or to the effects of living in an area with relatively poor amenities regardless of individual circumstances, remains unclear. However, the association between many types of ill health and deprivation means that area-level deprivation is often used as a proxy measure in estimating health care need and attempting to allocate resources equitably.

1.7.2 Measures of deprivation

Deprivation indices were created to identify concentrations of poverty and poor living standards. They generally use census data, aggregated at an area level such as the output area (OA), enumeration district (ED) or ward to act as a proxy measure of low income and a poor standard of living. The specific composition of these indices varies slightly depending on how they are derived. Two of the most commonly used indices: the Townsend score (Townsend, Phillimore, & Beattie 1979) and the Carstairs score (Carstairs & Morris 1989) were developed to identify variations in the standard of living – material deprivation. The Jarman Under Privileged Area score (Jarman 1983), frequently used in health studies, was developed to predict workload in General Practice. Other geodemographic area classifications (for example the SuperProfiles scheme (see, for example Aveyard, Manaseki, & Chambers 2002), ACORN classification (as used by the internet search utility 'Up My Street' http://www.upmystreet.com and also in, for example, Langford (Langford & Bentham 1996), and ONS families of areas (Wallace, Charlton, & Denham 1995)) were developed to identify social differences between areas and have been relatively little used for health research. Finally, the Indices of Multiple Deprivation (the IMD2000 and the updated ID2004) were developed from a wide range of census and other data to describe different types of deprivation (including health, educational and housing deprivation) and to give an overall picture of deprivation for areas (Department of Environment Transport and the Regions 2000a; Noble et al. 2004).

1.7.3 Problems with deprivation measures in rural areas

There are doubts about the capacity of commonly used deprivation indices such as the Townsend and Carstairs scores to capture the complexity of rural areas. The pervasive idea of the 'rural idyll' supports the impression that rural areas are pleasant and attractive places to live, exempt from the social problems of the cities. However, if deprivation indices are a marker for poverty, then there is deprivation in rural areas as there are people who live in poverty in rural areas in the UK. If deprivation is a marker for low levels of social contact and for social exclusion then there are deprived people in rural areas. If deprivation is a marker for a poor quality physical environment, bad housing and a lack of services and facilities, then there are deprived people living in rural areas. The tendency to associate the idea of deprivation with a certain type of urban environment, and a certain type of urban population can mask these rural problems, as can the ways in which deprivation is traditionally measured. Inappropriate measures of need for health care coupled with poor access to services may result in unrecognised and unmet need for care, and consequent inequity in the distribution of resources.

Standard deprivation measures are strongly related to health only in urban areas of the UK, and have been criticised for being a better reflection of urban than of rural deprivation (Barnett 2001; Barnett et al. 2002; Knox 1985; Townsend, Phillimore, & Beattie 1979; Watt, Franks, & Sheldon 1994). There are many reasons why deprivation may not be associated with health in rural areas. It may be that the experience of being materially deprived in a rural area does not have the same impact as in an urban environment. Alternatively, it has been suggested that the relationship is still strong, but that the deprivation indicators were developed for an urban context and the markers they use to identify deprivation are not appropriate to the rural setting. Car ownership is one such variable. In urban areas, relative poverty may result in people choosing not to own and run a car. In rural areas it is more likely that relative poverty will result in families choosing to own an older, less expensive car and to sacrifice other amenities to avoid the isolation of having no transport. Similar arguments can be applied to the use of ethnic groups (rare in rural areas) as an indicator of deprivation. A final argument applied to the use of deprivation indicators in rural areas is that rural populations are more heterogeneous than urban ones. The lack of concentrations of poverty and the absence of the extremes of deprivation found in urban areas, it is argued, makes deprived individuals in rural areas difficult to identify. Work by Haynes (Haynes & Gale 2000) has used aggregations of rural areas to demonstrate closer associations between deprivation and ill health when rural areas are carefully selected and aggregated to enhance their homogeneity.

Deprivation may take a different form in rural areas to towns and cities. Problems experienced by rural populations include difficulty in gaining access to services; in obtaining full time stable employment; in securing affordable housing; and problems of immobility (Cloke, Milbourne, & Thomas 1997). One study concluded that, in each of five rural areas of England, about a quarter of the population may be deprived (McLaughlin 1986), but problems of deprivation tend to be hidden in rural areas (Shucksmith et al. 1996). Cloke, Milbourne, & Thomas (1997) point out that the mixing of rich and poor may mask some indicators of poverty and claim that unemployment (measured as benefit claimants) was an unreliable measure in rural areas as people were reluctant to claim and tended to rely on the 'informal' job market to supplement their income. Low wages and seasonal work were hidden in this way.

As well as the indicators they use to denote deprivation, standard indices can also be criticised for the variables they do not include. One aspect of deprivation that is relatively under-researched is the effect of spatial variations in the provision of health services. Rather than acting as an indicator of other social problems, distance from health services may be a form of deprivation that acts directly on individuals. Greater travel distances to health services may delay contact with primary care, resulting in less timely diagnosis and treatment, and may also impact on the availability of specialist care as well as creating further stress for the patient. Distance may also be a factor in multiple deprivation. Greater travel distances to health services are likely to disproportionately affect the less well off: travel expenses are likely to be a greater burden for those with less disposable income; taking the time to attend more distant appointments may be more difficult for those with less flexible working arrangements; and distance from health services is more likely to affect those living in rural areas than those in urban areas of the UK.

One deprivation index which includes geographical access to services as an indicator of deprivation is the Index of Multiple Deprivation 2000 (IMD) (Department of Environment Transport and the Regions 2000a). At the time it was created, the IMD was unique in including a measure of the distance to local services, including health services, and will be discussed in more depth in chapter six. The inclusion of the access to services domain in the IMD may make it a useful indicator of rural deprivation, as may complex markers for poverty (including data on employment and housing circumstances).

In conclusion, barriers of geography such as travel time and distance to health services operate in the context of variations in the need and demand for health services. Both need and demand are likely to vary geographically. Establishing the level of need for health services is often done through the use of proxy measures such as area-based deprivation indices, which may not be an appropriate measure in some rural areas. Some variations in demand may not be related to need. The focus of this thesis is on the geographical element of access to health services, and the need for health care is measured using deprivation measures. Such measurement cannot provide a comprehensive overview of equity of access, but should be interpreted as one part of a wider picture.

1.8 Public transport and access

My particular concern in this thesis is restricted access to health services for those in greatest need: the elderly, the very young and the most deprived, all frequent users of health services. These groups are amongst the most likely in the population to find travel to health services difficult and inconvenient, and to be unable either to afford or to drive a car of their own. In areas close to health services, or areas with a comprehensive public transport system, travel problems are minimised. Where the distances to health services are highest and where public transport services are both infrequent and expensive such restricted mobility is likely to be a particular problem, and there is evidence that it is those people in remote rural areas who do not own a car who make the least use of both primary and secondary health services (Bentham & Haynes 1985). Describing the availability of public transport to health services, and relating transport availability to the need for health care and the distance from services is central to this thesis.

Where the availability of public transport has been considered, rural areas are often the focus of attention. This focus on rural areas has been more recently upheld by the 2003 report of the Social Exclusion Unit on transport and social exclusion (Social Exclusion Unit 2003). The report noted that one in three people without a car had difficulty in getting to hospital, and that knowledge of patient's experiences of travel to non-emergency health care was limited. A study of contemporary rural lifestyles in Britain in the 1990s found that one in four households did not have access to a private car, suggesting pockets of non-mobile households in areas not well served by public transport. Women and the elderly were disproportionately affected by lack of access to a car (Cloke, Milbourne, & Thomas 1997). The 1994 Strategic Framework for Gloucestershire identified 'distances from major centres of population and limited transport availability' as a barrier to achieving good health for the population of rural areas (Moseley 1996), and the cases of a patient who felt 'stranded' at hospital facing an expensive taxi journey home in the middle of the night, of a woman whose pre-booked ambulance failed to arrive, and of a new mother who felt isolated at hospital because of the difficulty of travelling for visitors, have all been cited as illustrations of the problems of transport deprivation and the variety of people affected (Heward 1997).

Voluntary transport is a key resource in many rural areas, plugging the gap between hospital transport and the use of private cars. The study of a single voluntary medical transport project ('Rural Wheels') showed that before the inception of the voluntary scheme, poor public transport and access to medical facilities were the two major problems affecting residents. Almost half of all pensioner households in the area did not have access to a car, and one in five of all households did not (in 1995). The scheme had been widely used and was under pressure to expand its remit to cover many 'medical' journeys including trips to clinics, chiropodists, hairdressers and regional hospitals as well as the original idea of trips to the local health centre. Most users of the scheme were older women, and many used the service regularly. Most of those surveyed had mobility impairment, and a few were housebound with the exception of the 'rural wheels' trips (Sherwood & Lewis 2000). However, a small core of dedicated but elderly volunteers often runs voluntary transport schemes, and provision is patchy and uncoordinated. Indeed, many areas without regular public transport services also had no voluntary transport services, leaving residents to rely on lifts, taxis and hospital transport for all non-emergency medical journeys (Rural Development Commission 1996).

1.9 Summary

Three ideas are brought together in this thesis: that geographical access to health services may be unequal; that any such inequality is likely to disadvantage the residents of rural areas more than those of urban areas; and that within those areas which are most affected by poor geographical access to health services it is likely to be the poor who are most disadvantaged. Variations in geographical access to health services have been related to a range of poor health outcomes, as will be demonstrated in chapter two, and considerable work remains to be done, both in summarising what is already known about the effects of variations in access and in evaluating equity of access. Methods for the measurement of geographical access are not well established and methods for identifying deprived groups within the areas that are most likely to be affected have been criticised.

1.9.1 Aims and objectives

The aim of this thesis is to explore the relationships between geographical access to health services, health, deprivation and rurality, and to develop a method of describing geographical access to health services that incorporates public transport. The objectives are:

- To review the literature on the measurement of geographical access to health services and on the relationships between geographical access, the use of health services and health
- To measure access to health services in the study area using the previously developed measures of straight-line distance and car travel time
- To investigate the Index of Multiple Deprivation 2000 (IMD) as a measure of the need for health care in both urban and rural areas
- To develop a measure of access to health services by public transport
- To compare the different measures of access (straight-line distance, car travel time and public transport travel time); to explore the integration of measures of access based on public and private transport; and, if possible, to identify and describe those parts of the study area with the poorest access to health services using these measures

1.9.2 Thesis structure

Chapter two reviews the empirical literature from the UK, Europe, the USA, Australia, Canada and New Zealand on geographical access to health services and the use of health services, and health. Chapter three introduces the geographical setting of this study, describing the census geography of the UK, including 1991 enumeration districts and wards, 2001 Census Output Areas and postcode geography. I also introduce the health service geography of the area, explaining the role of General Practitioners and District General Hospitals in providing health care. Chapter four sets out the methods used to achieve the objectives of the thesis, describing the data management and methods of analysis used. In chapter five I describe geographical access to primary and secondary health services in the study area, and in Chapter six I present the results of the analysis of the IMD and the Townsend score as an indicator of health, and hence the need for health care, in urban and rural areas. In chapter seven I describe the development of a public-transport based measure of geographical access to health services and, in chapter eight, demonstrate the final public transport model and present the results of an analysis of geographical access to secondary care in Cornwall. Chapter nine is the concluding chapter.

Chapter 2: Literature review

2 Chapter overview

In this chapter, I review the literature on three aspects of geographical access to health services: the distance between populations and health services; the relationship between geographical access and the use of health services; and the relationship between geographical access and health. In the first section I describe the search strategy, and set out the criteria for selecting studies for inclusion in the review. I then present the evidence for variations in geographical access to primary, secondary and specialist health services in the UK, Europe, North America and Australia and New Zealand, and review the evidence for the impact of geographical access on the use of services and on the population health. The assumptions underlying the discussion of access to health services are discussed and the need for a measure of public transport in a full measure of access is explored. Finally, I discuss the literature in the context of the need and demand for, and the supply of, health services, and the importance of establishing the level of need for health care when assessing equity of access is highlighted.

2.1 Search strategy

Literature on geographical access to health care is dispersed amongst public health, social medicine, medical sociology and medical geography journals, and it is unusual for these sources to reference one another. Every effort has been made to systematically and comprehensively search the available literature, but the range of sources and lack of formal indexing mean some studies may have been missed.

The criteria for searching for articles for this literature review are broad. Due to differences in health care systems and transport infrastructure around the world, the search was restricted to the literature of the UK and Ireland, continental Europe, Canada and the United States of America, Australia and New Zealand. The databases searched were

MEDLINE[4], 1984-2004

Embase[5], 1980-2004

The Science Citation Index (SCI)[6], 1981-2004

[4] MEDLINE is the bibliographic database of the National Library of Medicine, 1966-present

[5] Embase provides access to the world's literature on pharmacology and biomedicine. 1980-present

Social Science Citation Index (SSCI)[7], 1981-2004
HMIC[8], 1980-2004
HELMIS[9], 1984-1998
ASSIA[10], 1987-2004
Transport[11], 1988-2004
Searches covered the whole time-span of the database wherever possible, but were curtailed at 1980 if the database went further back. Differences in the structure of the databases led to some inconsistencies in the exact years searched, as it was not always possible to select the same time range. Where a search term produced too many hits for the abstracts to be effectively searched, the time-span was reduced until no more than 500 abstracts were recalled by the term.
"Access" to health care in the sense of geography is not indexed in the medical databases, and no formal search strategy for the concept exists. Search terms were identified through pilot searches and review of abstracts and key words of relevant papers. The terms used were "health" with the words and phrases listed in table 1. The number of references retrieved for further review using each term is given in the table.

Wildcard characters (*, ?) were used to truncate words with a range of possible endings (*) and to indicate alternative spellings (?). It should be noted that the sum of references retrieved using all search terms across all databases does not equal the final number of papers selected for further review as it contains duplicate references both within databases (where a reference was identified by more than one search term) and between databases (where a reference was identified in more than one database). The bibliographies and reference lists of reviewed articles were also used to identify relevant studies, and formal literature searches were complemented by searches for the work of key authors in the field and hand searches of the recent editions of key journals.

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[6] The Science Citation Index, 1981-current, covers over 2,500 core medical journals

[7] The Social Sciences Citation Index, 1981-current, covers over 1700 major social science journals

[8] HMIC covers material in the library of the Kings Fund, 1979 to current. It has a mostly UK focus, including health management and services, community care, and NHS organisation and administration.

[9] The Health Management Information Service (HELMIS) database is produced by Leeds University Library. It contains over 54,000 records (1984 to 1998) relating to community care and health systems management.

[10] The Applied Social Sciences Indexes and Abstracts, 1987-current, contains over 255,000 records from 650 journals in 16 different countries, including the UK and US. Coverage includes health and NHS reforms

[11] Transport is a bibliographic database of transportation research information, 1972-current

Table 1: Search terms

Term	Number of references retrieved for review[1]
acces* and barrie* or boundar*	13
acces* and rural	56
acces* and primary, secondary or tertiary care	19
acces* and transpor*	23
acces* and utili?ation	34
analysis and (small area or spatial)	26
demographic and factors	6
distance	137
geograph* and differenc*	60
geograph* and proximity	69
geograph* and dimension	10
GIS (including geographical information science or system)	58
location and clinic	1
location and residen*	14
public transport	11
servic* and utili?ation	22
spatial and analysis	13
spatial and distribution	16
time and (journey or travel)	76
utili?ation and behaviour	7

[1] Some references may be duplicated in two or more databases

Tables are used to present the key features of the studies, in particular the measurement of access used, and the key findings in terms of health service use or health outcomes. 'Greyed out' cells within the tables indicate that no data were available. For comparability between studies, reported distances were converted between miles and kilometres as necessary using the web utility http://www.convert-me.com, accessed between June 2003 and April 2004.

2.1.1 Selecting studies for review

Initial structured searches of the eight databases selected for review yielded over twenty five thousand published papers. The titles and, where available, abstracts of these papers were scanned and six hundred and forty eight articles on the theme of access to health services were identified. After duplicate references within each database were removed from the set, four hundred and thirty one articles remained for further review (this number still includes references duplicated in two or more databases). After all duplicates were removed from the dataset, two hundred and eighty two unique articles were identified through structured database searching and assessed for inclusion in the literature review.

To be included in the literature review studies had to meet the following criteria. Articles had to:

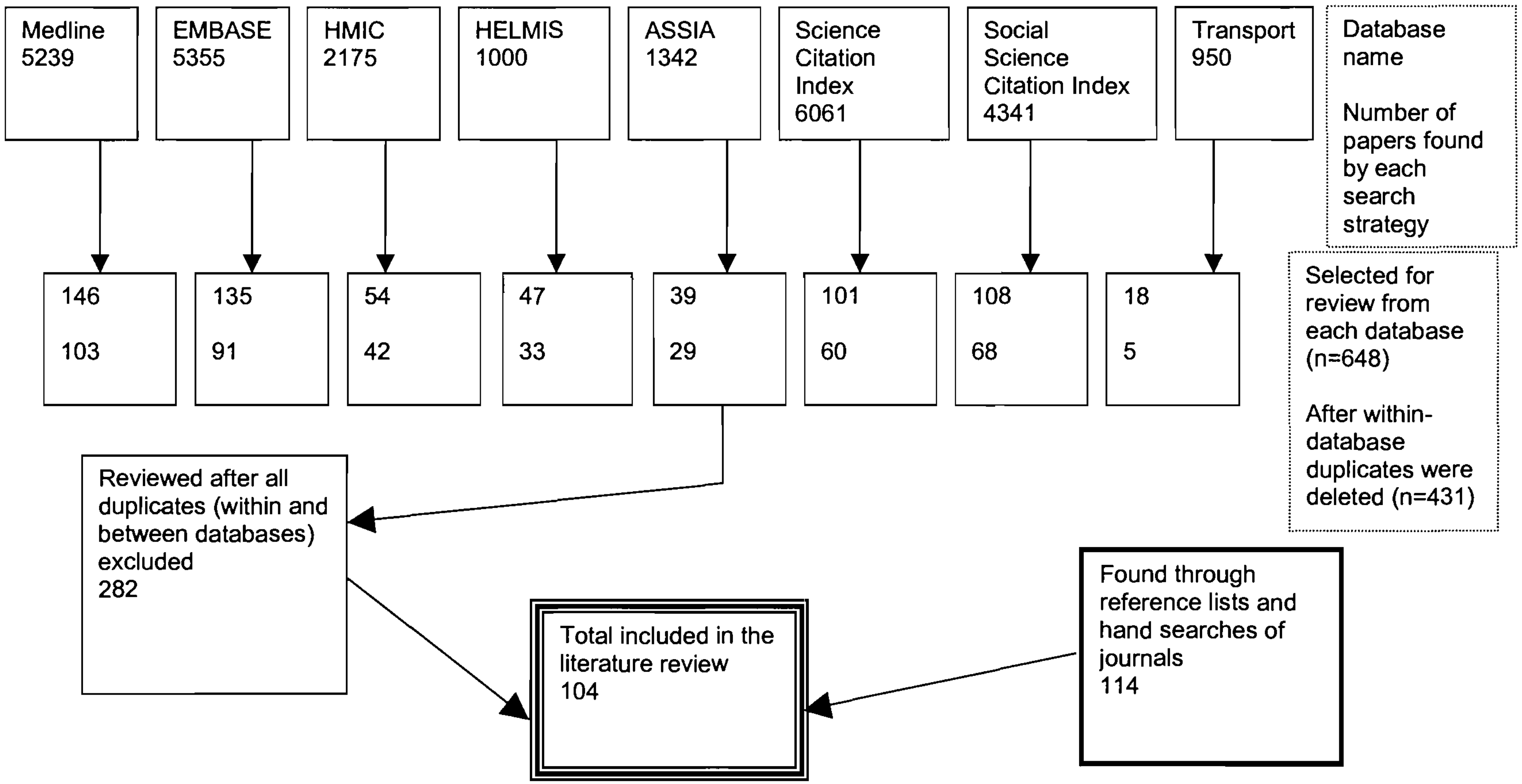
- Give the results of primary research
- Refer to the developed world countries of the UK and Europe, North America, Australia and New Zealand
- Refer to access to medical services (rather than dental or social services)
- Measure geographical access using some element of time or distance.

For inclusion in the part of the review considering the impact of geographical access on the use of health services and on population health studies also had to:

- Include empirical findings relating to at least one health outcome or use of health services
- Report the effect of geographical access independently from the effect of other variables

The numbers of papers reviewed and accepted from each of the databases and through other literature searches searched is shown in figure 4.

Figure 4: References selected for review



2.2 How far do people travel to use health services?

Geographical access to health services is a measure of the location of health services relative to the population who need to use them. The spatial distribution of health services is rarely reported in research literature. Determining how far people travel to get to health services is the first step in determining and in being able to compare the geographical accessibility of health services between rural and urban areas, deprived and affluent populations, between countries and between the types of health service approached. Without knowing the distribution of distances to health services we have no evidence of what is meant by poor geographical access, and have no standards against which to judge such claims when they occur. For the purposes of this review, the literature is divided into reports on geographical access to primary care and those on geographical access to hospital (including specialist) services. As outlined in section 1.7 the existence of gatekeepers to health services means that geographical access may have different implications for these different types of health service, particularly within the UK.

2.2.1 Distances to primary care

There is little published work that sets out to determine distances to primary care as the sole objective. An exception is a single Swedish study, which reports a range of distances from three to 41km to the closest Primary Health Centre (Kohli et al. 1995). Other studies report distances to primary care as part of a wider remit, for example as part of a comparison of alternative measures of access, or an analysis of different influences on patterns of attendance at general practice. Unfortunately, this often results in an incomplete picture of the distance to health services: average distances are more often reported than maximum and minimum distances, and very little indication of the distribution of distances is given (table 2). The difference in the distribution of health services which can exist between urban and rural areas is clearly demonstrated by two Australian studies, where travel distances range from approximately one kilometre in an urban area (Hyndman & Holman 2001) to over 58 kilometres in rural Australia (Bamford et al. 1999).

Table 2: Distance to primary health care

Travelling distance to primary care (km)							
	Destination	Minimum	Median	Mean	Maximum	Method	Reference
Perth, Australia	General practice surgery			1.04		Straight line	Hyndman & Holman 2001
Urban New Zealand	General practice surgery attended		1.7	2.2		Road distance	Hays, Kearns, & Moran 1990
Sweden	Primary Health Centre	3	1.16	3.43	41.21	Straight line	Kohli, Sahlen, Sivertun, Lofman, Trell, & Wigertz 1995
North West England	GP Practice	0	0.85	1.23	4.81	Straight line	Bojke C et al. 2004
Rural Colorado, USA	Primary care physician		4.02			Straight line	Fryer et al. 1999
Arkansas, USA	Physical health physician			5.63		Straight line[12]	Fortney, Rost, & Warren 2000
Arkansas, USA	Physical health physician			7.2		Road distance	Fortney, Rost, & Warren 2000
Rural south Australia	Locations with a GP service	0		58.0	677.0	Road distance	Bamford, Dunne, Taylor, Symon, Hugo, & Wilkinson 1999

Rather than reporting the distance to health services, studies of the geographical accessibility of primary care often report the distribution of the population around a site, for example giving the proportion of people within ten kilometres of a primary care centre. Although the amount of evidence from the literature is very limited, and refers to regional access rather than giving a national picture, different countries appear to have very different distance profiles for travel to primary care. Based on the limited number of studies available, the USA appears to have a far more dispersed population with respect to primary care than the UK. Distance bands used to report the distances to health services vary between studies, making exact comparisons difficult, but two of the three available studies from the UK indicate that less than 5% of the population live more than 8km from their closest GP. Although

[12] sample based estimate

the third UK study showed that just over 20% of callers to an out of hours primary care service lived more than 8km from the Primary Care Centre this is a sample of callers rather than the population of all patients and may be skewed towards those living at a greater distance (Munro J, Maheswaran R, & Pearson T 2003). In comparison, two studies from the USA show that between a third and a half of people live over 8km from their closest primary care provider, and 5% or more appear to live over 30km from primary care services. One study shows that the Swedish population distribution appears to be more similar to the American than the British situation, showing the smallest cumulative population within 20km of primary care of any of the studies here. In terms of travel time, the few studies available show striking similarities between Britain and the USA, with the vast majority of the population within 15 minutes drive of their GP or primary care physician (table 3).

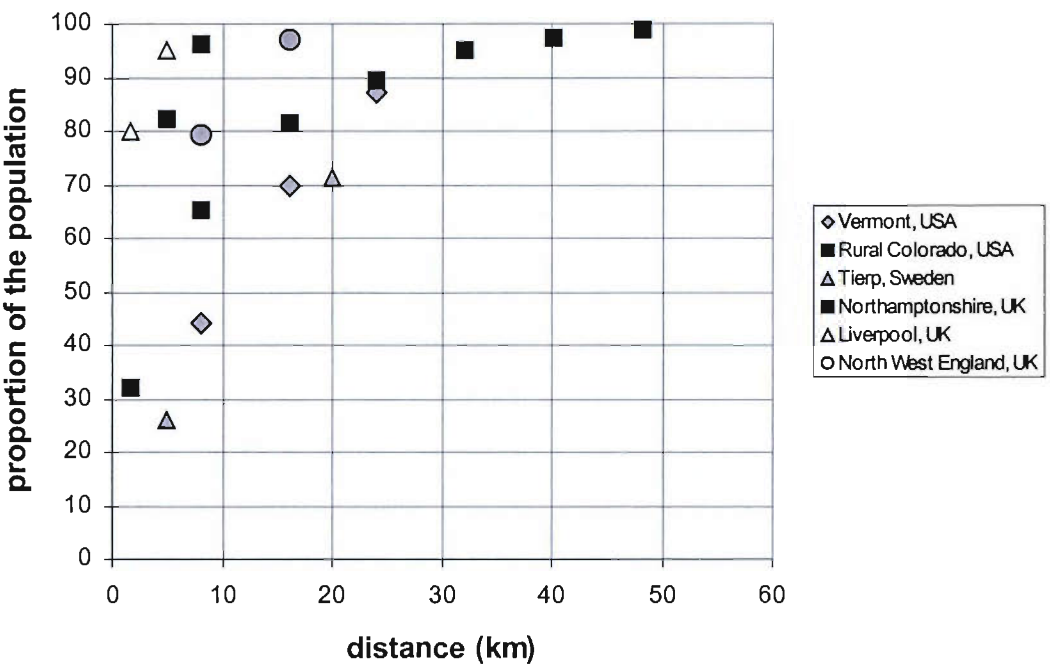
Table 3: Cumulative proportion of the population at each distance*

Cumulative percentage of the population at each distance from primary care (km)												
Study location	Destination	Distance (km)*									Method	Reference
		1.6	5	8.1	16.1	20	24.1	32.2	40.2	48.3		
Vermont, USA	Physician's office			44	70			87			Self-reported	Nemet & Bailey 2000
Rural Colorado, USA	Primary care doctor			65.2	81.4		89.4	95.2	97.5	99	Straight line	Fryer, Drisko, Krugman, Vojir, Prochazka, Miyoshi, & Miller 1999
Tierp, Sweden	Health centre		25.9			71.2					Straight line	Isacson & Haglund 1988
Liverpool, UK	GP surgery	80	>95								Straight line estimate	Hopkins et al. 1968
Northamptonshire, UK	GP practice	32.1	82.1	96.3							Self reported	Field & Briggs 2001
North West England	Primary Care Centre			79.1	96.8						Road Distance	Munro J, Maheswaran R, & Pearson T 2003
Cumulative percentage of the population at each travel time from primary care (minutes)												
		Time (minutes)*										
		0	3	5	10	11	12	15	17	30		
East Anglia, UK	Nearest GP surgery				90.7			97.5			Drive time	Lovett, Haynes, Sunnenberg, & Gale 2002
Norfolk, UK	Nearest GP surgery		50				95		99		Drive time	Haynes R, Lovett A, & Sunnenberg G 2003
	Nearest GP surgery			67	90			98				
	Own GP surgery			47	80			93				
New England, USA	Primary care doctor	80						93		97	Drive time	Goodman et al. 1997

*time and distance bands are taken directly from the published studies, not all distance bands shown

Figure 5 shows the population distribution around primary health services from the six available studies.

Figure 5: Cumulative proportion of the population by distance to primary care



Information on whether the areas studied are rural or urban is limited, although one study explicitly states that it is in 'rural Colorado' (Fryer, Drisko, Krugman, Vojir, Prochazka, Miyoshi, & Miller 1999), and a second that it is in a rural part of the UK (Lovett, Haynes, Sunnenberg, & Gale 2002).

2.2.2 Distances to hospital and specialist services

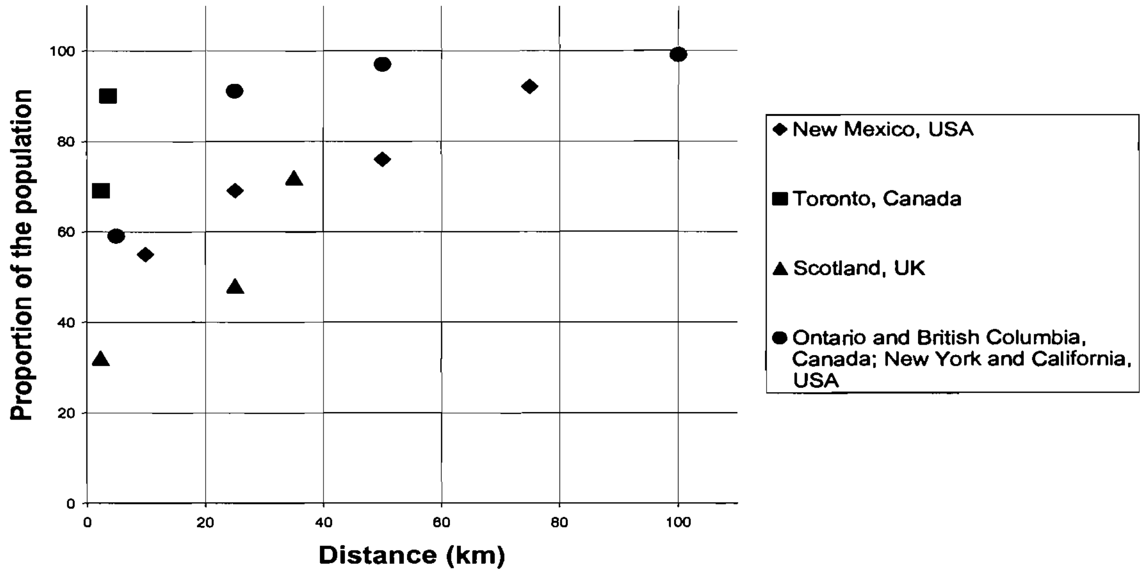
Unsurprisingly, distances to hospital are generally greater than those to primary health care. Hospitals offer more specialised services. As demand for such services is limited, a single centre must serve a large and often dispersed population. However there is very little published information demonstrating travel times or distances. Just seven studies identified for this review report distances to hospitals or specialist facilities: of these, one gives the mean distance to the nearest hospital (just over eight miles) (Rosenheck & Stolar 1998), and another the maximum distance to both the closest acute care hospital (13 miles) and the closest hospital with specialist cardiac revascularisation services (70 miles) (Gregory et al. 2000). The distances to more specialist hospitals are covered by two studies, one of which gives minimum, maximum and average distances to three types of hospital offering cancer treatment, starting at the least specialised end with a hospital offering radiation therapy (at a mean distance of 22 miles) and ending with a National Cancer Institute (USA) Centre (at a mean distance of 128 miles) (Hadley, Mitchell, & Mandelblatt 2001). The other gives average distances to four hospital alternatives: the closest rural hospital (at an average of 5.6 miles), another rural hospital, an urban teaching hospital (average 172.7 miles) and finally another urban hospital, but for rural Medicare beneficiaries only, and identifying the 'other rural' and 'other urban' hospital choices by criteria other than travel distance. The distance to a selected hospital (not necessarily the closest) is also described by a fifth study – although at an average distance of just over 2 miles it seems likely that the selected hospital would be the closest hospital for many people in the study (Ingram, Clarke, & Murdie 1978). All of these studies were set in North America. One UK study gives the average travel distance along the road network to a renal dialysis centre (O'Riordan et al. 2003) and a final study (from Sweden) gives travel times by public transport to the nearest Emergency Department (median is 46 minutes, maximum 70 minutes) (Magnusson 1980). The data clearly show the increasing travel distances associated with obtaining some more specialised forms of medical treatment, but give very little grounds for comparison of travel times and distances between countries, regions or different population groups (Table 4).

Table 4: Distance to hospital and specialist services

Study location	Destination	Min	Median	Mean	Max	Method	Reference
		Miles					
New Jersey, USA	Nearest acute care hospital				13	Straight-line distance	Gregory, Malka, Kostis, Wilson, Arora, & Rhoads 2000
	Nearest hospital with cardiac revascularisation facilities				70	Straight-line distance	
Toronto, Canada	A single metropolitan hospital			2.37		Straight-line distance	Ingram, Clarke, & Murdie 1978
USA	National cancer institute centre	2.1		128.8	407.7	Straight-line distance	Hadley, Mitchell, & Mandelblatt 2001
	Council of teaching hospitals hospital	1.0		63.5	334.1		
	Radiation therapy hospital	0.0		21.5	103.4		
		Miles					
USA	Closest rural hospital			5.56		Straight-line distance	Tai W-TC, Porell FW, & Adams EK 2004
	Other rural hospital			96.14			
	Urban teaching hospital			172.70			
	Other urban hospital			211.42			
USA	Nearest non-VA hospital			8.6		Unclear	Rosenheck & Stolar 1998
West Pennines, UK	Dialysis centre			12.7		Network distance	O'Riordan E, Lambe D, O'Donoghue DJ, New J, & Foley RN 2003
Travelling distance to hospital (minutes)							
Stockholm, Sweden	Hospital emergency department	5	46	41.6	70	Public transport travel time	Magnusson 1980

Population distribution around hospitals follows a slightly different pattern to that around primary care providers, with a higher proportion of people travelling greater distances and a more linear pattern of accrual of patients (Figure 6).

Figure 6: Cumulative proportion of the population by distance to hospital and specialist services



The difference between urban and rural areas, specialist and more general facilities is marked, with a hospital in urban Canada taking just under 70% of patients from within three miles, and a cancer centre in rural Scotland drawing just over 70% of its patients from within 35 miles. A final two studies give an impression of the population distribution by travel time to hospital showing that, in New England, USA, 36% of the population are in the same zip code as their closest hospital (an effective travel time of zero in this study), two thirds are within fifteen minutes travel time and 90% are within 30 minutes travel time (Goodman, Fisher, Stukel, & Chang 1997). This compares to a rather more dispersed population in Wales, where just 51% are within 30 minutes of their closest hospital offering tertiary facilities (Christie & Fone 2003) (Table 5).

Table 5: Cumulative percentage of the population at each distance

Cumulative percentage of the population at each distance from hospital (miles)												
Study location	Destination	Distance (miles)										
		2.4	3.6	5	10	25	35	50	75	100		
Toronto, Canada	A single metropolitan hospital	69	90								Straight line	Ingram, Clarke, & Murdie 1978
Scotland, UK	Cancer centre	32				48	72				Straight line	Campbell et al. 2001
New Mexico, USA	Nearest radiation treatment facility				55	69		76	92		GIS network distance	Athas et al. 2000
Illinois, USA	Nearest general hospital (elderly population only)	60		80		<100					Straight line	Love & Lindquist 1995
Illinois, USA	Nearest specialist geriatric hospital (elderly population only)		40	60					100		Straight line	Love & Lindquist 1995
Canada (national study)	Hospital with stroke treatment capability					67 (20)	78 (40)		85 (65)		Straight line	Scott et al. 1998
Ontario and British Columbia, Canada; New York and California, USA	Nearest hospital performing coronary artery bypass surgery			59		91		97		99	Straight line	Grumbach et al. 1995

Cumulative percentage of the population at each distance from hospital (minutes)									
		Time (minutes)							
		0[13]	15	30	60	90	120		
New England, USA	Nearest hospital	36	67	90				Road network distance weighted for road category and congestion	Goodman, Fisher, Stukel, & Chang 1997
Wales, UK	Nearest tertiary hospital provision			51	76	89	95	As above	Christie & Fone 2003

[13] ie same zip code

Provision of specialist health services can also occur at clinics and specialist treatment centres. Four American papers quote mean distances to mental health services: three of these are interested in distances to services provided at Veterans Association (VA) centres, reporting average travel of either just under 54 miles (Rosenheck & Stolar 1998) or just under 13 miles (McCarthy & Blow 2004) to a VA outpatient clinic and just over 27 (McCarthy & Blow 2004) or 15 miles to a VA mental health centre (Fortney et al. 1995). The fourth study reports mean distances of over 150 miles to a single specialist treatment unit within a VA hospital (Prue et al. 1979). There are problems comparing these distances. Not only do they refer to different types of treatment for different health problems, they also refer to different population groups, with two studies based on patient samples while the others calculate distances for the whole population. A further study reports travel times to mental health services from five to twenty seven minutes, but uses the unusual method of public transport drive time, and gives no comparison of this with more commonly used measures such as straight-line distance, or explanation for using the measure (Burgy & Hafner-Ranabauer 1998) (Table 6).

Table 6: Distance to mental health services

Study location	Destination	Minimum	Median	Mean	Maximum	Method	Reference
USA	VA medical centre			15.5 miles		Straight line	Fortney, Booth, Blow, & Bunn 1995
USA	VA outpatient service			12.7 miles		Straight line	McCarthy JF & Blow FC 2004
	VA psychiatric care			27.7 miles		Straight line	
USA	VA mental health outpatient clinic			53.9 miles		Unclear	Rosenheck & Stolar 1998
Mississippi, USA	Alcohol treatment unit of a single VA hospital	12 miles		154.3 miles	378 miles	Road distance	Prue, Keane, Cornell, & Foy 1979
Travelling distance to mental health care (minutes)							
Mannheim, Germany	Central Institute of Mental Health	5	18	17	27	Public transport drive time[14]	Burgy & Hafner-Ranabauer 1998

[14] derived from published table of area times

2.2.3 Summary

Rather than measuring 'access' alone, the majority of work on geographical access to health services has been interested in determining equity of access for different populations. For this review, I looked for papers reporting the average distance to health services (as a median or, more usually, a mean value), and the distribution of distances (as a range, inter-quartile range, or standard deviation of the distribution of distances). As this review shows, literature detailing the distances to health services is sparse, and it is particularly unusual to find an estimate of the distribution of distances. This lack of detail in the literature makes it difficult to form a clear understanding of geographical access to health services.

There are two main ways in which geographical access to health care is reported: as the straight-line distance to services or as the drive time to services, which assumes the use of a private car. The use of other measures such as gravity models, road distance, or travel times based on public rather than private transport is less common.

There is little ground on which these different measures can be compared, although there has been some work on this (discussed in more detail in chapter 3). The situation is further complicated by the use of pre-defined time or distance bands for the reporting of results, by the selection of areas to study (for example rural areas are often selected due to their assumed problems with access), by the study of facilities which are only available to a sub-group in the population, and by the study of a sub group of facilities with no consideration of the alternatives available. The work on access to VA facilities in the USA illustrates this last problem: the distance to VA facilities is often considered for eligible veterans only, and the relative availability of alternative health care is overlooked.

Other than by the choice of sub-groups for analysis, access measures do not appear to be selected with different populations or area types in mind. Straight-line distances, drive times and (very occasionally) public transport travel times are used without comment on their suitability for the situation being investigated. There is very little information available on the way in which these measures compare to one another, or on their appropriateness in different situations. For example, an estimate of straight-line distance may be misleading if some of the population being studied lives in an area with sparse road links or other major physical barriers to straight-line travel such as coastline or mountain ranges. An estimate of access based on drive time may be inappropriate if the majority of the population do not have access to a car, and an estimate based on public transport inappropriate if some regions of the study area are not covered by regular public transport services.

Distances to health services vary enormously between countries and between types of health service. Distances between some populations and their health services in the USA appear to be far greater than in Europe, although it must be borne in mind that many of the studies in this review are not nationally representative and may reflect the experience of areas which are unusual in terms of distances to health services. For example, the UK's combination of a centrally planned health service and many densely populated areas may explain why the distances to health care are the shortest of any country covered by this review, but the literature gives no idea of national average distances or of how distances vary between regions: the distance to a cancer centre in Scotland may be a very poor reflection of the distance to maternity services in Sussex, or to accident and emergency treatment in Staffordshire. It is also unclear how the distance to health services might differ between different population groups. We know little of communities who consider their access to health services poor, and have no standards against which to judge such claims when they occur.

In conclusion, there is little information on the distance that people must travel to use primary, secondary or specialist health services, or of the way in which that distance varies between countries, between urban and rural regions, or between different groups in the population. The relationships between different measures of access are unclear, and there has been little discussion of the circumstances under which different measures are appropriate. There is considerable scope to improve on the current level of knowledge about the basic state of geographical access to health services.

2.3 What is the relationship between access and the use of health services?

As outlined in chapter one, variation in the use of health services is influenced by the level of need for health care, the services offered, and by demand for those services. The interplay of use, need and demand is complex. Geographical access forms just one part of the pattern, but one that is rarely evaluated. Poor geographical access may deter the use of health services which are needed by imposing barriers related to travel such as time and cost, and may influence demand by forming a barrier to the spread of knowledge about the availability of health services. These barriers of time, distance, cost and knowledge may affect patients, their families and also health professionals. Doctors may be unwilling to refer patients over large distances, or unaware of services which are available outside their own locality. However, poor geographical access may also suppress demand for health services that are not needed, resulting in lower levels of use, but not in inequity of access.

Studies on the effects of geographical access on the use of health services cover a wide range of health services, from primary care to specialist services with a wide catchment area (such as hospital-based mental health care and cancer treatment). The influences on the use of health services will depend, at least in part, on the structure of the health system. For example, direct patient access to secondary and specialist care is not possible in the UK health service. This review is therefore divided into parts which deal separately with primary care and more specialist care. Within these sections, this review examines the evidence for the effect of geographical barriers to access on making an initial contact with health services, then on the choice of facility, on continuing with treatment and on the likelihood of being referred within the health system. Finally the effect of geographical access on patterns of patient visiting is described.

2.3.1 Distance and the use of primary care

The first way in which geographical access can impact on the use of health services is as a barrier to initial contact with the health service provider. In the UK, direct access to the health system is only possible through primary care providers such as GPs and A&E departments, as outlined in section 1.7. Rates of consultations in primary care are subject to considerable variation depending on the level of need for health care, on the services offered and on demand from the local population. They are also influenced by the nature of the condition for which a consultation is needed. Patients with chronic conditions that may be managed in primary care, such as asthma and diabetes, are likely to be frequent users of primary care. Consultations within primary care for a specific, chronic condition are therefore treated as ongoing care in this review.

2.3.1.1 Initial contact with primary care

For patients seeking a first contact with their own primary care physician in the USA a national study recorded an Odds Ratio (OR) of 0.86 for those living more than 30 minutes travel time from their physician (Forrest & Starfield 1998). In rural Vermont, USA, having a physician within the area commonly visited for shopping and everyday tasks was a significant predictor of use, although the linear distance to the doctor was less important (Nemet & Bailey 2000). However, there is not always a relationship between geographical access to primary care and the rate of contact with the service: in a Spanish study (which, unusually, included adjustment for indicators of the need for health care) there was no effect of travel time to general practice on the proportion of the population using GPs (Abasolo, Manning, & Jones 2001).

Where different population groups have been compared, there appears to be a differential effect of distance with age and sex: women seem more affected by distance than men, and elderly people more affected than younger groups. In England and Wales as a whole rates of GP consultations decreased with distance for young women and for men over age 65, even after adjustment for a range of socio-economic variables (Carr-Hill, Rice, & Roland 1996). In the London borough of Lambeth, men aged between 15 and 65 were the only group not to show differences in consultation rate with distance and the over 65's were most strongly affected by distance, although no adjustment for differences in need between the three distance categories were made (Parkin 1979). In North West England, women, children, and those in lower social classes experienced the sharpest decline in consultation rates with distance. Although the consultation rates were not adjusted for differences in need, univariate analysis indicated no major variation in the prevalence of disease was found between the three areas studied (Whitehouse 1985). In Portland, Oregon, USA, distance and social class interacted to result in different patterns of health care use for members of one health insurance scheme: middle class patients tended to rely on telephone contact as distances to health services increased, whereas lower social classes turned to the emergency department rather than the primary care physician at greater distances (Weiss & Greenlick 1970). Providers as well as patients can initiate variations in the use of services. Distance from a general practice co-operative in the UK has been associated with less chance of seeing a GP out-of-hours and more chance of patients being managed through telephone advice (O'Reilly et al. 2001).

Distance decay effects in the use of Accident and Emergency (A&E) departments are well known (Parker & Campbell 1998; Magnusson 1980), but the reasons underlying the relationship between use of A&E and geographical access are unclear: it is not known whether it is over-use by people living close to A&E departments or under-use by those living further away which is responsible for the observed distance gradient in use, and the availability of a patient's GP may be a further influence on the use of A&E. Reducing perceived 'inappropriate' use of the A&E has been a focus of considerable research (see, for example Lowy, Kohler, & Nicholl 1994), and where measures of need have been considered in multivariate analysis of the relationship between distance and use of A&E, indicators such as deprivation have explained the differences in use with distance (Carlisle 1998), highlighting the importance of making adjustments for levels of need in studies of geographical barriers to access.

An estimate of workload in one remote A&E in Scotland showed differences in patient behaviour and characteristics with distance: there was some evidence of more severe injuries in patients attending from greater distances, and more likelihood of such patients having seen a GP before going on to the A&E, indicating less of a tendency to use the A&E as a first option in this more distant group (Giannikas, Maclean, & El Hadidi 1998). In Norwich, UK, young children were less likely to attend the A&E department for accidental injuries the further away they lived (OR of 0.96 for each km distance), even after adjustment for deprivation and other factors predictive of A&E attendance. However it remains unclear whether the variation in use with distance reflects differences in accidental injury rates or differences in access to health services (Reading 1999). Although distances were short, averaging just 1.8km, and were measured from the patient's GP surgery rather than from their home, distance to the nearest A&E department was also inversely associated with attendance rates in North London, UK. Again, it remains unclear whether use was lower for patients of practices further from A&E because of differences in geographical access or because of differences in need, but there was no indication that care in general practice was less available to patients of the surgeries closer to A&E departments (Hull, Jones, & Moser 1997). In Nottingham, UK, distance to the A&E department was also short, ranging from 0.8 to 9km, and also significantly (inversely) associated with use of A&E (Carlisle 1998), and in Northern Ireland, distance from patients' homes to the A&E department was the strongest predictor of attendance amongst a selection of socio-economic variables expected to influence rates, explaining over 50% of the variation in attendance rates (Pearson correlation for log of distance and log of attendance rate = -0.73) (McKee, Gleadhill, & Watson 1990).

2.3.1.2 Ongoing contact with primary care

Primary care consultations for ongoing, chronic conditions are likely to be subject to different influences than those for acute conditions as patients are more likely to be repeat attenders, having overcome any initial barriers to using the service. The role of regular attendance in overcoming distance barriers was highlighted in one study of clinic use in Michigan, USA where, although a general pattern of distance decay in the use of primary care was evident, regular clinic users showed no relationship between distance and the frequency of clinic use (Brooks 1973).

However there is evidence for distance decay even amongst patients with chronic conditions, who are expected to be regular users of health services. Two studies in the UK have shown that the likelihood of asthmatics consulting a GP Is highest for those living close to the surgery. In Norfolk, the likelihood of consulting a GP decreased with increasing journey time (OR 0.79 for a one minute increase in journey time) (Jones et al. 1998), and in Northamptonshire, a study of the use of primary care services by groups of asthmatics and diabetics found that higher rates of use were associated with shorter travel times, although there was an increase in use by those living furthest from the surgery (Field & Briggs 2001).

The relationship between distance and the use of health services might be expected to vary by personal characteristics influencing personal mobility such as income, car ownership and time constraints, and two studies have suggested that the measure of access used may be critical to understanding the effect of geographical access on the use of services. In Northamptonshire, UK, time constraints and family commitments were associated with perceived poorer access and tended to affect women more than men, the employed more than the unemployed and manual workers more than non-manual workers. Personal mobility was a strong indicator of perceived accessibility, with three-quarters of those reporting difficulties with access being non-car owners. The authors suggested that higher rates of use in the most distant groups might be explained by the higher reliance on cars, and hence easier travel arrangements in outlying areas, distorting the linear distance and use relationship (Field & Briggs 2001). A similar explanation was proposed for the observed relationship between geographical access and missed appointments in one family practice clinic in Midwestern USA. Although missed appointments were associated with travel distance it was patients close to the clinic (within three miles) who missed more appointments than those at greater distances. The authors suggested that differences in transport availability – patients at some distance from the clinic having better transport arrangements in place than those living nearby – may underlie the observed relationships, but this assertion was not tested (Smith & Yawn 1994).

2.3.2 Distance and the use of hospital and specialist services

The use of hospital and specialist health services is likely to be affected by need, demand and supply in the same way as the use of primary care, but is complicated by the process of referral. In the UK, referral from primary care is necessary to use any secondary or specialist health service and primary care services are contracted to deal largely with pre-selected secondary care providers. Real or perceived barriers to use, including geographical access, will therefore affect both patients and their primary care provider. Outside of the UK, patients are more often free to refer themselves to a wider range of health care providers, and distance may be a more direct influence on the choice of hospital or specialist care provider. Insurance status will, however, form a major financial barrier to the use of secondary and specialist care. The influence of these other factors must be considered when any relationship between geographical access and the use of secondary or specialist health services is explored.

2.3.2.1 Initial contact with hospital and specialist services

Distance decay in the use of hospitals is well recorded in the UK and elsewhere (Cohen & Lee 1985; Goodman, Fisher, Stukel, & Chang 1997; Haynes et al. 1999; Hippisley-Cox & Pringle 2000; Jones, Bentham, Harrison, Jarvis, Badminton, & Wareham 1998; Walmsley 1978). In the UK health system, some health service use is mediated through referrals from A&E, but most is through the patient's general practitioner: as well as acting as a barrier to patients, distance barriers may make it less likely for patients in the UK to be referred by their GP. This is likely to reflect contractual relationships between primary care and secondary care suppliers within the NHS, but may also reflect a lack of knowledge of more distant services, or a concern for the difficulties patients may face in travelling to receive care. Proximity to large teaching hospitals may reflect a diffusion of ideas and awareness amongst both patients and their local doctors and further influence the options available.

One of the first areas where a distance decay effect in use was recorded was mental health services, and a substantial body of literature on the relationship between distance and the use of mental health services exists. *Jarvis's Law* was a term coined in the late 19th century, and demonstrated that a high proportion of asylum inmates came from areas close to the asylum itself (referenced in Shannon, Bashshur, & Lovette 1986). All the studies identified for this review show a decrease in use of mental health care services with increasing distance.

A study in the town of Mannheim, Germany found that outside of office hours the rates of first-contact with a psychiatric emergency service decreased with increasing distance to the service. Rates of contact varied by population characteristics such as housing conditions and population density, especially at shorter distances, but the distance gradient persisted even when these factors were controlled for in a regression model. Geographical access was measured using both straight-line distance and the estimated travel time by public transport, and increases in both distance and time were associated with the rate of initial contacts with the service (Burgy & Hafner-Ranabauer 1998). The same authors showed that as travel time increased there was less demand for the emergency service (expressed as the proportion of patients who had been responsible for initiating contact) although need (as assessed by psychiatrists) remained constant, indicating that demand may be an important factor in the relationship between geographical access and the use of health services (Burgy & Hafner-Ranabauer 2000). In a national study of veterans in the USA, distance was the most powerful predictor of the use of VA mental health services, especially veterans whose mental health problems were connected to their military service (Rosenheck & Stolar 1998). The elderly also seem to experience a sharper rate of distance decay than other groups (Fortney, Booth, Blow, & Bunn 1995).

Variations in geographical access to secondary and specialist services may impact on the rates of use of different treatments. The local availability of specialist services may be an influence on referral by health professionals and on the choice of treatments by patients. The role of geographical access barriers in referral has been demonstrated by the relationship between referral and time of year: In two rural states in the USA the likelihood of referral to a cancer centre decreased in the winter (when travel was more difficult) for all groups except those living within 25 miles of the centre (Greenberg et al. 1988). Distance may also be associated with the chance of treatment as an inpatient rather than in the community. In the USA, veterans who presented for emergency psychiatric care were almost five times more likely to be hospitalised if they lived more than 60 miles from the treatment centre than if they lived closer. Whether this is due to the problems inherent in caring for a dispersed patient population or to a failure of earlier psychiatric care for this group is unclear (Fortney, Owen, & Clothier 1999).

Where different population groups have been compared, studies have shown a differential effect of distance with age and sex for hospital care, with distance having the greatest negative impact for those aged over 65 and on low incomes, and the least effect on children (Mooney et al. 2000). Referral to specialist services such as Renal Replacement Therapy (RRT) has been shown to be less likely as distance to a main renal unit increases (Martin, Roderick, Diamond, Clements, & Stone 1998). Distance has been shown to be more of an influence on the use of dialysis than on renal transplantation (Maheswaran et al. 2003), and to affect different age groups to a different degree, with distance acting as more of a barrier to people over the age of 60 (Boyle, Kudlac, & Williams 1996).

Geographical access to specialist services was found to be an influence on their use in the case of breast-conserving surgery (BCS). Patients in Michigan, USA, living near to a cancer centre were more likely than those living further away to be offered BCS as an alternative to mastectomy (Kreher et al. 1995). Nationally, patients on the Medicare insurance scheme in the USA also showed distance-decay in their use of BCS. In a study of the effects of demand and supply on the uptake of BCS, distance to three types of hospital offering radiation therapy was a significant predictor of use. Once adjustment had been made for other influences on the use of BCS (including the price of treatment) only distance to the most specialised hospital type (a National Cancer Centre Institution), was significant (Hadley, Mitchell, & Mandelblatt 2001). The travel distance to radiotherapy treatment was not a significant predictor of BCS in New Mexico, USA, but did influence the uptake of post-operative radiotherapy. The odds of receiving radiotherapy decreased sharply after 25 miles from a radiation-treatment facility – affecting almost half of the population eligible for treatment. Socio-economic status, insurance status and regional practice patterns were all suggested as possible influences on the observed relationship, and were not tested in the study (Athas, Adams-Cameron, Hunt, Amir-Fazli, & Key 2000).

Rates of cardiac revascularisation have been linked to distance from both the referring centre and the distance from the hospital. In Nottinghamshire, UK, the distance between primary care services and hospitals was correlated with the rates of admission for angiography and revascularisation, and with waiting times for angiography (Hippisley-Cox & Pringle 2000), while the distance from home to the nearest hospital with cardiac revascularisation services was associated with the odds of patients receiving a Coronary Artery Bypass Graft (CABG) or Percutaneous Translurninal Coronary Angioplasty (PTCA) in New Jersey, USA (Gregory, Malka, Kostis, Wilson, Arora, & Rhoads 2000). In New York and California, USA, the use of Coronary Artery Bypass Surgery (CABS) has been shown to decrease sharply with distance from the nearest hospital offering the procedure, with the highest rates for populations between 5 and 50 miles from a CABS hospital and the lowest rates (less than half the highest rate) for those more than 100 miles from their nearest hospital (Grumbach, Anderson, Luft, Roos, & Brook 1995). As with other treatments, there is some evidence that the effect of distance varies by population group: the effect of distance on receiving a coronary artery bypass graft within 90 days of being hospitalised with an acute myocardial infarction (MI) was greater for those aged over 65 than for younger patients (Gregory, Malka, Kostis, Wilson, Arora, & Rhoads 2000). The need for treatment will also play a strong part in establishing rates of revascularisation, as will supply and demand factors.

The evidence for distance decay in the rates of initial contact with secondary and specialist health services is not unanimous. For example, the uptake of particular treatments is not always related to geographical access. One American study looked at the receipt of pain therapy in pancreatic cancer patients in Minnesota and found that distance to a pain control centre was not a statistically significant influence on the proportion of patients receiving the therapy (Brown et al. 1997), and a UK study found no evidence that the use of radiotherapy was limited by travel times of up to an hour (Cosford, Garrett, & Turner 1997). In Scotland a study of influences on the time from presentation with colorectal or breast cancer to treatment found that, although initially it appeared those living furthest from cancer centres received the fastest treatment, this effect was fully explained by other differences in patients' clinical condition. No effect of distance on time to treatment was observed in multivariate analysis (Robertson et al. 2004). In the case of surgical interventions, the Canadian provinces of Ontario and British Columbia showed no decrease in the rate of CABS with distance to hospital (Grumbach, Anderson, Luft, Roos, & Brook 1995), and a Californian study found no difference in equity of access (measured as age at admission) for children with congenital heart problems across a range of distances (Chang, Chen, & Klitzner 2000). Finally, there was no delay in admission to a stroke unit in Lyon, France for those at greater distances, although means of transport to the unit (either a personal vehicle or emergency services transport) did have an effect. As in the case of rates of contact with primary care, this may demonstrate the importance of using more sophisticated measures of geographical access than simple distance, as any differences in speed of referral with distance from the unit may have been overcome by the use of fast transport (Derex et al. 2002).

2.3.2.2 Choice of facility

The effect of variations in geographical access is often cited as an influence on the choice of health provider. Within the USA particular attention has been paid to the influence of variations in geographical access on attendance at free health care facilities. Some groups in the USA are eligible for health care at free facilities, normally military or VA hospitals. Low rates of uptake of these facilities have prompted a range of studies on the possible causes, including geographical access.

Negative associations between travel time and the choice of a particular facility have been found by many authors (Burgess & DeFiore 1994; Luft et al. 1990; McGuirk & Porell 1984; Mooney, Zwanziger, Phibbs, & Schmitt 2000; Shahian et al. 2000), but not all (Smith et al. 1985). For example, distance decay appears to operate with respect to the choice of a free military facility in the USA for mammography, with 77% of eligible women who chose to have their mammogram at the military facility living within 20 miles of it (Brustrom 2001). The selection of a VA hospital over alternatives is also influenced by distance: effects of distance decay were found up to 60 miles from VA hospitals in the USA, and factors affecting the odds of choosing a VA hospital over alternatives included the distance to the closest VA facility and the type of VA hospital (Burgess & DeFiore 1994).

A limitation of studies of the relationship between geographical access and the choice of health service provider is that such studies often ignore the other factors which could influence attendance rates such as the cost, availability and attractiveness of alternative treatment centres. One American study of the use of VA hospitals showed that distance to alternative facilities, the number of beds, the presence of medical residents and recognised status as a teaching hospital of the alternatives all influenced use of the VA. The effect of distance was found to be complex: varying by age group and only apparent within 15 miles of the VA (Mooney, Zwanziger, Phibbs, & Schmitt 2000), and may indicate that studies which do not take these factors into account give misleadingly simple results. Finally, all the studies identified here that investigate the choice of secondary care facility come from the USA. Choice of facility may be particularly significant in the USA context, as primary care services do not take on the same gatekeeper role as General Practitioners in the UK, and it is important to remember that the data may not translate well to other health systems where individual choice is not such a strong influence on use.

2.3.2.3 Ongoing contact with hospital and specialist services

Maintaining long-term attendance at a treatment programme for mental or physical illness may be vulnerable to pressures of time, distance and the expense of travel, causing patients miss scheduled appointments or to drop out of long term health care programmes. For example when the continuing use of a mental health centre in Rhode Island, USA, was modelled using linear regression analysis there was a small decrease in both the average number of visits over four months (of between 0.2 and 0.3% per one-percent increase in distance) and in the average rate of use (of around 0.4% per one-percent increase in distance) over the same time period, even after personal factors such as income and education levels were controlled for (White 1986). In Mannheim, Germany, linear regression of the relationship between travel time and rates of repeat contact with the psychiatric emergency service showed a decrease in contact with increasing distance and travel time, even though all patients came from within the city and the maximum estimated travel time was 31 minutes. The effect persisted when area characteristics thought to influence use were adjusted for, and was stronger for repeated contacts than that for first contact rates, suggesting that previous use of the service did not break down barriers of geographical inaccessibility (Burgy & Hafner-Ranabauer 1998).

Access to outpatient services is a key part of community mental health programmes. Two studies in the rural USA and one across the entire USA have shown that rates of outpatient service use drop with distance to a treatment centre. The deterrent effect of the difficulty of making a journey as well as of distance is emphasised by both the rural studies: one found differences between counties with main roads (freeways) running through them and those with poorer transport links (Cohen 1972), and the other that miles travelled off highways are more important indicators of access problems than distance alone or miles travelled along highways (Prue, Keane, Cornell, & Foy 1979). In the national study patients living further from outpatient mental health clinics were considerably less likely to use aftercare services following treatment for substance abuse, with an OR for attendance of 2.56 for those living within 10 miles, 1.91 for those between 11 and 25 miles and 1.21 for those living between 26 and 50 miles from their closest source of treatment, compared to those living over 50 miles away (Schmitt SK, Phibbs CS, & Piette JD 2003). Although the distances considered in these studies were large, ranging from a 12 mile round-trip to one of over 300 miles, far shorter distances may provide a barrier to the use of outpatient services. For example, a syringe exchange programme in New York, USA, had considerably higher rates of use from intravenous drug users who lived within a ten minute walk of the centre than those who lived further away (81% versus 59% of drug users). No justification is given for the ten minute cut off point in the analysis, and no further details are given to identify whether this finding represents a true distance decay relationship in the use of the service, but the study does indicate that even a ten minute walk may be a significant deterrent to the use of some health services (Rockwell et al. 1999).

However, the evidence for a relationship between geographical access to health services and continuing use is far from conclusive. For ongoing treatment, distance may become less important as barriers have already been overcome to start treatment. Two American studies found that the deterrent effect of increasing travel time was stronger for first contact with a service than for subsequent contacts, suggesting that once contact has been made and the need for further treatment established, distance has only a limited impact on continuing care (Burgess & DeFiore 1994; Forrest & Starfield 1998). A further study of the effects of geographical access on the use of health services found that, once accepted onto RRT, the influence of distance is not necessarily strong. In Missouri, USA, keeping a familiar physician was found to be a stronger influence on the choice of treatment centre than travel time (Smith, Robson, Woodward, Michelman, Valerius, & Hong 1985). However, it has also been suggested by two studies that poor geographical access can affect other aspects of care. One study showed that doctors suggested a longer interval between visits to patients living further from a VA general medical clinic, suggesting that geographical barriers may affect the ease and frequency with which follow-up visits are made (Welch et al. 1999), and there is some evidence that travel distance to mental health services has an adverse effect on both the number of patient visits and the quality of care available, with less 'guideline compliant' care available to more distant patients (Fortney et al. 1999). For long term users of health services, such as the population of American Veterans with spinal cord injuries and disorders described by LaVela et al., distance to outpatient services was a small, but statistically significant deterrent to use (a 2% decrease with every 10 miles straight-line distance), especially for women and older people. For inpatient services, although distance was still a deterrent its effect did not differ with age or gender, and was very small, with a modelled decrease of just 3% per 100 miles. However, the distances travelled were high compared to distances to non-VA facilities and, although the authors emphasise the specialist nature of care required by many of these patients with spinal cord injuries, alternative and more local provision of care is likely to have been a factor in the observed distance decay (LaVela et al. 2004).

2.3.3 Distance and the use of other health services

Other health services are available at a range of locations: hospitals, clinics, primary care centres or mobile services such as mobile screening units. Such services are treated separately from primary and secondary or specialist care and are discussed in the following sections.

2.3.3.1 Initial contact with other health services

All the studies of the effect of geographical access on attendance for screening services identified for this review considered access to breast and cervical cancer screening facilities, and have shown mixed results. Three studies found the proportion of women who take up the invitation for mammography depended on the travel distance to the site. The proportion of women taking up the invitation was found to decrease from 41% at less than six miles from the screening site to 19% at over ten miles (a decrease of 9.8% per mile over the first six miles and 11.5% per mile over the four next miles) in one study (Stark, Reay, & Shiroyama 1997) and by 2.5% with every 10% increase in distance in another (Haiart et al. 1990). In a third study, an OR for receiving a mammogram of 0.97 per five mile increment of distance was found, after adjustment for age, race and level of education (all independently associated with variations in attendance for mammography) (Engelmann et al. 2002).

Meanwhile, two studies (Bentham 1995; Kreher, Hickner, Ruffin, & Lin 1995) found no influence of distance on the proportion of women with a current screening record, although one looked only at mammography records for women already attending the doctor's practice (Kreher, Hickner, Ruffin, & Lin 1995), which may have pre-selected for those without significant access problems. The other study looked at the impact of a recently introduced system for issuing cervical cytology screening invitations on the proportion of women attending for screening and found no differences in attendance rates by distance from the screening site once the new system was in place (Bentham 1995).

As well as looking at the effects of geographical access on the use of screening services, theoretical studies have been used to model likely attendance at screening centres. In Australia, the variation over distance in attendance at existing mammography screening centres was known for different socio-economic groups. This knowledge was applied to a new, theoretical distribution of clinics and showed that the most likely response to invitations to screening was that attendance decreased with distance to a clinic. A threshold effect at 2.5 to 3 km was identified, after which response was very low (Hyndman, Holman, & Dawes 2000). A further New Zealand study showed that 30 minutes travel time was the limit that women thought reasonable to travel to screening, and that mobile screening centres were the preferred choice for women outside the main city (Richardson 1990).

Finally, travel for women seeking abortion services in the USA has been associated with delays in receiving treatment, with women travelling over 75 miles seeking abortion services having a higher proportion of late terminations (12 weeks or later) (Dobie et al. 1999). In the UK, teenage conceptions have been shown to be associated with distance from a young persons' clinic. In urban areas of Wessex, South West England, young people living between 7 and 10 km from their closest specialist clinic were more likely to conceive than those living within 7km of the premises (OR of 1.10), indicating distance barriers to using the advice and contraceptive services offered. The trend did not continue in areas more than 10km from clinics, nor in rural areas, and the authors advise a cautious interpretation of the findings as many other factors can influence both the use of the clinics and other influences on conception rates (Diamond et al. 2002).

2.3.3.2 Distance effect on visiting

There has been little analysis of the effects of geographical access problems on visiting friends and relatives in hospital, but it is an important issue. Regular visits may help recovery, make patients feel happier and keep family members in touch with one another. These factors may become especially important in the case of a long illness, or the illness of a child. One study found that distance was important to the family when a child was ill, with greater travel distances for visiting associated with additional strains on the rest of the family, with less time spent with spouses and other children (Yantzi et al. 2001). Distances were dichotomized at 80km, selected to represent a day's travel, but the effects of access on visiting choices may be apparent at far lower distances. In Scotland, visitors travelling under five miles were found to be more likely to visit people in an elderly care centre more than once a week (Santamaria 1991), and in the USA travel time was a significant negative predictor of the frequency of visits to depressed in-patients, with an increase of just 60 minutes associated with a decrease in predicted visits (Fortney, Rost, Zhang, & Warren 1999). The effects of distance may be modified by other variables. A Canadian study on the related topic of care provision for elderly relatives found that although there was a weak relationship between increasing travel time and a decreasing frequency of visits to provide care, this was only true for male carers and for those whose elderly relatives were in reasonable health. Women were almost always willing to travel further and more often to visit elderly relatives and provide care (Joseph & Hallman 1998). The age, health, and mobility of visitors and carers have not been examined by any of these studies, but it is very likely that these personal factors will have a significant interaction with distance barriers.

2.3.4 Summary

The majority of published work has demonstrated a significant, if weak, correlation between geographical access to health services and their use. The correlation has been found for both primary care and for more specialist services. It also extends to referral for particular treatments and to the choice of facility.

There is little evidence of threshold effects, although few studies have investigated this, preferring to use linear modelling (which assumes a continuous effect across the entire range of distances), or categorical analysis, where thresholds are pre-set. Linear distance decay seems unlikely: where health services are tightly clustered people do not tend to use their closest provider, indicating that distance is not a strong influence on health seeking at short distances (see, for example, Martin, Roderick, Diamond, Clements, & Stone 1998). Also, there is some indication that at long distances, adding further mileage has a limited impact on rates of use. Just one study set out to determine threshold distances (Hyndman, Holman, & Dawes 2000), demonstrating sharp decline in attendance between one and three km, after which the impact of extra distance was minimal, but several more report that the effect of distance decreases after a certain point.

2.4 What is the relationship between access and health outcomes?

Geographical barriers to access such as distance and travel time can affect health outcomes through either the mechanism of early versus later (or no) referral for treatment, through the use of high volume centres versus lower volume centres and any associated effectiveness of treatment, or through patient drop-out from follow up care. This section considers the effect of distance on delayed referral and the choice of treatment facility before going on to look at the evidence for differential population health outcomes with distance from health facilities.

2.4.1 Distance effect on complications and severity of illness

Many conditions (such as diabetes, asthma, MI, stroke and cancer) benefit from early management of symptoms. Access problems may be related to poorer outcome or to a higher than expected prevalence of complications of an illness. In rural Australia, complications of diabetes mellitus have been associated with an increase in the remoteness of areas. The odds of having diabetic complications were 1.06 (rural versus urban residents). Although this odds ratio increased with increasing remoteness, the most remote areas had a rate of complications comparable to the least remote, a feature which remains unexplained by the study (Ansari et al. 2000). Deaths from asthma were investigated in Norfolk, England, and distance from hospital was shown to be a significant predictor of mortality, with a relative risk of 1.31 for the furthest areas (>30 minutes away) compared to the nearest areas (Jones, Bentham, & Horwell 1999) and a relative risk of 1.27 for people living more than 25km from hospital compared to those living 0 to 5 km from the hospital (Jones & Bentham 1997). Mechanisms underlying these effects remain unclear: delay in treatment, the quality of primary and preventative care, reluctance to travel when ill, reluctance from doctors to refer over longer distances and cultural norms of self care in more remote areas have all been suggested, but not tested.

In a French study, survival following a diagnosis of colorectal cancer was not related to distance from the cancer centre for males, but was for females, who showed significantly worse survival if they lived more than 15km from the cancer centre (Desoubeaux et al. 1997). In Scotland, an analysis including cases of colorectal, lung, breast, stomach, prostate and ovarian cancer showed that the odds of death on the date of diagnosis were raised for those living over 5km from the cancer centre for all six cancers. The only cancers not to show a linear trend in the odds of death with increasing distance were prostate and ovarian cancer. For survival after diagnosis, although increasing distance from a cancer centre was associated with slightly higher odds of death for all six cancers, it was only a statistically significant disadvantage for lung cancer and prostate cancer patients (Campbell et al. 2000). The stage of cancer at diagnosis and first treatment may be a mechanism through which the distance effect operates, with patients living further from cancer centres less likely to visit their GP or to be referred at an early stage of disease. For example, the stage at which colorectal and lung cancers are diagnosed may be an explanation for the poorer survival of patients further from cancer centres: in Scotland patients living more than 58km from the cancer centre were found to have more disseminated disease at diagnosis than those living within 5km of the site (OR 1.47). Once adjusted for other predictors of stage at diagnosis, the OR for distance became stronger (1.59) (Campbell, Elliott, Sharp, Ritchie, Cassidy, & Little 2001).

However, for some conditions no relationship was found, for example, the risk of still birth was investigated in the mainly rural area of West Cumbria, UK, and showed no relationship between stillbirth rates and the distance to the nearest maternity services (Parker, Dickinson, & Morton 2000).

2.4.2 Distance effect on the outcome of surgery

Centralisation of health services is often supported on the grounds that bigger, centralised services offer economies of scale and that high volume services are both safer and more effective than lower volume ones (for example, see Barros D'Sa 1990). However, if higher patient volumes for specialised services are to be achieved, fewer centres will be needed. This will increase the travel distance to these services for many people. It is not clear whether increased travel distance has a deterrent effect with could undermine the increased safety and efficacy of larger centres. A study of the regionalisation of cardiac surgery in North America showed a clear deterrent effect of distance to the use of Coronary Artery Bypass Surgery (CABS) in the USA (although not in Canada). However, negotiating the line between high volume provision and any inhibiting effect of distance is difficult as lower volume hospitals were associated with higher mortality and generally increased the choice of provider only for those who have a nearby provider anyway (Grumbach, Anderson, Luft, Roos, & Brook 1995).

Just four studies were identified which considered the effect of geographical access to health services on the outcome of surgery. No study provided strong evidence for an effect of distance on outcome once other factors were taken into account, although two initially indicated that patients living or being treated further from health serviced fared worse than those at shorter distances.

Firstly, patients who were admitted to a hospital with on-site revascularisation facilities seemed to have better outcomes (lower rates of cardiac readmissions and emergency department use) than those admitted elsewhere, indicating that on-site access to revascularisation conferred an advantage. However, when teaching hospital status and the distance to a tertiary centre were added to the analysis, there was no protective effect proximity to services. This implies that it is not immediate access to revascularisation at the initial hospital of admission which is protective, but other factors, including the proximity of specialist treatment facilities (Alter et al. 2001). Similarly, although no mechanism was proposed for the action of travel distance on survival, a significant increase in the number of deaths related to surgery from colorectal cancer was recorded in a group of patients living over 30km from their treatment site. Patients living in two closer distance categories (10-20 and 20-30 km) did not show the same reduced chance of survival, suggesting a threshold effect of travel distance on the outcome of the surgery. However, the survival differences may have been due to an area effect as, in multivariate analysis, district of treatment was highly significant and distance of borderline significance in predicting survival (Kim, Gatrell, & Francis 2000).

A ruptured aneurysm requires immediate surgical care. Although the travel distance to treatment seems clearly critical, and may directly influence survival, two studies found no effect of distance on survival rates. However, this may be confounded by death before surgery, more likely in those who had to travel long distances to care, and by other unmeasured factors (Barros D'Sa 1990; Cassar, Godden, & Duncan 2001).

2.4.3 Summary

Relatively little has been written about the relationship between geographical access to health services and health outcomes, and results are mixed with little clear evidence of a distance effect. Only two studies suggested a relationship between distance to health services and the outcome of a specific treatment, and both found that the effect was explained by other factors (Alter, Naylor, Austin, & Tu 2001; Kim, Gatrell, & Francis 2000). The evidence for a distance effect on seeking treatment is stronger, with later presentation with chronic conditions such as asthma (Jones & Bentham 1997; Jones, Bentham, & Horwell 1999) and diabetes (Ansari, Simmons, Hart, Cicuttini, Carson, Brand, Ackland, & Lang 2000), and with several types of cancers (Campbell, Elliott, Sharp, Ritchie, Cassidy, & Little 2000; Campbell, Elliott, Sharp, Ritchie, Cassidy, & Little 2001) suggested as the reason for poorer survival from these conditions in patients more remote from hospitals. However, the evidence is not as strong as it may appear, as two of the papers are from the same data set. More work is still needed to test the hypothesis that distance from health services results in a delay in presentation, diagnosis or treatment that has an impact on health. At present, the main health outcome considered has been mortality – other measures of health may be more sensitive to the effect of geographical barriers to access.

2.5 Underlying assumptions

The literature on the relationship between geographical access to health services, the use of services and health outcomes makes a number of assumptions, both in the measurement of access and in the interpretation of the observed relationships. These assumptions may affect both the validity of the results, and the chances of finding a relationship between geographical access and the use of health services where one exists. The most significant of these assumptions are that observed relationships with distance are not confounded by other factors and that the chosen measure of geographical access will operate equally well under different circumstances (in different areas, for different populations, at different seasons and for different types of health care). These assumptions are discussed in the following sections.

2.5.1 Need, demand and supply

The central question underlying this thesis is whether geographical barriers result in inequitable access to health care. If health services are needed (and supplied), geographical barriers may reduce or even prevent demand for them, and thereby discourage their use (the relationships between need, demand and supply are discussed in more detail in section 1.7). Much of the literature reviewed uses measures of the distance to health services and the use of health care to infer the presence or absence of distance barriers. Yet geography as a barrier use is often considered out of the context of need, demand and supply of services, and results may be confounded by these factors.

Firstly, the supply of services is often assumed to be more limited than is the real case. Alternative sources of health care are often overlooked, a particular issue in studies of VA medical facilities in the USA. Secondly, many studies do not assess the need for health care. Some measure, either of ill health, or of a proxy known to be highly correlated with ill health (such as deprivation, or age), is needed if population rates of the use of health services are to be fully understood. And finally, aspects of demand are rarely separated from need. Need does not necessarily translate into the use of health services – those who need health care sometimes do not demand it, and therefore do not use available services, and those who do demand health care sometimes do not need it, but may use services anyway. Geographical barriers may act to reduce demand, but so may a wide range of other factors, including the 'predisposing' and 'enabling' factors identified in the work of Aday and others (see, for example, Aday & Andersen 1974).

There have been few very health care use studies which have controlled either for the need for health care or for the provision of alternative health facilities. It therefore often remains unclear whether differences in the use of health care with distance are due to barriers of time or distance, or to other confounding factors such as variations in health or the presence of more attractive alternative health services. Need is vital in determining equity of access and may be a major confounder of studies investigating variations in health seeking behaviour. Without an estimate of need for health services, it is not possible to determine whether variations in use are due to over-utilisation or under-utilisation. With few exceptions (such as Boyle, Kudlac, & Williams 1996; Fortney, Booth, Blow, & Bunn 1995; Martin, Roderick, Diamond, Clements, & Stone 1998), there is little adjustment for need, either through proxy measures such as income or socio-economic status, or through direct measures of health. Social class may also influence the distribution of need: a U shaped pattern was identified by Hyndman et al in Australia – areas closest to GPs showed the most disadvantaged population were closest to and furthest from surgeries, with the middle ground occupied by the more affluent (Hyndman & Holman 2001).

One of the main findings from the literature is the interaction between individual characteristics and the effect of distance on health service use. Where different population groups have been compared, studies have shown a differential effect of distance with age (Boyle, Kudlac, & Williams 1996; Carr-Hill, Rice, & Roland 1996; Fortney, Booth, Blow, & Bunn 1995; Mooney, Zwanziger, Phibbs, & Schmitt 2000; Parkin 1979), race (Solis et al. 1990), sex (Carr-Hill, Rice, & Roland 1996) and social class or income (Carlisle 1998; Carr-Hill, Rice, & Roland 1996; Mooney, Zwanziger, Phibbs, & Schmitt 2000; Weiss & Greenlick 1970). Women, the young, the elderly and those on restricted incomes appear to be most deterred by geographical inaccessibility of health care. This may indicate differences in the need for health care, differences in demand or differences in mobility and ease of travel between these groups, or (more likely) a combination of several of these factors. Yet studies that examine the effects of distance separately for different groups are in the minority: most consider the entire study population. This is likely to either reduce the chance of finding a relationship where one exists, or to weaken any observed relationship.

As Joseph and Bantock state in their paper on measuring potential physical accessibility (Joseph & Bantock 1982), "post facto measures of accessibility based on utilisation are constrained in their usefulness by the complexity of utilisation behaviour". They therefore recommend a measure based on potential rather than revealed access, which will not be influenced by the complex interrelationships which result in use of health services. The measures of access developed in this thesis are measures of potential access to health services.

2.5.2 Measurement

The second group of assumptions relate to the measurement of the geographical accessibility of health services. The most commonly used methods for measuring geographical access to health services are straight-line distance; road (or network) distance; travel time (usually based on car travel) and self-reported travel time or distance. Most studies use just one of these methods. Although more complex statistical models (such as gravity models) and custom made indices of accessibility (e.g. ARIA, the Accessibility / Remoteness Index of Australia (Ansari, Simmons, Hart, Cicuttini, Carson, Brand, Ackland, & Lang 2000)) are available, they are rarely used in the health services literature.

Straight-line distance is the most commonly used measure of geographical accessibility. This is easy to calculate and seems simple to compare between studies, but is likely to overestimate access for those who live in areas with physical barriers such as coastline, rivers or mountains – in these areas the road distance is likely to be longer than expected as detours are made around barriers in the landscape. Travel time estimates are more computationally intensive to calculate, and can be less straightforward to compare. Travel speeds can be self reported or calculated. If calculated, the speeds can be based on road category (Cosford, Garrett, & Turner 1997), on 'traffic zones' (McGuirk & Porell 1984), or even on public transport routes (Burgy & Hafner-Ranabauer 1998; Burgy & Hafner-Ranabauer 2000; Magnusson 1980). Distances may be to the nearest health care facility or to the facility actually used. Often, the details of the method are not stated in research papers, especially if distance was included as a confounding variable rather than as the main outcome of interest in a study. It is implicit in the lack of discussion of measures of geographical access that the exact measure used is not thought to be significant: justification of the use of one measure rather than another is not a feature of the literature, and no direct comparisons of access measures were identified as part of this review. Little is yet known about the applicability of different access measures to different circumstances, and one of the aims of this thesis is to compare different measures and identify points of disagreement between them.

2.5.3 Transport

Measures of geographical access are growing more sophisticated as computing power increases and information becomes more readily available. Proxy measures such as population density or the presence of a health care facility within a region have been superseded by distance measures such as straight-line distance and drive time. This review of the literature suggests that there is distance decay in the use of health services. Furthermore, it is likely to affect the very young and the elderly, women and the less well off to the greatest degree. Of the two measures of access – distance and time – it is drive time which appears the most sophisticated, and which is most likely to closely represent the experience of people travelling to health services. Yet, for the groups most affected by distance decay, access to health services may not be well represented by measures of travel time which assume the use of a private car: women, the poor and the elderly are less likely to own a car than the general population. Very few studies have used public transport as the basis for a model of access to health services, but the growing availability of data (particularly in PC and web based journey planning software) has made the measurement of single trips by public transport relatively straightforward. In this thesis, I aim to extend the use of this data to produce an accessibility model based on public transport, similar to the drive time models already in use.

2.6 Conclusions

The literature on the relationships between geographical access, the use of health services and health is described in this chapter. This review of the literature has demonstrated that there is little knowledge about the distances people must travel to use health services or consensus on the most appropriate way to measure geographical access to health services; limited evidence for whether a threshold exists beyond which the effect of distance declines; little evidence for which groups in the population are most (or least) affected by distance barriers to using health services; and little evidence on the nature of barrier created by distance – whether it delays contact with health services, referral for treatment, provision of treatment, all three or none.

This review has also shown that a wide variety of methods are used to measure geographical access to health services. These include straight-line distance, road distance, and drive time. The methods used to measure geographical access to health services will be discussed in more detail in chapter four, but it is clear from this review that little attention has been paid to modelling geographical access by different forms of transport.

The following chapters of this thesis go on to describe access to health services in the study area using straight-line distance and car travel time, and to develop a measure of access to health services by public transport. Those parts of the study area with the poorest access to health services are identified and described, and the different measures of access (straight-line distance, car travel time and public transport travel time) are compared. Finally, the integration of the measures of access based on public and private transport is explored and a model of geographical access, which can be applied to the understanding of variations in the use of health services and variations in health outcomes, is presented.

Although there is considerable evidence that geographical barriers to access decrease rates of contact with health services, different measures of distance and of the effects of variations in access make studies difficult to compare. Much of the research lacks adjustment for important confounding factors such as variations in deprivation, age, race, income and education that could influence the use of and need for health services. The extent to which geographical barriers to access influence the use of health services differs by age and sex, and by the type of service needed. Understanding levels of need for health services is vital if geographical barriers to access are to be accurately evaluated.

Chapter 3: Geographical data

3 Chapter overview

In the previous chapters, I have presented the evidence that geographical access to health services is a consistent, but often overlooked, influence on the use of health services and on some health outcomes. Although the evidence for the effects of geographical inaccessibility of health services is scattered, and the measurements of geographical access are varied and difficult to compare, there is considerable evidence that people who face long or difficult journeys to health services are less likely to use them in a timely and appropriate way. The evidence points to a stronger effect of geographical access on women, children, and the elderly than on men of working age, indicating that some barrier over and above simple distance is affecting the use of health services.

Two questions are therefore presented: firstly, is geographical access to health services in the UK equitable? And secondly, are the currently used measures of geographical access the most appropriate way of estimating the real geographical barriers to using health services?

In attempting to answer these questions, it is necessary to answer a number of more detailed questions. For example, in assessing equity of access to health services we need to know where the areas with the worst geographical access to health services are located, whether they are in urban or rural areas, and whether poor geographical access disproportionately affects those people who are already disadvantaged, or those who are most in need of health care. In deciding on the most appropriate way to measure the geographical barriers to using health services, we need to discover how applicable measures such as drive times are in different areas and for different social and demographic groups – for example it is not clear what proportion of those in need of health care can travel by car to health services.

The empirical study that forms the main body of this thesis uses area-level data to address these problems. Data describing the characteristics of areas in terms of accessibility, rurality and the need for health services, and data describing the distances between postcodes, the speed of travel along transport networks and the characteristics of local populations are brought together to describe the equity of geographical access to health services in one area of England.

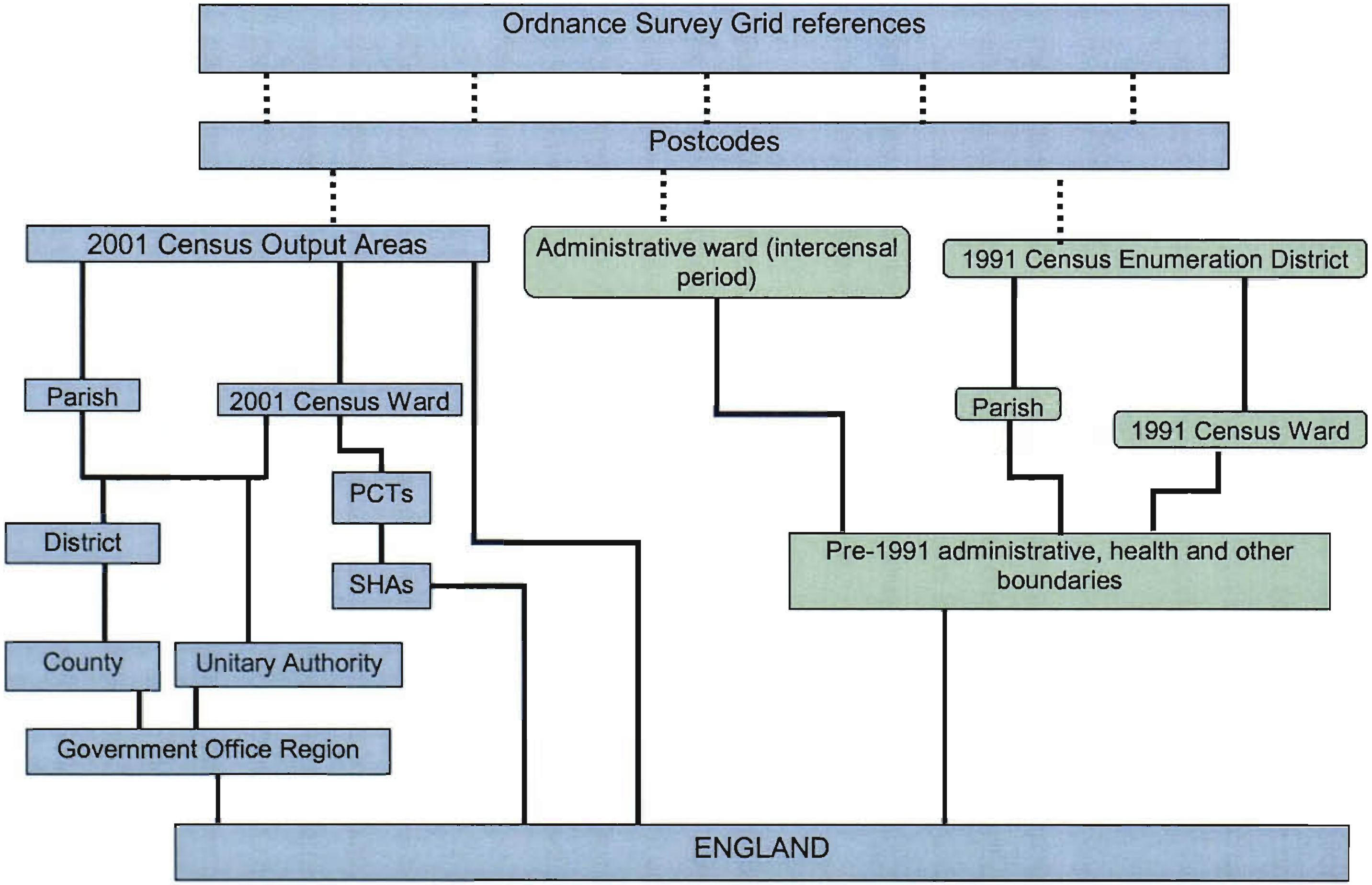
Area level data are available for a range of geographical units: at the lowest level of aggregation, data (for example distances to health services) are available for Ordnance Survey grid referenced points and unit postcodes. Other data (such as census data) are available only for larger areas such as 2001 Census Output Areas (OAs), 1991 Census Enumeration Districts (EDs) and wards. One of the challenges of working with area-level data is to combine data from two or more different geographies: for analysis, all data had to be converted to a single geographical framework.

In the following sections I describe the basic units of postal geography; census geography; and the administrative and health geographies of England, the resources available for estimating the overlap between different geographies and some of the limitations of an area analysis.

3.1 UK Geography

In the UK, a complex and changing network of boundaries created by different bodies for different purposes defines areas. There is a postal geography; an administrative geography of counties, districts and wards designed for electoral purposes; and a geography of health services, comprising directorates of health and social care, strategic health authorities and Primary Care Trusts in England and their equivalents in Scotland and Wales. There is also a census geography which includes areas used for the output of data from the decennial censuses of England and Wales, Scotland and Northern Ireland, and which is unique to each census. The boundaries of postal and other geographies do not match exactly, and the boundaries of all these geographies are subject to a continuous process of revision over time. The relationships between key geographies in England are shown in Figure 7.

Figure 7: Grid references, postcodes and area boundaries in England



Source: ONS Geography

3.1.1 Ordnance Survey grid references

OS grid references can be used to identify a location precisely, and are not subject to the regular changes that are part of administrative and other geographies. However, grid references are very rarely included in data sets: the grid references of houses, hospitals or GP surgeries are not in everyday usage. In the empirical work that follows, the locations of bus stops are grid referenced and these grid references have to be associated with census and administrative areas to allow links with other data to be made. There is no definitive link between a postcode and a grid reference (although several options for applying a grid reference to a postcode and vice versa exist and are of interest to the work in this thesis).

3.1.2 Postal geography

Postcodes are lists, on average covering 15 addresses, with a range from a single address to about 50. Postcodes were not designed as a spatial location tool, but can be related to grid references and hence to administrative areas, and are frequently quoted to identify a location. Houses, hospitals and GP surgeries are all commonly georeferenced using postcodes.

For the 2001 Census, a near direct match between postal and output geography can be made. Unit postcodes were given digital boundaries using Thiessen polygons[15], created around individual addresses and merged for entire postcodes (Martin 1998). A small proportion of unit postcodes straddle statutory boundaries: these are split into separate polygons for the purposes of census output, and will be matched to more than one OA.

The 2001 Census geography is unusual in this direct relationship with postal geography. Previous systems for linking postcodes to administrative, health and other areas created a geographical reference point by taking the grid reference of the first house in the postcode list and applying it to a 100m grid square, resulting in considerable scope for mis-assignment of postcodes. These grid references were given in the PCED directory (described in section 3.2). As numerous organisations create and use georeferenced postcode data, the Gridlink[16] project was established in 2002 by a consortium of organisations including the Ordnance Survey and the

[15] Thiessen polygon creation is a standard GIS function, allowing the creation of space-filling polygons around a point dataset such that each polygon encloses the space which is closer to its own point than to any other.
[16] http://www.statistics.gov.uk/geography/gridlink.asp, accessed 06.01.2004

Office for National Statistics. Gridlink uses standard methods to assign postcodes to administrative areas, producing a central postcode location database. However, even standardised methods of georeferencing postcodes necessarily involve some misclassification of individual addresses as a postcode may straddle more than one area.

3.1.3 Census geography: Enumeration districts and Output Areas

Prior to the 2001 Census, wards were subdivided into Enumeration Districts (EDs) for the collection and output of data in censuses of England and Wales. An ED contains on average about 400 people in 200 households[17]. As EDs were developed for data collection they have numerous disadvantages for data output, including having a large range of population sizes, occasionally falling below the threshold population size needed to maintain confidentiality, and their mismatch with commonly used postal geographies.

For the 2001 Census, Output Areas were developed as the new output geography, replacing EDs (although EDs were still used for data collection). As wards are subject to a continuous process of boundary revision, OAs are subdivisions of wards at 31st December 2002. There are 175,434 Output Areas in England and Wales, the majority of which cover between 110 and 139 households. About 5% cover between 40 households - the confidentiality threshold - and 99 households, and many of these are single parishes (or Communities in Wales).

The ED is the smallest geographical area at which data from censuses prior to 2001 are released, and the OA is the smallest geographical area at which data from the 2001 census are released. Data are therefore commonly presented at these levels, and the match between EDs / OAs and other geographies is vital to many geographical analyses. EDs / OAs are the building blocks of census wards, but do not have the same one to one relationship with intercensal wards.

3.1.4 Administrative geography: Electoral, Statistical and CAS Wards

Electoral wards cover the whole of the UK and are the basic building block of many other geographies. On average, a ward population is about 5,500 people. There

[17] Martin, D and Higgs, G. Population georeferencing in England and Wales: basic spatial units reconsidered. Environment and Planning A. 1997, 29:333-347

are over 10,000 wards in the UK, and boundaries are under a process of constant review and change. In order to minimise the impact of frequent changes in ward boundaries, statistical wards were introduced in 2003. Statistical wards are a snapshot of electoral ward boundaries laid down in statute on 31st December 2002 and are used for statistical purposes from 1st April to 31st March the next year. Census Area Statistics (CAS) wards are a subset of the 2003 statistical wards, with particularly small wards merged to protect data confidentiality - these are used by most 2001 Census outputs.

In England, wards are the building blocks of the administrative areas of London Boroughs, non-Metropolitan Districts; Unitary Authorities and Metropolitan Districts. These in turn are the building blocks of Greater London, the counties and Metropolitan counties. At the top level of administrative geography there are ten Government Office Regions, built up of complete counties or unitary authorities.

3.1.5 Health geography

Health geography is different in each of the four countries of the UK, and subject to considerable change over time.

In England, from 1982 until 1996 there was a structure of Regional and District Health Authorities. In April 1996 this was changed to comprise eight Regional Offices and approximately 100 Health Authorities. In 1999, over 480 Primary Care organisations (PCOs), mostly Primary Care Trusts (PCTs), were established. In 2002 four Directorates of Health and Social Care (DHSCs), each covering one or more Government Office Regions, formed a top layer of administration. The current structure for health administration in England came into effect on 1 July 2003. It comprises 28 Strategic Health Authorities (SHAs), which are constituted from groups of local authorities. These manage over 300 PCTs which were (mostly) aligned with the administrative boundaries existing at the time of the last major health reorganisation on 1 May 2002 (ONS 2004).

3.2 Combining data from different geographies

Before data analysis can be carried out, it is necessary to convert area data to a single geographical framework. The following section describes the resources available to match data from different geographies, and an outline of the available methods is given in table 7.

Table 7: Combining different geographies

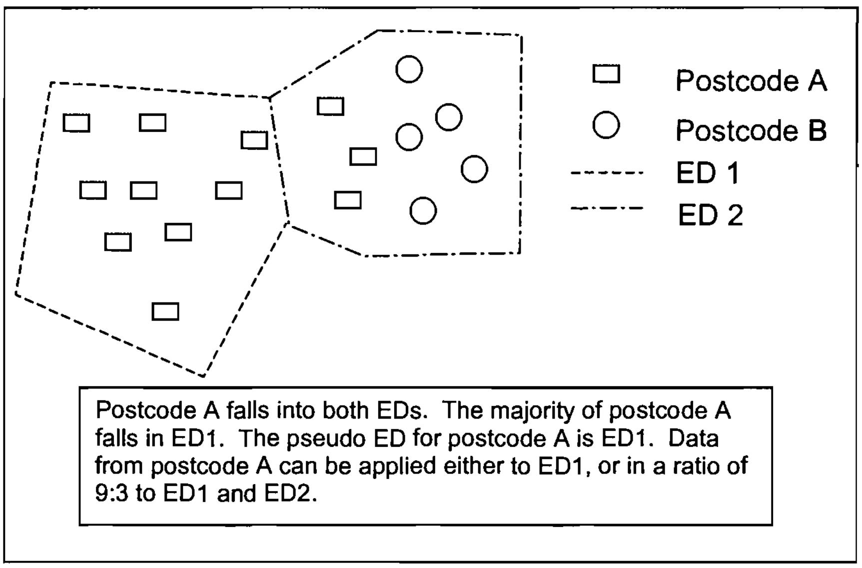
	Destination geography						
		Postcodes	1991 EDs	1991 Census wards	2001 Output Areas	2003 CAS wards	Other wards (eg 1998 wards)
	Grid references	All Fields Postcode Directory (AFPD)	Via postcodes	Via postcodes	Via postcodes	Via postcodes	Via postcodes
	Postcodes		AFPD	AFPD	AFPD* or lookup tables supplied with census data	AFPD* or lookup tables supplied with census data	AFPD
	1991 EDs			Directly nested	Overlap estimated through enhanced lookup tables based on the AFPD	Overlap estimated through enhanced lookup tables based on the AFPD	Overlap estimated through enhanced lookup tables based on the AFPD
	1991 Census wards					Overlap estimated through enhanced lookup tables based on the AFPD	Overlap estimated through enhanced lookup tables based on the AFPD
Source geography	2001 Output Areas					Directly nested	Overlap estimated through enhanced lookup tables based on the AFPD

** The latest edition of the AFPD is not available to the academic community: lookup tables of postcodes and 2001 OAs and CAS wards are available from the census but make no provision for assigning split postcodes to a particular area.*

3.2.1 Lookup tables

Postcode lookup tables (LUTs) are a vital tool for matching postcodes to different geographies. The most comprehensive, and best maintained, postcode LUT is the All Fields Postcode Directory (AFPD). The AFPD is produced by ONS and combines data from the Central Postcode Directory and the Postcode-Enumeration District Directory (PCED). The PCED provides part postcode units (PPUs), created for each intersection of unit postcode and 1991 Census Enumeration District. The number of households in each PPU is known (from the census). The ED into which the majority of households in the unit postcode fall is the 'pseudo-ED'. Postcodes can therefore be matched to data for EDs by either assuming that the data belong to the pseudo-ED (and its associated postcodes), or by assigning data to PPUs in the same proportion as households in the ED fall into the PPUs (figure 8) (Martin 1992).

Figure 8: Part postcode units



The latest version of the AFPD (1999) has been cleaned and enhanced in order to allow data to be converted between 25 postal, census, administrative, statistical and health geographies using web-based conversion software (Simpson 2004). The AFPD is used to estimate the overlap between the any two areas in terms of the number of unit postcodes. Data are re-assigned from source to target areas in proportion to the overlap, as with PPUs. The web-based conversion software assigns data to target areas with an element of uncertainty: they are estimates for the new set of units (Simpson 2001).

Other LUTs are available, for example ONS offers look-up tables of 2001 OAs by postcode, and MIMAS provides access to a range of LUTs such as the 1991 Area Master File (relating 1991 census geography to administrative, electoral and postal areas) and older postcode LUTs such as the Postcode-Enumeration District Directory and the Central Postcode Directory. However, these do not offer the same facilities as the AFPD for dealing with postcodes that are split over area boundaries and their use may result in a relatively greater miss assignment of data.

3.2.2 Electronic boundary sets

ONS offers digital OA boundaries (vector format), and the UK Borders service (http://edina.ed.ac.uk/ukborders/) provides digital boundary data for use with GIS for a wide range of administrative and census areas.

3.2.3 Published lists of area codes

Health geography can be matched to electoral wards using the Area of Residence Classification Manual, available from the Office of National Statistics. This lists the names and codes of the electoral wards/divisions in each SHA across the UK [18]. Local authorities are related to health authorities through the annual publication of the NHS Organisation Manual.

3.3 Working with area data: geographical analysis

Data on populations, the provision of services and social and economic characteristics of areas are available at a range of scales from grid references and postcodes to broad administrative areas. The focus of this thesis is on modelling geographical access to health services at a small area level, an undertaking that requires the use of area data. When area data are used, there are a number of limitations that must be borne in mind. These limitations are set out in the following section.

3.3.1 Misclassification of data to areas

As set out in section 3.2, data are often supplied at a different level of aggregation than they are needed at and need to be re-grouped to different areas. At the smallest scale, point data such as OS grid references can be assigned exactly to any other geographical area. However, data for postcodes or for areas are more difficult to assign accurately to any particular geographical framework as few geographies have a one to one relationship with other area types. As outlined in the previous section, there are many resources available to match area data to different areas, but matching areas frequently involves estimation in assigning data, which may result in the misclassification of data. Non-differential misclassification results in a loss of power to detect a difference between areas, but differential misclassification, or bias, is a more serious problem and may result in false conclusions being drawn.

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[18] http://www.statistics.gov.uk/geography/geog_products_health.asp, accessed 06.01.2004

3.3.2 The ecological fallacy

Ecological studies use data collected about an entire population rather than about individuals, which may weaken any real associations in the data but, more importantly, ecological studies cannot be fully adjusted for confounding. Where observations are made about a group of people who live in an area, rather than about individual people, it is important to be careful when extrapolating the area characteristics to the individuals. For example, if an area has a high proportion of elderly residents and a low proportion of car owners, it is not necessarily the case that elderly people in the area do not own cars.

3.3.3 Compositional or contextual effects?

It is sometimes assumed that area characteristics can be thought of as an aggregation of the characteristics of all the individuals living in an area. However, area characteristics may also be extra to the characteristics of the local population, and may act independently adding to or even altering the characteristics of the local population. For example, area may have an effect on health and social status over and above that conferred by the composition of the population. These different aspects of areas are called 'compositional' and 'contextual' effects, and where aggregate data are used it can be difficult to determine whether effects are compositional or contextual. For example, a problems of poverty may be due to large numbers of poor people moving into an area, or to features of an area (such as lack of employment opportunities) resulting in large numbers of people with a low income. Ecological data are often assumed to be a poor substitute for individual data, but some issues are features of areas and best explored in an area analysis.

3.3.4 The modifiable areal unit problem (MAUP)

A third problem associated with area data is the MAUP. Area data can be grouped and regrouped in numerous ways to provide an appropriate geographical setting for research. However the correlation between area level variables has been shown to change with the degree of aggregation. The way in which the correlations change is not predictable, and analogous to running repeated statistical tests (under which circumstances normal levels of statistical significance cannot be relied on.) Equally sized but alternative areas to census wards could give a very different picture, for example by changing the amount of heterogeneity within an area. As GIS become more powerful, more sophisticated and easier to use, areas become more modifiable and different data aggregations become more available to researchers. Issues raised by the MAUP will become more pressing as this trend continues.

3.4 Summary

UK geography is complex and ever changing, characterised by boundary changes and the presence of different administrative areas for government, health and the decennial census. Area level data are available for a wide range of area types, few of which share boundaries. Much transferring of data between different area types involves a degree of estimation, and Look Up Tables of 'best fit' matches have commonly been used for this. Recent developments with the AFPD have resulted in more accurate transfer of data between areas, and clearly defined and consistent methods for manipulating area data, but some loss of information is inevitable when data are transferred between different geographies.

Chapter 4: Data management and methods

4 Chapter overview

This chapter covers the data and methods used to achieve the objectives of the thesis. This thesis is a development of a previous research project (Barnett 2001) and uses several data sets compiled for that project. Methods and data that were developed as part of previous work are clearly indicated in the following sections.

4.1 Data sets

This section details the data sets used to define rurality, deprivation and access to health services, the extent of the study area and its population.

4.1.1 The study area

The study area comprises the nine 1991 counties of Avon, Cornwall and the Isles of Scilly, Devon, Dorset, Hampshire, the Isle of Wight, Gloucestershire, Somerset and Wiltshire which made up the former South and West Health Region. Data were assembled for all wards in the study area (n=1448), using 1991 boundaries. Ward boundaries were obtained from digital boundary sets held by the UK borders service at EDINA (http://www.edina.ac.uk), and lists of ward codes were taken from the 1991 census. The grid references of all residential postcodes in the study area (n=276661) were taken from the EDPC directory, which includes x,y coordinates for each postcode (as described in section 3.2). As data on public transport routes were only available for the two counties of Devon and Cornwall, a reduced study area of the county of Cornwall was used for analysis of public transport data (avoiding the boundary effects which would have occurred had both counties been included in the analysis).

4.1.2 Population

Estimates of the area's population were taken from the 1991 and 2001 censuses. Mid-year population estimates were taken from the Estimating with Confidence figures, generated to account for under-enumeration in the 1991 Census.

4.1.3 Health status

The population health status was described using measures of mortality and morbidity. Mortality data were provided by the ONS, and comprised figures for all cause mortality, and for mortality from stroke, suicide and accidental death, and coronary heart disease for the years 1991 to 1996. Data were given by age, sex and postcode of residence. Morbidity data were taken from counts of self reported limiting long term illness (LLTI) in the 1991 census.

4.1.4 Rurality

Rurality was measured using the ONS classification of 1991 wards (Wallace, Charlton, & Denham 1995). Wards are allocated to 14 categories, shown in table 8.

Table 8: The ONS ward classification

ONS group	Rural / urban classification
Suburbia	Urban
Rural areas	Rural
Rural fringe	Rural
Industrial areas	Urban
Middling Britain	Urban
Prosperous areas	Urban
Inner city estates	Urban
Established owner occupiers	Urban
Transient populations	Urban
Metropolitan professionals	Urban
Deprived city areas	Urban
Lower status owner occupiers	Urban
Mature populations	Urban
Deprived industrial areas	Urban

4.1.5 Access

The measures of geographical access calculated for this thesis are:

- Straight-line distance to the closest primary and secondary health service
- Drive time by car to the closest primary and secondary health service
- Travel time by scheduled public transport to the closest secondary health service, and
- The availability of scheduled public transport journeys to the closest secondary health service

A substantial amount of the data needed to calculate these measures of access was obtained as part of a previous research project (Barnett 2001). These data include

- The locations of all primary health services. The postcodes of all main and branch General Practice surgeries in the study area (n=1469) were obtained from Family Health Services Authority lists for 1998.
- Acute DGHs (n=39) were defined as hospitals with general medicine and general surgery facilities and an Accident and Emergency department. DGHs were identified using the hospital Year Books (1992-97) and hospitals were phoned to clarify their status as necessary. Twenty-seven DGHs were identified within the boundaries of the study area and a further twelve were identified just outside the boundaries of the study area, to allow for the flow of patients over county boundaries.
- The locations of all postcodes in the study area were obtained from the 1991 postcode enumeration district directory, which gives an x,y coordinate and an ED code for each postcode.
- The digital road network was assembled from the 1:200,000 Bartholomew road atlas data available to the UK academic community and documented more fully at http://www.mimas.ac.uk/spatial/maps/barts/. All segments of the Bartholomew road network for the South West Region were assigned average travel speeds based on road class, using eight road types, listed in table 9.

Table 9: Road types and speeds

Road type	**Speed (mph)**	**Time (minutes/metre)**	**Time (minutes/200metre)**
Unclassified road	30	0.001250	0.25
Trunk road	60	0.000625	0.125
A road	50	0.000750	0.15
B road	40	0.000938	0.188
A road (dual carriageway)	60	0.000625	0.125
Motorway	70	0.000536	0.107
Trunk road	60	0.000625	0.125

In addition, and solely for work relating to this thesis, public transport data were taken from two sources:

- Data on bus routes to the two towns of Truro and Plymouth, and the two hospitals of the Royal Cornwall Hospital, Treliske, Truro and Derriford, Plymouth were extracted from the 2001 Cornwall bus timetable
- Data covering all bus routes in Devon and Cornwall for November 2004 were taken from South West Public Transport Initiative (SWPTI) databases

underlying internet-based journey planning software (http://www.traveline.org.uk/).

4.1.6 Deprivation

The Townsend deprivation score was calculated for all 1991 wards and 1991 Enumeration districts using 1991 Census data. The Index of Multiple Deprivation 2000 (IMD) is available to download as a pre-calculated score for all 1998 wards from the website of the Office of the Deputy Prime Minister (http://www.odpm.gov.uk), and as a published book with CD data (Department of Environment Transport and the Regions 2000a).

4.2 Data management

The following section describes the data management needed to convert raw data to useful estimates of health status, rurality, deprivation and access at an appropriate geographical scale.

4.2.1 Health status

Postcoded death data were aggregated to 1991 wards, and the number of events in each ward over the six years of data was summed. Morbidity data were available for 1991 wards. For each 1991 ward in the study area five-year age-sex bands were used to indirectly age-sex standardise the rate of premature mortality and morbidity to the regional population.

4.2.2 Rurality

Of the 14 categories listed by the ONS, 'rural' and 'rural fringe' were treated separately, the remaining twelve being combined to give a third 'urban' category. Of the 1448 wards in the study area, 253 (17.5%) were rural, a further 154 (10.6%) were rural fringe and 1031 (71.2%) were urban. Just 10 wards (0.7%) did not have an ONS classification of rurality.

4.2.3 Access

To assess the accessibility of health services within the South West of England ideally requires:

- The calculation of the straight-line distance to primary and secondary care
- The calculation of the drive time to primary and secondary care
- The calculation of travel time by public transport to primary and secondary care

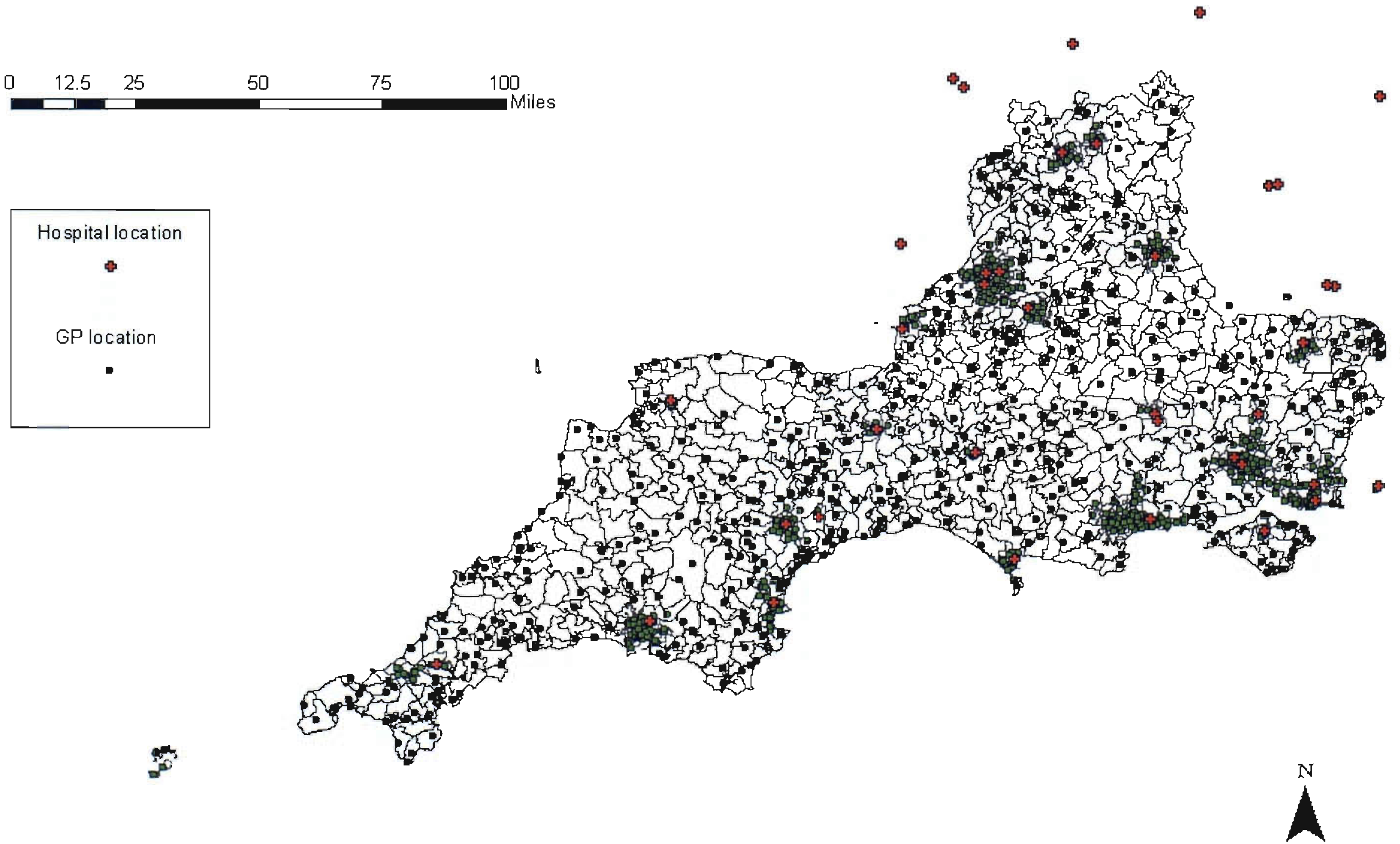
- The aggregation of travel times to standard geographical areas such as 1991 Census Enumeration Districts, 1991 Census wards and 2001 Census Output Areas

A Geographical Information System (Arc/Info) and custom written programs were used to calculate a range of measures of access to health services as part of data collection for previous work on the measurement of rural deprivation (Barnett 2001). The first access measure calculated was the shortest straight-line distance between every residential postcode, the closest main and branch GP surgery and the closest DGH. The second, more complex measure of geographical access was the shortest journey time from each residential postcode to the closest GP and the closest DGH (the "cost-surface"). A third measure of access was taken from the domain 'access to local services' in the Index of Multiple Deprivation 2000 (IMD) (Department of Environment Transport and the Regions 2000a), and finally a measure of travel time by bus was calculated, to represent access to health services using public transport. A pilot study was carried out using paper timetable records as the data source and a final, more complex, public transport model was created using electronic timetable data. The pilot study and the development of the final public transport model are described in chapter 7.

4.2.3.1 Selecting origin points and destination points

Distances to the closest hospital and the closest general practice were calculated from the grid references of all the residential postcodes in the study area to the grid references of the postcodes of primary care services (all main and branch General Practice (GP) surgeries) and secondary care services (acute hospitals) (figure 9).

Figure 9: The location of hospitals and GP surgeries



4.2.3.2 Calculating the straight-line distance to health services

The straight-line distance to all main and branch GPs and to all 39 DGHs was calculated using Arc/Info GIS. A custom-written Fortran program was used to enable Arc/Info to operate with the large matrix of data generated by the grid references of all postcodes in the study area. The distance between the grid reference of every residential postcode and every health service postcode was calculated, and the shortest distance was saved in Arc/Info. These distances were then exported as a text file of x,y coordinates and distances. Coordinates and distances were then matched to back to the original list of postcodes.

4.2.3.3 Calculating car travel time to health services

There are thousands of possible journeys along a road network between origin and destination points: to calculate the time taken for each possible journey is computationally very intensive, especially if such a calculation was to include real factors influencing journey time such as road congestion, one way systems and the time taken to park, as well as speed limits. A simpler model, using notional travel speeds across a rasterised land surface of 200m^2 cells, was therefore developed. Arc/Info was used to create a model with four layers of data influencing travel speeds, and the least-time route between origin and destination postcodes was calculated. The four layers of the model are described below, and are also detailed in an unpublished PhD thesis (Barnett 2001), and in Martin, Wrigley, Barnett, & Roderick (2002).

Layer One: the land grid

This layer distinguishes between areas of land and water. All 200m^2 cells covering a land area were assigned a background travel speed of 10 km/h. Cells covering areas of water are considered impassable in the model, and were assigned NODATA values. All land areas outside the South West study area were assigned NODATA values, meaning that hospitals outside the boundaries of the study area could not be included in the calculation of access to secondary health care (as in the straight-line distance measure of access).

Layer Two: the health service grid

The 12 hospitals outside the study area were excluded from the calculation of travel time as we had no data on drive times outside the regional boundaries and to collect and incorporate such data would have placed considerable strain on processing time and computer resources. The postcodes of all of the GP surgeries and the 27 acute DGHs within the boundaries of the study area were used to give each destination an OS grid reference. These grid references were imported into the GIS and cells were coded as containing a health service destination, or not.

Layer Three: the road grid

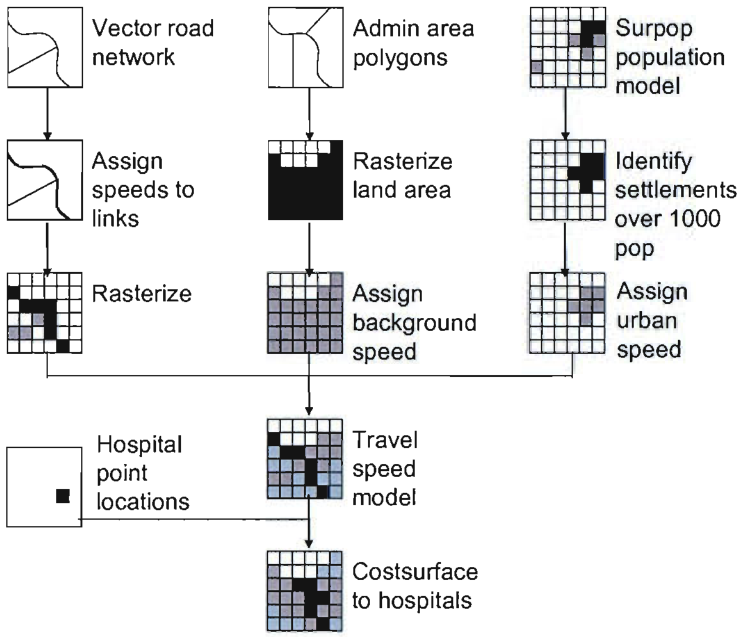
The digital road network was assembled from the 1:200,000 Bartholomew road atlas data available to the UK academic community and documented more fully at http://www.mimas.ac.uk/spatial/maps/barts/. All segments of the Bartholomew road network for the South West Region were assigned average travel speeds based on road class, using eight road types, listed in table 8 (above). Impedance values were calculated for each road type, computed as the time taken to travel 200m on each of these road segments. Cells that do not contain a road were assigned a background travel speed of 10 kph (0.006 minutes per metre). Some major ferry routes were also added, with appropriate time cost values derived from published timetable information.

Layer Four: the urban grid

This layer identifies urban areas that are likely to reduce travel speed due to traffic congestion. A population surface model was extracted from the Surpop database (http://census.ac.uk/cdu/software/surpop/). This contains population estimates for 200m^2 cells, derived from the 1991 Census. All settlements with populations over 1000 were identified by grouping clusters of adjacent populated cells into single zones (using Arc/Info's REGIONGROUP function) and calculating the total populations for the zones. Travel speeds on roads in all these areas were then reduced to an average urban speed of 25 kph (0.0015 minutes/metre), irrespective of the road type.

Summarising these data layers results in a travel cost model based on a 200m grid, and calibrated in minutes of travel time. A cost-surface calculation was used to compute travel times from all cells to the nearest DGH and GP surgery. The grid reference of each residential postcode located each postcode on the surface, and travel times for each postcode were then read off the cost surface grid. As patients do not necessarily choose to use the nearest primary health care facilities (Haynes, Lovett, & Sunnenberg 2003), this model is one of potential, rather than actual accessibility. The model is represented in figure 10.

Figure 10: Modelling travel time to health services



Source: Martin, Wrigley, Barnett, & Roderick (2002)

4.2.3.4 Aggregating access measurements to wards and EDs

Travel distances and times calculated using the methods described above are generated for the grid references of postcodes. The data then need to be applied to the landscape of wards and enumeration districts so that they can be used alongside other data (for example population, deprivation, health and car ownership). Distances were aggregated to 1991 EDs and wards by using the AFPD to assign postcodes to areas (as described in chapter 3). The resident population of each ward or ED was used to weight the individual postcode times and distances and create a population weighted average. The method used to weight the individual postcode times and distances to create a population weighted average is shown in table 10.

Table 10: Aggregating access data to EDs

ED	Postcode	N Households from each postcode in ED1	Time from PC to health services	Households * time
ED1	PC1	10	10	100
ED1	PC2	7	13	91
ED1	PC3	2	11	22
ED1	PC4	6	21	126
Sum (ED1)		25		339
Population weighted average time for ED1 ((hhds*time)/hhs)				

4.2.4 Deprivation

Two measures of deprivation were calculated: the Townsend score and the Index of Multiple Deprivation 2000. Several measures of deprivation are commonly used in the UK, including the Townsend score, the Carstairs score (commonly used in Scotland), the Jarman Underprivileged Area (UPA) index, the Index of Multiple Deprivation 2000 (IMD) and the Indices of Deprivation 2004 (ID 2004). The first three of these are calculated from census data, and the final two are derived from multiple data sources, including data on unemployment, education, local amenities and health of the population. One census based measure of deprivation and one measure of multiple deprivation were selected for comparison. The Townsend and Carstairs scores are very similar in structure, both providing an estimate of material deprivation, whereas the Jarman UPA index was calculated to predict GP workload patterns. The Townsend score was selected as the census based measure of deprivation to provide continuity with the work this thesis builds on (Barnett 2001). The IMD was chosen to reflect multiple deprivation as it was freely available at the time of writing and is calculated from data from a similar time to the transport and population data described in this thesis, whereas the more recent ID 2004 was published in 2004 when work on this thesis was already underway.

4.2.4.1 The Townsend Deprivation score

The Townsend score was calculated from 1991 Census small area statistics (Cole 1993). The variables used in the score are:

- Unemployment - unemployed residents over 16 as a percentage of all economically active residents aged over 16.
- Overcrowding - households with 1 person per room and over as a percentage of all households.
- Non car-ownership - households with no car as a percentage of all households.
- Non home-ownership - households not owning their own home as a percentage of all households.

A log transformation is applied to the overcrowding and unemployment variables. These logged variables and the car ownership and owner occupation variables are standardised by calculating z-scores for each value.

z = (value – mean) / standard deviation.

The four z-scores are summed to provide the final Townsend score. Townsend scores were standardised to give a mean of zero for England and Wales: any scores greater than zero represent relative deprivation; any less than zero indicate relative affluence.

4.2.4.2 The Index of Multiple Deprivation 2000

The IMD is a pre-calculated score for all 1998 wards and local authorities in England and Wales. The index comprises six elements, or domains: income; employment; health deprivation and disability; education, skills and training; housing; and geographical access to services. Thirty-three indicators are used to make up these domains including data on benefits claimants and academic qualifications in addition to information from the 1991 Census. The domains and their constituent indicator variables are listed in Table 11.

Table 11: Indicators and domains of deprivation in the Index of Multiple Deprivation 2000

Domain	Variables	Year(s)
Income	Adults in Income Support households	1998
	Children in Income Support households	1998
	Adults in Income Based Job Seekers Allowance households	1998
	Children in Income Based Job Seekers Allowance households	1998
	Adults in Family Credit households	1999
	Children in Family Credit households	1999
	Adults in Disability Working Allowance households	1999
	Children in Disability Working Allowance households	1999
	Non-earning, non IS pensioner and disabled Council Tax Benefit recipients	1998
Employment	Unemployment claimant counts	1998-9
	People out of work but in TEC delivered government supported training	Not stated
	People aged 18-24 on New Deal options	Not stated
	Incapacity benefit recipients of working age	1998
	Severe Disablement Allowance claimants of working age	1999
Health deprivation and disability	Comparative mortality ratio for men and women aged under 65	1997-8
	People receiving attendance allowance or disability living allowance	1998
	People of working age receiving Incapacity Benefit or Severe Disablement Allowance	1998 & 1999
	Age-sex standardised ratio of LLTI	1991
	Proportion of births of low birth weight	1993-7
Education, skills and training	Working age adults with no qualifications	1995-8
	Children aged 16+ not in full time education	1999
	Proportion of 17-19 year olds who have not successfully applied to higher education	1997-8
	KS2 primary school performance data	1998
	Primary school children with English as an additional language	1998
	Absenteeism at primary level	1998
Housing	Homeless households in temporary accommodation	1997-8
	Household overcrowding	1991
	Poor private sector housing	1996
Geographical access to services	Access to a post office	1998
	Access to food shops	1998
	Access to a GP	1997
	Access to a primary school	1999

Each ward and local authority has a score for each of the six domains and an overall score: a summary of the six domain scores. The original data and details of the methods used in calculating the original score are not publicly available. Recalculation of the IMD for different geographical areas from the original data was therefore not possible and a method of estimation, or re-weighting, of the score was developed.

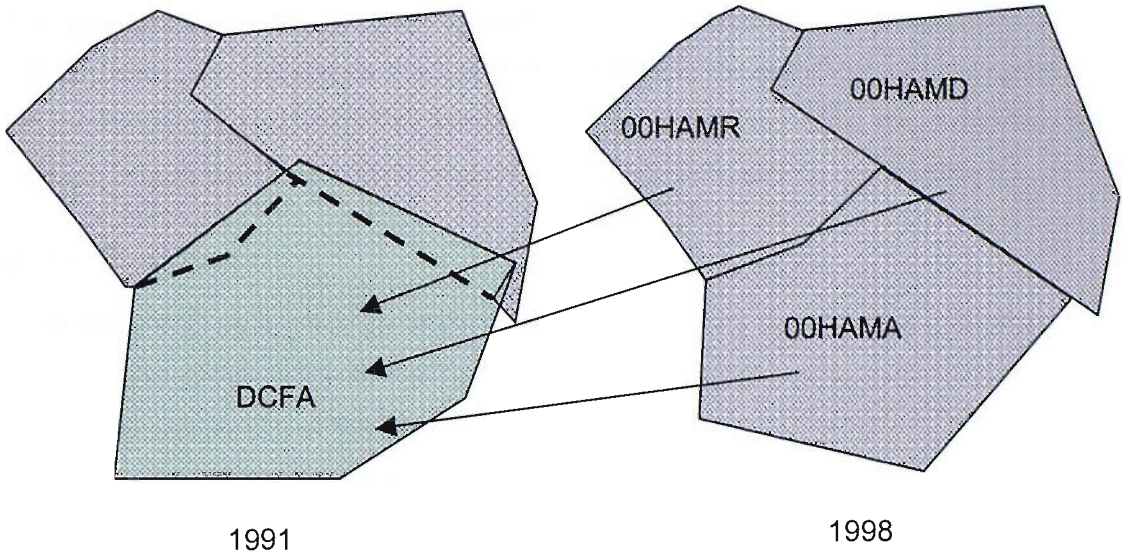
Between the 1991 Census and 1998, when the ward boundaries used in the IMD were chosen, the Boundary Commission for England revised the majority of boundaries in the study area. To match the IMD score to health and Census data for 1991 wards it was necessary to determine the degree of overlap between each ward described by 1998 boundaries and each 1991 ward. The UK Look-up Tables facility based on the ONS All Fields Postcode Directory quantifies the degree of overlap between the two sets of wards in terms of the number of households resident in each area (Simpson 2002). Each component of the IMD score was re-allocated from 1998 to 1991 wards in proportion to the numbers of households in the overlapping areas (Table 12).

Table 12: Example of calculating a re-weighted Index of Multiple Deprivation 2000 (IMD) score for two 1991 wards

1991 ward code	1998 ward code	Weight	IMD score of 1998 ward	Weight * IMD score of 1998 ward	Re-weighted 1991 ward IMD score
DCFA	00HAMA	0.9365	25.24	23.64	23.69
	00HAMD	0.0068	4.92	0.03	
	00HAMR	0.0010	22.07	0.02	
DCFB	00HAMA	0.0503	25.24	1.27	6.1
	00HAMC	0.0006	7.77	0.00	
	00HAMD	0.9777	4.92	4.81	
	00HAMK	0.0004	20.67	0.01	
	00HANN	0.0009	8.98	0.01	

The re-weighted IMD score for each 1991 ward is the sum of the weighted scores from the component 1998 wards. For example, the 1991 ward DCFA received a new score comprising the sum of approximately 93.6% of the IMD score for ward 00HAMA, 0.7% of the score for ward 00HAMD and 0.1% of the score for ward 00HAMR. Figure 11 shows an example of the overlap of the two geographies.

Figure 11: 1991 and 1998 wards



The resulting scores for each of the six domains of the IMD, and for the final score, are necessarily estimates of the 'true' scores.

4.3 Data analysis

All analysis was carried out for 1991 boundaries.

4.3.1 Access

To compare the different measures of access, straight-line distance and the more complex drive time measure were compared using correlation coefficients and a regression analysis of drive time against straight-line distance. Areas where straight-line distance appeared to underestimate the drive time more than expected were identified and mapped to investigate the extent of geographical clustering. Access to primary and secondary health services in the Region was described using median distances and inter-quartile ranges for both measures.

To identify and describe those parts of the study area with the poorest access to health services, a sub group of wards was classified as 'remote from health services' and examined in detail. No standard estimates of remoteness have been established by previous research. A range of cut off distances for 'remoteness' of between three and seven km from primary care and between 20 and 35 km from secondary care were initially selected, and the number of wards which would be classified as remote from health services at each distance was calculated. A straight-line distance of 5km to a GP or 25km to a hospital was then chosen to signify remoteness from health services: this cut off classified approximately 6% of the study population as 'remote' from secondary care and 3% as remote from primary care. To investigate the assumption that it is the residents of rural areas who are most disadvantaged by remoteness from health services, the proportion of 'remote' wards which were rural under the ONS classification were identified.

4.3.2 Deprivation

To test the IMD as a measure of the need for health care in both rural and urban areas and to compare it with the Townsend score requires:

- the calculation of the Townsend score;
- the selection of a definition of rurality which can be applied to 1991 wards;
- the re-weighting of the IMD from 1998 wards to 1991 ward boundaries to make comparisons with other data possible;
- the calculation of health outcomes for wards in the study area.

The methods used are described below.

To investigate the IMD as a measure of the need for health care in both urban and rural areas, scatter plots of the re-weighted IMD and the Townsend score against standardised rates of the two health outcomes (all-cause premature mortality and premature Limiting Long Term Illness (LLTI)) were used to assess the relationship between deprivation and ill-health in urban, rural fringe and rural wards. Pearson correlation coefficients were calculated for these relationships, and the role of access in determining the fit of the IMD to health outcomes was assessed. The access domain of the IMD and other measures of access were also compared, using scatter plots and correlation coefficients, and the correlation between the IMD and health data in the different area types was calculated.

To investigate relationships between distance to health services and the need for health care, straight-line distance to hospital was used to group wards into deciles. The deprivation score and the age profile of the population in each decile was described, with high deprivation and a raised proportion of elderly or very young residents of a decile of areas signifying relatively high need for health services. Standardised rates for premature all-cause mortality and LLTI were used to indicate health outcomes for each decile of wards, and car ownership (as reported in the 1991 census) was used to indicate how easy travel would be for the population in each group.

4.4 Summary

The methods described in this chapter are used to address three of the aims of the thesis set out in Chapter one: to measure and describe geographical access to health services; to investigate the IMD as a measure of the need for health care in urban and rural areas; and to identify and describe areas with the poorest geographical access to health services. The results of these analyses are presented in the following two chapters, and the need for a further development of access measures to include public transport is set out.

Chapter 5: Access to health services in the South West

5 Chapter overview

This chapter considers the measurement of access to health services in the South West. It describes the geographical accessibility of general practices and acute hospitals in the region at ward level; and compares three methods of measuring geographical access to health services at ward level (a simple straight-line distance between the population-weighted centroid of each 1991 ward and the nearest GP or DGH; a modelled drive time along the road network between the same points, and the access to health services domain of the IMD, recalculated for 1991 wards); and two methods of measuring access at ED level (straight-line distance and modelled drive time). It then goes on to describe geographical access to health care in the South West of England and to investigate the relationships between access, rurality and health.

5.1 Introduction

As demonstrated in Chapter two, poor geographical access has been associated both with a reduced rate of contact with primary and secondary health services and, less strongly, with poorer health outcomes. Despite these findings, the measurement and understanding of variations in geographical access to health services has remained peripheral to mainstream public health research. In part this may be due to the fact that determining the role played by geographical access in the use of health services is hindered by the lack of agreement on a standard measure of geographical access, as outlined in section 1.4, and in part to the assumption that geographical inaccessibility of health services is essentially a rural problem and thus linked to areas perceived as having low rates of health problems and social problems.

There is, however, little evidence demonstrating the differences in accessibility between rural and other areas. The geographical accessibility of health services in the UK (and elsewhere in the world), the circumstances under which simple measures such as straight-line distance could appropriately be used, or under which more complex measures of journey routes and travel times are necessary to accurately reflect geographical accessibility, are not known: few studies have attempted to quantify or set thresholds of poor access. In the UK threshold distances of between 24 and 50 miles to specialist hospital services (Campbell, Elliott, Sharp, Ritchie, Cassidy, & Little 2001; Cassar, Godden, & Duncan 2001), 10 miles to screening services (Stark, Reay, & Shiroyama 1997), 7km (4 miles) to family planning clinics (Diamond, Clements, Stone, & Ingham 2002) and 2.5 miles to primary care (Whitehouse 1985) have all been used in reporting 'poor access', but there is little consensus and no strong theoretical or empirical basis for these choices.

Furthermore, in any area the greatest disadvantage is likely to be experienced by individuals without access to a car (including members of one-car households without daytime access). With the well documented declining availability of public transport (Rural Development Commission 1996) it is likely that, outside of the relatively well served urban centres in Britain, a private car is the only convenient way to travel. Although the lowest levels of car ownership are found in central London and other city centres and car ownership is relatively high in rural areas, rates for the poor, the elderly and for women are far lower than average: the 2001 Census reports that more than two thirds of single-pensioner households still do not have access to a car. Many of these households will comprise single women, a group with high needs for health services, but this information is not directly available from the census. Distance may therefore be a further burden of disadvantage groups with a particularly high need for health care, raising issues of inequity. Furthermore, if geographical access to health services is a problem for some groups outside of traditional rural areas, then rural policies alone will not tackle the problem.

In the following chapter I investigate the accessibility of health services in the South West of England. I compare two measures of geographical access: the straight-line distance to the closest source of primary and secondary care and the drive time to the same destinations, providing an overview of geographical access to health care in the region. Internal variability means that zones of relative inaccessibility may be hidden within larger areas, in much the same way that zones of relative deprivation have been hidden within rural wards (Haynes & Gale 2000). To investigate the differences that scale of measurement makes to the relationship between straight-line distance and drive time to health services, the analysis was carried out twice: once at the level of 1991 Census wards and once at the smaller level of 1991 Census Enumeration Districts. The two measures are compared for both the ward and the ED analysis to show where areas of disagreement are located, identifying places where the simple straight line measure may underestimate travel times more than expected. Areas where the two measures diverge are characterised in terms of rurality, population structure, deprivation (including car ownership) and health. The areas most remote from GPs and acute hospitals are identified and described in the same terms.

The methods for calculating geographical access are described in detail in chapter four. The data underlying the measures of access are described in section 4.1 and the methods by which geographical access measures were calculated are given in section 4.2.

5.2 Ward level access to primary and secondary health services

The median distance from the centroid of 1991 Census wards to the closest acute general hospital was just less than 12 km (IQR 5.4 - 19.0), with a maximum of 50 km, corresponding to an estimated 13 and 48 minutes travel time. Distances to GPs were low, with a median distance of just 1 km to the closest practice (IQR 0.6 – 2.2), or 1.2 km if branch surgeries were excluded from the calculation.

95% of wards (98% of the population of 6.1 million) were under 4.4 km, or 6.3 minutes, from their closest GP. The maximum distance to a GP was just 9.4 km (13.7 minutes) (Table 13).

Table 13: Ward access to hospitals and GPs

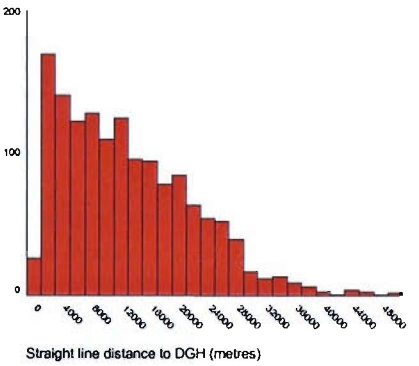
		25th centile	Popn (%)*	Median	Popn (%)	75th centile	Popn (%)	95th centile	Popn (%)	Max
Straight line (km)	**Hospital**	5.4	2.40 (39.3)	11.6	3.97 (65.1)	19.0	5.15 (84.3)	29.0	5.92 (97.1)	50.1
	Any GP surgery	0.6	2.24 (36.8)	1.0	4.17 (68.3)	2.2	5.39 (88.4)	4.4	5.96 (97.7)	9.4
	GP main surgery	0.7	2.45 (40.1)	1.2	4.14 (67.8)	3.0	5.38 (88.2)	5.5	5.98 (98.0)	10.3
Drive time ('minutes')	**Hospital**	7.1	2.38 (38.9)	13.4	3.93 (64.4)	20.5	5.17 (84.7)	31.6	5.93 (97.2)	48.3
	Any GP surgery	1.0	2.19 (35.9)	1.7	4.00 (65.5)	3.4	5.28 (86.5)	6.3	5.89 (96.5)	13.7

**population in millions (percent of the total population) living in wards within this distance of their closest DGH and GP*

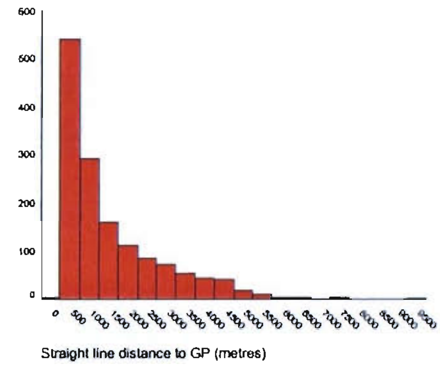
The distances to primary and secondary care from wards are positively skewed, with the majority of wards close to health services, but with a long tail to the distribution indicating a proportion of wards with long travel distances and times to hospital and main or branch GP surgeries (figure 12).

Figure 12: The distribution of distance and travel time to health services from 1991 wards

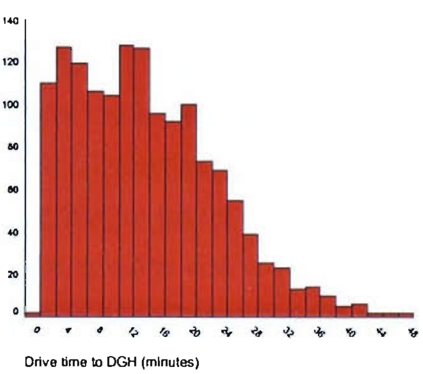
Distribution of straight-line distance to hospital



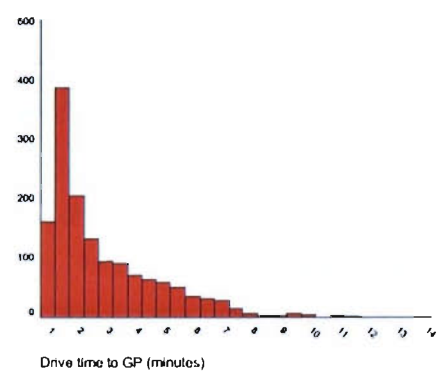
Distribution of straight-line distances to GPs (main or branch surgeries)



Distribution of drive times to hospital



Distribution of drive times to GPs



5.3 ED level access to primary and secondary health services

The median distance from the centroid of 1991 Census EDs to the closest DGH was 8.3 km (IQR 3.4 – 16.0), with a maximum of 51 km, corresponding to an estimated 10.7 and 52 minutes drive time. Distances to GPs were low, with a median distance of 0.8 km to the closest practice (IQR 0.4 – 1.6), or 0.9 km if branch surgeries were excluded from the calculation. 95% of wards (99 % of the population) were under four and a half km, or approximately six minutes drive time, from their closest GP. The maximum distance to a GP was 23.5 km (15.8 minutes), considerably more than estimated by the ward level analysis and illustrating that the access problems faced by some communities can be hidden by internal variability of areas in a larger scale analysis (Table 14).

Table 14: ED access to acute hospitals and GPs

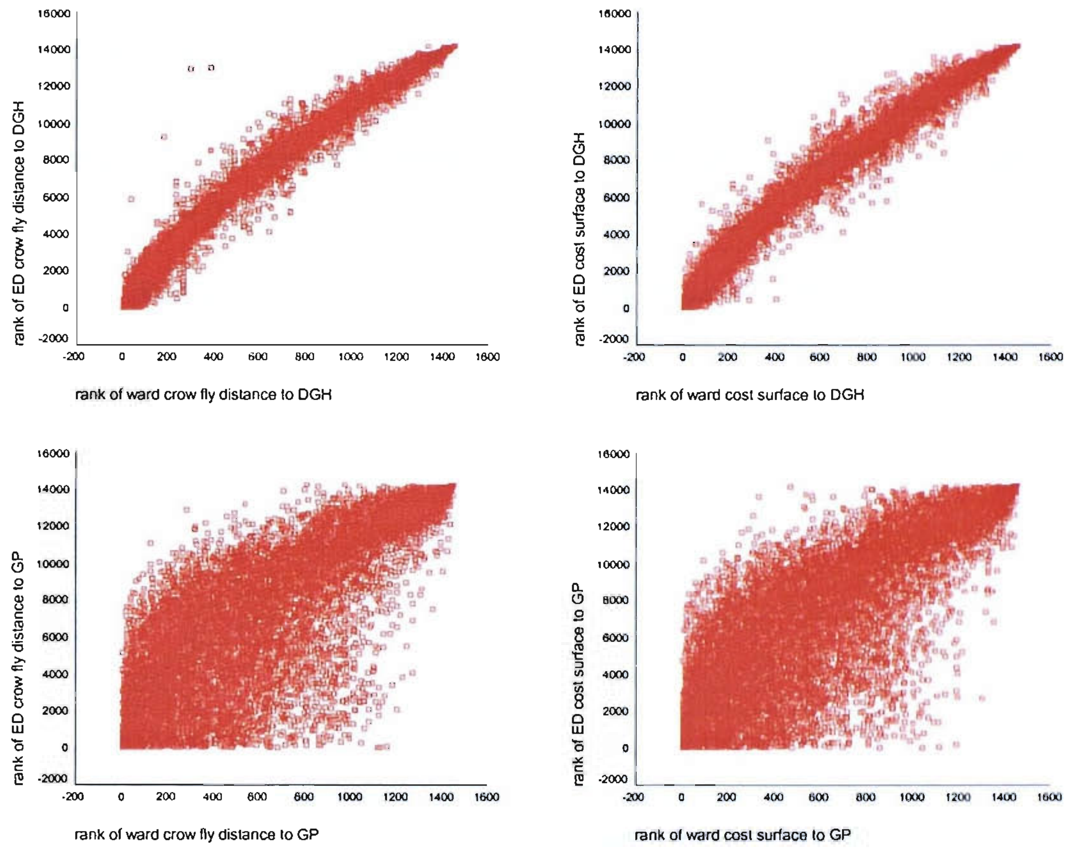
		25th centile	Popn (%)*	Median	Popn (%)	75th centile	Popn (%)	95th centile	Popn (%)	Max
Straight line (km)	**hospital**	3.4	1.6 (26.5)	8.3	3.3 (53.5)	16.0	4.9 (80.1)	27.4	6.0 (98.1)	51.0
	Any GP surgery	0.4	1.4 (22.1)	0.8	3.6 (58.8)	1.6	5.1 (84.3)	4.4	6.0 (99.0)	23.5
	GP main surgery	0.5	1.7 (27.3)	0.9	3.5 (57.1)	2.1	5.1 (83.7)	5.3	6.0 (99.0)	23.5
Drive time ('minutes')	**hospital**	4.9	1.6 (26.5)	10.7	3.3 (53.6)	18.0	4.8 (79.0)	29.5	6.0 (98.2)	52.3
	Any GP surgery	0.7	1.5 (24.8)	1.2	3.3 (53.7)	2.5	5.1 (83.6)	6.3	6.1 (99.1)	15.8

**population in millions (percent of the total population) living in wards within this distance of their closest acute hospital and GP*

5.4 The relationship between ward and ED access

Wards and EDs were ranked by the two measures (drive time and straight-line distance) of geographical access to health care to allow a comparison of the two scales of analysis to be made. A regression of the ward rank against the ED rank identifies EDs which are substantially more or less remote from health services by each of the measures of access than predicted by their ward ranking. For straight-line and drive time distances to hospital the correlation is very high (r^2=0.97 for both), but for travel to GP surgeries the correlations are considerably lower (r^2=0.65 for straight-line distance and 0.67 for drive time). When the correlations are graphed it is evident that the scatter is greatest around the lower distances and drive times, indicating that smaller travel distances to GPs are less well represented at the ward scale (Figure 13).

Figure 13: The correlation between straight-line distance and drive time to health services for wards and EDs



The unexplained variation in the regression model (the residuals in the analysis) can be mapped, to examine the areas where rank measured at the ED level of aggregation is considerably higher (or lower) than we would expect from the ward distance ranking. Residuals were standardised by dividing them by their standard error to give the number of standard deviations away from zero for each residual, and a distribution with a mean of zero and an SD of 1. 99% of standardised residuals should lie between +/-2.5, so this method can be used to identify outliers from the analysis. In this case the standardised residuals were mapped to identify any geographical pattern in differences between the scales of analysis for each measure of access. No distinct spatial patterns were seen in any of the four maps: straight-line distance to hospital, drive time to hospital, straight-line distance to GPs and drive time to GPs. Further analysis was therefore carried out at ward level only.

5.5 The relationship between different access measures

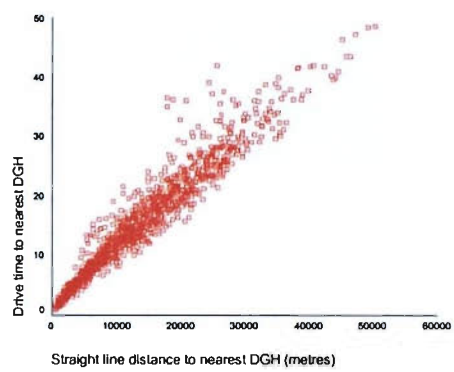
To investigate if straight-line distance was a valid proxy for the more complex drive time measure of access to GP and hospital services, the two measures were compared using correlation coefficients and a regression analysis of straight-line distance against drive time. Areas where straight-line distance appeared to underestimate the drive time more than expected were identified and mapped to investigate the extent of geographical clustering.

The straight line and drive time measures were highly correlated for both GP and hospital services (figure 14).

Figure 14: Straight-line distance and drive time measures to GP and hospital services

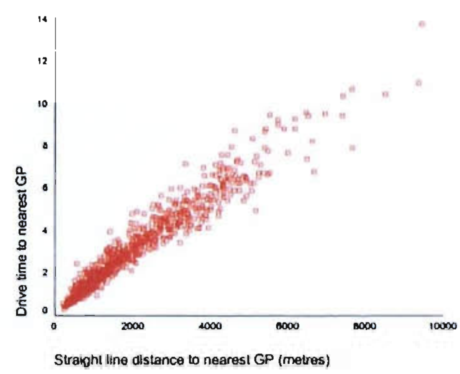
District general hospital

$r^2 = 0.93$



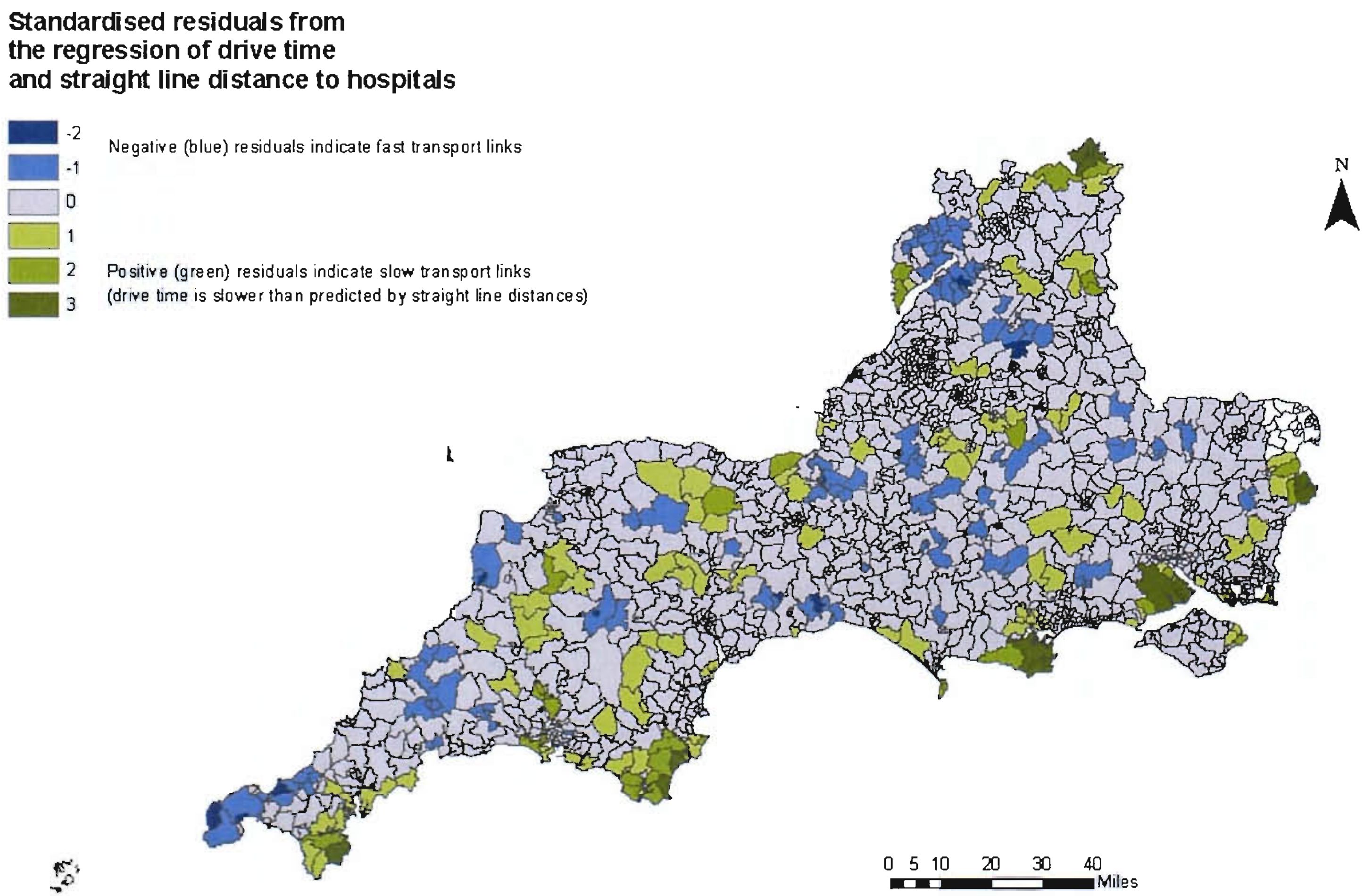
General practice

$r^2 = 0.95$



Areas where residuals from the regression analysis of straight-line distance and drive time to hospitals are more than two standard deviations from the norm were concentrated around the coastal areas of the Region (figure 15). As there were no data on drive time to hospital outside the regional boundaries, but straight-line distances to hospital did include hospitals over the regional border, the analysis was repeated with all wards along the boundary between the study area and neighbouring counties excluded to restrict the correlation to areas where the closest hospital by either measure was likely to be within the study area. The exclusion made no difference to the results.

Figure 15: Map of residuals from the regression of drive time and straight-line distances



The third access measure considered was the access domain of the IMD. This measure combines estimates of the straight-line distance to schools, local shops, a post office and a GP to give an overall indication of access to essential services. The relationship between the access domain of the IMD and the other measures of access to health services may indicate the extent to which areas which are deprived on this dimension of the IMD are likely to experience poor access to primary and secondary health services. The correlation with the access domain of the IMD is strongest for geographical access to primary care, as would be expected (as the IMD includes a measure of access to GPs). However, it is far more weakly correlated with either travel time or straight-line distance to hospitals (table 15).

Table 15: Correlations between the IMD access domain and other measures of access to health services

Access measure	**Correlation with access domain**
Population density	-0.694
Straight-line distance to nearest GP surgery	0.783
Straight-line distance to nearest hospital	0.445
Road travel time / distance by car to nearest GP surgery	0.768
Road travel time / distance by car to nearest hospital	0.480

5.6 Remoteness from primary and secondary care and rurality

Standard estimates of 'remoteness' from health services have not been established – there is no a priori definition of the distance regarded as 'remote from health services' and no consensus has been established in the literature on access to health services. Using a range of boundaries for remoteness allowed wards to be described by a gradient of access to health services. The proportion of rural, rural fringe and urban wards which were 'remote' from health services under the definition of a straight-line distance of three, five or seven kilometres to a GP and 20, 25, 30 or 35 km to a hospital was therefore calculated (table 16).

Table 16: ONS rurality and remoteness from primary and secondary care

	Rural	Rural fringe	Urban	No classification	Total wards
All wards	253 (18%)	154 (11%)	1031 (71%)	10 (1%)	1448 (100%)
GPs					
Remote (3km)	117 (53%)	14 (6%)	84 (38%)	6 (3%)	221 (100%)
Remote (5km)	20 (53%)	4 (10%)	12 (32%)	2 (5%)	38 (100%)
Remote (7km)	5 (71%)	1 (14%)	0 (0%)	1 (14%)	7 (100%)
Hospitals					
Remote (20km)	126 (39%)	36 (11%)	158 (49%)	4 (1%)	324 (100%)
Remote (25km)	69 (43%)	8 (5%)	81 (51%)	2 (1%)	162 (100%)
Remote (30km)	30 (49%)	1 (2%)	28 (46%)	2 (3%)	61 (100%)
Remote (35km)	17 (59%)	0 (0%)	12 (41%)	0 (0%)	29 (100%)

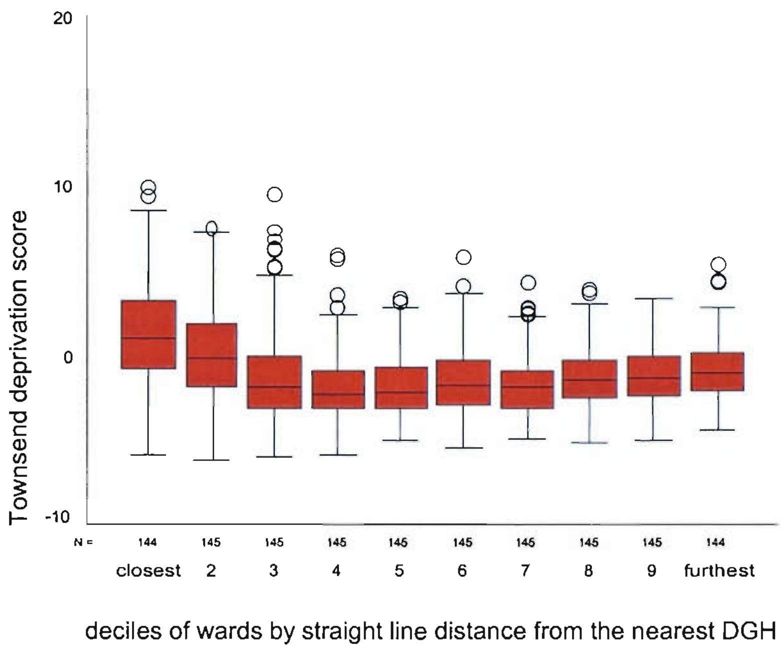
Distances of five kilometres to a GP and 25 kilometres to a hospital were used to denote remoteness from primary and secondary health services in further analysis, these distances combined an *a priori* decision on 'reasonable' travel distance with a number of wards (and residents) sufficient for statistical analysis. This definition classified approximately 6% of the study population as remote from secondary care and 3% as remote from primary care. There were 162 wards remote from hospitals (11% of the total, home to 6.5% of the region's population). All had travel times to hospital of over 21 minutes, and 81 (51%) were urban by the ONS classification. A further 69 (43%) were rural areas and the remaining eight (5%) were rural fringe. Four wards had no urban / rural classification. There were just 91 wards (6.3% of the total) remote from primary care. Of these the majority (63%) were ONS 'rural' areas.

Of wards that were remote from GPs, far more were rural than in the area as a whole for every level of remoteness considered. Just fewer than 18% of wards in the overall study area were rural. Even if the lowest, 3 km, cut off point was used to define remoteness from primary care, over half of 'remote' wards were rural. This rose to five out of seven if remoteness from a GP was defined as being 7 km or further from the closest surgery. Despite the strong association of remoteness from health services with rurality, a high proportion of 'remote' wards were not rural: 41% of wards over 35km from a hospital were not rural and 42% of those over 5km from their closest GP were classified as rural fringe or urban.

5.7 The need for health care and geographical access

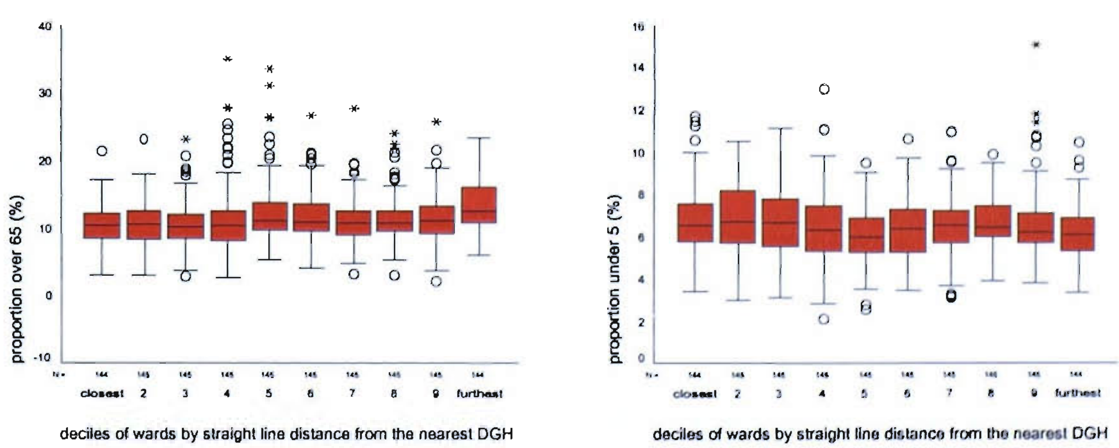
The study area had a relatively affluent profile with no extremes of deprivation. The most affluent wards were in the middle of the range of straight-line distances from secondary care. Deprivation increased in the wards furthest from hospitals, giving a slight 'U' shape to the relationship (Figure 16).

Figure 16: Townsend deprivation score by straight-line distance from hospital



The proportion of over 65 year olds increased slightly with straight-line distance from hospitals: more distant wards had a slightly higher proportion of residents over the age of 65, but there was considerable variation within deciles of distance, and the observed difference was small. The proportion of the population under five years old in 1991 showed no clear trend with ward distance from hospital, but was slightly lower in more distant wards (Figure 17).

Figure 17: Young and elderly population by straight-line distance from hospital



5.8 *The relationship between access and health*

The age-standardised rate of Limiting Long Term Illness (LLTI) was highest in the areas closest to hospitals. The LLTI rate decreased with increasing distance from hospital and then increased again in the most remote areas. The age and sex standardised rate of premature mortality from all causes showed no strong pattern with distance from a hospital, although median rates are high in areas close to hospitals and also slightly raised in the areas furthest from hospitals (Table 17).

Table 17: Pearson correlation coefficients for the relationship between access measures, mortality and morbidity

ONS*	Number of wards	Index of Multiple Deprivation 2000 access domain	Population density	Straight-line distance to nearest GP surgery	Straight-line distance to nearest hospital	Travel time to nearest GP surgery	Travel time to nearest hospital
Premature mortality							
Rural	253	0.010	0.090	-0.014	0.009	0.015	-0.029
Rural fringe	154	-0.073	-0.068	0.031	0.053	0.009	0.010
Urban	1031	-0.418	0.369	-0.272	-0.131	-0.297	-0.153
All wards	1448	-0.323	0.318	-0.203	-0.118	-0.220	-0.144
Premature Limiting Long Term Illness							
Rural	253	0.040	0.101	-0.099	0.315	-0.114	0.297
Rural fringe	154	0.102	0.031	-0.078	-0.028	-0.058	-0.037
Urban	1031	-0.470	0.403	-0.388	-0.064	-0.400	-0.098
All wards	1448	-0.387	0.383	-0.323	-0.059	-0.336	-0.090

**Office for National Statistics classification of rural and urban ward*

5.9 *Conclusion*

A variety of measures of geographic access of varying complexity and specificity exist (discussed in chapter one) and selecting an appropriate measure is not simple. Straight-line distances are widely used, easy to calculate and to compare and, in the South West of England, they are closely correlated with the more complex drive times. The measure of access to services included in the IMD is even easier to use as it is a pre-calculated score and it is well correlated with the distance to primary care.

There is some evidence that areas of low correlation between straight-line distances and drive times are concentrated in peripheral areas of the rural South West. In these areas straight-line distances underestimate the real impediment to travel, possibly reflecting sparse road networks and geographical barriers such as hills, rivers and coastlines. Access to health services in these areas could be misrepresented by the use of the simpler measure, masking problems facing their population. Furthermore, the IMD access domain, while strongly associated with drive time and distance to GPs, is only weakly associated with distances to hospital – wards that have good access scores do not necessarily have good access to secondary care, and vice versa.

Access to health services, as with other area measures, can be measured at a variety of scales. In this analysis, although measurement at the smaller scale showed up extremes of inaccessibility that are concealed by averages at the larger ward scale, there was no indication that the relationship between the two access measures differed with the scale of analysis.

No measure of geographical accessibility discussed in this chapter reflects the experience of people without access to a private car, although travel to hospital and GP appointments is already known to be a problem for some groups in rural areas of the UK. Rural areas (which are traditionally thought of as further from services) are often assumed to have high levels of car ownership, giving their residents a high degree of mobility and access to services. This assumption raises two questions: are the areas furthest from health services typically rural, and do the areas furthest from health services have high rates of car ownership?

An analysis of reported rates of car ownership at the 2001 Census showed that although car ownership is higher in areas further from hospitals than in the areas closest to them, even in the areas with the highest levels of car ownership one in five households is without any vehicle. Although this 80% car ownership is considerably higher than the 66% found in areas closest to hospitals it represents a substantial proportion of the population reliant on public transport, taxis and lifts. The proportion of households with two or more cars (giving an indication of the possibility of a car at home for daytime or emergency use as well as the existence of a vehicle for daily travel to work) rises from one in five in the areas closest to hospitals to one in three as remoteness from health services increases, leaving two out of three households with a single car or no car, and an unknown proportion of those households with no regular daytime access to private transport. There is some evidence that informal systems of 'lift-giving' and more formal 'voluntary taxi' schemes often exist (Sherwood & Lewis 2000), but these are not available everywhere (Cloke, Milbourne, & Thomas 1994; Mosley 1979), and it could be argued that a measure of travel by public transport is vital in determining accessibility for the most disadvantaged populations. Few studies have attempted this (Bentham 1995; Liu & Zhu 2004; Lovett et al. 2000; Lovett, Haynes, Sunnenberg, & Gale 2002), and composite measures, which include both public and private transport, are even more rare (Knox 1978). Better measures of access, which integrate private and public transport, are required to reflect the experience of vulnerable groups.

A surprising finding was the relatively low proportion of areas remote from health care that are defined as 'rural'. Fewer than half of the wards remote from hospital and under two-thirds of areas remote from primary care are classified as rural by the ONS. Analysis that concentrates on rural areas under the ONS definition, or even stretches this to include 'rural fringe' areas, will still miss over half of the wards which are remote from hospitals. There has been concern over the targeting of resources in concentrations of deprivation: the majority of deprived people live outside of these areas and are not reached by narrowly focused initiatives: similar caution should be exercised when evaluating and responding to poor access to health services, a high proportion of which occurs outside areas traditionally considered to be remote.

There was no clear threshold at which the need for health care, estimated through health status measures, becomes greater, as might be expected if poor access to health services was having an adverse impact on the populations' health. If anything, the converse was true with the worse health status and greatest need in urban areas. Increasing distance to health services was not associated with a high proportion of elderly or very young residents, but was related to deprivation. Deprivation was high in areas close to hospitals, more distant areas were relatively affluent, but the most remote wards showed an increase in deprivation. Deprivation indices have been criticised for failing to represent deprivation in rural areas (Barnett et al. 2001) and the relatively high proportion of rural areas in the most remote wards may mean that high need in these areas is concealed by inappropriate measurements.

Although the highest rates of morbidity and mortality were found in the areas closest to hospitals, there was some evidence of increasing rates in more remote areas. Rates of LLTI, particularly for those under 64, show an upwards trend in more remote areas. This supports previous findings that LLTI is higher in rural wards with the most dispersed populations (Barnett, Roderick, Martin, & Diamond 2001), but it is not clear whether this reflects a true increase in morbidity or a perception of handicap of those living in such areas. The assumption of high levels of mobility, expressed through high car ownership, in populations living far from services was upheld, but an indication of a decrease in levels of car ownership and multiple car ownership in areas most remote from hospitals was apparent. It is unlikely that this indicates a choice not to own a vehicle due to less need for a car, and may indicate a less wealthy or less physically able population for whom travel is a potential problem.

In conclusion, straight-line distances fail to represent true geographical barriers to health services in some coastal areas of the south west of England, making the use of this simple measure inappropriate in such areas. However, the more complex drive time measure is not appropriate for people without their own car – it is likely to seriously overestimate travel speed for those reliant on public transport and to conceal inaccessibility of health services to the part of the population for whom travel is slower and more costly, or simply harder to organise than it is for car owners.

Our understanding of the effect of distance on the use of services and on health outcomes is far from complete. Both the measurement of access and the understanding of need and deprivation require further exploration. The development of web-based public transport information systems can supply the data needed to enhance currently available measures of access by adding public transport travel times, likely to be relevant to access for the poorest and most deprived populations and the introduction of the Indices of Multiple Deprivation 2000 in England may present a clearer picture of the need for health care than traditional census-based indices (Department of Environment Transport and the Regions 2000a). This index contains a measure of geographical access to services, which has been of particular interest to rural populations and may provide a missing dimension to the measurement of deprivation. Linking geographical access with a wider range of health status measures and health care use in different populations is also vital if a clear picture of the impact of accessibility of health care is to be fully understood. The relationships between deprivation and access to health services are explored in the next chapter.

Chapter 6: Deprivation and access to health services: The IMD 2000

6 Chapter overview

In *chapter six* I present the analysis of the relationship between the need for health care, health and access to health services. Need is measured using the Townsend score and the Index of Multiple Deprivation 2000 (IMD), and access is measured using the access domain of the IMD, straight-line distance and drive time to hospital. The analyses are carried out for urban and rural areas separately, and the suitability of the IMD as a proxy measure for the need for health care is discussed. The access domain of the IMD and its relationship with health in rural areas is considered in detail.

6.1 Introduction

In the previous chapter it was shown that although poor access to health services was by no means an exclusively rural issue, a far higher than expected proportion of wards with poor access to health services were rural. However, the question remains of whether the areas that are furthest from health services have a high or low need for them. Equity, rather than equality of access, is based on the relationship between need and provision, and the clear measurement of the need for health care is a vital element of assessing the equity of access to health services.

Deprivation measures are often used as a readily available proxy measure of the need for health care. Although the strong correlation between deprivation and health is well known, this relationship does not hold in rural parts of the UK, where traditional census-based deprivation indices such as the Townsend score (Townsend, Phillimore, & Beattie 1979) are not strongly related to health (Barnett, Roderick, Martin, & Diamond 2001). The reasons for this are unclear. It has been suggested that rural areas are relatively affluent, and have low levels of need for health services, or that where deprivation does exist in rural areas it is not related to health in the same way as urban deprivation. However it has also been argued that the underlying relationship between health and deprivation is the same in rural as in urban areas, and that the difficulties lie in detecting rural deprivation (Phillimore & Reading 1992; Haynes & Gale 2000). However, it is also possible that deprivation and hardship in rural England is poorly captured by conventional deprivation indicators. These indicators may underestimate the degree of deprivation experienced in rural areas, which can suffer from problems of seasonal unemployment, low pay and isolation (McLaughlin 1986).

There are several reasons why this might be the case. Firstly, deprived populations in rural areas may be too scattered to be identified by aggregate measures like deprivation indices. In the UK, analyses of deprivation and health often use the census ward as a unit of analysis. A ward averages over two thousand households and, although a convenient source of readily available data, may not reflect natural communities. Rural wards are more likely than urban wards to be socially heterogeneous, and this may dilute the impact of that part of the population who experience deprivation (Haynes & Gale 2000; Cox 1998).

It has also been argued that the measurement of deprivation is specific to the urban situation: that the indices do not include the important markers of rural deprivation (Payne et al. 1996; Shucksmith, Roberts, Scott, Chapman, & Conway 1996). For example car ownership (an element of the Townsend deprivation score) may be a marker only of urban deprivation, as travel distances and poor public transport provision in rural areas make car ownership a necessity for rich and poor alike (Martin et al. 2000). Geographical accessibility to essential services may be a key concept contributing to deprivation in rural populations, but it has not been captured by census based measures of deprivation and it has therefore received relatively little attention in rural health related research in the UK.

The IMD, developed from the 1998 Index of Local Deprivation was, at the time of writing, unique in its inclusion of a measure of geographical access as an element of deprivation and in its direct measure of poverty (through data on benefit receipts) (Department of Environment Transport and the Regions 2000a). It differs from many other deprivation measures by going beyond census data and using a range of information from local government and other agencies to create a measure of deprivation comprising six themes, or 'domains', which are combined to create an overall score. Wards are ranked by their score in each domain, and overall by the combined IMD score. One of these domains (contributing 10% of the total IMD score) is 'geographical access to services', which captures the distance to local services. This measurement of access may potentially have captured an element of rural deprivation that had previously been neglected.

The inclusion of the access domain in the IMD has been perceived as adding a vital new dimension to the measurement of rural deprivation, and has resulted in a proliferation of analyses, identifying the ranking of individual health areas on this domain. However, there has been little research to investigate whether the IMD or the access domain of the score actually measure rural deprivation by demonstrating associations with health outcomes in the rural population (Asthana, Halliday, Brigham, & Gibson 2002). One reason may be that the IMD is a pre-calculated score, only available for 1998 ward boundaries. Many of the data available on health outcomes are for 1991 or 2001 Census wards, while alternative measures of deprivation and of rurality are readily available for similar geographical units. Geographical comparability between the IMD and other data has therefore been a problem.

In this chapter I describe the use of the IMD as a proxy measure of the need for health care in urban, rural fringe and rural areas of the south west of England by:

- Describing deprivation in the south west of England using the Townsend score, the IMD and its six separate domains
- Showing how well the IMD correlates with the widely used, census-based, Townsend score
- Investigating the association between the Townsend score and the IMD and two population health outcomes: premature limiting long term illness (LLTI), and all-cause premature mortality, and
- Examining the correlation between each of the six separate domains of the IMD and health to establish their independent contribution to the relationship between deprivation and health

The relationship between the need for health care and access to health services in urban and rural areas is then examined through a correlation of access to health services, measured using the straight-line distance to hospital, the drive time to hospital and the access domain of the IMD, with the two deprivation measures of the IMD and the Townsend score.

6.2 Results

The calculation of the Townsend score is shown in section 4.2.4 and the domains and constituent variables of the IMD are given in table 11. As the IMD is a pre-calculated score, available for 1998 ward boundaries, it was not compatible with the data on rurality, health and access to health services used here. It was therefore necessary to re-weight the IMD to obtain an estimate of the score for 1991 wards. Details of the methods used are given in chapter 4.

6.2.1 Deprivation in the south west of England

According to both measures of deprivation, the South West of England is less deprived than average. The mean Townsend score for the area is -1.04, where 0 is the mean for England and Wales (Table 18).

Table 18: Townsend score for the study area compared to England and Wales

	Minimum (affluent)	Mean	Maximum (deprived)	Standard deviation
England and Wales	-7.42	0	11.79	3.36
South West England	-6.23	-1.04	9.85	2.37

Under the IMD, the most deprived 1998 ward within the region was ranked 133 (rank one being the most deprived in England and rank 8414 the least deprived). The median rank in the region was 4404, compared to the national median of 4207, again suggesting that the study area is slightly more affluent than England overall. The different elements of deprivation covered by the IMD indicate that the area is more deprived than average in the access dimension, but is otherwise slightly more affluent than average (Table 19).

The two measures of deprivation - the Townsend score and the IMD - are closely correlated in the study area as a whole (r^2=0.73).

Table 19: IMD for the study area* (SW) compared to England and Wales (E&W)

		Highest score / rank of ward (affluence)		Median score / rank		Lowest score / rank of ward (deprivation)	
IMD	SW	76	8375	16.1	4404	2.7	133
	E&W	84	8414	16.9	4207	1.0	1
Income	SW	53	8406	15.1	4405	2.2	108
	E&W	74	8414	15.7	4207	1.0	1
Employment	SW	30	8407	7.8	4522	1.3	118
	E&W	51	8414	8.3	4207	1.0	1
Health	SW	2.0	8404	-0.1	4628	-3.0	125
	E&W	3.0	8414	0.0	4207	-3.0	1
Education	SW	2.8	8399	-0.2	4678	-2.0	7
	E&W	3.0	8414	0.0	4207	-3.0	1
Housing	SW	1.8	8399	-0.1	4525	-3.0	247
	E&W	3.0	8414	0.0	4207	-3.0	1
Access	SW	2.5	8406	0.2	3086	-2.0	7
	E&W	3.0	8414	-0.1	4207	-3.0	1

**the IMD for the study area is a re-calculated estimate for 1991 wards. Ranks of the IMD score are taken from the reported rank of any 1998 ward with an area contributing to the 1991 study area.*

6.2.2 Deprivation in urban and rural areas

The range of deprivation is greatest in urban areas: both the highest and the lowest deprivation scores are found in urban areas. Rural areas are, on average, more affluent than urban areas and show a far smaller range of deprivation (table 20).

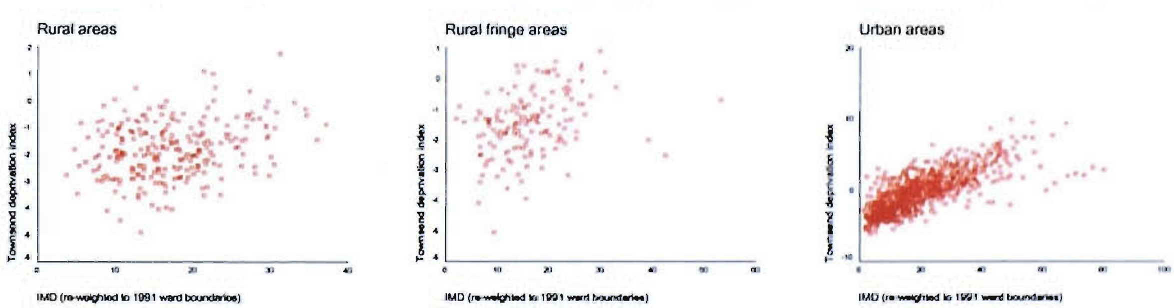
Table 20: Deprivation scores in urban and rural areas

	Minimum (affluent)	Mean	Maximum (deprived)	Standard deviation
	Townsend score			
Rural areas	-4.95	-1.84	1.71	1.04
Rural fringe areas	-5.09	-1.50	0.84	1.01
Urban areas	-6.23	-0.77	9.85	2.68
	IMD			
Rural areas	3.68	17.22	37.11	6.68
Rural fringe areas	1.98	16.11	53.18	7.42
Urban areas	0.78	18.08	79.98	12.36

The close overall correlation between the Townsend score and IMD is heavily influenced by the strong association between the indices found in urban wards, which make up just over 70% of wards in the South West. In rural and rural fringe areas, the two deprivation scores are much more weakly (although still statistically significantly) correlated, indicating that in rural areas the IMD is identifying a different set of deprived wards than the Townsend score (figure 18).

Figure 18: The relationship between the Townsend score and the IMD in urban, rural and rural fringe areas

Rural wards (n=253) | Rural fringe wards (n=154) | Urban wards (n=1031)

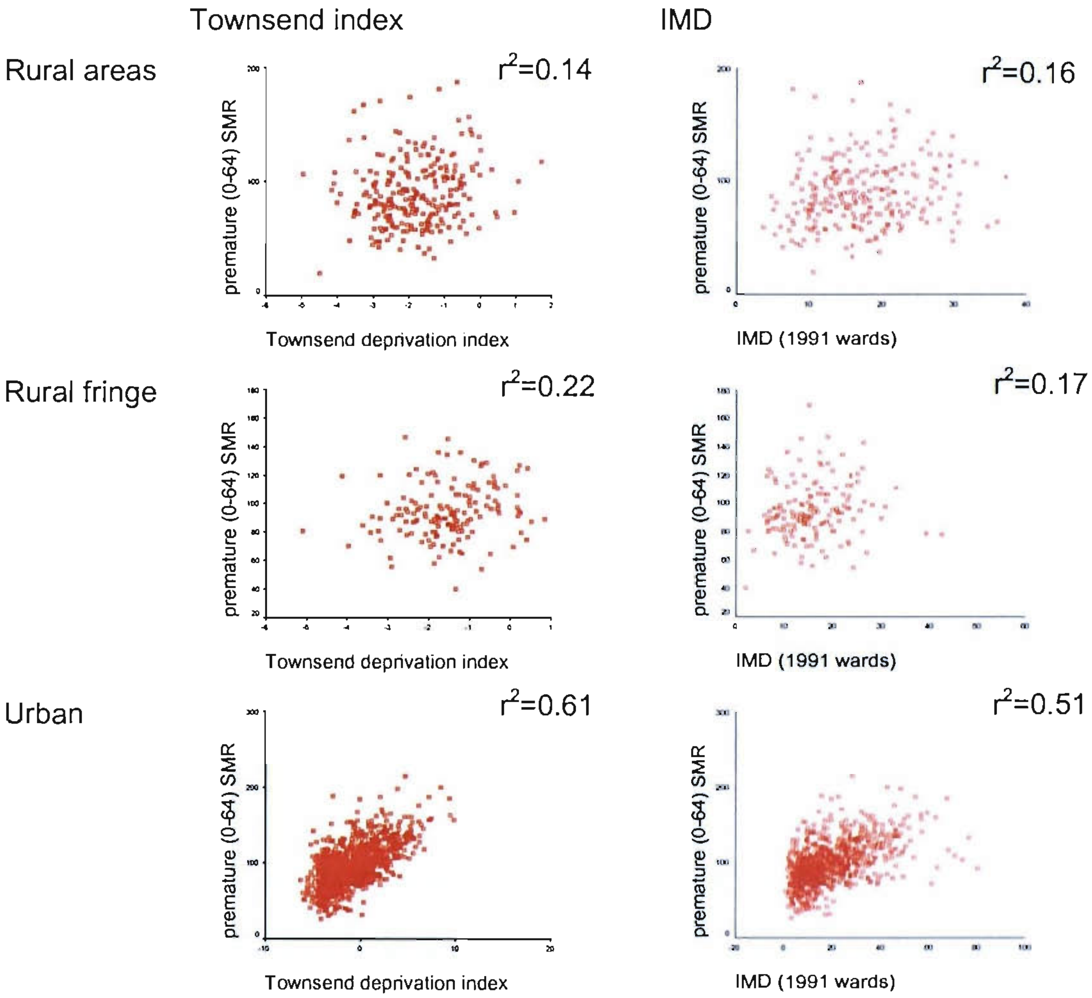


r^2=0.29 | r^2=0.33 | r^2=0.77

6.2.3 The association between deprivation and health in urban and rural areas

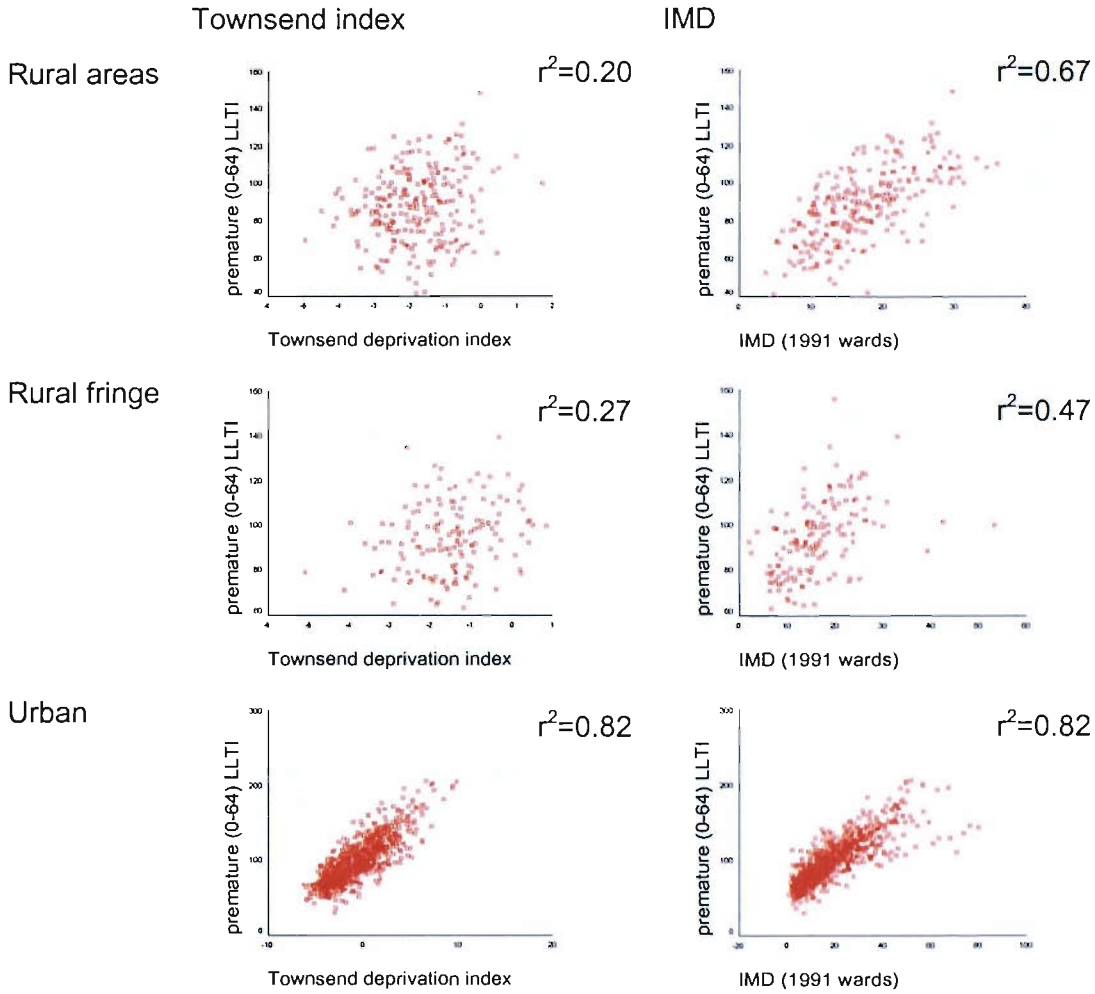
The IMD is comparable to the Townsend score in its correlation with both mortality and morbidity. The Townsend score was more closely related to premature mortality in all three area types, and overall (r=0.53 versus r=0.44), but neither deprivation measure had a strong linear relationship with all-cause premature mortality (Figure 19).

Figure 19: The relationship between premature mortality*, the Townsend score and the IMD in rural, rural fringe and urban areas



The overall relationship between deprivation and LLTI is also very similar for the two indicators (r^2 = 0.76 for the Townsend score versus 0.79 for the IMD) but the underlying pattern is different. The IMD has a strong relationship with premature morbidity in both rural and urban areas, whereas the Townsend score is only strongly related in urban areas. As urban areas make up the majority of wards in the region, the overall correlation is similar (figure 20).

Figure 20: The relationship between premature LLTI*, the Townsend score and the IMD in rural, rural fringe and urban areas



**The age/sex standardised rate of self reported Limiting Long Term Illness in those aged under 65*

6.2.4 The association of the separate domains of the IMD with health in urban and rural areas

The six domains of the IMD (income, employment, health deprivation and disability, education skills and training, housing, and geographical access to services) each characterise a different dimension of deprivation, and can be examined separately to identify the dimensions most closely associated with health. This may clarify the reasons why the IMD is so closely correlated with morbidity in rural areas, in particular whether it is the inclusion of the geographical access to services domain in the IMD which is responsible for the strong correlations.

The IMD is more strongly correlated with rates of LLTI than with rates of premature mortality in every domain and in all area types. The strongest relationships between deprivation and premature mortality are found with the health deprivation and disability and education domains in rural areas, and the income and housing domains in rural fringe and urban areas.

The strongest correlations between deprivation and LLTI are found in urban areas. Health deprivation and disability is the domain most strongly related to rates in all areas, with employment also highly correlated in rural and rural fringe areas, and income in urban areas (table 21).

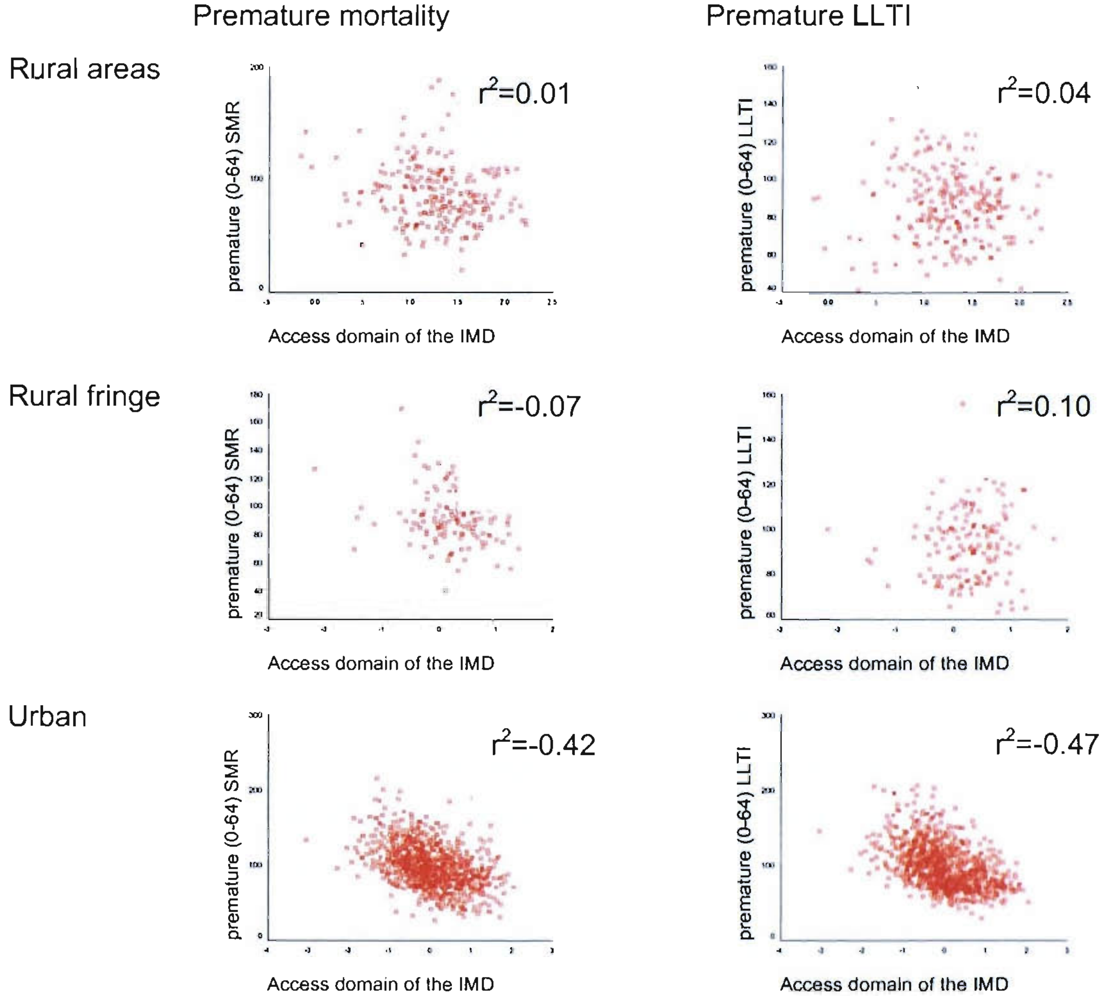
Table 21: Pearson correlation coefficients for the relationship between deprivation, mortality and morbidity

ONS*	Number of wards	IMD	Income domain	Employment domain	Health domain	Education domain	Housing domain	Access domain
				Premature mortality				
Rural	253	0.163	0.148	0.164	0.180	0.036	0.131	0.010
Rural fringe	154	0.171	0.196	0.137	0.145	-0.029	0.169	-0.073
Urban	1031	0.509	0.502	0.453	0.198	0.424	0.487	-0.418
All wards	1448	0.439	0.440	0.397	0.413	0.340	0.410	-0.323
				Premature Limiting Long Term Illness				
Rural	253	0.669	0.605	0.664	0.700	0.411	0.241	0.040
Rural fringe	154	0.468	0.346	0.410	0.625	0.192	0.282	0.102
Urban	1031	0.822	0.811	0.749	0.800	0.620	0.627	-0.470
All wards	1448	0.786	0.775	0.726	0.781	0.578	0.565	-0.387

**Office for National Statistics classification of rural and urban wards*

Although the south west of England scores badly on the access domain of the IMD, this dimension of deprivation does not contribute to the strong relationship between deprivation and LLTI in rural areas. There is no linear relationship between the geographical access to services score and either LLTI or premature mortality. In urban areas, the correlation between the access domain and health is negative, with areas with the poorest access to local services associated with lower rates of premature mortality and morbidity (Figure 21). In rural areas, the access domain has the weakest relationship with the two health measures of all the IMD domains.

Figure 21: The relationship between the IMD access domain, premature mortality and LLTI* in rural, rural fringe and urban areas

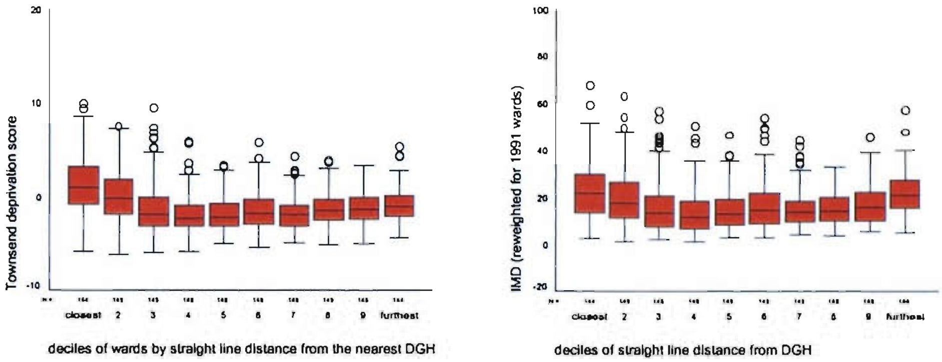


6.2.5 The association between deprivation and access

Although the access domain of the IMD is not correlated with rates of ill health or premature death in either urban or rural wards, geographical inaccessibility may still be a significant barrier to the use of health services for deprived populations. The relationship between access to health services and different measures of deprivation can indicate whether populations with poor geographical access to services are disadvantaged in other ways.

There was little evidence that deprivation as measured by the Townsend score was associated with poor geographical access to primary or secondary care in either rural or urban areas. Access appeared good in highly deprived areas, and areas with poor access appeared relatively affluent. However, when wards were grouped into deciles by the distance to the closest hospital, a slight 'U' shape to the relationship was evident. The most affluent wards were in the middle of the range of straight-line distances from secondary care, and deprivation increased in the most remote wards. The IMD was similarly uncorrelated with access to health services, but showed the same slightly U shaped relationship when wards were grouped into deciles by distance from hospital (Figure 22).

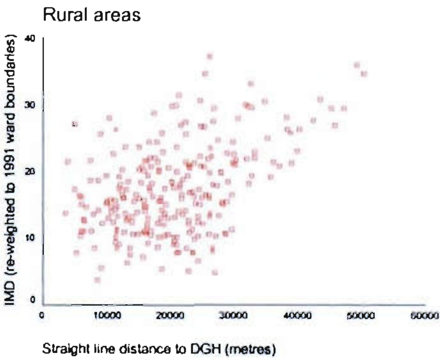
Figure 22: Deprivation by straight-line distance from hospital



The stronger relationship between distance to hospitals and deprivation in rural areas can be seen in figure 23. Although deprived wards were found at all distances from hospital, there was little evidence of affluence at the greatest distances from hospitals.

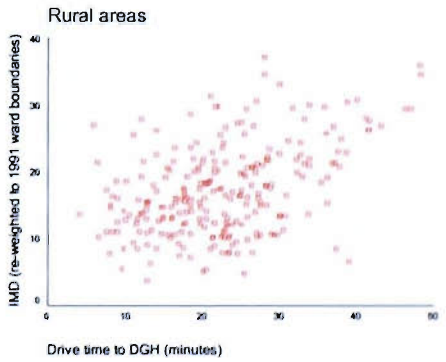
Figure 23: The relationship between the IMD and access to hospitals in rural areas

Straight-line distance to hospital



r^2=0.46

Drive time to hospital

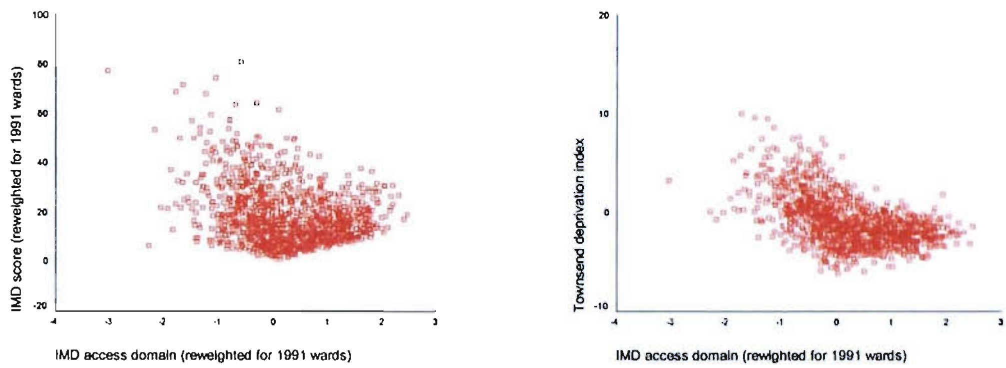


r^2=0.45

The overall IMD score was only weakly related to the access domain of the IMD (as a measure of geographical access to health services) in all areas, and in urban areas was negatively correlated, indicating that access is a very different dimension of deprivation to the education, economic and health indicators which comprise the rest of the IMD score. The Townsend score was slightly more closely correlated to the access domain of the IMD, with deprived areas (high Townsend scores) scoring well on the access domain, and wards with poor access to services neither particularly affluent nor particularly deprived (figure 24).

Figure 24: The relationship between deprivation and the access domain of the IMD

r^2=-0.27 r^2=-0.51



6.2.6 Other indicators of need and access to health services

One dimension of deprivation that may be significant to geographical access is the ownership of a car. If inaccessible areas have an unusually high proportion of residents who do not own a car, this may indicate the presence of a population who will find it difficult to overcome geographical barriers. As well as the ownership of any car, the ownership of two or more cars may be significant, indicating households where a car is likely to be available for household use during working hours, as well as for travel to and from work. Wards were grouped into deciles by the straight-line distance to the nearest hospital, and car ownership rates in each decile were recorded. The rate of non-car ownership was highest in the areas closest to hospital, but rose again in the most distant wards, with 23% of households in the most remote decile of wards not owning a car. Two-car ownership followed a similar pattern, with up to a third of households having two cars at the 2001 census, falling to 27% in the most remote wards (table 22).

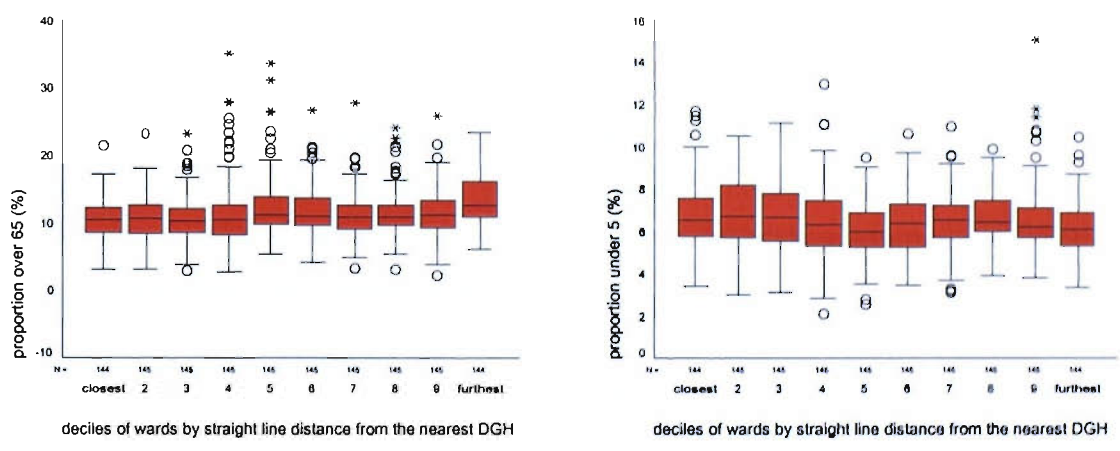
Table 22: Car ownership for deciles of wards by straight-line distance from hospital

Proportion of households with	Closest	2	3	4	5	6	7	8	9	Furthest
No car (2001)	34.2	29.3	25.4	20.4	20.3	21.0	20.	20.7	20.2	23.1
Two or more cars (2001)	20.0	23.2	27.8	32.1	33.2	32.0	32.8	32.5	31.2	27.0

Another indicator of the need for health services is the age profile of the population. A large proportion of NHS resources is spent on the care of the elderly and the very young: a higher proportion of high need groups in areas remote from health services could indicate inequity in the provision of services.

The proportion of over 65 year olds increased slightly with straight-line distance from hospitals: more remote wards had a slightly higher proportion of residents over the age of 65, but there was considerable variation within deciles of remoteness, and the observed difference was small. The proportion of the population under five years old in 1991 showed no clear trend with ward distance from hospital, but was slightly lower in more remote wards (Figure 25).

Figure 25: Young and elderly population for deciles of wards by straight-line distance to hospital



6.3 Discussion

The IMD is more strongly correlated with rates of LLTI in rural areas than the Townsend score, but it performs very similarly to the Townsend score for premature mortality, with poor correlation in rural areas, becoming stronger in urban areas. Overall, the income and health deprivation and disability domains provide the closest fit, with employment an important predictor of both health outcomes in rural wards, the association being much stronger for LLTI than mortality. The employment domain of the IMD contains two measures directly related to chronic ill health: the number of Incapacity Benefit claimants, and the number of Severe Disablement Allowance claimants of working age; the income domain is calculated using measures of Disability Working Allowance and disabled Council Tax Benefit claimants; and the health deprivation and disability domain also contains data on Disability Living Allowance, Incapacity Benefit and Severe Disablement Allowance claimants, as well as the two outcome measures we have used here: the age-sex standardised rate of premature mortality and of LLTI. In the IMD, mortality data are only available at the District Health Authority level, and are directly rather than indirectly age standardised. LLTI data were taken from 1991 census ward data: the same source as our measure. It seems very likely therefore that, despite our reallocation of data from 1991 to 1998 wards, the strong correlations we have seen with LLTI in all areas are due to the use of the same underlying data for this element of the index.

The IMD access domain is the most weakly related to health outcomes of all the domains in the index. In rural areas there is effectively no relationship and in urban areas there is an inverse relationship. It certainly appears to be capturing some elements of rurality: access scores are higher in ONS 'urban' areas than in 'rural' and in areas of high population density. Despite being calculated only for people receiving benefits, we found the access score correlated strongly with ward level measures of access to primary care, especially with the straight-line distance to a main GP surgery. The correlation with the distance to secondary care was far weaker. With the exception of the correlation between access to hospital and rates of LLTI in rural areas, no other measure of access calculated here improved on the IMD's poor correlation with health in any area.

Access as measured in the IMD or by the distance to health services thus does not help to explain the rural health outcomes used here. It is, however, a long established and important feature of rural deprivation and is a relevant consideration for health planners and policy makers. Equity of access is important to the NHS, influencing both the personal and financial costs of using health services for those in need of care, and possibly the timely and appropriate use of health services.

There may be several explanations why the geographical access to services domain of the IMD is not related to health outcomes. Firstly, and perhaps most importantly, distance barriers to accessing health care may impact on the timely use of services and quality of care but without directly affecting the global health outcome measures used here. However, from the perspective of equity of access, we still need to ensure that those with the highest need for health services in rural areas do have accessible primary and secondary care. Secondly, the IMD only measures access to local level services, and not access to secondary or tertiary health care. An interesting alternative model which deals with access to services at a range of different geographical scales is provided by the Australian ARIA index (University of Adelaide 1999) which uses GIS-based road distances to population centres of various sizes in the construction of a standard measure of remoteness which is considered suitable for a broad range of applications. Finally, the IMD uses straight-line distance as a global proxy measure of access for all modes of transport. The greatest disadvantage is experienced by those without access to a car (including members of one-car households without daytime access). For these groups, straight-line travel distance is likely to provide the least appropriate measure of the obstacles of access. Although the access domain focuses on the more vulnerable groups in society, there may also be considerable hidden poverty, for example relating to low pay and seasonal employment which are both especially prevalent in rural areas, but are inadequately captured by the index.

6.3.1 Limitations

There are several limitations to this work, the most serious of which is the re-weighting of the IMD to 1991 ward boundaries. The majority of variables in the score are calculated for postcodes for the period of the late 1990s. These were assigned to 1998 ward boundaries. When re-weighting to 1991 wards the allocation of the score is proportional to estimates of the number of households within each ward. This is likely to be an overestimate in some cases and an underestimate in others. The greatest misallocation will occur in areas that have experienced significant changes in socio-economic profile between 1991 and 1998. This misclassification is likely to be non-differential, however, and will tend to reduce any associations in the data.

Another potential limitation, which may have a similar effect, is the use of wards as the unit of analysis. Although data on health and deprivation were readily available at this level, wards may be too large and diverse to reflect local community boundaries, especially in rural areas, which tend to be more socially mixed than urban areas. This may reduce both the ability to detect rural deprivation and the chance of finding a relationship between access, deprivation and health.

This is an ecological study, and shares the limitations of all such studies: because measurements are averaged over populations the relationship between variables may be weakened, resulting in less power to detect relationships which exist, and the relationships between aggregate measures may not reflect the true relationships between individuals. Also, all of the measures are area based and unable to distinguish between the influence of the surrounding area ('contextual effects') or the individuals within an area ('compositional effects') (Macintyre, Maciver, & Sooman 1993), both of which may contribute to spatial inequalities in health. A multilevel analysis including both individual and area estimates of deprivation and access would be an interesting development of this work.

A further limitation that may act to attenuate any relationship between health and deprivation is the temporal mismatch between the data sets. The data used here come from several different time periods, ranging from 1991 for LLTI and Townsend deprivation score data to 2000 for IMD data. Although the relationships with access to health services should be less affected - both GP and DGH locations are from 1991-6 – it was not possible to take into account the possible effect of any lag between the pattern of access to health services and reported health outcomes. Future work relating changes in access over time to patterns of health deprivation would be a useful addition to this work.

Finally, this analysis has explored the relationship between health and the IMD score in just one region of England. This area is not only relatively affluent, but also does not display the extremes of remoteness seen, for example, in the Scottish Highlands. It may be that a threshold level of remoteness from services is needed before an effect of access is seen, and that this level is simply not reached in the South West of England. It has no substantial ethnic minority populations, and a generally good level of population health. I have used only general measures of health outcome. More work is needed to test the utility of this index as a general predictor of health in other areas of the country, and against different measures of health.

6.4 Conclusions

In conclusion, I have shown that the IMD has a strong relationship with health, particularly self reported illness, in both rural and urban areas, but this is likely to be the result of the inclusion of benefit claimant data related to ill health and disability, and to the explicit measures of health in the health deprivation and disability domain of the score. By contrast, the geographical access to services domain is not strongly correlated with global measures of rural health, and is inversely related to health outcomes in urban areas. The access domain, along with all other measures of access considered here, provides a relatively unsophisticated measure that does not include the influence of different modes of transport on distinct population sub-groups, and may in particular be a weak reflection of the rural access challenges facing the most vulnerable groups. Further, it concentrates primarily on access to local services which are relatively good in both urban and rural areas, but does not incorporate any measurement of access to more specialist services.

The policy importance of ensuring equitable access to health services as far as possible covers the principle of equity – it can be argued that the NHS should not disadvantage people in terms of cost or time to health services even if there are no directly detectable health disbenefits – and the effectiveness of health care: the need to minimise direct disbenefits to health from poor access to services. Measuring and understanding the effects of variations in geographical access to health services is important from both of these perspectives. Considerable work still remains to be done in developing a truly representative measure of access to health services. Such a measure should include a well developed measure of public transport access and an estimate of travel time by car. It should also be possible to apply the measure appropriately to selected populations. These issues are of particular importance in the period surrounding the release of 2001 Census data (http://www.statistics.gov.uk/census2001/) and the further enhancement of the government's Neighbourhood Statistics service (http://www.neighbourhood.statistics.gov.uk/), both of which will initiate a new round of debate concerning the construction of indicators such as IMD for policies focused on the eradication of area-based disadvantage. The IMD access domain covers a broad range of potential policy areas, but with only limited data. The access to services dimension, along with all the other measures of access considered here, is potentially important but as yet inadequately specified for health research. It would therefore be inappropriate to simply reproduce the IMD using updated data without a fuller evaluation of its interpretation, and particular caution should be exercised in its use as a deprivation measure for studies involving access to health care.

Chapter 7: Developing a public transport measure of access

7 Chapter overview

Straight-line distances, drive times and the access domain of the IMD all have limitations as measures of access to health services. Straight-line distances are an oversimplification of travel behaviour; drive times assume the use of a car and the access domain of the IMD, as discussed in chapter six, is limited by its focus on access to local services. In this chapter, I describe the development of a measure of accessibility based on public transport data. I discuss the need for such a measure in terms of UK health service policy and contemporary research and the concepts underlying the measure. I then present a pilot study in which public transport access to a single hospital in Cornwall was measured and discuss the limitations of this approach for addressing the research questions of this thesis.

7.1 Why develop a different measure of geographical accessibility?

Access to services, including health services, is increasingly topical in UK public policy. Improving patient access to health services is a cross-government problem, affecting the poor, the elderly and those living in rural areas disproportionately. Policies relating to social exclusion (Social Exclusion Unit 2003), to equity of access to NHS services *("Patients should have fair access and high standards of care wherever they live")* (The NHS Plan 2000, p58), and to life in rural areas (Department of Environment Transport and the Regions 2000b) have all considered the problem of variations in geographical access in recent years.

Poor access to health services is most likely amongst those who do not drive, with 17% of adults in car-owning households reporting difficulties in getting to hospital compared to 31% of those in households which do not own a car (Ruston 2002). Car ownership in the UK is generally high (in the 2001 census 73% of households in England and Wales reported that they own at least one car), but the proportion of households with no car is not evenly distributed throughout the population, raising issues of equity of access. The proportion of households without a car increases with increasing age, and it is more likely to be women who do not drive, even if there is a car available. For example, in the late 1990s, more than 60 per cent of men over 70 held a licence compared with under 25 per cent of women (Audit Commission 2001). Although the majority of journeys to hospital are made by car, the proportion drops from almost 90% of journeys in the most affluent areas to just over half in the most deprived (Hamer 2004). Non-emergency ambulances, private taxi services and hospital car services are all provided for the non-emergency transport of patients unable to make their own way to health services, but services are fragmented, and decisions on eligibility are taken at the local level (Audit Commission 2001). Furthermore, such services do not cater for patients who are not 'in medical need' (the definition of which may vary), or for their friends, relatives or carers.

Geographical access to services has also become important in the rural policy agenda. In 2001, the Audit Commission reported that *"Poor access to services because of a lack of, or infrequent, public transport, or high transport costs, can be a major factor in social exclusion and rural isolation."* (Audit Commission 2001). More recently the British Medical Association (BMA) has issued a report highlighting problems for rural practice, including the fact that in rural areas patients travelling to health services (often centralised in distant towns or cities) incur additional travel costs and times. The lack of public transport in rural areas can further disadvantage people on low incomes or those who do not drive (British Medical Association 2005, p 30-1).

In February 2003 a report by the Social Exclusion Unit, part of the UK government Office of the Deputy Prime Minister (http://www.socialexclusionunit.gov.uk) was published. The report, *Making the Connections*, recognised that for some, the lack of affordable and available public transport services presented a barrier to accessing health services and contributed to inequalities in health – a situation which could be tackled by transport policies and by improved geographical access to services. In response, the Department of Health (DH) undertook a policy commitment to broaden the eligibility criteria for the use of non-emergency patient transport services, to improve the provision of advice and information on getting to healthcare facilities, and to ensure that accessibility was part of the decision making process on the location and delivery of healthcare, declaring that

> "providing health services that are of consistently high quality and responsive to the needs of the patient lies at the heart of the government's vision of a modern and dependable health service. Ensuring that people can access these services when they need them is crucial to good health and transport

is a key factor in accessibility" (http://www.dft.gov.uk/stellent/groups/dft_localtrans/documents/page/dft_localtrans_025183.hcsp, accessed October 2004).

The DH recognised that

> "the ability to get to …key services is critical in addressing health inequalities …Local transport plans submitted in 2005 will include a more systematic assessment of whether people can reach the services they need. Health service providers will have a key role in supporting and contributing to the accessibility planning process" (Department of Health 2003)

The Department for Transport (DfT) is currently (2004-5) working closely with other government departments including the DH to develop a software tool, Accession, for "Accessibility Planning" (http://www.dft.gov.uk/stellent/groups/dft_localtrans/documents/divisionhomepage/032400.hcsp, accessed February 2005). This brings together local authorities, the NHS and other local partners in identifying and tackling the problems which some groups of people face in accessing health and other services. The development of Accession is described below.

7.1.1 Accessibility planning

The availability of timetable data in electronic format is a recent development, and underlies initiatives such as web based timetable enquiry systems (for example Traveline, http://217.171.103.36/nbindex.htm). The UK Department for Transport (DfT) are currently (2004-5) using these files to construct a measure of public transport accessibility for the use of local authorities in assessing whether government targets on accessibility are being met, but other than this little use has been made of electronic timetable data in measuring accessibility.

The software tool, Accession, is designed to read the timetable files, which are provided by bus service operators in a standard interchange format, ATCO CIF. The output from Accession is for the use of local authorities, in assessing whether government targets on accessibility are being met. Access to public transport is measured as the proportion of people within a 10 minute walk of a bus service at 5, 10 or 15 minute intervals and as the proportion of people in rural areas within a 10 to 13 minute walk of an hourly or better bus service (Department for Transport 2004). This compares to the standards put forward in the Social Exclusion Unit Report 'Making the Connections', of the proportion of people within 13 minutes walk of a bus stop and the proportion of people within 45 minutes (door to door time by public transport) of a hospital. The selection of 10, 13 and 45 minutes in the reports appears to be arbitrary and is not supported by any evidence that these times represent accessibility thresholds with an impact on either behaviour or health. This further supports the findings of the literature review in this thesis that there is little quantifiable information about the impact of geographical access on health or on health seeking behaviour.

From autumn 2004 these indicators of accessibility have been made available to all the local authorities in England (outside of London) that have to produce a local transport plan. The core indicators are to be described over six time periods as this is thought to give the clearest picture of accessibility (a claim based on work carried out in Devon, which was not referenced in the guidance). For access to GPs and hospitals, the six time periods are to be measured on a 'typical weekday (Tuesday or Thursday) at six times:

- Pre AM peak, 0800-0900
- AM peak, 0900-1000
- Pre Inter Peak hour, 1200-1300
- Inter Peak hour, 1300-1400
- Pre PM peak, 1600-1700
- PM peak, 1700-1800

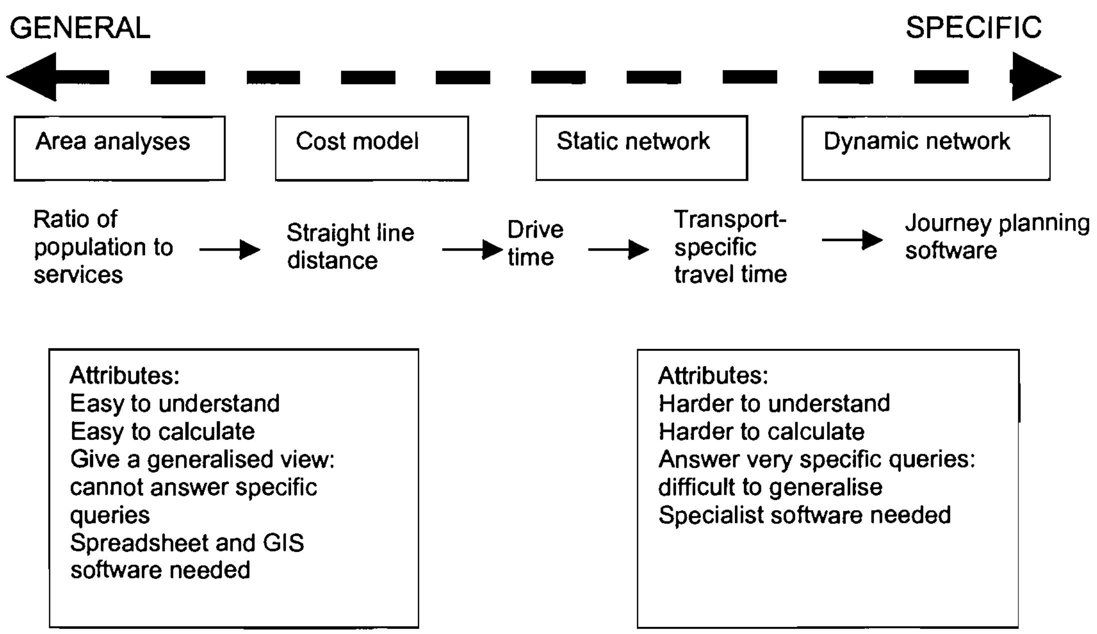
The formal baseline time for the accessibility measures will be 2005/6. Baseline measurements of the core indicators will be available to local authorities in the autumn of 2005.

7.2 Representing accessibility

The appropriate model for representing and measuring geographical accessibility depends on the questions being asked: different models are useful in different circumstances. In this analysis, the aim is to identify geographical areas in which the population are potentially disadvantaged by the poor accessibility of primary or secondary health services. Equity in access to health services in the context of rural poverty and exclusion make travel mode an important issue in modelling access to health services, and necessitate an area estimate of accessibility rather than the description of individual journeys. The Accession model of accessibility is designed with these issues in mind, giving a generalised view of access by public transport at specific times of the day and week. There are, however, many other ways of modelling accessibility, and these are discussed in the following section.

Models of accessibility have been extensively reviewed by, amongst others, Fortney, Rost, & Warren (2000); Connor, Kralewski, & Hillson (1994); Handy & Niemeier (1997); Martin & Williams (1992); Pirie (1979); Thouez, Bodson, & Joseph (1988); Vickerman (1974) and Shannon, Bashshur, & Metzner (1969) and include the measurement of the interconnectedness of networks, the supply of services, the distance between supply and demand locations and, occasionally, the measurement of time as a factor influencing the possibility of travel and the use of a service. Models of access can be thought of as belonging on a continuum from the very general to the very specific. As the modelling of geographical access becomes more complex, so the questions that can be answered by the models become more specific. Models of accessibility are used to determine how well connected a place is, whether the supply of services to an area is adequate, and to answer questions about travel between places. Achieving an appropriate balance between generalisation and specificity is essential when modelling access to services: the appropriate balance depends on the questions that the model is designed to answer (Figure 26).

Figure 26: Models of accessibility: from the general to the specific



At the most general end of the spectrum (to the far left of figure 26) are area analyses: models that can be used to describe accessibility for whole areas, but have little or no power to differentiate within an area. These models tend to use large areas, comprising a service and its catchment area, meaning that intra-area variability in access is likely to be significant, and can be strongly limited by boundary effects, as they treat services beyond the area boundaries as unavailable.

Models of access that use measured distances give an estimate of the cost of travel (or travel impedance), and are frequently found in the literature on geographical access to health services. Distances can be measured as straight lines, or weighted in terms of time or financial cost. Such distance measurements are often used alone, without reference to the supply dimensions of access such as service size and choice, which also influence the use of services. Such methods can be used to answer a different set of questions about accessibility, as distances to services both inside and outside the study area can be measured. However, transport networks are not considered, with straight lines between demand and supply locations representing travel paths. Although shorter journeys and urban areas seem less well described by these measures, little is known about the circumstances in which straight lines are not a useful representation of travel patterns (Fortney, Rost, & Warren 2000; Phibbs & Luft 1995) and they provide no information about how easy it is for those within that area to travel

Modelled networks can be used to answer more specific questions about accessibility, giving an idea of travel distances along transport networks. Networks can be modelled without incorporating any changes over time, but models that incorporate some estimate of the effect of time can be used to add further detail to estimates of accessibility. At the far right of figure 26 models of geographical access combine the measurement of travel impedance (the friction effect of distance) with estimates of the supply and attractiveness of services to produce a spatial picture of the likelihood of visiting a particular location, whether that is a shop, a hospital or some other opportunity. These models can give highly specific information about individuals' journey patterns, but little generalisable information about the accessibility of services to a wider population.

Identifying the appropriate balance between specificity and generalisability is key to selecting an appropriate model of accessibility. The work described here comprises only one aspect of the measurement of accessibility: the measurement and interpretation of travel impedance. No measurement of the attractiveness or the use of health services is attempted, but a transport network is described and modelled and transport-specific journey calculations are made.

As stated in chapter one, accessibility is a complex and multifaceted concept, which means different things to different people. In addition to thinking of models of accessibility along a continuum – from those used to answer general questions about area characteristics to those suitable for investigating very specific circumstances such as individual travel patterns – models of accessibility can be divided based on what aspect of accessibility they measure. Five categories of models of accessibility are given in table 23, and discussed in the following section in terms of their conceptual background, applications and limitations.

Table 23: What do models of geographical access to services measure?

	Interconnectedness	Supply	Distance	Time
Graph theory	✓	X	X	X
Supply based models	X	✓	X	X
Distance models	X	X	✓	X
Spatial interaction models	(✓)	✓	✓	X
Time in accessibility measurement: space-time models, dynamic networks and PTI systems	(✓)	(✓)	✓	✓

7.2.1 Graph theory

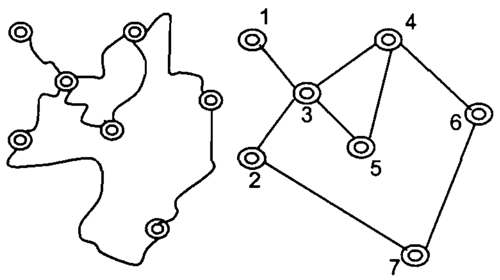
Some of the earliest models of spatial accessibility were based on graph theory and the interconnectedness of locations. Networks can be expressed as graphs, where topology, or pattern or interconnectedness, is important but the length and orientation of the links are unimportant, or as matrices, allowing matrix algebra to be applied to their analysis. The number of links between vertices can be counted, or presenting networks in matrix form can generate a record of whether any vertex is linked to any other.

The number of links in the network and the number of nodes in the network are the two basic measurable features of network structure using graph theory. The shortest path between two nodes in the network, measured as the number of links that must be traversed, is a measure of the integral accessibility of a node. The whole network can be described through the *diameter* of a graph, defined as the maximum number of links in the shortest path between any two nodes, and the *dispersion* of the graph: the sum of all of the elements in the shortest path matrix (figure 27).

Figure 27: Diameter, dispersion and accessibility of nodes in a network

Based on diagrams in (Haggett & Chorley 1969)

Transport Graph



Connectivity matrix with accessibility indices for nodes

	1	2	3	4	5	6	7	Row sum
1	0	2	1	2	2	3	3	13
2	2	0	1	2	2	2	1	10
3	1	1	0	1	1	2	2	8
4	2	2	1	0	1	1	2	9
5	2	2	1	1	0	2	3	11
6	3	2	2	1	2	0	1	11
7	3	1	2	2	3	1	0	12
Col sum	13	10	8	9	11	11	12	74

Row (or column) sums give the integral accessibility index for each node
Diameter = 3
Dispersion = 74

Such models are abstract and allow complex networks to be represented and compared, but both diameter and dispersion are directly affected by the size of the graph, limiting the usefulness of graph theory in comparing networks of different sizes. Nothing is known about travel times through the network or about the attractiveness or otherwise of any one destination, and the relative accessibility of one place compared to another is not considered.

7.2.2 Supply based models

From a different perspective, accessibility can be thought of without reference to networks or interconnectedness of transport systems. Measures of geographical accessibility in this group do not measure distance, but express geographical accessibility through the supply of services to a defined area or population. These measures have been summarised as 'supply-based contained-area' and 'supply-based partial-travel' studies (Connor, Kralewski, & Hillson 1994).

The most basic supply-based measure of access is whether there is a provider (such as a hospital or GP surgery) within an area or not: areas with a provider are described as having better access than those without one. Slightly more complex is the ratio of providers to population, with the additional information about the size as well as the presence of a service. Finally, supply-based measures include the 'cumulative opportunity' measure, or 'choice set', quantifying geographical access by counting the number of services available within a pre-defined area. Good access is associated with a higher number of services, poor access with fewer.

Supply has frequently been used to describe access to health services, either by calculating the supply per head of the population (for example the supply of vascular services in the UK (Arora et al. 2000)) or, more often, by simply determining the presence or absence of a supplier in a set geographical area (for example, access to coronary revascularisation facilities in the UK has been expressed in terms of supply factors (Black, Langham, & Petticrew 1995), as has access to GPs (Jones, Bentham, Harrison, Jarvis, Badminton, & Wareham 1998)).

These measures are easy to calculate and to understand, providing an area-wide estimate of access, but are very vulnerable to boundary problems: many people travel across area boundaries to reach health services, and providers serve a larger population than that of the area in which they are based. They can be improved somewhat by the introduction of estimates of cross-border flow, but essentially assume that accessibility is the same for all residents of an area, from the very closest to a facility to the very furthest away. They are appropriate for answering questions where decisions are not influenced by small-scale variations in accessibility, such as whether more staff or facilities are needed within a region, and can be thought of as being at the 'general' end of the spectrum of general to specific models shown in figure 26.

Models incorporating some measure of distance can provide information about variations in relative accessibility on a smaller scale, differentiating between places with good and poor access within an area.

7.2.3 Distance models

Distance models occupy a middle ground in the spectrum of general to specific accessibility. The distance between two points is one of the methods most commonly used in studies of geographical access to health services, and is the type of access measurement used throughout this thesis. Distance can be measured as a straight line between two points, as distance along the road network, or as travel time. The measurement of the distance between supply and demand points is one of the most frequently cited elements of geographical accessibility, and its measurement ranges from the simple to the sophisticated.

Models that rely on the measurement of impedance as straight-line distances, measured between the centre points of small areas such as postcodes, zip codes or census areas, predominate in the health literature. For example, access to renal replacement therapy in the UK (Boyle, Kudlac, & Williams 1996), to abortion services in Washington state, USA (Dobie, Hart, Glusker, Madigan, Larson, & Rosenblatt 1999), to primary medical care in Colorado, USA (Fryer, Drisko, Krugman, Vojir, Prochazka, Miyoshi, & Miller 1999), or to cardiac surgery providers in north America (Grumbach, Anderson, Luft, Roos, & Brook 1995) have all been measured using the straight-line distance between patients and providers.

The calculation of straight-line distance is easy, requiring relatively little data, and is intuitively easy to understand and to compare different locations, but is limited in its ability to describe accessibility. Firstly, distance provides no information on the attractiveness of destinations (for example their size, opening hours or reputation). Furthermore, it is likely that distance will have a different impact on different groups, given the variations in transport available to overcome barriers of distance, in the ability to meet the both time and financial costs of travel and in the real and perceived need for services. Straight-line distances do not consider the influence of the transport network – the connectivity of locations, the speed of transport links or the availability of transport will all influence travel impedance. Such models will underestimate travel impedance in some areas more than in others and are therefore most appropriate for answering questions where small variations in access are unlikely to be significant. Models which calculate impedance based on distances along the underlying transport network are more appropriate than straight-line measures when small scale variations in access are considered, but do not differentiate between areas where networks are fast and slow.

Alternatively, measures of impedance based on the journey time or cost can be applied to the network. Travel time is a more complicated measurement to calculate than straight-line distance, requiring more data, but can differentiate between fast and slow routes to services and is seen as a more realistic measure of the geographical barriers people face than straight-line distance. Static models of access may generalise transport networks by creating a cost-surface, applying time or cost values to rasterised cells on a surface, or may use vector links between points to represent travel paths. Travel time, usually calculated from car travel speed, has been used as a distance measure in several studies of access to health services (see, for example Cosford, Garrett, & Turner 1997; Fortney, Rost, Zhang, & Warren 1999; Goodman, Fisher, Stukel, & Chang 1997; Goodman, Barff, & Fisher 1992; Lovett, Haynes, Sunnenberg, & Gale 2002; Martin, Wrigley, Barnett, & Roderick 2002). Although travel time appears to be a more accurate measure than straight-line distances, and a more direct and appropriate measure of true impedance than network distances, it neglects the availability of transport. Transport-specific travel time is a little used measure of geographical accessibility, but measures of impedance based on travel by different modes of transport can be calculated if appropriate data are available. Travel times by bus have been used to describe access to health services, but infrequently (for example Burgy & Hafner-Ranabauer 1998; Lovett, Haynes, Sunnenberg, & Gale 2002; Martin, Wrigley, Barnett, & Roderick 2002), possibly due to the difficulty of obtaining up to date timetable information with which to assign speeds to transport links.

7.2.4 Spatial interaction models

Literature on access services other than health care (such as retail opportunities) has taken the measurement of geographical accessibility a step further, using more complex spatial interaction models in preference to simple distance measures. The simplest of these models are the gravity models, which combine the measurement of supply and of distance in an attempt to explain the use of services. Opportunities are weighted by distance (the closer a destination is, the more it contributes to accessibility). Accessibility is therefore measured as $A_i = \Sigma\ S_j d_{ij}^{-b}$, where accessibility at point i (A_i) is a function of the size of opportunity j (S_j) and the distance from i to j (d_{ij}), with the effect of distance expressed through a constant (b), usually estimated as a reciprocal or an exponential function, or as a modified normal distribution (Ingram 1971). Although common in other disciplines, gravity models are rarely used to describe access to health services (although the use of emergency departments has been examined using gravity models (Congdon & Best 2000; Roghmann & Zastonny 1979)).

This impedance function is usually a negative exponential, but this has been criticised as a poor representation of travel behaviour and a number of other functions suggested, including the normal (Gaussian) distribution and a reciprocal function (Ingram 1971). Linear functions are not used in gravity models, although distance measures of access are often entered into models of the use of health services as a linear effect. Other measures have added complexity to the gravity model, including population size and demand (Joseph & Bantock 1982) and the more complex measures of attractiveness such as the Hansen measure and log-sum measure (described in Martin & Williams 1992) and Economic Potential (described in Vickerman 1974). These measures help to predict the use of services and add a further dimension to the measurement of geographical access.

7.2.5 Time in GIS and accessibility measurement

Time is an often neglected element of accessibility. Time-space models look at the relationship between travel impedance and personal time budgets, but are limited in their usefulness for explaining wider relationships between geographical accessibility, time and the use of services as they rely on detailed personal information and occupy the 'specific' end of the spectrum of models shown in figure 26. When considering the measurement of geographical access in terms of public transport, time becomes an important factor. Other measures of travel impedance such as straight-line or road distance are independent of time, at least in the short term, and calculations of travel time by car can be made with little thought about the influence of time beyond the possible influence of rush hour traffic congestion. Modelling a system such as a public transport network, that changes both spatially and temporally, is a problem in GIS that has not been fully solved.

7.2.5.1 Public transport networks and time

Describing a transport network formed by public transport services is very different to describing a network formed by roads. The biggest difference is that the road network can be used at any time, whereas the public transport network only 'exists' when a service is running on it. The road network can be described independently of time without excessive loss of information (although there will be differences in travel speeds at different times of the day). The public transport network will, however, differ enormously by time of day, often barely existing in the evenings and at night, but relatively fast and consistent at other times of day.

7.2.5.2 Static and dynamic models

A static model of a road or other network can be made more or less specific by adding detail about the time (of day or year), about road conditions or transport availability, but essentially models accessibility for a whole area (be that a postcode, a PCT area or a wider area such as a county), generalised over a range of times (whether that is days, years or an unspecified time). However, in public transport systems, different networks exist for every minute of the day, and between every pair of origin and destination points. This most specific end of the spectrum of models of accessibility can be described through dynamic network models. These models allow specific journeys to be represented, containing data about dates, times and routes and, in the case of space-time models, about individual time budgets and commitments that restrict the options available to an individual. If areas rather than individuals are to be compared and a summary measure of accessibility produced, such dynamic network models are too detailed. Generalisations are not possible: the purpose is to plan an individual trip. Some summary of the dynamic network must be produced.

7.2.5.3 GIS technology and the representation of time

Dealing with the representation of time in GIS is a problem that has not been fully solved. In the case of measuring access to health services, it is not the changes over time themselves that are of interest, but the accessibility of services at different points in time.

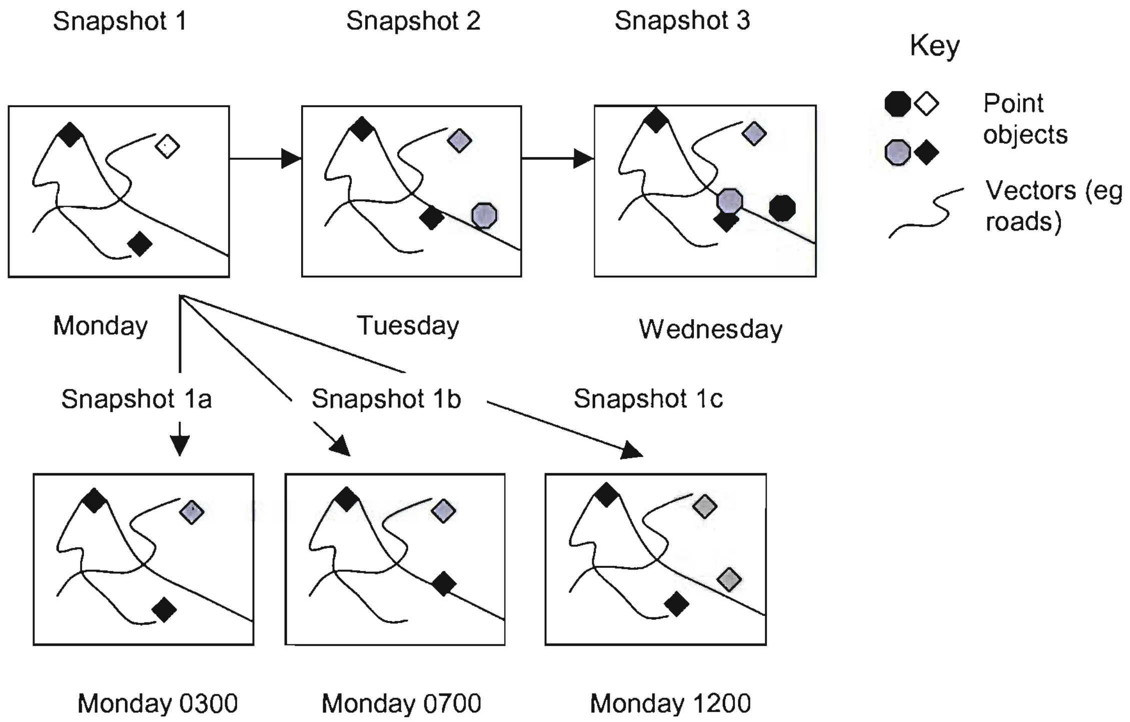
Within conventional GIS technology, data layers are used to display information. It is possible to create a series of layers which are each snapshots at a specific time, and which show the attributes of the same geographical space at a series of points in time. The more frequently changes happen, the more snapshots will be needed to represent reality, but the time lag between each snapshot need not be the same, and any number can be taken.

The problems with the snapshot approach are that:

- The data volume increases enormously as the number of snapshots increases
- Important, but short-lived, changes may take place between snapshots
- The time at which an individual change happened cannot be inferred from a snapshot
- Most areas will not change between snapshots, resulting in unnecessary duplication of data

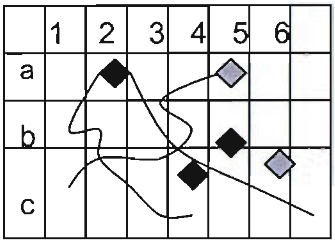
Figure 28 gives an impression of changes over time in a set area, with three 'snapshots' on consecutive days showing that the road network remains unchanged while the surrounding features change, and three 'snapshots' within a single day showing how some states would be missed by a daily recording.

Figure 28: time in GIS as a series of 'snapshots'



A modified version of this approach records a history for each cell on the grid of the data model. The history of changes to each cell is stored as a list, sorted in temporal order for each cell, as represented in figure 29. The recorded state for each cell can then be retrieved for any time, effectively producing a series of layers without all of the repetition of data that is needed for the creation of snapshots.

Figure 29: time in GIS as data about grid cells



Associated database

	Time of day (Monday)		
Cell	0100	→	2400
1a	[No change]		
...			
4a			
4b			
4c	-	0600: remove data	0945: add data point
5a			
5b		0530: add data	0930: remove data point
5c	[No change]		
6a			
6b			
6c			1130: add data point

Alternative models of time in GIS concentrate on the changes to objects (such as roads), rather than to locations (as in layer-based models). These object-based models have been called 'amendment vectors' (Langran 2005). For example, roads (represented as vectors) may be built or removed over time. The time when a change takes place can be recorded as an attribute of the vectors representing the roads and the data noting the time and nature of a change are stored in the GIS database. This approach works for tracking changes to spatial features, but becomes more complex as the number of changes, and hence the number of amendment vectors, grows. It is also difficult to link changing spatial features within the GIS to (also changing) non spatial features, which are usually stored in a separate relational database.

In the case of describing public transport access to health services, accessibility will change over time, both in the short term as buses arrive at and leave different stops, and in the longer term as services are introduced or discontinued on different days of the week or at different times of the year. Modelling such cyclical time changes adds complexity to the task of representing networks that change over time.

7.3 The measurement of accessibility: a pilot study of public transport access

The research questions posed by this thesis consider the possibility of making a journey from all parts of Cornwall to one of the two DGHs serving the county: the Royal Cornwall Hospital (Treliske) in Truro, and Derriford hospital in Plymouth, Devon. The objective of the analysis of access to health services in the south west of England, as set out in Chapter 1, is to describe the distribution of health services, locating areas which are distant from hospitals, and identifying areas where poverty and deprivation indicate a high need for health services and where those who have no access to a private car are likely to experience very different levels of access to services than would be expected if transport mode is not taken into account. A model of access that makes it possible to:

- describe access to health services in the study area by both public and private transport
- compare the measures and note areas of disagreement between them
- compare access measurements to deprivation and other measures of the need for health services
- compare access measurements between area types such as rural and urban areas
- locate areas where it is or is not possible to attend an appointment by a given time of day using public transport, and to
- locate areas where it is or is not possible to use public transport to make a return trip on the same day to attend an appointment

is therefore appropriate. A static network that uses travel time by public transport along the road network as the measure of impedance can be compared with a similar model that uses travel time by car as the impedance measure. Different models can be created for different times of day or year to answer questions about the possibility of reaching a destination by a certain time.

The balance between detail and generalisability is key to choosing an appropriate model of access. The detail of individual travel times under specific circumstances provides little in the way of generalisable information and is best left to transport planning systems. However, ignoring or averaging out travel speeds and the availability of bus services over different times of day will obscure the features of accessibility which are of most interest in determining the equity of access between travel by public transport and travel by private car. While noting every change in the network over the course of a day, a week or even longer times is data intensive and unnecessary, the development of different snapshots of access under different circumstances is necessary to illustrate the variability in access over time. Selecting appropriate snapshots is important, and recognising that they are snapshots, and that they conceal considerable amounts of information on micro level changes in access, is vital.

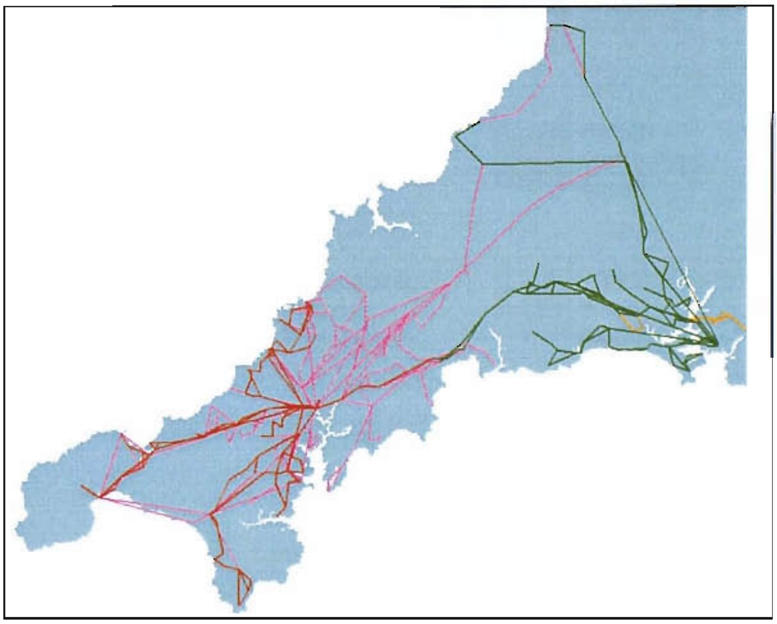
Travel time has been considered the 'gold standard' measurement of the impedance of distance, and models of dynamic networks are excellent for providing answers to questions relating to individual journeys, but provide no opportunity to generalise about an area or its population. Achieving an appropriate balance between generalisation and specificity is essential when modelling access to services. A model which bases the measurement of access on the transport network but which selects a single (representative) point in time, allows generalisations to be made about an area. Specificity can be achieved through using different impedance values along the network, and through allowing different models to be created for different transport types, differentiating between those people who can travel quickly and easily and those for whom mobility is likely to be a problem. An appropriate level of resolution makes it possible to observe differences between areas at without excessive intra-area variability.

The methods described here extend the previous work developing models of car travel time to health services, described in Chapter four (section 4.2.3.3), and were developed to pilot the use of paper timetable data in estimating public transport access to health services (Martin, Wrigley, Barnett, & Roderick 2002).

Bus links were taken from the Cornwall Public Transport timetable for 1999/2000. Only routes serving the two hospitals of Derriford, in Plymouth, and the Royal Cornwall, in Treliske, or the towns of Truro and Plymouth were included. Routes from any bus stop in Cornwall to these two hospitals were included in the model, providing that no change of bus was necessary to make the journey. This was a pragmatic decision, based both on the quantity of data and the likelihood of more complex journeys being impractical and less likely to be undertaken. All the named bus stops along each route to these destinations were identified from the timetables and assigned a six-figure grid reference using online gazetteers such as http://www.multimap.com.

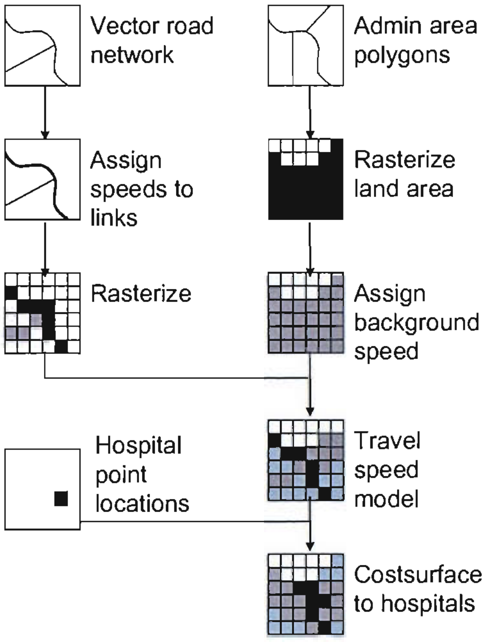
The bus routes were imported to Arc/Info as a series of straight-line segments between bus stops (n=764), as no data on the actual routes followed were available (figure 30).

Figure 30: bus routes in the pilot model



The total journey duration and the time taken to travel between each pair of stops, the number of services a day and the first and last journey times were all recorded from the timetables, allowing the speed at which each segment of a journey was covered by the bus to be applied to the links. The vector links were then rasterised to the same $200m^2$ grid as the road network, and a background walking speed of three kph was assigned to all cells not containing a bus route. The model is represented in figure 31. The main difference between this model, and the previously presented road speed model (figure 10) is the absence of the urban grid layer in the bus model, as bus journey times take account of urban traffic congestion. The background speed in the bus model is slower than that in the road speed model at three kilometres per hour, representing walking speed rather than a slow driving speed.

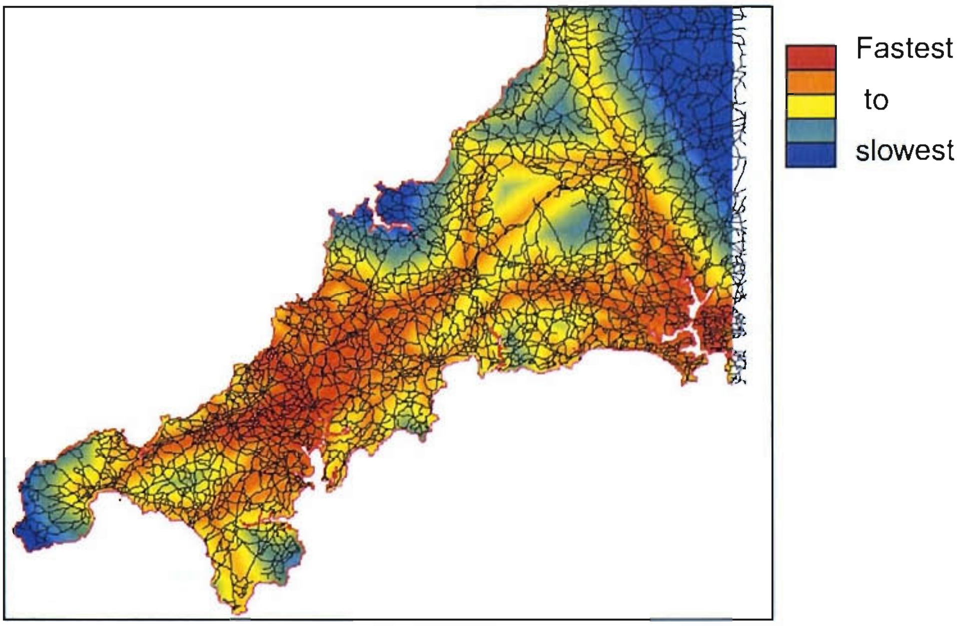
Figure 31: Modelling bus travel time to health services



Source: (Martin, Wrigley, Barnett, & Roderick 2002)

From this model a travel cost surface can be produced, which clearly demonstrates the location and speed of the bus links and their effect on the surrounding area (figure 32)

Figure 32: Cost surface of travel by bus in Cornwall



This initial use of paper timetables for bus routes in Cornwall as the data source for the public transport access model demonstrated that it was possible to create a travel time model with travel speeds based on public transport networks (Martin, Wrigley, Barnett, & Roderick 2002).

Paper timetables are, however, limited in their usefulness for this type of application for a number of reasons. The first group of limitations are a consequence of the need to transcribe paper records to an electronic data format. This is a time consuming and laborious process, and prone to errors in data entry, and the time taken to enter and check data severely restricts the size of area that can be covered by this kind of model. Also, data entry constraints restrict the complexity of the networks which can be represented – for example changes of bus service or of travel mode were not included in the first model, and issues of network changes over time were not addressed: a single surface was produced, which combined all bus journeys happening at any time. Such a result significantly overestimates the speed and ease of travelling by public transport.

Secondly, there are limitations due to the assumptions built into the model. These are significant, and must be held in mind when interpreting the results of the model. When creating the vector data layer containing bus travel information all routes included in the network were assumed to operate constantly. Travel along a route was not linked to the time of day or to the day of the week. Services that only operated on a single weekday or on the weekends were excluded from the network entirely; all other services were assumed to run all of the time. No distinctions were made between different bus routes – all routes were assumed to interconnect at all the nodes (bus stops) on the network. The network was limited to bus journeys which started or ended either at one of the two hospitals in the study area or in the towns containing those hospitals. Also, the locations of bus stops are known, but not the location of the routes connecting the stops. Straight-line segments were therefore used to connect bus stops.

Finally, when creating the cost surface the vector network was rasterised: no individual routes were retained and the travel speed over the landscape was determined solely by the presence of any bus running at any time in any direction. The grid references of postcodes were used to assign the population to locations and it was therefore assumed that people had to walk from a postcode centroid to a bus stop. Travel from postcodes to bus stops was therefore calculated as a walking distance, at a walking speed of 3 kilometres per hour.

7.4 Conclusions

Electronic databases of transport timetable information (ATCO CIF files) have recently become available and provide an alternative source of detailed data on public transport networks, which may help to overcome some of the limitations of the initial model. In particular, the simplified way in which the public transport network, so heavily influenced by changes in service provision over time, is treated in this pilot analysis is possibly the most significant limitation of this approach. Despite excluding very infrequent services, the assumption that all other bus services run at all of the time makes this model of the public transport network very much more like the (private transport) road network than is the case in reality. The ability to incorporate the influence of the time of travel as well as the speed and direction of transport links would be a major enhancement to the model and should highlight one of the most important differences between public and private transport access. Also the issue of connectivity – the pragmatic decision to exclude any journeys that required a change of bus (other than in Truro or Plymouth) will seriously limit the accuracy of accessibility estimates from the model. Both of these issues could be overcome with the use of more comprehensive data sets, which the advent of electronic timetable data can provide.

Chapter 8: Describing public transport access

8 Chapter overview

In this chapter I develop a measure of public transport access using electronic data. Using electronic files of public transport data has several advantages over the use of paper based timetable data. There are considerable time savings from not having to enter timetable data into databases by hand; moreover there is greater scope for analysis using the detailed information recorded in the electronic files – as well as the locations of bus stops and times of arrival and departure at each stop, information on where a change of bus service is possible and on days and dates of operation are recorded. This allows a model that is both larger and more complex than one based on paper timetable data to be built. A model using the available electronic format data could be used to determine the length of time a journey takes, the days or dates on which a particular journey could be made and could investigate journeys incorporating more than one bus route. This information could then be linked to the underlying population so that one could investigate the scale of and factors associated with accessibility.

The chapter describes the methods used to extract information from the ATCO CIF files of public transport data and to create a model of public transport access from the extracted information. I describe the data on which the model is based, the way in which the data were handled and reconfigured, and the nature of the model that was created. As an illustrative example of the accessibility of health services I then present data on access by public transport to two acute district general hospitals – Treliske, Truro and Derriford, Plymouth – from wards in Cornwall. These are the two acute hospitals that are accessible to the population of Cornwall for secondary care (for more specialised care it may be necessary for people to travel further, for example to Bristol, and this was not considered here). I compare journey times to hospital using private transport to journey times by bus, and describe the characteristics of the population of the most inaccessible areas. Finally, I outline the issues surrounding the development of a combined measure of accessibility based on a combination of public and private transport travel times and rates of car ownership.

8.1 Building the reader and the analyst

The availability of timetable data in electronic format is a recent development, and underlies initiatives such as web based timetable enquiry systems (for example Traveline, http://217.171.103.36/nbindex.htm). The UK Department for Transport (DfT) are currently (2004-5) using these files to construct a measure of public transport accessibility for the use of local authorities in assessing whether government targets on accessibility are being met (http://www.dft.gov.uk/stellent/groups/dft_localtrans/documents/page/dft_localtrans_033615.hcsp, accessed 22/04/05) but, as demonstrated by the literature review in chapter two, other than this little use has been made of electronic timetable data in measuring accessibility.

For this thesis, bus timetable data for the counties of Devon and Cornwall were obtained from the South West Public Transport Initiative (SWPTI), and were extracted from the database underlying the journey planning software on 10th November 2004. The data represent all bus services running in the two counties at that time. The data are arranged in 671 separate files, each file covering a single bus service. A previous data set, comprising just 183 files, was extracted in June 2003. This smaller data set was used for the majority of development work, investigating the structure of the data, creating and testing the computer programmes needed to read the information and restructure it into an appropriate format for the needs of this work.

For each service, the data are set out as a series of journeys. A standard interchange format – the ATCO CIF data format – was used for the supply of the data, and is described in more detail below.

In order to address our research questions it was necessary to convert timetable data into a more appropriate data structure, and to develop a software tool for this purpose. No standard software tool was available to read the data: although commercial route finding software is available, the resources to buy such tools were not available and, even if they had been, they are not appropriate to the tasks I needed to perform. The software tool had to be capable of conversion of very large numbers of journey enquiries without direct operator intervention, and of aggregating the results. In order to enable subsequent analysis involving changes between individual routes it is necessary for the software to assemble the entire set of individual route-based data files into a data structure representing the entire network.

Visual Basic (VB) was used to develop a program that would read the ATCO CIF data and output those parts of the data needed to describe accessibility. This program was named the '**ATCO Reader**' (the Reader). A further program was then needed which would take the output data and manipulate it, providing an estimate of travel time through the network. This program was named the '**ATCO Analyst**' (the Analyst). The specification, development and testing of the two programmes was conducted jointly with Professor David Martin. All of the Devon and Cornwall data preparation, testing and analysis presented in this chapter have been undertaken by the author using these programs. For the purposes of this study the Reader and Analyst were developed specifically to deal with bus timetable files, but they would be equally useful for describing any timetabled public transport system such as air travel, trains or ferry services, alone or in combination.

8.1.1 Data format

The ATCO CIF timetable data were provided as text files. Each file contains information on

- The grid referenced location of all the bus stops in a journey
- The operator (the bus company running each journey)
- The journey, identifying
    - Whether a stop is at the start, end or midway through a journey,
    - The time at which a bus arrives and departs from each stop,
    - Days and dates on which a bus service operates (including dates of bank holidays)
- Supplementary information such as whether a stop is one at which a change of bus service can be made, and the time needed to change between bus services.

Data from the ATCO CIF files can therefore be thought of as data on **bus stops**; **bus journeys** and **bus times**. Stops have a long name (such as "Opposite the Post Office, St Blazey"), a unique identification code and a grid reference comprising a six-figure northing (y co-ordinate) and a six-figure easting (x co-ordinate). Journeys are a slightly more complex concept, comprising a unique combination of a series of stops passed in a particular order. Along each bus route there will be one or more journeys made each day. The time at which each stop on a route is reached and the time at which the bus departs from that stop are recorded as timetable information.

8.2 ATCO CIF specification

A specification document, describing the file format in detail, was provided with the data (Appendix 1), and describes the exact locations of each item of data in the file. In summary, locations are presented as eight figure grid references, associated with a short (coded) form of the name of the bus stop and a long form of the name for the bus stop. For example, the record for Truro bus station is shown in table 24.

Table 24: ATCO CIF data example

Q	L	N	T	R	Y	3	8	4	2	2					T	r	u	r	o		B	u	s		S	t	a	t	i	o	n
Q	B	N	T	R	Y	3	8	4	2	2							1	8	2	8	0	0				4	4	7	3	2	

The short code form of the location is found on the line beginning QL, starts at the fourth column of data and continues for 12 characters, and again on the line beginning QB, in the same location (TRY38422____)
The easting is found on the line beginning QB, starts at the 16th column and continues for 8 characters (1828000); the northing starts at the 24th column and continues for 8 characters (_44732). The full text name of the stop can be seen on the line beginning QL, between the 16th and 64th columns of data (the table has been truncated).

8.2.1 Reading the data

Each data file was examined by the Reader to ensure it was an ATCO CIF file. The ATCO Reader then reads through the file, line by line, using the position of data items and the identifying letters at the head of lines to locate data. The first data extracted are details of individual bus stops. After details of each stop are read into the memory of the Reader, a check is made to see if this stop has been encountered before, or whether it is a new stop. Journeys were identified as a sequence of stops, and timetable data for arrival and departure at each stop were also read in. ATCO CIF files were added to the network data structure one at a time, and for each additional file stops, routes, journeys along routes and timetable data were extracted. When all ATCO CIF files had been added to the network database, four output files were written: stops; times; routes and index. The processing of the data is shown in table 25.

Table 25: Reading ATCO CIF data

CIF file in →

Checks format
Extracts all stops*
Extracts all routes
Extracts all times
Compares with the network so far
Identifies unique stops* and unique routes
Adds to the network data structure

Next CIF file

NB: stops separated by distances below the threshold of 50 metres, and which have similar names, were merged together and assigned to the same point on the network

8.2.1.1 Outcomes from the Reader

Each run of the Reader produces a single network database, which embodies all the connections between the routes. Every unique stop and route in the set of CIF files covering the two counties appears only once, and the lists are cross-referenced. The three lists of data produced by the Reader are summarised in table 26. Additionally, a log file is created which lists all the ATCO CIF files in the current network database.

Table 26: Output from the ATCO Reader

Stops file	**Routes file**	**Times file**
All stops in the data set with Name Code Location (six figure x,y grid reference) Routes served	All routes in the data set with List of stops served	All routes in the data set with Table of times at each stop in the route

This structure could be extended to include other forms of timetabled public transport such as air travel, trains, ferries etc, but for the purposes of this study only bus services have been included.

8.2.2 Analysing the data

The Analyst was developed with the objective of solving repeated journey enquiries from one or all of the stops on the network to one or all of the stops on the network. No consideration was given to aesthetics in terms of journey description, instructions, mapping or the user interface. The focus is on processing large numbers of journeys subject to a predetermined set of constraints and on recording basic information such as the time taken, the number of stops and the start and finish points of the journey in standalone long runs.

This is in contrast to the traveller-orientated journey planner software such as Traveline (http://217.171.103.36/nbindex.htm), or that used by the transport operators themselves – these are generally focused on fast answers to specific journey queries with detailed verbal and or cartographic instructions as output (for example the bus service number, waiting times, walking times, distances and directions which make up the instructions for completing an entire journey).

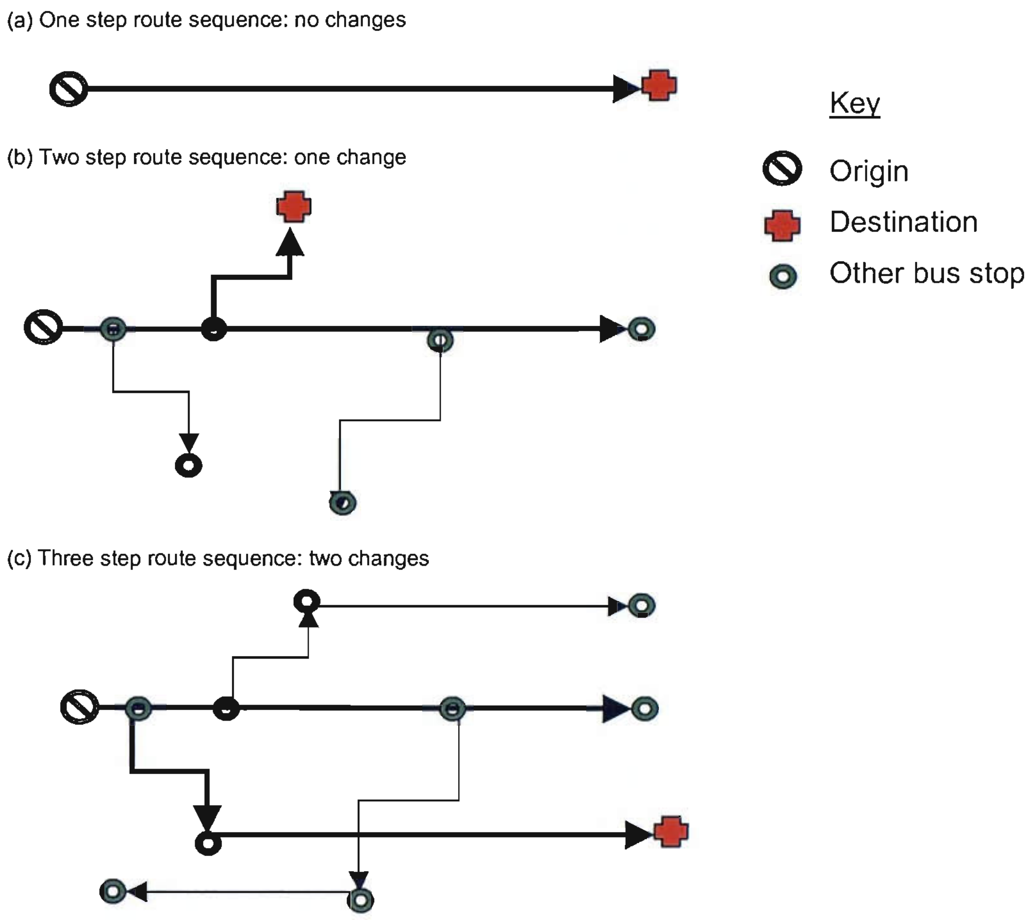
The Analyst's output is based on an analysis of the network database output from the Reader. Any journey within a single network database can be interrogated by the Analyst, hence it can only incorporate information processed in a single run of the Reader.

All journeys through the network database run 'FROM' an origin bus stop 'TO' a destination bus stop: for example from the village post office to a hospital. Journey parameters are specified by the research question: for example whether it is possible to arrive for a 10 am hospital appointment on a Tuesday. Other restrictions such as the maximum number of changes of bus service and the maximum duration of the journey can be entered into the Analyst and further refine the research question. The Analyst interrogates the network database produced by the Reader, checking for possible journeys between the FROM and TO stops along the routes in the database. If both stops are on the same route, the Analyst checks that the route can be travelled within the time, day and journey duration parameters specified. If it can, a simple route sequence is built. If the origin and destination stops are not on the same route, the Analyst extends its interrogation of the network data set. The network data set embeds the knowledge that changes from one route to another are possible: anywhere a stop occurs on more than one route is a possible interchange between bus routes. In theory, the Analyst could identify any possible route across the network if the parameters were set broadly enough. However, limiting the number of route changes and the journey duration is a pragmatic step, as with each additional route the workload for the program grows geometrically and processing speed is correspondingly slowed.

For any pair of stops, the Analyst first reads in the network database created by the Reader. The user sets the parameters of the question using a simple form window: the time of departure (or arrival) at the destination, the maximum duration of the journey, the time allowed for interchanges, the time window in which a journey can arrive at the destination, and the day of the week on which the journey must run. The Analyst then reads through the network database and discards any journeys that do not run on the selected day, reducing the size of the file for subsequent processing. For each bus stop in the database, the Analyst assembles a list of the routes that the stop is on – for example a large interchange such as a bus station may be part of many bus routes, a rural post office may appear on just one or two routes. The Analyst then interrogates the network database, searching for route sequences. Journey times are calculated directly from the timetable data, which contains the arrival and departure time for each journey passing through each stop.

For a journey from, for example, the High Street, St. Just to the Royal Cornwall Hospital at Treliske, Truro, the High Street is the origin ('FROM') stop and the Hospital is the destination ('TO') stop. If a bus service runs directly from the High Street to the Hospital, the origin and destination are on the same route, and the Analyst builds a simple sequence of the bus stops between the pair and returns the time taken to travel that sequence (Figure 33 (a)). If the High Street and the Hospital are not connected by a direct bus link, the Analyst extends the search of the network to routes that can be connected to from any of the stops on the High Street route. If the destination is on one of the 'one change away' routes, the Analyst builds a two-step sequence of the journey between the origin and destination, and returns the best time for that sequence (Figure 33 (b)). If the Hospital is not on any of the routes one change of bus service away from the High Street, the Analyst makes a further step and interrogates the database of routes a further change of bus service away from the High Street (Figure 33 (c)). The user sets the number of changes that are allowed: the main limiting factor is the processing time needed to run through increasingly data intensive scenarios.

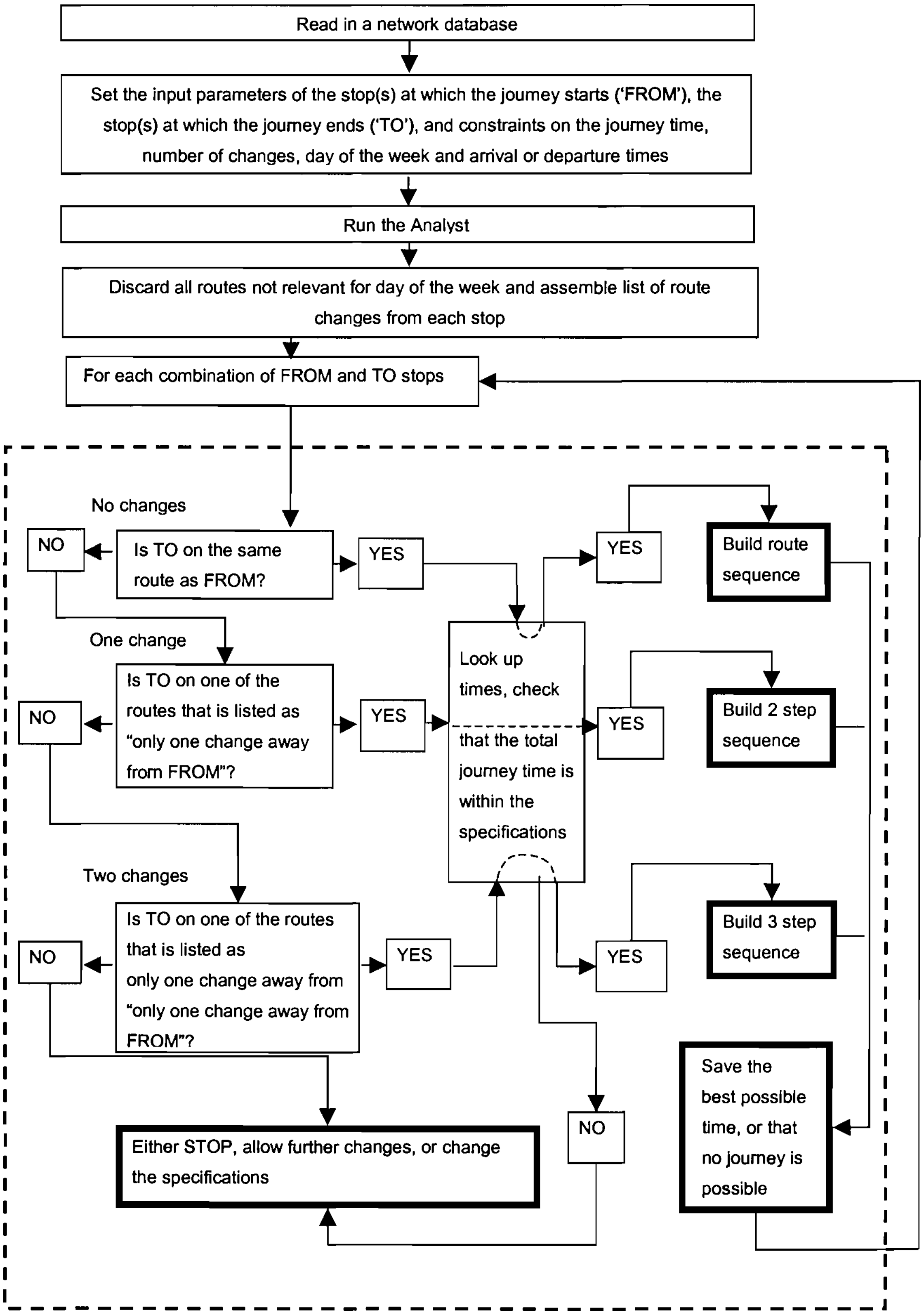
Figure 33: One, two and three step routes



Once a connection between the origin and the destination has been found, the best possible time for that journey is saved by the Analyst and written to an output file. If no connection is found within the number of changes set by the user, the Analyst returns the information that there is no valid journey between the origin and destination stops. The Analyst then returns to the next pair or origin and destination stops specified by the initial question. In the analyses for this thesis, travel from 'All stops' in the database to a single destination was specified – this resulted in 5677 pairs of origin and destination queries.

The process through which the Analyst builds up sequences of routes within the network is shown in figure 34.

Figure 34: route finding sequences in the Analyst



8.2.2.1 Outcomes from the Analyst

The Analyst generates a text file of data (the output file) which contains data identifying the FROM stop, its six-figure easting and northing, the TO stop (or destination) and its six-figure easting and northing, and the time taken to make the journey between the two points. The output can then be read into a GIS, such as Arc/Info and the grid-referenced information can be used to create data for public transport access to the destinations for different geographical areas. The output can also be used for a non-GIS analysis, as here – grid references can be linked to postcodes and then aggregated to wards.

8.3 Testing the programs using a synthetic environment

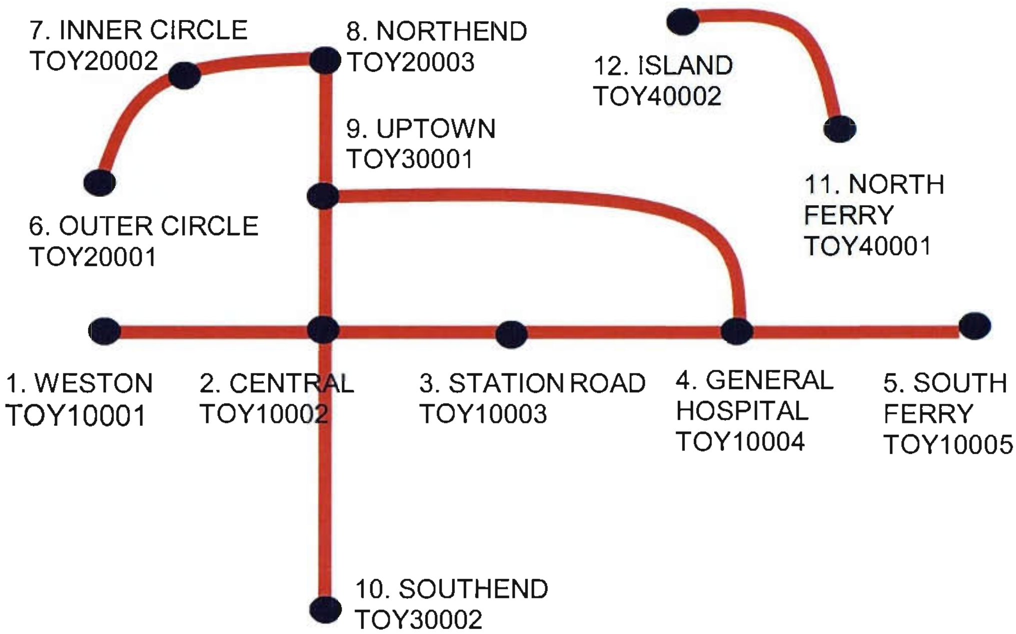
Once the structure of the Reader and Analyst had been developed, and the form of the required output had been decided on, the Reader and the Analyst were tested using a model environment. Using a simplified fictional network, all output from the Reader and Analyst could be checked by hand against the original data. A small area with a limited number of stops and routes was therefore invented, and named 'Toytown'. ATCO CIF files for these routes and times were constructed [Appendix 2], and used with the Reader and Analyst to refine the programs by setting different parameters for questions and extracting information about journey times around Toytown.

8.3.1 Describing the test environment

The simplified test environment is presented here to illustrate the steps involved in processing the very much larger and more complex Devon and Cornwall datasets on which the results reported later in this chapter are based.

Toytown comprises 12 bus stops, connected by 10 routes. A total of 35 bus journeys around the town along these routes exist, described by the map and timetables of figure 35.

Figure 35: the test environment of Toytown



Timetables

Outer Circle to Northend (Route 1)

Outer circle	0800	1000
Inner circle	0820	1020
Northend	0840	1040

Northend to Outer Circle (Route 2)

Northend	0900	1100
Inner circle	0920	1120
Outer circle	0940	1140

Northend to Southend (Route 3)

Northend	0830	0900
Uptown	0835	0905
Central	0840	0910
Southend	0845	0915

Southend to Northend (Route 4)

Southend	0845	0915
Central	0850	0920
Uptown	0855	0925
Northend	0900	0930

Weston to South Ferry (Route 5)

Weston	0800	0900	0930	1000	1100
Central	0805	0905	0935	1005	1105
Station Road	0810	0910	0940	1010	1110
General Hospital	0815	0915	0945	1015	1115
South Ferry	0820	0920	0950	1020	1120

South Ferry to Weston (Route 6)

South Ferry	0825	0925	1025	1125
General Hospital	0830	0930	1030	1130
Station Road	0835	0935	1035	1135
Central	0840	0940	1040	1140
Weston	0845	0945	1045	1145

Uptown to General Hospital (Route 7)

Uptown	0853	0903	0913	0923	0933	0943	0953	1003
General Hospital	0858	0908	0918	0928	0938	0948	0958	1008

General Hospital to Uptown (Route 8)

General Hospital	0859	0909	0919	0929	0939	0949	0959	1009
Uptown	0904	0914	0924	0934	0944	0954	1004	1014

North Ferry to Island (Route 9)

North Ferry	0855
Island	0900

Island to North Ferry (Route 10)

Island	0955
North Ferry	1000

8.3.2 Merging stops

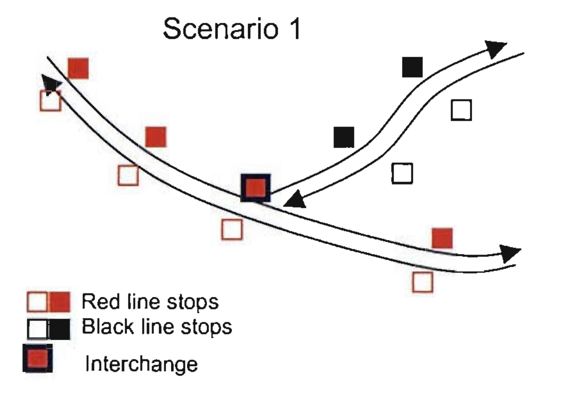
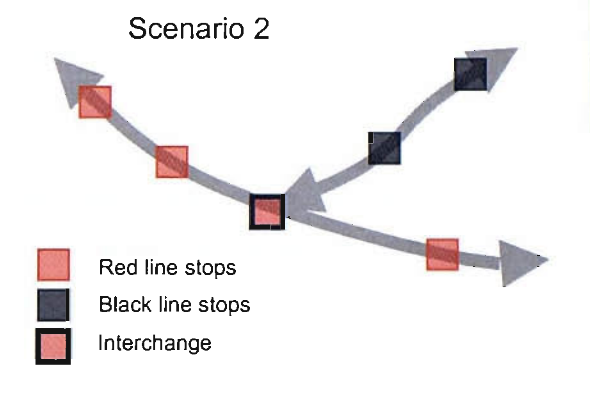
The initial conceptualisation of Toytown embedded the idea that it was possible to 'cross the road'. A single network, in which a single stop did service for both directions, was envisaged. As can be seen in figure 35, each bus route was shown as a single line, joining two stops. In reality, there are two (or more) traffic lanes in a road network – one (or more) for each direction of traffic flow – and bus stops are often on opposite sides of the road.

Where only a single stop had been used to cover both 'sides of the road', it was possible for the Analyst to find routes that required a change of direction on the network. When real world data were tested it became obvious both that there were often stops on opposite sides of the road and that it was not possible for the Analyst to identify routes in which a change between them was needed. Even though such stops were only a few metres apart in real space, in terms of the network they were on different paths, and no transfer between them was possible (interchange stops are a slightly different case: at these stops it is possible to connect with any other bus route which uses the stop - effectively they span the network, like an underground station connecting many different train lines. Interchange status is, however, a property of relatively few stops in the network, particularly major interchanges between many routes, such as bus stations).

Leaving the two sides of the road as separate networks would have meant that the Analyst would consider journeys that are entirely plausible on paper to be impossible, because of a short walk between stops on separate networks. Decisions about how long to allow for changes of bus service or waits for connections are part of the parameters in the Analyst, and give some indication of walking times. To disallow walking between stops mid-journey would therefore have been inconsistent. The decision to merge neighbouring stops, drawing the two networks together at those points, and effectively making neighbouring stops into interchanges, was therefore taken. If stops were 50 metres or less from one another (calculated using the grid references for each stop), and had the same long name as one another, for the purposes of creating the network characteristics they were assumed to be the same stop. Walking time between these stops was assumed to be zero, but the specification of an 'interchange time' gives some latitude for walking between bus stops to change services. When the Reader extracts data from the ATCO CIF files, stops that are less than the threshold distance apart and with similar names are merged to a single point.

The difference between the two possible models – with the stops unmerged (scenario 1) and with the stops on opposite sides of the road merged together (scenario 2) – is shown in Figure 36.

Figure 36: sides of the road and separate networks

 	
In this scenario it is possible to change between some red line stops (■)and some black line stops (■), using the interchange stop ■, but NOT to change your direction of travel on the red line (■ to □) or the black line (■ to □) or to change between the red line and the black line by going between ■ and □, □ and ■ or □ and □ stops	If stops on opposite sides of the road are merged, it is possible to change direction of travel along either line at any stop, and to change from ■ to ■ stops by using the interchange stop ■ regardless of the original direction of travel

A similar problem emerged when identifying the bus stops at the two hospitals in the study area. All origins and destinations in the Toytown model had been represented by a single bus stop. DGHs, however, are large and cover a considerable land area, and can be served by several bus stops. Although all of these stops can be described as 'the hospital', they may lie on different networks, accessible by following different routes, at different times of the day or week. A 400 metre buffer was selected by searching the online planner Traveline (http://www.traveline.org.uk) for journeys to the two hospitals. The most distant bus stop selected by the journey planning software was between 300 and 400 metres as the crow files from the central hospital stop. All other bus stops within the same radius were therefore considered equally valid destinations for journeys to the hospital. Journeys to and from any possible hospital bus stop were calculated separately: seven stops within a 400-metre radius of Derriford Hospital were identified, and six stops within a 400-metre radius of Treliske Hospital. The information was then merged using another custom-written Visual Basic program, and the shortest travel time to any of the thirteen stops was selected to represent accessibility.

8.4 Setting the parameters

Once the design of the Reader and Analyst programs was finalised, the next task was to set appropriate parameters for modelling journeys to and from health services within the study area.

To prepare the way for comparisons of this work, which uses data only from Cornwall and Devon, with work to be carried out by local authorities across England, parameters were set to provide feasible journeys and to fit in with recent government policy objectives. Other journeys across the network may be possible, and even useful, but journeys involving many changes of vehicle, lasting for several hours or involving long waits to change vehicle are intuitively less likely to be used, and in themselves represent limited accessibility due to the inconvenience of making such trips. Many of the parameters were set as the result of subjective judgements, as no definitive standard for acceptable length or complexity of journeys by public transport exists.

8.4.1 Origins and destinations

From the origin of all bus stops in the data base the analysis asked whether it is possible to make the journey to (the closest of) The Royal Cornwall Hospital (Treliske) in Truro, Cornwall and Derriford hospital in Plymouth, Devon by public transport. Valid journeys were selected under constraints of maximum journey duration, day of the week, number of changes of bus service and arrival and departure times, and the time taken to make each valid journey was extracted from the network database.

8.4.2 Journey duration

Realistically, any measurement of accessibility should take into account the time which people have available. The space-time approach to accessibility (discussed in more detail in section 7.2) takes account of individual time budgets, but it is difficult to summarise such measures, as specific individual cases must be considered. For this analysis I have assumed that people are not willing to spend more than 45 minutes travelling to health services by bus, though a further fifteen minutes are allowed to walk to the bus stop. This constraint was chosen to reflect the standards put forward in a recent government report (Social Exclusion Unit 2003). It is important to remember when interpreting the results that different people will have different time budgets and the parameters of the program can easily be changed to reflect this, the only constraints being processing time and computer memory limitations. A single time budget for all people is, however, not an unrealistic option, reflecting the importance of attending hospital appointments and the lack of flexibility open to individuals in deciding when to attend (a situation that may change to some degree with proposed changes to the NHS in England such as e-bookings and measures to enhance patient choice).

8.4.3 Day of the week

Analyses were restricted to bus services running on a Tuesday. This reflects the day of the week chosen by the DfT for their assessment of whether government targets on accessibility are being met. Access by public transport at the weekends was not considered. Weekends are likely to have different patterns of accessibility to week-days and, as with the other parameters, subsequent analyses using the same data and software could readily be carried out.

8.4.4 Changes of bus service

Two changes of bus service were allowed. This was a pragmatic decision, based on both the long processing time for more complex journeys, and the perceived difficulty of making journeys involving more than two changes. A two-change (three bus service) journey would allow a local journey to a major interchange or transport route, a change to undertake the main part to the trip and a further change of bus service for a final, local, journey – for example from a bus station to a hospital.

8.4.5 Other parameters

Arrival at hospital was set at 10 am. This was selected to fit in with outpatient clinic times which, at the Royal Cornwall Hospital (Treliske), run from 9 am to 4.30 pm with a break for lunch (personal communication with the hospital switchboard, 22/10/2004), allowing patients to arrive in time for a hypothetical morning outpatient appointment.

To lessen the impact of observed waiting times on journey duration, all journeys were set within a 120 minute window. Initial tests on the Toytown data set had raised the question as to whether waiting time penalties should be incurred for waits at the end of a journey (ie between arrival at the destination and the stated journey arrival time tested for). Allowing arrival at any time within a 120 minute window and setting the maximum journey time to 120 minutes allows a journey scheduled to arrive at 10 am to arrive any time between 8 and 10 am without incurring a wait penalty of the time elapsing between arrival and 10 am, as shown by the bottom line of table 27.

Table 27: Scheduled arrival times and 'waiting' penalty times for hypothetical 20 minute journeys, arriving for 10 am

Arrival time	8am	8.30am	9am	9.30am	10am
Journey (travel) time	20 minutes	20 minutes	20 minutes	20 minutes	20 minutes
End of journey 'waiting until 10' penalty without time window	120 minutes	90 minutes	60 minutes	30 minutes	0 minutes
Combined journey time without time window	140 minutes (no valid journey)	110 minutes	80 minutes	50 minutes	20 minutes
End of journey 'waiting until 10' penalty with time window	0 minutes	0 minutes	0 minutes	0 minutes	0 minutes
Combined journey time with time window	20 minutes	20 minutes	20 minutes	20 minutes	20 minutes

Minimum waiting times at interchanges were set to five minutes.

8.5 Creating the cost surface

The final stage in the journey time calculation was to aggregate data about journeys from individual bus stops to postcode locations and hence to 1991 wards.

First, the best journey time for every postcode was calculated. Comparing the grid references of bus stops and postcodes allowed the closest bus stop to each postcode to be identified. If there were no bus stops within a radius of 1.5km of a postcode, no further calculations were undertaken, as the postcode was considered too far from the closest bus stop for a valid journey to be made. If there was a bus stop within a 1.5 km radius, the time taken to walk the straight-line distance from the postcode to the bus stop was calculated at a walking speed of 3 km/hr, corresponding to the walking speed used in the pilot project described in chapter seven. A maximum walking time of fifteen minutes to the nearest bus stop was allowed. If the calculated walking time exceeded fifteen minutes no further calculations were made for the postcode. If the walking time was fifteen minutes or less, a five-minute wait was added to represent time to 'change' onto the first bus. The walking time and the waiting time were then added to the bus journey time calculated by the Analyst, resulting in a best journey time.

A household-weighted aggregation of postcode data to wards was then made. If less than 1% of the households in a ward belonged to postcodes with a valid journey time, the entire ward was assumed to have no valid bus journeys. Otherwise, the time for each postcode contributed towards the overall ward time in proportion to the number of households in the postcode (Table 28).

Table 28: Example of a household weighted aggregation of bus times from postcodes to wards

Ward	Postcode	N Households from each postcode in Ward1	Bus time from PC to health services (walk + wait + travel)	Households * time
Ward1	PC1	100	25	2500
Ward1	PC2	70	20	1400
Ward1	PC3	20	17	340
Ward1	PC4	60	15	900
Sum (Ward1)		250		5140
Household weighted average time for Ward1 ((hhds*time)/hhs) = 5140/250 = 20.6				

As with other elements of the journey time calculation, the parameters could readily be changed and are at present a matter of judgement: faster or slower walking speeds, or more or less time spent walking could be incorporated into the calculation, reflecting local knowledge, policy decisions or research evidence. These are all aspects which could be investigated by appropriately targeted research into patients' decision-making regarding transport to hospital, but are beyond the scope of this thesis.

Journey times to the two DGHs of The Royal Cornwall Hospital ('Treliske') in Truro, Cornwall and Derriford hospital in Plymouth, Devon were calculated in this way for all wards in the county of Cornwall.

8.6 Describing the wards in Cornwall by public transport access to hospital

The final aims of this thesis were to compare the different measures of access (straight-line distance, car travel time and public transport travel time); to explore the integration of measures of access based on public and private transport; and, if possible, to identify and describe those parts of the study area with the poorest access to health services using these measures. These aims are addressed in the following sections.

8.6.1 Valid journeys and ward averages for public transport access

The Cornwall dataset used for the calculation and analysis of public transport travel times is a subset of the larger 'South West England' dataset used elsewhere in this thesis. All wards in the county of Cornwall were selected from the original dataset for further analysis (n=133).

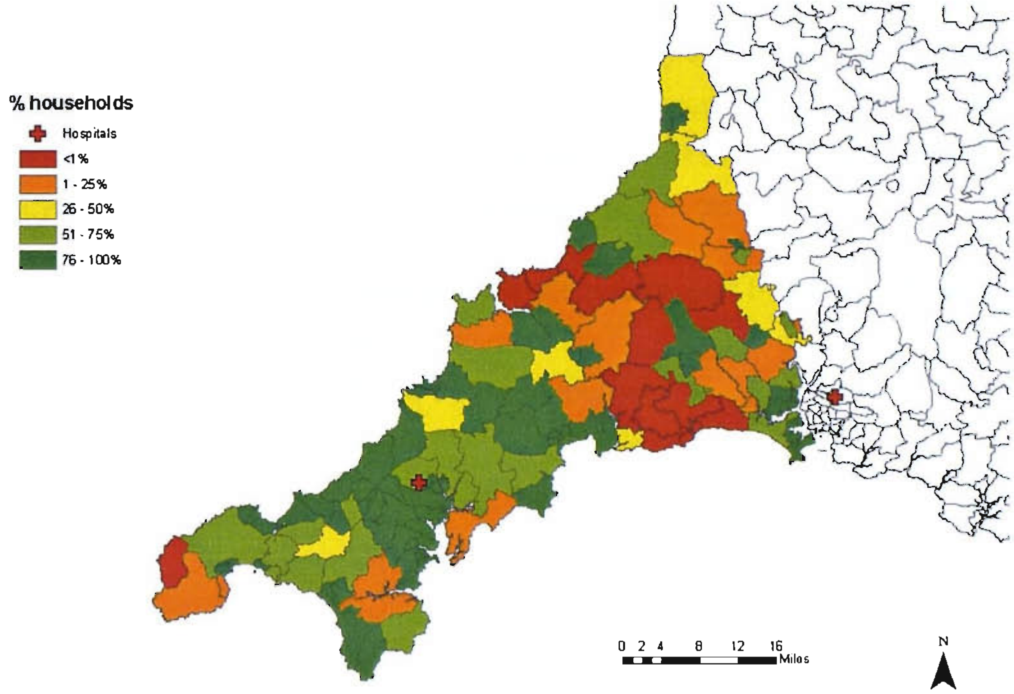
Over 90% of the wards in the study area could be assigned a bus travel time: in the others, less than 1% of households could make a valid bus journey and no average ward journey times were calculated. The 11 wards (8% of the total) for which no valid public transport journey time could be calculated have a population of 24,593 people, or just over 5% of the study area's population. Of the 122 wards where more than 1% of households *could* make a valid journey to hospital by bus, more than half of the households were able to make the journey in the majority – 96 wards. However, 18 wards have public transport journey times based on between 1% and 25% of households being able to make the journey (table 29), and this must be borne in mind when interpreting the journey times.

Table 29: Household journeys making up ward times for public transport access

Percentage of households with valid bus journeys	**>=90%**	**>=75%**	**>=50%**	**>=25%**	**>=1%**	**>=0%**
Number of wards	49	75	96	104	122	133
Percentage of wards **with valid times**	40%	62%	79%	85%	100%	n/a: no valid times
Percentage of all wards	37%	56%	72%	78%	92%	100%
Population	228,522	326,507	387,447	404,272	444,102	468,695

The majority of wards where very few households have a valid bus service available are in a line running from Padstow in the north, across the sparsely populated wards around Bodmin and down to the south coast between St Austell and Plymouth, but there are some areas of Land's End and some around Falmouth Bay on the South coast in which availability is also low (figure 37)

Figure 37: percentage of households in each ward able to make a valid (<65 minute) bus journey to hospital



8.6.2 Ward level access to secondary health services

Travel distances in Cornwall are higher than in the South West overall: the median distance from the centroid of the 1991 Census wards in Cornwall to the nearest of Treliske or Derriford hospitals was just under 22 km, with a maximum of 50 km, compared to just 12 km in the South West (section 5.2), and emphasizing the rurality of the county (table 30).

Table 30: Ward access to hospitals

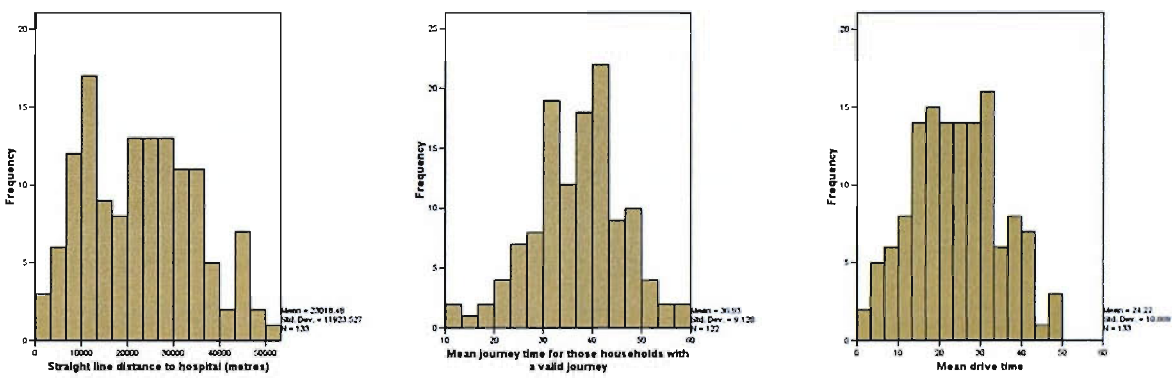
	25th centile	Popn (%)*	Median	Popn (%)	75th centile	Popn (%)	95th centile	Popn (%)	Maximum
Straight line distance	12.7	1.30 (27.8)	22.8	2.58 (55.1)	32.0	3.70 (78.9)	44.7	4.57 (97.5)	50.1
Drive time (all wards)	16.3	1.45 (31.0)	23.5	2.68 (57.3)	32.0	3.84 (81.8)	42.2	4.57 (97.5)	48
Drive time (wards with valid bus journeys)	15.7	1.39 (29.6)	23.1	2.47 (52.6)	30.5	3.54 (75.5)	42.9	4.32 (92.2)	48
Bus time (minutes)	31.8	1.16 (24.9)	37.5	2.34 (50.0)	43.0	3.66 (78.1)	50.9	4.31 (91.9)	59

**population (100,000) (percent of the total population) living in wards within this distance of their closest DGH*

The distribution of mean ward times and distances to hospital is not as positively skewed as the regional distribution shown in figure 12 (section 5.2). In Cornwall, drive times and straight-line distances are more normally distributed, with a less steep reduction in the number of wards at greater distances from hospital. Public transport journey times show a similar distribution, though with slightly more of a tendency than drive times towards longer journeys (figure 38).

Figure 38: The distribution of straight-line distances, bus times and drive times to hospital from 1991 wards

Straight-line distances | Public transport journey times | Drive times

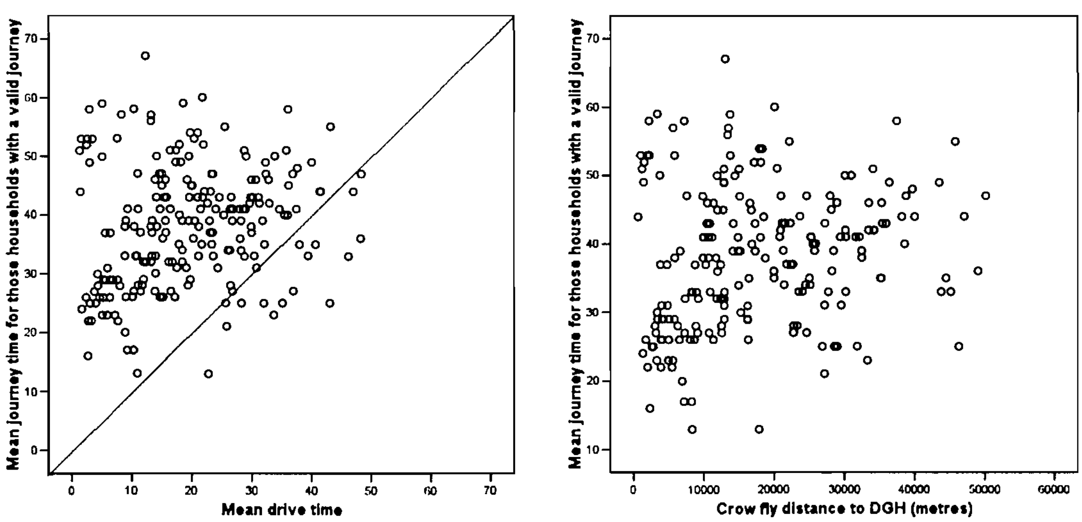


8.6.3 The relationship between public transport travel time and other access measures

To investigate how public transport travel times might differ from other measures of access, for all wards where a public transport journey time was calculable the public transport times were compared with drive times and straight-line distances, using correlation coefficients and regression analysis. Areas where the duration of journeys by public transport seemed to be over- or under-estimated by drive times were identified using the residuals from the regression analysis, and mapped to investigate the possibility of geographical clustering.

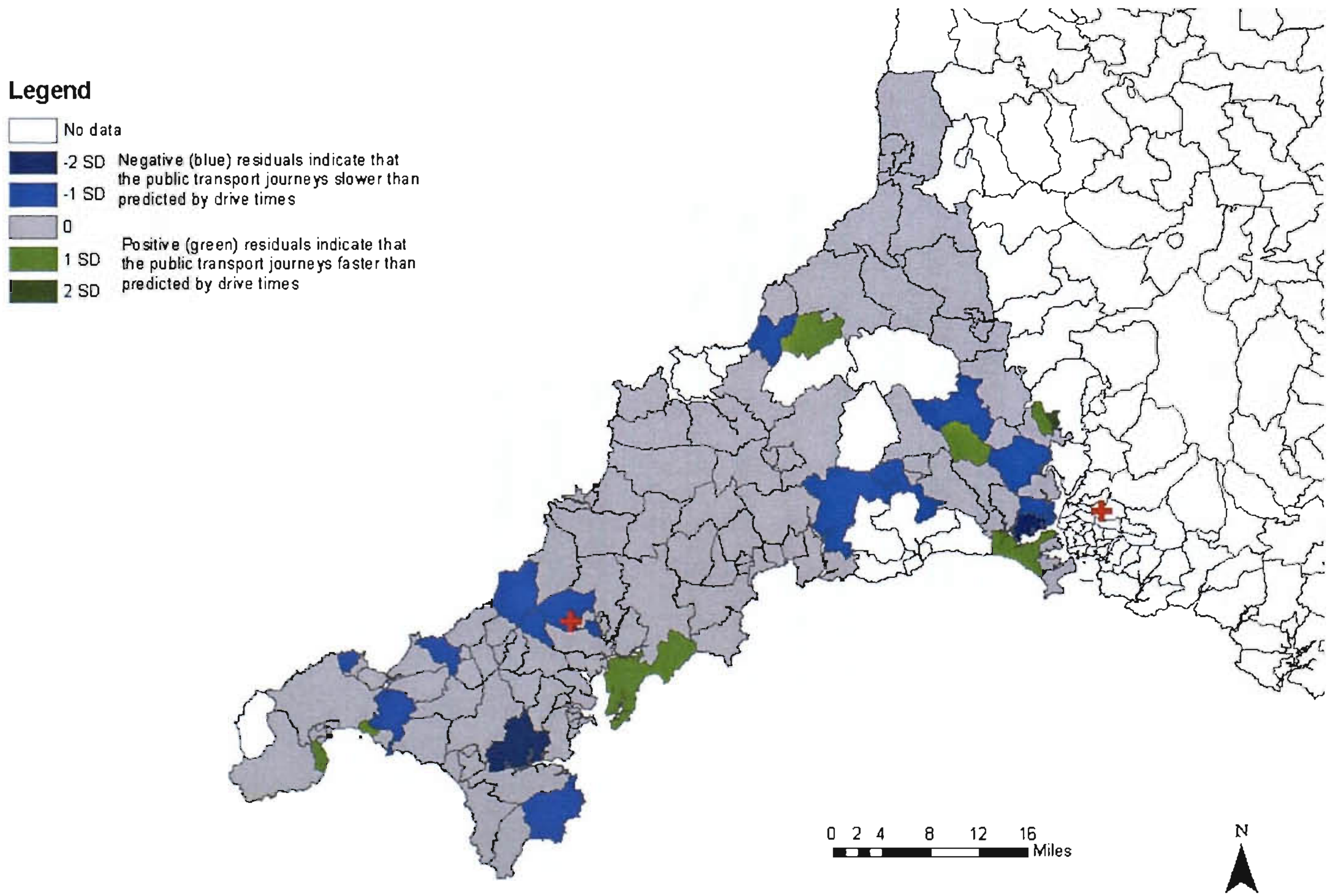
The correlation between the public transport journey times and drive times to hospital is weak. As the scatter plot in figure 39 shows, public transport journey times are systematically longer than drive times, but particularly for the shorter drive times: drive times of under 10 minutes can apply to the same wards as bus travel times of up to an hour. Conversely, a few wards have bus journey times faster than their drive times (below the diagonal line in the scatter plot), a finding which seems most likely to be an artefact of the assumptions made about drive time speeds. In reality, these very short journeys may be more heavily influenced by parking and access constraints (traffic lights, one way systems) than by actual driving times. The regression coefficient, r^2 (the proportion of the variance in drive time explained by public transport travel time), is just 0.035. The relationship between public transport journey times and straight-line distances to hospital is strikingly similar to that with drive time, with some long journeys completed remarkably quickly and some short journeys, of less than one kilometre, taking up to 60 minutes to complete. Correlation between public transport journey time and the access domain of the IMD is even weaker: a linear regression of public transport travel time and the access domain of the IMD returns an r^2 value of just 0.009: there is no linear correlation between the two measures.

Figure 39: Correlations between public transport journey time, drive time to hospital and straight-line distance to hospital for wards



Areas where the residuals from the regression analysis of drive times to hospitals and public transport journey times are more than two standard deviations from the norm show no obvious geographical pattern (figure 40), unlike the regression of straight line distance and drive time reported in figure 15, section 5.5. Interpreting these results is more complex than the drive time / straight-line distance correlation, as public transport journey times could not be calculated for every ward, and various assumptions are made that may effect the relationship. For many wards the result is based on only a proportion of the households: the measure may misclassify wards as. If only 20-25% of households are used to calculate a journey time then it probably overestimates access, as for the other 75-80% access by public transport will be poorer. Wards with 'no data' values are those where less than one percent of the ward population could make a valid public transport journey (one which required no more than 15 minutes walk to a bus stop, five minutes wait and a 45 minute bus journey with no more than two changes of bus service). Public transport journeys may be possible from these wards, and from households without a valid journey in other wards, but with longer journey durations than are allowed for in the current model, or there may be no usable scheduled public transport service from these areas.

Figure 40: Map of Residuals from the regression of public transport travel time and drive time to hospitals



8.6.4 The need for health care and public transport access

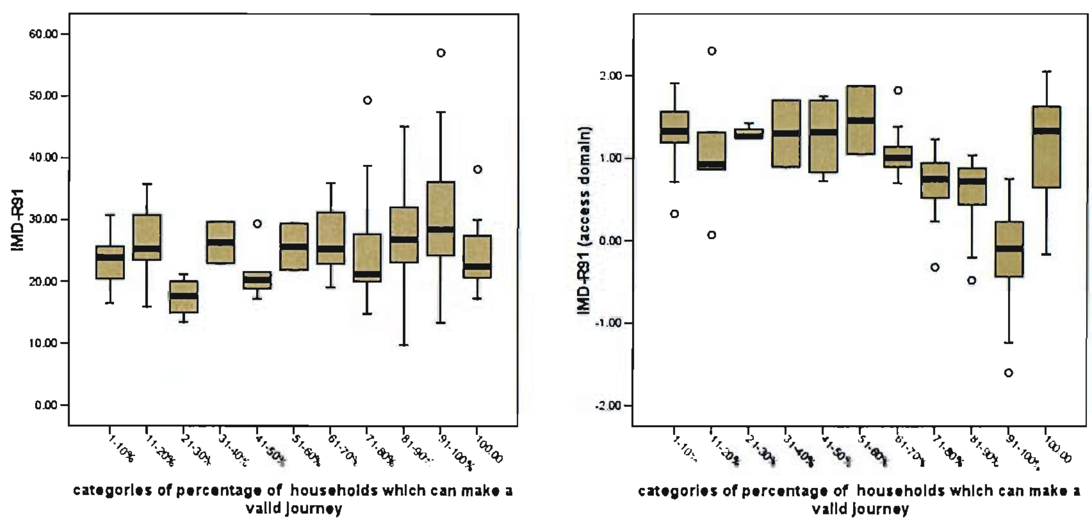
One third of the wards in Cornwall (43/133) are rural under the ONS definition used in this thesis, a further 7.5% (10) are rural fringe and the final 60% (80) are 'urban'. This proportion is far higher than in the South West Region overall, in which 18% of wards are rural. In chapter six, I demonstrated that the IMD was more closely correlated with morbidity in both rural and urban areas than the Townsend score and, although this appears to be due to the inclusion of morbidity data in the score itself, the IMD may still be a useful indicator of broader health needs in rural communities. I therefore use the IMD as the deprivation indicator and proxy measure of the need for health care in the following analysis.

Although Cornwall is often considered to be relatively deprived, the mean Townsend score is –0.2, very close to the England and Wales average of zero. Using the IMD, the most deprived ward in Cornwall was ranked 336, less deprived than some wards in the South West region where the minimum was 133 (rank one being the most deprived in England and rank 8414 the least deprived). It is in the access domain of the IMD that Cornwall appears both most deprived and most diverse, with a minimum rank of seven and a maximum of 8195.

There was no evidence of increasing deprivation in the wards with the longest public transport journey times to hospital: neither the IMD score nor the IMD access domain score showed a trend with increasing journey times. As the public transport journey times are based on far fewer households in some wards than in others, I also investigated the possibility of a relationship between the availability of any valid bus journey (that is one with a total duration of 65 minutes or less, including walking and waiting times), and the need for health care indicated by ward level deprivation.

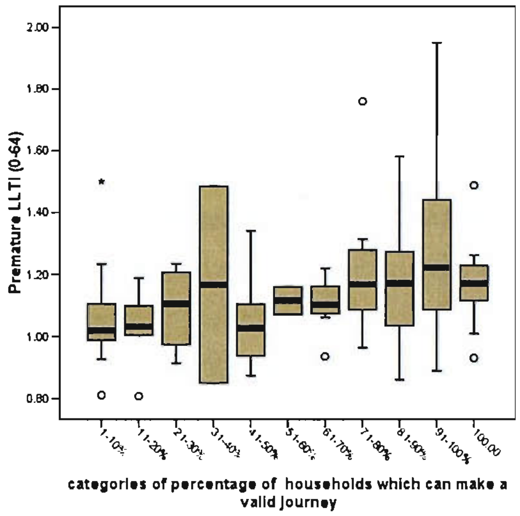
Although there is no relationship between the proportion of households who can make a valid bus journey to hospital and the IMD score, wards with a higher availability of a valid bus service appear to have lower IMD access domain scores (with the exception of the wards where between 90 and 100% of households could make the public transport journey, where access domain scores are markedly higher). The lower the IMD access domain score, the less access-deprived an area is: the least access-deprived 1998 ward in England has a score of –2.78 (rank 8414), and the most access deprived a score of 2.95 (rank 1). Following the re-weighting of the IMD described in section 4.2.4.2, the least access-deprived ward in Cornwall has a score of –2.07, and the most access deprived a score of 2.30. This means that greater availability of valid public transport journeys is associated with better access (measured as shorter straight line distances for those in the population on state benefits) to GPs, food shops, post offices and primary schools, except in the case of wards with very high public transport availability, where access to local services is worse (figure 41).

Figure 41: IMD deprivation and access domain by the proportion of households able to make a valid public transport journey



A further measure of the need for health services is the proportion of over 65 year olds and of under 5 year olds in each ward. This measure showed no association with either the public transport travel times or with the proportion of households with valid bus journeys in each ward. Age-sex standardised rates of all-age and premature Limiting Long Term Illness (LLTI) also showed no relationship with travel times, but there was some evidence that rates of premature LLTI were slightly raised in wards where the majority of households had access to a valid bus service to hospital (figure 42).

Figure 42: Premature LLTI by the proportion of households able to make a valid public transport journey



8.6.5 Rurality and public transport access

Rural wards in Cornwall have, on average, a lower proportion of the households able to make a valid public transport journey to hospital, with a median of 53% (range 1%-93%) of households in rural wards, 71% (7%-96%) in rural fringe wards and 94% (1%-100%) of households in urban wards in Cornwall able to make valid journeys. The availability of public transport is, however, the only indicator of variations in geographical access by rurality: public transport journey time does not vary strongly between the three ONS groups, nor do distance or drive time to hospital (table 31).

Table 31: Public transport access and rurality

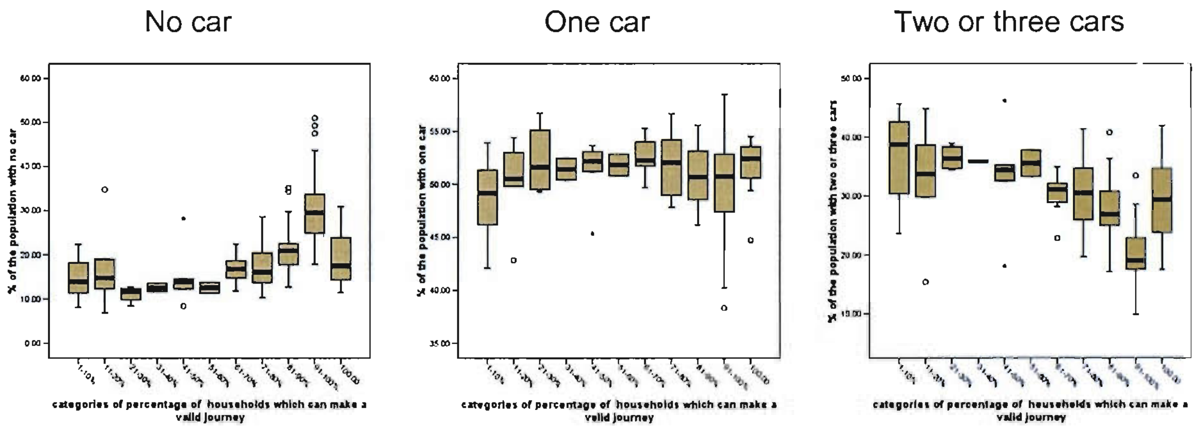
	Rural (n=37)	Rural fringe (n=10)	Urban (n=75)
	Median values for wards (maximum and minimum)		
Proportion of households with valid public transport journeys	53% (1 to 93%)	71% (7 to 96%)	94% (1 to 100%)
Mean public transport journey time to hospital	38.0 minutes (13 to 55)	40.5 minutes (21 to 59)	36.0 minutes (13 to 58)
Mean drive time to hospital	28.0 minutes (6 to 48)	20.1 minutes (11 to 32)	22.1 minutes (2 to 43)
Mean straight line distance to hospital	24.7 km (3.8 to 50.1)	15.3 km (8.4 to 32.5)	21.6 km (1.7 to 46.4)

8.6.6 Personal mobility and public transport access

To investigate whether those areas with poor public transport links to health services are also those where more people own cars, public transport journey times and the proportion of households in each ward that could make a valid journey to hospital were described using box plots of car ownership in each category of public transport travel time and of valid journeys.

There was no evidence of a relationship between journey time and car ownership in Cornwall: longer public transport journeys were not compensated for with higher rates of car ownership, nor were longer journey times a feature of areas where car ownership was especially low. There was some evidence that good availability of public transport was associated with lower levels of car ownership: in wards where the majority of the population could make a valid public transport journey to hospital there was an increase in the proportion of households not owning a car. Similarly, the proportion of the population owning two or three cars was lowest in areas where valid public transport journeys were available to most households, and higher in the areas where fewest households could easily travel to hospital by bus (figure 43).

Figure 43: Car ownership by the proportion of households able to make a valid public transport journey



As shown in table 29, only 5% of the population lives in wards where there is effectively no valid (i.e. < 65 minute duration, running on a Tuesday, arriving by 10am) public transport service to hospital. In these wards with the poorest public transport access to health services the tendency for car ownership to be higher than in the wards with valid public transport journeys continues. On average, 19% of the households in wards without valid bus journeys have no car, compared to 22% in wards with better public transport services; and 29% have two or three cars, compared to 27% in the other wards. However these averages over several wards can conceal potentially poor geographical access to hospital. In one ward of the eleven without valid public transport services, over 30% of the households have no car, and it is over 44km to the closest hospital. The proportion of households with more than one car is just 18%.

8.6.7 Combining public and private transport estimates: a weighted average

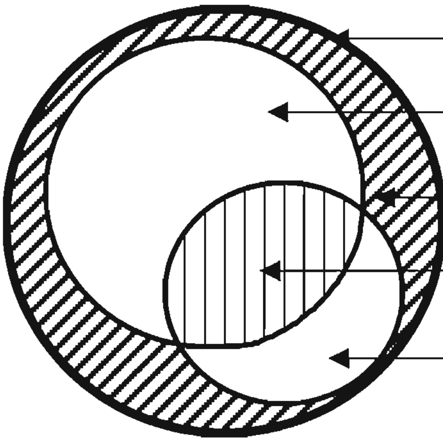
The final aim of this thesis was to explore the development of an integrated measure of public and private transport access. Based on the idea that the travel time by bus for each postcode and ward is known and the travel time by car for each postcode and ward is known, and the number of households in each 1991 ward who own a car is known, a weighted average based on the proportion of the population who would experience each travel time was to be created (table 32).

Table 32: Example of calculating a combined access measure

1991 ward	Total popn.	N (%) owning a car	Weight for car travel time	Weight for bus travel time (1-car)	Ward time for car travel	Ward time for bus travel	Weight * travel time for car and bus	Combined access time
DCFA	500	375 (75)	0.75	0.25	30 minutes	60 minutes	30*0.75=22.5 60*0.25=15	37.5 minutes
DCFB	130	26 (20)	0.20	0.80	15 minutes	75 minutes	15*0.20=3 75*0.80=60	63 minutes

However, this measure relies on everyone in the ward being either a car owner, or able to use a public transport service to travel to hospital. For the 133 wards in Cornwall, car ownership ranges from 37% to 94% of households, and the proportion that can use public transport to make a valid journey to hospital, from 0% to 100 % of households. Within each ward, there is an unknown degree of overlap between these two groups, and an unknown proportion of the population without access to either a car or public transport: it cannot be assumed that all of those without access to a car are able to use the bus, or vice-versa. In Cornwall, there are 22 wards (16% of the total) in which the proportion of households owning a car, plus the proportion of households unable to make a valid public transport journey to hospital is less than 100%. There are certain to be some households in these wards, and may be in others, that are both unable to make a valid bus journey *and* that do not own a car, although the exact number cannot be calculated (figure 44).

Figure 44: car ownership, public transport availability and ward populations



8.6.7.1 Patient-transport and other options

As I have demonstrated that scheduled public transport services are not necessarily a valid option for all those without access to a car, developing a weighted average travel time is not a straightforward task. A measure that is a true reflection of transport-dependent accessibility requires knowing the proportion of the population who can use neither scheduled public transport nor a car, and assigning them a journey time.

One option is to assign a journey time based on community, voluntary and NHS non-emergency Patient Transport Services (PTS): a 'patient-transport' rather than a 'public transport' journey time. The 2001-2006 Local Transport Plan for Cornwall identifies 13 community buses and at least 21 voluntary car schemes in the county and acknowledges that there is some overlap between community and voluntary transport and the PTS provided by the NHS trusts (http://www.cornwall.gov.uk/Transport/Ltp/detstr/Detstr2c.htm, accessed May 2005). Information on routes, schedules and journey times both by PTS and by other transport options would be needed to give a full picture of accessibility. This information could be used to calculate patient-transport journey times for all the postcodes in each ward, and these times could then be assigned to postcodes without a valid public transport service. The public transport and patient-transport postcode journey times could be aggregated to ward level, and a ward weighted-average calculated based on car ownership rates as outlined in table 32.

A second option is to assign all the postcodes without a valid public transport journey time a longer journey time, reflecting the possibility of catching a slower scheduled public transport service or the possibility of walking for longer to reach a bus stop.

Finally, it would be possible to calculate a combined journey time only for those wards in which car owners and potential public transport users together add up to 100% or more of households, making the assumption that either all those who do not own a car will be able to use public transport, or that all those who cannot use public transport will be able to use a car.

All of these options have substantial limitations. Gathering information on community and voluntary journeys is likely to be difficult as the sector is diverse and staffed largely by volunteers, but it may be possible to describe details of journey times by community buses and journeys by PTS, and further work to explore this option is needed. The second option, of simply assigning a longer public transport journey time to all postcodes without a valid public transport service would require a degree of subjective judgement in selecting the journey time and, whilst not unreasonable for households in wards with a good supply of public transport services, could substantially overestimate geographical accessibility for households in wards with few or no usable public transport services. Finally, to calculate a combined measure only for wards where the proportion of households with a valid public transport journey does not require any extra data, but there is no evidence that the assumptions are valid. The unknown degree of overlap between households with car ownership and households with available valid public transport services may mean that there are still households with access to neither mode of transport. It also risks omitting the wards with the poorest geographical access to health services: those in which the availability of public transport services is low and in which car ownership is low (as described in section 8.9.3).

Given the caveats outlined above, within the time constraints of this thesis I have not been able to develop a robust combined transport-specific measure of geographical accessibility. This is an obvious avenue for further work.

8.7 Summary

In this chapter, I have demonstrated a method for using electronic timetable data to create a model of generalised geographical access to hospital. This work has demonstrated that the two main limitations of using public transport data, identified in the pilot analysis, can been overcome: it has been possible to incorporate the time and day of a journey as well as the speed of travel as a parameter in the model, and it has been possible to specify the number of changes of bus in a journey, a major improvement on the pilot work in which only direct journeys to the two hospitals or to the towns in which they are located were included.

Reflecting the experience of geographical accessibility for people without a private car has been central to this thesis. In chapter five, I raised the questions 'are the areas furthest from health services typically rural?' and 'do the areas furthest from health services have high rates of car ownership?' When geographical access to health services was measured using straight line distance it could be seen that the answer to both of these questions was a qualified yes: rural areas were typically remote from hospitals (although areas remote from hospital were not necessarily typically rural), and the areas furthest from hospital did have higher rates of car ownership. However, whilst straight line distance and drive time measures of access were very highly correlated, their relationship with public transport accessibility was unknown: were areas with poor public transport accessibility typically rural, and did they have higher rates of car ownership? In this chapter I have shown that access measured as a function of public transport journeys gives a strikingly different picture of geographical accessibility, and has very low correlations with other measures of geographical access. I have investigated whether the areas in which public transport services are available to the fewest people, or where available services take the longest to get to hospital, are also predominantly rural; whether they have the highest rates of car ownership; and whether their populations have particularly high need for health care.

Limitations of time and resources mean that only a single journey to hospital is presented: travelling on a Tuesday, arriving at the hospital by 10am, with a maximum time of 65 minutes allowed to complete the walk to the bus stop, the wait for the bus and the journey itself. The data show that access to hospital by public transport in Cornwall is highly variable. Journey durations range from 13 to 59 minutes (with a theoretical maximum of 65 minutes), the proportion of households able to make a valid journey from under 1% to 100% of those in a ward.

Using the proportion of households able to make a valid journey as an indicator access by public transport, there is some evidence that the areas with the least availability also have poor access to local services (as measured by the IMD access domain), but no evidence that the same areas have higher levels of need for health care. Finally, there seems to be some indication that higher levels of car ownership may, in part, be compensating for lower availability of public transport services where necessary, but this information is only available at the level of the electoral ward: we have no information about whether the individual households with cars are those which have no valid public transport journey available.

The ward level may be too heterogeneous to identify relationships between the accessibility of health services and population characteristics. Work presented in chapter five demonstrated the differences between analysis of geographical accessibility at the ward and ED levels, with longer travel times within EDs obscured by aggregation to the larger geographical scale, although there was no evidence of spatial clustering of the differences (section 5.4). The calculation of accessibility measures for 1991 EDs or 2001 Output Areas may highlight areas differences in accessibility that are obscured in this analysis, and would be an interesting development of this work.

Both the availability of bus services and modelled transport times have previously been used to describe accessibility by public transport, but I am not aware of any previous work that has attempted to calculate both measures. Three studies have used an area measure of public transport journey time to describe geographical accessibility, but very little detail of the methods is given in any of the studies. One used 'tables of the travelling distance in minutes from each sub-area...supplied by the Stockholm County Council', but gave no indication of how the tables were calculated (Magnusson 1980); the other two used the same measure: 'average driving time by public transport' which, again, is not explained (Burgy & Hafner-Ranabauer 1998;Burgy & Hafner-Ranabauer 2000). There is no discussion of the limitations of the access measures in any of the papers, nor of how the authors chose to assign travel times to areas in which it is very unlikely that all of the residents had equal access to a public transport service.

More fully explained are the measures based on the availability of scheduled public transport. In the 1960s the availability of scheduled bus services was used to construct an index of accessibility for villages and towns in North West Yorkshire by combining the number of bus services departing from each village in the area at different times of day, and the number of 'return seat journeys' per week (Johnston 1966). Far more recently, the availability of scheduled bus services has been used to describe access to primary health care in East Anglia. Routes with at least one daytime return journey every weekday were selected, and further divided into those routes with four or more daytime buses in each direction (and where a return trip was possible within three hours), and those with fewer services. As with the pilot work described in chapter seven, basic restrictions were made to identify 'valid' bus services: journey to work services, where the outward journey is in the early morning and the return journey in the evening; and school-term only services were not included, nor were routes 'wholly within a town or a city', to 'limit the amount of work required': a clear indication of the workload limitations imposed by data entry when using non-electronic data sources. There are, however, striking similarities with the final way in which a measure of public transport accessibility was assigned to areas, with the proportion of the residents of each area within a given distance of a valid bus route identified and areas classified by the proportion of residents with daytime return services to a GP, in much the same way as the 'proportion able to make a valid journey' identified in this work has been used (Lovett, Haynes, Sunnenberg, & Gale 2002).

One unexpected outcome of the development of a public transport based measure of access was the finding that some wards had so few households able to make a valid journey by public transport, and the consequences of this for the calculation of a combined measure of access. Having calculated both mean journey times by public transport for each ward and the proportion of households in each ward able to make a journey within the time threshold of 65 minutes, it was the second of these measures: the availability of public transport within each ward, which was the most easily interpreted.

The public transport journey times are difficult to interpret clearly for two reasons, and could be further developed to make a more comprehensive and useful measure of access. Firstly, the mean journey time for each ward can be based on anything from 1% to 100% of the households in that ward, an issue that could be overcome by the inclusion of data on community or voluntary transport services, and / or of data on NHS non-emergency Patient Transport Services. This would allow all households in each ward to be given a journey time based on drive time for the proportion of the households with a car; scheduled public transport journey time for as many of the remaining households as have access to valid public transport journeys; and a time based on community, voluntary or PTS journey time allocated to the remaining households.

Secondly, The DfT 'Accession' project, which is also using the ATCO CIF electronic timetable data, reports that the calculation of journey times at six times of day is needed to give an impression of overall accessibility. An obvious extension of this work would be to increase the number of journeys calculated in a day, and the number of days of the week considered, or the inclusion of weekends. Further extensions of this work could look at the changes in public transport accessibility over different times of the year: for example summer and winter timetables are likely to be quite different in some areas.

Furthermore, in this thesis I have not attempted to include any scheduled public transport other than buses. Train services, light rail and, in some areas, ferries all play a part in the network of public transport, with trains and light rail potentially significant in and around large urban areas on commuter routes. The inclusion of other forms of scheduled public transport would be an interesting development of the work presented here. Finally, the measure of a 'valid' journey presented here is subjective and specific to a very limited set of circumstances. Further work is needed to test the robustness of these findings with different definitions of good and poor access.

Chapter 9: Conclusions

9 Chapter overview

In this chapter I review the main findings of the thesis. I discuss the strengths and limitations of the methods I have used, and set my work in the context of other research. Finally, I outline key areas for the future development of the work I have presented here.

9.1 Main findings

The central challenge of this thesis was to create a measurement of geographical access to health services, representative of the experience of people with and without a car, in urban and in rural areas. The measure had to give a general picture of accessibility in an area, and to take account of both spatial and temporal variation in the transport network. To achieve this, I developed a measure of access using newly available digital public transport data. This measure can be used to compare access by public transport with other measures of accessibility, and to identify areas where those who do rely on the public transport network are likely to experience very different access to those who can travel by car.

I also set out to review the literature on geographical access to health services; to examine the use and the limitations of two commonly used measures of access to health services – straight line distance and drive time – and to explore the use of deprivation measures as a proxy for health care need in rural areas, with particular focus on the IMD.

A comprehensive and structured review of the literature on the relationships between geographical access to health services, the use of services and health outcomes (*chapter two*) identified over 100 research papers in which a quantitative assessment of these linkages had been made.

Although the review demonstrated that considerable previous research into the geographical accessibility of health services had been undertaken, it also revealed that there is remarkably little published information about the distances people must travel in order to use health services: rather than reporting geographical access as an independent measurement, the majority of work has been interested in determining the equity of access for different populations.

Mean or median travel distances are occasionally reported in the literature, but it is unusual to find an estimate of the distribution of travel distances or times – a lack of detail which makes it difficult to form a clear understanding of what constitutes good or poor geographical access to health services. There is no clear definition of the distances which people are prepared to travel, or the points, if any, at which travel distance actually becomes a barrier to use. There is, however, consistency in the finding that increasing travel distance to a wide range of health services is associated with a decrease in the use of those services. Furthermore, this decrease seems to affect the most vulnerable populations the most, with the elderly, women and children showing particular sensitivity to problems with travel.

There is little consensus within the published literature on the most appropriate way to measure geographical accessibility. Access measures do not commonly seem to be selected with different populations or area types in mind: straight-line distances, road distances and drive times are used without comment on their suitability for the situation being investigated. For example, straight-line distances are the most commonly used measure of geographical access in the health literature. However, a straight-line distance may be misleading if the population being studied lives in heavily built up area with a complex road network, an area with sparse road links or one with major physical barriers to mobility such as coastline or mountain ranges. Drive time will be an inappropriate measure for all those who do not have the use of a car.

I also discovered that there are a number of assumptions embedded in much of the literature, which may affect both the validity of the observed relationships between geographical access and the use of health services (or between geographical access and health outcomes), and the chances of finding a relationship where one exists. The most significant assumptions are firstly that the observed relationships with geographical accessibility are not confounded by other factors – most importantly the need for health care, although some studies try to adjust for this – and secondly that the chosen measure of geographical access will operate equally well under different circumstances: in different areas; for different populations; at different times of the year; and for different types of health care. A final assumption apparent from the literature is that geographical inaccessibility of health services is essentially a rural problem.

The literature search was constrained to the UK, Europe, Australia and New Zealand and the US to limit the variability that would have confounded any comparisons if the worldwide literature had been reviewed. Even so, distances to health services vary enormously between countries and between different types of health services. This, and the structure of different health systems, can make the literature difficult to compare. For example, much of the literature is from the US, and from areas much more rural than any that would be found in the UK. The UKs combination of a centrally planned health service and many densely populated areas is in clear contrast to the private health care and vast distances found in the US.

The literature spans many different types of health care, but is not by any means comprehensive in its coverage. Mental heath care is strongly represented, as are breast cancer screening programs and the specialist treatments of cancer care and revascularisation services. Other services are not represented, for example children's health care, screening other than for breast or cervical cancer, routine outpatient appointments, antenatal care, or specific treatments in a primary care setting.

It is difficult to find the literature using systematic searches of research databases: searching for key words such as 'access' and 'distance' returns a huge amount of material, much of which is not relevant. Although this strategy resulted in a wide ranging and comprehensive review, much of the relevant literature was identified through hand searches of key journals, following up the references of useful articles and searching for work by key authors.

In summary, the review confirmed the relevance of geographical access to health services as a subject for further research, and identified several gaps in the literature that merit further attention.

- There is limited reporting of the distances (maximum, minimum, range) that people actually travel to health services or that they would have to travel to reach the closest health service
- There is limited reporting of the differential impact of distance on different groups in the population

- The assumption that poor geographical accessibility of health services is a feature of rural rather than urban or suburban areas has not been tested
- There has been little comparison of different access measures and little was known about the circumstances under which more complex measures would be worth calculating and those under which simple measures would give a representative view of geographical accessibility. In particular, very few studies had attempted to use public transport as a measure of geographical accessibility.

As computing power and the availability of data increases, it will become ever faster and easier to calculate precise measures of geographical access such as drive time, which has been acknowledged as a 'better' indicator of people's experience of travel than simple distance measures (Fortney, Rost, & Warren 2000; Martin, Roderick, Diamond, Clements, & Stone 1998). Straight-line distances have the possible advantage of being more obviously an estimate of true travel impedance. Drive times superficially appear to be more precise, but an increase in their use may result in the experience of the non car-driving section of the population going unrecognised. For example, a recent UK paper on patient choice concluded that '98% [of the population] had one hospital and 92% had two hospitals within 60 minutes travel time', basing their conclusion on drive times alone and stating only that public transport may 'reduce or increase the travel time' (Damiani, Propper, & Dixon 2005). Of the studies which had attempted to use a public transport measure of access, two confirmed that it was both useful and relevant (Lovett, Haynes, Sunnenberg, & Gale 2002; Magnusson 1980), whilst others used it without comment (Burgy & Hafner-Ranabauer 1998; Burgy & Hafner-Ranabauer 2000).

The South West peninsular of England is an appropriate setting in which to examine differences in accessibility, as it combines scattered settlements, long travel distances and rurality with problems of low pay, unemployment and other aspects of deprivation. Rural deprivation may have a significant transport component: a 1996 report for the Rural Development Commission points out that *"the availability of a means of transport for rural inhabitants is vital in determining their employment, service and recreational opportunities"*, and that it is a significant and socially distinct minority comprising the young, the elderly, disabled and women who are most reliant on public transport (Shucksmith, Roberts, Scott, Chapman, & Conway 1996). This group is also most likely to need frequent access to essential services such as heath care. The measurement of rural deprivation has received relatively little attention compared to its urban counterpart. The introduction of the IMD in 2000 was met with considerable interest by PCTs in rural areas, but the assumption that the IMD, and in particular its transport domain, would empirically demonstrate the deprivation that they perceived in their local areas had not been tested at the time this thesis was written. Finally, the public transport network in a rural region was simpler than a comparable network in a city or other large urban area. This allowed both piloting of the use of a manageable amount of public transport data and the construction (and running) of programs that could handle the data volume required to describe the public transport network more fully.

Following on from the literature review, in *chapter five* I report empirical work measuring access to health services in the South West of England. There were four objectives to this piece of work.

- To set the scene, describing travel times and distances to primary and secondary health care throughout the study area.
- To discover whether the assumption that rurality was synonymous with inaccessibility was true for the study area.
- To compare two commonly used measures of geographical access, and to determine what kinds of areas were not well represented by the simple measure of straight line distance
- To investigate the possibility that poor geographical access to health services would be associated with greater health and health care need in the population (represented by higher deprivation scores or higher rates of LLTI).

This work quantified access to hospital services and showed that access to primary care was good throughout the study area (a median travel distance of just 1km to a GP), and has since been published (Jordan et al. 2004). Although there is little other published work reporting distances to primary health care, this is similar to the distances which are reported: one UK study reporting distances to primary care gave a median of just under 1km (Bojke C, Gravelle H, Hassell K, & Whittington Z 2004), another found that very few settlements were over 2km from their nearest surgery (Martin & Williams 1992). Work from Sweden and New Zealand has also described medians of between one and two kilometres (Hays, Kearns, & Moran 1990; Kohli, Sahlen, Sivertun, Lofman, Trell, & Wigertz 1995).

I showed that half of the wards remote from a DGH were not classed as rural by the ONS: an important finding as, if geographical access to health services is a problem for some groups outside of traditional rural areas, studies concentrating purely on rural areas may underestimate geographical barriers to accessing health care. I also demonstrated that in South West England the greatest differences between the two access measures of drive time and straight-line distance were found in coastal and rural wards of the far South West, showing that drive time is a more accurate measure of access for peripheral and rural areas. Finally, I showed that almost a quarter of households in the wards furthest from hospitals had no car, and the proportion of households with access to two or more cars fell in the most remote areas. The finding that car ownership, while high, declined in some of the areas most remote from such an essential service as health care reinforced the need for a measure of access which did not rely on the ownership of private transport for its validity.

Having demonstrated that there was no clear distance threshold at which a traditional, census based, deprivation score (the Townsend score) indicated that the need for health services increased, I re-calculated the Index of Multiple Deprivation 2000 (IMD) to allow me to correlate it with 1991 census data, including data on morbidity (LLTI) and ONS data on premature mortality, also aggregated to 1991 ward boundaries. Strong correlations could indicate that the IMD was a useful proxy for the need for health services in urban and rural areas, vital if equity in geographical access was to be assessed, and relevant as the use of the traditional census based deprivation indicators such as the Townsend score in rural areas has been criticised on the grounds that the variables making up the score (such as overcrowding and car ownership) may not be appropriate indicators of deprivation in rural areas (Barnett, Roderick, Martin, Diamond, & Wrigley 2002). In *chapter six* I show that although the IMD was strongly correlated with health in both urban and rural areas, the domain 'geographical access to services', which had been considered particularly important in highlighting a previously unmeasured aspect of rural deprivation, had no influence on the strong correlation. Furthermore, the correlation with morbidity was far stronger than that with mortality. Further investigation of the six domains of the IMD showed that the strong correlations were almost certainly the result of co-linearity in the data – the IMD used measure of both morbidity and mortality in the 'health' domain. The IMD was, however, in clear contrast to the Townsend score, which showed only a weak correlation with health in rural areas.

I also presented the idea that the measure of access used in the IMD is likely to be a weak reflection of the access challenges facing people in rural areas, concentrating as it does on access to very local services (fairly good in both rural and urban areas) and only for a sub-group of the population on low incomes and claiming state benefits, work which has since been published (Jordan, Roderick, & Martin 2004).

From this I went on to investigate the possibility of creating a measure of geographical access to health services that used public transport data to describe journey times. In *chapter seven* I show that it is possible to build a model based on published public transport timetable data, but that without the use of electronic data sets such a model would always be limited by problems with data input, constraining it to highly simplified representations of travel and transport.

The final section, *chapter eight*, addresses the central challenge of this thesis: to reflect the experience of geographical accessibility for people without a private car, as well as that of those with their own transport. It covers the development of a measure of geographical access to secondary care health services (acute DGHs) that is based on electronic public timetable data. I have described the way in which the timetable data are structured to a standard (ATCO CIF) format, and the way in which that format can be used to read the data into a custom made computer program. The original electronic timetable data were restructured, providing the names and grid-referenced locations of bus stops; a list of bus routes and the stops that they serve; and a table of times at which buses stop at each stop in the dataset. I then go on to describe the way in which these output files can be analysed to produce journey times from any bus stop in the dataset to a selected destination stop, such as a hospital main entrance.

The model demonstrated in chapter eight of this thesis has two major advantages over the pilot work set out in chapter seven. It has been possible to incorporate the time and day of a journey as well as the speed of travel as a parameter in the model, and it has been possible to specify the number of changes of bus in a journey, rather than limiting the data collected to a few scheduled routes.

Whilst there is some published work which uses the availability of public transport to describe geographical access, for example by drawing a buffer around all bus routes and assuming that proximity to the network represented a certain level of accessibility (for example, Lovett, Haynes, Sunnenberg, & Gale 2002), and such measures can demonstrate the differences between places and populations with some access to public transport and those without such access, given the richness of the data used for this thesis, such an approach would have been wasteful of the information available.

Accessibility measurements that use complex matrices of public transport information are rare. With the advent of powerful GIS they are, however, likely to become more usual. A complex measure of accessibility, which incorporates travel by public transport, was developed by O'Sullivan (O'Sullivan, Morrison, & Shearer 2000). The work was carried out as a methodological exercise, and the results are not related to patterns of use of the transport network or of any services (such as health services) travelled to, but the methods show some interesting similarities and differences to those used here. Although O'Sullivan et al use real transport network data, a considerable number of assumptions are built into the modelling due to the amount and complexity of the data needed to describe real journeys. Some of these assumptions have been possible to overcome in this thesis due to the comprehensive nature of the ATCO CIF timetable data. For example, travel time along bus routes was estimated by establishing the timetabled journey time along mapped bus routes from beginning to end, then dividing the routes into segments and allocating a proportion of the whole journey time to each segment, rather than by locating individual stops and allocating times based on timetable data, as in the model shown here. Waiting times were assumed to be half the duration of the interval between buses – for example a five-minute wait is assumed if a service runs every 10 minutes. Connections between bus routes make use of a buffer zone around the current bus routes: connection is considered possible with any route falling within the buffer. Again, the availability of comprehensive electronic data makes such assumptions unnecessary. Although ATCO CIF may not endure as the industry standard format for public timetable information it is sufficiently sophisticated in its ability to represent the transport network that we can have a high degree of confidence in our future ability to further develop all the ideas examined here using digital data in the ATCO CIF format. By contrast, most of these issues are simply too complex to have tackled prior to the introduction of integrated digital timetables.

Another example of complex accessibility modelling using public transport data is the work currently being undertaken by the UK Department for Transport (DfT). In 2003/4, the DfT commissioned a piece of software, 'Accession', to calculate core measures of accessibility to a range of public services, including education, jobs and health care. 'Core indicators' of accessibility are calculated centrally by the DfT at the local authority, district and, occasionally, ward level and are passed on to local authorities to inform the development of 'accessibility strategies'. Accession can also be used to calculate different measures of access based on data entered by local authorities (Department for Transport 2004).

Accession is a commercial software product and, beyond the comment that it is the door-to-door travel time that is being calculated, the way in which the software handles public transport data is not detailed in the documentation. The underlying public transport data are from two sources: Traveline (the providers of ATCO CIF files for this thesis) and the NaPTAN (National Public Transport Access Nodes) database, which provides data on the locations of all bus stops, railway stations and other access points for public transport.

The results from my measurement of public transport access to health services show that the measure is very different to more traditional measures of geographical access, such as straight-line distance and drive time. I have shown that the correlation between public transport travel time and these other measures is very low: that drive time is not a reliable proxy for travel by public transport. There is no obvious geographical clustering to the areas where the relationship is poorest, and although the areas in which public transport services are available to the fewest people are predominantly rural, public transport journey time does not vary strongly between the three ONS groups of rurality used in this thesis. A different dimension of geographical accessibility is captured by the measure, and we are only beginning to explore it.

9.2 Limitations

The choice of starting time is critical to travel speeds and journey duration on the public transport network. Fair comparisons between different places can only be made by running the system a number of times using different starting times, and averaging the results. The DfT 'Accession' project reports that the calculation of journey times at six times of day is needed to give an impression of overall accessibility: a 'pre-a.m. peak' measure at 0800-0900; an 'a.m. peak' at 0900-1000; a further two measures at 1200-1300 and 1300-1400; and two p.m. measures at 1600-1700 and at 1700-1800. An obvious extension of this work would be to increase the number of journeys calculated in a day, to include both weekdays and weekends, and to increase the number of days of the week considered. Also the calculation of return journeys, identifying places where it is or is not possible to travel to an appointment and back in a single day, would be an interesting development. Further extensions of this work could look at the changes in public transport accessibility over different times of the year: for example summer and winter timetables are likely to be quite different in some areas.

As with the measures set out in this thesis, the Accession data set excludes community and voluntary transport, NHS patient transport services and other specialist transport. No attempt is made to incorporate these data into the core indicators, as they were felt to be too difficult to code successfully. Voluntary and community transport services are, by their nature, local and travel on unpredictable routes. The principal limitation of this work is the fact that it has not been possible to calculate an effective measure combining public and private transport access to give an overall impression of transport-dependent accessibility: a limitation that could be overcome with the inclusion of travel data for the section of the population who have neither access to a car nor to a valid scheduled bus service. Whilst undoubtedly having an impact on access it is a difficult feature of travel to health services to quantify, and merits further investigation.

9.3 Conclusions

The key contribution of this thesis is the demonstration that it is both theoretically possible and also practical to use public transport data as the basis for a model of geographical access to health services. The utility of this model is shown by the early work in which I showed that more traditional access measures diverged in key locations in peripheral and rural Cornwall and South West England.

The work presented in this thesis offers both a better understanding of the relationships between different measures of geographical access and the circumstances in which different measures may be appropriately used. It is both timely and important to investigate the development of transport-specific measures of geographical accessibility. We are only just beginning to explore the potential of newly available electronic timetable data, and to develop an understanding of its potential to capture an aspect of access that has not previously been addressed.

Future development of the measure will enable it to be combined with information on car ownership and drive times to health services, and with data on travel by community or voluntary transport (or NHS non-emergency Patient Transport Services) to produce an estimate of access to health services that is weighted by the proportion of people who are likely to rely on each form of transport. In combination with an appropriate measure of need for health care it will also be possible to use this combined measure to assess equity of access.

I would like to use the work developed here used as the basis for the calculation of a measure of accessibility which is as easy to calculate and to use as standard measures of deprivation. I believe that while transport and distance problems will not affect everyone, especially in the small and densely populated islands of the UK, the measurement and understanding of geographical access is important for the following reasons. Firstly, a thorough understanding of geographical access is important for evaluating and establishing the equity of health services. Assumptions about the ease and cost with which patients and their carers can arrange journeys may disadvantage those who do not fit the 'normal' model. Whilst this thesis did not demonstrate that populations of areas remote from health services were in significantly more need of health services, where there is an impact of geographical inaccessibility it is likely to be of overriding importance to the individuals affected. Qualitative work to establish the extent of any deterrent effect of distance and the reasons underlying such an effect would also be valuable in exploring the impacts of variations in geographical accessibility of health services, but a population or area overview of geographical accessibility is needed to compare accessibility with other area data and to influence policy or ideas about transportation and accessibility of health services.

The second important use for this work is in the planning of health services. At the time of writing, local government departments have been issued with the Accession software based on the data used for the access calculations presented in this thesis, which is to be used in producing local transport plans across England. Furthermore, with the re-election of the Labour Party in May 2005 it is likely that policies to enhance 'patient choice' will continue. Transport access is a key dimension in evaluating the impact of such public policy developments and the reality of 'choice' for all sectors of society.

Finally, social and environmental pressures to use the car less make an understanding of public transport access to major public services more and more important. As pressure on car parking at large hospital sites increases, the availability of adequate and appropriate public transport is likely to become ever more of an issue for patients, health professionals and planners. The Royal Cornwall Hospital at Treliske states on its website (http://www.cornwall.nhs.uk/rcht) that car parking is becoming "increasingly difficult for everyone using the Royal Cornwall Hospital site" and encourages the use of a car share scheme, provides links to bus timetables online and has commitments to improving bus timetables so that services are scheduled around times of peak demand, providing better facilities for cyclists and working with the County Council on ideas such as park and ride schemes. Derriford hospital also provides online information on bus timetables, taxi services and rail links to the hospital (http://www.plymouth.nhs.uk/plymouthhospitals/2003/finding_us/transport.htm).

The use of electronic data sources is vital to any serious attempt to map transport-specific access to health or other services. The richness and complexity of the available data and the substantial time savings offered compared to data entry from published timetable sources create more scope for analysis and allow users to quickly incorporate changes to the network for an up-to-date picture. The exploration of the potential of such data is at an early stage, but it offers many opportunities: a better understanding of the accessibility of local populations; use by local service commissioners or health care providers to target transport services; and an insight into the identification of potential problems with equity of access.

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Appendix 1: ATCO File Format for Interchange of Timetable Data

This version of the ATCO file format for interchange of timetable information uses the BR CIF interchange format as a model and adds additional records to take account of the specifics of bus timetables. Version 5.00 incorporated major revisions to record layouts and is not upwardly compatible with previous versions. This version (5.10) extends the location record to include a National Gazetteer ID for PTI2000 purposes, but is otherwise the same as 5.00.

In the BR CIF each record type is distinguished by a two letter identifier in characters 1 and 2 of an up to 80 character record. This principal has been continued in the transfer format. In this version of the format the record length has been allowed to extend to 120 characters.

The transfer format is intended as a general purpose transfer mechanism of the more common elements of timetable enquiry information between different proprietary databases. The transfer format does not define the quality of the data being transferred, nor the coding schemes being used within a database. It is expected that standard coding schemes will be adopted over time and added as appendices to the specification. The transfer format does include provision for some items of meta-data. Fields may be left blank where data is not available in the exporting database.

The principals of the transfer format (record identifier and fielded data content) can be extended by creating other record identifiers. Use of 'Z' series identifiers is suggested for proprietary extensions.

Definitions

A **Journey** is the movement of a vehicle (bus, train etc.) described by a chronologically increasing sequence of stopping points and times from an origin terminal point to a destination terminal point. Conventionally this is appears as a column in a printed timetable.

A **Service** is a label attached to a group of journeys with (more or less) common stopping points. A **Route** can comprise of one or more services. The **Route Number** is often used to identify the vehicle undertaking the journey to the public.

A service is operated by an **Operator**, normally described by company trading name. A route can be operated by more than one operator.

Stops define the geographical locations at which events happen during the course of a journey. Often a journey is described by a sub-set of the stops known as **Timing Points** which are the stops defined in a printed timetable.

Events during the course of a journey describe what happens to the vehicle at each stop or timing point.

Possible events are:- Stops to set down and pick up passengers
Arrives to set down passengers
Departs having picked up passengers
Does not stop for passengers

Valid days are days of the week and other special days (e.g. bank holidays, school term time) the journey operates.

Valid dates define the first and last date of operation of the journey. In this version of the format full four digit years are used. Previous versions used 2 digit years for compatibility with the BR CIF format. 99999999 may be used to define a journey with unknown last date.

Clusters are geographical groupings of stops at which it is possible to change from one journey to another.

The **Interchange Time** is the minimum time needed to change between journeys at a stop or within a cluster.

Record Layouts

Field	Size/ (Start)	Format	Comment

0. File Header This record must be the first record on any transfer file.

File Type	8 (1)	A	ATCO-CIF - File Identifier
Version (Major)	2 (9)	I	Release version of CIF format (currently 5)
Version (Minor)	2 (11)	A	Revision of release (currently 10)
File Originator	32 (13)	A	Name of source of file (Authority etc)
Source Product	16 (45)	A	Name of source product (Program name)
Production Date	8 (61)	I	Date of file production (yyyymmdd)
Production Time	6 (69)	I	Time of file production (hhmmss)

1. Journey Records

1a. Journey Header One record per journey. A journey header may be immediately followed by optional sets of date running records and journey note records and should then be followed by a set of journey records (origin, intermediate, destination) giving a set of records that completely define dates, times, places, operator and vehicle type of the journey. The entire set of records relating to a single journey may be immediately followed by one or more journey repetition records.

Record Identity	2 (1)	A	QS - Bus Journey Header
Transaction Type	1 (3)	A	N = New D = Delete R = Revise
Operator	4 (4)	A	Short code form of operator identifier
Unique Journey Identifier	6 (8)	A	Unique identifier of journey within operator This field with operator field will give unique identifier
First date of operation	8 (14)	I	Start date of operation of journey (yyyymmdd)

Last date of operation (yyyymmdd)	8 (22)	I	Last date of operation of journey
Operates on Mondays	1 (30)	I	} 0 = does not operate on day
Operates on Tuesdays	1 (31)	I	} 1 = operates on day
Operates on Wednesdays	1 (32)	I	}
Operates on Thursdays	1 (33)	I	}
Operates on Fridays	1 (34)	I	}
Operates on Saturdays	1 (35)	I	}
Operates on Sundays	1 (36)	I	}
School Term Time	1 (37)	A	Blank = Operates days defined above S = Operates school term time only H = Operates school holidays only
Bank Holidays	1 (38)	A	Blank = Operates days defined above A = Operates additionally on bank holidays B = Operates on bank holidays only X = Operates except on bank holidays
Route Number (identifier)	4 (39)	A	Route number used as public identifier
Running Board	6 (43)	A	Operator identifier of journey
Vehicle Type	8 (49)	A	User code for vehicle type
Registration Number	8 (57)	A	Traffic commissioners registration number
Route Direction	1 (65)	A	User code to indicate direction of route

1b. Journey Date Running Records These records can be used to identify exceptions to the first and last dates of operation in the journey header. There can be an indeterminate number of these records.

Record Identity	2 (1)	A	QE - Journey Date Running
Start of exceptional period	8 (3)	I	Date (yyyymmdd)
End of exceptional period	8 (11)	I	Date (yyyymmdd)
Operation code	1 (19)	I	0=Journey does not operate between these dates

1=Journey operates between these dates

1c. Journey Note Record These records can be used to append note information about the journey to timetable displays

There can be an indeterminate number of these records.

Record Identity	2 (1)	A	QN - Journey Note
Note code	5 (3)	A	Abbreviation for note appended to journey
Note text	72 (8)	A	Full text of note

Journey Records One origin record, followed by an indeterminate number of intermediate records and one destination record.

1d. Origin Record

Record Identity	2 (1)	A	QO - Bus Journey Origin
Location	12 (3)	A	Short code form of origin location
Published Departure Time	4 (15)	I	Public departure time (hhmm 24 hour clock 0001-2359)
Bay Number	3 (19)	A	Bay/Stop identifier
Timing point indicator	2 (22)	A	T1=Timing point T0=Not timing point
Fare stage indicator	2 (24)	A	F1=Fare stage F0=Not fare stage

1e. Intermediate Record

Record Identity	2 (1)	A	QI - Bus Journey Intermediate
Location	12 (3)	A	Short code form of intermediate location
Published Arrival Time	4 (15)	I	Public arrival time (hhmm 24 hour clock 0001-2359)

Published Departure Time	4 (19)	I	Public departure time (hhmm 24 hour
clock			
			0001-2359)
Activity Flag	1 (23)	A	B=Both Pick up and Set down
			P=Pick up only
			S=Set down only
			N=Neither pick up nor set down (pass
only)			
Bay Number	3 (24)	A	Bay/Stop identifier
Timing point indicator	2 (27)	A	T1=Timing point
			T0=Not timing point
Fare stage indicator	2 (29)	A	F1=Fare stage
			F0=Not fare stage

1f. Destination Record

Record Identity	2 (1)	A	QT - Bus Journey Destination
Location	12 (3)	A	Short code form of destination location
Published Arrival Time	4 (15)	I	Public arrival time (hhmm 24 hour clock
			0001-2359)
Bay Number	3 (19)	A	Bay/Stop identifier
Timing point indicator	2 (22)	A	T1=Timing point
			T0=Not timing point
Fare stage indicator	2 (24)	A	F1=Fare stage
			F0=Not fare stage

1g. Journey Repetition Record These records can be used to identify subsequent journeys which run to exactly the same sequence of stops as the immediately preceding journey records with exactly the same time differences between each stop.

Record Identity	2 (1)	A	QR - Bus Journey Repetition
Location	12 (3)	A	Short code form of origin location
Published Departure Time	4 (15)	I	Public departure time (hhmm 24 hour
clock			
			0001-2359)

Unique Journey Identifier	6 (19)	A	Unique identifier of journey within operator
Running Board	6 (25)	A	Operator identifier of journey
Vehicle Type	8 (31)	A	User code for vehicle type

2. Location Records One location record followed by an optional additional record and an indeterminate number of alternative location records.

2a. Location Record

Record Identity	2 (1)	A	QL - Bus Location
Transaction Type	1 (3)	A	N = New D = Delete R = Revise
Location	12 (4)	A	Short code form of location
Full Location	48 (16)	A	Full text form of location used for publicity (including supplemental information to ensure uniqueness of location)
Gazetteer Code	1 (64)	A	User code to indicate type of location entry
Point Type	1 (65)	A	B = Bay/Stand/Platform S = Bus stop on single side of street P = Paired bus stops (both sides of street together) R = Railway station I = Transport interchange/bus station D = Database boundary point
National Gazetteer ID	8 (66)	A	ID of entry in National Gazetteer for this location

2b. Additional Location Information Record

Record Identity	2 (1)	A	QB - Bus Additional location Information
Transaction Type	1 (3)	A	N = New D = Delete R = Revise

Location	12 (4)	A	Short code form of location
Grid reference easting	8 (16)	I	Grid reference easting of location
Grid reference northing	8 (24)	I	Grid reference northing of location
District name	24 (32)	A	Form of location to be used when
specific			
			location is not required
Town name	24 (56)	A	Higher level form of location to be used
when			specific location is not required

2c. Alternative Location Record

Record Identity	2 (1)	A	QA - Bus Alternative Location
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Location	12 (4)	A	Short code form of location
Full Location	48 (16)	A	Alternative full text form of location used
for			
			publicity (including supplemental
information to			ensure uniqueness of location)
Gazetteer Code	1 (64)	A	User code to indicate type of location
entry			

3. Cluster Record Indeterminate number of records

Record Identity	2 (1)	A	QC - Bus Cluster
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Cluster Code	12 (4)	A	Short code form of cluster
Cluster Name	48 (16)	A	Full text form of cluster name for
identification			
			(Optional)
Location	12 (64)	A	Short code form of location contained
within			cluster

4. Operator Records One pair of records per operator

4a. Operator Record 1

Record Identity	2 (1)	A	QP - Bus Operator
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Operator	4 (4)	A	Short code form of operator identifier
Operator Short Form	24 (8)	A	Short form of operator name used for
publicity			
Operator Legal Name	48 (32)	A	Full form of operator name
Enquiry Phone	12 (80)	A	Phone number of travel enquiry service
Contact Phone	12 (92)	A	Phone number for other enquiries

4b. Operator Record 2

Record Identity	2 (1)	A	QQ - Bus Operator Continuation
Operator Address	78 (3)	A	Operator contact address in comma separated form

5 Interchange Records Indeterminate number of records

5a. Location Interchange

Record Identity	2 (1)	A	QG - Bus Location Interchange
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
First Location	12 (4)	A	Short code form of location
Second Location	12 (16)	A	Short code form of location
Interchange time	3 (28)	I	Minimum recommended interchange
time from			
			first location to second location
First Location	12 (31)	A	Short code form of location
Second Location	12 (43)	A	Short code form of location
Interchange time	3 (55)	I	Minimum recommended interchange
time from			

			first location to second location
First Location	12 (58)	A	Short code form of location
Second Location	12 (70)	A	Short code form of location
Interchange time	3 (82)	I	Minimum recommended interchange
time from			
			first location to second location
First Location	12 (85)	A	Short code form of location
Second Location	12 (97)	A	Short code form of location
Interchange time	3 (109)	I	Minimum recommended interchange
time from			
			first location to second location

5b. Cluster Interchange

Record Identity	2 (1)	A	QJ - Bus Cluster Interchange
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Cluster	12 (4)	A	Short code form of cluster
Interchange time	3 (16)	I	Minimum recommended interchange
time			
			within cluster
Cluster	12 (19)	A	Short code form of cluster
Interchange time	3 (31)	I	Minimum recommended interchange
time			
			within cluster
Cluster	12 (34)	A	Short code form of cluster
Interchange time	3 (46)	I	Minimum recommended interchange
time			
			within cluster
Cluster	12 (49)	A	Short code form of cluster
Interchange time	3 (61)	I	Minimum recommended interchange
time			
			within cluster
Cluster	12 (64)	A	Short code form of cluster
Interchange time	3 (76)	I	Minimum recommended interchange
time			

			within cluster
Cluster	12 (79)	A	Short code form of cluster
Interchange time	3 (91)	I	Minimum recommended interchange
time			
			within cluster
Cluster	12 (94)	A	Short code form of cluster
Interchange time	3 (106)	I	Minimum recommended interchange
time			
			within cluster

5c. Cluster Walk Links

Record Identity	2 (1)	A	QW - Cluster Walk Link
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Origin Cluster	12 (4)	A	Short code form of cluster
Destination Cluster	12 (16)	A	Short code form of cluster
Interchange time	3 (28)	I	Minimum travel time from
			origin cluster to destination cluster
Origin Cluster	12 (31)	A	Short code form of cluster
Destination Cluster	12 (43)	A	Short code form of cluster
Interchange time	3 (55)	I	Minimum travel time from
			origin cluster to destination cluster
Origin Cluster	12 (58)	A	Short code form of cluster
Destination Cluster	12 (70)	A	Short code form of cluster
Interchange time	3 (82)	I	Minimum travel time from
			origin cluster to destination cluster
Origin Cluster	12 (85)	A	Short code form of cluster
Destination Cluster	12 (97)	A	Short code form of cluster
Interchange time	3 (109)	I	Minimum travel time from
			origin cluster to destination cluster

6. Vehicle Type Records Indeterminate number of records

Record Identity	2 (1)	A	QV - Vehicle Type
Transaction Type	1 (3)	A	N = New

			D = Delete
			R = Revise
Vehicle Type	8 (4)	A	User code for vehicle type
Vehicle long type	24 (12)	A	Description of vehicle type

7. Route Description Records Indeterminate number of records

Record identity	2 (1)	A	QD - Route Description
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Operator	4 (4)	A	Short code form of operator identifier
Route Number	4 (8)	A	Route number used as public identifier
Route Direction	1 (12)	A	User code for route direction
Route Description one	68 (13)	A	Text description of route to distinguish direction from another

8. Bank Holiday Dates Indeterminate number of records

Record identity	2 (1)	A	QH - Bank Holiday
Transaction Type	1 (3)	A	N = New
			D = Delete
			R = Revise
Date of bank holiday	8 (4)	I	Date of bank holiday (yyyymmdd)

9. Association Records The two types of association record allow journeys on particular routes to be associated with each other, or allow two identified journeys to be associated. The form of association can be journey splits, journey joins, journey changes route number, journey is linked to a journey in another database (cross border) or journey has a guaranteed connection with another journey.

9a. Route Association Record This type of association is applied to all journeys on the route(s) defined by a pair of operator, route and direction codes.

Record Identity	2 (1)	A	QX - Route Association
Transaction Type	1 (3)	A	N = New D = Delete R = Revise
Operator 1	4 (4)	A	Short code form of first operator
Route Number 1	4 (8)	A	First route number
Route Direction 1	1 (12)	A	Direction code of first route
Operator 2	4 (13)	A	Short code form of second operator
Route Number 2	4 (17)	A	Second route number
Route Direction 2	1 (21)	A	Direction code of second route
First date of operation (yyyymmdd)	8 (22)	I	Start date of operation of association
Last date of operation (yyyymmdd)	8 (30)	I	Last date of operation of association
Operates on Mondays	1 (38)	I	} 0 = does not associate on day
Operates on Tuesdays	1 (39)	I	} 1 = associates on day
Operates on Wednesdays	1 (40)	I	}
Operates on Thursdays	1 (41)	I	}
Operates on Fridays	1 (42)	I	}
Operates on Saturdays	1 (43)	I	}
Operates on Sundays	1 (44)	I	}
Location association	12 (45)	A	Short code form of location of
Association Type through route	1 (57)	A	J = Routes join – route 1 should be
through route			S = Routes split – route 1 should be
			B = Routes cross border G = Guaranteed connection C = Vehicles change route number

9b. Journey Association Record This type of association is applied to a pair of journeys defined by a pair of operator and journey identifier codes.

Record Identity	2 (1)	A	QY - Journey Association
Transaction Type	1 (3)	A	N = New

			D = Delete
			R = Revise
Operator 1	4 (4)	A	Short code form of first operator
Journey Identifier 1	6 (8)	A	First journey identifier
Operator 2	4 (14)	A	Short code form of second operator
Journey Identifier 2	6 (18)	A	Second journey identifier
First date of operation (yyyymmdd)	8 (24)	I	Start date of operation of association
Last date of operation (yyyymmdd)	8 (32)	I	Last date of operation of association
Operates on Mondays	1 (40)	I	} 0 = does not associate on day
Operates on Tuesdays	1 (41)	I	} 1 = associates on day
Operates on Wednesdays	1 (42)	I	}
Operates on Thursdays	1 (43)	I	}
Operates on Fridays	1 (44)	I	}
Operates on Saturdays	1 (45)	I	}
Operates on Sundays	1 (46)	I	}
Location	12 (47)	A	Short code form of location of
association			
Association Type	1 (59)	A	J = Journeys join – journey 1 should be
through			
			S = Journeys split – journey 1 should be
through			
			B = Journeys cross border
			G = Guaranteed connection
			C = Vehicles change route number

Appendix 2: ATCO CIF files for Toytown

Weston - South Ferry ATCO CIF file (Annotated)

```
ATCO-CIF0500AIM EMS                          MIA 4.10.4
20040719150700
```

This line tells you it is an ATCO file, the version of ATCO and the fact it was created on 19th July 2004, at seven minutes past three in the afternoon

LOCATION AND ADDITIONAL LOCATION RECORDS FOLLOW

```
QLNTOY10001     WESTON, TOY TOWN                             1
```

QL: bus stop location in short form and longhand, for stop 'TOY10001', which is at Weston, Toy Town.

```
QBNTOY10001     201532   43984
```

QB: additional location information for stop 'TOY10001': the GR easting and northing

Stops are listed in the direction followed by the following journey(s)

```
GSTOY10001XX
```

Unclear what this line means, but it always contains the short code ('TOY10001') for the bus stop

```
QLNTOY10002     CENTRAL STOP POINT, TOY TOWN                 1
QBNTOY10002     201083   41531
GSTOY10002XX
QLNTOY10003     STATION ROAD, TOY TOWN                       1
QBNTOY10003     200720   41547
GSTOY10003XX
QLNTOY10004     GENERAL HOSPITAL, TOY TOWN                   1
QBNTOY10004     200562   41697
GSTOY10004XX
QLNTOY10005     SOUTH FERRY, TOY TOWN                        1
QBNTOY10005     199883   42281
GSTOY10005XX
```

OPERATOR RECORDS FOLLOW

```
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
```

QP: Bus operator record. TTB is the short form of the bus company name, the rest is long forms and contact phone numbers

QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT

QQ: more about the bus operator

JOURNEY RECORDS FOLLOW

QSNTTB 10000120040101 1111100 XR01 O

QS: Bus journey header: the service is run by TTB, has journey reference 100001, starts on the 1st Jan 2004, has no end date, runs Monday to Friday inclusive but not weekends (seven characters cols 30-36 show Monday to Friday, 1=running, 0=not running), is route number(i.e. bus number) R01 (R01), and is outbound (O)

Stops, times and fare information for journey 'TTB 100001' follow

QOTOY10001 0800 T1F1

QO: bus journey origin for stop 'TOY10001', departure time 0800, timing point and fare stage

QITOY10002 08050805B T1F0

QI: bus journey intermediate stop 'TOY10002', arrival and departure times 0805, timing point but not fare stage

QITOY10003 08100819B T1F0

QITOY10004 08150815B T1F0

QTTOY10005 0820 T1F0

QT: bus journey destination stop 'TOY10005', arrival time 0820, timing point but not fare stage

LOCATION AND ADDITIONAL LOCATION RECORDS FOLLOW

QLNTOY10005 SOUTH FERRY, TOY TOWN 1

QL: bus stop location in short form and longhand, for stop 'TOY10005'. The repetition of a QL line in the ATCO file tells us that a new journey is about to be described for stops in a different order.

QBNTOY10005 199883 42281

QB: additional location information for stop 'TOY10005': the GR easting and northing

Stops are listed in the direction detailed in the following journey(s)

GSTOY10005XX

QLNTOY10004 GENERAL HOSPITAL, TOY TOWN 1

```
QBNTOY10004    200562   41697
GSTOY10004XX
QLNTOY10003    STATION ROAD, TOY TOWN                      1
QBNTOY10003    200720   41547
GSTOY10003XX
QLNTOY10002    CENTRAL STOP POINT, TOY TOWN                1
QBNTOY10002    201083   41531
GSTOY10002XX
QLNTOY10001    WESTON, TOY TOWN                            1
QBNTOY10001    201532   43984
GSTOY10001XX
```

OPERATOR RECORDS FOLLOW

```
QPNTTB TOY TOWN BUS COMPANY   THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
```

QP: Bus operator record.

```
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
```

QQ: more about the bus operator

JOURNEY RECORDS FOLLOW

```
QSNTTB 10000220040101        1111100 XR01                  I
```

QS: Bus journey header: the service is run by TTB, is journey reference 100002, starts on the 1st Jan 2004, has no end date, runs Monday to Friday inclusive but not weekends, is route 1 (R01), and is Inbound (I)

Stops, times and fare information for journey 'TTB 100002' follow

```
QOTOY10005    0825    T1F1
QITOY10004    08300830B    T1F0
QITOY10003    08350835B    T1F0
QITOY10002    08400840B    T1F0
QTTOY10001    0845 T1F0
QSNTTB 10000320040101        1111100 XR01                  I
```

QS: Bus journey header: the service is run by TTB, is journey reference 100003, starts on the 1st Jan 2004, has no end date, runs Monday to Friday inclusive but not weekends, is route 1 (R01), and is Inbound (I)

Stops, times and fare information, for a journey 'TTB 100003', an hour later than the previous journey, follow. The names, codes and GRs of stops are not *repeated here because the journey follows exactly the same route as the previous one*

```
QOTOY10005     0825    T1F1
QITOY10004     09300930B    T1F0
QITOY10003     09350935B    T1F0
QITOY10002     09400940B    T1F0
QTTOY10001     0945 T1F0
```

LOCATION AND ADDITIONAL LOCATION RECORDS FOLLOW

```
QLNTOY10001     WESTON, TOY TOWN                                   1
QBNTOY10001     201532    43984
```

QL & QB: bus stop location and additional location information for the stops again. This information has already been given once, but was 'changed' to a different order for the Inbound journey. So it is repeated in the correct order for the Outbound journey here.

```
GSTOY10001XX
QLNTOY10002     CENTRAL STOP POINT, TOY TOWN                       1
QBNTOY10002     201083    41531
GSTOY10002XX
QLNTOY10003     STATION ROAD, TOY TOWN                             1
QBNTOY10003     200720    41547
GSTOY10003XX
QLNTOY10004     GENERAL HOSPITAL, TOY TOWN                         1
QBNTOY10004     200562    41697
GSTOY10004XX
QLNTOY10005     SOUTH FERRY, TOY TOWN                              1
QBNTOY10005     199883    42281
```

OPERATOR RECORDS FOLLOW

```
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
```

QP: Bus operator record.

```
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
```

QQ: more about the bus operator

JOURNEY RECORDS FOLLOW

```
QSNTTB 10000420040101        1111100 XR01                         O
```

QS: Bus journey header: the service is run by TTB, is journey reference 100004, starts on the 1st Jan 2004, has *no end date, runs Monday to Friday inclusive but not weekends, is route 1 (R01), and is Outbound (O) Stops, times and fare information for journey 'TTB 100004' (an hour later than journey 'TTB 100001') follow*

```
QOTOY10001    0900   T1F1
QITOY10002    09050905B   T1F0
QITOY10003    09100919B   T1F0
QITOY10004    09150915B   T1F0
QTTOY10005    0920   T1F0
```

The ATCO file may finish with a list of bank holiday dates, each line headed QH, but these probably aren't going to be relevant for the type of analysis we are doing. There is no line header to tell you that you have reached the end of a file.

Weston - South Ferry ATCO CIF file

```
ATCO-CIF0500AIM EMS                         MIA 4.10.4
20040719150700
QLNTOY10001    WESTON, TOY TOWN                         1
QBNTOY10001    201532   43984
GSTOY10001XX
QLNTOY10002    CENTRAL STOP POINT, TOY TOWN             1
QBNTOY10002    201083   41531
GSTOY10002XX
QLNTOY10003    STATION ROAD, TOY TOWN                   1
QBNTOY10003    200720   41547
GSTOY10003XX
QLNTOY10004    GENERAL HOSPITAL, TOY TOWN               1
QBNTOY10004    200562   41697
GSTOY10004XX
QLNTOY10005    SOUTH FERRY, TOY TOWN                    1
QBNTOY10005    199883   42281
GSTOY10005XX
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 10000120040101       1111100 XR01                O
QOTOY10001    0800   T1F1
```

```
QITOY10002     08050805B    T1F0
QITOY10003     08100810B    T1F0
QITOY10004     08150815B    T1F0
QTTOY10005     0820    T1F0
QLNTOY10005     SOUTH FERRY, TOY TOWN                              1
QBNTOY10005     199883    42281
GSTOY10005XX
QLNTOY10004     GENERAL HOSPITAL, TOY TOWN                         1
QBNTOY10004     200562    41697
GSTOY10004XX
QLNTOY10003     STATION ROAD, TOY TOWN                             1
QBNTOY10003     200720    41547
GSTOY10003XX
QLNTOY10002     CENTRAL STOP POINT, TOY TOWN                       1
QBNTOY10002     201083    41531
GSTOY10002XX
QLNTOY10001     WESTON, TOY TOWN                                   1
QBNTOY10001     201532    43984
GSTOY10001XX
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 10000220040101        1111100 XR01                      I
QOTOY10005     0825    T1F1
QITOY10004     08300830B    T1F0
QITOY10003     08350835B    T1F0
QITOY10002     08400840B    T1F0
QTTOY10001     0845 T1F0
QSNTTB 10000320040101        1111100 XR01                      I
QOTOY10005     0925    T1F1
QITOY10004     09300930B    T1F0
QITOY10003     09350935B    T1F0
QITOY10002     09400940B    T1F0
QTTOY10001     0945 T1F0
QSNTTB 10000320040101        1111100 XR01                      I
QOTOY10005     1025    T1F1
QITOY10004     10301030B    T1F0
```

```
QITOY10003    10351035B   T1F0
QITOY10002    10401040B   T1F0
QTTOY10001    1045 T1F0
QSNTTB 10000320040101        1111100 XR01                  I
QOTOY10005    1125    T1F1
QITOY10004    11301130B   T1F0
QITOY10003    11351135B   T1F0
QITOY10002    11401140B   T1F0
QTTOY10001    1145 T1F0
QLNTOY10001    WESTON, TOY TOWN                            1
QBNTOY10001    201532   43984
GSTOY10001XX
QLNTOY10002    CENTRAL STOP POINT, TOY TOWN                1
QBNTOY10002    201083   41531
GSTOY10002XX
QLNTOY10003    STATION ROAD, TOY TOWN                      1
QBNTOY10003    200720   41547
GSTOY10003XX
QLNTOY10004    GENERAL HOSPITAL, TOY TOWN                  1
QBNTOY10004    200562   41697
GSTOY10004XX
QLNTOY10005    SOUTH FERRY, TOY TOWN                       1
QBNTOY10005    199883   42281
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 10000420040101        1111100 XR01                  O
QOTOY10001    0900    T1F1
QITOY10002    09050905B   T1F0
QITOY10003    09100910B   T1F0
QITOY10004    09150915B   T1F0
QTTOY10005    0920    T1F0
QSNTTB 10000420040101        1111100 XR01                  O
QOTOY10001    0930    T1F1
QITOY10002    09350935B   T1F0
QITOY10003    09400940B   T1F0
QITOY10004    09450945B   T1F0
```

```
QTTOY10005     0950    T1F0
QSNTTB 10000420040101        1111100 XR01                  0
QOTOY10001     1000    T1F1
QITOY10002     10051005B    T1F0
QITOY10003     10101010B    T1F0
QITOY10004     10151015B    T1F0
QTTOY10005     1020    T1F0
QSNTTB 10000420040101        1111100 XR01                  0
QOTOY10001     1100    T1F1
QITOY10002     11051105B    T1F0
QITOY10003     11101110B    T1F0
QITOY10004     11151115B    T1F0
QTTOY10005     1120    T1F0
```

Outer Circle - Northend ATCO CIF file

```
ATCO-CIF0500AIM EMS                            MIA 4.10.4
200407231114
QLNTOY20001     OUTER CIRCLE, TOY TOWN                      X
QBNTOY20001     243002    58870
GSTOY20002XX
QLNTOY20002     INNER CIRCLE, TOY TOWN                      X
QBNTOY20001     242971    58864
GSTOY20001XX
QLNTOY20003     NORTHEND, TOY TOWN                          X
QBNTOY20003     242726    58906
GSTOY20003XX
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 20000120040101        1111100 XR02                  0
QOTOY20001     0800    T1F1
QITOY20002     08200820B    T0F0
QTTOY20003     0840    T1F0
QSNTTB 20000220040101        1111100 XR02                  0
QOTOY20001     1000    T1F1
QITOY20002     10201020B    T0F0
QTTOY20003     1040    T1F0
QLNTOY20003     NORTHEND, TOY TOWN                          X
```

```
QBNTOY20003    242726   58906
GSTOY20003XX
QLNTOY20002    INNER CIRCLE, TOY TOWN                      X
QBNTOY20001    242971   58864
GSTOY20001XX
QLNTOY20001    OUTER CIRCLE, TOY TOWN                      X
QBNTOY20001    243002   58870
GSTOY20002XX
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 20000320040101        1111100 XR02                  I
QOTOY20003    0900   T1F0
QITOY20002    09200920B   T0F0
QTTOY20001    0940   T1F1
QSNTTB 20000420040101        1111100 XR02                  I
QOTOY20003    1100   T1F0
QITOY20002    11201120B   T0F0
QTTOY20001    1140   T1F1
```

Northend - Southend ATCO CIF file

```
ATCO-CIF0500AIM EMS                          MIA 4.10.4
200407231201
QLNTOY20003    NORTHEND, TOY TOWN                          X
QBNTOY20003    242726   58906
GSTOY20003XX
QLNTOY30001    UPTOWN, TOY TOWN                            X
QBNTOY30001    242368   58808
GSTOY30001XX
QLNTOY10002    CENTRAL STOP POINT, TOY TOWN                X
QBNTOY10002    201083   41531
GSTOY10002XX
QLNTOY30002    SOUTHEND, TOY TOWN                          X
QBNTOY30002    242167   58608
GSTOY30002XX
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
```

```
QSNTTB 30000120040101        1111100 XR03                   O
QOTOY20003     0830  T1F1
QITOY30001     08350835B  T0F0
QITOY10002     08400840B  T1F1
QTTOY30002     0845  T0F0
QSNTTB 30000220040101        1111100 XR03                   O
QOTOY20003     0900  T1F1
QITOY30001     09050905B  T0F0
QITOY10002     09100910B  T1F1
QTTOY30002     0915  T0F0
QLNTOY30002     SOUTHEND, TOY TOWN                          X
QBNTOY30002     242167   58608
GSTOY30002XX
QLNTOY10002     CENTRAL STOP POINT, TOY TOWN                X
QBNTOY10002     201083   41531
GSTOY10002XX
QLNTOY30001     UPTOWN, TOY TOWN                            X
QBNTOY30001     242368   58808
GSTOY30001XX
QLNTOY20003     NORTHEND, TOY TOWN                          X
QBNTOY20003     242726   58906
GSTOY20003XX
QSNTTB 30000320040101        1111100 XR03                   I
QOTOY30002     0845  T0F0
QITOY10002     08500850B  T1F1
QITOY30001     08550855B  T0F0
QTTOY20003     0900  T1F1
QSNTTB 30000420040101        1111100 XR03                   I
QOTOY30002     0915  T0F0
QITOY10002     09200920B  T1F1
QITOY30001     09250925B  T0F0
QTTOY20003     0930  T1F1
```

North Ferry - Island ATCO CIF file

```
ATCO-CIF0500AIM EMS                          MIA 4.10.4
200407231259
QLNTOY40001     NORTH FERRY, TOY TOWN                       X
```

```
QBNTOY40001    242588   58348
GSTOY40001XX
QLNTOY40002    ISLAND, TOY TOWN                               X
QBNTOY40002    242587   58448
GSTOY40002XX
OPERATOR RECORDS FOLLOW
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
JOURNEY RECORDS FOLLOW
QSNTTB 40000120040101        1111100 XR04                     O
QOTOY40001    0855  T1F1
QTTOY40002    0900  T0F1
QLNTOY40002    ISLAND, TOY TOWN                               X
QBNTOY40002    242587   58448
GSTOY40002XX
QLNTOY40001    NORTH FERRY, TOY TOWN                          X
QBNTOY40001    242588   58348
GSTOY40001XX
OPERATOR RECORDS FOLLOW
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 40000220040101        1111100 XR04                     I
QOTOY40002    0955  T1F1
QTTOY40001    1000  T0F1
```

Uptown - General Hospital ATCO CIF file

```
TCO-CIF0500AIM EMS                           MIA 4.10.4
200409161757
QLNTOY30001    UPTOWN, TOY TOWN                               X
QBNTOY30001    242368   58808
GSTOY30001XX
QLNTOY10004    GENERAL HOSPITAL, TOY TOWN                     1
QBNTOY10004    200562   41697
GSTOY10004XX
```

```
QPNTTB TOY TOWN BUS COMPANY    THE TOY TOWN BUS COMPANY INC.
01 8118055  01 8118055
QQBUS STATION, 1 THE HIGH STREET, TOY TOWN, TT1 1TT
QSNTTB 50000120040101        1111100 XR05                    O
QOTOY30001    0853  T1F1
QTTOY10004    0858  T0F1
QSNTTB 50000220040101        1111100 XR05                    O
QOTOY30001    0903  T1F1
QTTOY10004    0908  T0F1
QSNTTB 50000320040101        1111100 XR05                    O
QOTOY30001    0913  T1F1
QTTOY10004    0918  T0F1
QSNTTB 50000420040101        1111100 XR05                    O
QOTOY30001    0923  T1F1
QTTOY10004    0928  T0F1
QSNTTB 50000520040101        1111100 XR05                    O
QOTOY30001    0933  T1F1
QTTOY10004    0938  T0F1
QSNTTB 50000620040101        1111100 XR05                    O
QOTOY30001    0943  T1F1
QTTOY10004    0948  T0F1
QSNTTB 50000720040101        1111100 XR05                    O
QOTOY30001    0953  T1F1
QTTOY10004    0958  T0F1
QSNTTB 50000820040101        1111100 XR05                    O
QOTOY30001    1003  T1F1
QTTOY10004    1008  T0F1
QLNTOY10004    GENERAL HOSPITAL, TOY TOWN                    1
QBNTOY10004    200562   41697
GSTOY10004XX
QLNTOY30001    UPTOWN, TOY TOWN                              X
QBNTOY30001    242368   58808
GSTOY30001XX
QSNTTB 50000920040101        1111100 XR05                    I
QOTOY10004    0859  T1F1
QTTOY30001    0904  T1F1
QSNTTB 50001020040101        1111100 XR05                    I
```

QOTOY10004	0909	T1F1		
QTTOY30001	0914	T1F1		
QSNTTB 50001120040101			1111100 XR05	I
QOTOY10004	0919	T1F1		
QTTOY30001	0924	T1F1		
QSNTTB 50001220040101			1111100 XR05	I
QOTOY10004	0929	T1F1		
QTTOY30001	0934	T1F1		
QSNTTB 50001320040101			1111100 XR05	I
QOTOY10004	0939	T1F1		
QTTOY30001	0944	T1F1		
QSNTTB 50001420040101			1111100 XR05	I
QOTOY10004	0949	T1F1		
QTTOY30001	0954	T1F1		
QSNTTB 50001520040101			1111100 XR05	I
QOTOY10004	0959	T1F1		
QTTOY30001	1004	T1F1		
QSNTTB 50001620040101			1111100 XR05	I
QOTOY10004	1009	T1F1		
QTTOY30001	1014	T1F1		