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# **Assessing Transport Accessibility for Healthcare Facility Reconfiguration Using GIS and Multilevel Modelling**

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## Abstract

Transport accessibility to healthcare facilities is a major issue in the United Kingdom, as recently demonstrated by the shift away from 'providing healthcare in acute hospitals' to 'care closer to home'. Common measures of accessibility focus on the creation of distance or travel time contours around a destination and devote less attention to individual differences such as user perceptions, their transport usage, and area-wide factors including income deprivation, safety and security. Failure to account for such factors may result in imperfect decision making in terms of healthcare relocation and reconfiguration. This thesis therefore aims to develop a user-based accessibility model by focusing on both individual socio-economic (e.g. age, gender, access to transport modes) and area-wide characteristics (e.g. income deprivation, public transport provision, safety and security).

In order to identify important factors that affect accessibility and to develop the user-based accessibility model, two revealed preference questionnaire surveys were undertaken at Loughborough and Hinckley. The purpose of the first questionnaire was to understand underlying factors affecting accessibility to a healthcare facility. The results revealed that both individual and area-wide factors affect transport accessibility to a healthcare facility. The purpose of the second questionnaire was conducted to capture data relating to users' perception of accessibility and their socio-economic factors so as to develop a user-perception based accessibility model. Network-based travel time and travel distance as well as public transport provision data from a respondent home to a healthcare facility were generated using a GIS technique. Individual-level questionnaire data were then integrated with the other secondary datasets (e.g. Census, Index of Multiple Deprivation, Accidents) using postcodes of survey respondents.

Both single-level and multilevel mixed-effects linear regression models were employed to develop a relationship between user-perceptions relating to accessibility and the factors influencing accessibility. Multilevel models that can control data from the two levels (i.e. individuals nested within local areas) provided better goodness-of-fit statistics compared with those of single-level regression models. The results indicate that travel distance by car, number of available direct bus services, age, and destination choices affect user-perceptions of accessibility to a healthcare facility. For instance, if travel distance by car increases by one mile then the perception of accessibility to a healthcare facility decreases by four units (on a scale of 0-100). Surprisingly, many area-wide factors such as security and safety, income deprivation were found to be statistically insignificant.

In order to see which healthcare facility is more accessible, calibrated multilevel models along with number of people within the catchment area were then employed to predict the overall accessibility score related to a healthcare facility. This is important for policy makers in healthcare facility relocation and reconfiguration with respect to user perception of transport accessibility. Also it would be valuable to organisations that need to make decisions based on their users' perceptions who are the real decision makers as to whether to use a facility or not.

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## List of Abbreviation

**AIC:** Akaike Information Criterion  
**APM:** Accessibility Prediction Model  
**ARS:** Accessibility Rating System  
**BIC:** Bayesian Information Criterion  
**BREEAM:** Building Research Establishment's Environmental Assessment Method  
**DfT:** Department for Transport  
**DH:** Department of Health  
**EPSRC:** Engineering and Physical Sciences Research Council  
**FCA:** Floating Catchment Area  
**GIS:** Geographical Information System  
**GP:** General Practitioners  
**HaCIRIC:** The Health and Care Infrastructure Research and Innovation Centre  
**HBCH:** Hinckley and Bosworth Community Hospital  
**HDH:** Hinckley and District Hospital  
**HES:** Hospital Episode Statistics  
**HPSA:** Health Professional Storage Areas  
**IMD:** Index of Multiple Deprivations  
**LCC:** Leicestershire County Council  
**LCH:** Loughborough Community Hospital  
**LCR:** Leicestershire County and Rutland  
**LIFT:** Local Improvement Finance Trust  
**LLSOA:** Lower Layer Super Output Area  
**MAE:** Mean Absolute Error  
**MAPE:** Mean Absolute Percentage Error  
**ML:** Multilevel  
**NHS:** National Health Service  
**NMT:** Non-Motorized Vehicle  
**ONS:** Office of National Statistics  
**PCO:** Primary Care Organizations  
**PCT:** Primary Care Trust  
**PFI:** Private Funding Initiative  
**QS:** Questionnaire Survey  
**SDSS:** Spatial Decision Support System  
**SHA:** Strategic Health Authorities  
**SHAPE:** Strategic Health Asset Planning and Evaluation  
**SOA:** Super Output Area  
**VMT:** Vehicle Miles Travelled  
**WHO:** World Health Organization  
**WIC:** Loughborough Walk in Centre NHS

# 1 INTRODUCTION

## 1.1 Background

While healthcare providers are keen to provide facilities for all through a reasonable fair accessibility policy, increasing demands and expectations for healthcare services, as a result of the growth in population and life expectancy, has made reconfiguration of accessible healthcare facilities more problematic in recent years (CBI, 2012).

Accessibility to healthcare facilities is a major issue in the United Kingdom, as demonstrated recently by the shift away from 'providing healthcare in acute hospitals' to 'care closer to home' in order to obtain the benefits of integrating health and social care with other local service providers and to address health inequalities (Darzi, 2007). Ease of access to healthcare facilities is a priority in the United Kingdom and elsewhere since there is a direct relationship between health inequalities and access to healthcare facilities (Asthana and Gibson, 2008). Individuals and organisations have identified the need for improved transport accessibility, such as:

*"To create a fairer NHS, we have to focus on improving access to health and social services"* (Darzi, 2007; pp. 21).

*"Poor access to healthcare imposes costs on both the patient and the health provider"* (SEU, 2003; pp. 111).

*"There was a strong message that people can still find it difficult to access services. Improving access is a priority articulated in every vision, across every pathway of care. Each region will continue to improve the quality of access by reducing waiting times for treatment, whilst ensuring that services are available regardless of where a patient lives. The plans to improve dementia services in the West Midlands, and South Central's goal to deliver round the clock palliative care for children, are just two of the many examples where the local NHS will transform access to services for patients"* (NHS CM, 2008; pp. 19).

*"Unemployment and low incomes are both linked to poorer health, which can be made worse in rural areas by limited access to transport"* (Dorset PCT, 2008; pp. 109).

As a result of these observations and recommendations, healthcare services within the UK are being reconfigured to make available high quality and 'close to home' care facilities so as to renew the NHS for the new century (CIB, 2012). Meanwhile, the most



important principle of the NHS in the UK, and health services elsewhere, is equal (or at least fair) access to health (NHS, 2009).

While travel time, travel distance or travel cost are the main factors in assessing whether a journey to a destination is accessible or not, many other factors may impact users' perception of accessibility to a healthcare facility. Factors such as the availability of different travel modes, safety and security are factors which may need to be considered, for example, transport modes could be important from two different aspects:

- their impact on public health: in line with Commission for the Built Environment (2007) recommendations, new healthcare facilities and sites should be planned and developed across England according to principles that promote active transport and healthy lifestyles (NHS, 2009);
- their impact on the environment: in view of the recent UK policy decisions aimed at decreasing energy consumption and CO<sub>2</sub> emissions, and given the contribution of the transport sector in this area, consideration should be given to the transport implications for accessibility issues.

According to the NHS Sustainable Development Unit (NHS, 2009) report, the NHS is responsible for five per cent of all road traffic in England and travel accounts for 18 per cent of the NHS CO<sub>2</sub> emissions in England. Research reveals that CO<sub>2</sub> emissions from transport are projected to rise quickly (PBL, 2012).

On the other hand, distribution, accessibility and availability of healthcare services are unavoidably unequal since distance travelled and available modes of transport for accessing healthcare facilities are changing over time. Also, the spatial distribution of population and demand for healthcare requires planning for accessing healthcare facilities. Individuals are geographically scattered and have different age, gender, needs, socio-economic status and deprivation characteristics. This affects their demands for healthcare, their ability to travel to obtain care services, and the modes of transport they are willing and able to use.

Common measures of accessibility focus on the creation of distance or travel time contours around a destination and devote less attention to individual differences such as users' perception, their transport usage and area-wide factors including income deprivation, safety and security. Failure to account for such factors may result in poor decision making in terms of healthcare relocation and reconfiguration and may result in health inequality with respect to accessibility to healthcare facilities.

As mentioned, barriers such as distance, time and cost are not the only concern of users to access to healthcare facilities. In addition to these factors, users' preference must be considered to measure the accessibility (Liu and Zhu, 2004; Geertman and Van-Eck, 1995), therefore, the concept of accessibility is not necessarily limited to distance, time or cost. Therefore a user-based accessibility model can provide more accurate measurement of accessibility by focusing on both individual socio-economic and area-wide characteristics.

## **1.2 Aim and Objectives**

This research aims to model user's perception of accessibility by focusing on both individual socio-economic (e.g. age, gender, access to transport modes) and area-wide characteristics (e.g. income deprivation, public transport provision, and safety and security). This research also seeks to support the philosophy of providing fairer access to healthcare facilities and help make better decisions about future healthcare facility reconfigurations and developments. In order to achieve this aim, the following objectives have been formulated.

1. To explore accessibility and transport issues associated with travelling to healthcare facilities.
2. To investigate the potential of employing GIS and statistical methods in measuring and assessing transport accessibility to healthcare facilities.
3. To determine important factors that affect accessibility to healthcare facilities.

4. To develop a user-based accessibility model of healthcare facilities using statistical methods.
5. To develop recommendations for assessing accessibility to healthcare facilities with respect to reconfiguration and relocation.

### **1.3 Thesis Outline**

This thesis is organised into nine chapters namely:

**Chapter 2** explores different study areas of this work and the necessity of this research. Furthermore, this chapter provides a literature review of accessibility definition and the related issues of accessibility in healthcare, transport and CO<sub>2</sub> emissions.

**Chapter 3** provides a literature review of main approaches and theories in measuring accessibility and the various factors which influence accessibility to healthcare facilities. This chapter introduces several previous practical studies and the tools developed in assessing accessibility to healthcare facilities. It also presents the capabilities of geographic information system (GIS) in analysing the required spatial and non-spatial data.

**Chapter 4** presents the methodology of this thesis using different methods such as: quantitative and qualitative questionnaire surveys; multilevel regression modelling; and accessibility prediction modeling. Details of the econometric model used to analyse the users' perception of accessibility are presented in this chapter.

**Chapter 5** explores the data from the questionnaire surveys and from various spatial and non-spatial secondary datasets. It looks at the merging, cleansing and processing of the datasets to be used in the modelling using GIS techniques. This chapter presents the descriptive statistics of the data along with the data characteristics.

**Chapter 6** presents the results of the first questionnaire survey to identify important factors affecting accessibility to healthcare facilities. This chapter studies underlying factors used for the statistical models of this research.

**Chapter 7** presents the findings from the multilevel modelling. Eight types of multilevel models are tested using the data described in Chapter 5. Separate models are also developed for all respondents, for the respondent with car ownership, and for direct and indirect bus services to the hospitals of the study area hospitals.

**Chapter 8** discusses the results of the first questionnaire survey and the findings of the multilevel modelling from Chapter 6 and Chapter 7. This chapter also presents implications and applications of this research.

**Chapter 9** concludes this research including: the limitations of the methodology used in this thesis; direction for further research; and contribution to knowledge.

## **1.4 Summary**

Current approaches to measuring accessibility primarily focus on the creation of accessibility contours based on distance or travel time and therefore such methods ignore individual differences and area-wide factors. This may result in health inequality with respect to accessibility to healthcare facilities.

This research intends to develop a user-based accessibility model by focusing on both individual transport usage (i.e. users' perception and their transport usage) and area-wide factors (e.g. transport network, public transport provision, safety/security and area deprivation).

Findings from this research have value to organisations such as NHS that need to make decisions based on the users' perceptions as to whether to use a facility or not.

## 2 REVIEW OF TRANSPORT, HEALTHCARE AND ENERGY

### 2.1 Introduction

*"Transport can be a barrier to accessing care. The Social Exclusion Unit estimates that 1.4 million people miss, turn down, or simply choose not to seek health care because of transport problems" (Department of Health, 2006).*

International organisations such as United Nations and the World Health Organization (WHO) consider accessibility to healthcare facilities as an essential right (Humphreys and Smith; 2009). Accessibility to a care service for all is important as we know faster accessibility can save lives. Many people cannot gain proper healthcare services just because of poor accessibility and not because of poor care. Accessibility to facilities for human needs such as healthcare have their own special characteristics because of the users' different requirements and its speciality or even unique limitations. Social Exclusion Unit (SEU, 2003) stated that 20% of patients had difficulty to access a hospital; also 50% of older people have difficulty to travel to London hospitals and 30% to visit their doctor.

Accessibility to healthcare is actually poorer in areas of greater need (Darzi, 2007), for example, Figure 2-1 shows the area-wide spatial distributions of life expectancy for men and GPs per 100,000 populations and, although the spatial units are different, these two factors are correlated to each other. For instance, areas concentrated in London, the Midlands, Yorkshire, North West, and North East are broadly matched. This is also true for the case of life expectancy for women and the figure is same for women (Darzi, 2007).

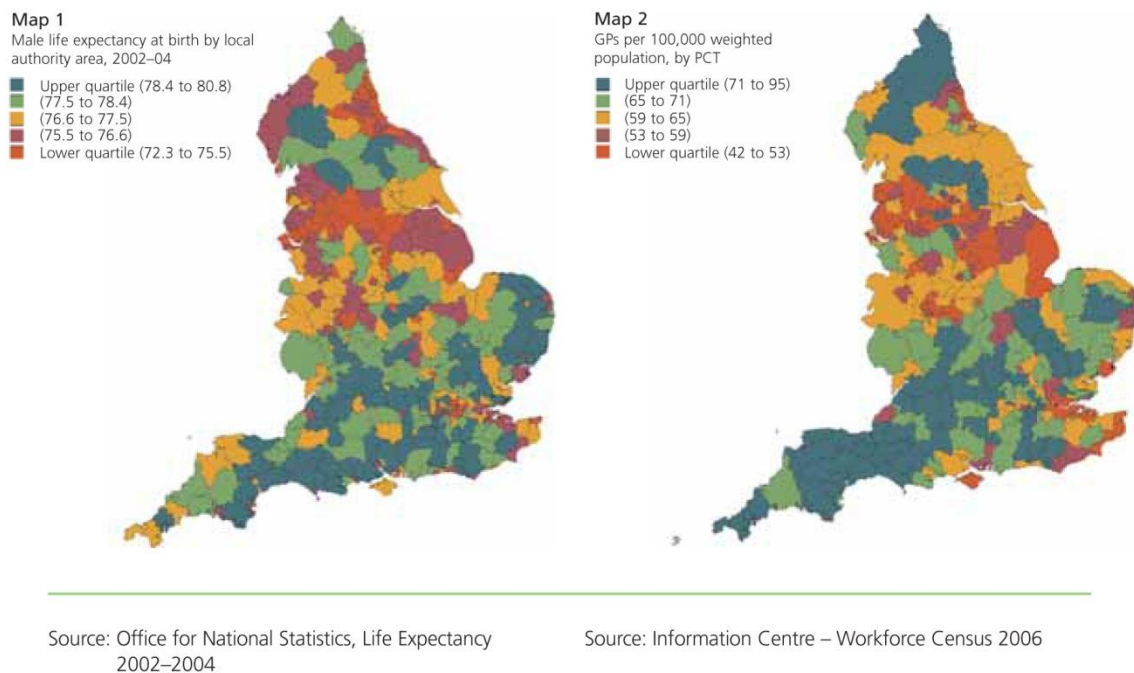


Figure 2-1: Relationship between access to GPs and life expectancy in the UK

There are a wide range of issues that could be considered regarding the assessment of transport implications associated with healthcare facilities reconfiguration. *'Healthcare'*, *'Transport'* and *'Energy'* are the three main potential study areas of this research (see Figure 2-2). In terms of the stakeholders, three main policy makers may be able benefit from this research including: *'Users'* who are going to access healthcare facilities, care service providers or *'NHS'*, and *'Energy Policy Makers'* who are looking for reducing carbon emissions. These three different stakeholders may have three different criteria to assess accessibility. For example, *'Users'*, who are the real decision makers as to whether to use a healthcare facility or not, seek easy access to healthcare facilities. The NHS look for 'care close to home' which is their main current criterion in terms of accessibility. Finally reduction of fuel consumption and carbon emission can be one of the targets for *'Energy Policy Makers'*. Figure 2-2 shows that there are several common areas among healthcare, transport and energy issues that can express regarding the research approach. Therefore, there are many different variables and factors need to be considered to assess accessibility to healthcare facility.

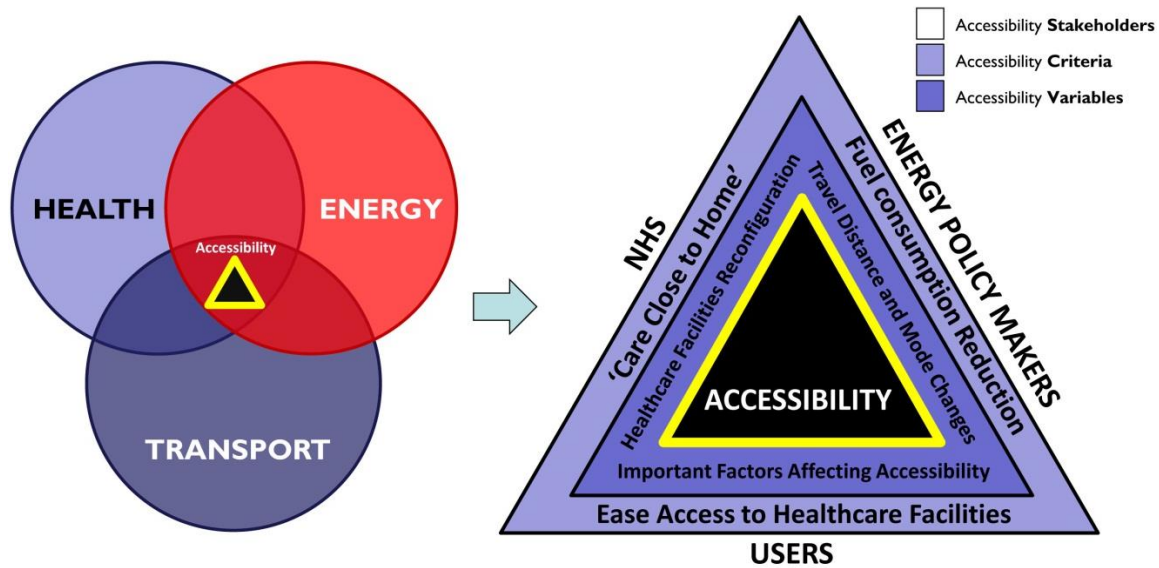


Figure 2-2: A schematic relationship between the study areas of this research

Current drivers to change, healthcare trends and related methods of assessing accessibility relate directly to this research, these include: equity, transport fuel consumption, transport plan, care close to home, reconfiguration of healthcare facilities; population care needs (e.g. age, obesity, and expectations); and quality of care provision (e.g. GP, community and acute hospital) and location of GP surgeries.

This chapter explores the necessity of this research by considering a number of issues related to healthcare, transport and fuel consumption. A literature review is provided which highlights the necessity of carrying out the present work.

This chapter is designed as follows: section 2.2 discusses the definition of accessibility from different points of view. Subsequently sections 2.3, 2.4 and 2.5 explore the relationship between different issues of accessibility to healthcare facilities such as healthcare reconfiguration issues, transport issues, and the relationship of CO<sub>2</sub> emissions and public health. Finally a summary concludes this chapter by introducing the problems in accessing different levels of healthcare facilities.

## 2.2 Definition of Accessibility

Ease of access to appropriate healthcare facilities is essential for health, quality of life and some social activities. Accessibility to different places such as hospital, school, park, and business centres can be different according to the different criteria and usage (Van-Ristell, 2011). Also, people may have different priorities regarding ease of access according to the time, distance, cost, available mode and many other factors (Humphreys and Smith, 2009).

‘Accessibility’ and ‘access’ concepts are often used interchangeably in many disciplines such as social science and health, but they are not same (Humphreys and Smith; 2009). Access refers to the capability of healthcare users to gain services at the right place and time without considering of geographical location, socioeconomic status or social conditions (Humphreys and Smith, 2009). In the broad view of access, there are five related concepts: ‘accessibility’, ‘availability’, ‘accommodation’, ‘affordability’ and ‘acceptability’ (Penchansky and Thomas, 1981).

- ‘Accessibility’ relates to the location of suppliers and the location of users.
- ‘Availability’ refers to the timely provision of appropriate healthcare facilities and services that meet users’ demands.
- ‘Accommodation’ refers to allocation of healthcare services and the method which have been organised to meet users’ needs and demands.
- ‘Affordability’ is the relationship between cost of healthcare services and the ability to pay.
- ‘Acceptability’ discusses to users manners toward healthcare providers, and providers’ approaches in regards to characteristics of the users (Penchansky and Thomas, 1981).

Due consideration of these definitions need to be taken into account when exploring related factors affecting users’ physical accessibility and their perceptions, for example, a report released by the UK Social Exclusion Unit (SEU 2003) to measure healthcare



accessibility using some main questions as: “can people get to key services at reasonable cost, in reasonable time and with reasonable ease? Does transport exist between the people and the service? Do people know about the transport, trust its reliability and feel safe using it? Are people physically and financially able to access transport? Are the *services and activities within a reasonable distance?*” (SEU, 2003, pp. 1). In addition to using geographical measurement of healthcare facilities accessibility, users’ social backgrounds and their attitudes need to be considered. Consequently, there are many different factors and methods that need to be used when defining and assessing accessibility.

### **2.3 Transport Implications of Healthcare Reconfiguration**

Poor access can reduce the utilisation of healthcare services and result in poorer health results and illness (Joseph and Phillips, 1984; Haynes, 1987; Watt et al., 1993; Jones and Bentham, 1997). Low utilisation of facilities and services is of major concern to the patients, as the primary care provides an access gate to secondary and higher levels of care provision. Also, a lack of general practitioner (GP) services may reduce patients’ use of more acute hospital services (Cox, 1995). There are concerns regarding current levels of an inequality in primary care provision in the UK, for example, Mid Devon PCT has over twice as many GPs per head compared to Oldham PCT (Darzi, 2007). Unequal access and distribution of GPs across the UK over the past few decades has started to change and measures taken to improve equity in the availability and accessibility of GP services (Asthana and Gibson, 2008). Because of the important role of the quality of healthcare facilities and influence of healthcare reconfiguration on accessibility studies, this section explores the healthcare reconfiguration issues associated with accessibility.

There are several levels of care; also care providers categorise their services in several types and levels. Accessibility to each of these levels may need to be discussed separately according to the users’ demand and the healthcare facilities provided. On the other hand, users may choose different modes of transport to access different levels of healthcare facilities. The average travel time to a hospital is longer in comparison to access to a GP. Figure 2-3 shows that the longest average travel time in England occurs in case of accessing hospitals which is increased up to 2011 (DfT, 2012a). It is perhaps

due to the factors such as: longer travel distance; serious illness of the hospital users; or lack of public transport services to hospital.

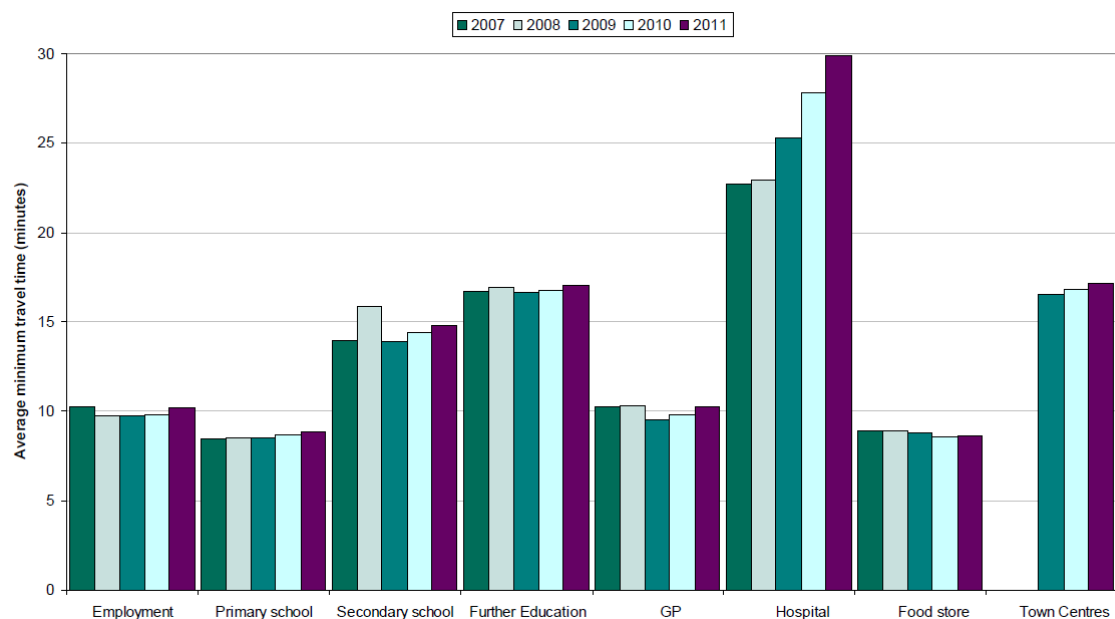


Figure 2-3: Average minimum travel time by public transport and walking (DfT, 2012a)

Furthermore, accessibility to different level of healthcare facilities (e.g. GP, dentist, and hospital) may vary depending on the area (e.g. urban or rural). Figure 2-4 compares the percentage of users in accessing key services by using public transport/walking in rural and urban areas. It shows that 52% of people in rural areas accessed to a GP by public transport/walking, while only one third used public transport (17%) to access to a hospital (DfT, 2012a). It is perhaps due to higher availability of closer GPs in comparison with hospitals as well as the poor availability of bus services in urban areas.

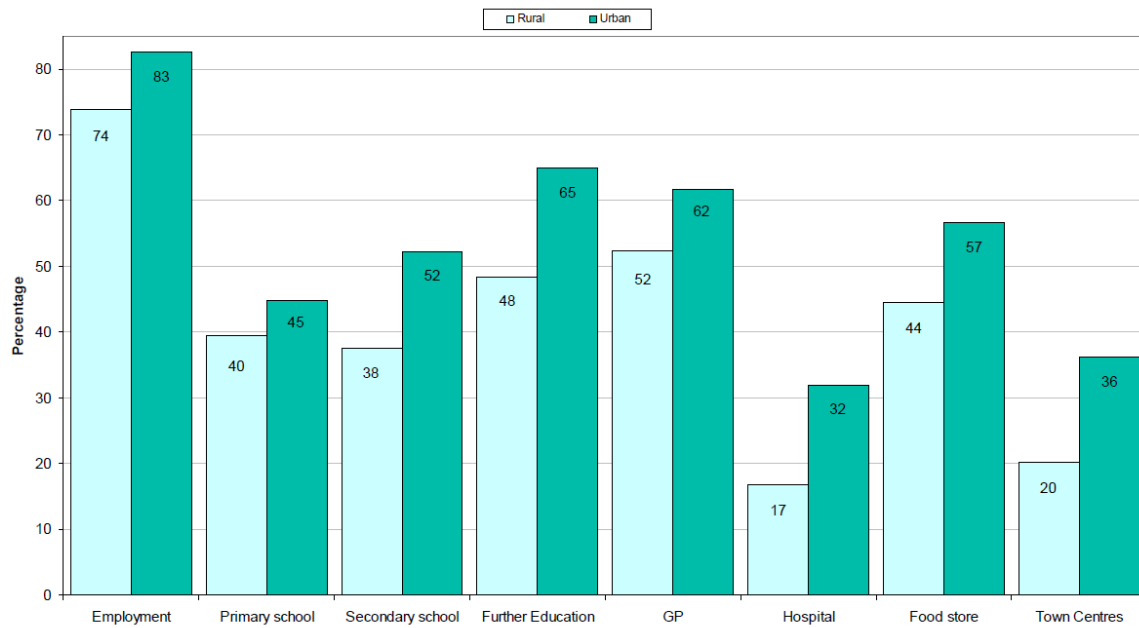


Figure 2-4: Access to key services in England in rural and urban areas (DfT, 2012a)

By considering the recent changes in the UK care levels and reconfiguration of hospitals and primary care facilities, accessibility studies will be given a priority (Darzi, 2007). The trends of providing healthcare facilities and the services have changed over time. For example, England health administration was considerably reorganized in 2006 (ONS, 2009) and the number of Strategic Health Authorities (SHAs), Primary Care Organisations (PCOs), and Primary Care Trusts (PCT) have been changed in recent years too. Some of the current trends of NHS system can affect healthcare facilities configuration; and these reconfiguration or relocation might affect users' perception of accessibility to the healthcare facilities. Any reconfiguration of healthcare facilities (e.g. healthcare facilities, size, building services) has the potential to influence users' perception of accessibility.

Some of the current reconfiguration in NHS can have implications on users' accessibility to the healthcare facilities. There is a need to study the users' accessibility for any reconfiguration such as following approaches:

- **NHS Local Improvement Finance Trust (LIFT)** was set up in 2001 to introduce a new model for investing in primary care. This model establishes new companies for co-locating healthcare facilities and services by integrating primary and community care services (Russell, 2008).

- **Telecare or Telehealth** technologies are part of NHS strategy to reconfigure healthcare systems. These systems enable users to stay in their own homes to reduce traveling to healthcare facilities (NHS Humber, 2012)
- **Private Funding Initiative (PFI)** allows NHS to get support from the private sector to build, finance and operate a new healthcare facility (Broadbent et al., 2004).

Employing the above approaches may provide different facilities or services in comparisons to previous situation. The location of healthcare facilities may change in order to provide improved services. All of these changes have the potential to change users' perception of accessibility; and a healthcare with poor accessibility may put the entire project at risk (NHS, 1999). Therefore studies on users' perception of accessibility can help the NHS policy makers to evaluate their on-going reconfiguration in terms of accessibility.

Since the reconfigurations would change over time, therefore, it is also required to update the assessment of accessibility by employing an appropriate methodology. The assessment methodology needs to be independent from system reconfiguration and has a good connection with the users' expectations and accessibility perceptions.

According to the Department of Health definition, primary care centres have care for minor injuries and illnesses, and minor surgery. The GPs, nurses, dentists, pharmacists and opticians are the first contact point for most people (NHS, 2008). Secondary care provides hospital care for conditions which cannot be dealt with by primary care trusts. This includes hospital trusts (or acute trusts), mental health trusts, foundation trusts, care trusts, and ambulance trusts (DH, 2007). PCTs commission primary care services from "GP practices, dentists, opticians and pharmacies", and secondary care services from "the acute, mental health and care trusts" in their area.

Most health services (such as primary care, dentists, optometrists and other private health practitioners) generally operate in unclear market boundaries or geographical catchments, therefore, flexible spatial analysis will help the care policy makers to provide holistic and accurate assessment for healthcare accessibility (McGrail and

Humphreys, 2009). By understanding and defining the role and demands of each care level and other care services (e.g. emergency or hospital-based care), healthcare availability could be considered as well as the healthcare spatial accessibility.

In the UK, more than 80 per cent of the patients use primary care level. Second and third levels of care accessed through the primary care and millions of the UK population gain community based care, however, in terms of people's experience to access the primary care services, many people faced pressing challenges, such as long waiting times, poor building facilities and winter crisis. Therefore, accessibility to the primary care needs to take further action now to resolve these challenges (Darzi, 2007).

In conclusion, assessing accessibility to healthcare facilities helps the NHS decision makers to identify the implications of any new configuration. Since people have different specifications (e.g. care demands, expectations and perceptions) and they come from different locations (e.g. urban or rural area, and accessibility to public transport), any reconfiguration has different impacts on peoples' accessibility. Therefore a study on transport implications of healthcare facility reconfiguration can help the NHS investors to reduce their construction and development risks (NHS, 1999)

## 2.4 NHS Transport and Energy Consumption

More than 95 per cent of motorised transport systems use fossil fuel and it is evaluated that almost half of this fuel is used for transport. Figure 2-5 shows the historic and forecast traffic and the emissions in England (DfT, 2012b).

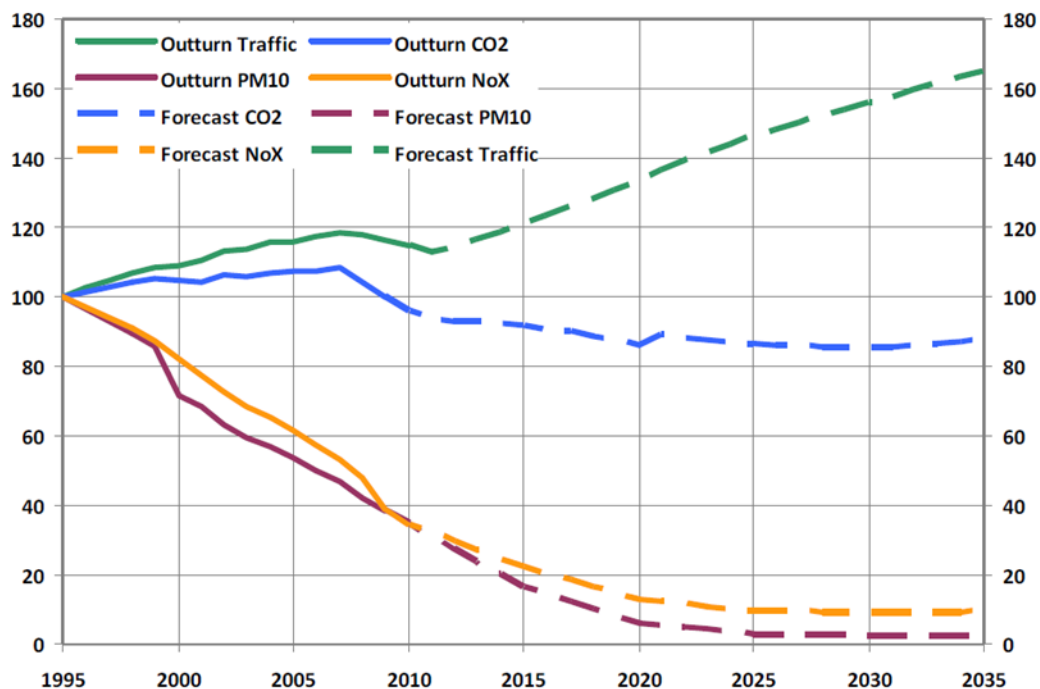


Figure 2-5: Predict traffic and the emissions in England (DfT, 2012b)

The only sector in the UK economy which its current emissions are higher than in 1990 is transport (CIT 2007). Private cars CO<sub>2</sub> emissions rose from 59 million tons in 1990 to 63 million tons in 2002, an increase of six per cent (Woodcock et al., 2007).

The NHS is the largest single organisation in the UK and responsible for average ten per cent of regional economies in England alone (EERA, 2001). Its annual budget is around £100 billion and has an important contribution to goods and energy deliveries in the UK. The NHS consumption of goods and services are vast and represent nearly 60 per cent of its total CO<sub>2</sub> emissions (NHS, 2009). According to the NHS Sustainable Development Unit (NHS, 2007), the NHS is responsible for five per cent of all road traffic in England and travel accounts for 18 per cent of the NHS CO<sub>2</sub> emissions in England.

The NHS also has the largest workforce of the NHS in Europe – with 1.3 million staff – and has a carbon footprint of more than 18 million tonnes of CO<sub>2</sub>, which is the biggest single public sector contributor to climate change (NHS, 2009).

Given the direct responsibility of the NHS for health and its vast energy consumption and resulting CO<sub>2</sub> emissions which impact on health, the NHS should aim be leading the way in CO<sub>2</sub> reduction and set an example for other organizations in the UK to follow. Because of this situation and position, the NHS has a vision to lead the population for reducing carbon emissions by shifting to low carbon travel such as public transport, cycling and walking. Having care for climate change, saving natural resources and the environment, all of these will have benefit for patients, staff and the all communities which the NHS service.

Building Research Establishment's Environmental Assessment Method (BREEAM) is a system for assessing the sustainability of buildings. BREEAM recommended all newly-built and existing healthcare facilities to reach or exceed excellent in the BREEAM travel and transport criteria (BREEAM, 2012). Besides many criterions, the issues of accessibility to healthcare facility have been considered as important assessment criterion for the BREEAM rating. The UK health authorities require assessing their healthcare facilities buildings to achieve the 'Tra' credit (BREEAM Healthcare, 2012). Some of the assessment criterion in transport section are: Tra 1, Provision of public transport; Tra2, Proximity to amenities; Tra 3, Cyclist facilities; Tra 4, Pedestrian and cyclist safety; Tra 5, Travel plan; Tra 6, Maximum car parking capacity; and Tra 7, Travel information point (BREEAM, 2012). All of these 'Tra' are going to assess the user's accessibility to a building. For example, 'Tra 3' wants to "encourage building users to cycle by ensuring adequate provision of cyclist facilities" (BREEAM Transport, 2012; pp:7); and 'Tra 6' intends "to encourage the use of alternative means of transport to the building other than the private car" (BREEAM Transport, 2012; pp:16).

Figure 2-6 shows a 3% rise per year in total emissions of England NHS during period 1992 to 2004. Travel issues are part of these carbon emissions (NHS, 2008a).

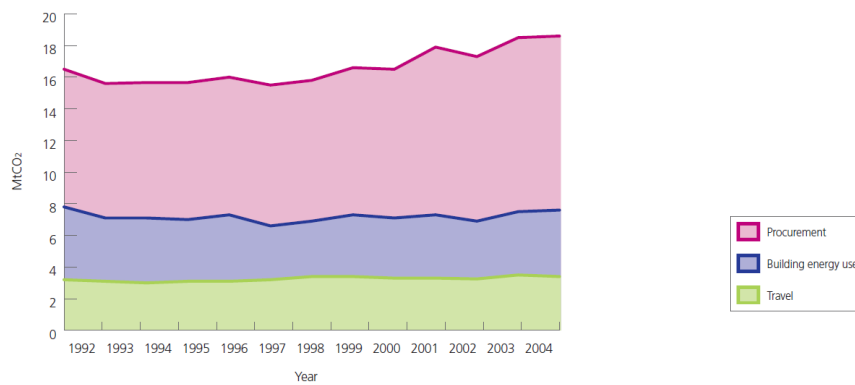


Figure 2-6: NHS England expenditure and emissions 1992-2004  
(NHS, 2008A)

The UK Department for the Environment, Food and Rural Affairs' (DfT, 2006) reported that transport emissions between 1990 and 2004 increased by nine per cent. According to the Department for Transport (DfT, 2006), carbon dioxide emissions from cars consist 13 per cent of the UK total by source, and transport CO<sub>2</sub> emissions will raise by 35 per cent between 1990 and 2030 if there is no change in current energy consumption patterns. Most travel to access healthcare facilities involves short distance and 56 per cent of all journeys by car are less than five miles (DfT, 2007), therefore healthcare accessibility and travel issues can be considered to be associated with these activities.

In total, the NHS contributes of 3.2 per cent of all CO<sub>2</sub> emissions for the whole of England. Figure 2-7 shows the three main section of carbon footprint in NHS sector. Travel comprises 18 per cent of the NHS carbon footprint which is equal 3.41 Mt CO<sub>2</sub>. Travels issues include all ranges of the NHS users as patients, visitors and staffs (NHS, 2008a).



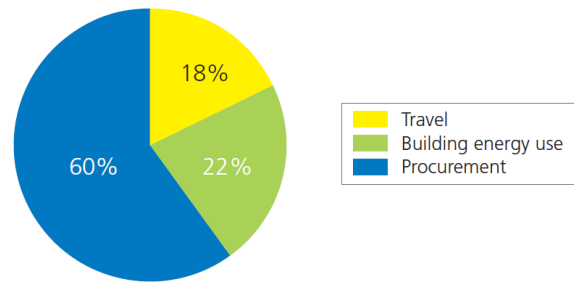


Figure 2-7: The NHS CO<sub>2</sub> emissions (NHS, 2008a)

Improving accessibility and reducing travel will have beneficial impacts on both health and CO<sub>2</sub> emissions. Encouraging people to change their travel mode from private car to public transport or other modes such as walking and cycling will also reduce health problem and CO<sub>2</sub> emissions (NHS, 2008b). The NHS SDU and the Stockholm Environment Institute have developed an analytical model to determine the impact of CO<sub>2</sub> emissions which can be used by the NHS to 2020 (NHS SDU, 2009). Figure 2-8 shows historical emissions data from previous work, future expenditure profiles and forecast emissions for NHS (NHS ECE, 2009).

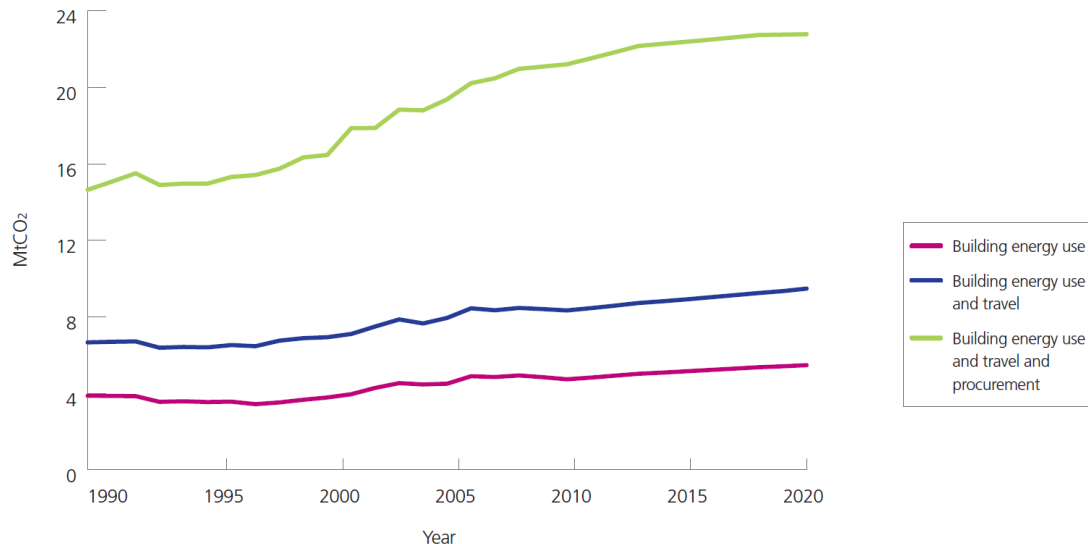


Figure 2-8: NHS England emissions forecast 2020 (NHS ECE, 2009)

In summary, by considering the fact that the NHS has a considerable contribution in energy consumption in the UK, it seems there is a considerable margin of reductions in CO<sub>2</sub> emissions specifically from NHS transport, therefore fuel consumption in travel to healthcare facilities has been included within this research.

## **2.5 Transport, CO<sub>2</sub> Emissions and Health Relationships**

Chronic disease including diabetes related to physical inactivity has been on the increase due to current life style and excessive car use. Physical activity has a key effect on health. Insufficient physical activity causes various problems for health (Littman, 2009).

Woodcock et al., (2007) explored relationships between transport, energy and health for land transport. As Figure 2-9 shows, some issues are associated with these three study areas (healthcare, transport and energy) such as injuries, lack of physical activity, global warming, air pollutions, access, and disability.

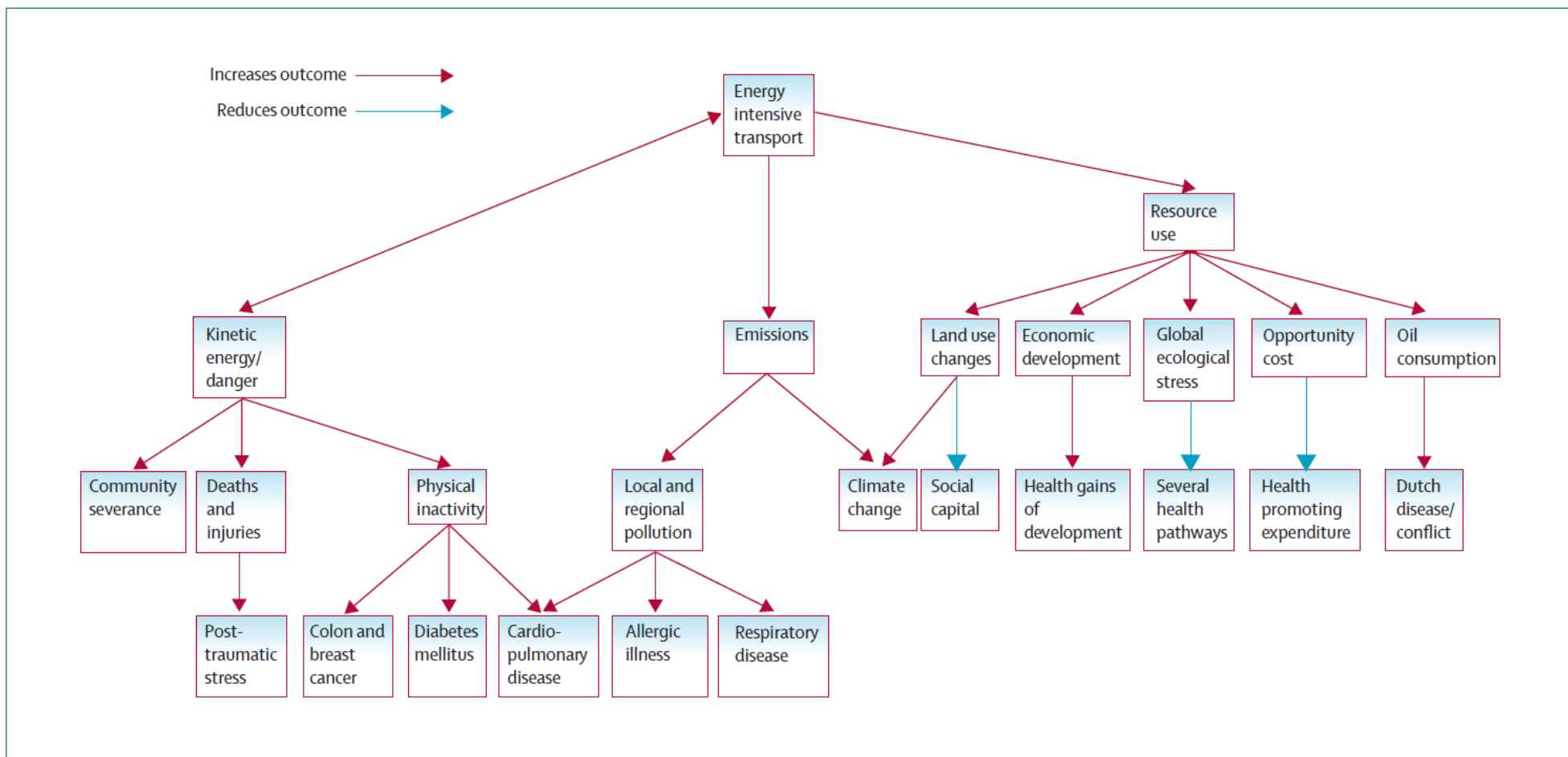


Figure 2-9: Selected pathways among transport, energy and health  
(Woodcock et al., 2007)

Driving cars reduces physical activity, while walking or using bike and public transport usually include more physical activity. Heinrich et al. (2005) established that as a result of increased transport pollution, there are many evidences of increased death, respiratory morbidity, allergic sickness and symptoms, cardiopulmonary death, non-allergic respiratory illness, and myocardial infarction and lung cancer. Also air pollution interrelates with physical inactivity on cardiovascular disease, as well as diabetes illness.

WHO (2011) stated that air pollution is responsible of 1.3 million deaths per year, mainly in developing countries. In terms of 'access and community severance' high level accessibility to markets, employment, education, healthcare services, and social networks is necessary for health and life quality. Woodcock et al., (2007) believe that there are four main plans to reduce CO<sub>2</sub> emissions of transport while access and equity are improving: avoiding journeys as much as possible; improving energy efficiency and considering alternative energy sources; decreasing travel distances; and choosing suitable mode of travel. Therefore there are many factors and strategies which can be considered during this research investigation.

NHS Good Corporate Citizenship Assessment Model (GCCAM, 2012) is a toolkit which is developed by the Sustainable Development Commission to help NHS organizations to become a low carbon organization. Figure 2-10 shows virtuous circle going to push the NHS to consider serious responsibilities and behaviours as a good corporate citizen to save money, benefit population health, and reduce health inequalities (NHS, 2009). As it can be seen in the figure, encourage more active travel such as walking and cycling can lead increase physical and mental health of people also will reduce traffic with fewer injuries and better air quality. Therefore all of these achievements will reduce levels of demand for health services and saving money for more investments in NHS.

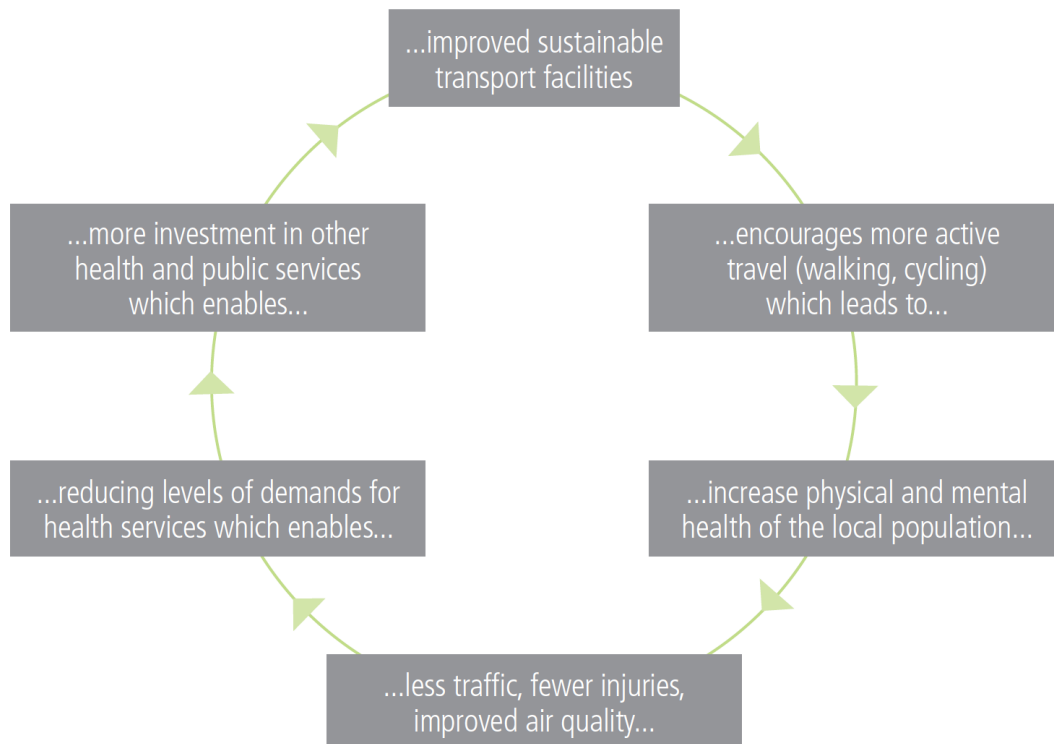


Figure 2-10: Virtuous circle for NHS Travel (NHS, 2009)

Since two-thirds of all trips in the UK are less than 5 miles, many of these journeys could be travelled by non-motorised vehicle (e.g. walking or using bike) or public transport (DfT, 2012c). Reducing the energy consumption will not only reduce carbon emissions and its bad effects, but also has other health benefits directly. Action to provide better accessibility to healthcare facilities will reduce the fuel consumption and benefit to improve health care system as a whole.

## 2.6 Summary

The concept of 'Access' is more complex than just measuring distance; it includes a broader set of factors relating to user's behaviours and perceptions (Boulos, 2003; Maroko et al., 2009). There are many factors and approaches to define the access and assess accessibility. While travel distance is important to measure accessibility, users' social backgrounds and their attitudes need to be considered.

Besides stakeholders who may be able to benefit from this research, users of healthcare facilities are the key stakeholders who are the real decision maker as to whether to use a healthcare facility or not, therefore, their priorities in accessibility as well as their demands on different levels of care need to be considered. Any new reconfiguration can

affected accessibility to existing different levels of care; therefore all important stakeholders, criteria and variables need to be considered in this research to measure accessibility to healthcare facilities.

More active travel such as walking and cycling can increase physical and mental health of people and also will reduce road traffic. Travel by bus or walking and cycling not only will reduce fuel consumption but also has other health benefits directly. Action to assess accessibility to healthcare facilities will help policy makers to understand the current usage of alternative modes of transport such as public transport, walking and cycling versus private car.

Users' demands and the NHS system configuration change over time. Users' perception of accessibility can also be altered over time due to changing expectations and available transport infrastructure. There is a need to study a flexible methodology to assess accessibility for different situations and scenarios. The methodology needs to be generalised in assessing accessibility to healthcare without dependency to any specific conditions such as: healthcare system; locations; available mode of transport; and individual and area-wide characteristics. There is a lack of research to identify the most important criterion and factors influencing accessibility and develop a generalizable methodology to be used by different stockholders.

Regarding to this chapter's literature review and discussions, research problem can be introduced as five following problems in terms of accessibility and considering different levels of healthcare:

1. Assess accessibility to existing hospital.
2. Impact of reconfiguring or relocating a hospital on accessibility considering:
  - a) closer hospital and open new one; and
  - b) closer facility and use other hospital.
3. Impact of access when relocate services from a big hospital to several community hospitals.
4. Assess location of GP services to integrate in several new GP (care in London).
5. Impact of resolve PCT's to GP's according to the recent policy of the UK government.

### **3 REVIEW OF ACCESSIBILITY MEASUREMENT APPROACHES**

#### **3.1 Introduction**

This chapter reviews previous research relating to accessibility and the approaches used. In addition, some previously developed tools and models which are useful for this research have been critiqued. Since the research involved spatial and non-spatial data processing and analyses, part of this chapter has been allocated to GIS as a versatile tool. The review of literature is therefore structured as follows:

- accessibility measurement and approaches;
- access by different travel modes;
- geographic information systems (GIS) analysis and accessibility modelling;
- factors affecting on accessibility (spatial and non-spatial);
- review of proper tools and techniques; and
- review of previous research and gaps.

The review starts by looking into accessibility measurement approaches, theories of accessibility and mode of transport. This chapter then introduces applications of GIS in modelling and discuss factors affecting accessibility, as spatial and non-spatial in healthcare accessibility. This chapter reviews some models and tools in assessing accessibility to healthcare facilities which have been developed and used around the world. More than 30 studies relating to practical application of accessibility research have been summarised and categorised to review their methods, criteria, and achievements and to identify any gaps which have not been discussed.

#### **3.2 Approaches and Theories of Accessibility**

Evaluating existing healthcare services in terms of transport accessibility, investigating relocation and reconfiguration of healthcare facilities, using service area profiles to assess accessibility, processing spatial and non-spatial data, and involving CO<sub>2</sub> emissions studies need to use comprehensive research approach to consider all important factors

influencing accessibility. This section of the literature review intends to review the main theories and useful approaches in assessing transport accessibility associated with healthcare facilities' relocation and reconfiguration. Transport infrastructures are designed in such a way that people spend less time to access more destination or facilities. When moving to activity and resource locations is the main concern, accessibility will be one of the most important issues for providing a better service. In addition, there are several concerns and challenges to make a fair policy to access healthcare facilities and provide proper health services. One of these challenges is the relationship between distance to healthcare facilities and the healthcare demands. Other factors such as financial status, time limitations, social inconvenience and difficulty of the journey to the healthcare facilities affect healthcare accessibility (Roovali and Kiivet, 2006).

Access to a destination can be categorised according to two aspects (Khan, 1992): 'potential' versus 'realized', and '*spatial*' versus '*non-spatial*'. These can be further categorised into four aspects: (i) potential spatial access, (ii) potential non-spatial access, (iii) realized spatial access, and (iv) realized non-spatial access. While realized accessibility focuses on the real use of healthcare services, potential accessibility indicates the possible access to the healthcare facility, but does not guarantee the routine use of the provided services (Joseph and Phillips, 1984; Khan, 1992). Spatial access focuses on the importance of the spatial/distance barrier, where the non-spatial access emphasizes non-geographic barriers, such as socio-economic status, health status, ethnicity, age and gender (Joseph and Phillips, 1984; Khan, 1992; Meade and Earickson, 2000). Since the late 1970s and early 1980s, many efforts have been made to develop quantitative measures of healthcare accessibility and spatial access research in health care services (Khan, 1992; Comber et al., 2011; Blanford et al., 2012).

Joseph and Phillips (1984) expressed measures of spatial accessibility in two sections: regional 'availability' and regional 'proximity'. The regional availability is expressed as a population (users/demand) to healthcare provider (supplier) ratio within an area, which is simple and easy to apply. But high regional availability of services does not provide assurance of high accessibility, because it depends on the regional proximity of users to



those services. On the other hand, close regional proximity does not assure high accessibility because it depends on how many residents there are to use the available services (Luo and Wang, 2003), therefore to measure spatial accessibility, both of these two components, availability and proximity, need to be measured together.

Geertman and Van-Eck, (1995) stated that any accessibility measurements need to combine distance between origin and destination, and the utility of the destinations. These two components are incorporated by using 'comparative' or 'composite' measures. The first considers distance between origin and destination; and the second considers the benefit of different destinations. Comparative measures deal with the numbers of accessible destinations within a distance. Composite measures combine distance and benefits of various destinations. Composite measures can be easier and more useful to use GIS as a potential model which this tool will be used in this research (Geertman and Van-Eck, 1995).

In order to study accessibility, it needs to identify existing methods and criteria to measure accessibility. There are several approaches which can be different according to the aim and conditions of a measurement. Miller (1999) categorised measuring accessibility into three major theoretical approaches as follows.

- 1) *Constraints-based approach:*** This theory is the best implemented space-time prism (Hagerstrand et al., 1975). The space-time prism sets the limits of all locations in space-time that can be accessed by an individual based on locations such as home and work and durations of compulsory activities and the travel speed limitations. This theory does not deal with the varying attractiveness of different opportunities (Miller, 1999). A time geographic approach is a more sensitive measure for different accessibility studies especially when the research is involved with some limitations and constraints such as a demographic, social, economic and cultural context. Hagerstrand's (1970) space-time framework is a powerful and structured approach for analysing constraints to access to facilities and opportunities. It considered the most necessary conditions for most human interaction (Miller, 2003). One way to apply this approach is to identify the address

of the user (home or work) so that a network model can be utilised to estimate travel time for given OD pairs.

**II) Benefit Approach:** This theory's approach is according to the benefit of accessibility, it means the benefits of a person to a destination should be measured. *User benefit* and *location benefits* are the two approaches which are available for this theory. First, user benefit, has been developed by a random utility framework. This approach presupposes to measure individual benefits or preferences within a random utility framework (Williams, 1976; Ben-Akiva and Lerman, 1985). It means that accessibility is the expected maximum benefit of an option situation. Wilson (1976) transformed this strategy as a spatial interaction model to create a linear measure of the net benefits of interaction. According to the benefit approach, this research will develop a user-based model or customer-oriented approach so as to consider the users' benefit in accessing healthcare facilities. The users will score accessibility according to their benefit.

**III) Attraction-accessibility Measures (AMs):** This is the most frequent accessibility measure theory in spatial interaction-based. This theory weights the attractiveness of opportunities against cost of the travel to access the destination (Geertman and Van-Eck, 1995; Hansen, 1959). Weibull (1976) developed a framework to define accessibility measurement, but this framework does not state what we should be measuring exactly when we want to measure accessibility. Attraction can be employed for both sides of origin and destination, therefore, it can be useful when the research needs to measure accessibility from the users side as well as the provider side. Since this research approach will be based on the incorporation of many factors into users' perceptions of accessibility, this means the users will score overall accessibility based on their interests and the attraction of destination against travel cost, travel distance, safety and security. This research approach can also support providers in identifying and prioritising the most attractive healthcare facility from the user point of view.

In order to employ the theoretical approaches to measure accessibility, three main practical methods are introduced to measure spatial accessibility as population to provider ratios, travel time/distance, and gravity model (Talen and Anselin, 1998; Guagliardo, 2004; Bagheri et al., 2006).

**I) *Population to Provider Ratios:*** The population to provider ratios approach is a simple ratio between populations within a specific boundary to the healthcare services within the boundary. While this simple ratio cannot be seen as an accurate measurement of accessibility analysis, ease of calculation and understanding of the result has made this approach a popular tool for initial policy analysis for healthcare accessibility (McGrail and Humphreys, 2009). There are two assumptions in population to provider ratios which should be considered: (1) the populations only have access to services within their own region; and (2) dimension is negligible within each region because no consideration is given to proximity. Therefore, large regions should be used because a lack of sensitivity to local accessibility differences may result. For the second assumption, this approach needs to be used for small regions to achieve an acceptable accuracy for proximity, but not for availability (Asada and Kephart, 2008; Fortney et al., 2000; Guagliardo, 2004; Luo and Wang, 2003; Pong and Pitblado, 2001). Also, users sometimes access healthcare services from other regions because of the proximity. It is not appropriate to assume any region as an island without any overlap or interactions with other near regions; and this is not a spatial analysis of accessibility. Since this research needs to measure accessibility from all spatial units within the catchment area to the healthcare facility, an accessibility prediction model will be developed based on the population and the age groups of each spatial unit in addition to other significant factors.

**II) *Travel time or distance:*** Measuring accessibility to the nearest service by calculating travel time or travel distance is a simple and regularly used measure of spatial accessibility (Fortney et al., 2000; Hewko et al., 2002; Rosero-Bixby, 2004; Murad, 2007; and Cheng et al., 2012). Because of using contour maps to show the accessibility, this measurement often introduced a 'contour measurement' (Curl et

al, 2011). While the nearest service to the user can be measured by this approach, this measurement does not consider regional availability. In this approach, proximity between users and location of service provider is considered instead of considering service provider capacity or the demand; however, a weakness of this model has been observed that, when several healthcare services are available for the users, they would bypass the nearest service in favour of other options. (Fryer et al., 1999; Goodman et al., 2003; Hyndman et al., 2003). Therefore, understanding the difference between accessibility and availability should be considered to measure accessibility. Travel distance and travel time will be the main factors of modelling accessibility in this research. Therefore user's home (or work) address will be employed to calculate their travel distance and time to the healthcare facility.

**III) Travel Gravity:** In addition to consider travel time or distance, by this approach a model can be developed to measure the spatial accessibility by considering proximity and availability together (Joseph and Phillips, 1984; Weibull, 1976). This model considers both the supply and demand side by reducing attractiveness of a healthcare service when distance or travel time to the service has been increased. Choosing or empirically determining the distance-decay function is one of the primary disadvantages of this approach, (Guagliardo, 2004; Joseph and Phillips, 1984; Luo and Wang, 2003). In addition, the gravity model tends to over emphasise the decay function, meaning that results are highly spatially smoothed (Luo and Wang, 2003), with significant concentric patterns of accessibility appearing. Thus, when rural areas are modelled, this pattern is aggravated for towns which are isolated, and where there is a low level of overlap for existing health care services. The demand and the supply sides of the gravity model will be considered in this research by considering the population and age groups of the origin (e.g. spatial unit) and the destination (e.g. healthcare facilities). In terms of the impedance between these two sides, some factors such as travel time, travel distance, fuel consumption, safety and security will be incorporated in this statistical modelling.

Besides the above reviews on accessibility measurement approaches, some other categorisations have also been classified such as 'infrastructure', 'utility', and 'activity' based measures (Curl et al, 2011). Bocarejo et al (2012) have classified urban mobility measurements into three main indicators as: 'infrastructure-based', 'activities/land use-based', and 'people-based'. Although some of these approaches have a stronger theoretical background and support, but they are hardly employed in practical studies because of their complexity and difficulties to use their output by a non-expert users (Curl et al, 2011).

The formulation for healthcare accessibility can be different according to the different approach of healthcare providers, users and stakeholders. For this reason and other differences such as social, political, cultural and the local environment, it needs to explore different existing approaches and models to measure accessibility. In addition there are many factors which affect the 'accessibility' to healthcare facility such as travel time, mode of transport, road network connectivity, users mobility, socio-economic barriers, health status including disability (Humphreys and Smith; 2009). Therefore, all factors, status and situation as well as policy makers and stockholders viewpoints should be considered in accessibility issues.

### **3.3 Private Car and Public Transport**

In the North Cornwall PCT's transport survey, around 80 per cent of respondents had problems in traveling to their local care facilities. Flexibility, independency and convenience are advantages of using the private car. Therefore compared with other travel modes such as public transport, walking and cycling, most people prefer to use the private car instead of other modes of transport (Hagman, 2003; Anable, 2004; Banister, 2005; Steg, 2005).

According to the DfT (2008), car ownership per household has increased dramatically since 1951 in the UK. Results show that the majority of households in the UK have more than one car per household. Increasing car ownership around the world has not only reduced public transport demand but also has increased CO<sub>2</sub> emissions and its negative effects (White, 2009). On the other hand, decreasing travel by car will reduce risk of

obesity, diabetes, heart disease, and mild mental illness, as well as reducing road traffic and the issues such as injuries and deaths, air pollution (NHS, 2009). Therefore, reducing travel by car and encouraging people to move by other modes of transport, will be one of the advantages of healthcare accessibility improvements.

### **3.4 GIS and Accessibility Modelling**

Geographic information systems (GIS) have been used as a versatile tool for analysing data. GIS has also been employed to model a spatial related phenomenon. 'Model' as a word has at least two meaning for GIS. While Burrough (1994) stated that GIS can be considered as a model of the real world, there are some who argue that GIS is not a modelling tool but can be integrated with models (Birkin et al, 1987). This disagreement can be understood when it is realized that the first argument refers to a descriptive model, while the second refers to an analytical model. A model can be defined as 'an idealized and structured representation of a part of reality' (Johnson-Liard, 1980). In this research, GIS has been used for pre-processing and post-processing of data as well as for data integration into the model.

In recent years measuring accessibility in a GIS environment has greatly improved and many tools have been developed using GIS advantages. Some of these tools have been introduced in Section 3.7 of this thesis. Besides using GIS as a tool, some analytical methods and analyses have been incorporated within the GIS software to use it as a model. Since accuracy and value of a model output depends on the quality of input data, using suitable GIS models and incorporated methods is important for accuracy of the modelling. On the other hand, GIS and the related applications have the ability to check accuracy of some data by comparing data from several sources. For example, by allocating patient location according to the geographical coordinate of each patient postcode, the patient information can be linked to many other available data such as census data, deprivation indices, available public transport, and accident data around the location. GIS has two main abilities, one is creating a relationship between map features and the data and the other is doing analysis according to the existing data and running different models in the study area. To measure accessibility to a facility, a

variety of models and tools have been developed and used; some of these models have been introduced in this chapter.

There are many research projects and studies using GIS applications for healthcare facility site selection. Most of these studies were applicable for very specific situations and were not able to generalize their applications for any other issues (Parker and Campbell, 1998; Nobre et al., 1999; Cromley and McLafferty, 2002; Rosero-Bixby, 2004; Murad, 2007). Most of this research was developed to be used for location-allocation purposes to determine an optimal location for one or more healthcare facility (Cromley and McLafferty, 2002; Vahidnia et al., 2009). For example, some studies have employed GIS technique in measuring accessibility to primary health care in an isolated or poor region (Perry and Gesler, 2000; Ahlström et al., 2011). Hare and Barcus (2007) likened the spatial distributions of healthcare services and travel times to heart-related hospitals in Kentucky to identify the spatial relationship between accessibility and health. Also, some combinations of GIS and Location-Based Services (LBS) have been developed to manage emergency situations (Sadoun and Al-Bayari, 2007; Maglogiannis and Hadjiefthymiades, 2007).

GIS as a versatile tool has been used in theoretical and practical purposes in transportation and accessibility analysis to improve the condition of access to healthcare services. Some of these analyses have been introduced and discussed in Section 3.8. Luo and Wang (2003) addressed the advantages of using GIS when integrating and defining the relationship between spatial and non-spatial attributed data, mapping spatial patterns interactively and amending any criteria adjustment and analysing the spatial relationship and complex computational tasks on the spatial data. Lovett et al. (1998) conducted research to assess healthcare demands by adding in GIS data and using patient data provided by general practitioners in an area. In order to quantify accessibility to healthcare services, a GIS-based network analysis (i.e. service area analysis) can be applied to measure the closest distance from each spatial unit (origin) to a healthcare facility (destination), therefore, employing GIS techniques can help this research to benefit the advantages of this versatile tool in assessing accessibility to healthcare facilities. GIS can be used to integrate collected data from different

secondary data sources; also it can create new data layers by cleansing and processing the required data as well as visualising the accessibility modelling results.

### **3.5 Factors Affecting Accessibility**

The people who can use healthcare services are determined by the difference in the availability or quality of services and by difficulties to access them. The difficulties to access healthcare facilities have a relationship with many factors and criteria such as values and beliefs, social and cultural, and even the incapability to pay. They are also caused by the difficulty of overcoming physical distance, which can be the main factor in rural regions (Joseph and Bantock, 1982).

Because of the scattered distribution of healthcare facilities and population (spatial factors), healthcare accessibility issues vary across space. In addition to these spatial factors, the population groups have different socioeconomic and demographic characteristics (non-spatial factors). The spatial factors are dealing with the geographical barriers (distance, time) between healthcare service providers and users, whereas the non-spatial factors emphasize the non-geographic barriers such as social class, income, ethnicity, age, and gender (Joseph and Phillips, 1984).

Since the 1960s, healthcare providers and policymakers have tried to improve healthcare accessibility in the United States by considering both spatial and non-spatial factors together (Meade and Earickson, 2000). According to the accurate assessment of the healthcare accessibility criteria by the US Department of Health and Human Services (DHHS, 2004) showed that both spatial and non-spatial factors are important to find Health Professional Shortage Areas (HPSA). DHHS provided a score ranking system by both factors for determining primary care HPSAs of greatest shortage. Travel distance/time to nearest source of accessible care is one of the scores for the assessment (DHHS, 2004).

Despite researchers considering the importance of both spatial and non-spatial factors for healthcare accessibility assessment, most of them assessed the two factors separately, for example: Khan (1992) and Luo and Wang (2003) studied spatial factors



for healthcare accessibility assessment; and Carr-Hill et al. (1994) and Field (2000) focused on non-spatial factors of healthcare accessibility. Integrating the two types of factors, spatial and non-spatial, are important in developing an effective assessment of healthcare accessibility into one framework. Wang and Luo (2005) adopted an integrated approach by assessing spatial and non-spatial factors for healthcare accessibility in defining health shortage area in Illinois, USA.

Accessibility measurement has a close relationship with different physical and social indicators and socio-economic factors (Ahlstrom et al., 2011). In terms of healthcare levels of demand and accessibility, population can be divided into various groups of users according to their age, gender, social class, ethnicity, and other non-spatial characteristics. Field (2000) provided a list of factors for healthcare accessibility studies and developed an index of relative advantages. According to the literature review and the DHHS guidelines (1998) for health professional shortage areas (HPSA) survey, the following variables are introduced.

**Demographic variables and characteristics** such as age and gender affect healthcare demand, for example, three population groups need special consideration for their care services: seniors with ages over 65; children age 0–4; and women age 15–44 have a higher demand to healthcare services (DHHS, 1998; Meade and Earickson, 2000). As different age groups have different demands, age profiles need to be considered when assessing accessibility to healthcare facilities.

**Health status** is obviously an important factor to determine the primary healthcare demand, and difference across the population. Specific common illness in special locations and long term illness should be considered but rarely available from data sources (Field, 2000). The type of urgent health problem, disability and help required are considered in health status of some researches (Humphreys and Smith, 2009). If health status data are available, it is recommended to consider it in accessibility assessment such as the UK 'Health and Disability' deprivation indices.

**Socioeconomic status:** may incur people to access care services, then socioeconomic factors such as income, home ownership, poverty, female headed households, are important factors to access care services (Meade and Earickson, 2000; Field, 2000).

**Living environment** and living conditions can be a factor in assessing accessibility to healthcare facilities. This factor respects to the characteristics of the living environment such as number of room per household. For example, Paez et al. (2010) considered household structure and urban form to investigate inequality in accessibility to healthcare facilities in their research area in Montreal, Canada.

**Awareness** can be an issue due to linguistic barrier, ethnicity, low level education, lower educational attainment may be associated with lower service awareness (Field, 2000), and linguistic isolation may make barrier to healthcare access (DHHS, 1998).

**Transportation mobility:** can be influenced by lack of household car(s) numbers, access to public transport, mobility and accessibility to physicians create important barrier to healthcare access (Field, 2000). Good mobility does not have necessary meaning of good accessibility. Considering both accessibility and mobility provides more potential to change users' travel behaviour (Handy, 2002).

### 3.6 Review of Practical Tools and Techniques

GIS is a suitable tool and platform for transportation and accessibility analysis. GIS Tools are useful to enhance, assess and improve research in healthcare accessibility and geography studies. Luo and Wang (2003) expressed three main GIS applications: to integrate and define the relationship between spatial and non-spatial attribute data; to map spatial patterns interactively and amend any criteria adjustment and modification; and to analyse the spatial relationship and perform complex computational tasks on the spatial data as the most important ability of GIS.

Also, cartographic GIS data are used for location-based studies in many place-based models. During these recent years, GIS accuracy and complexity of analyses has greatly improved to measure accessibility, therefore GIS has been used for many aspects such as the measurement of healthcare facilities proximity, distance to nearest care services and relationships between road network accessibility and disease pervasiveness. This versatile tool can be used to define the administration areas to provide primary care services, finding ratios of users per care services, determine impact of travel time and spatial factors analysis in service use patterns (Humphreys and Smith, 2009).

In order to identify applications and methods behind the developed tools as well as users' requirements, some related and useful software in measuring accessibility are introduced in this section. One of the first GIS-based software in measuring accessibility was developed by Miller and Wu (2000). This tool was named **Space-time accessibility measures (STAMs)**. STAMs can consider the locations and travel velocities which can be defined by a transportation policy as well as individuals' daily activity schedules. It has good link with ArcInfo and has user-friendly interfaces and project management tools. Stahle et al. (2007) developed the **Place Syntax Tool (PST)** as an extension of MapInfo. The extension is developed to measure accessibility and to analyse urban pedestrian movement. The model was added to MapInfo and it called the Place Syntax Tool.

**Accession** is an accessibility planning software commissioned by the DfT for transport system using GIS tools. Accession was developed to measure accessibility to and through a multi-modal transport system. This tool can calculate accessibility indices and apply

the indices and travel time information to identify the accessibility convenience for the users and can describe the transport system serving the public. Accession's contour maps can be spatially linked with demographic data for accessibility analysis (Figure 3-1). This software can transfer GIS formats data with MapInfo, ESRI or CAD (Accession Overview, 2012). This software can measure accessibility for specific times of day and days of the week as well as specific modes such as selected bus services running on selected routes (Titheridge, 2004).

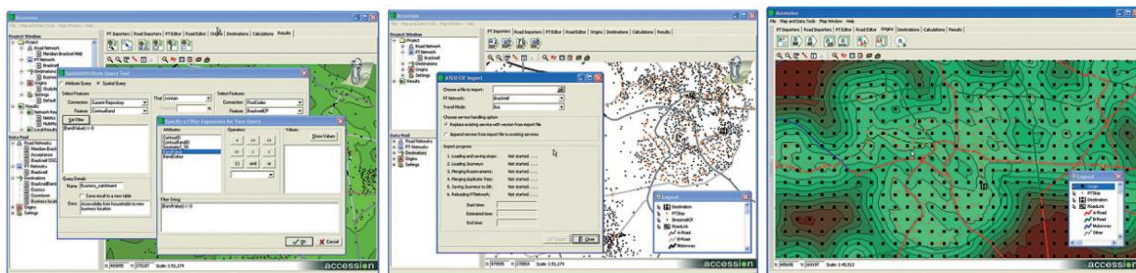


Figure 3-1: Accession calculates routes to the destination  
(Accession Overview, 2012)

**SHAPE (Strategic Health Asset Planning and Evaluation)** has been developed by the UK Department of Health for SHAs and PCTs. SHAPE is a web based tool in GIS environment. This software is pre-loaded with recent existing Hospital Episode Statistics (HES) data and 2001 census demographics, including GP practices and private hospitals (DH, 2009). The datasets include Key Performance Indicators (KPIs) relating to the Trust and PCT owned estate. It is aimed at SHAs and PCTs delivering service reconfiguration within a whole health economy. SHAPE is a helpful tool by using GIS mapping, demographic data and travel time analysis (DH, 2009). SHAPE website, <http://shape.dh.gov.uk> introduced it as an integral tool in the strategic planning process that can answer three key questions: Where are the users now? Where do the users want to be? How can the users get there?

Accessibility contours to a healthcare facility can be created by the SHAPE (Figure 3-2). The contours can be shown by car travel time, defined travel time as well as for specified location, postcode sector, age, and gender. While the SHAPE can calculate travel time by car, it cannot generate accessibility contours using travel time or travel distance by different travel modes (e.g. bus, bike, and walk). As this tool has been linked into the

NHS data, it has a good source of update data from existing healthcare facilities which is a valuable advantage of this tool.

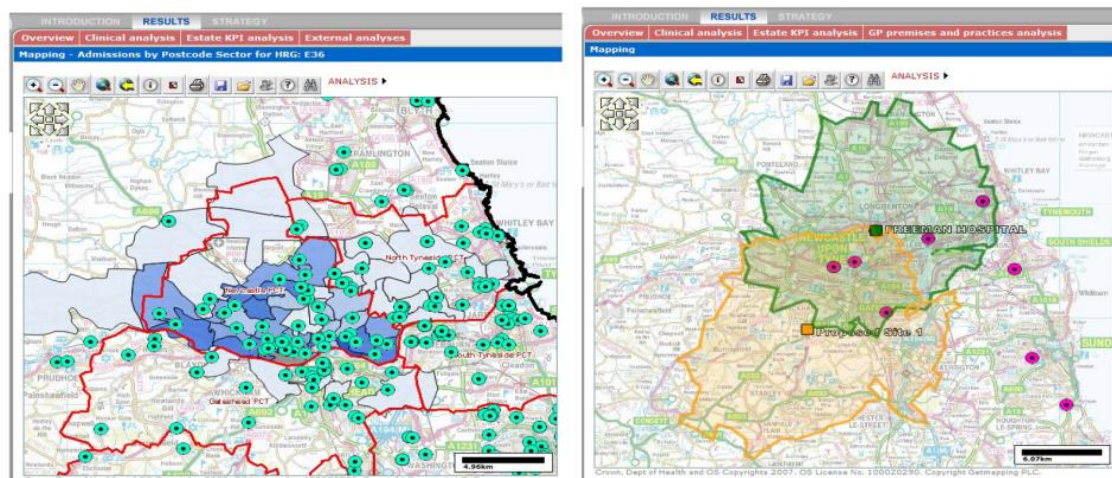


Figure 3-2: GP location and Travel time analysis in SHAPE  
(Source: [www.nepho.org.uk](http://www.nepho.org.uk))

**AccessMod** has been developed by World Health Organization (WHO) which works as an extension to the ESRI ArcView 3.x software which measures physical accessibility to health care (Figure 3-3). This extension introduced as “Modeling Physical Accessibility to Health Care and Geographic Coverage” with two other abilities: estimating geographical coverage for an existing healthcare facility network by combining availability and accessibility coverage; and when there is not sufficient information of the existing network, AccessMod can provide cost effectiveness analysis for the network (AccessMod, 2009). AccessMod can: analyse accessibility to healthcare facilities using terrain information and census data; define catchment area by travel time, measuring accessibility by combination of accessibility and healthcare facilities availability; and introduce solutions to balance existing healthcare facilities are the main abilities of this tool (Ray and Ebener, 2008).

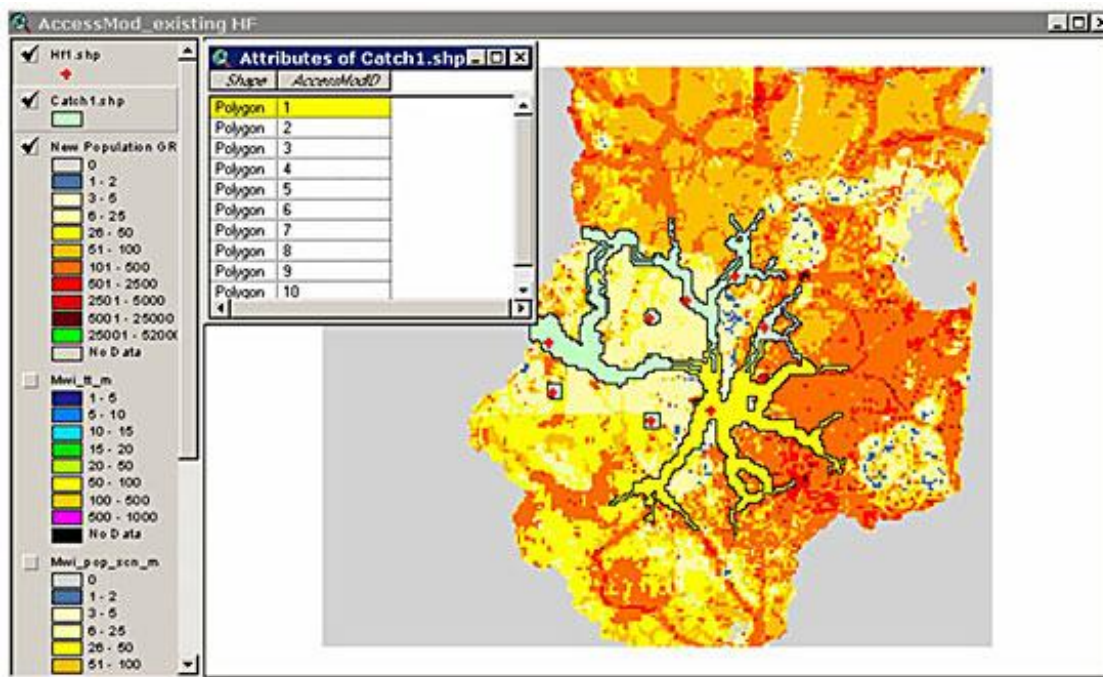


Figure 3-3: AccessMod works as an extension of ESRI ArcView (AccessedMod, 2009)

**SIGEpi** (Geographic Information System in Epidemiology and Public Health) provides tools and interfaces to perform bio statistical and spatial analysis to support decision-making in public health (Figure 3-4). This software has a good ability of data visualization and using files in Shapefile and ArcInfo coverage formats from ESRI (SIGEpi, 2009).

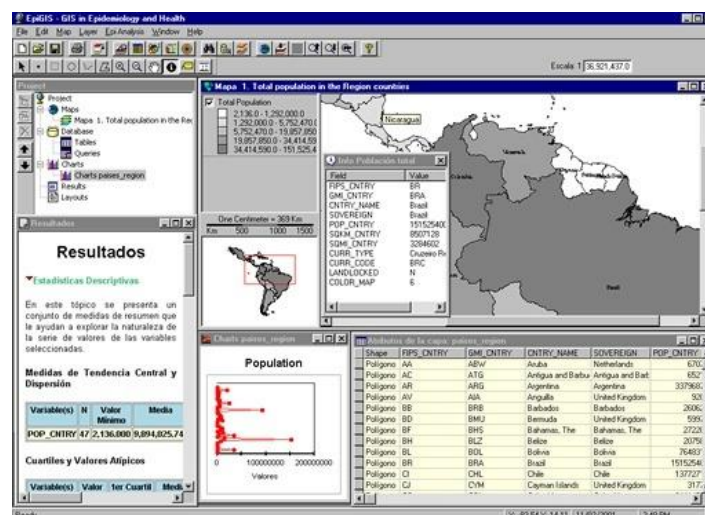


Figure 3-4: SIGEpi interface works in GIS environment of ArcView (SIGEpi, 2009)

The two recent applications, AccessMod and SIGEpi, use travel time and distance as a spatial indicators for measuring accessibility to healthcare facilities; and can use data



such as demographic data, land cover, road network, elevation, administrative boundaries, and healthcare facilities location.

One useful software for this type of research is **CommunityViz** which works as an extension of ArcGIS from ESRI (Figure 3-5). This software helps planners, decision makers, local authorities, and other users to make decisions as a GIS-based decision-support tool. It is possible to use AHP (Analytic Hierarchy Process) method in GIS environment and define several scenarios about development, growth modelling, transportation, land use and more. Create custom analyses for geographic decision-making process, export resulted map to Google Earth, create scenes and using SiteBuilder 3D to develop interactive 3D scenes is possible in this software (CommunityViz, 2012).

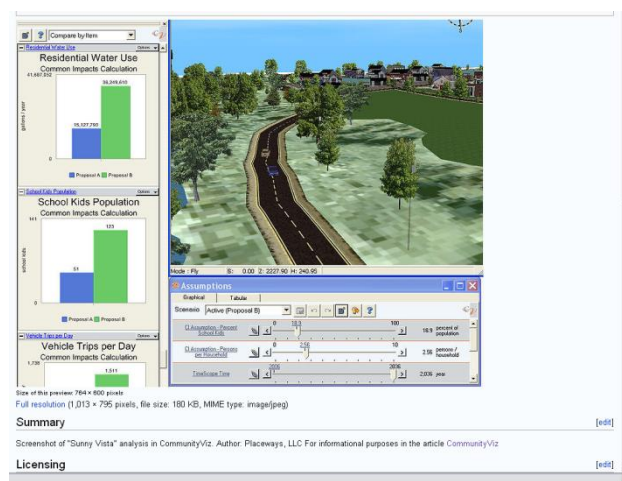


Figure 3-5: Screenshot of "Sunny Vista" analysis in CommunityViz (Placeways, LLC)

Transport Scotland (2008) categorized accessibility modelling to three categories: Category 1: accessibility by walking and cycling by considering mode, frequency, time, and type of destination; Category 2: accessibility modelling for transport network by using travel planning techniques; and Category 3: accessibility demand models with considering spatial relationships.

While the tools are useful to measure accessibility, there is a lack of consideration in relationship to a user's preference in travelling to healthcare facility. Different people

have different demand on healthcare services and it can vary for different locations, for example, safety and security may be able to affect their priority to choose a healthcare facility in terms of accessibility.

### **3.7 Review of Previous Practical Research in Healthcare**

In order to explore appropriate methods in assessing accessibility to healthcare facilities, this section introduces selected previous practical research applications and explores the: research problems; available data sources; employed methods; potential gaps; and the related approaches. It also intended to identify main objectives of the previous practical research and identify important criteria and factors which were considered in assessing accessibility to healthcare facility. Potential capabilities of GIS in integrating and visualizing of data have been investigated in this section.

The practical research presented in Table 3-1 have been summarised under five headings: author(s); research year and location; aim and objectives of the research; methods and approaches; considered important criteria and factors; the research area (urban or rural); and finally the research outputs. Among many journal papers and real world projects, more than 30 piece of research have been selected for this review (see table 3-1).



Table 3-1: Previous practical research review

No	Author, Year	Aims/Objectives	Location	Area	Method/Approach	Criteria/Factors	Output/Result/Conclusion
1	Ahlström et al., 2011	Develop an accessibility model. Find door-to-door traveling speeds of three road classes.	Southern Sri Lanka	Rural	Integration of local knowledge and physical geographical data using interview data and a raster-based approach in a GIS	Calculate travel speed on different landscape entities	Find frictions for cost surface. Show strong relationships between poverty indicators and estimated spatial accessibility.
2	Akerman P., 2006	Joint between transport and health authorities, Understand the role of transport and health issues to each other, Awareness of transport and health	South West England, UK	Urban & Rural	Questionnaire Survey	walking, cycling, road safety, school travel, rural access	recommendation to improve partnership working between public health and transport managers
3	Alegana et al., 2012	Spatial modelling of healthcare operation to define healthcare facilities catchment areas and populations	northern Namibia.	Urban & Rural	Modelling probability of using healthcare facilities against a travel times using logistic model using RS (AccessMod software)	Travel time, probability of attendance	Defining health facility catchments and catchment population for children. Estimating the effect of fever
4	Al-Taïar et al., 2010	Investigate impact of the relationship between different physical accessibility measurement on the vaccination of children	Taiz province, Yemen	Urban & Rural	develop unconditional logistic regression model; and using GPS, odometer and stop-watch for measuring travel distance and time.	Straight-line distances, driving distance and driving time	There are highly correlation between straight-line distances, driving distance and driving time in Yemen. There are strong relationship between vaccination of children and distance.
5	Azizy et al., 2007	Assessing and allocate location of healthcare services GIS	Mahabad, Iran	Urban	Using Index Overlay to allocate healthcare facilities location, Assign weight to the indices	road network, land use, slope, neighbourhood, healthcare catchment area	Preparing a guideline for finding optimal location of healthcare facility in the case study,
6	Blanford et al., 2012	Analyse accessibility to healthcare facilities to identify poor area in terms of accessibility to enough healthcare services, drugs and vaccinations in wet and dry seasons for walk and car travel modes.	Niger	Urban & Rural	Using RS and GIS to find four surface friction as: road network, land cover, slope and water. Using Multi-level model in two levels as: household resources (L1) and time to health centre <1 hour (L2)	Travel time and cost-distance by walk and car	Identify areas where accessibility to health facilities were critical. Seasonal differences must be considered to assess accessibility. Barrier to access healthcare services will be increased for more people in wet seasons.

Table 3-1: Previous practical research review (Continue)

No	Author, Year	Aims/Objectives	Location	Area	Method/Approach	Criteria/Factors	Output/Result/Conclusion
7	Carrillo et al., 2011	Develop a Health Care Access Barriers Model (HCAB) to classify, analysis and report modifiable healthcare access barriers	New York, USA	Urban & Rural	community-based health interventions by targeting measurable and modifiable determinants of health status.	Financial, structural, and cognitive health care access barriers	Provide a taxonomy and a practical framework to support interventions that can help reduce modifiable health care access barriers faced by the poor and underserved
8	Cheng et al., 2012	Investigate spatial accessibility to healthcare services considering future demand for older people for allocation future healthcare facilities.	Beijing, China	Urban	Combination of two methods: shortest path analysis method; and two-step floating catchment area (2SFCA) using GIS	Travel time and travel distance	The distribution of healthcare services are highly related to the road network. There are needs for a future multi-level residential care system planning using GIS analysis.
9	Comber et al., 2011	Analyses relationship between public accessibility perception to healthcare facilities against health status, car ownership and geographic distance	Leicestershire, UK	Urban & Rural	Using questionnaire survey data, GIS, and Geographically Weighted Regression (GWR) model	geographic distance, health status and car ownership	Geographic distance was not a significant in accessing hospitals but was for GPs. Bad health and non-car ownership were significant predictors of difficulty in accessing healthcare facilities.
10	Field K., 2000	Defining and modelling the determinants of the need for health care based on components of relative need and accessibility	Northampton District Health Authority, UK	Urban & Rural	Patient questionnaires survey (668 respondents), Drive proxy indicators, Create an Index of Relative Disadvantage (IRD)	need for primary health care	Finding advantages and disadvantages of Index of Relative Disadvantage (IRD), and the index is worthy of wider testing and application for measuring the need for primary healthcare
11	Foley and Darby, 2002	Using GIS to aid decision-making to identify new surgery relocations in the city	Brighton & Hove, UK	Urban	GIS modelling by using GP patient data (age, gender, registered GP and unit postcode), and Surgery data (location and individual practice catchment areas)	Travel distance, travel time, GP patient data, surgery data	Identify which patients went to which practice, Visualisations of clusters, Modelling PST's patient accessibility based on a travel time and distance, Identify potential locations for the placement of new GPs.

Table 3-1: Previous practical research review (Continue)

No	Author, Year	Aims/Objectives	Location	Area	Method/Approach	Criteria/Factors	Output/Result/Conclusion
12	Foley R., 2002	assess the potential applicability of GIS in the through a study of informal carers and the provision of short-term care services to those carers	East Sussex, UK	Urban & Rural	interviews with key local agencies and service gatekeepers, GIS modelling, present some of the GIS data outputs to local strategic planners and users to help	Strategic planning, Key policy, Knowledge and Awareness of using GIS for planning and decision making, Data availability	SWOT analysis of GIS by local primary care groups representatives, GIS can deliver and successfully incorporate qualitative data into a fundamentally quantitative structure,
13	Freeman et al., 2008	Study of accessibility to healthcare services to improve the service to people and remote serving	South West & Dorset, UK	Urban & Rural	Assessing cross-boundary travel, Shortage of hospital car services, Cost of hospital cars, PTS / HTCS eligibility criteria	GP opening hours, service frequency, cost of transport, Bus environment, Bus information.	Finding transport inequalities lead to health inequalities, Showing The poorest access to Dorset GPs services by contoured map
14	Fryers P., 2002	analysis of variations in a range of health indicators, and socio-economic factors for preparing inequalities atlas	South Yorkshire, UK	Urban & Rural	Spatial smoothing techniques	mortality rates, cancer incidence rates, hospital admission rates and deprivation indicators	inequalities atlas, identifying high and low areas, most being correlated strongly with deprivation
15	Hare and Barcus, 2007	assess geographical accessibility and service utilization related to ambulatory care sensitive Cardiovascular diseases (CVDs), assessing the relationship between accessibility and health	Kentucky, USA	Urban & Rural	Assist a spatial statistical comparison of the geographical distribution of service usage and travel time to hospitals	travel time, variety sets of facilities	Rural areas travel further to services, access more than 45 min to health facilities are socially and economically marginalized, Spatial clustering of high rates of hospital utilization occurs in areas with lower accessibility.

Table 3-1: Previous practical research review (Continue)

No	Author, Year	Aims/Objectives	Location	Area	Method/Approach	Criteria/Factors	Output/Result/Conclusion
16	NHS SDE, 2008	Trust travel plan to reduce car use and increase sustainable travel modes	Winchester and Eastleigh, UK	Urban	offer staff to cycle to work	bike security, car travel, bus trace	Saving 4000 patient bus journeys per annum, equating to a reduction of 68000 miles, Saving 1540 staff car journeys per week equating to a reduction of 500000 miles per annum
17	Jordan et al., 2004	geographical accessibility, identify the areas most remote from hospitals	South West England, UK	Urban & Rural	use postcode and 1992 census wards	straight-line distance, drive time,	Drive time is a more accurate measure of access, private & public transport availability with distance and travel time analysis is required for better accessibility measurement
18	Khan, A.A., 1992	Integrated approach to measure potential spatial access to health care services	Akron, Ohio, USA	Urban & Rural	Drive access index as the culmination of a series of individual measures, definition and conceptualization of potential spatial access	index to the ambulatory medical care system	SMSA Tool, demonstration the validity of the measure, and its suitability as a potential health care planning tool.
19	Lovett et al., 2002	calculate measures of accessibility to GP surgeries by public and private transport (bus)	East Anglia, UK	Urban & Rural	Using patient registers, GP surgery locations, road network, bus routes and community services information and GIS	car travel times, indicators of bus services	10% could access to GP more than 10min. 13% could not reach GP by bus. 5% could access to GP longer than 10 min and without available bus service. In the remoter rural parishes, the lowest levels of personal mobility and the highest health needs indicators were found in the places with no daytime bus service each weekday and no community transport.
20	Luo and Wang, 2003	Measuring and assessing the variation of spatial accessibility to health care	Chicago, USA	Urban & Rural	synthesizes two GIS-based accessibility measures into one framework: floating catchment area (FCA) method and gravity-based method	travel time, travel friction coefficients	help the US Department of Health and Human Services and state health departments improve designation of Health Professional Shortage Areas.

Table 3-1: Previous practical research review (Continue)

No	Author, Year	Aims/Objectives	Location	Area	Method/Approach	Criteria/Factors	Output/Result/Conclusion
21	Martin et al., 2008	measurement of geographical accessibility in the analysis of health care, retailing, and other public services	Devon, UK	Urban	Explore social and spatial pattern of accessibility by bus, hierarchical geodemographic classification	travel time, private and public transport,	software tool to analysis of bus travel times under specified journey scenarios, Evidence for increasing sophistication in GIS approaches for access modelling
22	McGrail and Humphreys, 2009	Measuring spatial accessibility to primary care in rural areas	Victoria, Australia	Rural	critically review of the two-step floating catchment area (2SFCA) method	maximum travel time or catchment size	2SFCA method provides the best available framework upon which an improved measure of spatial accessibility can be developed
23	Murad A.A., 2007	GIS modelling for distribution of health demand, classification of hospital patients and the definition of hospital service area	Jeddah, Saudi Arabia	Urban	network analysis, overlay analysis	travel time	Developed model to help health planners to evaluate spatial distribution of hospital demand and define hospital service area for private or public hospital. The model can be used to build a spatial decision support system for hospitals in Jeddah.
24	NHS Cambridge, 2007	reduce traffic onto site and increase travel choices as safe fair and accessible for all, to encourage healthier behaviour and to reduce carbon emissions.	Cambridge University Hospital, UK	Urban	encourage and create opportunity for all staff, patients and visitors, to travel to alternative mode of transport	traffic onto site, travel modes, travel safety	Reduce staffs travelling onto site by single occupancy car journeys from 50% in 2000 to 34% in 2007. Reduced patients and visitors travelling by car from 92% in 2002, to 85% in 2007.
25	Paez et al., 2010	Identify poor accessibility areas by investigating mobility situation of senior and non-senior residents and spatial distribution of the healthcare facilities.	Montreal Island, Canada	Urban & Rural	Using spatial modelling and regression techniques to estimate travel behaviour considering location- and person based accessibility	Age, income, household structure, mobility tools, occupation, urban form	There is considerable inequality in accessibility to healthcare facilities between seniors and non-seniors, between urban and suburban seniors, and between car ownership and non-car ownership seniors

Table 3-1: Previous practical research review (Continue)

No	Author, Year	Aims/Objectives	Location	Area	Method/Approach	Criteria/Factors	Output/Result/Conclusion
26	Ricketts et al., 2001	Examine relationship between ambulatory care sensitive condition (ACSC) hospital admission rates and primary care resources and the economic conditions in primary care areas	North Carolina, USA	Urban & Rural	GIS modelling, cluster analysis, Analysis of patient admission rate data,	physician location data, ZIP code,	There is high degree of correlation between the rates and income, access to effective primary care reflected in lower rates of ACSC admissions is a function of more than the professional resources available.
27	Roovali and Kiivet, 2006	Analyse geographical factors affecting the utilization of hospital care (inpatient)	Estonia	Urban	travel time calculation, statistical analysis by SAS	travel time, age, sex	geographical access and travel time
28	Strong et al., 2007	develop a GIS based model for better prediction a practice population-weighted deprivation score in the absence of patient level data than simple practice postcode linkage.	Rotherham, UK	Urban & Rural	Linked the practice postcode to an IMD 2004 score, and used a GIS model. Compared the two sets of predicted scores for practices in Doncaster, Havering and Warrington.	practice level Index of Multiple Deprivation (IMD) 2004	A GIS based model can be used to predict a practice population-weighted area-based deprivation measure in the absence of patient level data. The method may be used when do not have access to patient level spatially referenced data.
29	Tanser et al., 2006	Modelling and understanding primary health care accessibility and utilization in rural South Africa to quantify the effect of physical access to clinic on usage	South Africa	Urban & Rural	using GIS model to investigate differences in rural, urban and peri-urban usage of clinics	travel time, public transport, walking time, road network quality, natural barrier	Predict the reported clinic used with an accuracy of 91%. The median travel time to nearest clinic is 81 min and 65% of homesteads travel 1 h or more to attend the nearest clinic.
30	Wang and Luo, 2005	accessibility to primary healthcare for defining Health Professional Shortage Areas (HPSA)	Illinois, USA	Urban & Rural	measure spatial accessibility based on travel time, analyse sociodemographic variables (socioeconomic disadvantages, sociocultural barriers & high healthcare needs)	spatial and nonspatial (age, sex, ethnicity, income, social class, education & language ability)	Integration of spatial and nonspatial factors into one framework, and identify the areas and population groups for HPSA

After exploring the research in assessing accessibility to healthcare facilities and their GIS analysis, some of these studies have been selected and categorized relating to the aim and objectives of this research. The previous practical piece of research (Table 3-1) have been summarized and discussed in the following categories.

**Research Year and Location:** Besides some fundamental approaches and conceptual models (Khan, 1992), most of them have been used GIS tools in healthcare accessibility studies such as Blanford et al. (2012), Alegana et al. (2012), Martin et al. (2008), Comber et al (2011), McGrail and Humphreys (2009), and Luo and Wang (2003). In terms of research location, because of considering the UK Health Authority budgets and service levels in local health services, GIS modelling and assessment has a good background in the United Kingdom (Congdon, 1999; Mohan 1993). Therefore, approximately half of previous studies have been chosen from the UK research. After that North America with seven sample researches and rest of the world with ten studies has been selected and summarized. While most studies have done in developed countries, many recent practical studies have been conducted in developing countries in Asia and Africa (Al-Taiar et al., 2010; Blanford et al., 2012; Alegana et al., 2012, Cheng Y. et al., 2012).

In terms of transport, public transport has been more emphasised in the UK. There are more considerations for other mode of transport (e.g. not car such as bus, walking and cycling) in the UK research in comparison with USA studies. Lovett et al. (2002), Martin et al. (2008), Akerman (2006) and Healthcare NHS Trust (2007) studies are useful research in this regards.

**Urban and Rural area:** Most of the previous practical research has been focused on urban area. The most poor accessibility to healthcare facilities has been in rural area (Paez et al., 2010; Lovett et al., 2002; Akerman, P., 2006, Blanford et al., 2012). Whereas more than 20 per cent of population in the Britain are living in rural areas, and the measurement of healthcare accessibility to rural primary care services are unclear and poorly understood (Cox, 1995; Freeman et al., 2008), these area need more research and considerations. Because of spatial accessibility analysis difficulties in rural health services, and poorer healthcare services accessibility and availability in rural

communities, McGrail and Humphreys (2009) has done a research only for rural region to improve the healthcare accessibility by considering rural area characteristics as a new approach. In comparing with urban areas, providing equitable access to healthcare in rural areas need more accurate, reliable and robust measures of spatial accessibility to healthcare services (Humphreys, 1998). Furthermore, Blanford et al. (2012) investigated in Niger that accessibility to healthcare facilities will be worst in rural areas in different season; due to increasing barriers to access healthcare services in wet seasons. Moreover Africa, there are considerable inequality around the world in accessibility to healthcare facilities between urban and suburban areas such as Montreal, Canada (Paez et al., 2010).

**Aims and Objectives:** Significantly high aims of research have been studied for spatial assessing and measuring of accessibility to healthcare services using GIS tools. Through this measurement and defining health professional shortage areas (HPSA), some research have done for analysing both spatial and non-spatial factors together (Roovali et al., 2005; Fryers, 2002) and performing GIS analysis for healthcare accessibility (Strong et al., 2007; Martin et al., 2008; McGrail and Humphreys, 2009; Luo and Wang, 2003). While most of the practical research are focused on assessing and demonstrating the existing situation (Paez et al., 2010; Alegana et al., 2012; Tanser et al., 2006), considering the future population growth and future transport arrangement should be considered more (Cheng et al., 2012). According to the aim and objectives of these studies, assessing accessibility is studied for several purposes; therefore it needs to consider different factors which are discussed in the literature review as were considered in the research objectives.

**Method and Approach:** While most of the researchers assessed accessibility by GIS modelling and spatial analysis, some researcher such as Akerman (2006), Field (2000) and Foley (2002), Comber et al. (2011) also used questionnaires and/or interview surveys. In terms of using data, three main types of data have been applied and manipulated for these studies as census data, patient data and GIS data. Besides using survey data and GIS analysis, some researchers developed statistical models to investigate user's accessibility to healthcare facilities (Blanford et al., 2012; Paez et al.,



2010; Comber et al., 2011); also some researchers used floating catchment area methods (FCA) such as Cheng et al. (2012); McGrail and Humphreys (2009) and Luo and Wang (2003).

In terms of available data sources, raster maps data were very useful to explore surface frictions in remote area such as road network, land cover, slope and water streams; due to unavailability of required data in some developing countries (Blanford et al., 2012; Alegana et al., 2012). In comparison, using census and GIS data versus patient data, Hospital Episode Statistics (HES) has some advantages such as being up to date and more accurate (Ricketts et al., 2001; Lovett et al., 2002; Foley and Darby, 2002), then using patient data beside of census data will improve the modelling accuracy as well as GIS analysis. In order to consider all factors which are important to measure accessibility, there was not any research to consider the factors according to their weights or introduce a guideline to assign the weight. Therefore, there is a need to develop a generalizable method considering the most important factors in assessing accessibility to healthcare facilities.

**Criteria and Factors:** Measuring accessibility to the nearest service by calculating travel time or travel distance is a common and regularly used measure for spatial accessibility (Fortney, Rost, and Warren, 2000; Hewko, Smoyer-Tomic, and Hodgson, 2002; Rosero-Bixby, 2004). Al-Ta'iar et al (2010) investigate the relationship between different physical accessibility measurement using straight-line distances, driving distance and driving time in Yemen for vaccination of children. In addition of using travel time or travel distance, some researches considered other factors such as socio-economic, age, gender, income, household structure, mobility tools, occupation, urban form and more (Foley and Darby, 2002; Roovali et al., 2005; Strong et al., 2007; Wang and Luo, 2005, Paez et al., 2010). While many studies considered different factors, their results and achievements could not be used or generalised to another location or situation as their method specified for investigating their research area characteristics.

**Outputs and results:** The most important outputs of these studies can be categorised as: the current situation of accessibility to healthcare facilities (Alegana et al., 2012; Field, 2000; Hare and Barcus, 2007; Lovett et al., 2002); develop a model and visualize the accessibility problems (Tanser et al., 2006; Paez et al., 2010; Foley, 2002; Luo and Wang, 2003); find optimal location for healthcare facilities in terms of accessibility (Azizy et al., 2007); identify poor or critical areas in terms of accessibility to healthcare facilities (Blanford et al., 2012; Cheng et al., 2012 ; Jordan et al, 2004; Luo and Wang, 2003; Freeman et al., 2008); improve accuracy of accessibility measurement (Al-Taiar, et al., 2010 ; Ahlström A, et al., 2011); improve public transport services to healthcare facilities (Akerman, 2006; Martin et al., 2008); study important indicators and criteria regarding accessibility to healthcare facilities (Comber et al., 2011; Fryers, 2002; Roovali et al., 2005; Strong et al., 2007; Wang and Luo, 2005); and develop a method or tool to evaluate and improve accessibility to healthcare facilities (Khan, 1992; McGrail and Humphreys, 2009; Murad, 2007; Carrillo et al., 2011).

Evaluating the current situation of healthcare accessibility and providing recommendation for existing situation is the main outcomes of the previous applied studies. Over all, most of these research results have provided recommendation for a specific case, but comprehensive approach is needed for future planning. While investigation of important factors to assess the accessibility is useful for future research, providing a generalizable methodology is one of the gaps in the previous research outputs.

### **3.8 Research Gaps and Questions**

Based on the literature review and exploring the previous practical research, there is a lack of a holistic approach that considers important factors related to accessibility measurement to a healthcare facility. Also there is a need for modelling that can support key decision makers to make better decisions in assessing accessibility. It is not easy to measure transport accessibility since it is often highly subjective. Current approaches to measure accessibility primarily focus on the creation of accessibility contours based on distance or travel time and therefore such methods ignore individual differences such as: user perception and their preference, available travel modes, and user socio-

economic status; and area-wide factors such as: road safety, security, deprivation indices, and level of access to public transport. Moreover weighting of each factor needs to be considered to develop accurate accessibility measurement.

As a specific catchment area for the hospital has not been defined in the UK, it is not required for a user to use the specific healthcare and services, therefore, healthcare facilities catchment area can be vary according to their users' perceptions of accessibility. It means users' opinions have an important role to plan a policy for healthcare facilities reconfiguration or relocation. Hence, any new accessibility assessment must be able to develop based on user's perceptions because they are the real decision makers as to whether to use a healthcare facility or not.

On the other hand, there are varieties of different and unknown factors which can affect user perception on accessibility; for example a bus stop without shelter or crossing a road with high speed cars or without zebra crosses can effect on some user's perception. Hence it is not possible to include all of these different factors for all people as it can affect just some user perception. The error term in a statistical model captures all factors that cannot be recognised, cannot be modelled or do not have enough data to be measured, therefore, it may be possible to explore important factors effects on user perception using a statistical model.

A new model needs to consider user's perception of accessibility to support key decision makers in assessing accessibility to healthcare facilities and in making better decisions aided by GIS-based analysis. More parameters and criteria can be added to this modelling by integrating spatial and non-spatial data as well as survey data. These models are developed through statistical methods in the GIS environment to cover and integrate all significant variables. As one of these research objectives, a statistical model will be developed by considering users' perception of accessibility using GIS analysis and techniques. In order to develop clear research questions, the following stages have been designed according to the literature review.

**Exploring accessibility to healthcare facilities and services:** Why is an accessibility study of healthcare facilities important? What are the transport implications of better

accessibility to healthcare facilities? Which method is suitable to identify important accessibility factors to a healthcare facility? What are the issues and gaps in UK healthcare accessibility? Which holistic methodology can be suitable to do the studies?

***Assessing accessibility to a healthcare facility:*** What are the most important factors to consider in terms of accessibility to a healthcare facility? What are the weights of the significant factors in this assessment?

**Devising recommendations:** How can one generalise the research achievements to other cases? How can methods be developed for future works? What and how can the model be validated?

### **3.9 Summary**

Although there has been considerable research into healthcare accessibility, there is a lack of approach for accessibility analysis in integration travel impedance and accessibility measurement in GIS environment (Liu and Zhu, 2004). According to the literature review and exploring in the previous practical research, there is a lack of holistic approach that considers important issues related to accessibility measurement to a healthcare facility.

There is also a need to develop a generalizable model that can support the key decision makers to plan better decisions regarding the accessible location of a care service. In order to help decision makers to assess and improve accessibility to healthcare facilities, this research aims to: model user's perception of accessibility by considering all important factors on both individual socio-economic and area-wide characteristics. Besides other methods, considering the users' perception can provide further support to the decision makers to measure accessibility as a customer-oriented approach. As one of the research objective, a new accessibility model will be developed to assess transport accessibility to a healthcare facility using statistical models and GIS.

Among many approaches to measure accessibility, the main approaches advantage and disadvantage were: (Bagheri et al., 2006; Guagliardo, 2004; Langford and Higgs, 2006; Talen and Anselin, 1998).

- 'Population to Provider Ratios' provide simple calculation and suitability for initial policy analysis are the advantages of this approach; but it is not a spatial analysis and is suitable just for small regions which can be used for evaluate proximity of healthcare facilities and not for availability. However the population and age group of spatial units within the catchment area of a healthcare facility should be considered in measuring accessibility to the healthcare facility.
- 'Travel Time or Distance' is a simple and regular measure of accessibility but it is not accurate because some users may bypass the nearest service; and this approach does not consider users favour of other options; it also does not consider regional availability. While travel time or travel distance is not the only factors influencing accessibility, they are considered the most important in this statistical modelling.
- 'Gravity Model' has some considerable advantages such as: considering both supply and demand sides; considering proximity and availability together as well as changing attractiveness using travel distance or travel time impedance. Determining the distance-decay function of the gravity model is one of complexity of this model. Assessing the level of accessibility from home to the healthcare facility also needs to be considered in this research.

By exploring on more than 30 previous studies into healthcare facility accessibility, the results have been summarised below.

- About their methods and approach: most accessibility measurements have been assessed by spatial analysis; some questionnaire or interview surveys have done; and three main data were: census, patient and GIS data.
- Important criteria and factors for the previous research were calculating of travel time or travel distance which the travel time was the most common factors; and both spatial and non-spatial factors have been considered.

- Main applications of the previous research were evaluating the current situation and visualizing problems; finding optimal location; saving journey time for the users and explore available travel mode.

## **4 RESEARCH METHODOLOGY**

### **4.1 Introduction**

Research methodology refers to “the principles and procedures of the logical thought process which are applied to a specific investigation” (Fellows and Liu, 2008; pp. 30). The main purpose of this chapter is to develop the research methodology to achieve the aim and objectives of the thesis.

Literature review presented in Chapters 2 and 3 revealed that accessibility to healthcare facilities is an important area of research that greatly influences the decision on healthcare facility reconfiguration and relocation. There are also a wide range of factors that should be considered while assessing and evaluating transport accessibility associated with healthcare reconfiguration and there are many methods available to analyse the relevant data.

This research intends to model the effects of important factors on users’ perception regarding assessment of accessibility to healthcare facilities with respect to reconfiguration and relocation. In order to conduct the assessment, it is important to employ a suitable accessibility measurement and related methods for modelling.

This chapter is organised as follows: firstly research design covering the research stages and methods employed in this research is presented. This is followed by a description of survey methods employed in collecting relevant data. Finally, a detailed discussion on the statistical models used to develop a relationship between user-perception on the level of overall accessibility to a healthcare facility and the factors affecting their accessibility is provided.

### **4.2 Research Design**

Yin (2009, pp. 26) described research design as a “logical plan for getting from here to there, where here may be defined as the initial set of questions to be answered, and there is some set of conclusions (answer)”. Research design enables the researcher to answer the initial research questions clearly as far as possible and helps the researcher

as a framework to consider all components of the research such as: literature review, research questions, data collection, data analysis and the results (Fellows and Liu, 2008).

As stated in Chapter 1, the aim of this research is to model users' perception of transport accessibility to support the assessment of the transport accessibility for healthcare facility reconfiguration and relocation. This is to achieve by the following objectives.

1. To explore accessibility and transport issues associated with travelling to healthcare facilities.
2. To investigate the potential of employing GIS and statistical methods in measuring and assessing transport accessibility to healthcare facilities.
3. To determine important factors that affect accessibility to healthcare facilities.
4. To develop a user-based accessibility model of healthcare facilities using statistical methods.
5. To develop recommendations for assessing accessibility to healthcare facilities with respect to reconfiguration and relocation.

In order to achieve this aim and related objectives, a research approach containing the following building blocks have been considered:

- questionnaire and field surveys for the research as a scoping study;
- GIS analysis including data collection, cleansing and processing;
- specific questionnaire survey to obtain the relevant data for statistical modelling;
- multilevel (i.e. users nested with areas) linear regression modelling to develop a user-based accessibility model.
- predicting the overall accessibility to a healthcare facility using the calibrated multilevel models; and
- assessment of transport accessibility using a GIS technique.



Table 4-1 shows how these stages are linked to each of the objectives so as to achieve the research aim. The required data and the methods used to achieve the research objectives are shown. The relevant chapters are also indicated.

Table 4-1: Research Design

Objectives	Data required to achieve the objective	Methods to achieve the objective	Chapter(s)
To explore accessibility and transport issues associated with travelling to healthcare facilities.		Literature review on NHS and related documents, GIS applications, previous applied research and approaches to measure accessibility	Chapter 2 and Chapter 3
To investigate the potential of employing GIS and statistical methods in measuring and assessing transport accessibility to healthcare facilities.	Maps, road network data, questionnaire survey data	Explore mathematical and statistical methods for accessibility measurement, creating preliminary service area contours using GIS	Chapter 4 and Chapter 5
To determine important factors that may affect accessibility to healthcare facilities.	Primary data from a questionnaire survey (patients/users) and field surveys	Quantitative and qualitative questionnaire surveys, study area exploratory data analysis of the surveys, literature review of factors influencing accessibility perception	Chapter 3 and Chapter 6
To develop a user-based accessibility model of healthcare facilities using statistical methods.	Census, deprivation, road network, maps, digital boundary, site survey, accident and second questionnaire survey data	Second questionnaire survey, develop statistical multilevel modelling, identify significant factors on accessibility perception, employ GIS analysis and visualization tools	Chapter 7
To develop recommendations for assessing accessibility to healthcare facilities with respect to reconfiguration and relocation.	-----	Generalise the model achievements to other areas using Accessibility Prediction models	Chapter 8 and Chapter 9

Table 4-2: Structure of the thesis

Chapter	Chapter Objectives	Tasks Undertaken
Chapter 1 Introduction	Introduce the significance of the proposed research.	Explore background and issues of accessibility to healthcare facility in the UK.
Chapter 2 Review of Health and Transport	Literature review related to accessibility to healthcare facilities (1*).	Review different definitions of accessibility and related issues of accessibility to healthcare facility.
Chapter 3 Review of accessibility measurement approaches	Review of literature exploring the current approaches and tools. Identify important factors affecting accessibility leading to the research gap (1,3).	Review of current accessibility measurement approaches, issues and applications of GIS tools. Looking in-depth into previous practical research methods and identify spatial and non-spatial factors affecting accessibility.
Chapter 4 Research Methodology	Introduce and develop research methodology (2).	Formulation of the statistical models and the data analysis process regarding accessibility to healthcare facility.
Chapter 5 Data Collection, Cleansing and Integration	Outline of the data collection and cleansing from different secondary sources and the two questionnaire surveys (2).	Integration of the survey data with various datasets from the secondary sources such as National Census, Ordnance Survey, Deprivation Indices data using GIS analysis and mapping tools.
Chapter 6 Result of the First Questionnaire Survey	Preliminary analysis of the research data using statistical analysis and GIS technique (3).	Analyse the first questionnaire quantitative and qualitative survey data.
Chapter 7 Modelling Results	Develop multi-level statistical model and interpret the results (4).	Employ multilevel statistical models to find relationship between user perception on the accessibility to healthcare facility and the factors influencing accessibility.
Chapter 8 Discussion and Implications	Discuss the research achievements, implications and its generalizability (5).	Discuss on the strengths and weaknesses of the research results, generalizability of the research methodology, and its application for different scenarios.
Chapter 9 Conclusions	Conclude the research and provide recommendation (6).	Provide the conclusions and recommendation for healthcare facility reconfiguration; explore the research contribution to knowledge.

\* Values in ( ) indicate the relevant research objectives.

### 4.3 Research Flow Diagram

In order to achieve the aim and objectives of the research, the following stages have been designed as a flow diagram consisting of four main stages.

- '*Factors*' stage includes the literature review and the first questionnaire survey to identify important factors affecting accessibility of healthcare facilities. In this stage the identified factors are divided into two-levels (i.e. individuals and areas) in order to conduct the next stages as data collection and model development.
- '*Data*' stage includes data collection, cleansing, processing and analysis. Data collection from different sources, carrying out the second questionnaire survey and data cleansing and analysis using GIS tools from three main sections of this stage. All different types of data including non-spatial data (e.g. demographic and socio-economic factors) and spatial data (e.g. census data, deprivation indices data, accident data, road network data, maps, digital boundary data and respondents origin coordinate) are integrated together to be used in the statistical modelling.
- '*Modelling*' stage is the core stage of this research. A multi-level mixed effect linear regression model is employed to find relationship between users' perception of accessibility and the two levels of individual factors and area-wide characteristics. This stage has a mutual interaction the data stage.
- '*Applications*' of the model achievements is the last stage of this flow diagram. Relevant maps have been created for better understanding of the model results in the GIS environment. In order to generalise applications of this research methodology, the calibrated accessibility model has been employed to assess accessibility to healthcare facilities based on users' perception of overall accessibility.

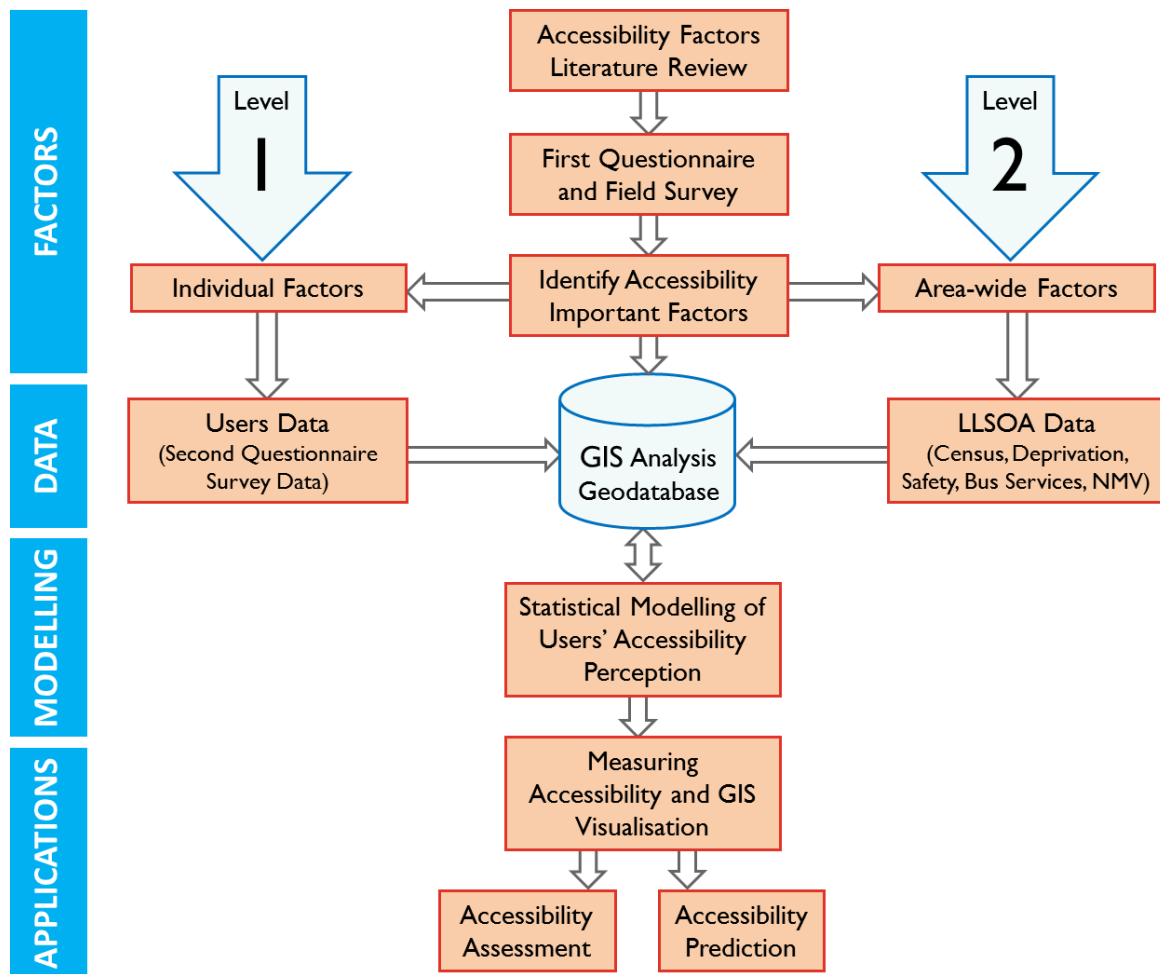


Figure 4-1: Flow diagram of the research methodology

In order to design the first stage of this research, a broad literature review has been undertaken to explore accessibility measurement methods and important factors affecting accessibility to healthcare facilities so as to identify required data by designing the questionnaire surveys. By selecting the study area and employing qualitative and quantitative questionnaire surveys, the next stage of the research was undertaken. Important factors and variables which may influence users' accessibility perception are identified in the first questionnaire survey as well as a field survey of the study area including taking photos from the access roads. Using a variety of data in a GIS environment supports the integration of individual-level and area-level factors to be used in the statistical modelling. Results of the developed accessibility model have been used to measure accessibility to healthcare facilities; also the model has been employed to predict accessibility for the catchment areas using GIS visualisation tools.

#### 4.4 First Questionnaire Survey

Two revealed preference (RP) questionnaire surveys in two different stages of this research were designed and carried out. These questionnaire surveys were used to obtain different views and issues from users of healthcare facilities in the Loughborough and Hinckley areas of Leicestershire. The purpose of the first questionnaire survey was to identify the factors which are important for the users of healthcare services. For this reasons a quantitative and qualitative questionnaire survey was used as an exploratory study in order to provide a better understanding of the accessibility issues to healthcare facility (Appendix B).

The survey involved for four hospitals in two study areas: Loughborough and Hinckley both in Leicestershire. More details of the first questionnaire survey method and results have been discussed in Chapter 6 of this thesis.

Table 4-3: Four hospitals of first questionnaire survey

Town	Hospital Name	Postcode	Abbreviation
Loughborough	Loughborough Walk in Center NHS	LE11 1BE	WIC
	Loughborough Community Hospital	LE11 5JY	LCH
Hinckley	Hinckley and Bosworth Community Hospital	LE10 3DA	HBCH
	Hinckley and District Hospital	LE10 1AG	HDH

The first questionnaire survey includes four Sections: Section 1 looked into the purpose and mode of user travel; section 2 asked about the sites in Loughborough and Hinckley; section 3 asked about further information on user preferences to travel and their awareness about public transport information; and section 4 asked some questions about the respondent's background (see appendix B).

Summary of the survey's questions which have been designed as quantitative and qualitative are introduced as follows:

- The 'place' where the users come from (home, work or leisure place) by inputting the location postcode (origin);
- 'Frequency' of travel;
- 'Prefer' and also 'usual mode' of transport to access the hospital;

- 'Rank' their priorities and important items on accessibility as: travel time or cost, travel distance by foot, quality of care, quality of building and facility, more services provided, safety and security of access, public transport availability and car parking;
- 'Affordable walking distance' and how far the users can walk;
- 'Preference' of walking, cycling, public transport and car;
- 'Quality of public transport'; Bus service quality and changing;
- 'Awareness' about different available mode of transport information;
- 'User background' information (e.g. age, gender, disability);
- 'Car Ownership'.

#### **4.5 Second Questionnaire Survey**

In order to develop a statistical model, 'overall accessibility perception' is considered as dependent variable of the model, therefore, a second questionnaire survey was carried out after analysing the first questionnaire survey to obtain the dependent variable (e.g. user's perception on accessibility to the healthcare facility). The dependent variable on the left hand side of the statistical model (i.e. user's overall perception on accessibility) must be obtained in a different way in comparison with the independent variables on the right hand side of the model (e.g. travel time, public transport availability, car ownership). Therefore respondents were asked to provide the level of accessibility (on a scale from 0 to 100) from their home to a healthcare facility in Loughborough (Appendix C).

Since modelling user's perception of accessibility was the aim of this research by focusing on both individual socio-economic and area-wide characteristics, undertaking the second questionnaire survey for one of the two towns provides a more in-depth approach. Loughborough was selected to investigate and evaluate the validity of the multilevel modelling. It has two hospitals within a similar catchment area that enable a

comparison of the results of the ML modelling on one map. Loughborough also has larger catchment area and population than Hinckley. The catchment area of Loughborough includes three counties: Leicestershire, Nottinghamshire and Derbyshire. This could help the research to collect data from wider areas and the rural area between the three counties.

Furthermore, a similar question was designed to compare these scores with another feedback of the respondent as well as to do some more statistical analysis. The question asked in Likert scale to know the respondent's overall perception on accessibility by choosing one of the following five options: 'Very poor', 'poor', 'neither good nor poor', 'good' and 'very good'.

The survey captured the following variables.

- Destination and origin of respondents
- Full digit postcode or local area identified on a hard-copy map
- Overall accessibility score (a continuous scale from 0 to 100 and a likert scale such as very poor, poor, neither poor nor good, good and very good)
- Importance of the factors (Travel time by car, frequency and reliability of bus, fuel consumption, access by bike, access on foot, proximity to a bus stop, road accident and crime, bus fare) influencing their accessibility
- Car ownership or access to a car
- Socio-economic status such as age, disability, ethnicity, gender, income.

Before starting the final survey, a pilot survey (via both hard copy and online) was used to identify issues and difficulties associated with the completion of the survey. A pilot survey or 'exploratory' survey is often used to test a questionnaire, to determine the required time, and to check if the questions can be easily understood and not ambiguous. The online survey was uploaded using Bristol Online Survey (BOS) and some respondents were invited via email to fill it. Based on the pilot study, the questionnaire survey was re-designed and conducted as a face-to-face questionnaire survey (Appendix C). Based on the pilot study, the questionnaire surveys were re-designed and conducted as a face-to-face interview survey.

## 4.6 Sampling

The sampling process can be introduced as four main stages: define the research population, determine the sampling frame, select sampling technique, determine the sample size, and execute the sampling process (Zikmund et al., 2012). Two important factors were considered for this survey: sample size and sampling. It is difficult to choose a sample size for a survey as it has not a straightforward and definitive answer. It is related to many considerations as well as time and cost of the research. Therefore, some limitations such as time, cost, and level of precision required should be considered to make a decision for the sample size of the survey (Bryman, 2012). However some descriptive statistical analyses have been undertaken on the collected data which are explained in the next Chapters.

In terms of the research sample population, all users of the hospitals (e.g. patients, staff, and visitors) were considered as the population of the surveys. Sample population are the people who are living within the hospitals' catchment areas.

In terms of population demographics, all people with different age, background, gender, disability and ethnicity have been selected randomly through an on-street survey, therefore, the survey technique employed can be termed as a probability-based simple random sampling (SRS) in which each of the members of the population has equal opportunity to be selected.

While specific catchment areas have not been defined by healthcare providers in the UK, catchment areas of a healthcare facility can be identified using Hospital Episode Statistics (HES) data which are available for most hospitals in the UK. However, 98% of the respondents of the second questionnaire survey in Loughborough came from maximum 20 miles distance from the two hospitals.

All face-to face surveys of the second questionnaire survey were carried out during working hours of the hospital between 9am to 5 pm.



## **4.7 Field Survey**

Physical site survey, taking photos and recording videos can provide valuable data for the research. Site survey can support this research to achieve the information which cannot be collected or clarified by other survey methods such as finding pedestrian safety in crossing the streets near the hospital, exploring bus and pedestrian lanes, safety and security of walking or cycling specially during the night, bus stops quality and locations, car park availability, disable people accessibility considerations, cycle racks, road blocks and car driver convenience to entry or exit from hospital site.

Therefore besides the first questionnaire survey, field surveys were undertaken in the vicinity of four hospitals. Photos were taken from the access roads for better understanding of the accessibility issues to the four hospitals, also videos were recorded from the areas around the hospitals to explore transport situation and problems during day light as well at night.

## **4.8 Statistical Modelling**

The objective of this section is to develop a user-level accessibility model that can explain the relationship between user-perception on the level of overall accessibility to a healthcare facility and the factors affecting their accessibility. Three types of factors are considered: (1) socio-economic factors (e.g. age, gender, income) of individuals; (2) factors related to individual transport usage (i.e. access to different transport modes, travel time and fuel usage); and (3) area-wide factors (e.g. transport network, public transport provision, safety/security and area deprivation). It is apparent that user-perception on the level of accessibility can be modelled using data from two distinct levels namely: individual-level and lower super output area (LSOA) (i.e. a census tract) as shown in Figure 4.2.

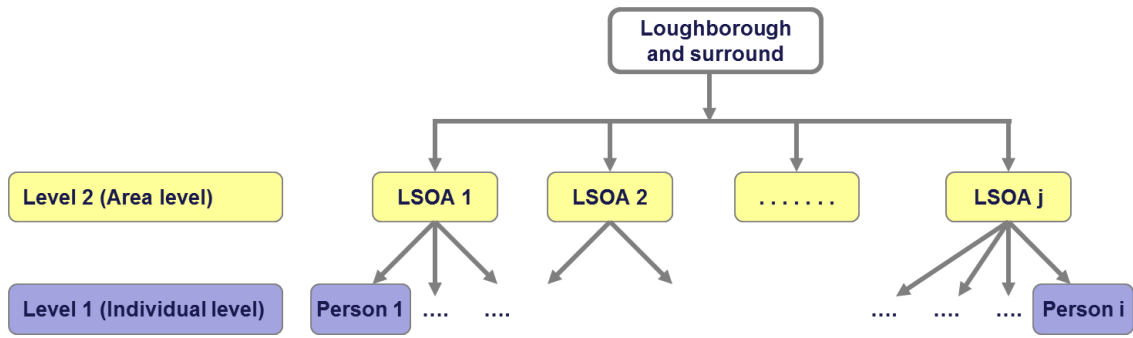


Figure 4-2: Individual level (level 1) and Area level (level 2) of the multilevel modelling

Since individuals are clustered within areas of residence, people from a specific geographical area may perceive the similar level of accessibility to a particular healthcare facility as they share the same transport infrastructure and other area characteristics (i.e. within-cluster correlations). Individuals from different clusters may also perceive different levels of accessibility due to the fact that their personal circumstances and attitudes (e.g. income, access to car, health conditions and gender) are different and there are variations in area characteristics (i.e. between-cluster variations). Therefore, a statistical model needs to be selected which is capable of jointly controlling both within- and between-cluster variations. One such statistical model is a multilevel linear regression model that allows for dependency of accessibility scores within areas and can examine the extent of between-area variation in the perception of accessibility. The model is shown in the following equation:

$$Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + e_{ij} \quad (4-1)$$

Where  $Y_{ij}$  is the dependent variable representing the level of accessibility score of person  $i$  in area  $j$ ,  $X$  is a user-level independent variable,  $e$  is the user-level residual that is independent across observations and follows a normal distribution with a zero mean and a constant variance i.e.  $e \sim N(0, \sigma_e^2)$ .

$$\beta_{0j} = \gamma_{00} + \gamma_{01}Z + u_{0j} \quad u_{0j} \sim N(0, \sigma_{u_0}^2) \quad (4-2)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}Z + u_{1j} \quad u_{1j} \sim N(0, \sigma_{u_1}^2) \quad (4-3)$$

$$\begin{pmatrix} u_{0j} \\ u_{1j} \end{pmatrix} \sim MVN(\mathbf{0}, \boldsymbol{\Sigma}_u), \quad \mathbf{0} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \boldsymbol{\Sigma}_u = \begin{pmatrix} \sigma_{u_0}^2 & \sigma_{u_{01}} \\ \sigma_{u_{10}} & \sigma_{u_1}^2 \end{pmatrix}$$

Where  $\gamma_{00}$  is the overall mean accessibility score (per person) across areas,  $u_{0j}$  is the effect of area  $j$  on the accessibility score (i.e. an area-specific effect or area-level residual that follows a normal distribution with mean zero and variance  $\sigma_{u_0}^2$ ,  $\gamma_{01}$  is the coefficient for the area-level variable,  $Z$  is an area-level independent variable,  $u_{1j}$  is the area-specific random slope for the person-level variable and this is also assumed to follow a normal distribution with a mean of zero and variance  $\sigma_{u_1}^2$ ,  $\sigma_{u_{10}} = \sigma_{u_{01}}$  indicates the covariance between  $u_{0j}$  and  $u_{1j}$ . Using equations (4-2) and (4-3) into equation (4-1) yields the following model:

$$Y_{ij} = \gamma_{00} + \gamma_{01}Z + \gamma_{10}X + \gamma_{11}XZ + u_{0j} + u_{1j}X + e_{ij} \quad (4-4)$$

Where  $\gamma_{11}$  is the coefficient for the cross-level interaction term. If it is thought that equation (4-3) should not include any upper-level covariates (i.e.  $Z$ ) then equation (4-4) would not have any cross-level interaction terms.

It is noticeable that Equation 4-4 contains both fixed-effects ( $\gamma_{00} + \gamma_{01}Z + \gamma_{10}X + \gamma_{11}XZ$ ) and random-effects ( $u_{0j} + u_{1j}X$ ) and therefore, this can be termed a multilevel mixed-effect (random-intercept and random-coefficient) linear regression model. Equation 4-4 can easily be generalised into the case in which multiple person-level and area-level independent variables can be incorporated as follows:

$$Y_{ij} = \boldsymbol{\theta} \mathbf{W} + \boldsymbol{\delta} \mathbf{V} + \boldsymbol{\varepsilon} \quad (4-5)$$

In which  $\mathbf{W}$  is a matrix containing the fixed effects independent variables,  $\boldsymbol{\theta}$  is a vector of fixed effects parameters,  $\mathbf{V}$  is a matrix containing the random effects,  $\boldsymbol{\delta}$  is the vector of random effects and  $\boldsymbol{\varepsilon}$  is the vector of errors. A model without the inclusion of  $\mathbf{V}$  can be termed random-intercept linear regression model and a model without  $\mathbf{W}$  can be termed as random-coefficient linear regression model. Equation 4-5 can be estimated using the maximum likelihood estimation method (Heck et al., 2010).

#### 4.9 Assessing the Overall Level of Accessibility

The multilevel model as shown in Equation 4-5 can be employed to estimate the overall level of accessibility of a healthcare facility. The final model therefore should only contain statistically significant variables that affect user-perception of accessibility. This is involved with the following steps.

1. Estimate an individual-level accessibility score from an origin location to a destination hospital using equation (4-5).
2. Calculate the average LLSOA-level accessibility score for a destination hospital  $k$  by considering all individual-level accessibility scores within the LLSOA i.e.

$$A_{jk} = \frac{\sum_{i=1}^n \hat{Y}_{ij}}{n} \quad (4-6)$$

where  $A_{jk}$  is the average LLSOA-level accessibility score of hospital  $k$  for LLSOA  $j$ ,  $\hat{Y}_{ij}$  is the estimated accessibility score for person  $i$  from LLSOA  $j$  to be obtained from the calibrated accessibility model shown in equation (4-5), and  $n$  is the total respondents within the LSAO  $j$ . Equation (4-6) can be employed to estimate  $A_{jk}$  for LLSOAs that are within the catchment of healthcare facility  $k$  (Figure 4-3).

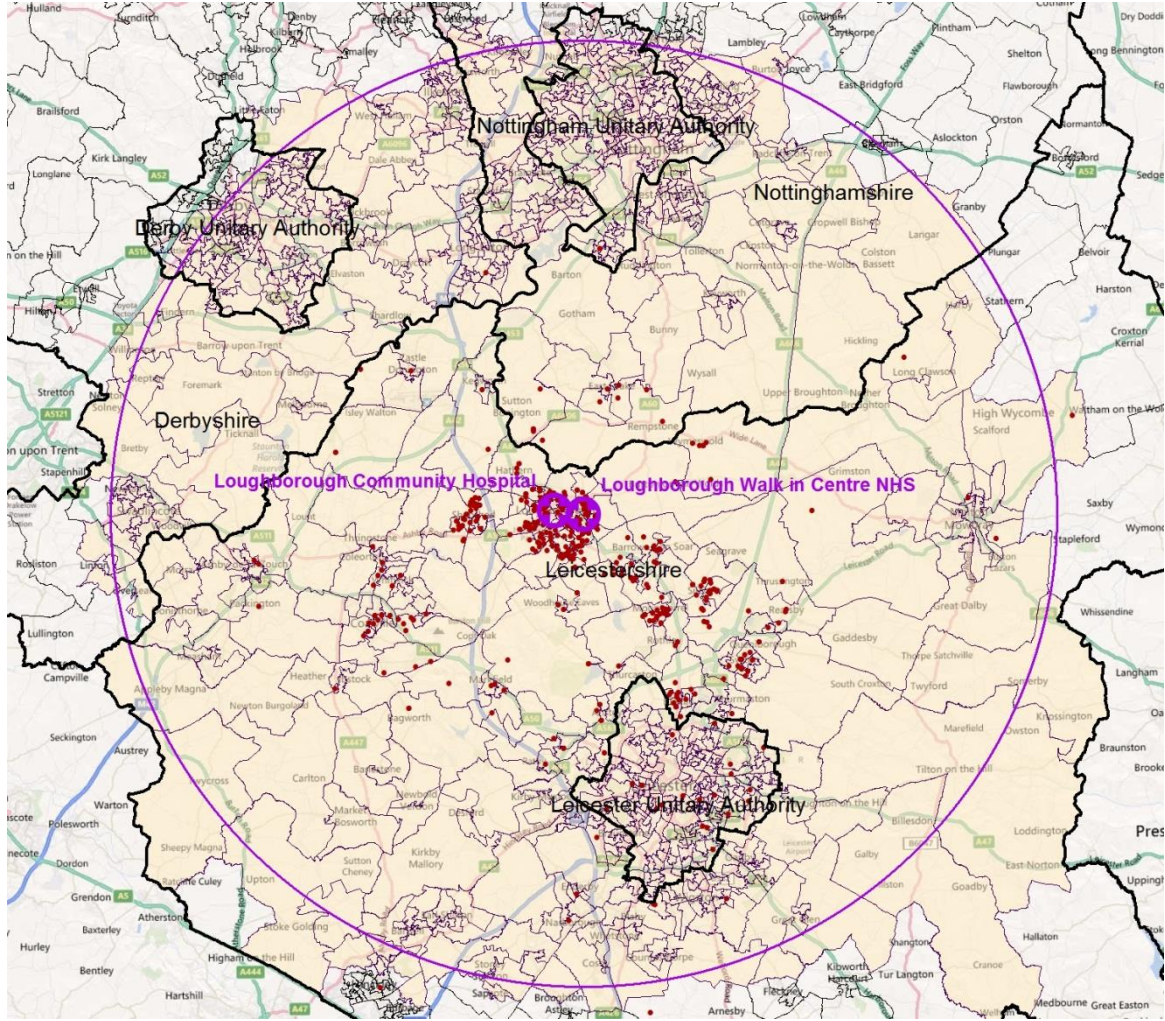


Figure 4-3: Catchment area for the hospital sites with 20 miles radius

3. Given the fact that there is a large variation in the number of people live in each of these LLSOAs, the overall accessibility to a destination healthcare facility can be obtained by the weighted average of  $A_{jk}$  as shown in the following equation.

$$\tilde{A}_k = \frac{\sum_j^m p_j A_{jk}}{\sum_j^m p_j} \quad (4-7)$$

Where  $\tilde{A}_k$  is the final overall accessibility score for healthcare facility  $k$ ,  $m$  is the total number of LLSOAs within the catchment area of healthcare facility  $k$  and  $p_j$  is the total population in LLSOA  $j$ .

Equation 4-7 can then be employed to assess and compare the overall level of accessibility scores among multiple healthcare facilities so as to identify the best accessible healthcare facility.

#### **4.10 Summary**

This research methodology intends to examine user perception of transport accessibility to healthcare facilities by employing multilevel statistical models that relate the accessibility score with individual and neighbourhood characteristics. Data from a questionnaire survey are integrated with other secondary data on area-wide factors (e.g. deprivation indices, provision of public transport) that influence individual perception of accessibility. While traditional deterministic measures of accessibility have been primarily based on travel time and travel distance, this research methodology had also taken into account other factors such as socio-economic and neighbourhood characteristics in predicting accessibility under a statistical modelling framework.

The multilevel statistical model can then be employed to predict accessibility score associated with LLSOAs that fall within the catchment areas of the hospitals. LLSOA-level accessibility scores are then accumulated by population (total as well as sub-group) to obtain the final accessibility score for a hospital.

## **5 DATA COLLECTION, CLEANSING AND INTEGRATION**

### **5.1 Introduction**

Traditional approaches to accessibility assessment are based on the creation of accessibility time or distance contours, preferably in a GIS environment. However, the purpose of this research is to examine public perceptions of accessibility to healthcare facilities. Specifically, this research investigates the underlying factors that affect users' perceptions of accessibility. As indicated in the previous chapters, area characteristics such as level of public transport provision, safety, security and the level of deprivation may affect individual perceptions of accessibility. Individual's socio-economic characteristics such as age, gender, car ownership, residential location and travel time for accessing a healthcare facility may also influence the level of accessibility. Therefore, this research needs to use both area-level and individual-level data. It was also necessary to obtain the data on individual perceptions of accessibility to healthcare facilities.

To achieve reliable results from a statistical modelling, it is necessary to access clear, specific, measurable, approved and realistic information and data (Erlander and Stewart, 1990). As identifying important factors which can affect accessibility of healthcare facilities and the data requirements is one of the objectives of this research, and due to the fact that data will be collected from a range of sources, this chapter looks at the merging, cleansing and processing of datasets to be used in the modelling and the subsequent analysis.

This chapter is organised as follows. Firstly, a brief discussion is provided on the study areas chosen for this research. This is followed by a detailed discussion of the sources of secondary datasets along with the data characteristics. The next section presents the details of two questionnaire surveys that were conducted to obtain the data not available from the secondary sources. This is followed by a description of datasets merging, cleansing and processing using a GIS technique.

## 5.2 Study Areas

A study area is often chosen to explore characteristics of an area to realise research problems, and identify related studies and the key available solutions to deal with the research problems and gaps. A review of the study area's achievements can support the research to make a plan for further studies using their real data. While choosing a study area can be useful for a wide and complex research, it is also a good approach to face research which has not been reviewed broadly yet (Fulop et al. 2001).

Following public consultation in 2008, NHS Leicestershire County and Rutland endorsed the proposal to relocate Hinckley and District Hospital to the Hinckley and Bosworth Community Hospital site; and also relocate the Loughborough Walk in Centre NHS, Pinfold Gate to Loughborough Community Hospital, Epinal Way. This would have a number of benefits, including quicker access to diagnostic tests. These two study areas were a good opportunity and real case study to develop this research practically. Therefore, four hospitals of the two study areas, Loughborough and Hinckley, have been considered as the study areas of this research.

NHS Leicestershire County and Rutland planned to review Community Health Services. They were developing an overall strategic direction for the future of their ten community hospitals services as part of a 10 year vision; also they are going to develop recommendation for their sites reconfiguration and relocation. Being Leicestershire and Rutland as healthiest place in the UK and provide good access to healthcare services as local as possible is their vision by 2018 (NHS LCR, 2009). Ease of access to healthcare facilities has been a priority for NHS Leicestershire County and Rutland to provide better healthcare services and reduce carbon emissions.

The vision for Hinckley and Bosworth Community Hospital and Loughborough Community Hospital is to be reconfigured as a 'one-stop health hub' which can provide the variety of services and as a core community hospital services; By relocating or reconfiguring all hospital services onto a single extended hospital, NHS Leicestershire County and Rutland planned to decrease the need to travel to big acute hospitals.



On the other hand, the Leicestershire Accessibility Partnership was encouraging people to walk, cycle and use public transport instead using car to reduce carbon emissions. In order to improve accessibility to healthcare facilities and reduce usage of private car travel, it was proposed to develop a travel to health plan. Therefore, these study areas had good potential to be considered for this study to achieve the research objectives.

In Loughborough case, Loughborough Walk in Centre NHS would have moved from Pinfold Gate, LE11 1BE (easting coordinate = 453880, northing coordinate = 319579) to the Loughborough Community Hospital on Epinal Way, LE11 5JY (easting coordinate = 452320, northing coordinate = 319790). The first location was in the town centre and had good access by bus as well as by walking and bike (Figure 5-1).



Figure 5-1: Photo from walk in Centre NHS and the Loughborough Community Hospital

Figure 5-2 shows the two sites in Hinckley, Hinckley and District Hospital, LE10 1AG (easting coordinate =442941, northing coordinate =293759), would have moved to Hinckley and Bosworth Community Hospital, LE10 3DA (northing coordinate =442930, northing coordinate =295904).



Figure 5-2: Aerial photos from the two study area hospitals location in Hinckley

Loughborough Walk-In Centre NHS (WIC) is situated in Loughborough town centre. The WIC is open 24 hours a day and the main services of this centre are: contraceptive advice; flu symptoms; advice to being healthy and health promotion; minor cuts; muscle and joint injuries; skin illness, sunburn and head-lice; stomach ache, indigestion, constipation, vomiting and diarrhoea; and women's health problems, such as thrush and menstrual advice.

Loughborough Community Hospital (LCH) provides general rehabilitation and palliative and end of life care with 72 beds. The LCH provide the following services: diagnostic and/or screening services; and surgical procedures.

### **5.3 Data Sources**

One of the main aspects of this research was dealing with many different types of data from different sources. Data collection from valid, real and up-to-date sources was essential to this research. It was also essential to plan at the first stage of this research which type of data were required; and which alternative sources and methods of data collection were suitable. Similar to many statistical modelling, the accuracy of a model output depends on the quality of input data (Humphreys and Smith; 2009). While identifying suitable and update data sources was important, using data to check accuracy of other data could be helpful to prepare more accurate data. While using quantitative and qualitative survey data were required for this research, geographical contexts of collected data were important so as to merge multiple data sources in a GIS environment. Therefore, most data were collected with geographical references to be used in the research data analysis and modelling. The following data sources were explored and employed in this research.

**Census Data:** Demographic data were extracted from the Census data using Census Dissemination Unit website (<http://cdu.mimas.ac.uk>) and UK data archive (<http://www.data-archive.ac.uk>). Spatial data such as coverages of census tracts, postcode areas and road networks were also available from these sources. The primary variables included: population by age cohort and census tracts (e.g. Lower Layer Super Output Areas - LLSOA), car ownership and older and disabled people by LLSOA.

Supplement data was also available from the following data sources for any further research:

- Casweb aggregate information from UK census data: <http://census.ac.uk/casweb>
- ESRC Census Programme for UK higher and further education users: <http://census.ac.uk>
- GeoConvert tool for online geography matching and conversion to manipulate complex geographical and postcode data: <http://geoconvert.mimas.ac.uk>
- Linking Censuses through Time interface : <http://cdu.mimas.ac.uk/lct>
- Scotland's Census Results Online: <http://www.scrol.gov.uk>

**Road Network Data and Maps:** EDINA is a website which provided 'Digimap' service for UK academics and needs 'Athens' ID to access the data. Detailed information about road networks were downloaded from this website using <http://edina.ac.uk/digimap> link. Other related maps and GIS data were gathered from UKBORDERS (<http://edina.ac.uk/ukborders>) which was added as a new data or layer into the GIS environment for network analysis and GIS modelling purposes.

**Deprivation Indices:** There is relationship between social deprivation and the accessibility to primary care (Ashworth et al., 2007), therefore, different deprivation indices were considered in this research as one of potential influences of social-economic factors in users' accessibility perception to healthcare facilities.

English Indices of Deprivation (2010) data were obtained for various spatial levels (e.g. district level, Lower Layer Super Output Areas) from the 'Department for *Communities and Local Government*' website (Department for Communities and Local Government, 2010 ). The indices were produced by the Social Disadvantage Research Centre at the University of Oxford. The data were available from following link.

[www.communities.gov.uk/publications/corporate/statistics/indices2010](http://www.communities.gov.uk/publications/corporate/statistics/indices2010)

The Indices of Deprivation have a concept more than just poverty and lack of enough money, the deprivation refers to all types of shortage of resource and opportunity. In total 38 indicators, the deprivation data were available within seven grouped barriers and domains as: 'Income', 'Employment', 'Health and Disability', 'Education, Skills and Training', 'Barriers to Housing and Services', 'Crime' and 'Living Environment'. All of these domains were sorted based on their own score or rank. If a Lower Layer Super Output Areas (LLSOA) had a higher rank (closer to 1) or higher deprivation score than another LLSOA, it meant that the people in the area were more deprived.

Also these seven grouped domains were combined together as an index called Index of Multiple Deprivation 2010 (Department for Communities and Local Government, 2010 ) using following weights: Income (22.5%), Employment (22.5%); Health and Disability (13.5%); Education, Skills and Training (13.5%); Barriers to Housing and Services (9.3%); Crime (9.3%); and Living Environment (9.3%).

Among these domains, there was a sub domain as "Barriers to Housing and Services Domain" which was called "Geographical Barriers"; it was used to determine area-wide accessibility issues which were called "Road Distance to a GP surgery". In addition to this, there were other available data for Security from the "Crime Domain" that was used to determine area-wide Security issues (burglary, theft, criminal damage, violence); In the "Living Environment Deprivation Domain", there were two sub domains 'indoors' and 'outdoors' living environment. Both of these sub domains were used in this research. One of the 'outdoors' data was road traffic accident that was involving injury to pedestrians and cyclists. It was used to determine area-wide road Safety issues (Department for Communities and Local Government, 2010 ).

More useful sources were available from Office for National Statistics about Neighbourhood Statistics Services using <http://www.neighbourhood.statistics.gov.uk> link. Scottish Index of Multiple Deprivation (IDB) and Scottish Neighbourhood Statistics were available from the following links:

<http://www.scotland.gov.uk/Topics/Statistics/SIMD/Overview>

<http://www.sns.gov.uk>

**Bus Route and Stops Data:** These types of data were provided from Transport and Streets section of the City Council. For the study area of this research, these data and information was fortunately provided by the “Passenger Transport Unit Marketing Division” of Leicestershire County Council. Also these data were subsequently updated using their website, especially on the changes of bus services and any new bus routes.

**Location and GIS Data:** In addition to the above available GIS maps and data from the EDINA website (<http://www.edina.ac.uk>), it was possible to get a map service from Ordnance Survey website using [www.ordnancesurvey.co.uk](http://www.ordnancesurvey.co.uk) link address.

In order to show respondents of the questionnaire surveys on the map, it was necessary to find geographical coordinate of the respondents’ location according to their address or postcode. In addition to the Ordnance Survey data there were other available datasets which could be obtained from the following web mapping sources such as:

- Google Earth: <http://earth.google.com>; and Google Maps: <http://maps.google.com>
- Microsoft live search map: <http://maps.live.com>
- Royal Mail online postcode or address finder: <http://www.royalmail.com>
- Search for a location information in the UK: <http://www.nearby.org.uk>
- International postal code and addressing resources: <http://www.grcdi.nl/links.htm>

**Patient Data:** This sort of data was available from Hospital Episode Statistics (HES) data. Accessing to update data was one of advantages of the patient data in comparison with census data which were updated after 10 years; also patient data might help the researcher to explore population characteristics and their demands more precisely for their research and modelling. Some of available data from patient data sources were: postcode, gender, ethnic, age, disability, date/time of appointment, frequency and referral.

**Pilot survey:** Collecting data using questionnaire survey methods were taken in this research. In order to develop and improve the questionnaire surveys, they were designed through several meetings with the stakeholders. Feedback from these

meetings was considered in designing the questionnaire. These surveys were useful to identify important factors affecting accessibility as well as for developing the statistical model.

Online questionnaire surveys were used in this research as part of the first questionnaire survey and a pilot survey for the second questionnaire survey using the two following online survey websites.

Bristol Online Surveys: <https://www.survey.bris.ac.uk>

Survey Monkey: <http://www.surveymonkey.com/>

**Future Demand and Forecasted Data:** There were several sources of future forecast data for population such as UK National Statistics website (<http://www.statistics.gov.uk>). In order to develop more practical and update research, estimated population were used from latest census data.

#### **5.4 First Questionnaire Survey**

As explained in the methodology chapter, two different questionnaire surveys were carried out in order to identify important factors affecting accessibility to healthcare facilities. The first questionnaire was designed by obtaining feedback from a reference group made up with some experts from NHS Leicestershire County and Rutland, Leicestershire County Council, Public Representatives and Loughborough University. The survey was developed in three main sections including purpose and mode of travel, individual sites characteristics, and further information about background of the respondent as optional questions. The questions were formulated based on the following issues (Appendix B).

Total respondents of the questionnaire were 633 which were 23% of the distributed surveys. In terms of the respondents location, 76.5% of respondents (n=481) were from Loughborough and 23.5% were from Hinckley (n=148).

Some descriptive statistics were prepared to understand the facts related to the survey data. Table 5-1 shows summary statistics of the first questionnaire survey data.

Table 5-1: Descriptive statistics of first questionnaire survey data

Variable	Observations	Percentage
Age groups	551	16-19: 0.5%; 20-29: 5.6%; 30-39: 7.1%; 40-49: 12.2%; 50-59: 17.2%; 60-69: 25.2%; 70-79: 19.6%; 80+ and over: 12.5%
Gender: Male, Female	530	Male: 41.3%; Female: 58.7%
Available mode choice: Walk, Bike, Motorbike, Taxi/Friend, Car, Bus, Ambulance, Voluntary	1343	Walk: 19.7%; Bike: 6.3%; Motorbike: 0.9%; Taxi/Friend: 12.7%; Car: 33.9%, Bus; 23.1%; Ambulance: 2%; Voluntary: 1.5%
Preferred mode choice: Walk, Bike, Motorbike, Taxi/Friend, Car, Bus, Ambulance, Voluntary	82	Walk: 6.1%; Bike: 1.2%; Motorbike: 1.2%; Taxi/Friend: 7.3%; Car: 48.8%, Bus; 30.5%; Ambulance: 4.9%; Voluntary: 0.0%
Area: Loughborough, Hinckley	629	Loughborough: 76.5%; Hinckley: 23.5%
Disability: Yes, No, Prefer not to say	514	Yes: 23.7%; No: 67.3%; Prefer not to say: 9%
Ethnicity (White and non-white)	513	White: 96.8%; Non-white: 3.2%
Number of cars in a household: 0, 1, 2, 3, 4 and over	491	0: 18.9%; 1: 53.8%; 2: 22.4%; 3: 3.5%; 4+ and over: 1.4%

More details of first questionnaire survey and the results are provided in Chapter 6 of this thesis.

## 5.5 Field Survey

Field surveys helped the research to explore some issues which were not collected or clarified by the questionnaire survey such as road conditions, availability of bike and pedestrian lanes, pedestrian safety in crossing the streets near the hospital (e.g. availability of zebra crossing and car speed), safety and security of walking or cycling specially during the night, bus stops quality and locations, car park availability, disabled people accessibility considerations, cycle racks, road blocks and car driver convenience to entry or exit from hospital site. Therefore, some photos were taken from the both study areas of this research; also the videos were recorded from the areas around the hospitals to explore transport situation and problems during day light as well at night, for example, Figure 5-3 shows Ashby road in front of Hinckley and Bosworth Community Hospital. This road had some problems in terms of accessibility and transport issues such as: difficulties in crossing the road due to and volume without zebra crossing; lack of traffic light; poor lighting; and bus stop without shelter near the hospital side (left hand side of Figure 5-3). Although most of the traffic issues were reported by respondents of first questionnaire, the field survey was very helpful to recognise the problems as far as possible; and to confirm whether some important factors identified in the first questionnaire survey are relevant to the study area or not.



Figure 5-3: Ashby road in front of Hinckley and Bosworth Community Hospital

## 5.6 Second Questionnaire Survey

Although area-wide data such as deprivation indices data (e.g. income, employment, health and disability, education, crime, living environment and barriers to housing and services), accident data, and population of different age were available from different sources, but data on the perception of accessibility were not available and therefore another questionnaire survey was designed and carried out to obtain the accessibility perception of users to two healthcare facilities in Loughborough, Leicestershire (Walk-In-Centre NHS and Loughborough Community Hospital) in October 2011 to February 2012 (Appendix C).

First question asked respondents to select their destination from one of the two hospitals (i.e. Walk in Centre NHS and Loughborough Community Hospital) then the second question was asked about their travel mode(s) to access the selected destination. Respondents introduced their origin as 'home', 'work' or 'other'. In order to find the respondents origin location, they could put their origin full postcode at least with 5 digits postcode or they could state their origin by looking for their address on the given map with delineated LLSOA, Lower Layer Super Output Area on it(Figure 5-4).





area-wide factors. The respondents were also able to choose a healthcare facility while determining accessibility. Due to the broad nature of accessibility, a generic explanation of accessibility was provided to each respondent. Figure 5-5 shows spatial distribution of final sample size of respondents (515 users) which was considered as a representative sample.

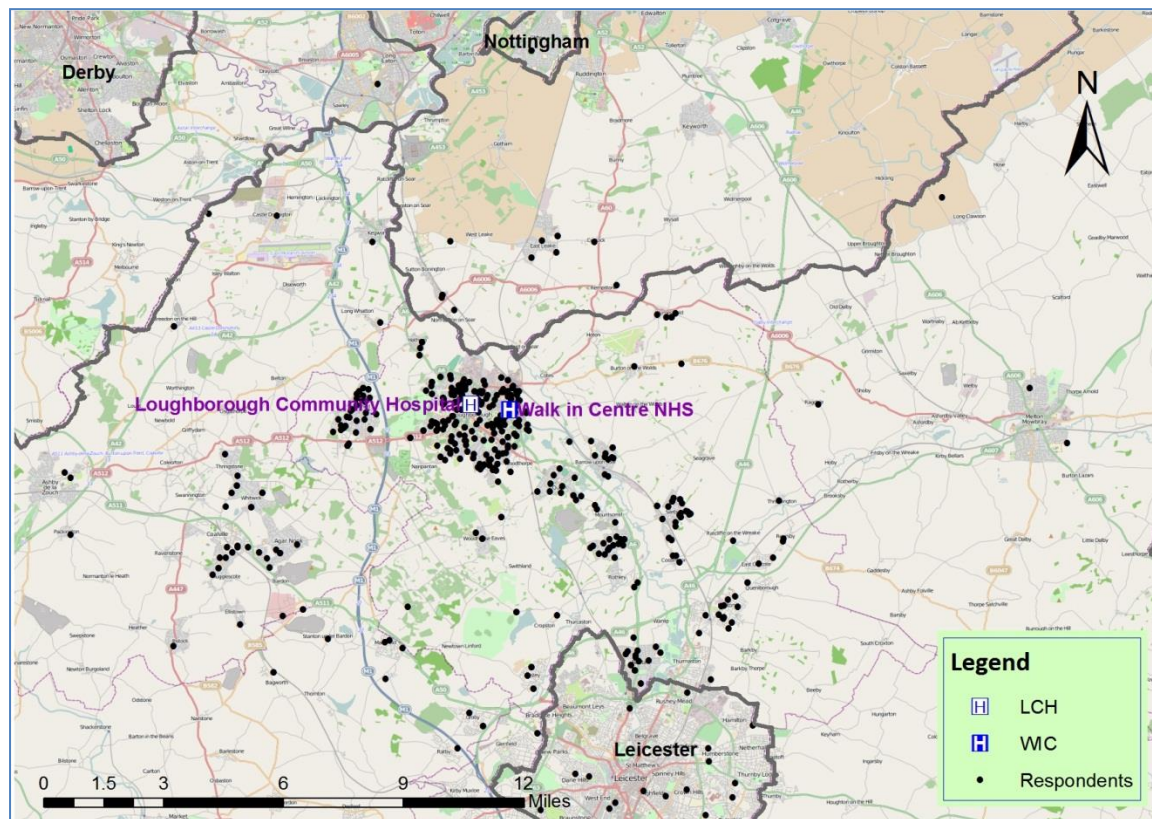


Figure 5-5: Spatial distribution of the respondents

Regarding the multilevel statistical modelling which was introduced in Chapter four, the modelling variables were separated into two levels as ‘individual’ level and ‘area’ level; the information asked in the second questionnaire survey were used to identify individual variables.

For instance, asking postcode of users’ origin could support the research to develop required variables for statistical modelling. Postcode of ‘origin’ and ‘destination’ locations of the users were used to calculate their travel distance and travel time by car as well as to calculate their fuel consumption; also any correlation between travel time, travel distance and fuel consumption were checked.

Information about 'Travel mode' of the users supported the model to calculate their fuel consumption as well as in finding significant factors affecting users' perceptions of accessibility regarding different travel modes (e.g. car, bus, bike, and walk). In terms of using public transport, by identifying users' origin on the map it was possible to find available bus stops around the respondents' origin. Therefore, level of public transport activities within the area around the respondents' addresses were calculated to consider bus availability as one of the statistical modelling variables.

After defining 'bike catchment area' and 'walk catchment area' around the hospitals on map, it was possible to find whether being in bike or walk catchment area can affect users' perception or not. Acceptable walking distances for the hospital users were already identified from the first questionnaire survey and literature reviews.

Various descriptive statistics were generated to understand the facts related to the survey data. Table 5-2 shows summary statistics of the variables included in the model. The average accessibility score was found to be 80.7 (for the whole sample) and 81.7 (for the respondents who had an access to a car). This seems very high but reflecting the fact that the survey area was predominantly rural.

Table 5-2: Summary Statistics of Variables Used in the Analysis

Variable	Observations	Mean	Standard deviation	Min	Max
<b>Overall Accessibility Score</b>	514	80.61	28.24	10	100
<b>Individual-level variables</b>					
Travel distance (mile)	503	5.34	4.56	0	19.7
Travel time (minutes)	503	12.25	7.67	0	43
Fuel consumption for the trip (grams)	503	1.52	1.55	0	6.76
Number of services available per hour within the 400m buffer	503	12.87	16.54	0	77
Number of bus stops within the 400m buffer	503	5.57	6.88	0	28
Age groups	485	16-19: 5.2%; 20-29: 20.2%; 30-39: 13.3%; 40-49: 15.5%; 50-59: 13.4%; 60-69: 17.3%; 70 and over: 15.3%			
Gender (Male = 1; Female = 0)	497	Male: 42.25%; Female: 57.75%			
Mode choice: Car, Bus, Bike, and Walk	514	Car: 81.91%; Bus: 4.28%; Bike: 0.58%; Walk: 13.04%			
Destinations (A=1; B=0)	515	A(WIC): 39.61%; B (LCH): 60.39%			
Whether the respondent from the walking catchment (Yes=1; No=0)	503	Yes:14.76%; No: 85.24%			
Whether the respondent from the cycling catchment (Yes=1; No=0)	503	Yes:43.88%; No: 56.12%			
Income	356	£14,999 and under: 40.73%; £15,000-£24,999: 23.03%; £25,000-£49,999: 24.72%; £50,000-£74,999: 7.03%; £75,000 and over: 4.49%			
Disability (Yes=1; No=0)	493	Yes: 7.51%; No: 89.25%; Prefer not to say: 3.25%			
Ethnicity (White and non-white)	494	White: 84.41%; non-white: 15.59%			
Car ownership (Yes=1; No=0)	510	Yes: 83.14%; No: 16.86%			
<b>Area-wide factors</b>					
Accidents per 1000 population		14.86	11.42	1.8888	67.25
Index of multiple deprivation (IMD)		0.05	0.06	0.0017	0.817754

Figure 5-6 shows distributions of travel distance and travel time for the whole sample. As can be seen, most of the respondents' origins were less than 15 miles or 30 minutes far from the two hospitals.

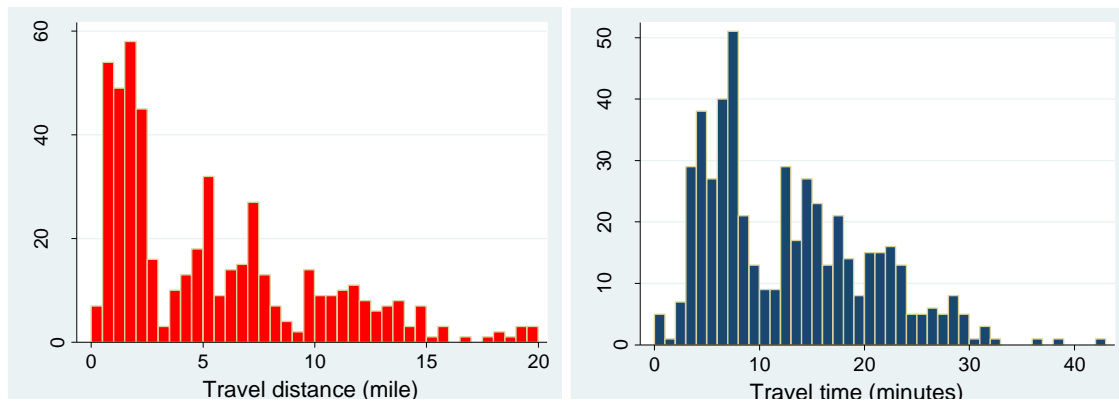


Figure 5-6: Distributions of network-level travel time and travel distance for all respondents

Question 7 asked respondents to rank important factors in accessing their destination. The factors were selected among the most important factors identified by the first questionnaire survey including: travel time by car; frequency and reliability of bus provision; fuel consumption; access by bike; access on foot; proximity to a bus stop; road accident and crime; and bus fare. Figure 5-7 shows percentage of the ranks which were assigned by respondents. It indicates that travel time by car (79.3%) and access on foot (28.9%) had the highest rank for the respondents in accessing the Loughborough sites. While 44.6% of respondents selected the fuel consumption as the second important item, 23.8% believed that frequency and reliability of bus was their second priority.

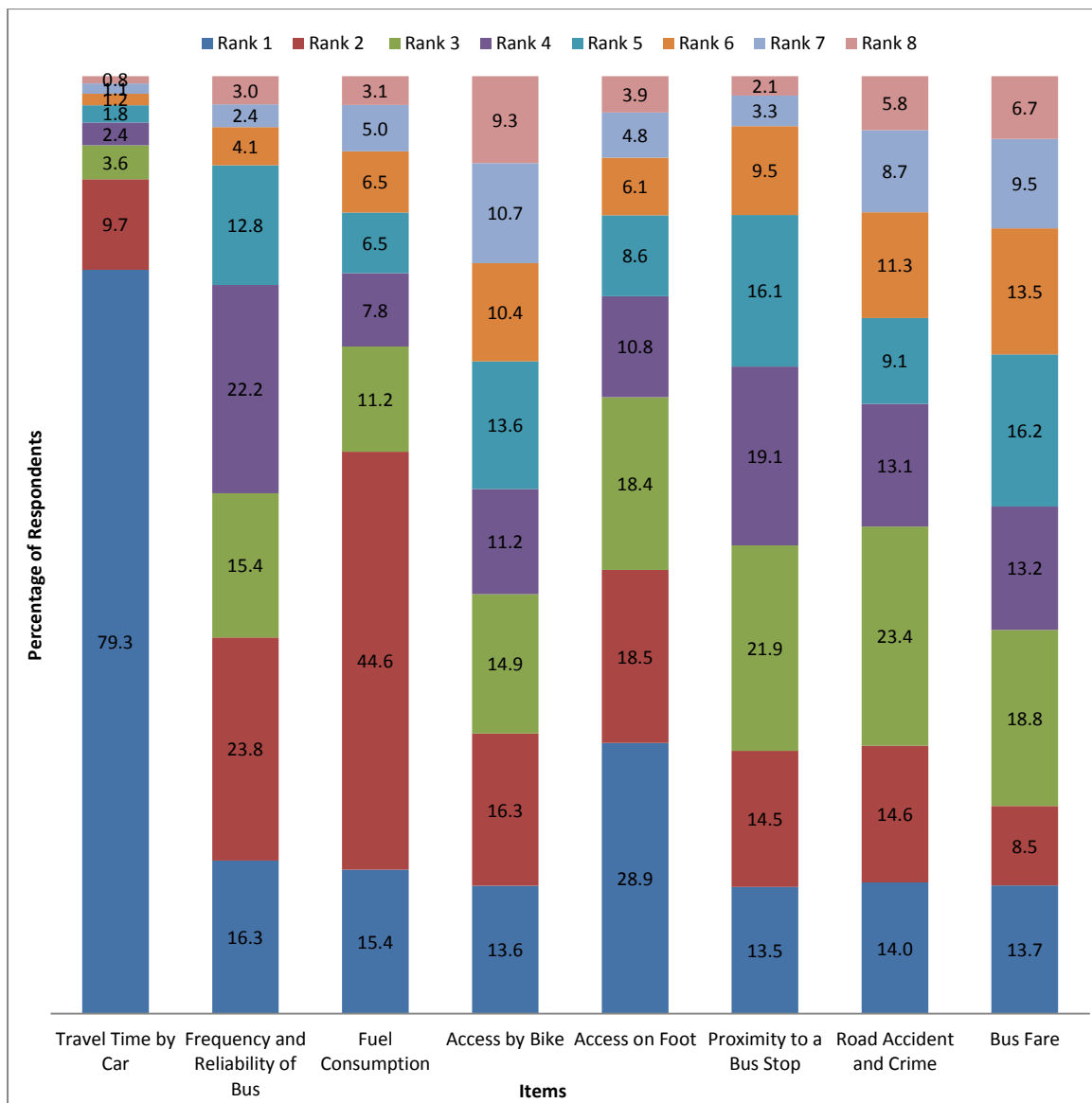


Figure 5-7: Percentage of assigned ranks for important factors of accessibility

In order to compare the importance of each item for the respondents, Figure 5-8 was prepared for each item separately. Figure 5-8 also shows the overall scores of the eight items. The given scores were based on assigning maximum score as 8 for the item which was ranked as the first important factor, and minimum score as 1 for the item with the lowest importance (8<sup>th</sup> rank). While travel time by car and fuel consumption had considerable difference in respondents' ranking, access by bike, bus fare and road accident and crime did not have much variation in ranking. Overall scores of the items showed that access by bike, road accident and safety, and bus fare had less importance

for the respondents. As majority of respondents (82%) used car to access the hospital sites, using bike or bus and safety and security did not have priority for them.

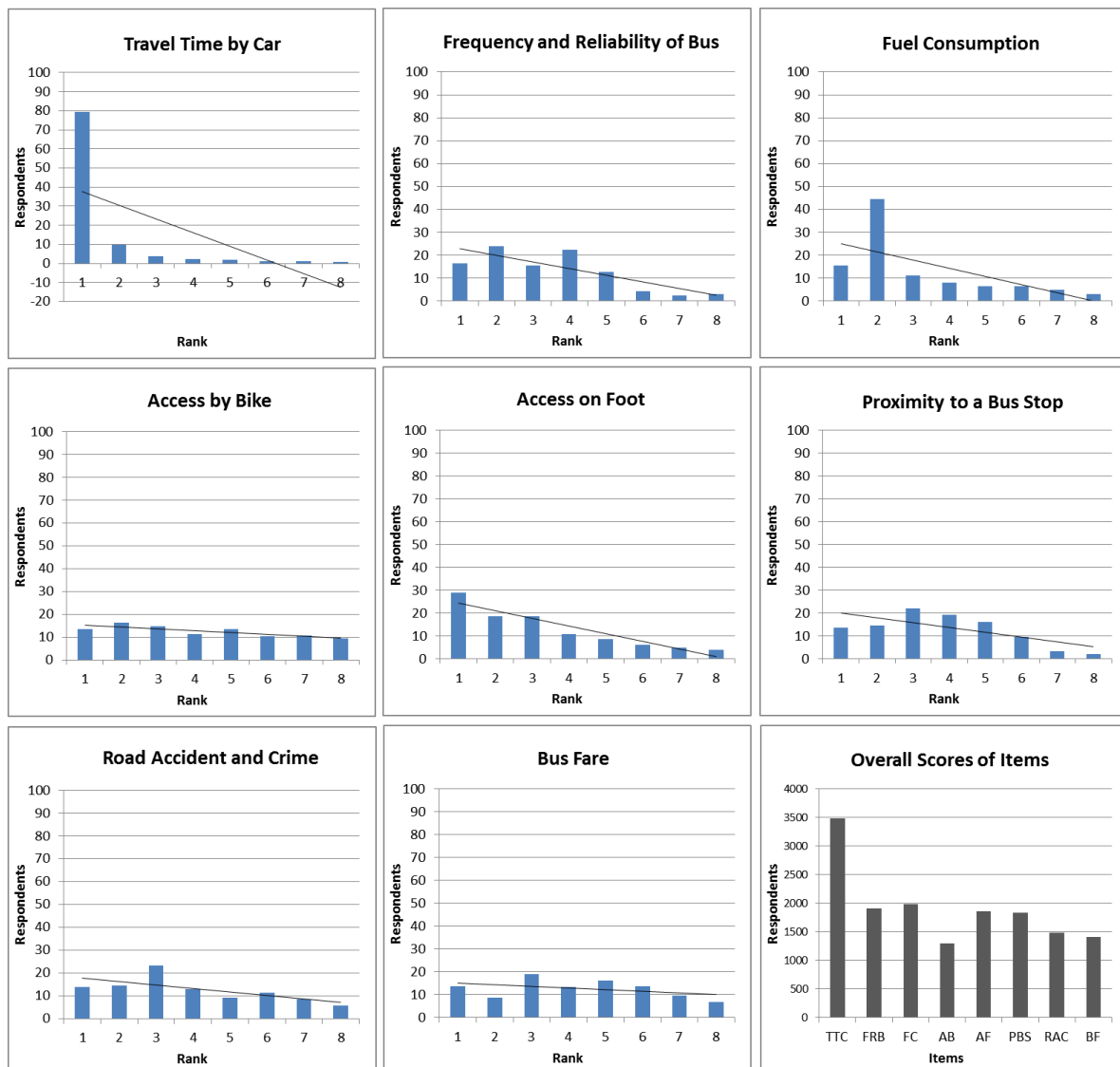


Figure 5-8: Changes of ranks and overall score of items in accessing the sites

The results showed an overview of respondents' preferences and priorities in traveling to the study area sites. However, statistical modelling of the users' perceptions can reveal significant factors which can affect their perceptions.

## 5.7 Data Merging, Cleansing and Processing

In addition to collecting individual level data from the second questionnaire survey, the statistical model needed to deal with many area-wide factors such as demographic data, deprivation indices, accident data, and provision of public transport. These kinds of data

were collected from different data sources (Table 5-3) to be tested as the area level factors of the multilevel statistical modelling.

Table 5-3: Datasets and their sources

Data	Resources
Accident data	<a href="http://www.dft.gov.uk/statistics">www.dft.gov.uk/statistics</a>
Bus frequency	<a href="http://www.leics.gov.uk">www.leics.gov.uk</a>
Bus routes and stops	Leicestershire City Council data
Census Data and maps	<a href="http://www.data-archive.ac.uk">www.data-archive.ac.uk</a>
Deprivation Indices	<a href="http://www.communities.gov.uk">www.communities.gov.uk</a>
Fuel consumption	<a href="http://www.defra.gov.uk">www.defra.gov.uk</a>
Postcode coordinate	<a href="http://www.ordnancesurvey.co.uk">www.ordnancesurvey.co.uk</a>
Road network data	<a href="http://edina.ac.uk/digimap">edina.ac.uk/digimap</a>
Travel time calculation	STATA and Google Map

As can be seen from Figure 5-9, the survey respondents were scattered over different areas within Loughborough and beyond. It was therefore necessary to identify a good spatial unit for the analysis of a UK census tract - Lower Layer Super Output Areas LLSOA (roughly 1,450 households in a LLSOA) seems to be the right choice given the size of the study area. Various LLSOA-level area characteristics data such as deprivation indices and crime domains were therefore obtained from the Census estimated data for 2011. Data on accident, bus services, bus stops location, and road network data were also obtained from various secondary sources. Then integration of individual-level data and area-wide factors was carried out in GIS environment using ArcGIS 10 software.



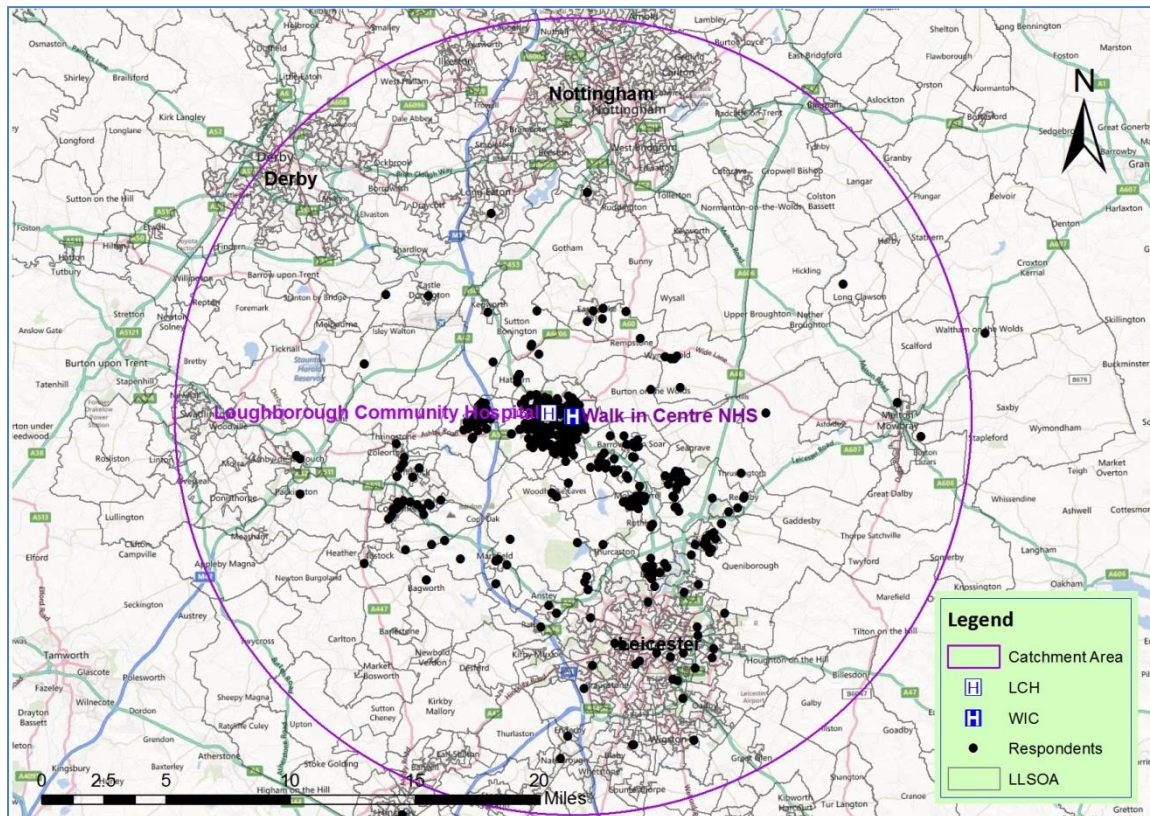


Figure 5-9: The spatial distribution of survey respondents

All spatial and non-spatial data were linked into the respondents as well as the LLSOA based map according to their spatial location. In order to gain the most advantages of related useful software, some data were imported from different software such as MapInfo, STATA, SPSS and Microsoft Excel.

After importing the LLSOAs map for the study area into GIS environment (ArcGIS 10) as a polygon layer, the layer was clipped for the research areas as Leicestershire, Derbyshire and Nottinghamshire counties. Then Census estimated data for 2011 including population, car ownership and deprivation data 2010 (e.g. crime, income and IMD score) were superimposed based on LLSOA zone code using ArcGIS spatial join tool. Figure 5-10 shows the LLSAOs map of Leicestershire county and the logos of the secondary data sources.

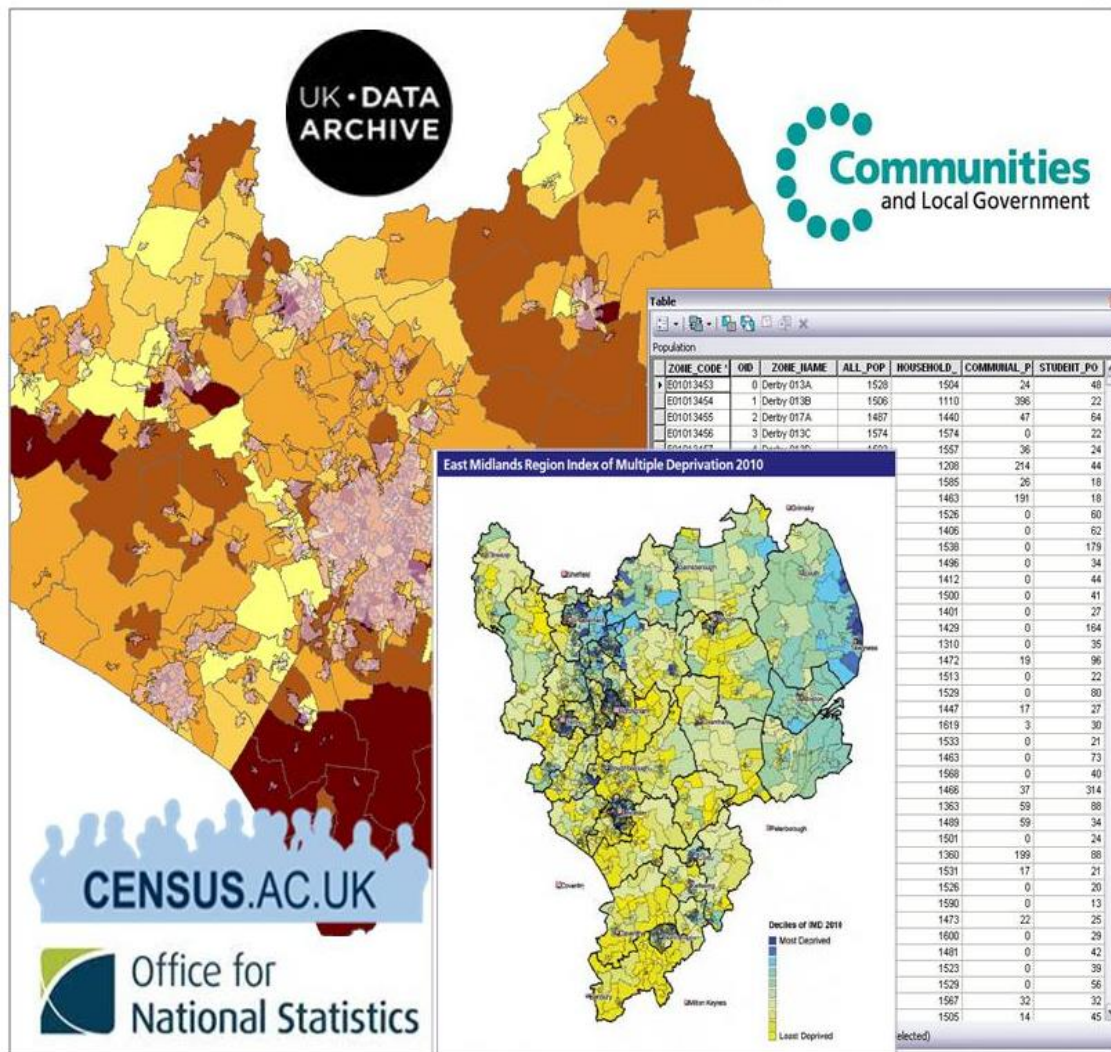


Figure 5-10: Join census data and deprivation indices to LLSOAs map layer

In order to join LLSOAs attribute data to all correspondent respondents, it needed to locate them on the map based on their given postcode. Therefore, coordinates of the respondents (X, Y) were identified using provided information from 'Ordnance Survey' website which had coordinates (X, Y) of all postcodes. After creating the new point layer from all respondents' location, the respondents were joined with all related data such as census, deprivation, and the questionnaire survey data by joining the LLSOAs polygon layer to this respondents' point layer. Figure 5-11 shows the respondents location over the LLSOAs layer on map within the research study area.



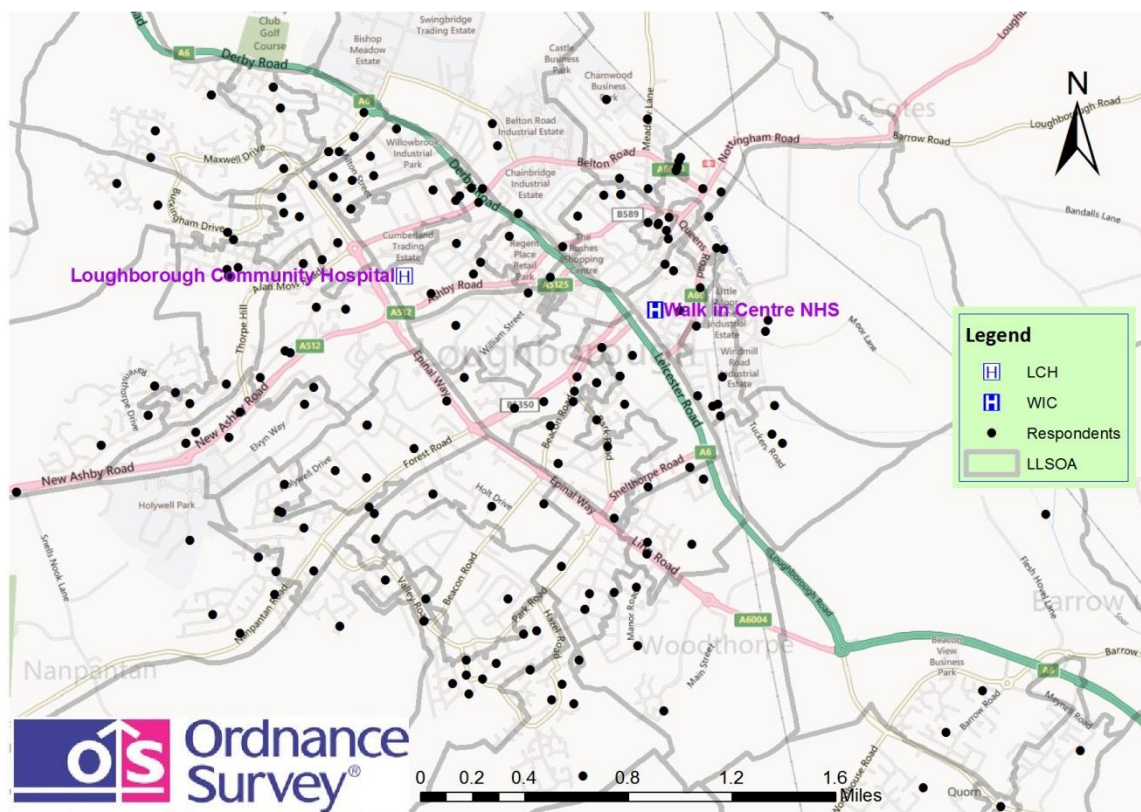


Figure 5-11: Join of LLSOA data to the respondents' questionnaire data

In order to find availability of public transport around a respondent's origin, it needed to know how many bus services per hour were available; also needed to determine which bus routes were running to the healthcare facilities. Therefore, location of bus stops and bus routes layers were imported into the map, and also updated tabular data of bus frequency were collected from Leicestershire County Council website. Figure 5-12 shows selected bus routes to the two hospitals within the research study area and the bus stops which had direct service to the hospitals in two different colours.

The required information of the existing bus stops and routes, were extracted from the study area map by sorting the services number in 'service\_no' fields of the bus routes layer. Then number of bus services per hour of the selected bus routes was inserted into 'bus\_services' field. Finally, bus frequency was joined to the bus stops (i.e. joining line layer to point layer) based on their spatial location.

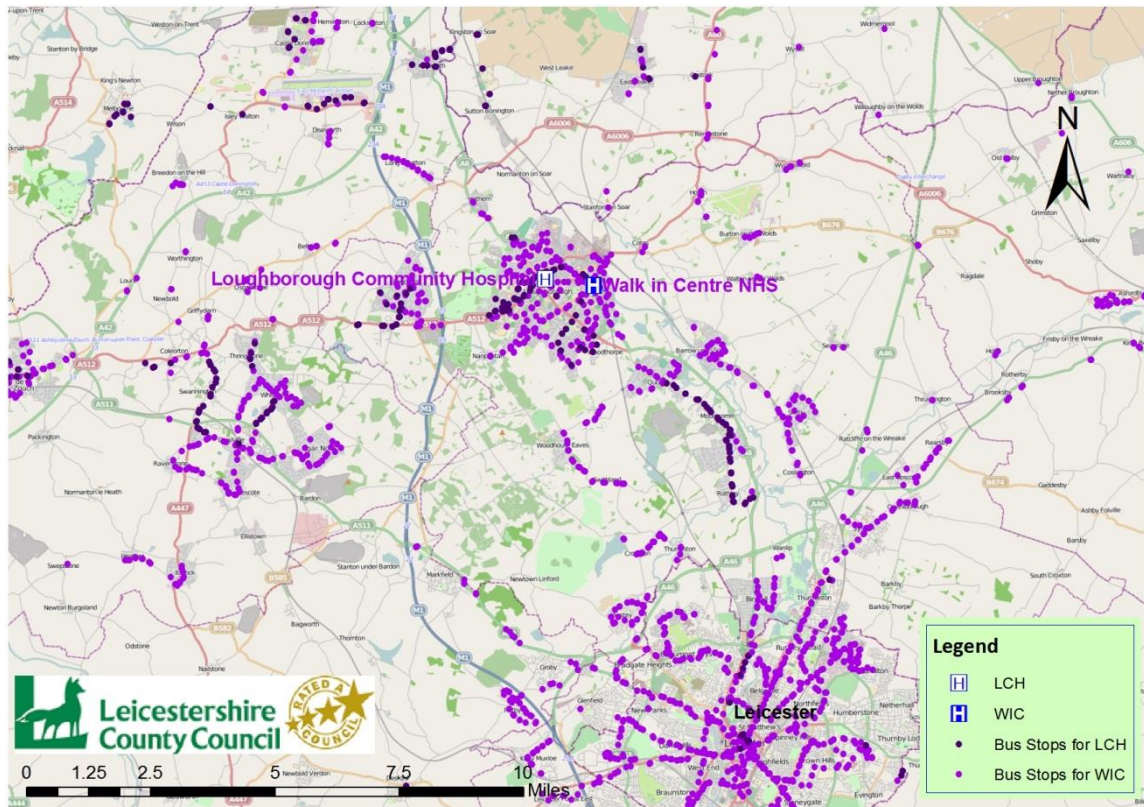


Figure 5-12: Location of selected bus stops and bus routes to the destinations

In order to find bus availability and frequency for each respondent, a 400 meter buffer was created around each respondent's origin or home. Then bus stops layer was joined to the buffer layer to determine total number of bus stops which falls into the 400 metre buffer. Then attributes table of the buffer layer was joined to respondents' layer based on their common field (Figure 5-13).

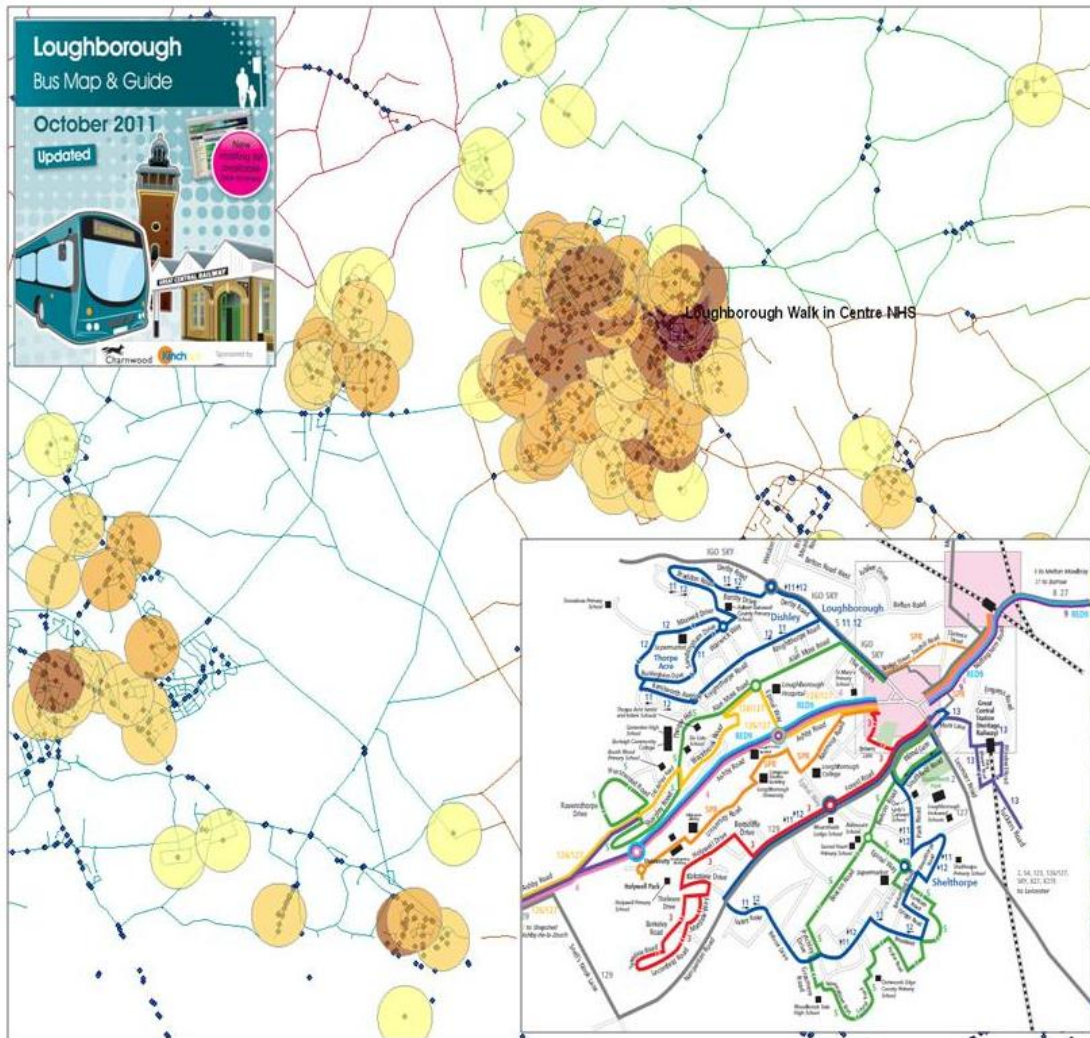


Figure 5-13: Identify existing bus stops within 400m distance from respondents' origin

In order to find whether being in walk or bike catchment area could effect on user's perception on accessibility or not, based on an acceptable distance for pedestrians and cyclist, two buffers were created around each destination to define walk and bike catchments areas. A buffer with a 1,200 metre radius was defined for the walk catchment area; and a buffer with a 3,000 metre radius was defined for the bike catchment area.

Then the layers of these two buffers were joined to the respondents' layer (i.e. Joining polygon layer to point layer) to find which respondents were within the walk or bike catchment area, or both (Figure 5-14). The resulted data was used in the model as a dummy variable (1 for the respondents with in the catchment and 0 for out of it).



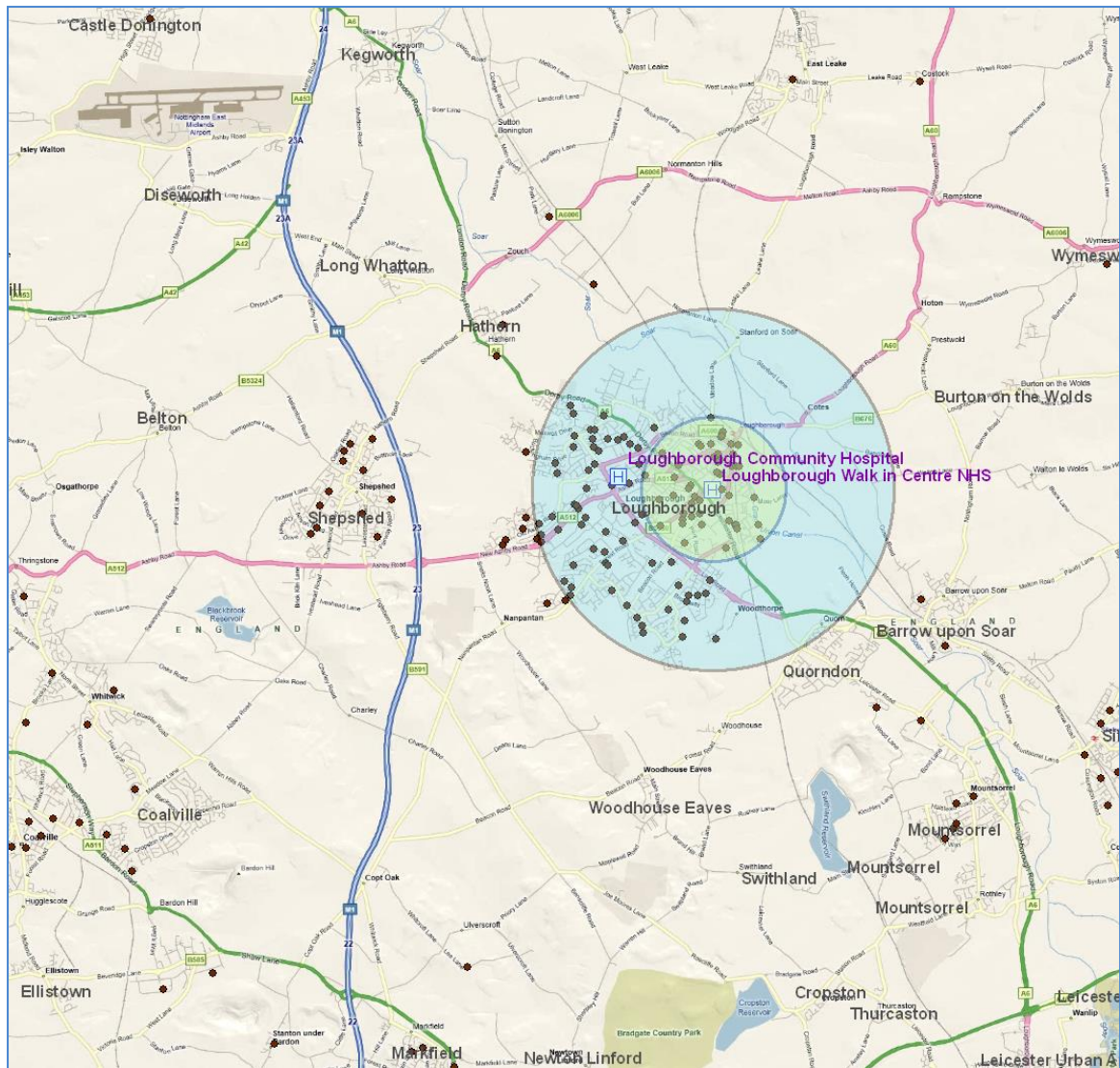


Figure 5-14: Define walk and bike catchment area around the destination

In order to employ safety factor of each LLSOA area to the model, accident data (1996-2009) was imported as a point layer using X, Y coordinate of each accident point. Then these accident data were joined to the study area (LLSOA) layer (i.e. joining point layer to polygon layer). Figure 5-15 shows accidents point, road network of the research area, and the LLSOA in different colours based on their safety.

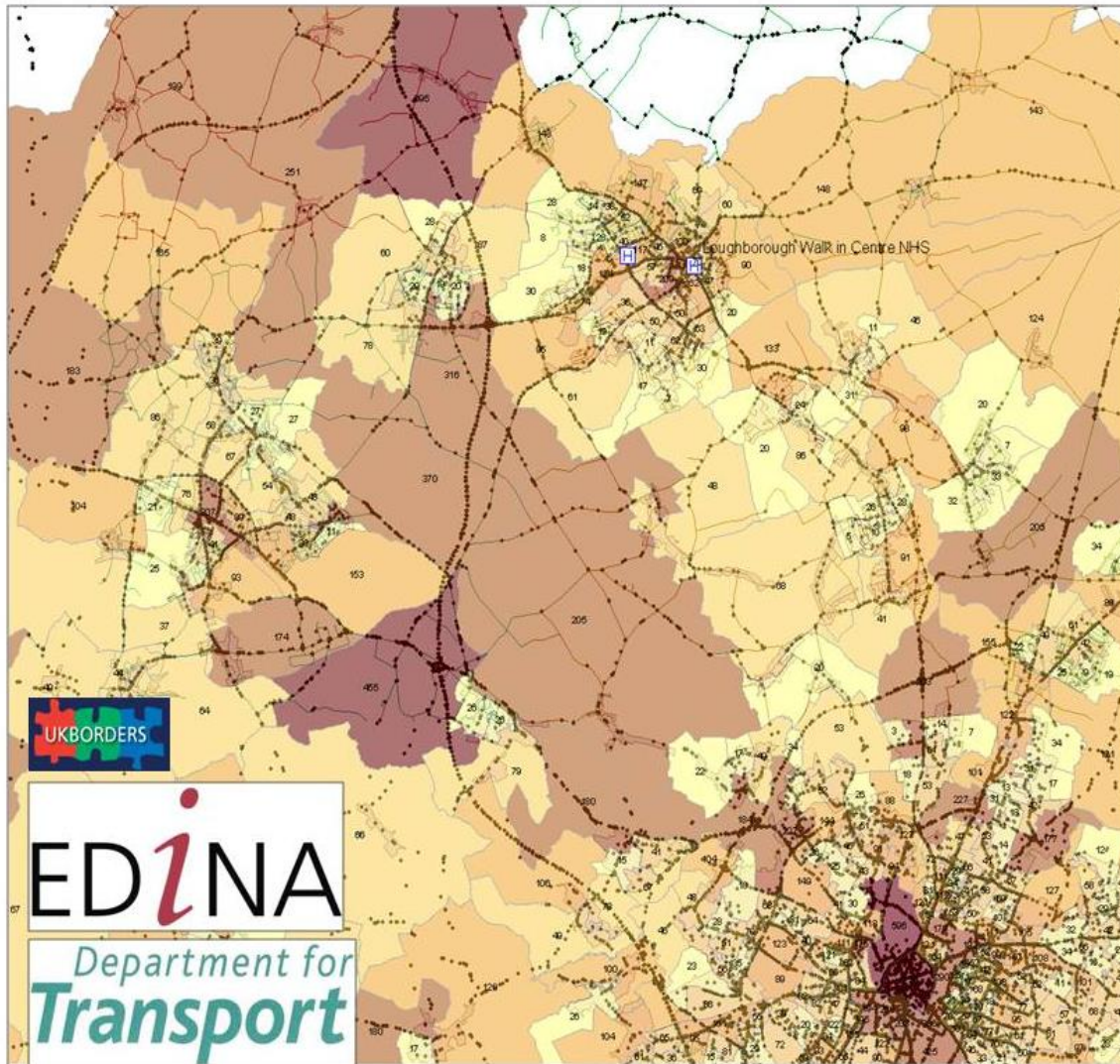


Figure 5-15: Find LLSOAs' safety by joining accident data (1996-2009)

In order to calculate network-based travel time from an origin of a respondent to the destination, STATA software was used. STATA had a user-written program to calculate both travel distance and travel time by utilising the Google map. The fuel consumption or gram CO<sub>2</sub> emission for each of the respondents were calculated by multiplying travel distance between the origin and the destination with the emission factors (g/km).

## 5.8 Calculation of Real Travel Time

Using straight-line distance is an often-used shortcut to estimate travel time (Ozimek and Miles, 2011). The main reason of using straight-line distance is the difficulties of estimating real travel time based on 'driving' time or distance. Accurately measuring the

driving distance must be undertaken into consideration with some other factors such as the available road networks, one way roads, the shortest or alternative roads and the shortcuts. On the other hand, accurate estimation of travel time will be more complicated than estimation of travel distance because it needs to consider more factors related to driving time such as traffic congestion, traffic lights, speed limits, turning time, and stop signs. The problem will be very complicated when a study needs to consider different travel modes such as public transport, bike and walk rather than car.

Using straight-line distance is inaccurate (Al-Taiar, et al., 2010) for this research and may add some errors which can be correlated with other variables of the statistical model. For example, if traffic congestion in high density area has not been considered, it may be possible to correlate it with the area's socio-economic factors; because people with lower income people probably live in more dense areas (Ozimek and Miles, 2011). Therefore real driving distance and time were considered in this research to be used as examined variables of the statistical model.

Ozimek and Miles (2011) designed a 'traveltime' command in Stata software to estimate travel time from an origin to a destination using Google Maps. Also, it has a travel mode option to specify the calculation for three different travel modes as car, bus and walk. The 'traveltime' command uses Google Maps to generate travel time and calculate distance between two points. The two points latitude and longitude must be presented in decimal degree. This command generates travel time in days, hours, minutes and can calculate travel distance in kilometres (km) or mile unit (Stata, 2012).

## **5.9 Preliminary GIS Analysis**

In order to study and evaluate collected data as well as being familiar with applications of GIS in accessibility measurement, a preliminary GIS analysis was generated at the beginning stages of the research. This analysis was based on traditional way of measuring accessibility by creating accessibility contours around a destination using travel distance or travel time by car which was called 'service area'. As mentioned in Chapter 3 (Section 3.7) of this thesis, this method was used by the UK Department of



Health in developing SHAPE tool to assess accessibility to healthcare facilities based on travel time by car (DoH, 2009). While SHAPE was developed based on generating travel time by car, travel time by public transport needed to be considered. Therefore accessibility by bus was considered in this preliminary GIS analysis to evaluate bus related data and maps.

The required maps and GIS layers were selected and extracted from available data sources for Loughborough. Then some related tabular data were downloaded from online data sources such as census data. Also road networks, hospital sites location, bus stops location, and bus routes map were imported as GIS layers to do the preliminary service area analysis (Figure 5-16).

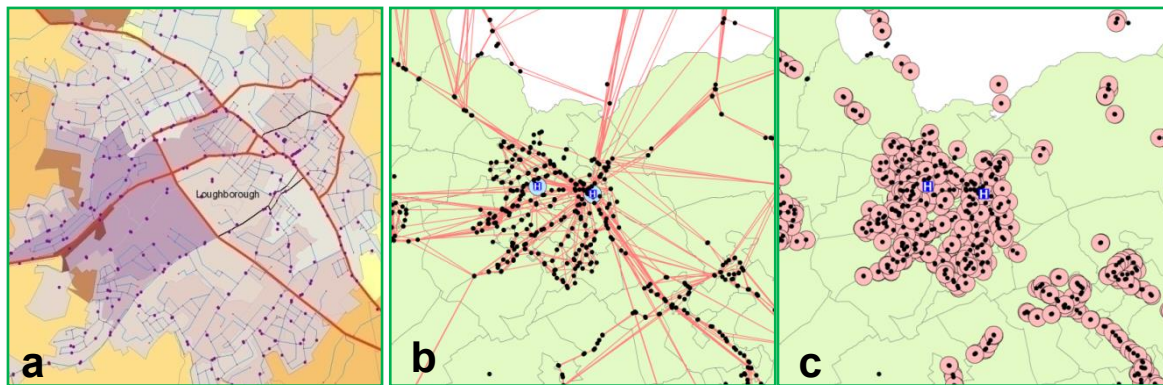


Figure 5-16: Loughborough road networks, hospitals location, bus routes and stops

After importing all required layers and data, service areas to the healthcare facilities were created using ArcGIS Network Analyst software. In order to study availability of bus in Loughborough area to access the two hospitals, it needs to know where people are near a bus stop to go to Walk in Centre NHS or Loughborough Community Hospital.

In summary, the following main steps were taken for the GIS analysis to assess the accessibility by bus to the two hospitals.

1. Prepare the downloaded road network layer as three types of road as motorway, major and minor roads (see Figure 5-16a).
2. Prepare the downloaded bus stops and the routes layer and update collected data (see Figure 5-16b).

3. Assign 500 meter buffer around the hospitals to identify bus stops inside the buffer to find the nearest bus stops to the hospital (see Figure 5-17b).
4. Select the correspondent's bus routes which have bus stops inside the hospital buffer among existing bus routes in Loughborough area.
5. Assign 400 meter buffer around the bus stops which had bus service to the hospitals; this buffer helped to identify the areas which included bus stop to access hospitals with less than 400 meter walking distance (see Figure 5-16c).
6. Define service area of each hospital according to the travel time by bus (see Figure 5-17a).
7. Cumulate all areas which had access to the bus stops.
8. Clip areas which had bus stops from the created service area. The new clipped layer included the area within the created contours where the people had access bus to go to the hospitals (see Figure 5-17b).
9. Overlap clipped area with census data layer to use related demographic data. As each LLSOA has their own demographic characteristics (e.g. population, age groups), therefore by overlapping bus available areas on it, it was possible to find how many individuals had access to bus within the created contours based on the contour assigned travel time.

Figure 5-17 shows contours around the two hospitals in Loughborough which were employed to identify their service areas; and Figure 5-17b shows the 500 meter buffer around a hospital and the area with accessibility to bus within the service area.

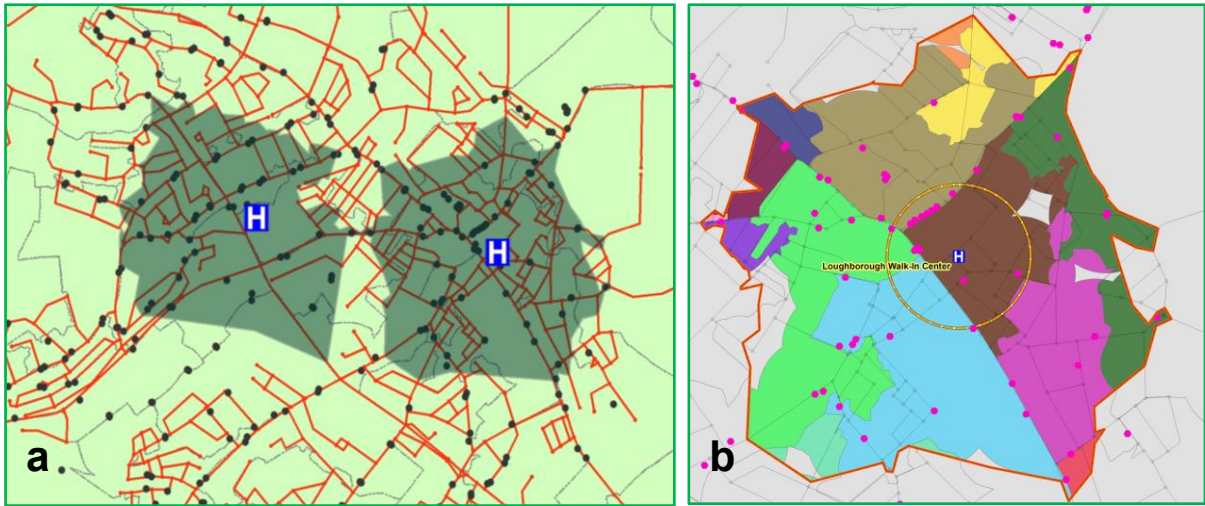


Figure 5-17: Service areas contour around the hospitals

Figure 5-18 shows the three service areas for 4, 8, and 12 minutes travel time by bus to the Walk in Centre NHS in Loughborough; the generated map also shows how many users could access to the hospital within the defined travel time. For example, 6700 users could access to a hospital by maximum 400 metre walk to access the bus stop; then travel by bus within maximum 4 minutes; and finally egress the hospital by maximum 500 meter walk.

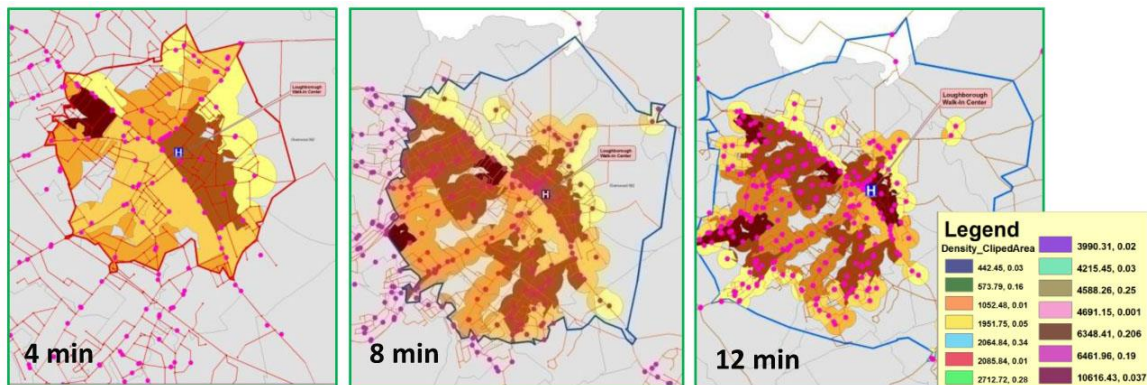


Figure 5-18: Service Area during 4, 8 and 12 minutes

## 5.10 Summary

In addition to a review of the research literature, a questionnaire survey was developed to identify important factors and required data to measure accessibility. Therefore, four existing hospitals in two middle-sized towns, Loughborough and Hinckley, were chosen as the study areas of this research to explore any differences between them and identify important factors affecting accessibility as far as possible.

At the first stage of data collection from these study areas, the first questionnaire survey and a field survey were undertaken to help the research in exploring important factors, and identifying required data sources to conduct the research for the next stages of further study. The scope of the first survey was to know the requirements and preferences of users of healthcare facilities to identify the available travel modes which they used and preferred; and to explore the participants' experiences to access the hospitals.

After identifying important factors and their required data sources for measuring accessibility by the first questionnaire survey, further works were completed by second questionnaire survey which was designed specifically to develop an accessibility model; the second questionnaire survey was designed with less number of factors which were identified as the most important factors from the first questionnaire survey. In the second questionnaire survey, the respondents were asked to provide the level of accessibility (on a scale of 0 to 100) from their home to one of the healthcare facilities in Loughborough.

In order to investigate all important individual-level and area-level factors using a statistical model, it was essential to prepare and integrate required data in a GIS environment. Therefore, the required data collected from various datasets obtained from a range of secondary sources (e.g. National Census, Ordnance Survey, Deprivation Indices) using different data collection methods; these data were processed to extract important area factors such as availability of bus services, safety, and security. Then these data were linked to the respondents' data which were collected from the second questionnaire survey.

## 6 RESULTS OF THE FIRST QUESTIONNAIRE SURVEY

### 6.1 Introduction

In order to identify important factors that affect accessibility to healthcare facilities and develop the multilevel statistical model, two questionnaire surveys were undertaken in this research for Loughborough and Hinckley sites. While the purpose of the first questionnaire was to understand underlying factors affecting accessibility to healthcare facilities, the second questionnaire survey was undertaken to capture data relating to users' perception of accessibility and their socio-economic factors. Besides the questionnaire surveys, a field survey was also undertaken to identify the important factors as far as possible such as exploring safety and security with respect to walking or cycling, bus stops locations, and accessibility considerations for disabled people. Figure 6-1 shows a summary of the collected data and the analyses which have been carried out alongside the first questionnaire survey by employing two types of data (i.e. quantitative and qualitative).

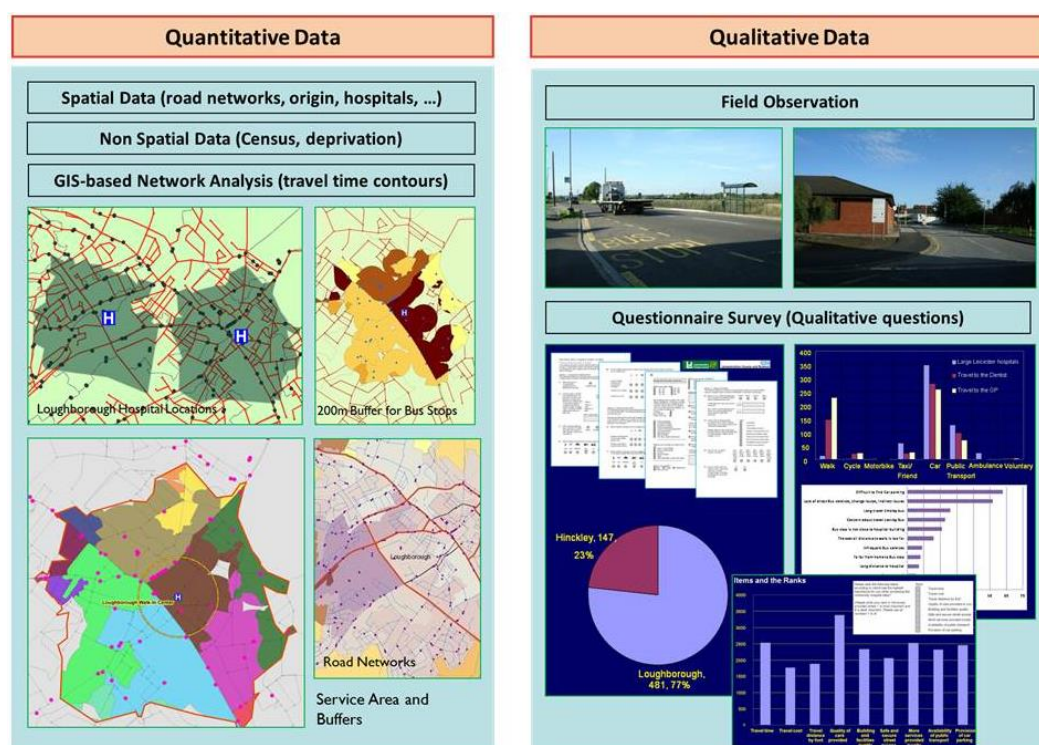


Figure 6-1: Dividing data collection and analysis into two types of data



While this chapter aims to analyse the first questionnaire survey data, some results have been used for the next stages of this research. Figure 6-2 shows the process flow-chart chain from the beginning to the end of this research; it shows that results from each of the stages have been used for the further stages as a chain, for example: the findings from the first questionnaire survey were employed to design the second questionnaire survey; and the second questionnaire survey data were then integrated with the other secondary datasets to develop various multilevel models.



Figure 6-2: Process flow-chart chain of data analysis

In 2009, as part of this research and in collaboration with other researchers within the School of Civil and Building Engineering, a study on transport issues in assessing accessibility to Loughborough and Hinckley hospitals was conducted. The result of this study and the questionnaire survey contributing to it, have been included in a report to NHS Leicestershire County and Rutland under the title ‘Loughborough and Hinckley Hospitals: Travel and Access Report’. This document is available on NHS Leicestershire County and Rutland website (NHS LCR, 2009).

This chapter is organised as follows. Firstly, a brief introduction is provided on the first questionnaire survey. This is followed by providing overall results of the four hospitals within the study area such as respondents' origin, destination, frequency of travel, and selected travel modes in accessing the sites. The two consecutive sections present the results of quantitative and qualitative analysis for Hinckley and Loughborough sites separately including respondents' mode of transport and their problems and experiences in travelling to the hospital sites. Finally, respondents' willingness to Walk, using Public Transport or Cycle is discussed before the summary section.

## **6.2 First Questionnaire Survey**

The first questionnaire survey identified transport issues and potential factors affecting accessibility to four hospitals at Loughborough and Hinckley, Leicestershire (see Appendix B for the questions of the first survey). Major reasons to undertake the first questionnaire survey at the study areas for this research were:

- review the research necessity and relevant issues;
- finding important factors influencing accessibility;
- exploring main data sources and data collection;
- examining literature review and the research gaps;
- scoping survey of stakeholders criteria;
- suggesting priorities for next stage and extensive modelling;
- preliminary GIS analysis to set out more on-going process; and
- studying the feasibility of GIS analysis.

The survey was supported by NHS Leicestershire County and Rutland (NHS LCR), and Leicestershire County Council (LCC) on the way of reaching the NHS LCR vision. The NHS LCR aims to become the healthiest place in the UK by 2018 in Leicestershire and Rutland. The NHS LCR believes that easy access to healthcare facilities is one of the most significant priorities to provide better healthcare services and to reduce their carbon footprints (NHS LCR, 2009).

The NHS LCR has planned to transfer the Loughborough Walk in Centre NHS (WIC), from Pinfold Gate to the Loughborough Community Hospital (LCH), Epinal Way. At the same time, the NHS LCR has intended to relocate the Hinckley and District Hospital (HDH), Mont Road to the Hinckley and Bosworth Community Hospital (HBCH) site, Ashby Road. After receiving a number of comments about transport and access issues, this survey was undertaken to understand the accessibility issues and to improve local transport and access to the future sites.

The questionnaire was designed and improved by obtaining feedback from a reference group including NHS LCR, LCC, Public Representatives and Loughborough University. This reference group discussed their opinion by attending meetings as well as leaving feedback for a pilot questionnaire survey.

### **6.2.1 Overall Responses**

This section provides a general discussion about results of the questions that were not asked for a specific site in Loughborough or Hinckley. A total of 633 questionnaires were completed by respondents, out of which 629 were valid; and 76.5% (n=481) of all questionnaires returned from Loughborough (with 92,149 population) and 23.5% (n=148) completed from Hinckley (with 17,753 population). For overall frequency of travel from Home, Work or Leisure to the healthcare facilities, most of respondents' origin were home address with 93% (n=513), and 7% (n=41) of them accessed to the healthcare facilities from Work (Figure 6-3). However, there was a significant difference between Loughborough and Hinckley in accessing healthcare services from Work with 9% versus 2% respectively.



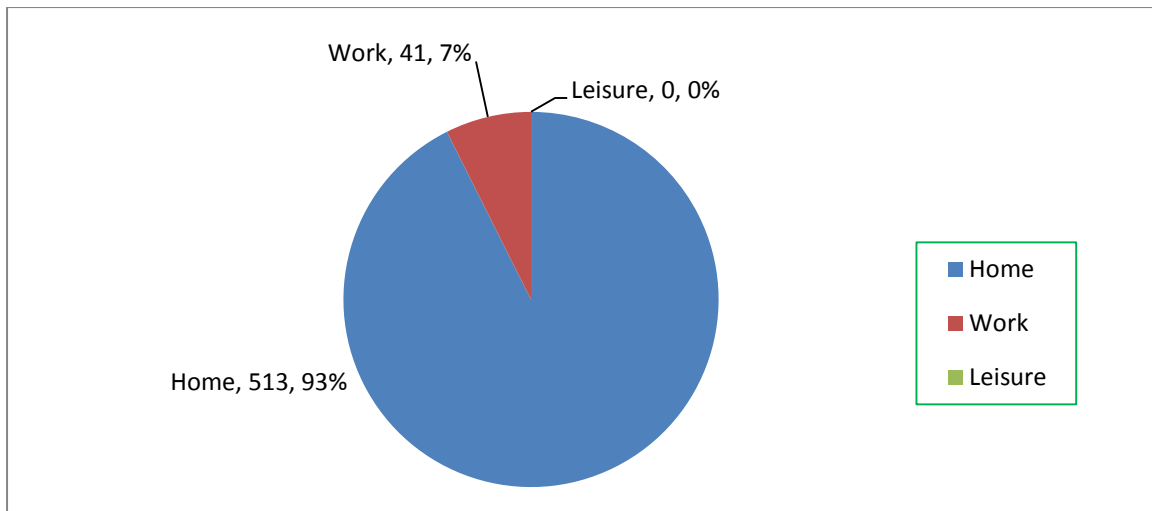


Figure 6-3: Overall frequency of travel from Home, Work or Leisure (Q14)

Hinckley had more disabled respondents while the Loughborough had more elderly respondents, therefore, many of the respondents were disabled and/or old who had certain issues for walking or cycling long distances. In terms of the respondents origins: 59% (n=520) were Patients; while 30% (n=266) were Visitors; and 11% (n=102) hospital Staff (Figure 6-4). Since the most questionnaire results collected from the hospitals' patients and visitors, these results may not be representative of staff needs.

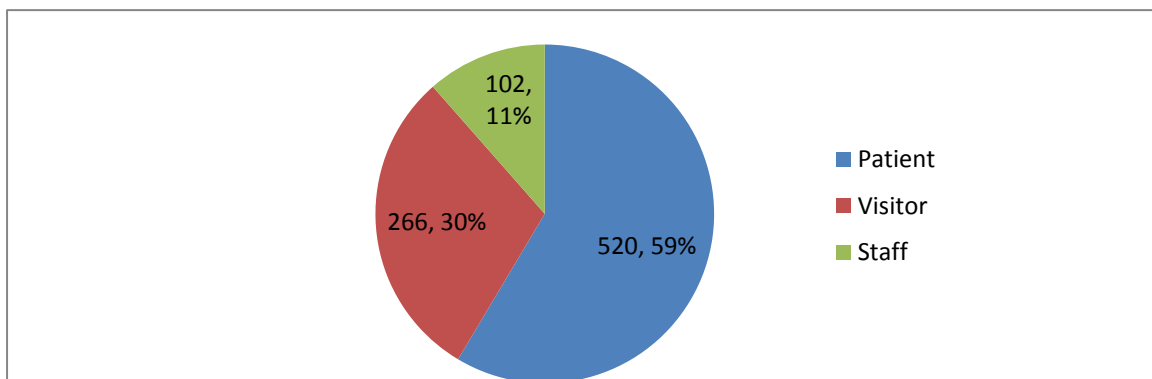


Figure 6-4: Type of all respondents (Q2)

In terms of frequency of travelling (Q2): 75% (n=664) of respondents visited the hospitals infrequently (0-5 times in the last twelve months); 17% (n=153) were frequent visitors (6-20 times in the last twelve months); and 8% (n=71) very frequent visitors (21 and more than 21 times). Figure 6-5 shows, the majority of respondents travelled infrequently.

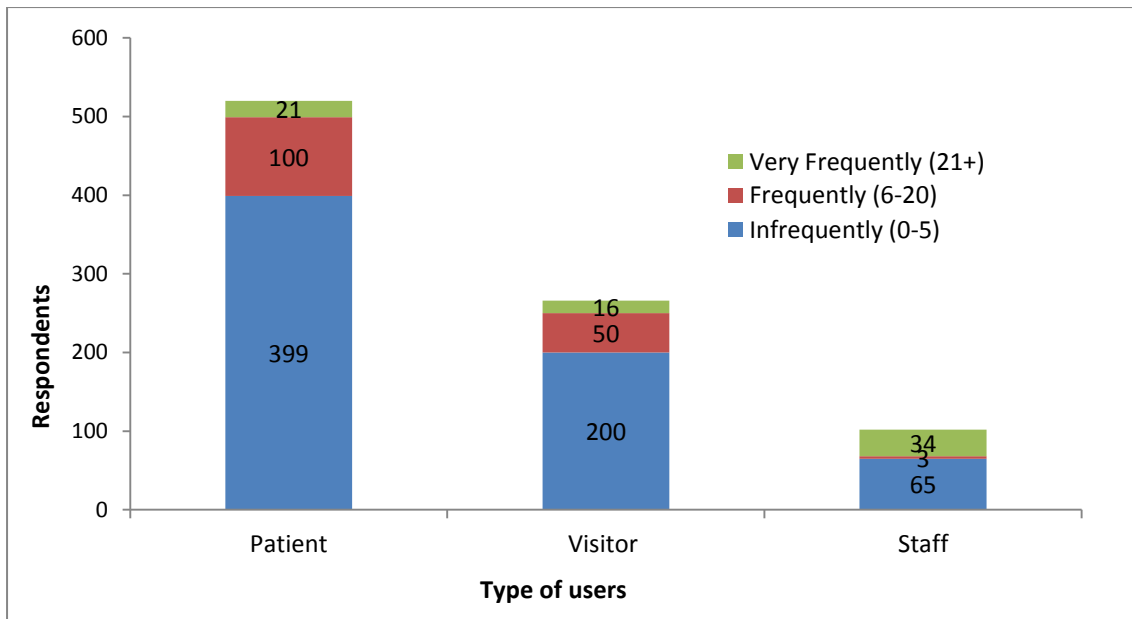


Figure 6-5: Travel frequency during past 12 months to the four hospitals (Q2)

In order to identify available travel modes for the respondents, Question 4 asked respondents what modes of transport they had access for getting to the hospitals at Loughborough or Hinckley. Figure 6-6 shows that 34% of respondents had access to a car, 24% had access to Public Transport and 20% could travel by walking from their origin to the hospital.

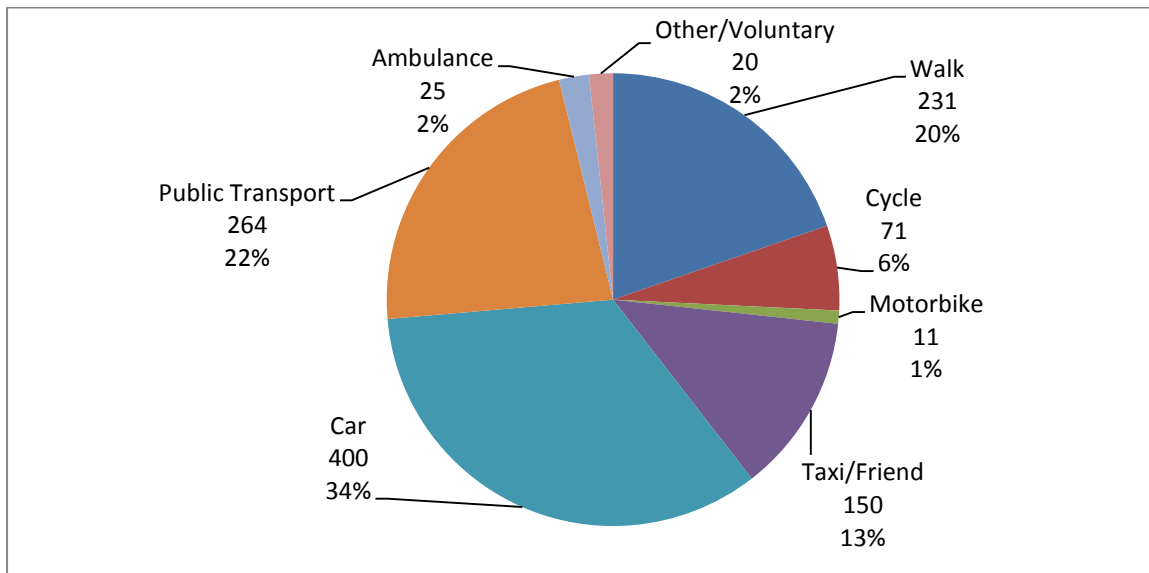


Figure 6-6: Single mode of transport which respondents have access to (Q4)

Figure 6-7 shows the available modes to access the four hospitals according to the different age groups (a combination of Q4 and Q26). This figure shows that Car (34%) and Public Transport (22%) were the most accessible modes of transport and Motorbike, Ambulance and Other/Voluntary modes were the least accessible modes to all age groups. In comparison to the size and proportion of other modes and age groups, as expected, Walking was the less accessible travel mode to the 80+ age group. Also, it shows that the proportion of different age groups have been changed through different travel modes.

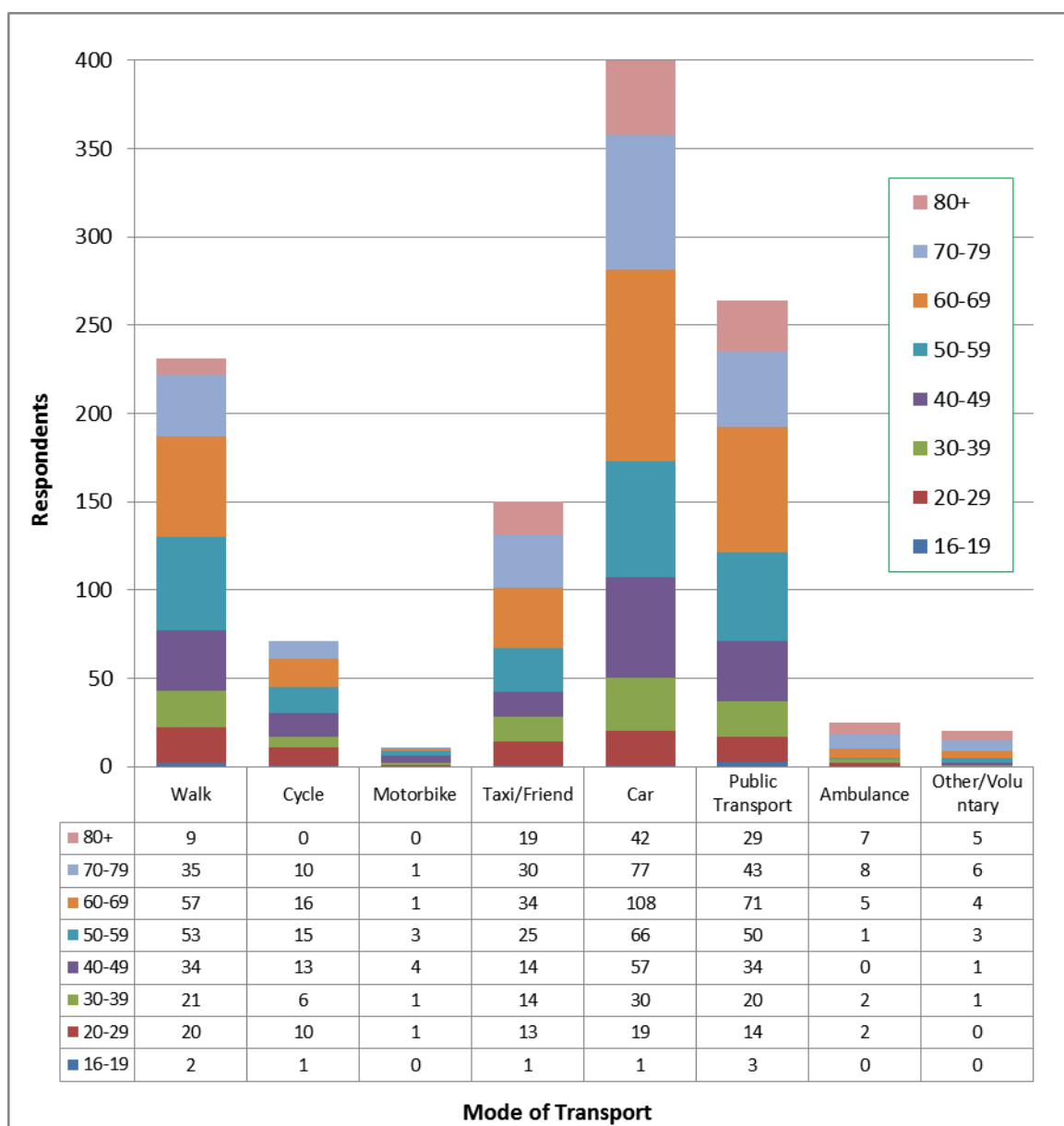


Figure 6-7: Transport modes accessible to respondents (Q4, Q26)

In addition to respondents' answers about their travel modes used to access the sites (Q4), another question (Q5) was asked to indicate the modes of travel that they 'usually' use to different healthcare sites including Large Hospital, Dentist and GP. Figure 6-8 shows that the travel modes vary significantly in travelling to the three different healthcare facilities especially in accessing on foot. For example, 3% of respondents usually walked to a Large Hospital, while 26% walked to a Dentist and 36% to a GP. It shows that GPs are more accessible destination for the users by non-motorised vehicle (e.g. walking and cycling).

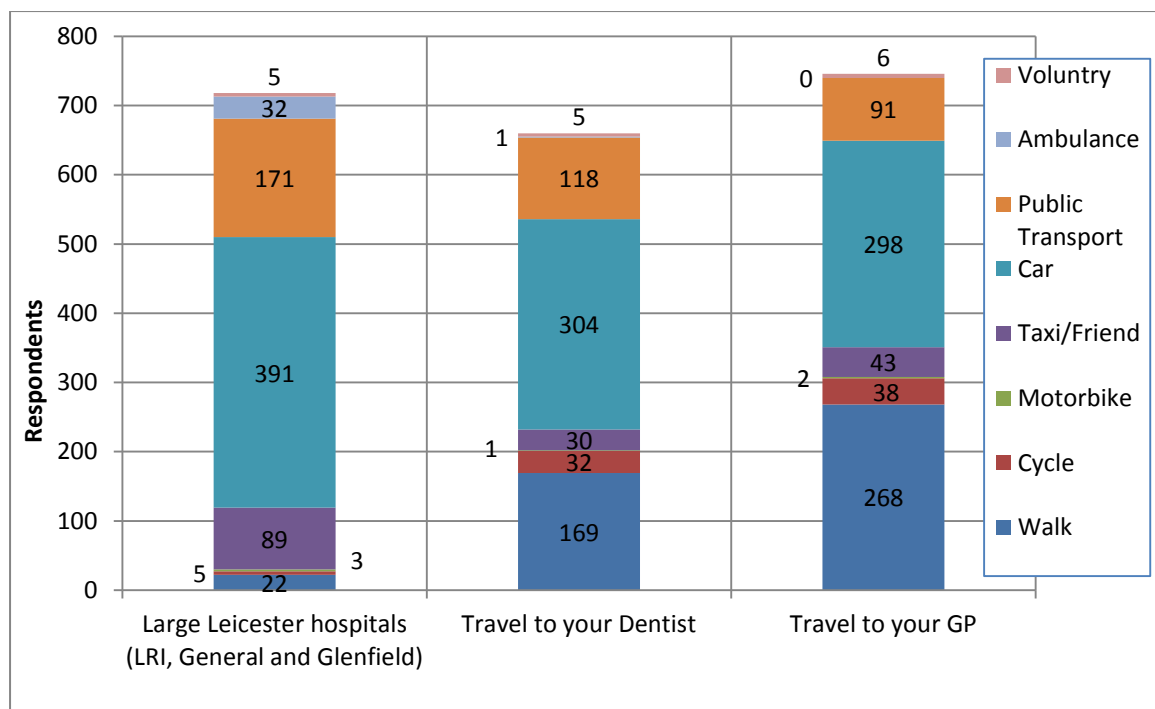


Figure 6-8: Usual Travel modes to three different healthcare facilities (Q5)

### 6.2.2 Overall Rank of Important Factors

In order to identify the most important factors which can affect the accessibility to healthcare facilities, Question 15 was used to rank nine important factors associated with travelling to the sites. The question asked respondents to rank following items according to the highest importance when accessing the community hospital sites: (1) Travel time; (2) Travel cost; (3) Travel distance by foot; (4) Quality of care provided; (5) Building and facilities quality; (6) Safe and secure street access; (7) More services provided locally; (8) Availability of Public Transport; and (9) Provision of car parking.

For better understanding of the question results, three different charts are presented here. Figure 6-9 shows overall scores of the nine items. The given scores were based on assigning maximum score as 9 for the item which was ranked as the first important factor, and minimum score as 1 for the item with the lowest importance (9<sup>th</sup> rank). It shows that the first important factor for respondents was Quality of Care Provided (score=3379), while Provision of Car Parking (score=2461) was the second important item; then Travel Time (score=2533) and More Service Provided Locally with similar score (2530) were the third important factors in accessing the community hospital sites.

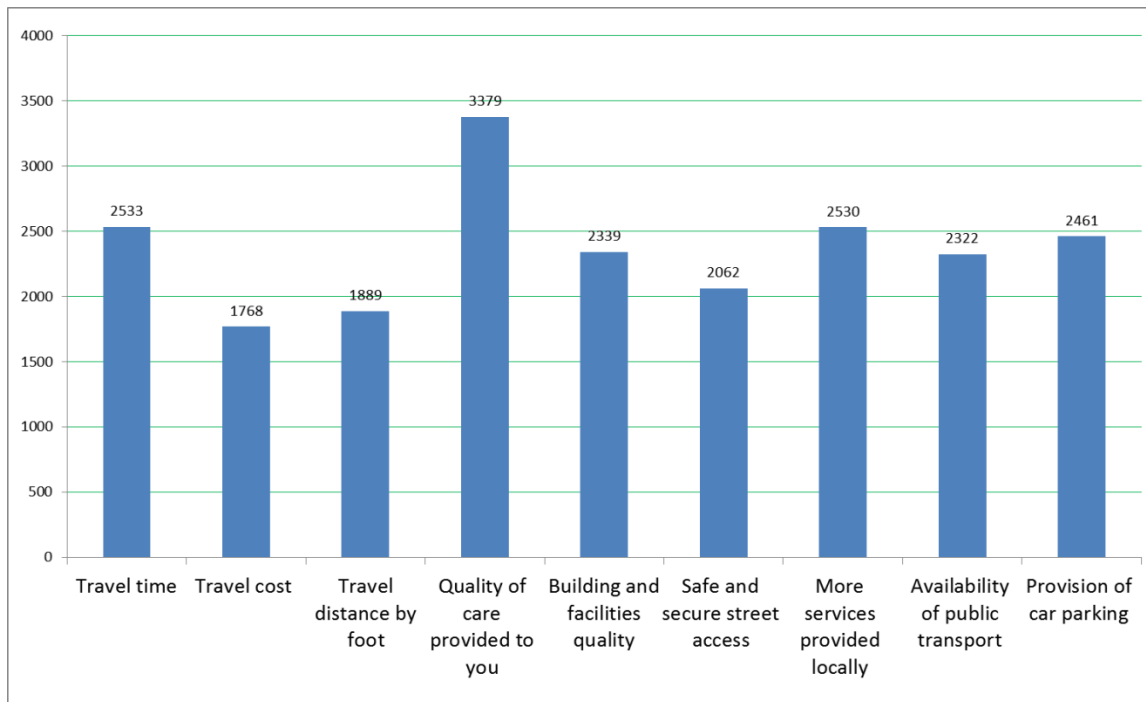


Figure 6-9: Overall score of items in accessing the community hospital site (Q15)

Figure 6-10 shows the same results in more detail as 49.8% (n=225) of the respondents identified Quality of Care Provided as the most important factor, while Provision for Car Parking and Travel Time were assessed by 18.9% (n=86) and 17.6% (n=80) of respondents respectively as the next important factors.

Figure 6-11 shows how assigned ranks by respondents have been changed for each item separately. It shows while the Quality of Care Provided had the highest importance for the respondents, Travel Cost had the lowest importance in accessing the community hospital sites.

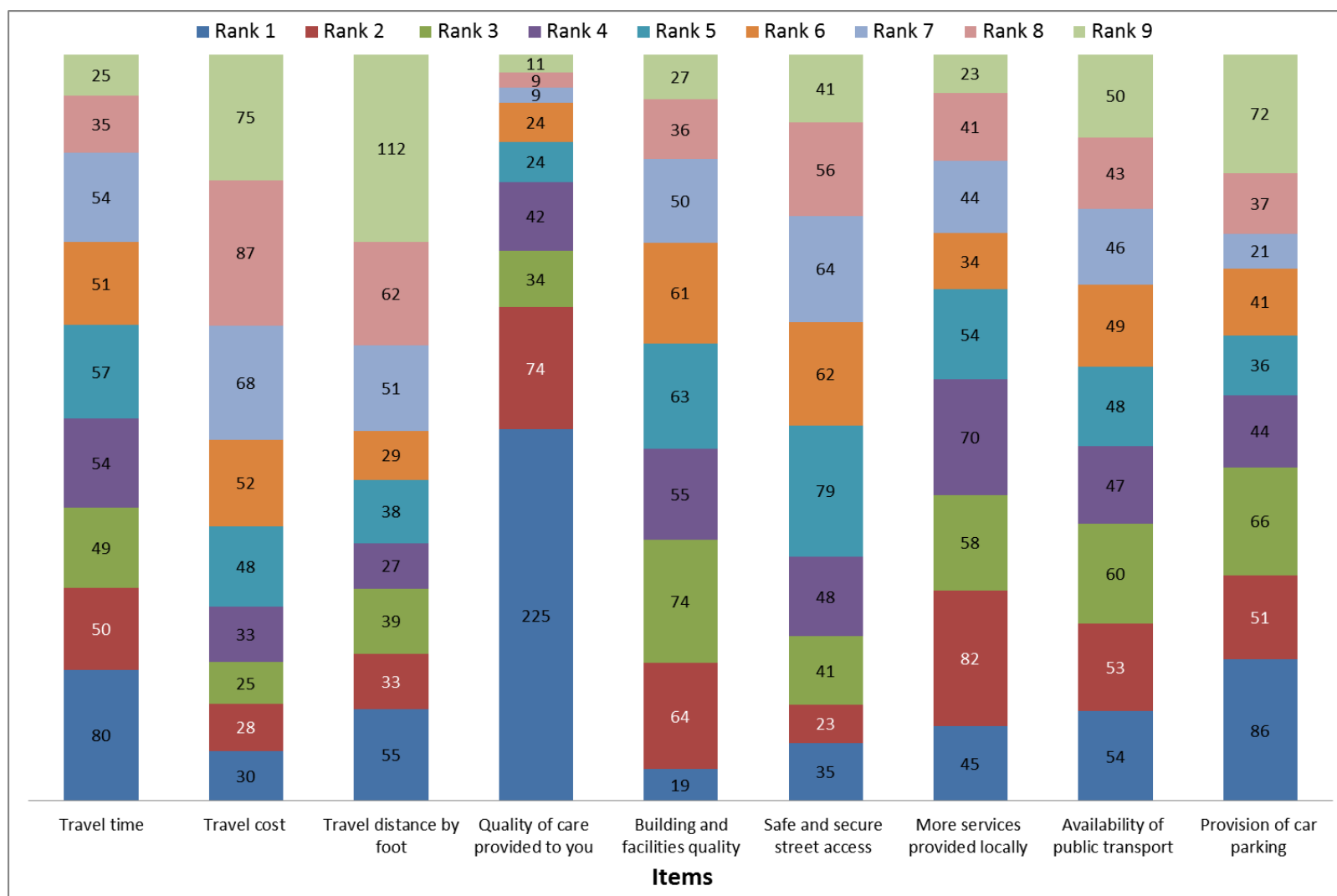


Figure 6-10: Important factors rank changes (Q15)

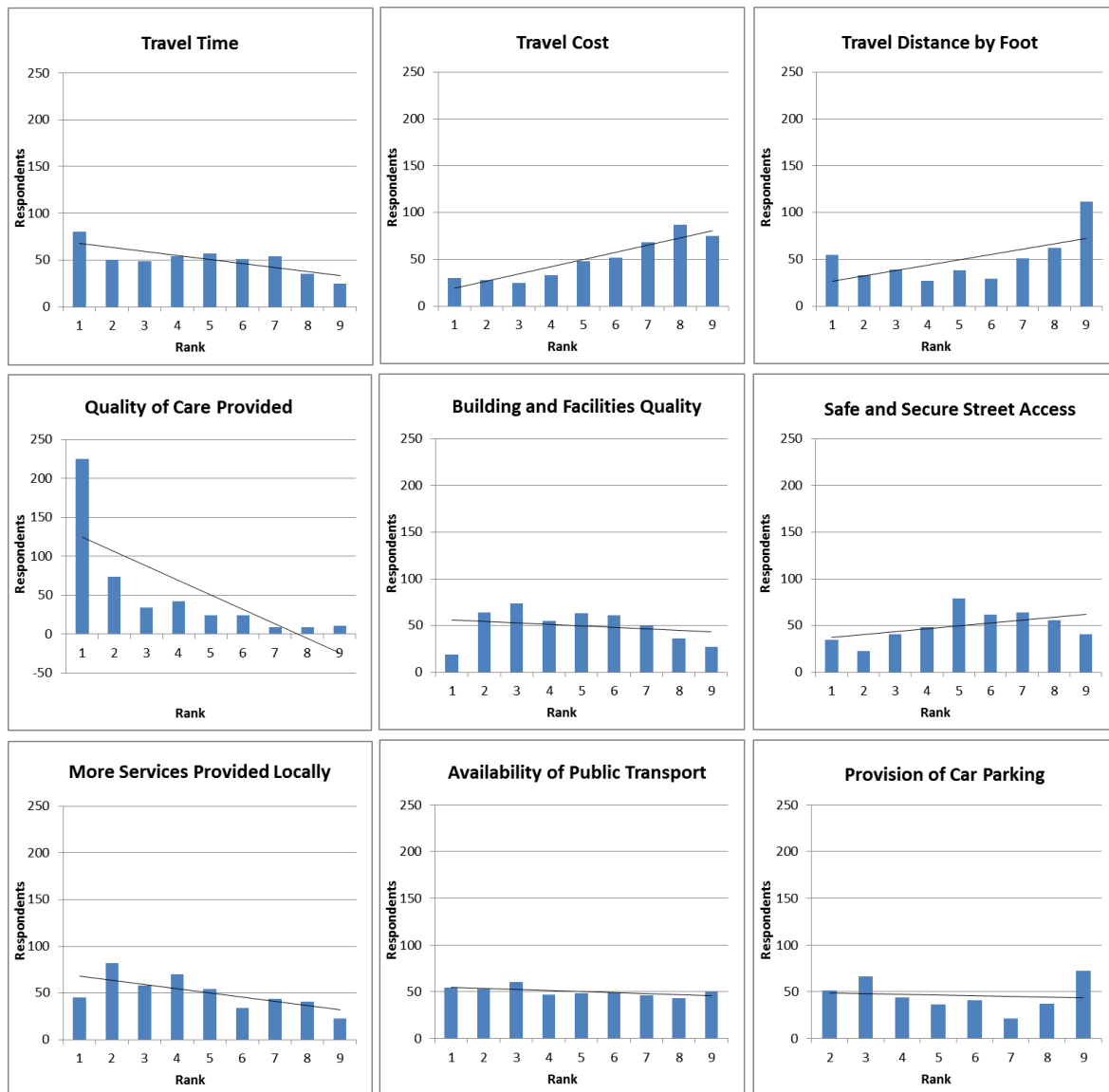


Figure 6-11: Changes of rank for an individual item (Q10)

### 6.2.3 Overall Walking Distance

Question 16 asked respondents how far they can walk to access a bus stop. Figure 6-12 shows that 42% of the respondents were happy to walk more than 500 meters, while 22% could walk maximum 100 meters, 15% could walk 100-200 meters, 9% could walk 200-300 meters, 7% could walk 300-400 meters and 5% could walk 400-500 meters. These percentages may show that walking around 400 meters could be acceptable for 47% of the respondents.



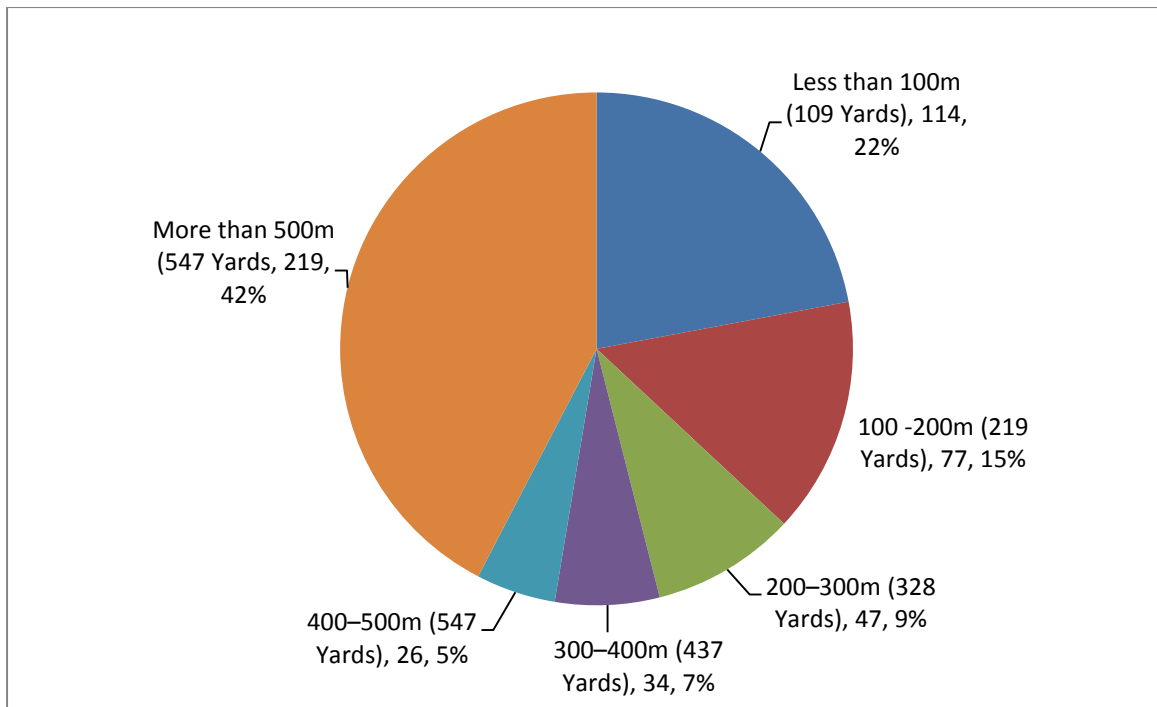


Figure 6-12: Acceptable walking distances to access a bus stop (Q16)

#### 6.2.4 Overall Access to a Car

An optional question (Q35) asked respondents about number of cars which they had in their household. Figure 6-13 shows that 54% of respondents have one car, while 27% had more than one Car and 19% of households had no car.

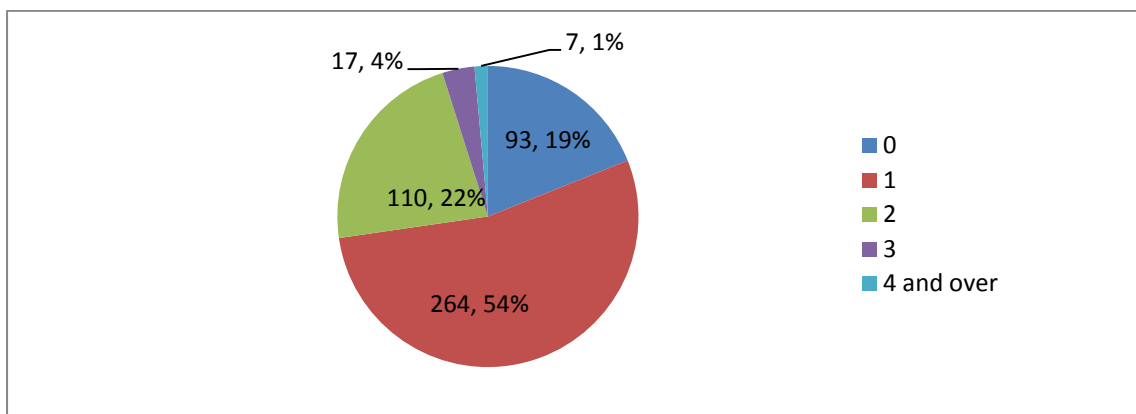


Figure 6-13: Number of households with car (Q35)

In order to identify accessibility to a Car during different times for different members of a household, another question asked respondents to indicate how many members of their household have had access to a car during three circumstances: during the day

(8.30am – 5.30pm) in an emergency, during the day (8.30am – 5.30pm) for a pre-booked appointment or for a drop-in session, and out of hours (before 8.30am and after 5.30pm). Figure 6-14 shows that 22% of household members do not have access to a car during the day (8.30-5.30pm) either in an emergency or for a pre-booked appointment, moreover 19.3% do not have access to a car out of hours (before 8.30pm and after 5.30pm).

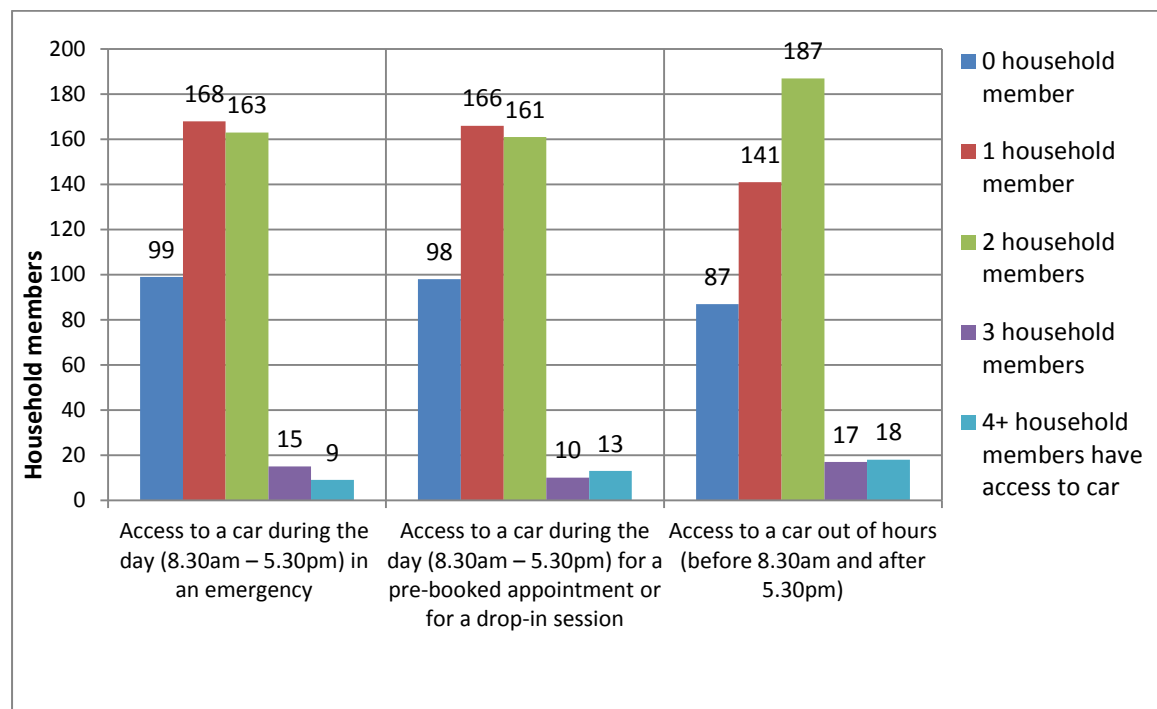


Figure 6-14: Household members either access to a car (Q36)

The last question of the survey asked respondents to state any other information that they may feel relevant. In addition to transport issues, some respondents specified that the age-related factors affect in accessing a healthcare facility. There were some opposite comments regarding relocation or reconfiguration of the hospitals due to difference in priorities and perceptions of respondents. As an example, respondents comments as follows.

- *“Situations change for everybody. We may have access and ability to drive a car at present but **this could change as one gets older.**”*
- *“I think the Walk-in-centre is excellent and very well positioned in the town centre”*
- *“... I wouldn’t be able to get to the Walk-in-centre. Moving the Walk-in-centre next to the hospital would be the best thing ever done.”*

- *“Support the Walk-in-centre move to Loughborough Hospital Site, but improved **transport is vital to its success**. Maybe paying taxi fares in certain cases.”*
- *“Many people who will be attending H&B Community Hospital will not be **feeling well**, may not be able to walk very far and may have to make numerous journeys. Any provision of public transport needs to take this into account.”*
- *“... I would like to be able to cycle (I have one) but **the roads are too narrow and dangerous for cycling**.”*
- *“The public transport system is inadequate.”*
- *“1/4 of the adult population in the Hinckley/Bosworth **area are retired**. This is above the national average.”*
- 

## 6.3 Hinckley Site Results

### 6.3.1 Travel Modes

In order to identify the modes of transport which respondents ‘usually’ use or they would ‘prefer’ to use, two questions were designed for the four hospital sites in Loughborough and Hinckley.

Question 6 asked respondents to select the travel mode that they usually use to access the two hospitals in Hinckley (Hinckley and Bosworth Community Hospital (HBCH), Ashby Road; and the Hinckley and District Hospital (HDH), Mount Road). Figure 6-15 shows the travel modes that the respondents ‘usually’ used to access the two hospitals. The figures show that the used travel modes to both Hinckley sites were similar. It means that the respondents may have better walking access to HDH.

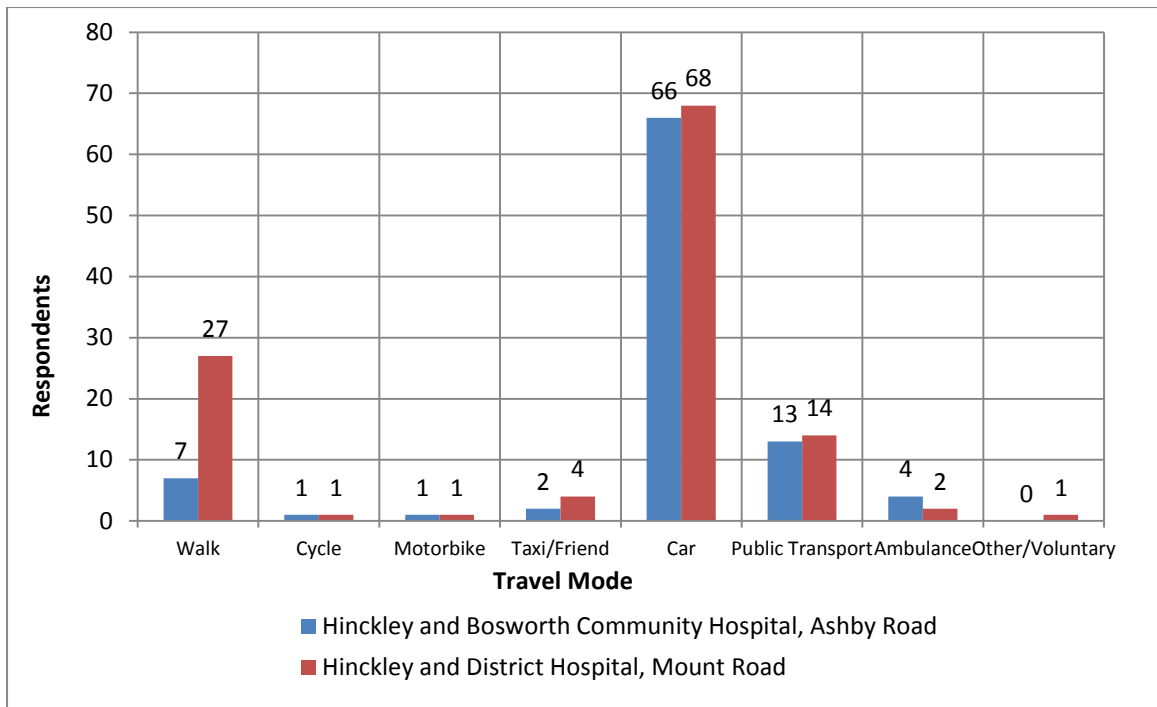


Figure 6-15: Usual travel modes to access Hinckley sites (Q6)

Questions 7 asked respondents to select the travel modes that they would 'prefer' to use to access HBCH site. Figure 6-16 shows the travel modes which the respondents would prefer to use. It shows that most respondents preferred to access to HBCH by Car (n=40, 48.8% of all respondents) or by Public Transport (n=25, 30.5% of all respondents).

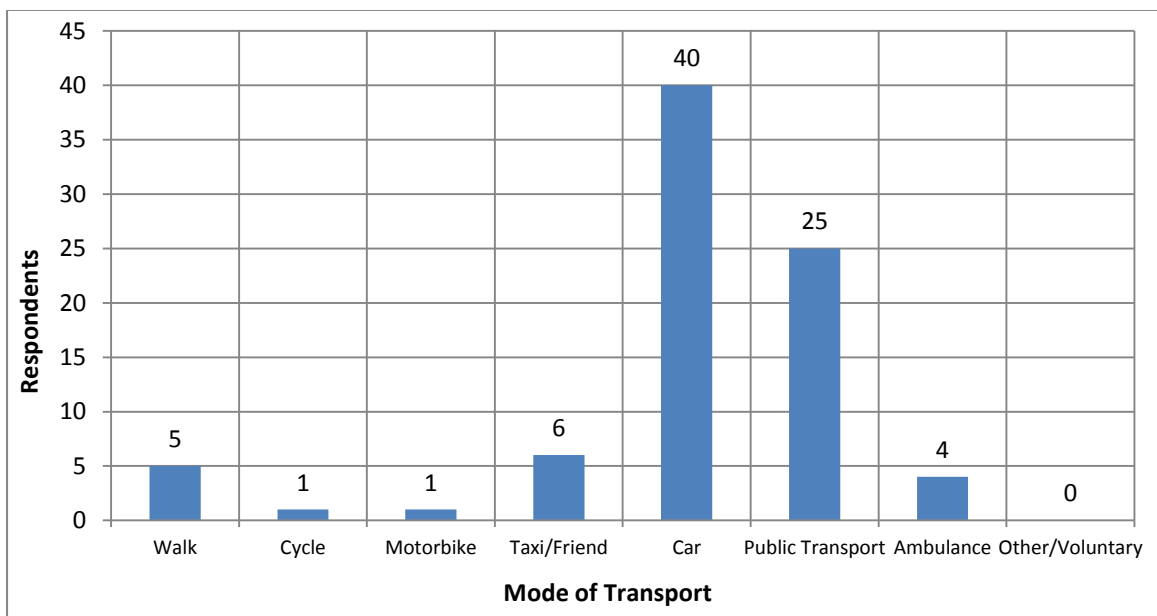


Figure 6-16: Preferred travel modes to access HBCH (Q7)

To compare 'available', 'used', and 'preferred' travel modes that the users selected, the results of Questions 4, 6 and 7 for HBCH are shown in Table 6-1.

Table 6-1: Available, used, and preferred travel modes to HBCH

Travel Mode	Car	Public Transport	Walk	Car and Public Transport
Available (Q4)	52 (35%)	5 (3.42%)	2 (1.37%)	9 (6.16%)
Used (Q6a)	61 (43%)	9 (6.34%)	4 (2.82%)	2 (1.41%)
Preferred (Q7)	35 (27%)	21 (16.3%)	4 (3.1%)	18 (14%)

Table 6-1 shows that 27% of respondents preferred to travel by Car and 43% of respondents used Car to access the HBCH site. While 6.3% of respondents actually used Public Transport to access the HBCH site, 16.3% of respondents preferred to travel by Public Transport. This may indicate that travelling by Public Transport can be increased (i.e. from 6.3% to 16.3%) if the respondents' awareness of the available Public Transport was improved or the Public Transport services were improved.

Following Question 7, a qualitative question asked respondents why they do or do not use their preferred to travel modes to access the HBCH site. Most comments were related to why they preferred travelling by car to other mode of transport (e.g. Bus, Bike, and Walking); also commented that why they could not use their preferred travel modes instead of using Car.

Some of the respondents who chose travelling by Car as their first preference commented:

- *"Need car or voluntary transport as **the nearest bus stop (bus station) is too far (1/2 mile distant)...**"*
- *"I cannot **walk far because of my back and hips...**"*
- *"Not 100% reliable (i.e. arriving too late to keep appointments)"*
- *"Public transport service **not reliable**, car is quicker and reliable"*
- *"**Convenient** to use car. Good parking facility"*

While some respondents' preferred to travel by bus or bike, they could not use their preferred mode of transport because of reasons such as:

- *"Cannot stand at bus stop for long. **No shelter** either."*
- *"Public transport with bus pass not very good as it is **too far to walk to catch a bus....**"*
- *"....Would use bus but **crossing road is dangerous.**"*
- *"The bus from Market Bosworth to Hinckley does not pass by the hospital..."*

- *"Bus services are **not available**"*
- *"**Inconvenience of changing buses**"*
- *"I would like to take public transport but **if the weather is bad**, you don't want to be out in the rain"*
- *"Bus Company goes by hospital and although you can **depart outside**, there is a **long walk before entrance to hospital...**"*
- *"Because the bus stop is on other side of the road and **it is an awful road to cross. Traffic lights needed**"*
- *"When I get off the bus it is **difficult to cross the very busy Ashby Road.**"*
- *"Use bike [is] easy to access, [but there is] **not very good bike lanes**"*

While some comments were on unavailability of bus services or access to a nearest bus stop, many comments were about different factors unrelated to the bus services; factors such as difficulties in crossing the road to get to bus stop, inconvenience of changing buses, lack of suitable bus stop shelter, and different perceptions of walking convenience to get to a bus stop.

This indicates while transport issues are important in accessing healthcare facilities, other personal factors also influence the decision whether to use a travel mode or not. People may change their travel modes according to their different perceptions on accessibility. Safety in crossing the road from the bus stop to the hospital was one of the important issues to use bus to get to the HBCH site, therefore assessing accessibility to a healthcare facility needs to consider respondents' perception on accessibility.

### **6.3.2 Problems to Access HBCH Site**

A qualitative question, Q8, asked respondents to identify their three main problems in accessing the HBCH site by Car, Bus or Walking and Cycling. Figure 6-17 shows the most important problems and the number of times that were described by the respondents.

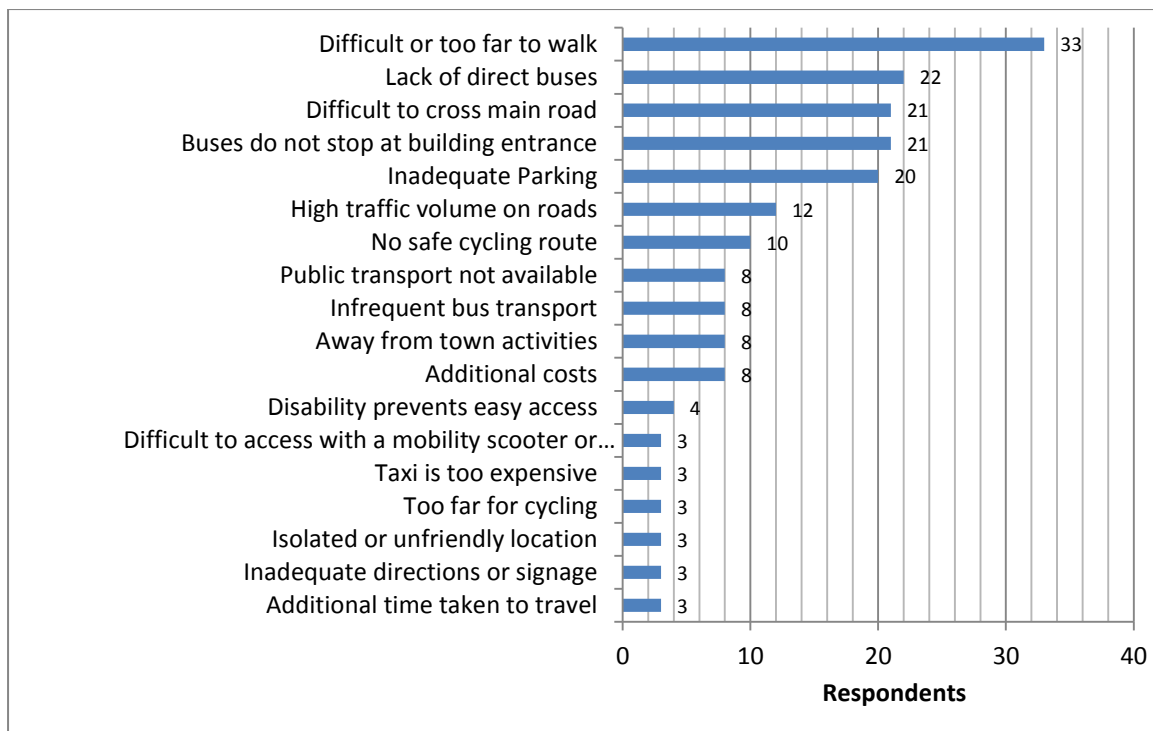


Figure 6-17: Main problems to access HBCH (Q8)

It shows that walking distance was a problem for 17.1% of respondents, and lack of direct bus services to get to the site was another main problem for 11.4% of respondents; also 10.9% of respondents had difficulties to cross the road to the hospital, and 10.9% commented that the bus stop was not in a suitable location which causes difficulties for ill, old and disabled people to access the hospital. In addition to a lack of adequate car parking facilities (10.4%), some respondents were unhappy with high traffic volume on the roads (6.2%) and were concerned about the safety in accessing the site by Bike due to the lack of safe cycling routes (5.2%).

Unavailability of bus, infrequent bus services, far from town centre activities, and additional costs were some other problems that 4.1% of respondents stated in accessing the site. While disability and infirm matters were a concern for 1.6% of respondents, some other issues with the same percentage (1.6%) commented such as: too far for cycling, being isolated or unfriendly location, expensive taxi fare, and without enough signage or directions to guide people towards the hospital. As an example, respondents comments as follows.

- *"It is too far to 'walk' [and] the bus is not an option for me as a **wheelchair user***

- "...there is **no safe cycle route** on Ashby Road anyway."
- "Taxi it is **very expensive**"
- "Local transport links all converge on the town centre - this is not the case with the new site. People may have to use 2 buses, or train and bus,... a **busy road**, with **fast moving traffic**, ...and traffic volumes [will] increase further"
- "No access lane on Ashby road. Lack of quantity of disabled spaces"
- "... **poor exit facilities when leaving by car**"
- "No proper crossing facilities ..... **difficulty in leaving and re-entering Ashby Road**)"
- "**No pedestrian crossing** by bus stop on busy main road"
- "With a car you have a **problem pulling out into a Main Road....**"
- "Roads too **busy for cycle (not safe)** ..."
- "Trying to exit from the hospital busy road. Speeding vehicles. Speed limit too high and insufficient signs"
- "Danger of crossing main road lack of signs warning of hospital entrance, high hedges, lack of pedestrian crossing, difficulty when leaving hospital due to volume of traffic, traffic lights would be a definite advantage".

### 6.3.3 Hinckley Travel Experience

A qualitative question, Q9, asked respondents to provide details of their travel 'experiences' to the HBCH site. It asked respondents to give details such as time, cost, distance travelled by foot, quality of bus stops, number of bus changes and bus route.



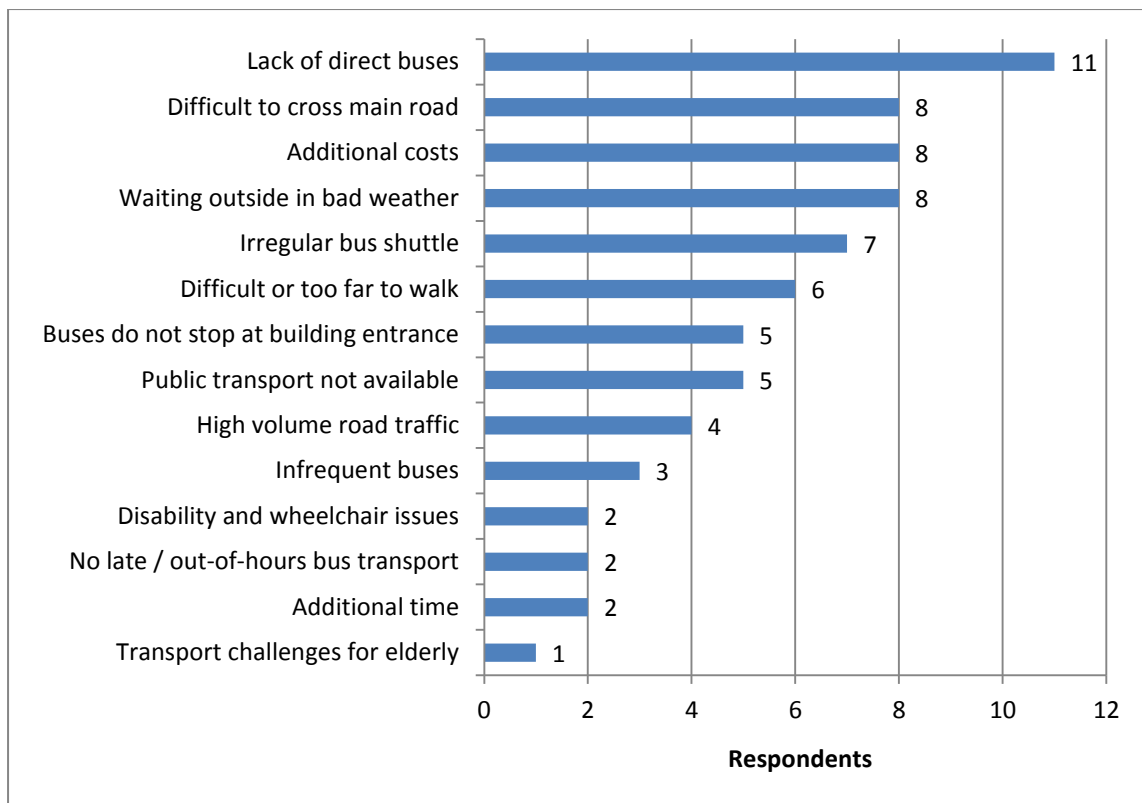


Figure 6-18: Travel experiences to HBCH site (Q9)

Figure 6-18 shows that 10.1% of respondents specified a lack of direct bus services and 7.3% indicated the difficulty to cross the main road to access the hospital site. While 7.3% of respondent were unhappy to wait outside in bad weather due to lack of a bus stop shelter, the same percentage of respondents were concerned about the cost of travelling to and from the HBCH site.

Irregularity (6.4%) and infrequency (2.8%) of bus services, difficulties in walking long distance to access the hospital site (5.5%) because of unsuitability location of bus stop near the hospital (4.6%), and unavailability of bus services (4.6%) were some important concerns of the respondents. Same as Question 8, some comments were related to the respondents' disability and using wheelchair.

As an example, respondent's comments are as follows.

- "...[the] bus stop is **outside main entrance of hospital**"
- "...**No shelter** at bus stops"
- "Better sited **disabled parking places** and larger size"

- *"I often find it **difficult to turn right** out of the hospital in my car and this problem will increase with more traffic to the site"*
- *"... there is no direct bus access at all from [some] areas .... All of which have direct buses to Hinckley town centre...."*
- *"... **change** onto another bus at Barwell, which goes via the hospital site. This can involve waiting. At busy times there can be a tail back from the hospital (i.e. between 4.15 - 5.30). There is **no transport after 6pm**. So if you needed to see the out of hours emergency doctor someone would have to take you by car"*
- *"2 **bus changes**. Either by Leicester bus or Barwell bus. Bus stops are a good walk if you have problems walking about 3 miles away. About 3/4 hr either way"*

As mentioned before, majority of respondents' problems and experiences were related to their preference or physical conditions. Their perceptions on accessing the hospital site were different regardless of the transport issues or available bus services.

## 6.4 Loughborough Site Results

### 6.4.1 Travel Modes

Question 10 asked respondents to select the travel mode that they usually use to access the two sites in Loughborough (Walk in Centre NHS, Pinfold Gate; and Loughborough Community Hospital site, Epinal Way).

Figure 6-19 shows the travel modes that respondents 'usually' used to access the two hospital sites. It shows that Car was the most frequently travel modes to access all Loughborough sites. Travel by Car to Loughborough Community Hospital (LCH) site was more frequent (59.3%) in comparison with Loughborough Walk in Centre (WIC) site (42.4% for an appointment and 56.4% in an emergency), Walking and Public Transport modes were more frequently used in accessing the WIC site. For example, 24.3% of respondents usually go to the WIC by Walking for an appointment while the percentage of respondents for LCH was 14.3%. It means that the respondents may have had better access to WIC by Walking and also by using Public Transport.

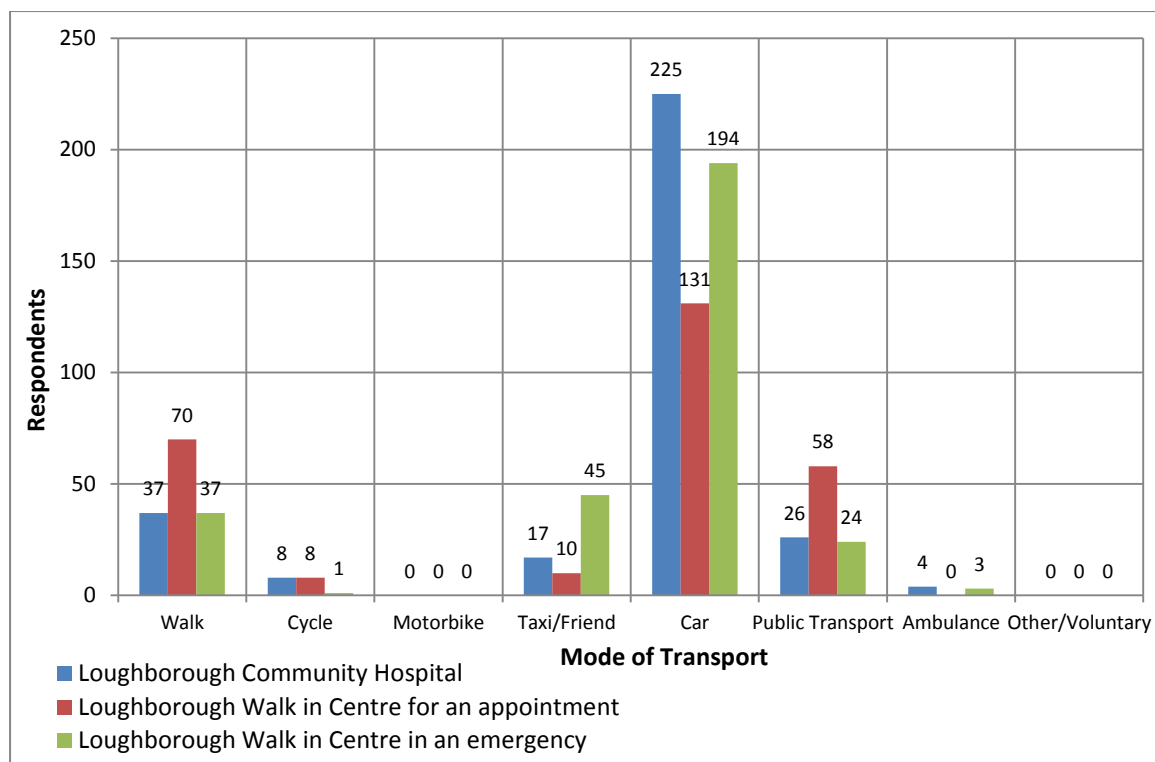


Figure 6-19: Usual travel modes to access to Loughborough sites (Q10)

Unlike travelling by car, Taxi/friend was most frequently used in accessing the Loughborough WIC in an emergency (17.5%) in comparison with LCH (9.8%). Other modes were less frequently used. This indicates that respondents' preferences to use a healthcare service can affect their perception to choose a travel mode.

Figure 6-20 shows the multiple modes were preferred by 27% of respondents in accessing the Loughborough sites. While the preferred multiple travel modes were pretty similar in accessing the Loughborough site, the combination of Taxi/Friend and Car modes was less frequently used in accessing the WIC for an appointment (n=11) in comparison with the LCH (n=22) and WIC in an emergency (n=23). This indicates that respondents prefer to travel by car to the Loughborough sites in an emergency.

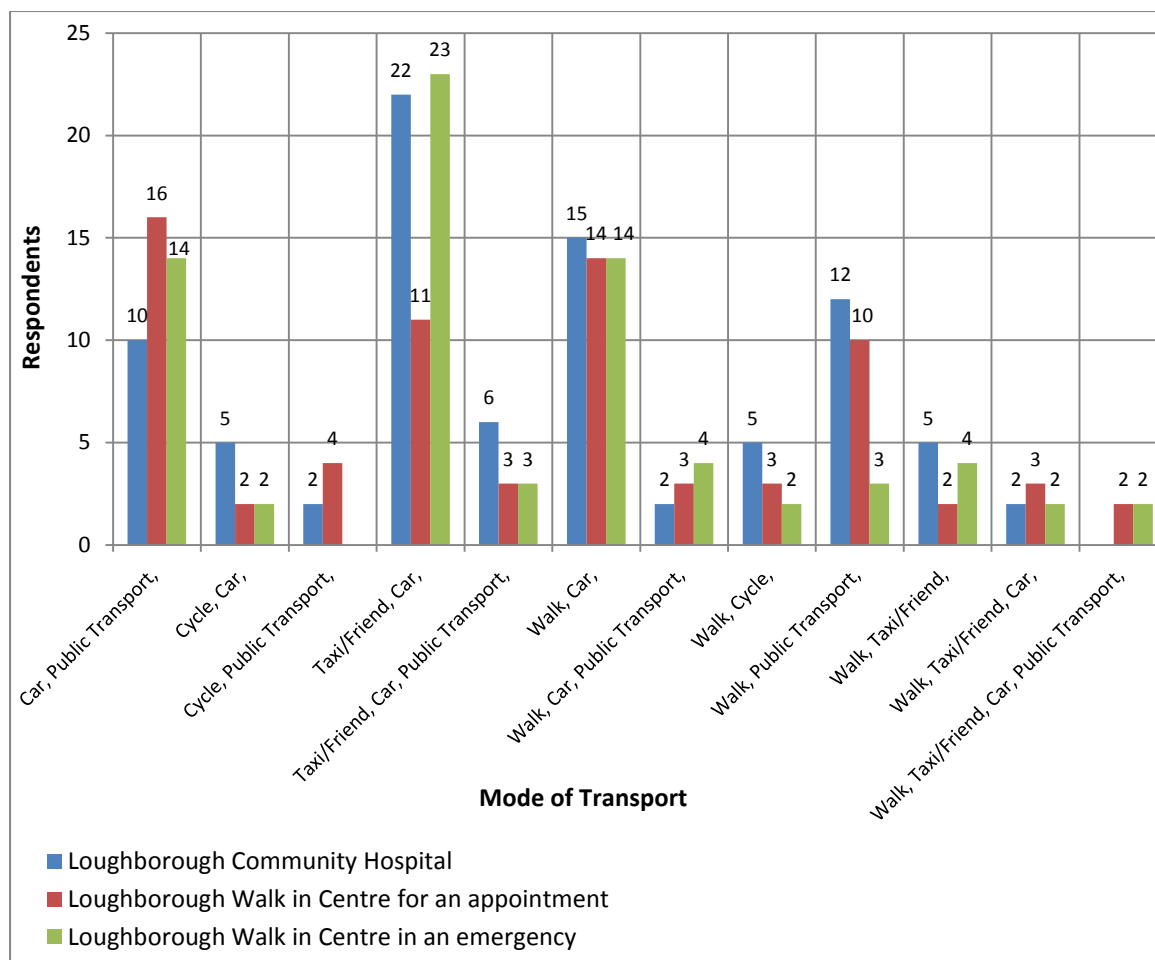


Figure 6-20: Multiple usual travel modes to access to Loughborough sites (Q10)

Questions 11 asked respondents to select the travel modes that they would 'prefer' to use to access the two hospitals in Loughborough (WIC and LCH). Figure 6-21 shows that 59.3% (n= 92) of all respondents preferred to travel to LCH by Car, while 20.6% (n=32) preferred to travel by Public Transport. Also 9% (n=14) of respondents preferred to use Taxi/friend and 7% (n=11) preferred to walk.

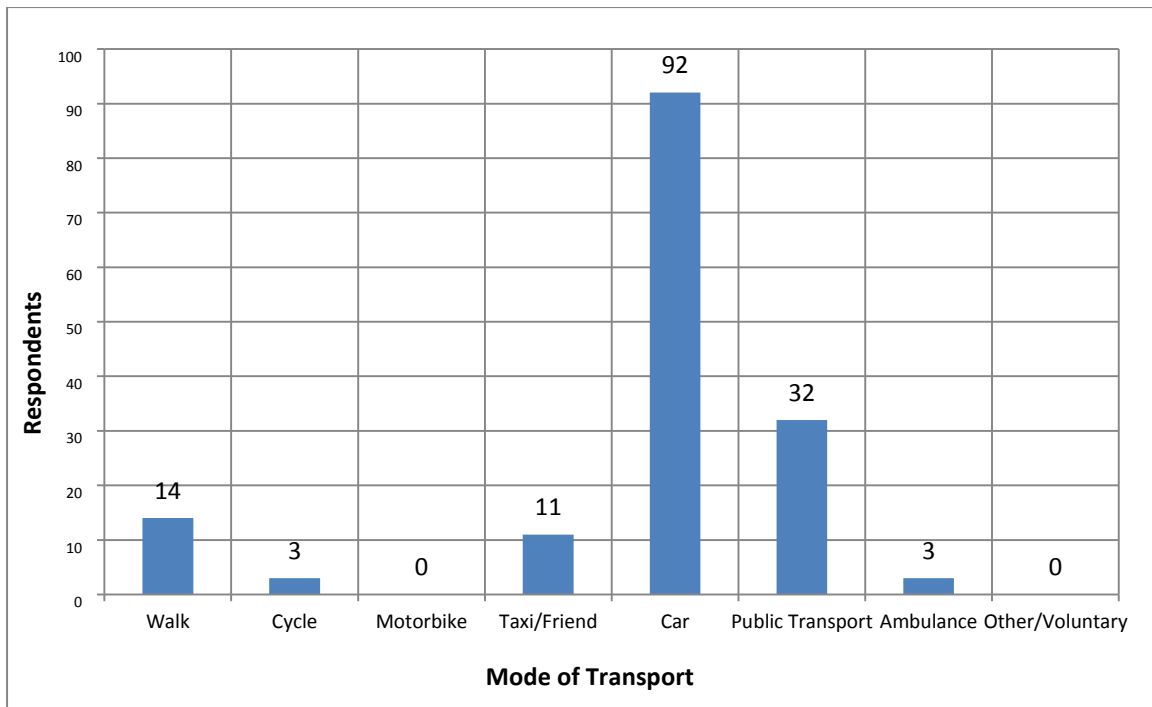


Figure 6-21: Preferred travel mode to LCH (Q11)

To compare 'available', 'used' and 'preferred' travel modes that the respondents selected, the results of questions 4, 10 and 11 for LCH have been shown in Table 6-2.

Table 6-2: Available, used, and preferred travel modes to LCH

Travel Mode	Car	Public Transport	Walk	Car and Public Transport
Available (Q4)	114 (24%)	23 (4.8%)	19 (4%)	44 (9.17%)
Used (Q10a)	219 (48.6%)	24 (5.3%)	37 (8.2%)	10 (2.2%)
Preferred (Q11)	88 (35.9%)	29(11.8%)	14 (5.7%)	23 (9.4%)

Table 6-2 shows that there is a difference between percentages of respondents who actually used (5.3%) and the respondents who preferred (11.8%) to travel by Public Transport to access the LCH site. It shows that 35.9% of respondents preferred to travel by car, while 48.6% of respondents used Car to access the LCH site. Same as the Hinckley sites, this may indicate that travelling by Public Transport can be increased (i.e. from 5.3% to 11.8%) if the respondents made more aware of available Public Transport or the Public Transport services were improved.

Following Question 11, a qualitative question asked respondents why they do or do not use their preferred travel modes to access the LCH site. Figure 6-22 shows a summary of respondents' comments about their preferred modes in accessing LCH. It shows that the two main concerns of respondents were related to Public Transport provision; while

20.1% (n=57) of respondents were unhappy about the lack of direct Public Transport services, unavailability of Public Transport to get to the site was a concern for 11.4% of respondents; also 11.7% of respondents had difficulties to Walk and 8.5% of respondents indicated the lack of adequate car parking facilities. Similar to WIC comments, 8.1% were concerned that bus stop was not in a suitable location which causes difficulty for ill, old and disabled people to access the hospital site. In addition to disability and wheelchair issues (7.4%), some respondents were unhappy with irregular bus shuttles (7.4%) and were worried about spending additional time (4.2%) to access the site. Unavailability of late time bus services and lack of safe cycling route services were the other main reasons of respondents that may not allow them to use their preferred mode.

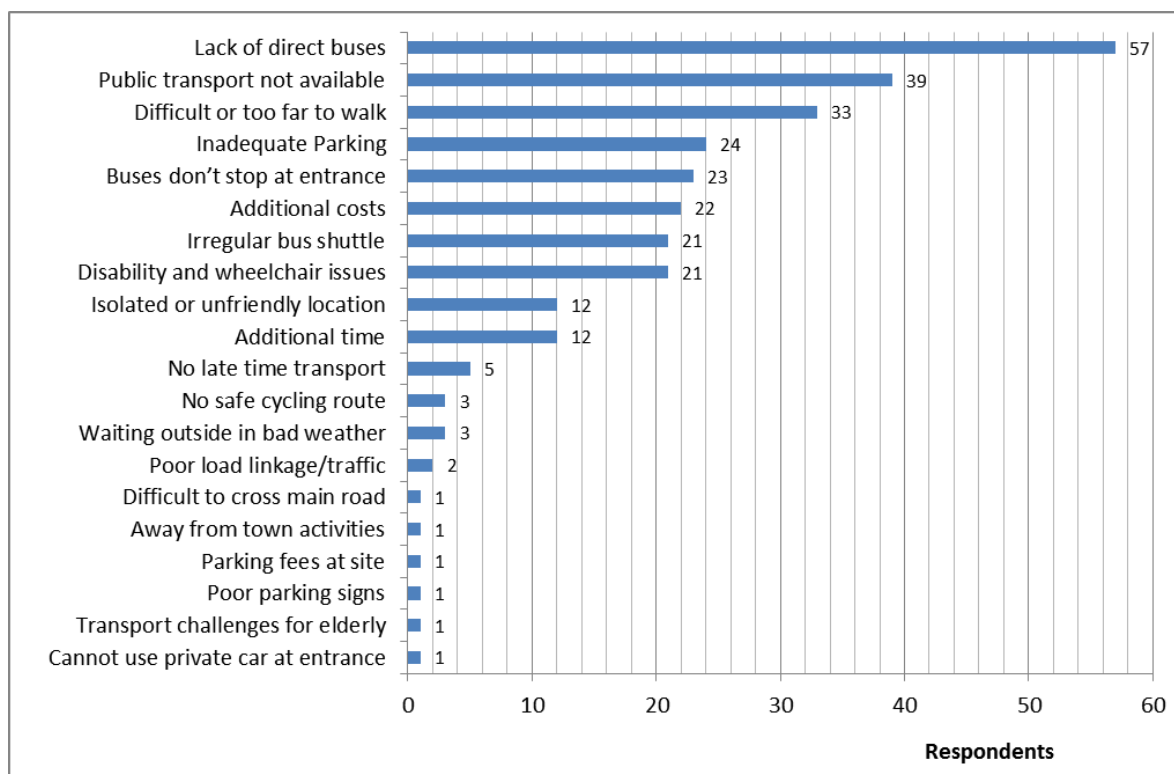


Figure 6-22: Reasons that restricted to use preferred travel mode to LCH (Q11)

As an example, respondents' comments are as follows.

- "... have to arrive 30 minutes early to find **parking space** at Epinal Way site."
- "If ill or injured we prefer the privacy and security of the car."
- "**Lack of convenient links** between Thurmaston and Loughborough."
- "...bus is not suitable in **bad weather or emergency**."

- *"I walk or cycle because public transport is **too complicated** and car parking is impossible."*
- *"**Not enough parking spaces** and cannot drive after certain procedures."*
- *"...I am disabled and travel better by car: **I feel safer and more in control.**"*
- *"I use the car because it is **too far to walk** to bus stop. I would prefer to use Public Transport to the Hospital."*
- *"There are no buses from where I live to anywhere near the hospital."*
- *"...Except for the 126/7 service **it is necessary to change** in Loughborough.... So you may be left stranded at the hospital if you go to the Walk-in-centre in the evening, and then **have to wait** a long time for your bus. At present it is possible to wait in the town centre cafes in the evening. There are no similar **facilities near the hospital.**"*

#### 6.4.2 Problems to Access LCH Site

A qualitative question, Q12, asked respondents to identify their three main problems in accessing the LCH site by Car, Bus or walking and Bike. Figure 6-23 shows the most important problems and the number of times that were described by the respondents.

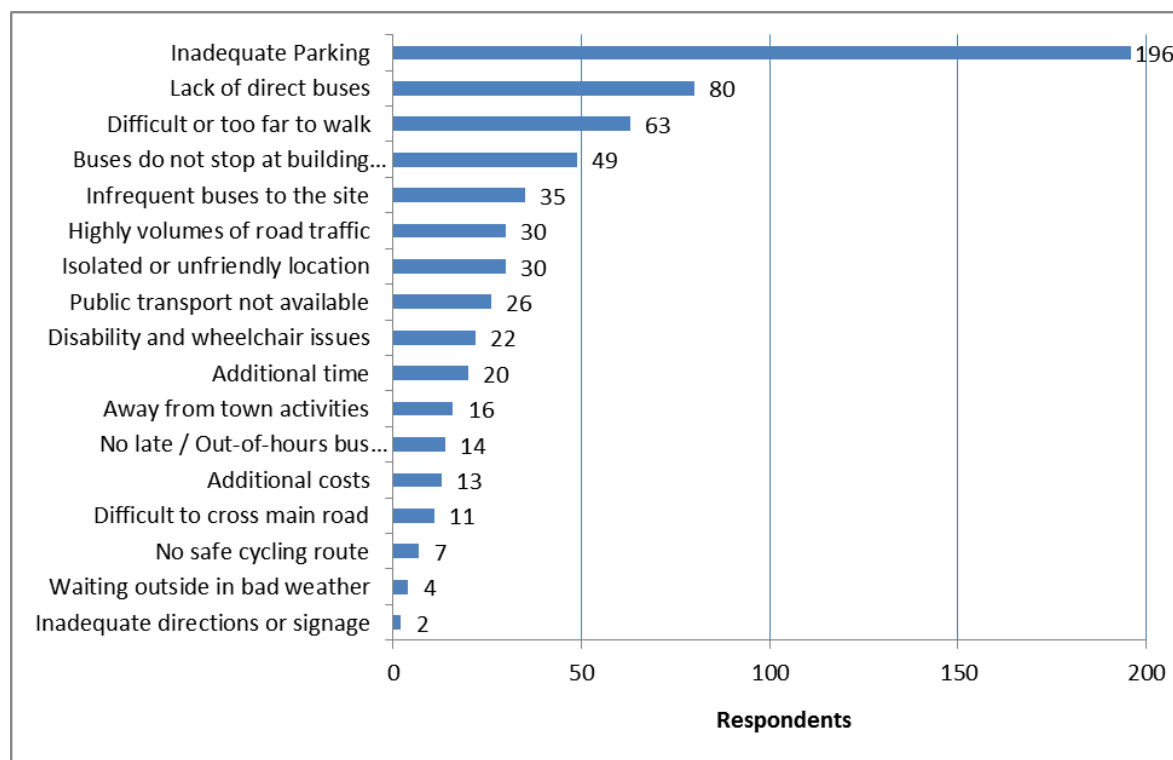


Figure 6-23: Main problems to access LCH (Q12)

The Figure 6-23 shows that inadequate car parking facilities was one of the most important problems for 52.3% (n=196) of respondents. The two other main problems were regarding the lack of direct bus services to the hospital site (21.3%, n=80) and

difficulties to Walk and distance (16.8%, n=63). Also, some respondents were unhappy about the location of bus stop which was not near the main entrance of the hospital building (13.1%, n=49). Figure 6-23 shows that other important concerns of respondents were infrequency of the bus services, traffic issues (e.g. congestion, high volume and speed of road traffic, and traffic signals), disability and wheelchair issues and no out of hour bus services.

As an example, respondents comments as follows.

- *"...The present [Walk-in-centre] is easily accessible by public transport."*
- *"**No direct bus** from Barrow.... Takes a very long time & likely to miss appointment or not be able to get back in time."*
- *"... **Congestion** on the roads leading to the hospital, extra time required to get there."*
- *"...**traffic delays**...."*
- *"Lack of links between Thurmaston and the Hospital."*
- *"No Sunday bus service...."*
- *"**Safe cycling routes** to and from the hospital site and secure, covered and **lockable parking for cyclists**."*
- *"**Cycling is dangerous** as very busy roads & storage of the **bike safely**."*
- *"Lack of **cycle parking**."*
- *"No convenient cycle lock up."*
- *"There is no bus station in Loughborough ...."*
- *"...I live in Long Whatton and would **need to take 2 or even 3 buses** to get to it without the help of a friend or neighbour who may not be available."*
- *"Located on a busy road, so **cycling not very safe**...."*
- *"...At present it is possible to wait in the town centre **cafes in the evening**. There are no similar facilities near the hospital."*
- *"Frequency of public transport outside 'working hours'..."*
- *"Cycling/walking - **not keen on dark nights and early mornings**. Shifts start 7.30am end latest 10pm. **Not safe in winter**."*
- *"Pedestrian crossing needed between hospital and care home sites."*
- *"Cycle compound for **security**?"*

### 6.4.3 Loughborough Travel Experience

A qualitative question, Q13, asked respondents to provide details of their travel 'experiences' to the LCH site. It asked respondents to give details such as time, cost, distance travelled by foot, quality of bus stops, number of bus changes and bus route.



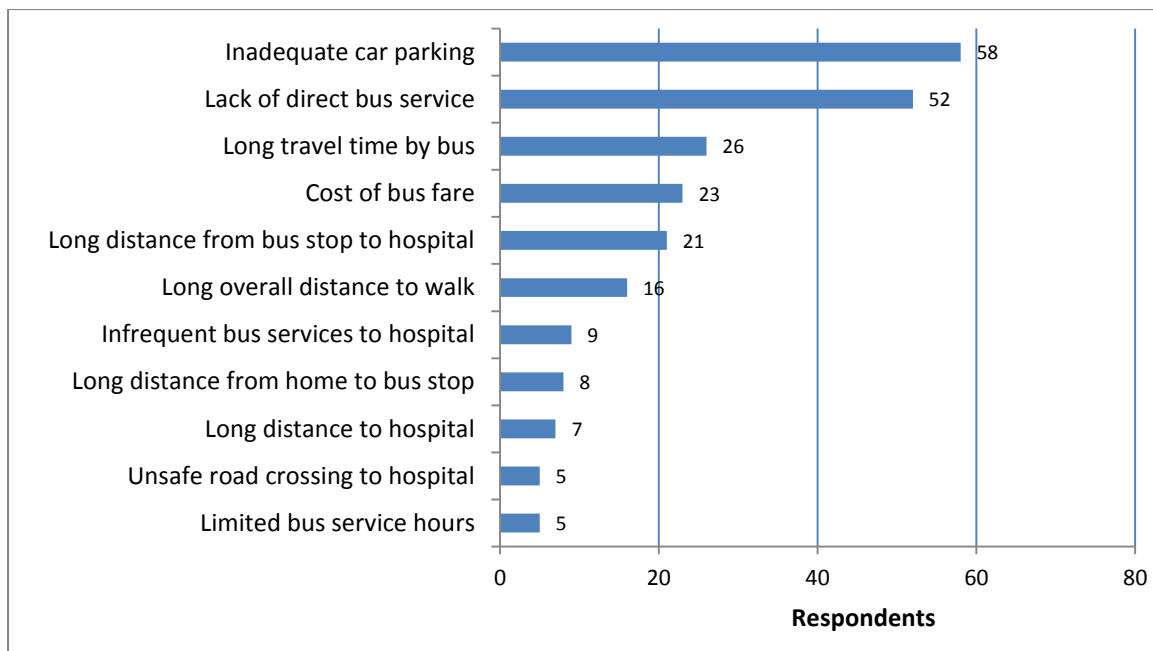


Figure 6-24: Travel experience to the Loughborough Hospital site (Q13)

Figure 6-24 shows that 25.2% of respondents experienced inadequate car parking at hospital sites, while the next four important were related to travel by Bus as the lack of direct bus service (22.6%), long travel time by Bus (11.3%), cost of bus fare (10%), and long distance from bus stop to hospital (9.1%). Also some respondents specified long overall distance to Walk (7%), infrequent bus services to hospital (3.9%), long distance from home to bus stop (3.5%), and difficulty to cross the main road, Epinal Way, to access the hospital site (2.2%).

The results of question 13 show that while although the first rank of travel issues belonged to Car (i.e. 25.2% experienced inadequate car parking), more than 62.6% of the respondents concerns and worries were related to Public Transport issues. It indicates that the number of factors affecting different travel modes vary according to the respondents' perception in accessing by a specific mode of transport.

As an example, respondent's comments are as follows:

- *"From where we live in Broadway there is **no direct bus** that would take us to the hospital. We can get to the present site of the Walk-in-centre by one bus ride."*
- *"There are **no bus links** between Thurmaston and the Hospital."*
- *"Where is the information available at the hospital or in the town about public transport to the hospital?... How would non-residents ever find out? "*

- *"I took so long to park that I was late for an appt. Having waited 45 minutes."*
- *"It is **too dangerous to walk** there **at night** and there is no public transport during night time."*
- *"...the bus stops are not actually near the Outpatients block."*
- *"Walking crossing Alan Moss road **dangerous**. Wouldn't try by bus if I had a child to take to emergency **very distressing**"*
- *"I do not know of any bus the goes close enough as to avoid any a long walk. Some patients cannot walk from the "11/12" bus stop which is the closest one I know."*
- *"The **walking distance** from the stop on Epinal Way is no further than the distance from the High Street to the present site of the Walk-in-centre."*
- *"Due to location on a busy route through the Town, at Rush hour times it is very **inconvenient** to get to."*
- *"The cycle parking is **not very secure** (wheel benders)..."*
- *"**Two stage journey** - one bus per hour from Barrow"*
- *"The cycle rack is not safe to use (cycles been stolen recently)"*
- *"If you miss a bus, it's half an hour to the next one"*
- *"The buses don't coincide with each other so I have long waits in between"*
- *"Need special buses from town to avoid **changes** and up to hospital entrance."*
- *"I travel from Forest Road, **take 2 buses**."*
- *"The bus stop too far away from hospital."*

## 6.5 Willingness to use Public Transport

As stated in this chapter (in Sections 7.3.1 and 7.4.1), travelling by Public Transport may be able to increase (i.e. from 6.3% to 16.3% for the Hinckley site, and from 5.3% to 11.8% for the Loughborough site) if the respondents' awareness of available Public Transport or the Public Transport services were improved. Question 17 was designed to know the respondents awareness about bus routes and also about walking and cycling routes in travelling to LCH and HBCH sites. Figure 6-25 shows that 68% of respondents were aware of the accessibility routes, while 32% of respondents were not, hence there is a need for further publicity. The ratio of awareness for both Loughborough and Hinckley sites were similar.

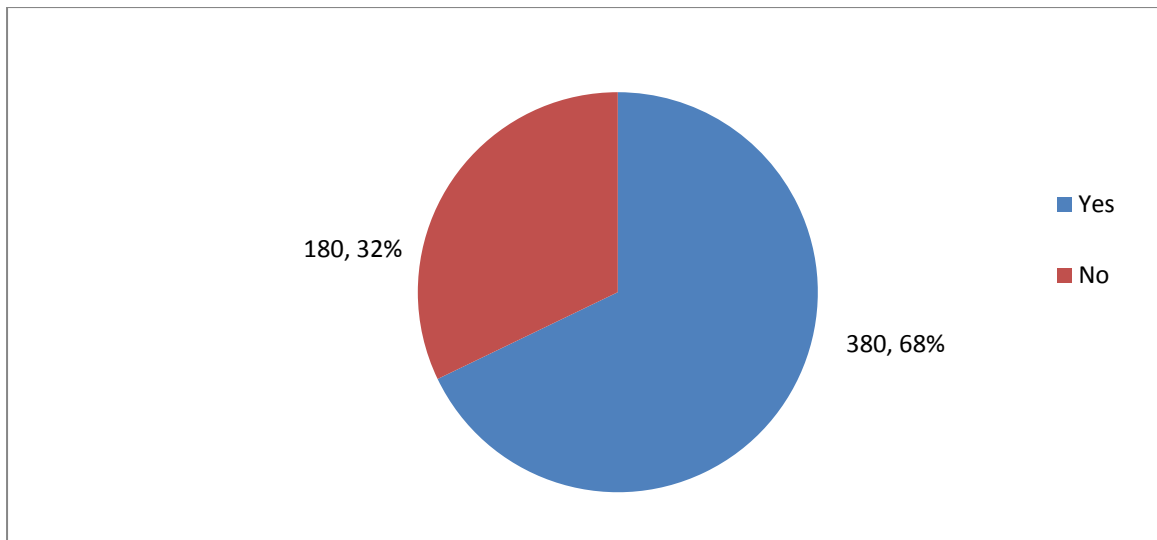


Figure 6-25: Awareness of the bus, walking and cycling routes (Q17)

Q17 also asked respondents to provide comments on their reasons why they were not aware of alternative travel modes (e.g., Bus, Walking and Cycling routes) rather than Car. A number of respondents specified their long distance to the sites, unavailability of bus services or their disability such as:

- *"There are **very few and none direct [buses]** from the outlying villages and towns. All routes go to the centre of Loughborough, within walking distance of the current Walk-in-centre."*
- *"The only bus available from Thurmaston to Loughborough is **once an hour** and takes almost an hour to get to Loughborough and then there is the problem of getting out to Epinal Way."*
- *"... the Walk-in-centre is ideal where it is."*
- *"No bus service to new Loughborough Walk-in-centre [LCH]."*
- *"I am unable to use the bus because you cannot get onto a bus in a **power chair**"*
- *"I need to use a **wheelchair accessible vehicle**."*
- *"I am not sure if there are any busses that go past the hospital."*
- *"Service information is **not readily available** in Broughton Astley."*
- *"Could not get a time table for the bus"*

Question 18 asked respondents if they were made more aware of what Public Transport is available, would they use it to travel to LCH or to HBCH. Figure 6-26 shows that 30% of respondents wanted to use Public Transport if they were aware about the available Public Transport, while the rest of respondents with a same percentage (35%) stated might or would not to use.

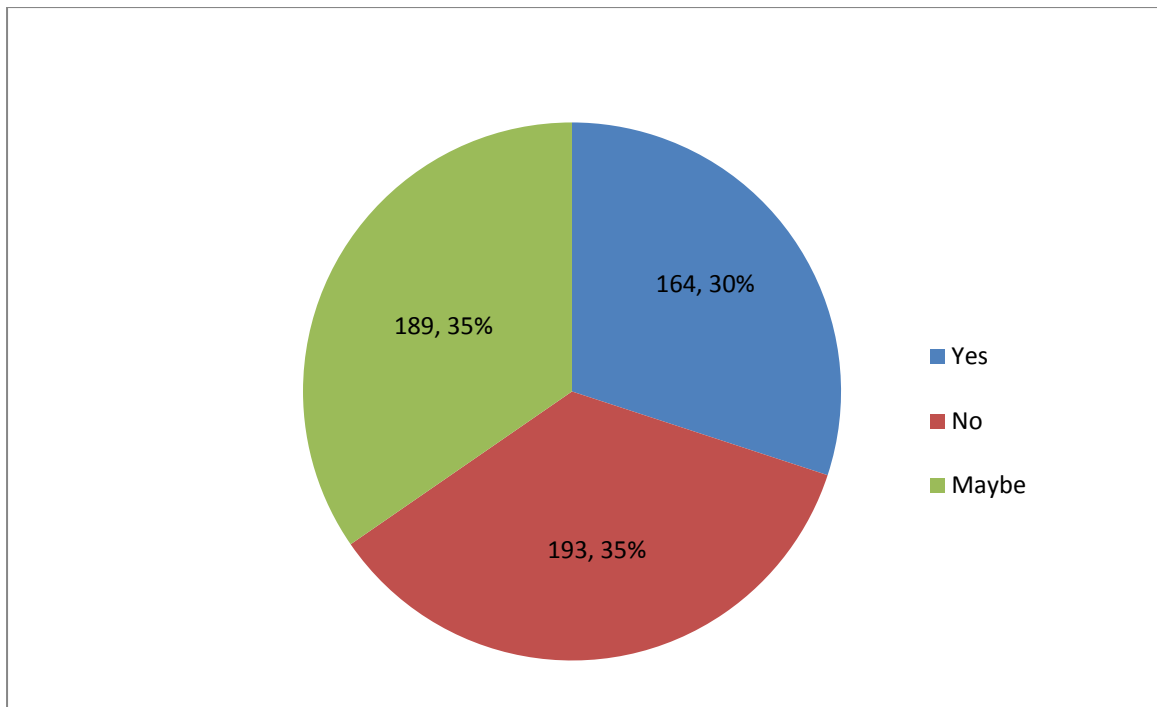


Figure 6-26: Impact of awareness on Public Transport usage (Q18)

Furthermore, Q18 asked respondents to provide comments on their reasons why they may not want to use Public Transport. Figure 6-27 shows that 21.7% (n=30) of respondents did not want to use Public Transport because of their disability and wheelchair issues, while the second reason was additional time to access the sites (18.1%). Then three main reasons were provided by respondents was related to Public Transport challenges such as the lack of direct bus service (15.2%), unavailability of bus service (12.3%) and infrequent bus services (8%).

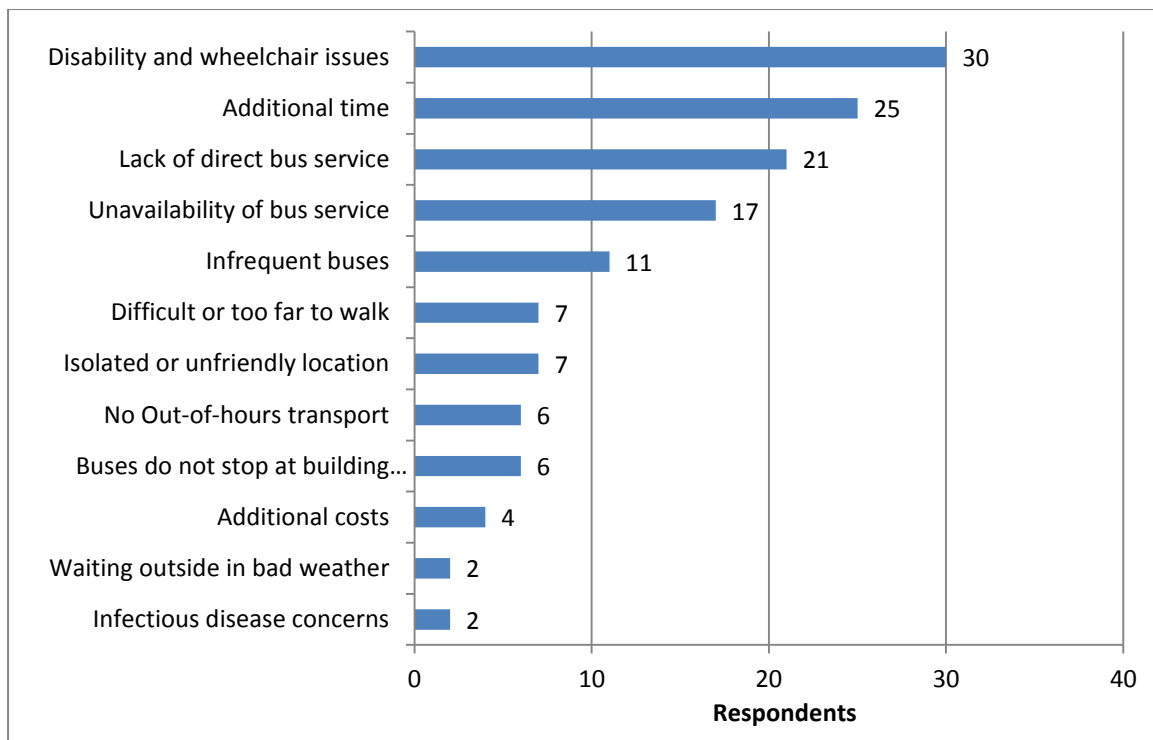


Figure 6-27: Willingness to use Public Transport (Q18)

A review on the comments shows that there are considerable factors which can affect respondents' perceptions in willing to use Public Transport; and it varies among different respondents.

As an example, respondent's comments are as follows.

- *"I am fully aware of all bus services that go anywhere near Epinal Way hospital and they are totally **inadequate**. Why there are bus stops on the site I can't imagine as no bus enters the site at any time."*
- *"I prefer to use my car, as **I am always in a hurry**"*
- *"It's quicker and easier for me by bike. Even if I couldn't cycle I'd probably go by car or taxi as it's quicker and easier than public transport but if public transport more convenient would use it."*
- *"Buses are **NOT ACCESSIBLE** for someone who uses a **wheelchair!** "*
- *"Change of bus necessary - journey too long timewise"*
- *"Walking involved in **catching two buses** What about times of no services of busses - nights, Sundays - **illnesses do not flourish only in office hours.**"*
- *"It's not just a matter of awareness but access. Currently **the transport system is extremely poor.** "*
- *"I am well aware of the **poor provision of public transport to the hospital.**"*
- *"Because it does not always fit with appointment times and **public transport is not that reliable**"*
- *"Unless it is a **disabled-access bus**, public transport irrelevant"*

## 6.6 Willingness to Walk or use Bike

Question 19 asked respondents regarding their willingness to Walk or use Bike to the Loughborough and Hinckley sites. Figure 6-28 shows that 20% of overall respondents from the two sites were willing to Walk or Bike, while 70% answered 'No' and 10% stated 'Maybe' to this question. The figure shows that Hinckley respondents were less willing to Walk or Bike (7%) compared with Loughborough respondents (24%).

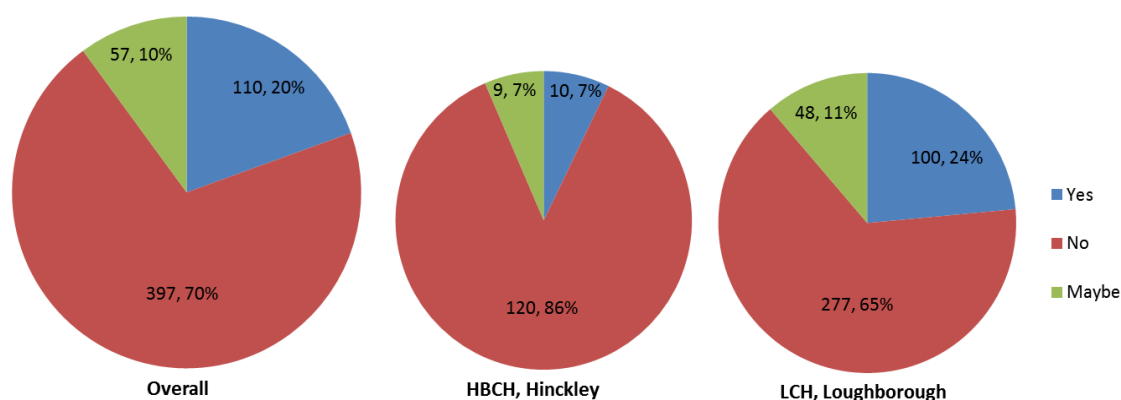


Figure 6-28: Willingness to Walk or Cycle(Q19)

Question 19 also asked respondents to provide reasons regarding their answer. Figure 6-29 shows that 29.3% of respondents were not able to Walk or Cycle due to long walking or cycling distance, while 23.7% could not walk or cycle without a specific reason given. While 7.5% of respondents simply commented that they were not able to walk, some others specified that they could not walk or cycle because of their health condition (12.6%) and/or age (7.2%). However, 3.6% and 2.7% of respondents were able to Walk or Cycle respectively.

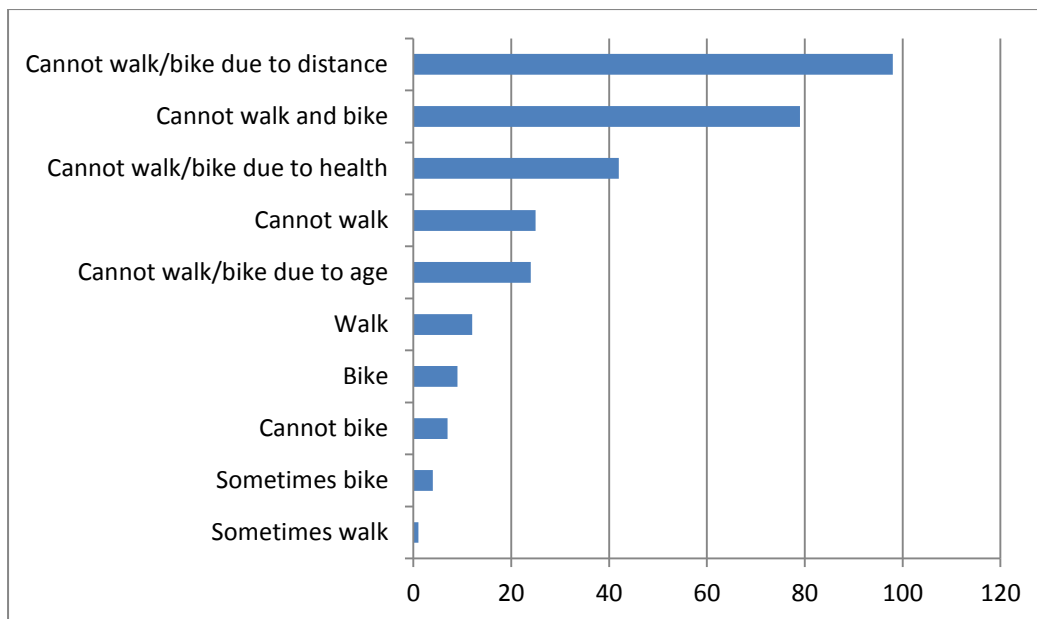


Figure 6-29: Comments on willingness to Walk or Bike (Q19)

As an example, respondent's comments are as follows.

- *"Road to Hinckley Community hospital is **too busy for cycling**, prefer to walk and use pedestrian crossings to cross the road"*
- *"Too far from Baxter gate where bus from Barrow upon Soar terminates"*
- ***"Too far"***
- *"I am pregnant"*

## 6.7 Age and Willing to Use Different Modes of Transport

In order to investigate perceptions of respondents' in travelling by different modes of transport, some results were categorised by age groups. For example, a combination of responses to two of the questions (Q16 and Q18) illustrates respondents' willingness in using Public Transport for different age groups. Figure 6-30 shows impact of awareness on Public Transport usage for different age groups. About 40% of respondents between 60-69 years were willing to use Public Transport if they were made more aware of what Public Transport was available. This was never above 30% for other age groups. However, a minimum of 30% of the respondents in all age groups indicated that they may consider using Public Transport. This shows an opportunity for improving public awareness of the benefits of using Public Transport and investing in improving accessibility and quality of Public Transport.

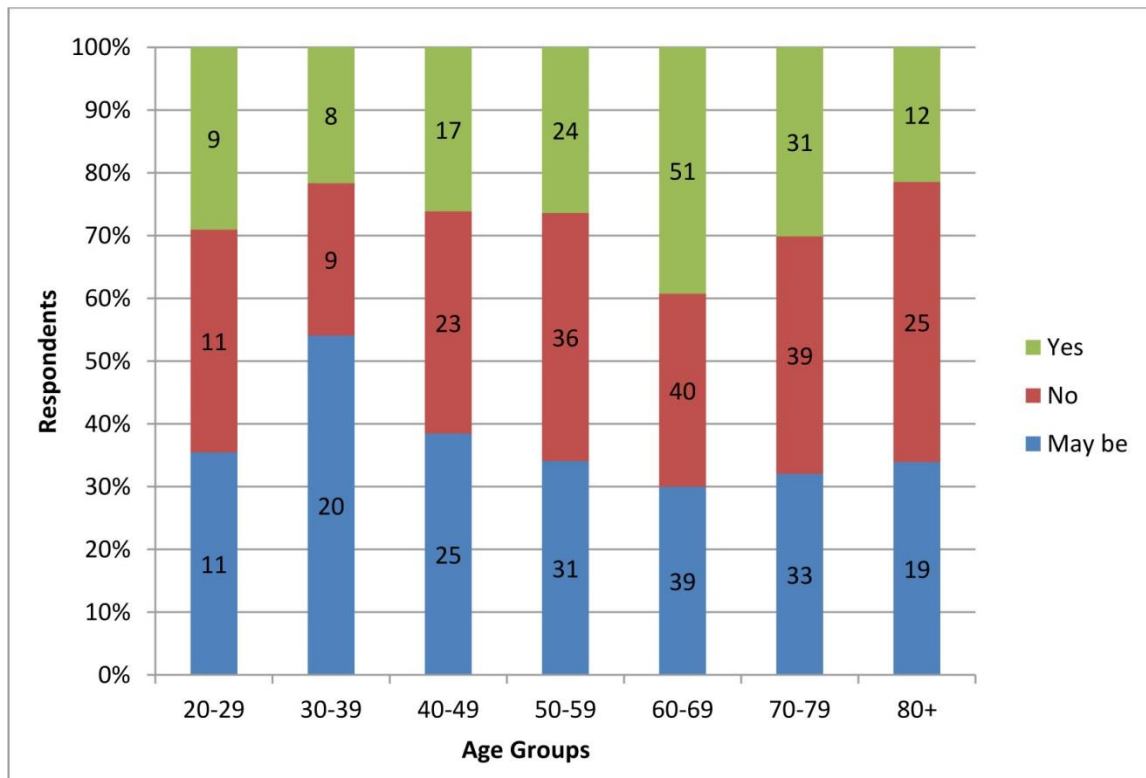


Figure 6-30: Impact of awareness on Bus usage for age groups (Q16 and Q18)

Question 19 asked respondents about their willingness to Walk or use Bike to LCH and HBCH. Figure 6-31 shows that respondents' willingness was decreased after 50 years and more significantly after 70 years of age. Unlike previous question (Q18), less than 15% of the respondents had decided about their intention whether or not to consider walking and cycling as an option. It may indicate that there is reduced flexibility to encourage respondents to Walk or use Bike in comparison with using Public Transport. It seems significant number of respondents answered 'No' to this question because of difficulties to Walk or use Bike due to their illness, disability or senility.



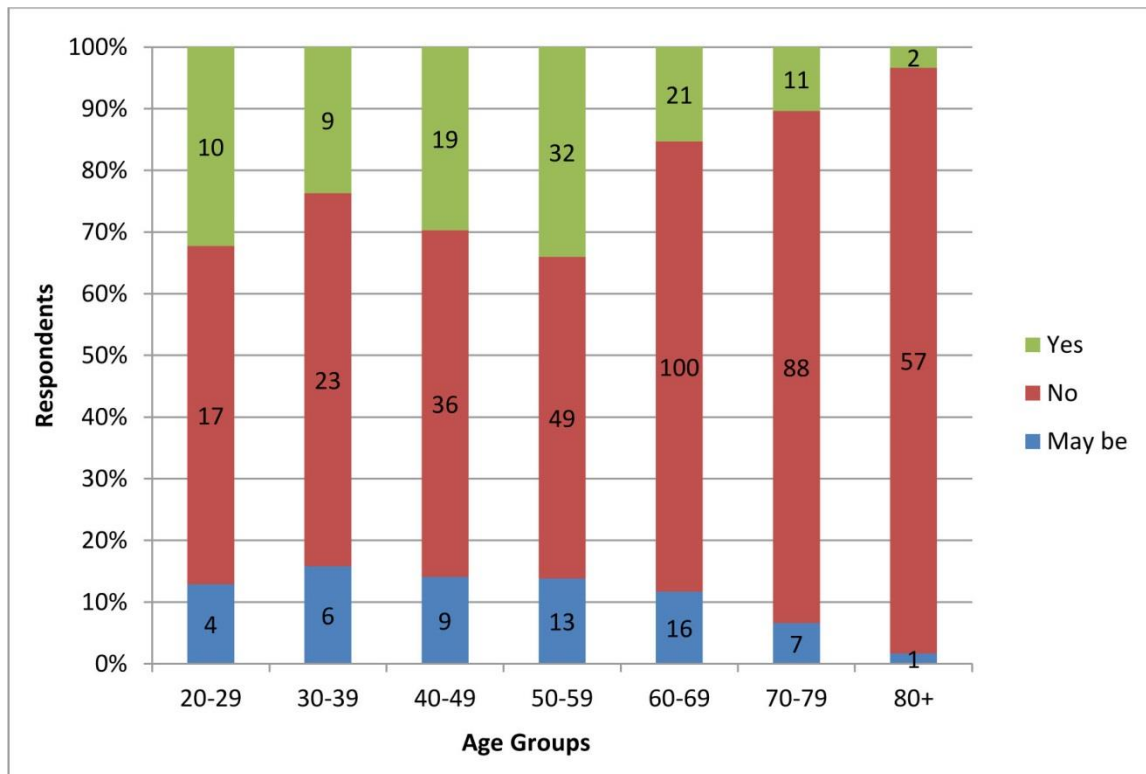


Figure 6-31: Willingness to Walk or use Bike for different age groups' (Q16 and Q19)

Questions 20 asked respondents if they would be willing to ask a friend or family member to drop-off and pick-up from LCH and HBCH. Figure 6-32 shows that more than 60% of young respondents with age between 20-29 years were willing to ask and it was more than other age's willingness. Age between 50-69 years had less interest to ask a friend or family in comparison to other ages.

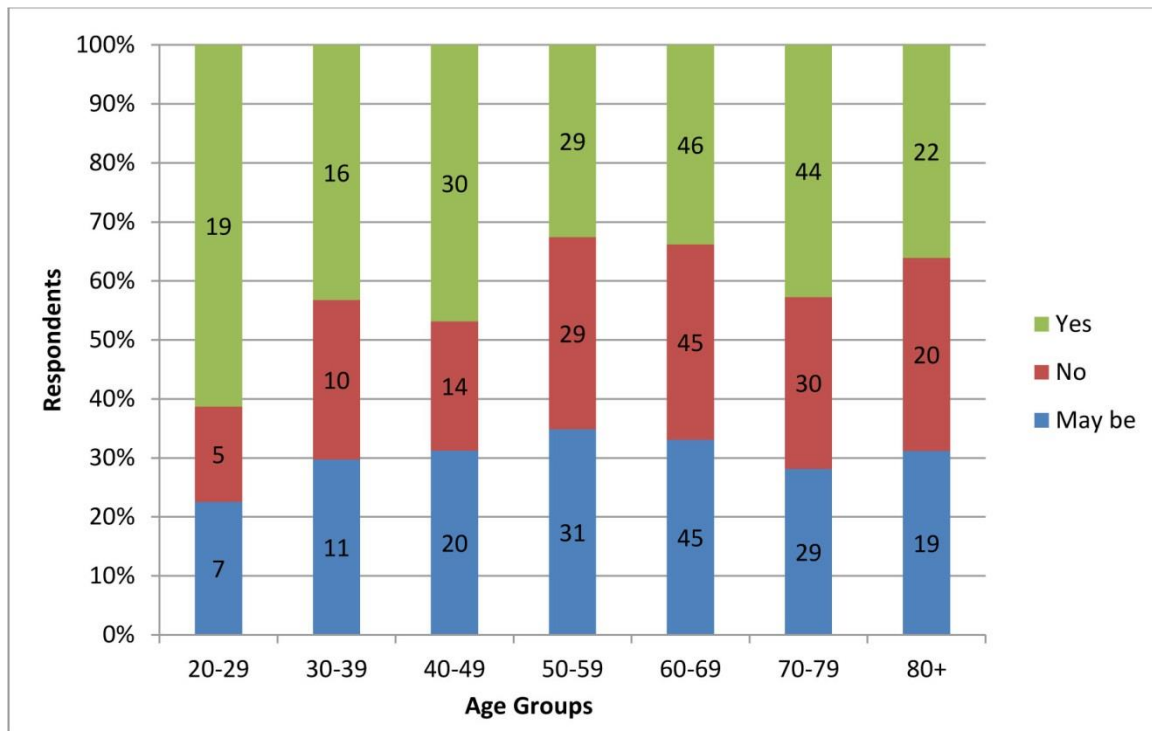


Figure 6-32: willingness to ask a friend or family to drop-off and pick-up (Q16 and Q20)

Figure 6-33 illustrates the percentages of respondents who were willing to use community or voluntary transports (Q21). Figure 6-33 shows that about 50% of elder respondents with age 60 and over were happy to use community transport, while age groups 30-39 and 50-59 were less willing to do so.

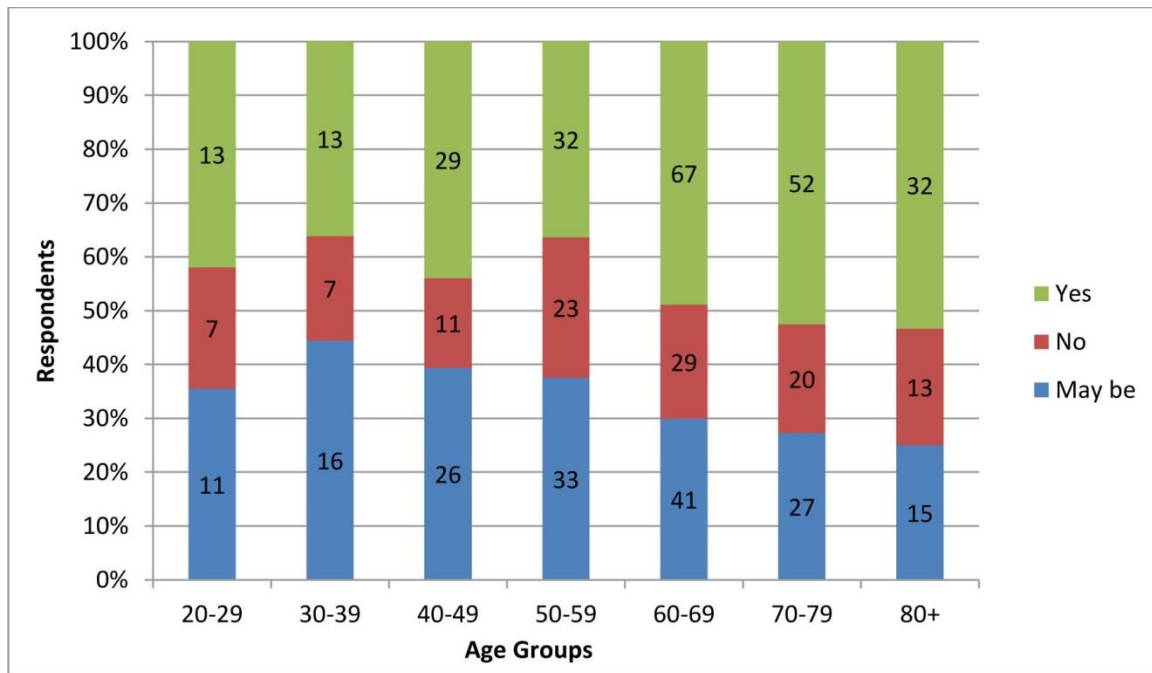


Figure 6-33: willingness to use community transports to drop-off and pick-up (Q16 and Q21)

Furthermore, Figure 6-34 shows that more than 50% of respondents for age groups of 30-39, 40-49, 50-59 and 60-69 year olds willing to walk more than 400m to access a bus stop, while 40% of respondents with 16-19, 20-29, and 70+ year olds willing to walk less than 400m. This result has been used to estimate how far the people are happy to walk to access their nearest bus stop within their area.

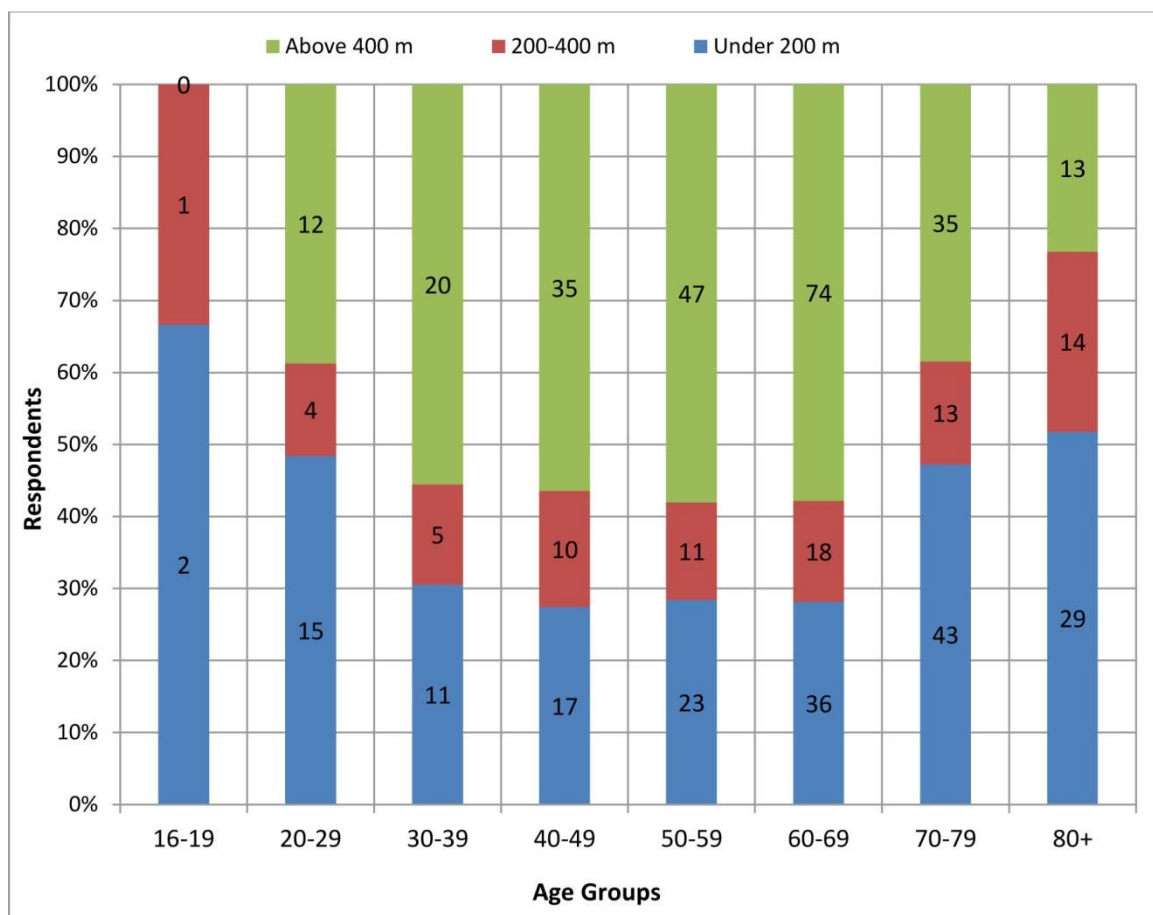


Figure 6-34: Walking distance of different age groups to access a bus stop (Q16 and Q26)

## 6.8 Summary

In order to gain better understanding of users' opinion and the transport issues associated with accessibility to healthcare facilities, a questionnaire survey with more than 40 questions was designed. The survey was taken in two middle-sized towns, Loughborough and Hinckley, and for two healthcare facilities in each town. Similarities and differences of the study areas revealed that many factors affect accessibility to healthcare facilities. In addition to transport issues, other factors such as individual socio-economic background and area-wide characteristics were also identified as being relevant when assessing accessibility to healthcare facilities.

Some questions asked respondents regarding their 'actual used, 'available' and 'preferred' modes of transport. This helped the research to identify respondents' preferences and attitudes, especially when comparing walking with using public

transport or cycling. Some results were categorised by age group to investigate age-related influences on accessibility. The results indicate that some factors can affect respondents' perception of transport accessibility to reach healthcare facilities. The survey also indicated that some factors have no direct relationship with transport issues such as modes, time or cost. Individual preference factors were also specified by respondents such as: inconvenience of changing buses; wait outside in bad weather due to lack of suitable bus shelter; different perceptions of walking convenience; and difficulties of crossing the road to get to the bus stop. The qualitative, and to some extent the quantitative analyses revealed that different respondents had different attitude about such factors. However, it may not possible to cumulate all of the non-transport related factors to develop a formula to measure transport accessibility, if not easy.

As discussed in the methodology chapter, the statistical model had the potential to accommodate this complexity because the error term was considered when the model was developed. The error term in a statistical model should capture all factors that cannot be recognised, or modelled. It considers the random component or residual of the model to help the determination of dependent variable (Tarling, 2009). For example, when 'availability of bus services' has been identified as a significant factor in assessing accessibility, it means that the error term of the statistical model should have considered other related factors. It helps the model to select the significant factor and to assign a weight to the factor.

The number of important factors varies through different travel modes, while people have different perceptions on different travel modes and the related factors. Furthermore, a comparison between the results obtained from the four sites show that their locations affect the respondents' decision in choosing a travel mode. Therefore, user's perception of accessibility has a relationship with both travel mode and destination; and the two factors should be considered in the next chapter statistical modelling.

The results of this survey were used for assessing accessibility to the study area sites. The results were also used to develop the second questionnaire survey and the statistical model which is discussed in next chapter.

## **7 STATISTICAL MODELLING AND RESULTS**

### **7.1 Introduction**

The concept of 'accessibility' has more complexity to be measured by travel time or distance; it includes a broader set of factors relating to user's behaviour (Boulos, 2003; Maroko et al., 2009). The previous chapter's results also revealed that many factors affecting users' perceptions of accessibility to healthcare facilities. There were a few researches that studied non-spatial factors related to users' perceptions of accessibility against spatial factors (Comber et al, 2011). Modelling individual behaviour is valuable when looking to understand their approach patterns. Statistical modelling is useful in modelling accessibility and studying users' behaviour change (McKenzie and Thomas, 1984). As discussed in the Methodology Chapter, multilevel (ML) linear regression modelling was considered as a potential model to achieve this research's aim. This chapter intends to present the results of the ML modelling by considering users' perception as dependent variable of the statistical model.

This chapter is organised as follows: firstly, a brief introduction on a linear regression modelling and its results which will be compared with the ML modelling results later. This is followed by a presentation of the ML linear regression variables used in this research. Then the finding of the ML models will be presented and discussed by developing four types of ML models. The next section will explain calculation of real travel time which was used in the modelling. Finally a prediction model of accessibility will be presented which was developed using the ML regression model. This is followed by a visualisation of the prediction model for LLSOAs within the research catchment area using GIS.

## 7.2 ML Modelling Variables

As discussed in Section 4.8, a ML modelling was developed to examine users' perceptions of accessibility in travelling to healthcare facilities. This is based on the integrated dataset discussed in Section 5.7. The user perception of accessibility to a healthcare facility measuring on a scale of 0 (i.e. not accessible) to 100 (i.e. perfectly accessible) was used as the dependent variable in the ML modelling. Since individuals are nested within areas, the multilevel models developed in this research have two distinct levels and Figure 7-1 shows all explanatory variables used in the models. As discussed, individual-level explanatory variables were obtained from the second questionnaire survey. This includes travel mode, age, gender, income, disability, ethnicity and car ownership. Area-level explanatory variables such as level of traffic safety and security, IMD scores and availability of bus services of LLSOA where an individual resides were primarily obtained from the various secondary sources.

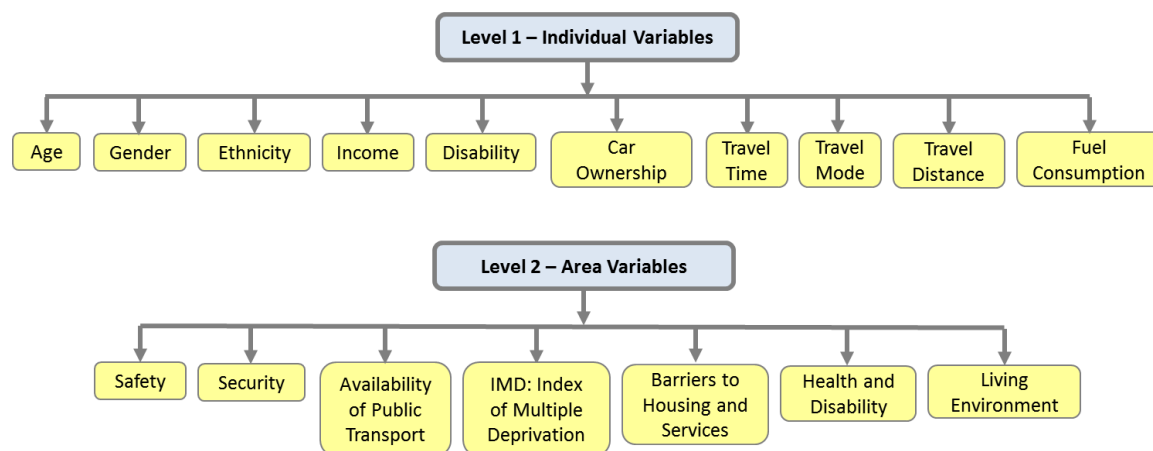


Figure 7-1: Multilevel variables

While some of the individual variables (level 1) were obtained directly from the second questionnaire survey, some others were needed to be generated according to the users' origin and destination locations. These variables included travel time, travel distance, and fuel consumption. Level 2 focused on the area level (LLSOA level) variable which most of them collected from available data sources (see Section 5.3 for details). Two variables (i.e. safety and available bus services) were extracted by employing a GIS analysis. The number of total accidents (i.e. safety) for each LLSOA was obtained from



the geo-coded national traffic accident data. The availability of public transport provision was generated using bus routes map and the available bus services data (see Section 5.7 for details). All variables were examined in the ML modelling and a total of eight models were developed and the results are presented in the following section.

### 7.3 ML Modelling Results

Two types of multilevel model were estimated: (1) random-intercept model; and (2) random-intercept and random-slope model. Each of the lower-level (i.e. individual-level) variables was examined to determine whether or not the effect of the variable (i.e. the slope coefficient) varies across areas. As travel time and travel distance were correlated with each other (showing a correlation coefficient of 0.87), both variables were not included in the same model. Separate models were therefore developed for travel time and travel distance.

Statistical software STATA was used in developing the ML statistical models. A total of eight models were developed as shown in Table 7-1.

Table 7-1: Modelling Strategy

Model	Description
For All Respondents	
M1	Travel distance as a fixed parameter
M2	Travel distance as a random parameter
M3	Travel time as a fixed parameter
M4	Travel time as a random parameter
For Respondents with access to car	
M5	Travel distance as a fixed parameter
M6	Travel distance as a random parameter
M7	Travel time as a fixed parameter
M8	Travel time as a random parameter

#### 7.3.1 Model for All Respondents

In the Models for all respondents, there were a total of 480 individuals from 152 different areas of residence (i.e. 3.2 respondents per area). Table 7-2 shows two developed models (M1 and M2) considering travel distance as fixed and random parameter variables. The intra-class coefficient was 0.023 for M1 and 0.096 for M2. These indicate that 2.3 and 9.6 per cent of the variation in the accessibility score were

explaining by the multilevel or hierarchy data structure in M1 and M2 respectively. The log-likelihood ratio statistic were approximately same for both models as 5 per cent which was comparable with existing statistical models that used the ML estimation method (see Wang et al., 2009). The variance for the intercept term was estimated as 7.4 for M1 and 8.8 for M2 reflecting the between-area variance in the accessibility score.

The most statistically significant variables influencing the user-perception of accessibility were found to be travel distance (by car) and the dummy variable representing destination choices (whether WIC or LCH) at the 95 per cent confidence level. Travel distance showed the expected negative sign indicating that the increase in travel distance from home to a healthcare facility decreased the perception on the level of accessibility. If all else are equal, a 1-mile increase in travel distance by car would reduce the perception of accessibility by about 3.6 units (on a scale of 0 to 100) for the fixed effects model (M1) and 3.8 units for the random effects model (M2). In terms of destination choice, both models provided similar results indicating that the average perception of accessibility is low in travelling to Walk in Centre (WIC) relative to that of in travelling to Loughborough Community Hospital (LCH).

Another statistically significant variable was age of the respondent. This variable was entered in the models as a categorical variable with seven distinct categories in which the category - age between 16 to 19 years was considered as the reference case. The result of first four developed models (i.e. M1, M2, M3 and M4) indicated that age cohorts were marginally significant at the 90 per cent confidence level.

Table 7-2: Model estimation results for all respondents (M1 and M2)

Dependent variable = Overall accessibility perception				
Multilevel (ML) Modelling for All Respondents				
<b>Fixed-effects</b>	Travel Distance as Fixed (M1)		Travel Distance as Random (M2)	
<i>Level 1: respondent-level variables</i>	Coefficient	t-stat	Coefficient	t-stat
Travel distance (miles)	-3.6448	<b>-2.45*</b>	-3.8031	<b>-2.04*</b>
Travel Time (minutes)				
Fuel Consumption (gCO2e/miles/passenger)				
Number of services of bus stops within the 400m distance from origin/home	0.1122	1.21	0.1258	1.33
<b>Age groups:</b> 16 - 19 (reference)	0.0000		0.0000	
20 - 29	1.0321	0.25	1.1799	0.29
30 - 39	4.9453	1.14	5.1077	1.17
40 - 49	6.3053	1.49	6.5286	1.53
50 - 59	4.2479	0.97	4.2894	0.98
60 - 69	7.6979	<b>1.81**</b>	7.8165	<b>1.83**</b>
70 and over	7.0318	1.61	6.7800	1.55
Gender (male = 1; female = 0)	0.3367	0.20	0.1401	0.08
<b>Mode choice:</b> Walk (reference)	0.0000		0.0000	
Car	-1.3159	-0.56	-1.4586	-0.62
Bus	-7.3536	-1.56	-7.4148	-1.58
Whether the respondent from the walking catchment (Yes=1; No=0)	-1.9507	-0.9	-1.4642	-0.67
Destinations (WIC=1; LCH=0)	-5.5950	<b>-2.62*</b>	-5.6542	<b>-2.61*</b>
Intercept	77.9138	16.62	78.0641	16.53
<i>Level 2: area-level variables</i>				
Index of multiple deprivation (IMD) score	0.1178	1.43	0.1114	1.36
<b>Random-effects</b>				
Variance of Travel Distance (miles)			23.2731	0.88
Variance of Travel Time (minutes)				
Variance of Intercept	7.4110	0.66	8.8119	0.77
Covariance (Intercept and travel dist.)			-3.3025	-0.21
Covariance (Intercept and travel time)				
Variance of Residual	310.9258	13.82	302.4710	13.14
Statistics				
Number of observations	480		480	
Number of groups (i.e. LLSOA)	152		152	
Intra-class correlation (ICC)	0.0233		0.0959	
Pseudo R-square	0.0506		<b>0.0511</b>	

\* Significant by **95%** confidence level\*\* Significant by **90%** confidence level

As can be seen in Table 7-3, two separate models were also developed considering travel time as a fixed (M3) and random effects (M4) parameters. The log-likelihood ratio statistic of the models (i.e. M3 and M4) was about 5 per cent and similar to the models with travel distance. The intra-class coefficient was 0.021 for M3 and 0.038 for M4. These coefficients indicate that the variation in the accessibility score was explained by the hierarchy data structure. It was 2.1 per cent in M3 and 3.8 per cent in M4 and the difference in percentage between M3 and M4 (i.e. 1.7 per cent) indicates that M3 is a better model than M4.

Unlike the modelling with travel distance, travel time was found to be statistically insignificant variable in the developed models; and the destination dummy was the only significant variable in the models. Since the models with travel distance fit the slightly better than the models with travel time, it can be argued that M1 and M2 should be employed for further analysis in accessing the perception of accessibility.

A categorical variable for mode choice (i.e. car, bus and walk) was included in all the four models with car as being the reference case, however Table 7-2 and Table 7-3 show that there was not any statistically significant difference in the accessibility scores for different transport modes within the four models and that 83 per cent of the respondents used car for travelling to a healthcare facility. It was trivial that transport modes play a key role in the perception of accessibility but the models did not pick the difference. The goodness-of-fit of multilevel models can be obtained by calculating the Pseudo R-square of a model. Literature suggests that a model with a Pseudo R-square close to 0.1 suggests a reasonably good fit (Abdel-Aty and Radwan, 2000).

Table 7-3: Model estimation results for all respondents (M3 and M4)

Dependent variable = Overall accessibility perception				
Multilevel Modelling for All Respondents				
<b>Fixed-effects</b>	Travel Time as Fixed (M3)		Travel Time as Random (M4)	
<i>Level 1: respondent-level variables</i>	Coefficient	t-stat	Coefficient	t-stat
Travel distance (miles)				
Travel Time (minutes)	-0.9149	-1.20	-1.3519	-1.57
Fuel Consumption (gCO <sub>2</sub> e/miles/passenger)	-0.0040	-0.24	-0.0026	-0.16
Number of services of bus stops within the 400m distance from origin/home	0.1161	1.22	0.1079	1.11
<b>Age groups:</b> 16 - 19 (reference)	0.0000		0.0000	
20 - 29	1.1287	0.27	1.1017	0.27
30 - 39	4.9390	1.13	4.8844	1.12
40 - 49	6.3138	1.47	6.3395	1.49
50 - 59	4.1474	0.94	4.0569	0.93
60 - 69	7.9651	<b>1.86**</b>	7.8186	<b>1.84**</b>
70 and over	6.9005	1.57	6.4292	1.47
Gender (male = 1; female = 0)	0.1490	0.09	0.0846	0.05
<b>Mode choice:</b> Walk (reference)	0.0000		0.0000	
Car	-0.6960	-0.23	-0.8772	-0.30
Bus	-6.5839	-1.38	-6.4662	-1.37
Whether the respondent from the walking catchment (Yes=1; No=0)	-1.9368	-0.89	-1.8937	-0.87
Destinations (WIC=1; LCH=0)	-5.7409	<b>-2.67*</b>	-5.9472	<b>-2.74*</b>
Intercept	77.5610	15.51	77.9191	15.61
<i>Level 2: area-level variables</i>				
Index of multiple deprivation (IMD) score	0.1139	1.38	0.1128	1.37
<b>Random-effects</b>				
Variance of Travel Distance (miles)				
Variance of Travel Time (minutes)			3.9041	0.97
Variance of Intercept	6.7293	0.60	8.2293	0.72
Covariance (Intercept and travel dist.)				
Covariance (Intercept and travel time)			2.1307	0.35
Variance of Residual	314.2942	13.84	306.9923	13.46
Statistics				
Number of observations	480		480	
Number of groups (i.e. LLSOA)	152		152	
Intra-class correlation (ICC)	0.0210		0.0380	
Pseudo R-square	0.0496		0.0501	

\* Significant by **95%** confidence level\*\* Significant by **90%** confidence level

As can be seen in Table 7-2 and Table 7-3, the statistical insignificant variables (individual-level) were found to be: gender, fuel consumption and mode choice. This was perhaps due to the low number of observations (i.e. 480 individuals and 152 areas) or their effects were being captured by other factors such as disability. Moreover, the variation in accessibility was somehow limited (i.e. the interquartile range was 25 implying that 50 per cent of the accessibility scores fell between 70 and 95 (on a scale of 0 to 100)). It should be noted that the area-level variable – index of multiple deprivation (IMD) was also found to be statistically insignificant. Other area-wide variables (e.g. crime rate and accident rate) have also been tested but found to be statistically insignificant, therefore, the final model does not include any cross-level interaction terms as shown in Equation 4-4 (i.e. XZ).

### **7.3.2 Models for Respondents with Car Ownership**

Since 83 per cent of the respondents either own a car or have an access to a car, further models (M5, M6, M7 and M8) were developed for the respondents who had an access to a car. This was to investigate whether the results are different from the whole sample.

In the model for the respondents with car ownership, there were a total of 396 individuals from 146 different areas of residence (i.e. 2.7 respondents per area). As can be seen in Table 7-4, the intra-class coefficient of the model with travel distance as a fixed effect parameter (M5) indicated that six per cent of the variation in the accessibility score was explained by the hierarchy data structure, while it was twice as many (12.5 per cent) as the model with random effects parameter (M6). The log-likelihood ratio statistic was around 4.9 per cent for the both models.

These two models (M5 and M6) in Table 7-4 had more significant variables in comparisons with the four models for all respondents. Besides travel distance and the destination choice, the number of bus services and age were also found to be statistically significant variables. This model indicated that number of services of the bus stops within 400 metre distance from origin/home address of respondents was a significant variable; it was for the respondents who had an access to a car.

Table 7-4: Model estimation results for respondents with car ownership (M5 and M6)

Dependent variable = Overall accessibility perception		ML Modelling for Respondents with Car Ownership			
<b>Fixed-effects</b>		Travel Distance as Fixed (M5)		Travel Distance as Random (M6)	
<i>Level 1: respondent-level variables</i>		Coefficient	t-stat	Coefficient	t-stat
Travel distance (miles)		-3.9780	<b>-2.58*</b>	-3.8881	<b>-2.09*</b>
Travel Time (minutes)					
Fuel Consumption (gCO2e/miles/passenger)					
Number of services of bus stops within the 400m distance from origin/home		0.1754	<b>1.68**</b>	0.1867	<b>1.76**</b>
<b>Age groups:</b> 16 - 19 (reference)		0.0000		0.0000	
20 - 29		6.1554	1.17	6.2359	1.17
30 - 39		8.9680	<b>1.66**</b>	8.9825	<b>1.65**</b>
40 - 49		10.9695	<b>2.07*</b>	10.8559	<b>2.02*</b>
50 - 59		11.1209	<b>2.07*</b>	10.9704	<b>2.02*</b>
60 - 69		10.3783	<b>1.95*</b>	10.2091	<b>1.89*</b>
70 and over		11.5231	<b>2.13*</b>	11.0576	<b>2.02*</b>
Gender (male = 1; female = 0)		0.0714	0.04	-0.0755	-0.04
<b>Mode choice:</b> Walk (reference)		0.0000		0.0000	
Car		-3.2363	-1.32	-3.0549	-1.21
Bus		-6.3965	-1.17	-7.4644	-1.30
Whether the respondent from the walking catchment (Yes=1; No=0)		-0.4462	-0.18	-0.9458	-0.36
Destinations (WIC=1; LCH=0)		-6.4823	<b>-2.93*</b>	-5.1700	<b>-2.61*</b>
Intercept		75.9458	13.17	74.6221	12.95
<i>Level 2: area-level variables</i>					
Index of multiple deprivation (IMD) score		0.1153	1.23	0.1133	1.20
<b>Random-effects</b>					
Variance of Travel Distance (miles)				16.4540	0.90
Variance of Travel Time (minutes)					
Variance of Intercept		17.1375	1.09	20.7901	1.27
Covariance (Intercept and travel dist.)				-5.1066	-0.26
Covariance (Intercept and travel time)					
Variance of Residual		267.8836	11.61	259.4976	11.17
Statistics					
Number of observations		396		396	
Number of groups (i.e. LLSOA)		146		146	
Intra-class correlation (ICC)		0.0601		<b>0.1255</b>	
Pseudo R-square		0.0490		<b>0.0495</b>	

\* Significant by 95% confidence level

\*\* Significant by 90% confidence level

Availability of bus services close to respondents' residential location showed the expected positive sign indicating that the increase in bus services around the respondent home would increase the perception on the level of accessibility. In order to clarify the findings of a model, it is better to explain the changes of the dependent variable according to the changes of an independent variable. For example, if the destination choices considered as the only significant variable of the modelling, it is possible to find how much it can effect on the dependent variable if the destination choices was the only important factor for the user. Therefore such discussions have been presented here for each factor individually. If all else are equal, an additional bus service within the 400 metre distance from the respondent's home would increase the perception of accessibility by about 0.2 units (on a scale of 0 to 100) in M5 and M6 models. In terms of the destination choice, changing the destination from Loughborough Community Hospital (LCH) to walk in Centre NHS (WIC) reduces the perception of accessibility by 6.5 units (on a scale of 0 to 100) for M5 and 5.2 for M6.

Two more models were developed considering travel time as fixed and random effects parameter, as presented in Table 7-5. The significant variables of models M7 and M8 in Table 7-5 were age, number of bus services and destination choices. The travel time was not a significant variable. As in the first four examined models (M1, M2, M3 and M4), the two last models (M7 and M8) were not a good fitted models in terms of number of significant variables. Unlike the developed models for all people (Table 7-2 and Table 7-3) the number of direct bus services was a significant variable in the models for respondents with car ownership (Table 7-4 and Table 7-5). This means that the number of bus services could influence the perception of the users who had access to a car; and it was not a significant factor in the models developed for all respondents. The result of the last four models (e.g. M5, M6, M7 and M8) indicated that the user-perception of accessibility increased with the increase in age up to 70. There was no significant different in the perception of accessibility between youngers (16 to 19). This was perhaps due to lack of their experience in travelling or travelling with another person to take or accompany them to the hospital. For instance, people aged 50-59 perceived that their level of accessibility to a healthcare facility is 11 units higher than people aged under 20.



Table 7-5: Model estimation results for respondents with car ownership (M7 and M8)

Dependent variable = Overall accessibility perception		ML Modelling for Respondents with Car Ownership			
<i>Fixed-effects</i>		Travel Time as Fixed (M7)		Travel Time as Random (M8)	
<i>Level 1: respondent-level variables</i>		Coefficient	t-stat	Coefficient	t-stat
Travel distance (miles)					
Travel Time (minutes)		-0.6147	-0.77	-1.0762	-1.15
Fuel Consumption (gCO2e/miles/passenger)		-0.0027	-0.16	-0.0013	-0.08
Number of services of bus stops within the 400m distance from origin/home		0.1989	1.85	0.2031	1.86
<b>Age groups:</b>	16 - 19 (reference)	0.0000		0.0000	
	20 - 29	6.4817	1.22	6.7149	1.27
	30 - 39	9.2101	<b>1.69**</b>	9.0723	<b>1.68**</b>
	40 - 49	10.8277	<b>2.01*</b>	10.9690	<b>2.06*</b>
	50 - 59	11.2339	<b>2.07*</b>	11.2592	<b>2.09*</b>
	60 - 69	10.9033	<b>2.02*</b>	10.8644	<b>2.03*</b>
	70 and over	11.2284	<b>2.06*</b>	10.7256	<b>1.98*</b>
Gender (male = 1; female = 0)		-0.1467	-0.08	-0.4196	-0.24
<b>Mode choice:</b>	Walk (reference)	0.0000		0.0000	
	Car	-2.4287	-0.78	-2.5016	-0.81
	Bus	-6.1131	-1.10	-5.9850	-1.09
Whether the respondent from the walking catchment (Yes=1; No=0)		-0.8652	-0.34	-0.7369	-0.29
Destinations (WIC=1; LCH=0)		-6.5198	<b>-2.97*</b>	-6.9465	<b>-3.13*</b>
Intercept		75.2123	12.42	75.5946	12.58
<i>Level 2: area-level variables</i>					
Index of multiple deprivation (IMD) score		0.1109	1.18	0.1093	1.17
<i>Random-effects</i>					
Variance of Travel Distance (miles)					
Variance of Travel Time (minutes)				6.3622	1.26
Variance of Intercept		16.5311	1.06	19.8749	1.22
Covariance (Intercept and travel dist.)					
Covariance (Intercept and travel time)				5.2947	0.58
Variance of Residual		272.6110	11.65	259.8128	11.18
Statistics					
Number of observations		396		396	
Number of groups (i.e. LLSOA)		146		146	
Intra-class correlation (ICC)		0.0572		0.0917	
Pseudo R-square		0.0473		0.0486	

\* Significant by **95%** confidence level\*\* Significant by **90%** confidence level

Selection of a model between several competing models is a problem. Akaike information criterion (AIC) and Bayesian information criterion (BIC) are two closely related criteria to compare and select the best model among a set of models. They are based on the likelihood function. AIC and BIC cannot test a null hypothesis of a model and cannot tell about the fitness of a model (Liddle, 2008). Since the data of different levels of this research has a different sample size, the AIC can provide more straightforward answers in selecting the best ML model. The model with the lowest AIC and BIC can be selected as the better model (Hox, 2010).

All of the eight developed models in this Section are summarised in Table 7-6. Based on the log-likelihood value at convergence and the Bayesian Information Criterion (BIC), it was found that the model with travel distance outperformed the model with travel time. As can be seen in Table 7-6, the best model was M5 fitted the data better compared to other models as Akaike Information Criterion (AIC) was the lowest among the eight models. Similar to M6, there were also more significant variables in M5 relative to other models, for instance, age cohorts were statistically significant.

The model M5 was considered as the best fitted model according to the criteria and priorities including: number of significant variables; lowest AIC; and highest intra-class correlation.

As 17 per cent of the respondents were without car or no access to a car therefore was not possible to examine the ML modelling due to lack of enough data.

Table 7-6: Model estimation results with direct bus service to the sites

Dependent variable = Overall accessibility perception	Multilevel (ML) Regression for All Respondents								Multilevel (ML) Regression for Respondents with Car Ownership							
<b>Fixed-effects</b>	<b>TD Fixed (M1)</b>		<b>TD Random (M2)</b>		<b>TT Fixed (M3)</b>		<b>TT Random (M4)</b>		<b>TD Fixed (M5)</b>		<b>TD Random (M6)</b>		<b>TT Fixed (M7)</b>		<b>TT Random (M8)</b>	
<i>Level 1: respondent-level variables</i>	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Travel distance (miles)	-3.6448	-2.45	-3.8031	-2.04					<b>-3.9780</b>	<b>-2.58</b>	-3.8881	<b>-2.09</b>				
Travel Time (minutes)					-0.9149	-1.20	-1.3519	-1.57					-0.6147	-0.77	-1.0762	-1.15
Fuel Consumption (gCO <sub>2</sub> e/miles/passenger)					-0.0040	-0.24	-0.0026	-0.16					-0.0027	-0.16	-0.0013	-0.08
Number of services of bus stops within the 400m distance from origin/home	0.1122	1.21	0.1258	1.33	0.1161	1.22	0.1079	1.11	0.1754	<b>1.68</b>	<b>0.1867</b>	<b>1.76</b>	0.1989	1.85	0.2031	1.86
<b>Age groups:</b> 16 - 19 (reference)	0.0000		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000		0.0000	
20 - 29	1.0321	0.25	1.1799	0.29	1.1287	0.27	1.1017	0.27	6.1554	1.17	6.2359	1.17	6.4817	1.22	6.7149	1.27
30 - 39	4.9453	1.14	5.1077	1.17	4.9390	1.13	4.8844	1.12	8.9680	<b>1.66</b>	8.9825	<b>1.65</b>	9.2101	1.69	9.0723	1.68
40 - 49	6.3053	1.49	6.5286	1.53	6.3138	1.47	6.3395	1.49	10.9695	<b>2.07</b>	10.8559	<b>2.02</b>	10.8277	2.01	10.9690	2.06
50 - 59	4.2479	0.97	4.2894	0.98	4.1474	0.94	4.0569	0.93	11.1209	<b>2.07</b>	10.9704	<b>2.02</b>	11.2339	2.07	11.2592	2.09
60 - 69	7.6979	1.81	7.8165	1.83	7.9651	1.86	7.8186	1.84	10.3783	<b>1.95</b>	10.2091	<b>1.89</b>	10.9033	2.02	10.8644	2.03
70 and over	7.0318	1.61	6.7800	1.55	6.9005	1.57	6.4292	1.47	11.5231	<b>2.13</b>	11.0576	<b>2.02</b>	11.2284	2.06	10.7256	1.98
Gender (male = 1; female = 0)	0.3367	0.20	0.1401	0.08	0.1490	0.09	0.0846	0.05	0.0714	0.04	-0.0755	-0.04	-0.1467	-0.08	-0.4196	-0.24
<b>Mode choice:</b> Walk (reference)	0.0000		0.0000		0.0000		0.0000				0.0000		0.0000		0.0000	
Car	-1.3159	-0.56	-1.4586	-0.62	-0.6960	-0.23	-0.8772	-0.30	-3.2363	-1.32	-3.0549	-1.21	-2.4287	-0.78	-2.5016	-0.81
Bus	-7.3536	-1.56	-7.4148	-1.58	-6.5839	-1.38	-6.4662	-1.37	-6.3965	-1.17	-7.4644	-1.30	-6.1131	-1.10	-5.9850	-1.09
Whether the respondent from the walking catchment (Yes=1; No=0)	-1.9507	-0.9	-1.4642	-0.67	-1.9368	-0.89	-1.8937	-0.87	-0.4462	-0.18	-0.9458	-0.36	-0.8652	-0.34	-0.7369	-0.29
Destinations (WIC=1; LCH=0)	-5.5950	-2.62	-5.6542	-2.61	-5.7409	-2.67	-5.9472	-2.74	-6.4823	<b>-2.93</b>	-5.1700	<b>-2.61</b>	-6.5198	-2.97	-6.9465	-3.13
Intercept	77.9138	16.62	78.0641	16.53	77.5610	15.51	77.9191	15.61	75.9458	13.17	74.6221	12.95	75.2123	12.42	75.5946	12.58
<i>Level 2: area-level variables</i>																
Index of multiple deprivation (IMD) score	0.1178	1.43	0.1114	1.36	0.1139	1.38	0.1128	1.37	0.1153	1.23	0.1133	1.20	0.1109	1.18	0.1093	1.17
<b>Random-effects</b>																
Variance of Travel Distance (miles)			23.2731	0.88							16.4540	0.90				
Variance of Travel Time (minutes)							3.9041	0.97							6.3622	1.26
Variance of Intercept	7.4110	0.66	8.8119	0.77	6.7293	0.60	8.2293	0.72	17.1375	1.09	20.7901	1.27	16.5311	1.06	19.8749	1.22
Covariance (Intercept and travel dist.)			-3.3025	-0.21							-5.1066	-0.26				
Covariance (Intercept and travel time)							2.1307	0.35							5.2947	0.58
Variance of Residual	310.9258	13.82	302.4710	13.14	314.2942	13.84	306.9923	13.46	267.8836	11.61	259.4976	11.17	272.6110	11.65	259.8128	11.18
Statistics																
Number of observations	480		480		480		480		396		396		396		396	
Number of groups (i.e. LLSOA)	152		152		152		152		146		146		146		146	
Intra-class correlation (ICC)	0.0233		0.0959		0.0210		0.0380		0.0601		<b>0.1255</b>		0.0572		0.0917	
Pseudo R-square	0.0506		<b>0.0511</b>		0.0496		0.0501		0.0490		<b>0.0495</b>		0.0473		0.0486	
AIC (Akaike information criterion)	<b>4161.94</b>		4163.52		4168.07		4169.98		<b>3394.08</b>		3396.21		3401.96		3401.42	
BIC (Bayesian information criterion)	4232.89		4242.82		4243.20		4253.46		3461.76		3471.86		3473.62		3481.05	
LL(B), Log-likelihood (restricted) at convergence	-2063.97		-2062.76		-2066.03		-2064.99		-1680.04		-1679.10		-1682.98		-1680.71	
LL(0) Null Log-likelihood	-2173.94		-2173.94		-2173.94		-2173.94		-1766.52		-1766.52		-1766.52		-1766.52	

Two continuous variables (*i.e. travel distance and available bus services*) were found to be statistically significant in influencing *users' perception of accessibility*. *Travel distance* was negatively associated with the *users' perception of accessibility*, while the *available bus service* was positively associated with the users' perception of accessibility.

In order to discuss the percentage changes of a dependant variable in response to the corresponding percentage change in an independent variable, the elasticity of the variable needs to be calculated (Chatterjee and Simonof, 2012). Elasticities of users' perception of accessibility with respect to these two variables were estimated in their mean values by using model M5. The elasticity of users' perception of accessibility with respect to travel distance was found to be -0.25 implying that a one per cent increases in travel distance would decrease the users' perception by 0.25 per cent. The elasticity of users' perception of accessibility with respect to bus services was found to be 0.046 suggesting that a one per cent increase in the number of bus services per hour (within 400m distance from a user home address) would increase the users' perception of accessibility by 0.046 per cent.

### **7.3.3 Models including Indirect Bus Services**

Direct bus services were the considered variable for the all of the developed ML models (M1, M2, M3, M4, M5, M6, M7, and M8). It means that the indirect bus services were not included in the first eight models. Figure 7-2 and Figure 7-3 show the bus stops which have direct bus services to WIC and LCH. As can be seen, higher numbers of bus stops were in accessing to the WIC due to its location in town centre.

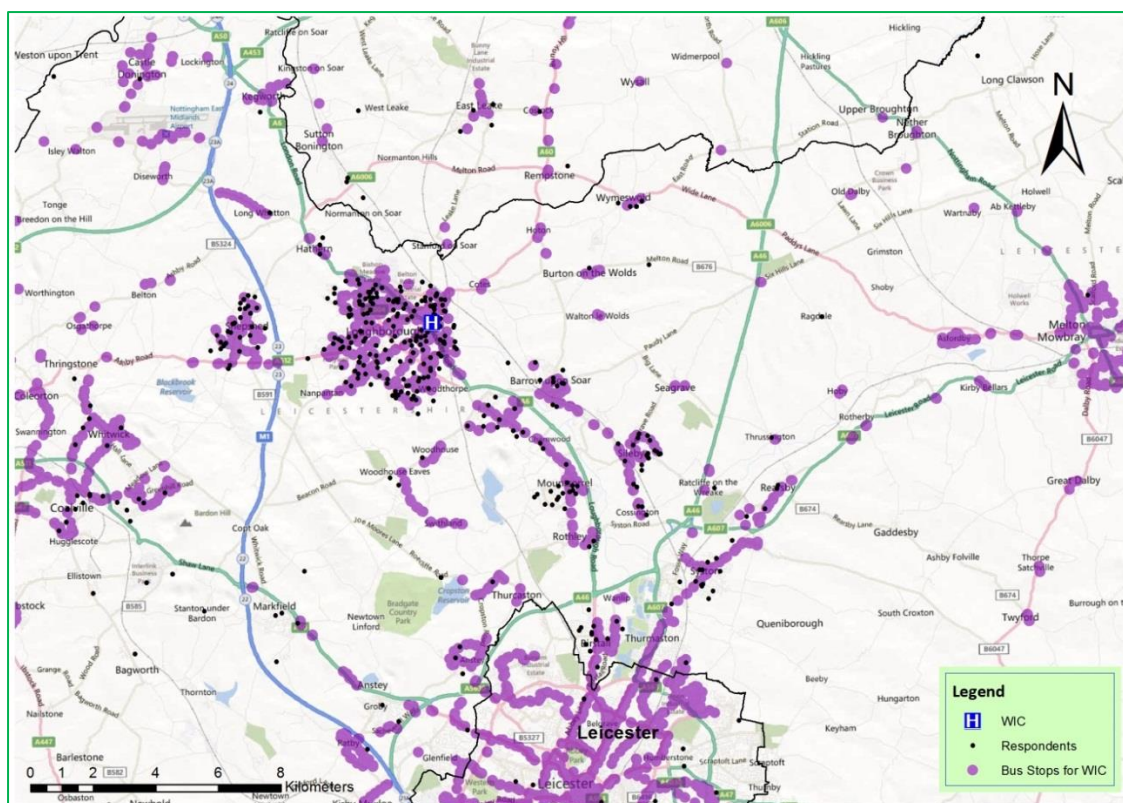


Figure 7-2: The bus stops which have direct bus services to WIC

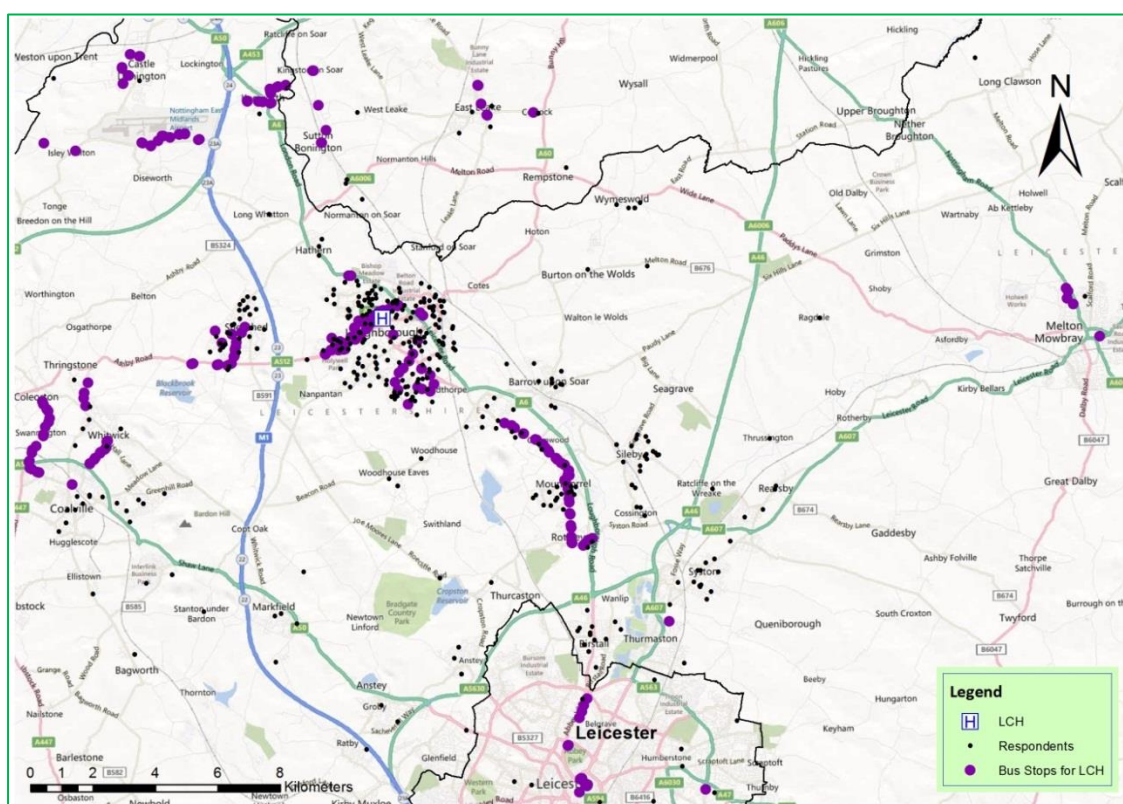


Figure 7-3: The bus stops which have direct bus services to LCH



However, it was possible to use bus to travel from WIC to LCH and from LCH to WIC. This means that all the respondents who could access to one of the hospitals by bus, they also could travel to another one by changing their bus in town centre (i.e. near the WIC location). Figure 7-4 shows all direct and indirect available bus stops in accessing to both sites.

Therefore, further new eight models were examined by considering the direct as well as indirect bus services. These two separate series of models were developed to identify any statistical differences between them. The new models investigate whether the model results are different comparing the area with direct bus services or not. In other words, the models considered all respondents who could go to the sites whether using direct or indirect bus services.

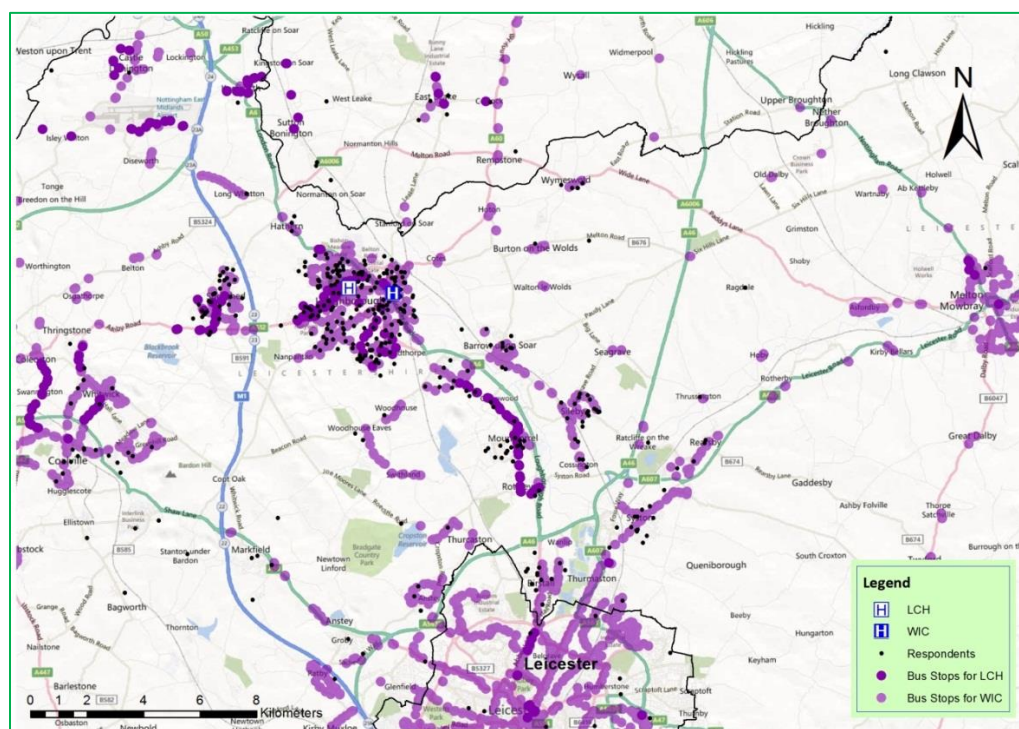


Figure 7-4: All bus stops which have direct and indirect bus services to WIC and LCH

Table 7-7 shows the results of eight models. Except the bus services variable, the numbers of all other significant variables were same as the first eight models (the results of Table 7-7). The result revealed that the bus service was not a significant variable for the new models. It indicates that the respondents preferred to go to the healthcare facilities using direct bus services rather than changing buses.

Table 7-7: Model estimation results for all available bus service to the sites

Dependent variable = Overall accessibility perception		Multilevel (ML) Regression for all Respondents								Multilevel (ML) Regression for Respondents with Car Ownership							
<b>Fixed-effects</b>		<b>TD Fixed (M1)</b>		<b>TD Random (M2)</b>		<b>TT Fixed (M3)</b>		<b>TT Random (M4)</b>		<b>TD Fixed (M5)</b>		<b>TD Random (M6)</b>		<b>TT Fixed (M7)</b>		<b>TT Random (M8)</b>	
<i>Level 1: respondent-level variables</i>		Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Travel distance (miles)		-5.6880	-3.13	-5.6775	-2.65					-6.3976	-3.43	-6.5329	-3.42				
Travel Time (minutes)						-1.9038	-2.20	-1.9176	-2.19					-1.9003	-2.04	-1.8425	-1.89
Fuel Consumption (gCO2e/miles/passenger)						-1.0426	-0.49	-1.0265	-0.48					-0.9855	-0.47	-0.9311	-0.45
Number of bus stops within the 400m distance from origin/home		0.0410	<b>0.32</b>	0.0237	<b>0.18</b>	0.0505	<b>0.39</b>	0.0452	<b>0.35</b>	0.0138	<b>0.10</b>	0.0101	<b>0.08</b>	0.0345	<b>0.26</b>	0.0311	<b>0.23</b>
<b>Age groups:</b> 16 - 19 (reference)																	
20 - 29		1.6462	0.40	1.4512	0.35	1.1181	0.27	1.0745	0.26	7.1247	1.34	6.9491	1.32	5.8061	1.09	6.2312	1.18
30 - 39		5.4843	1.25	5.2981	1.20	4.7632	1.08	4.7084	1.07	9.7042	1.79	9.4106	1.74	8.2314	1.51	8.5190	1.57
40 - 49		7.2898	1.70	7.2102	1.68	6.8417	1.59	6.7788	1.58	12.6520	2.35	12.3711	2.31	11.1733	2.07	11.5207	2.15
50 - 59		4.6142	1.04	4.4454	1.00	3.8592	0.87	3.7969	0.86	12.1495	2.23	11.8909	2.19	10.6768	1.95	11.0561	2.03
60 - 69		7.7280	1.78	7.6351	1.76	7.2743	1.67	7.1171	1.64	10.8519	2.01	10.6477	1.98	9.6610	1.77	10.0528	1.86
70 and over		7.1789	1.62	7.0365	1.59	6.3688	1.44	6.3454	1.43	11.7817	2.16	11.4857	2.11	9.9895	1.82	10.3048	1.89
Gender (male = 1; female = 0)		-0.1017	-0.06	-0.1008	-0.06	-0.3084	-0.18	-0.2997	-0.17	-0.6310	-0.36	-0.6572	-0.37	-0.9218	-0.51	-1.0397	-0.58
<b>Mode choice:</b> Walk (reference)																	
Car		-1.1818	-0.48	-1.0376	-0.42	-0.0252	-0.01	-0.0154	0.00	-3.0945	-1.22	-3.0549	-1.21	-1.9606	-0.60	-1.8680	-0.57
Bus		-7.2891	-1.49	-7.3082	-1.50	-5.9694	-1.18	-5.9732	-1.18	-7.3623	-1.28	-7.4644	-1.30	-6.6422	-1.11	-7.0558	-1.19
Whether the respondent from the walking catchment (Yes=1; No=0)		-1.7931	-0.81	-1.9611	-0.89	-1.9499	-0.88	-2.0887	-0.94	-0.7593	-0.29	-0.9458	-0.36	-1.0975	-0.42	-1.2290	-0.47
Destinations (WIC=1; LCH=0)		-4.8284	-2.57	-4.5559	-2.39	-5.0604	-2.65	-5.0365	-2.64	-5.1571	-2.60	-5.1700	-2.61	-5.3033	-2.63	-5.2928	-2.62
Intercept		77.0976	16.15	77.0636	16.14	76.9275	15.14	77.0296	15.17	74.3094	12.84	74.6221	12.95	75.0204	12.33	74.8514	12.37
<i>Level 2: area-level variables</i>																	
Index of multiple deprivation (IMD) score		0.1173	1.37	0.1158	1.36	0.1163	1.36	0.1146	1.34	0.1233	1.24	0.1206	1.22	0.1255	1.26	0.1173	1.19
<b>Random-effects</b>																	
Variance of Travel Distance (miles)				20.9187	0.47							2.3449	0.28				
Variance of Travel Time (minutes)								0.4336								2.8365	0.57
Variance of Intercept		9.8637	0.82	10.8456	0.88	8.6138	0.73	9.4382		24.8248	1.43	25.3378	1.47	22.8469	1.33	23.5114	1.42
Covariance (Intercept and travel dist.)				3.7131	0.21							7.7081	0.54				
Covariance (Intercept and travel time)								2.0230								8.1663	1.06
Variance of Residual		313.3177	13.57	308.5219	12.70	316.8322	13.60	315.6386		265.3843	11.33	264.3490	11.35	271.5867	11.38	268.2362	11.48
Statistics																	
Number of observations		480		480		480		480		396		396		396		396	
Number of groups (i.e. LLSOA)		152		152		152		152		146		146		146		146	
Intra-class correlation (ICC)		0.0305		0.0934		0.0265		0.0303		0.0855		0.0948		0.0776		0.0894	
Pseudo R-square		0.0778		<b>0.0779</b>		0.0771		0.0771		0.0801		<b>0.0802</b>		0.0783		0.0786	
AIC (Akaike information criterion)		<b>4056.84</b>		4060.58		4062.31		4058.13		<b>3297.27</b>		3300.94		3305.48		3308.35	
BIC (Bayesian information criterion)		4127.33		4139.36		4136.94		4124.47		3364.43		3376.00		3376.59		3387.36	
LL(B), Log-likelihood (restricted) at convergence		-2011.42		-2011.29		-2013.15		-2013.07		-1631.64		-1631.47		-1634.74		-1634.17	
LL(0) Null Log-likelihood		-2181.22		-2181.22		-2181.22		-2181.22		-1773.65		-1773.65		-1773.65		-1773.65	

#### **7.3.4 Comparison Linear Regression and ML modelling Results**

In order to compare the results of the ML modelling with a linear regression model, similar estimations with the same data were also undertaken. Table 7-8 shows the results of the linear regression as well as the ML modelling.

It was estimated from the null multilevel model that: the between-area (level-2) variance in the overall accessibility score was 11.17; and the within-area between-individual (level-1) variance was 293.40 thus resulting in an intra-class coefficient (also known as variance partition coefficient) value of 0.06. This indicated that six per cent of the variance in the overall level of accessibility could be attributed to differences between areas of residence. In order to see whether there exists an area-wide effect in the perception of the overall accessibility to healthcare facilities, the likelihood ratio test comparing the null multilevel model with a null single-level linear regression model was carried out. The result suggested that there was overwhelming evidence in the favour of a multilevel model against a single level model at the 95 per cent confidence level.



Table 7-8: Linear and ML models estimation results

Dependent variable = Overall accessibility perception					
<b>Fixed-effects</b>		Linear	Regression	Multilevel Regression	
<i>Level 1: respondent-level variables</i>					
Travel distance (miles)		-4.0949	<b>2.54*</b>	<b>-3.9780</b>	<b>2.58*</b>
Number of services of bus stops within the 400m distance from origin/home		0.1830	<b>1.69**</b>	0.1754	<b>1.68**</b>
<b>Age groups:</b>	16 - 19 (reference)	0.0000		0.0000	
	20 - 29	6.3911	1.18	6.1554	1.17
	30 - 39	9.1755	<b>1.66**</b>	8.9680	<b>1.66**</b>
	40 - 49	11.2752	<b>2.07*</b>	10.9695	<b>2.07*</b>
	50 - 59	10.9733	<b>1.98*</b>	11.1209	<b>2.07*</b>
	60 - 69	10.2909	<b>1.88**</b>	10.3783	<b>1.95*</b>
70 and over		11.4415	<b>2.07*</b>	11.5231	<b>2.13*</b>
Gender (male = 1; female = 0)		0.2990	0.17	0.0714	0.04
<b>Mode choice:</b>	Walk (reference)	0.0000		0.0000	
	Car	-2.8442	2.51	-3.2363	-1.32
	Bus	-6.2374	-1.11	-6.3965	-1.17
Whether the respondent from the walking catchment (Yes=1; No=0)		-0.9752	-0.41	-0.4462	-0.18
Destinations (WIC=1; LCH=0)		-6.3749	<b>-2.89*</b>	-6.4823	<b>-2.93*</b>
Intercept		75.5440	12.98	75.9458	13.17
<i>Level 2: area-level variables</i>					
Index of multiple deprivation (IMD) score		0.1021	1.13	0.1153	1.23
<b>Random-effects</b>					
Variance of Intercept				17.1375	1.09
Covariance (Intercept and travel dist.)					
Covariance (Intercept and travel time)					
Variance of Residual				267.8836	11.61
<b>Statistics:</b>					
Number of observations		396		396	
Number of groups (i.e. LLSOA)				146	
Intra-class correlation (ICC)				<b>0.0601</b>	
R-squared (linear) or Pseudo R-square (ML)		0.0423		<b>0.0490</b>	

\* Significant by **95%** confidence level\*\* Significant by **90%** confidence level

#### 7.4 Accessibility Prediction Model

In order to assess and compare accessibility to the destination hospital sites, there was a need to define an accessibility score for each of them. The scoring must be based on the modelling of significant factors which were affecting users' perceptions of accessibility. Therefore, an accessibility prediction model (APM) was developed to generate a score from a LLSOA to two hospitals. The calibrated statistical model was employed to predict

LLSOAs' accessibility score that fell within the catchment areas (approximately 20 miles) of the study area. Therefore only statistically significant variables such as age, travel distance and bus services were utilised in the prediction models. The spatial distribution of predicted accessibility score of each LLSOA is also presented in this section.

As it can be seen in Figure 7-5, the population are varying among of LLSOAs across the study catchment areas. Figure 7-6 shows that the proportion of different age groups' population varies across the LLSOAs. In order to visualise these variations, the data were sorted in ascending order with respect to the percentage of population for ages between 20-29 years; subsequently it is illustrated that the percentage of population for older people has opposite general trend (e.g. proportion of ages more than 60 years were decreased).

As discussed in the literature review, different population groups need special consideration for their care services and have different demand to healthcare services (DHHS, 1998; Meade and Earickson, 2000). The ML modelling also revealed that different age groups have different perceptions of accessibility, therefore, different LLSOA-level accessibility scores were accumulated by population (total as well as sub-group) to obtain the final accessibility score for a hospital.

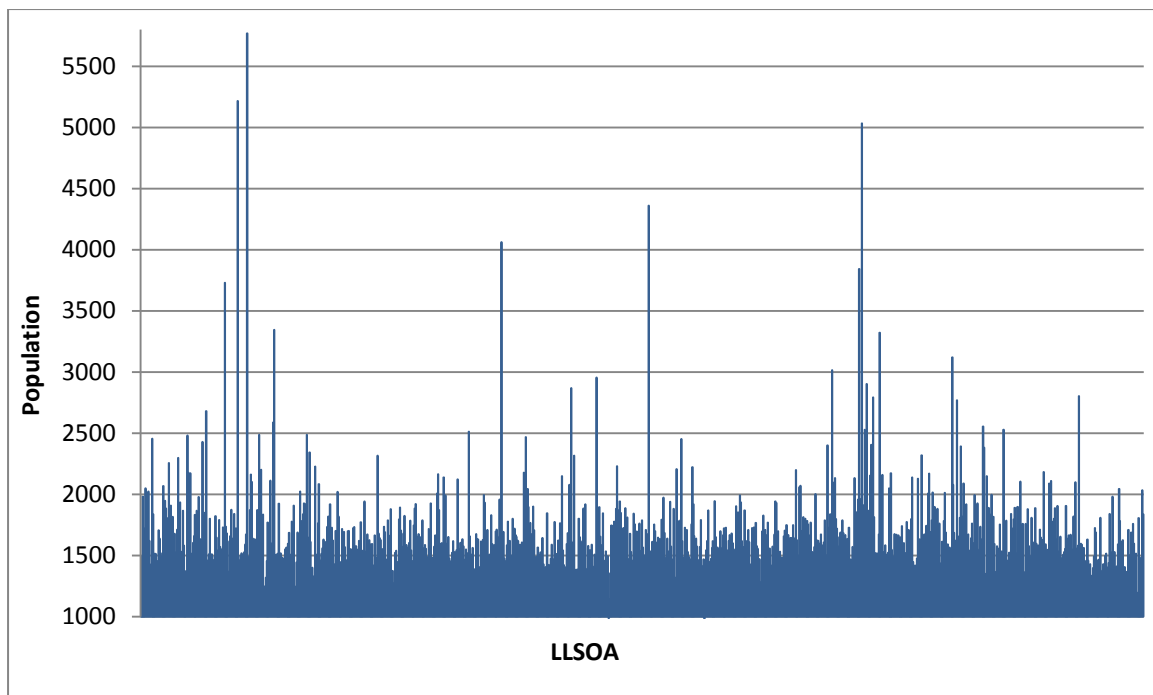


Figure 7-5: Population variation among LLSOAs of the catchment area

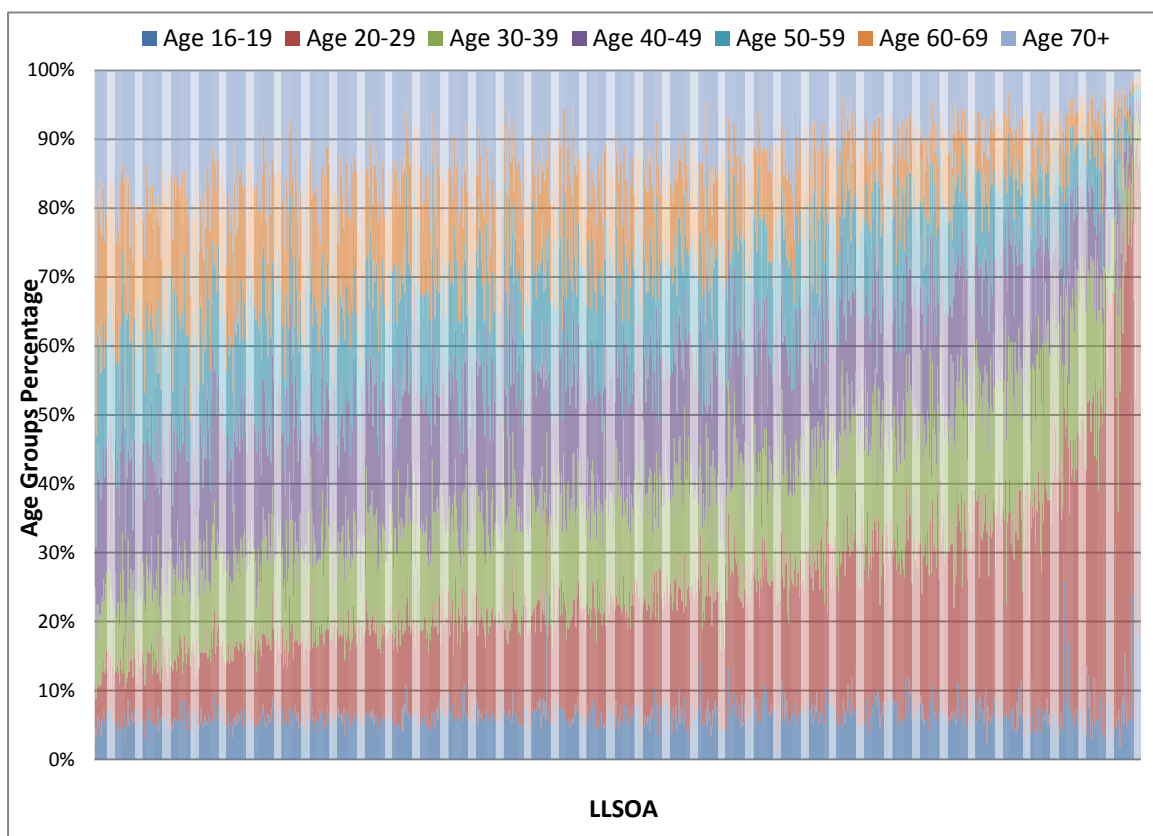


Figure 7-6: Variation of different age groups among LLSOAs

The APMs were created including the significant variables to predict accessibility for all LLSOAs within the catchment area (see model M5 in Section 7.3.2). As there are different intercepts for different age groups; following random-intercept model was employed.

$$\hat{Y}_{jk} = \hat{\beta}_0 + \hat{\beta}_1 \mathbf{TD}_{jk} + \hat{\beta}_2 * \mathbf{Age2} + \hat{\beta}_3 * \mathbf{Age3} + \hat{\beta}_4 * \mathbf{Age4} + \hat{\beta}_5 * \mathbf{Age5} + \hat{\beta}_6 * \mathbf{Age6} + \hat{\beta}_7 * \mathbf{Age7} + \hat{\beta}_8 \mathbf{BS}_{jk} + \hat{\beta}_9 \mathbf{DD}_k + \hat{u}_{oj} \quad (7-1)$$

$\hat{Y}_{jk}$  = Predicted accessibility for LLSOA  $j$  to hospital  $k$

$\hat{\beta}$  = Predicted model coefficients from the ML modelling

$\mathbf{TD}_{jk}$  = Travel distance from the centroid of LLSOA  $j$  to hospital  $k$

**Age2 to Age7** = the categorical variables representing 7 Age groups (Age2 for age 20-29 years, Age3 for 30-39, Age4 for 40-49, Age5 for 50-59, Age6 for 60-69, and Age7 for 70 and over)

**BS<sub>jk</sub>** = Number of available bus services per hour within the 400m distance around centroid of LLSOA  $j$  to hospital  $k$

**DD<sub>k</sub>** = Destination dummy variable (0 for Loughborough Community hospital (LCH) and 1 for the Walk in Centre NHS (WIC))

$u_{oj}$  = LLSOA-level random effect for multilevel data (obtained from model M5)

For example, accessibility from the first LLSOA ( $j=1$ ) to the first destination, WIC, for the first age group (between 16-19 years) was calculated by the following formula.

$$\hat{Y}_{1WIC}^{Age1} = \hat{\beta}_0 + \hat{\beta}_1 \mathbf{TD}_{1WIC} + 0 + 0 + 0 + 0 + 0 + 0 + \hat{\beta}_8 \mathbf{BS}_{1WIC} + \hat{\beta}_9 * \mathbf{1} + u_{oWIC}$$

And for the second age group (between 20-29 years):

$$\hat{Y}_{1WIC}^{Age2} = \hat{\beta}_0 + \hat{\beta}_1 \mathbf{TD}_{1WIC} + (\hat{\beta}_2 * 1) + 0 + 0 + 0 + 0 + 0 + \hat{\beta}_8 \mathbf{BS}_{1WIC} + \hat{\beta}_9 * \mathbf{1} + u_{oWIC}$$

Then the LLSOA-level accessibility scores ( $\hat{Y}_{jk}$ ) were accumulated by its population for the different age groups using the following equation (see equation 4-6 in Chapter 4):

$$LLSOA\_TS_{jk} = \frac{\sum_{p=1}^7 n_{pj} \cdot \hat{Y}_{jk}^p}{\sum_{p=1}^7 n_{pj}} \quad (7-2)$$

Where:

$LLSOA\_TS_{jk}$  = Accessibility score from LLSOA j to hospital k

p= Number of age groups (1 for 16-19, 2 for 20-29, ... 7 for 70+)

$\hat{Y}_{jk}^p$  = The prediction accessibility score from LLSOA j to hospital k as estimated by model M5 (see Section 7.3.2) for age group p

$n_{pj}$  = The total population of age group p in LLSOA j

In order to obtain the total accessibility score for hospital k, equation 4-7 (see Chapter 4) can be re-written as follows:

$$TS_k = \frac{\sum_{j=1}^m n_j \cdot LLSOA\_TS_{jk}}{\sum_{j=1}^m n_j} \quad (7-3)$$

$TS_k$  = Total Accessibility score of hospital k

$n_j$  = Total population of LLSOA j

j= Destination hospitals (WIC or LCH)

m= Total number of LLSAOs within the hospital catchment area

## 7.5 Accessibility Prediction Models Results

The spatial distribution of predicted accessibility score (estimated by Equation 7-2) is presented in Figure 7-7 and Figure 7-8. These figures show accessibility scores of each LLSOA within the catchment area including the bus stop locations which have had direct bus services to the destination (e.g. WIC and LCH).

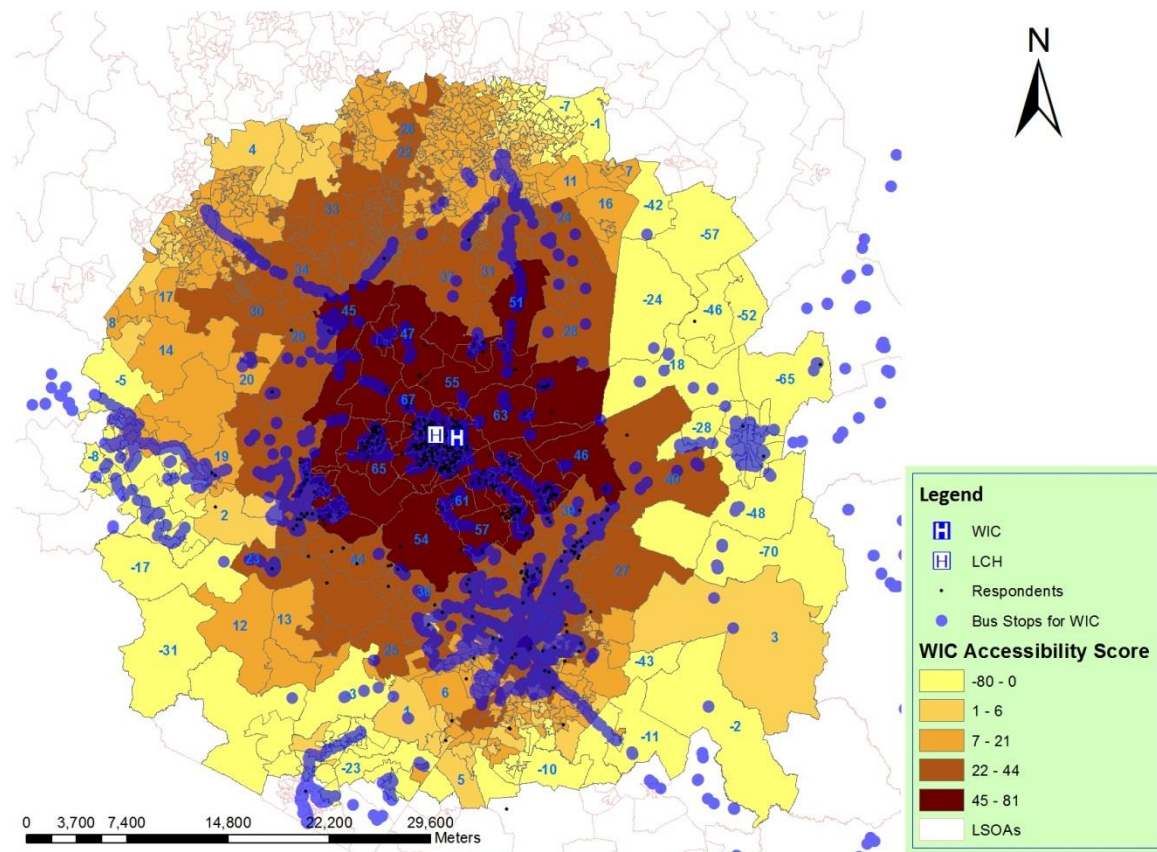


Figure 7-7: Accessibility Scores of LLSOAs in accessing to WIC

As can be seen in the figures, negative scores were also generated for some areas on the maps which were illustrated by yellow colour. The negative scores were calculated by the model due to effects of negative factors on the developed ML modelling such as travel distance. Access from far LLSOAs to the two sites and lack of bus services within the area generated negative overall accessibility score. As the ML modelling was developed based on obtained score on a scale of 0-100, therefore the LLSOAs with negative score were not considered in calculating total accessibility score of the two hospitals.

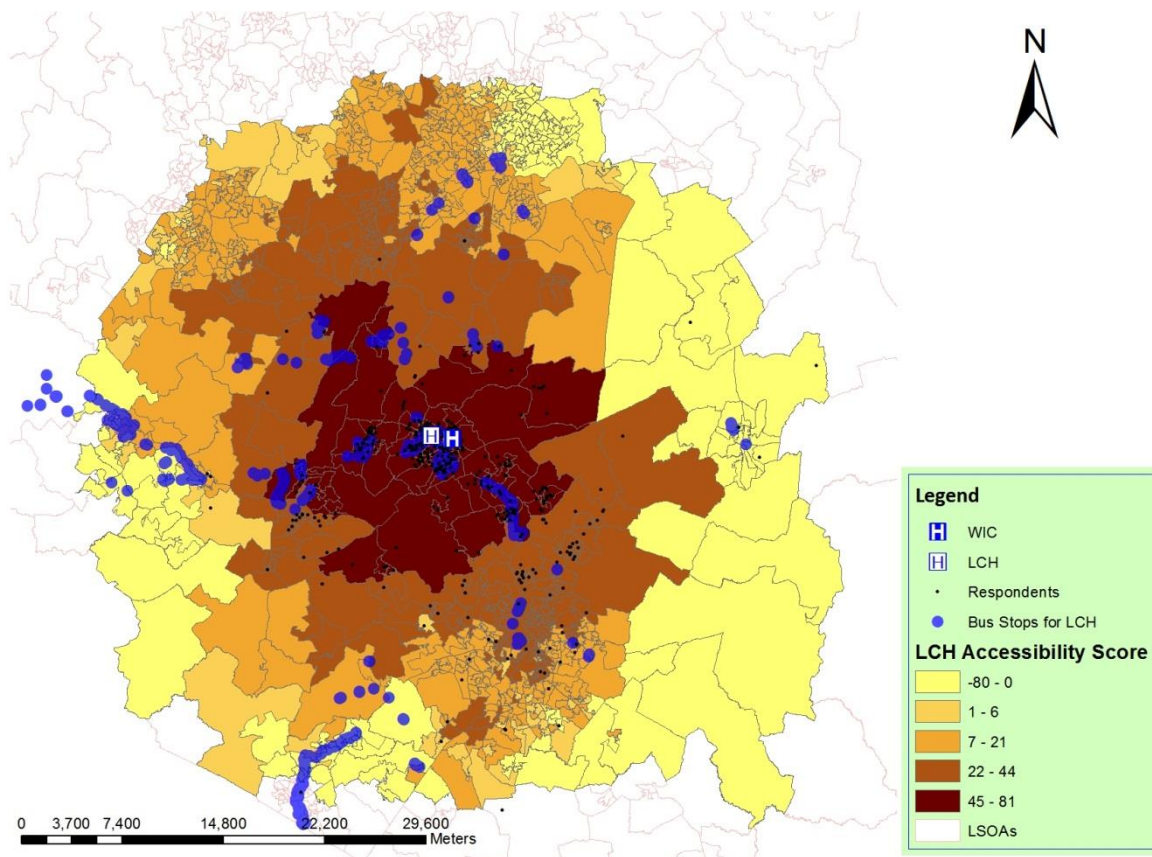


Figure 7-8: Accessibility Scores of LLSOAs in accessing to LCH

To show the results in another way, travel distance from the LLSOAs' to the hospital were sorted in ascending order, and then the generated overall accessibility scores were illustrated in Figure 7-9 and Figure 7-10. The figures show the variation of the predicted scores across the LLSOAs for different age groups. While the scores decreased in ascending order to access to the sites, the scores for LCH have had more noise compared with WIC's scores. This can happen due to availability of bus services within some limited areas, while there were more direct bus services in accessing WIC.

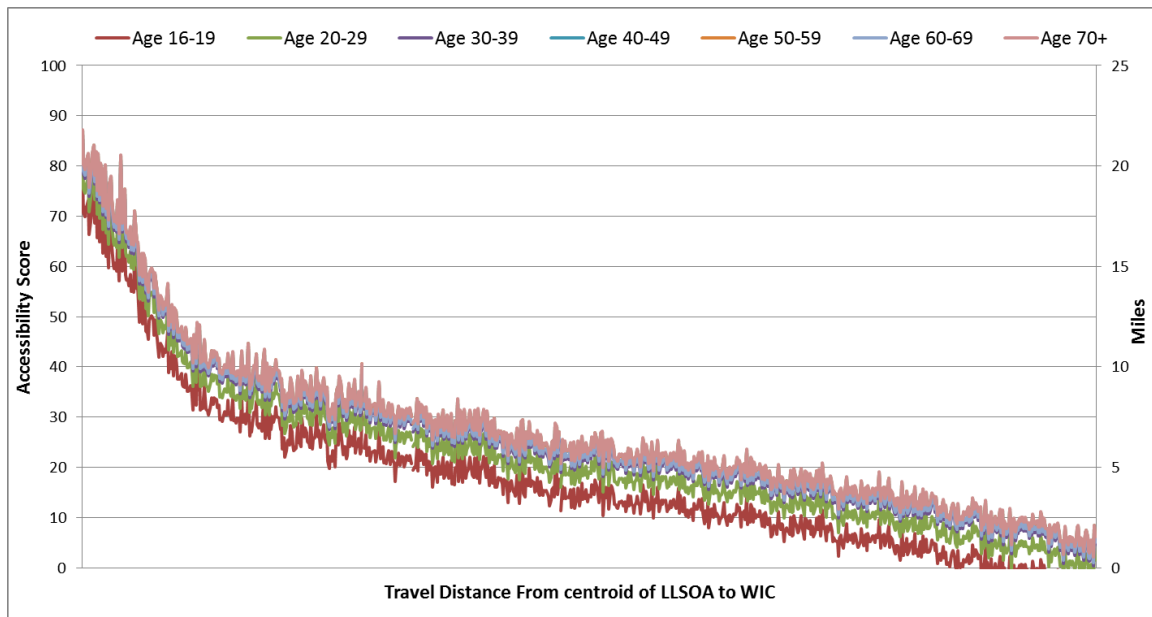


Figure 7-9: Predicted overall accessibility scores to WIC

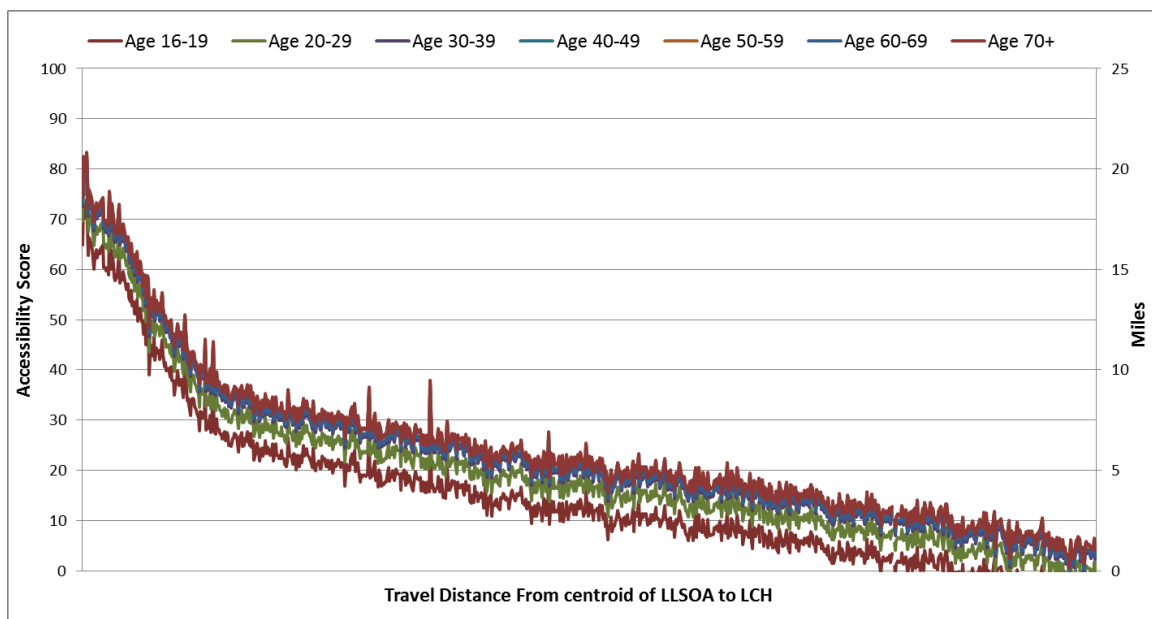


Figure 7-10: Predicted overall accessibility scores to LCH

## 7.6 Accuracy of the ML Models

Two commonly employed statistics such as the *mean absolute percentage error* (MAPE) and the *mean absolute error* (MAE) are calculated to measure the accuracy of the accessibility prediction model. The MAPE indicates the accuracy of the predicted model



as a percentage; and the MAE expresses the mean absolute errors of the predicted accessibility. The following formulas were used to calculate the MAPE and MPE (Hyndman and Koehler, 2006).

$$MAPE = \frac{100\%}{n} \sum_{i=1}^n \frac{|A_i - \hat{A}_i|}{\hat{A}_i} \quad (7-4)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |A_i - \hat{A}_i| \quad (7-5)$$

Where:

$A_i$  = Observed (reported perceived) accessibility score for respondent  $i$

$\hat{A}_i$  = Predicted accessibility score for respondent  $i$

$n$  = number of total respondents

The values of MAPE and MPE are presented in Table 7-9. Owing to the fact that the perception of accessibility varies linearly with travel distance, the model accuracy will largely be dependent on the values of travel distance. Therefore, these errors were calculated for different travel distance bands.

The best-fit ML model, M5, was employed in estimating the users' perceptions of accessibility for two cases: (1) all respondents and (2) respondents with car ownership.

Table 7-9: MAPE and MPE of accessibility prediction model for different distance bands

Travel Distance Bands (miles)	For All Respondents			For Respondents with Car Ownership		
	Statistics		Population Cumulative Percentage	Statistics		Population Cumulative Percentage
	MAPE1	MAE1		MAPE2	MAE2	
0-1.9	14.54	7.55	33.5	10.86	6.94	33.5
2-3.9	14.08	8.61	48.3	13.12	8.10	42.3
4-5.9	12.23	10.19	62.7	12.08	10.24	58.8
6-7.9	16.69	14.14	76.4	16.35	13.69	73.3
8-11.9	23.02	19.94	81.8	24.56	20.76	88.5
12-15.9	28.01	23.41	98.2	30.26	25.62	98.0
16-20	40.86	33.17	100.0	40.08	31.55	100.0

Figure 7-11 and Figure 7-12 depicts the values of MAPE and MPE. The results show that the MAPE and MPE errors in the model for all respondents were larger than for respondents with car ownership.

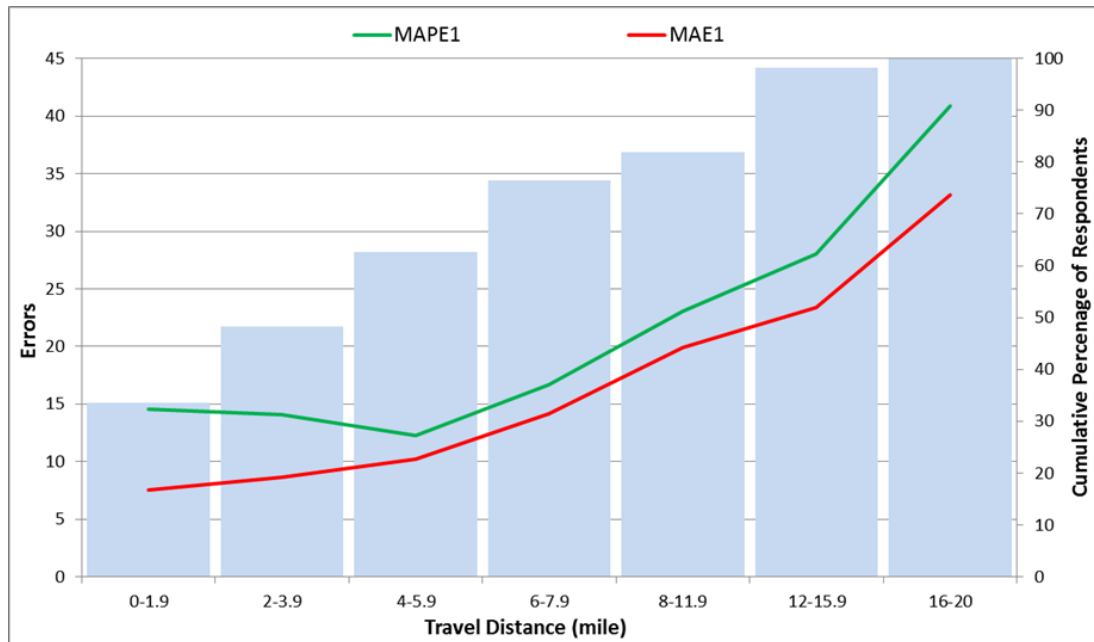


Figure 7-11: MAPE and MPE for all respondents

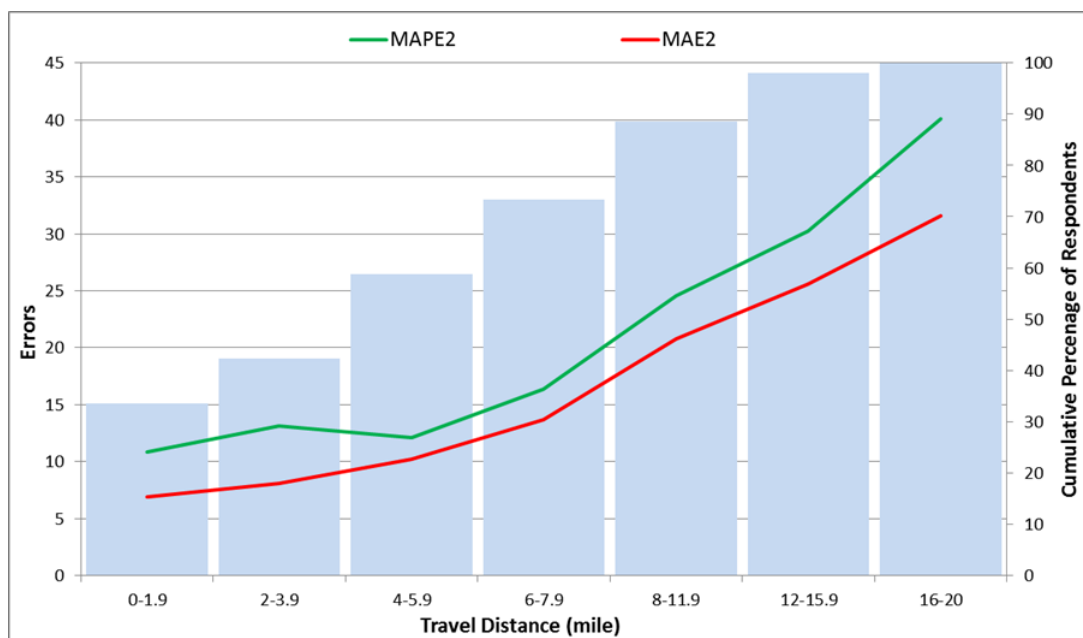


Figure 7-12: MAPE and MPE for the respondents with car ownership

Figure 7-13 shows the MAPE and MAP results with respect to travel distance from the destination. It indicates that errors begin to decrease as travel distance approaches two miles. Most likely because walking predominates as a travel mode at shorter (< 2 miles) distances. However, the errors also begin to increase at distances longer than two miles, arguably because respondents from more remote areas may have less knowledge of travel in the vicinity of the hospital than those who live closer to the hospital. Figure 7-13 also reveals that about 25% of the respondents live beyond 8 miles from the hospital. It is therefore logical to expect that the model is bound to predict accessibility scores more accurately for this range (i.e. < 8 miles) which contains a higher density of respondents (i.e. approximately 75%). It can therefore be deduced that the most valid range (distance) for this model is approximately between 2 miles and 8 miles.

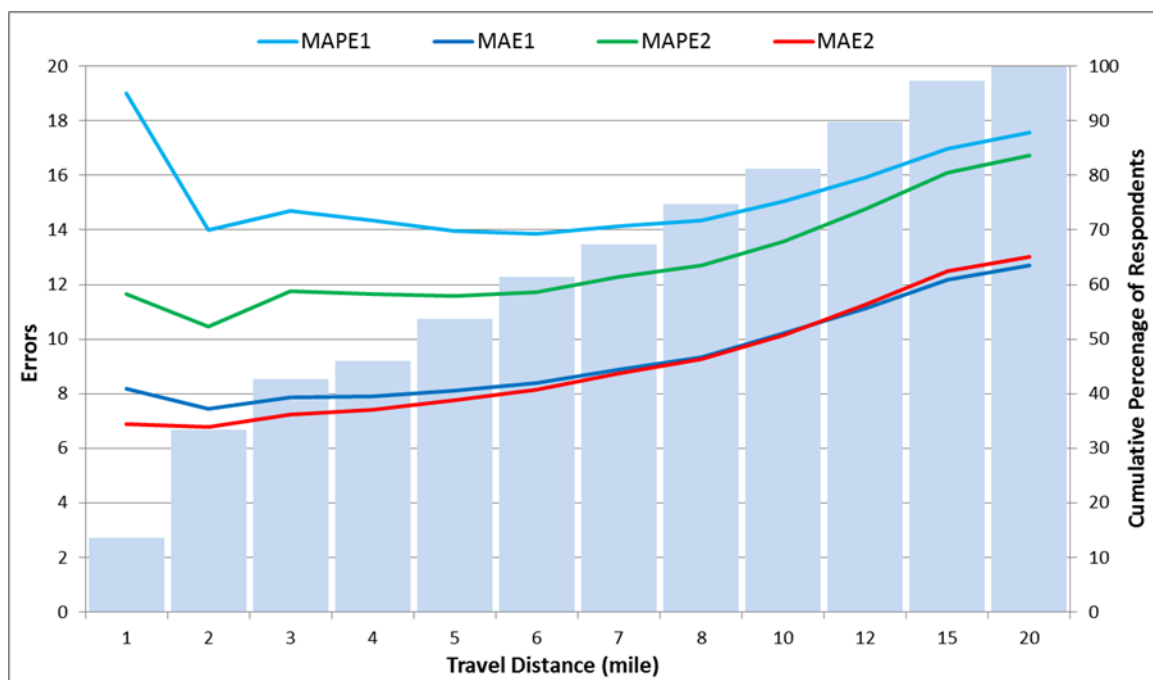


Figure 7-13: MAPE and MPE for different travel distance

Figure 7-13 also reveals that for distances shorter than two miles, the accuracy of predictions is also low. Another source of the model error (which occurs in travel distances below 2 miles) is due to comparing different perceptions obtained from various respondents. Previously (in travel distances beyond 2 miles) the comparison was only made among respondents who were only using the bus or car (Due to the long distance). However in shorter travel distances (e.g. below 2 miles) an additional option

of transport mode arises which is walking. Having the Walking as an alternative transport mode brings about extra influential factors such as weather conditions, safety and security to the perception of accessibility. In this case different respondents who are using various transport modes (e.g. bicycle, bus, car, walking) come up with different perceptions. It is worth stating that the aforementioned points only apply below two miles travel distance.

Figure 7-14 illustrates the errors of the accessibility prediction model which can be compared with the respondents' score. The logic behind this may be justified due to the influential weight of the travel distance factor on the perception score. Ascending order the travel distance magnitude paves the way to clearly notify that as the travel distance increases, the predicted perception decreases accordingly.

To provide a better general view, the results are also presented in terms of correlation as shown in the graph. It explains that the respondents' scores could not be fitted to a linear ( $R^2 = 0.001$ ) or nonlinear ( $R^2 = 0.003$ ) regression models while the predicted scores had a goodness of fit with linear ( $R^2 = 0.7$ ) or nonlinear ( $R^2 = 0.8$ ) regression model.

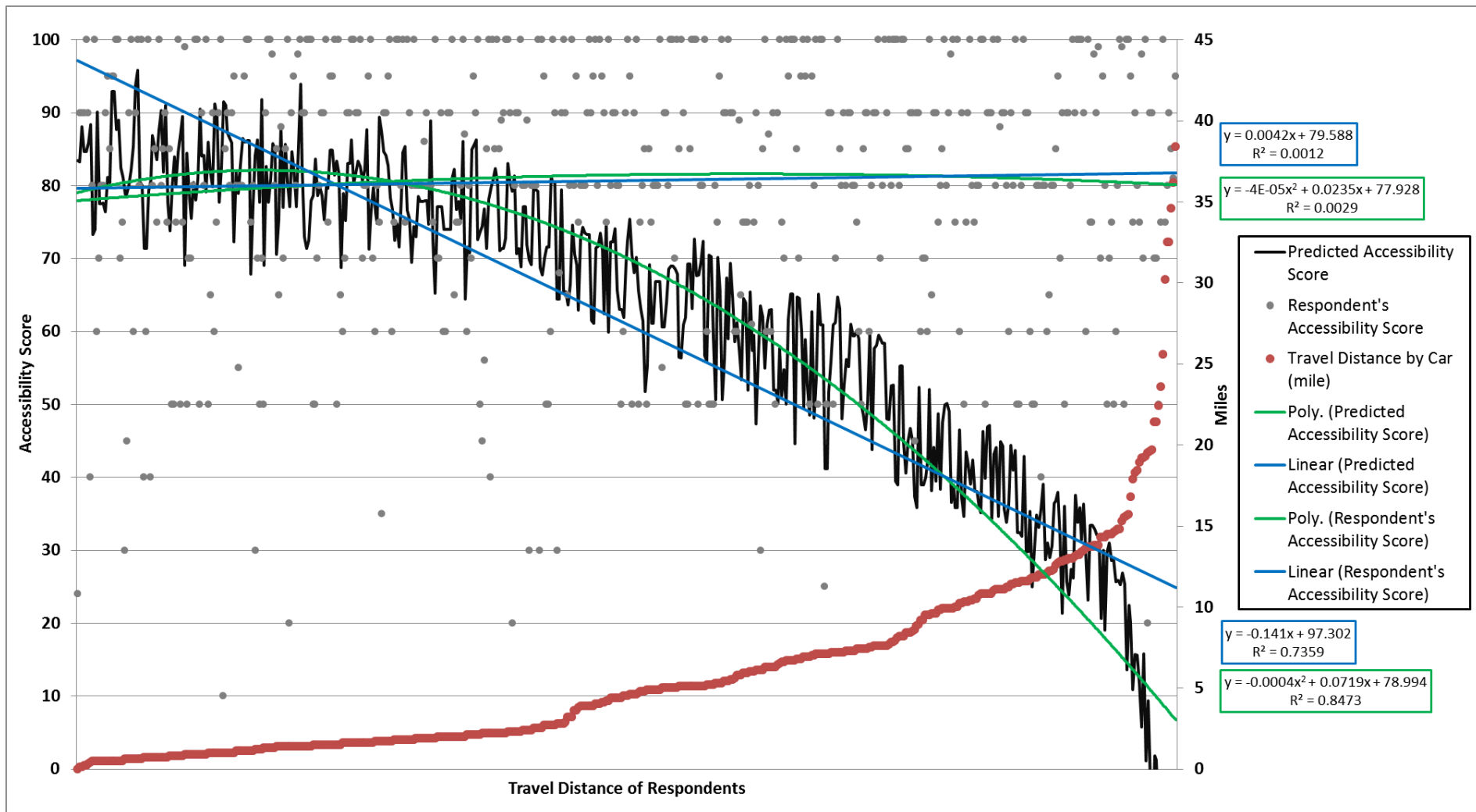


Figure 7-14: Prediction Model Errors

## 7.7 Summary

The result of the ML modelling is presented and discussed in this Chapter. After identifying some important factors from the literature review and the first questionnaire survey, the factors were used as the independent variables of this modelling. The required data for the modelling were obtained directly from the second questionnaire survey and available data sources or from the processed data in the Chapter 5. All of the data was examined by ML modelling in this chapter to develop an appropriate model.

In order to investigate the potential of the ML modelling, sixteen models were selected to be presented in this chapter. The models were categorised based on the following criteria:

- for all respondent and for the respondents with car ownership;
- for travel distance as a fixed or random effects variables;
- for travel time as a fixed or random effects variables; and
- for direct and indirect bus services.

The results revealed that both individual and area-wide factors affect transport accessibility to a healthcare facility. The developed models show that travel distance (by car), number of direct bus services, the destination choices and age were the most significant variables affecting users' perception of accessibility to the sites; also the perceptions were varied according to factors such as different age groups.

Finally, a model (Model 5) was employed to predict accessibility score associated with LLSOAs that were felt within the catchment areas (approximately 20 miles) of two hospitals; and only statistically significant variables such as age, travel distance and bus service were utilised in the prediction models. LLSOA-level accessibility scores were then accumulated by population (total as well as sub-group) to obtain the final accessibility score for a hospital. It revealed which hospital had better overall level of accessibility to find more accessible hospital in terms of user's perception of accessibility. This approach was developed based on users' perceptions who are the real decision makers as to whether to use a healthcare facility or not.

In order to investigate the model accuracy, the values of MAPE and MAP of the model were calculated and utilised as a scale to obtain the model outcome and actual data discrepancies. It was observed that the model prediction better fits to the actual data for 2 to 7 miles travel distances. Clarifications were also provided to justify the model weakness for predicting for specific travel distances.

## 8 DISCUSSION AND IMPLICATIONS

### 8.1 Introduction

This thesis explores the relationship between *users' perceptions of accessibility* to healthcare facilities and the *factors* affecting those perceptions. This has been achieved by: analysing results of the first questionnaire survey of the accessibility of four healthcare facilities (Chapter 6); and then examining multilevel (ML) modelling on two levels of important factors affecting users' perception of accessibility (Chapter 7). The ML modelling was supported by a second questionnaire survey. Appropriate econometric models were employed using GIS data analysis (Chapter 5).

The current chapter develops the results and findings of Chapters 6 and 7 to provide a deeper understanding of the relationship between users' perception and the process of assessing accessibility. Section 8.2 explores the results of the first questionnaire survey whilst Section 8.3 discusses the findings from the ML models. Section 8.4 discusses the strength and weakness of the methodology. This is followed by Section 8.5 which summarises the implications of this research and Section 8.6 which presented the potential of generalizability of this thesis methodology to be used in different applications. Finally, a summary of overall finding of this thesis has been provided.

### 8.2 First Questionnaire Survey Results

Chapter 6 presented the results of the first questionnaire survey obtained by asking 40 questions from 629 respondents. Similarities and differences of four hospitals within the study areas revealed that there were varieties of spatial and non-spatial factors that can influence accessibility to healthcare facilities. The survey showed that the numbers and types of factors varied with respect to the respondent's origin and destination. Additionally, users' observations were different according to respondent-to-respondent characteristics such as age and disability.

Although the results confirmed that travel time and travel distance were the most important factors in accessing healthcare facilities, the concept of 'accessibility' is more complex than those two factors. The result suggested that in order to measure the level



of accessibility, a broader set of factors needs to be considered. These factors are directly linked to user's behaviour and perception which are presented in previous studies (Boulos, 2003; Maroko et al., 2009; Aditjandra et al., 2012; Nurlaela and Curtis, 2012; and Deng and Nelson, 2012). In the survey, while many respondents specified different factors related to transport issues, some factors were related to their perceptions such as: difficulties in crossing the road; inconvenience in changing buses; different perception of convenient walking conditions (e.g. distance, weather and level of daylight); and lack of a suitable structured bus shelter. These indicate that the personal-related characteristics influence the respondents' behaviour whether or not to utilise a travel mode.

The result showed that over half of the respondents wanted or might be willing to use public transport; therefore, there was a possible potential in order to encourage them to use public transport by improving the services and infrastructure. Furthermore, another approach in order to enhance public transport usage was to increase public awareness of its benefits. Understanding users' perceptions could thus pave the research way to study users' travel behaviour and encourage them altering their mode of travel in a sustainable way.

Unlike public transport, a significant number of respondents (about 70%) had difficulties walking or using a bicycle. Since it is the matter of physical condition (e.g. illness, disability or senility), this means that it was not negotiable to convince any respondent to use non-motorised vehicle (NMV). It is worth stating that the aforementioned point may not be generalised to other destinations (e.g. school, work, airport or sports centre).

In terms of comparing using the car and NMV (e.g. walking and cycling) mode of transportation in travelling to different healthcare facilities (e.g. large hospital, GP and dentist), opposite results were observed. It was evident that most of the respondents preferred to travel by car to a large hospital rather than GP or dentist. In contrast, walking or cycling to access large hospitals was the least preferred option. The reason may be justified by availability and distance constraints. The higher number of existing

GPs and dentists provides more opportunities to select the closest of them among a wide spectrum of healthcare facilities and subsequently no driving is essential. Besides illness, intensity may also play an important role in the patient choice. The more serious the illness is, then less the ability for the patient to walk or cycle to the healthcare facility (e.g. large hospitals) and hence driving would be a preferred substituted mode of transport. It is convenient to state the type of healthcare facility have an influential impact on how close it could be as well as travel mode (e.g. car, NMV) selection.

In summary, the results suggest that there was a need to identify the significant factors affecting accessibility. Also it is required to investigate the weight of each significant factor in assessing accessibility to find their importance. However, there are usually some factors which cannot be recognised or there is not enough data to be measured; this will be more complex by the fact that people have different perceptions. Hence, the research has taken advantage of statistical modelling in order to overcome these complexities.

### **8.3 Factors of Multilevel Modelling**

The multilevel modelling results in the Chapter 7 indicate that the travel distance (by car), number of direct bus services, destination choices and age groups are significant variables affecting the users' perception of accessibility. Various goodness of fit statistic derived from the model suggests that multilevel linear regression modelling is an appropriate method in the studying users' perception of accessibility. For instance, the intra-class coefficients of ML modelling indicate that dividing contributory factors into two levels (e.g. individual and area) was a suitable method in the modelling of the perception. The significant and insignificant variables of the ML modelling are discussed in the following sections.

#### **8.3.1 Travel Distance/Time**

As expected from the first questionnaire survey, the ML modelling shows that travel distance had the highest negative impact in reducing the users' perception of accessibility. The model indicates that if all the other variables are kept constant, a one-mile increase in travel distance by car would reduce the perception of accessibility by

about four units (on a scale of 0 to 100) for the best fitted model (M5, see Chapter 7, Section 7.3.2). Travel time or travel distance has also been employed to measure spatial accessibility in the literature (e.g. Lovett et al., 2002; Luo and Wang, 2003; Tanser et al., 2006; Murad, 2007; and Cheng et al., 2012).

While the travel distance or time is the most important factor in assessing accessibility, considering non-spatial factors is essential for more accurate measurement (Field, 2000; Wang and Wei, 2004; Roovali et al., 2005; Ahlstrom et al., 2011; and Comber, 2011). For example, when several healthcare services are available for users, many researchers specified that users might prefer to bypass the nearest service due to their different perceptions (Fryer et al., 1999; Goodman et al., 2003; Hyndman et al., 2003). Therefore, there are other factors which play an important role in the preference of users in traveling to a healthcare facility. Considering travelling distance or time, other factors are also investigated in this research so as to see whether other factors also influence the perception of accessibility.

### **8.3.2 Public Transport**

The ML model reveals that the users' perception increases by increasing the number of bus services around the trip origin of users. A comparison between two separate models for direct and indirect bus services showed that the available bus service was a significant variable in the former while being an insignificant variable in the later. These results from the middle-sized towns revealed that the respondents preferred to travel by direct bus services to access to the healthcare facility. This shows the importance of direct bus services in travelling to a healthcare facility. The model indicates that if all the other variables are kept constant, an additional direct bus service per hour within the 400 metre distance from the respondent's origin would increase the perception of accessibility by about 0.2 units (on a scale of 0 to 100) in the final model.

Some accessibility measurement approaches have been classified as infrastructure or utility based measurements, however, dealing with these approaches and using their results is difficult for non-expert users (Curl et al., 2012; and Bocarejo et al., 2012). The

result of the ML model does not have such complexities as it can identify the significance of different public transports (e.g. bus, and underground) as well as their coefficients.

### **8.3.3 Age Groups**

The findings of the ML modelling and the first survey results show some similarities such as travel distance or travel time were the most important factors in both results. Age groups were also one of the significant variables and this is in line with results of the first survey. The first questionnaire survey indicated that different age groups have a different perception of accessibility to healthcare facilities; this was confirmed by the ML modelling.

Paez et al. (2010) also used spatial modelling to estimate travel behaviour of different age groups in Montreal, Canada. This thesis also revealed that there is a considerable difference in accessibility to healthcare facilities between seniors and non-senior citizens.

### **8.3.4 Destination Choices**

The destination choice (e.g. WIC and LCH) is one of the significant factors which affect users' perception. The best fitting ML model, M5, showed that changing the destination from LCH to WIC reduces the users' perception of accessibility by 6.5 units (on a scale of 0 to 100), despite the obtained total score from the accessibility prediction model. The prediction model specified that WIC was more accessible compared to that of LCH. It is concluded that despite of LCH attractions, WIC was a preferred healthcare facility in terms of accessibility by the respondents. This outcome is similar to the first survey feedback; the first survey's respondents considered 'Quality of care provided' as the most important factor in choosing healthcare facilities. The research focused on transport accessibility factors rather than quality of care, therefore, the second survey was designed to investigate accessibility-related factors.

As discussed in the literature review, one of the practical approaches in measuring accessibility is 'travel gravity' which was presented by Joseph and Weibull (1976) and Phillips (1984). This approach considers both the origin (e.g. number of users) and

destination (e.g. healthcare services) side in measuring accessibility; however, determining the distance-decay function is one of the primary disadvantages of this approach (Guagliardo, 2004; Joseph and Phillips, 1984; Luo and Wang, 2003). Since the destination choice is also identified as a significant variable, it is worth mentioning that users' perception is highly dependent on both destination attractiveness and travel impedance (e.g. distance and time). All of the aforementioned parameters are considered in this thesis.

### **8.3.5 Insignificant Factors**

*Being within the walking or cycling catchment area* was not a significant variable in the modelling; however, different results might be expected from different study areas or different type of destinations. Also, as discussed in Chapter 6, a considerable percentage of respondents (about 70%) did not want to walk or use the bicycle.

One of the second questionnaire survey results (Q7) indicated that the respondents ranked *fuel consumption* as their second most important factor in accessing a hospital. But the fuel consumption was not a significant variable in the ML modelling. While most respondents preferred to use less fuel, the opposite results were perhaps due to a lack of data from the respondents who used public transport or NMV (14% for NMV and 3% for public transport users).

The statistical insignificant variables (individual-level) were: gender and mode choice (e.g. car, walk and bus). This is perhaps due to the low number of observations or their effects are being capturing by other factors (e.g. age groups and availability of public transport). Moreover, the variation in accessibility was somehow limited (i.e. the interquartile range is 25 implying that 50% of the accessibility scores fall between 70 and 95 on a scale of 0 to 100). The area-level variables were tested but found to be statistically insignificant. Some of the variables including: the index of multiple deprivation (IMD); accident rate (safety); crime rate (security); and barriers to housing and services; and the living environment.

Acquiring larger datasets from more respondents who are using different travel modes (e.g. bus, bike and walk) might be useful to support the model in finding more significant variables. For example, in a middle-sized town such as Loughborough which has a good safety and security in all LLSOAs, safety or security effects are insignificant variables on users' perception.

The hierarchy data structure suggested that the ML modelling might find more significant factors from the areas with more diversity. As an example, a metropolitan city such as London has got a higher diversity in terms of individual characteristics (e.g. income, ethnicity and age) and area-wide factors (e.g. safety, security, and public transport infrastructure such as bus, underground and bike). Therefore, the adopted methodology may be able to identify more significant factors for larger areas.

#### **8.4 Strength and Weakness of Generalising the Model**

Since there is uncertainty in the definition of good sample size, the dependence of the ML modelling in conducting a questionnaire survey can be a weakness for the generalization of the model. Furthermore, the quality of respondents' feedback could also be varied due to their different travel experiences. For example, the perception of the users with more experiences is more accurate compared to that of a less experienced one. It seems that people can reveal their perceptions with a more accurate score in the travelling to their frequent destinations such as work or their child's school. Therefore, accuracy of the score can be lower for destinations where people had less or even a single experience such as a hospital or a museum.

Since "people's behaviour is based on their perception" (Robbins and Judge, 2006; pp. 91), modelling of user's perception for accessibility can be the strong point of the ML model results. The obtained results in this thesis showed that the ML modelling could model and then predict the users' perception on accessibility for all areas. Therefore, modelling and prediction of users' travel behaviour to a new or inexperienced destination become feasible. The statistical method helped to accommodate different varieties of individual or area-wide characteristics in assessment of accessibility using the perception.

Some previous studies and technical reports stated that the poorest accessibility to healthcare facilities are in rural areas and the accessibility assessment to rural area are unclear and poorly understood (e.g. Cox, 1995; Paez et al., 2010; Lovett et al., 2002; Akerman, P., 2006; Freeman et al., 2008; and Blanford et al., 2012). The flexibility of the methodology employed in this thesis allows for generalising the ML modelling for specific respondents such as rural residents by obtaining the required survey data from them. The model has also the potential of generalizability to be developed for specific time periods. For example, Blanford et al. (2012) reported that accessibility to healthcare facilities was worst in rural areas in wet seasons in Niger.

Obtaining the required data for the ML modelling makes this method applicable for different purposes and locations. In order to generalize this approach and methodology, a shorter survey could be designed, for example, ethnicity or gender was not a significant factor of the ML modelling. By deleting such questions, the survey can be shorter.

## **8.5 Implications**

This study has implications in the following areas.

### **8.5.1 Accessibility Assessment**

**Accessibility score** for a destination estimated in this research introduced by this thesis has the potential to employ as a quality indicator of a location (similar to BREEAM ratings for building energy consumption). This score-based measurement can be used as a universal unit to assign an accessibility score for a destination (e.g. a building or an urban or rural open space) and compare scores of different destinations. The ML modelling has the ability to assign separate scores for different significant factors or purposes such as: public transport modes; non-motorised modes; safety and security; perception of different age groups; and area-wide characteristics.

Traditional approaches employ travel time contours to measure accessibility of a healthcare facility in the UK (DH, 2009). The approach is only based on travel time by car. This thesis not only employs different travel impedances (e.g. travel time and travel

distance) but also considers other significant factors (e.g. accessibility to bus, different age perceptions and destination facilities) in order to assess accessibility. Therefore, the proposed scoring system can summarise and simplify the important factors in developing a comprehensive score. The factors can be based on: different modes of transport; location functions (e.g. hospital, supermarket and school); or land use. The comparison of scores for different destination can also be used based on a universal benchmark according to a localised scale.

**A customer-oriented approach** can be employed in the measurement of accessibility of a healthcare facility. Since the users are the main decision maker for using a facility, therefore considering user's perceptions on accessibility will help service providers to respect their transport behaviour. The methodology developed in this thesis provides a new approach to measure accessibility based on a customer-oriented method. Beside many criteria and goals in the developing of business, considering the users' perception can support providers in performing their services as easy as possible. This ability can be added into a spatial decision support system (SDSS) to make a holistic and realistic decision.

**Defining the catchment area** would be possible considering the users' perception in travelling to a healthcare facility. Since most healthcare facilities (e.g. primary care, dentists and optometrists) usually work in unclear market boundaries or catchment areas, therefore, flexible spatial analysis will support the care policy makers to provide accurate assessment for healthcare accessibility and their boundaries (McGrail and Humphreys, 2009). Furthermore, there is not any specific obligation for the users in the UK to use a specific healthcare facility; therefore, they can travel to any healthcare facility according to their perceptions. The methodology developed in this thesis has the potential to determine which areas have a higher accessible score for the users in accessing a healthcare facility.

In addition to generating a total score for a healthcare facility by the accessibility prediction model (APM), the model can calculate a score for separate LLSOA. Figure 8-1 shows a generated map based on the average score of user's perception of accessibility



to travel to the sites at Loughborough. It illustrates the poor and good areas in accessing to both sites (LCH and WIC). Such a map could help policy makers to identify the poorest areas in order to undertake any reconfiguration or relocation of future healthcare facilities.

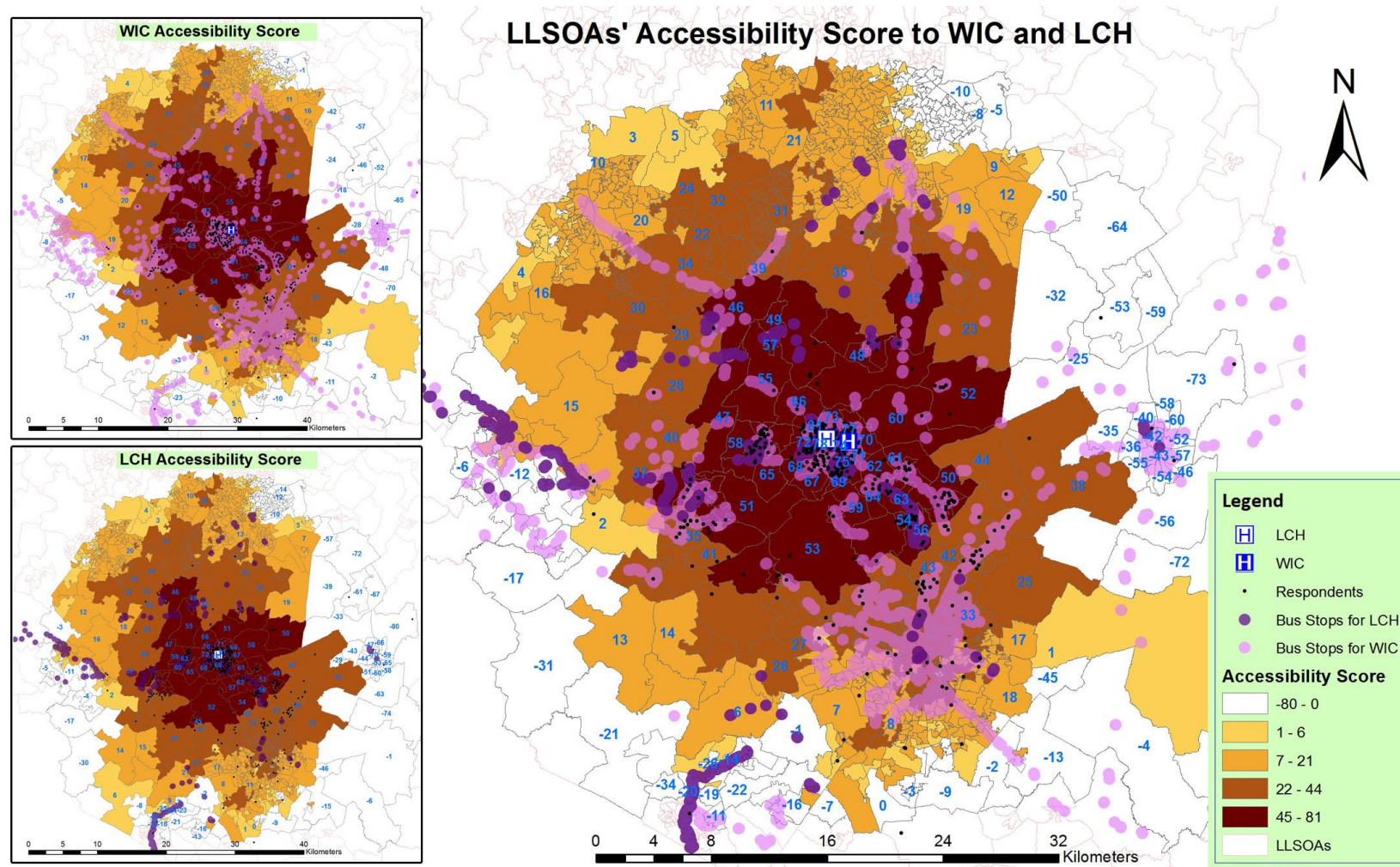


Figure 8-1: Accessibility map to both WIC and LCH sites

On the other hand, the total score of a healthcare facility varies according to the defined catchment area. For example, Figure 8-2 shows variation of the total scores' for WIC and LCH related to the following assigned catchment areas.

- 5 miles travel distance contains 53% of the respondents' origin.
- 10 miles travel distance contains 81% of the respondents' origin.
- 15 miles travel distance contains 95% of the respondents' origin.
- 20 miles travel distance contains 98% of the respondents' origin.

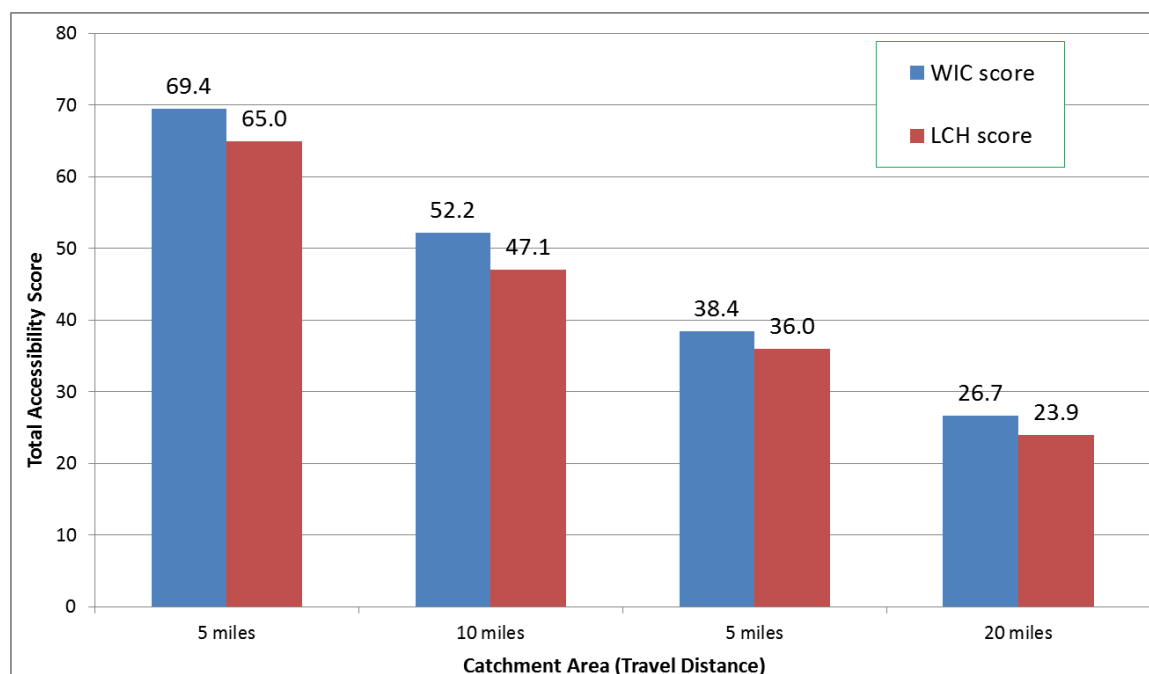


Figure 8-2: Total scores of WIC and LCH

Figure 8-2 shows that the total scores of the sites are reduced by increasing the size of catchment area. Besides considering the scores, investigation of total population of the catchment area can help to identify the appropriate catchment area. For example, Table 8-1 shows that the catchment areas with a 5 mile and 10 miles travel distance to the sites have a more related population. However, assigning a specific catchment area needs to undertake the same process for other healthcare facilities around the study area. It needs to find any potential overlaps or gaps among them by providing a whole map (e.g. NHS Leicestershire County and Rutland).

In conclusion, Figure 8-1 and Figure 8-2 show that WIC has a better overall level of accessibility in comparison with LCH. It can therefore be said that users perceive that WIC is more accessible than LCH.

Table 8-1: Population of the catchment areas

Catchment Area (Travel Distance)	WIC Total Score	LCH Total Score	Average Population
5 miles	69.4	65.0	8000
10 miles	52.2	47.1	181,000
15 miles	38.4	36.0	758,000
20 miles	26.7	23.9	1,528,000

**Assessing future accessibility** became easier and more accurate by considering future demographic changes and improvement of transport infrastructure using the method presented in this research. As mentioned in Chapter 7, the ML modelling can be employed to predict accessibility. Furthermore, individuals' perception and their significant factors (e.g. age and provision of public transport) might be changed over time.

For example, CBI (2012) reported that people over the age of 85 will double over the next 25 years in the UK. Therefore, the total score of users' perception will be changed in future. The prediction could be generated based on the future changes such as: variation of demographic data; improvement of transport infrastructure; and people's perception and awareness of safety and security.

In order to compare the current situation with the future demands, estimated census data can be provided from available sources such as UK National Statistics website (ONS, 2009). This allows the NHS to predict and plan any future reconfiguration and relocation of healthcare facilities based on future users' perception, which will have significant implications on accessibility of different facilities. This supports the policy of providing fairer access to healthcare facilities according to the future healthcare facility reconfigurations.

### 8.5.2 Transport energy consumption

Fuel consumption can be studied by investigating the impact of healthcare reconfiguration on users' perception about using specific modes of transport (e.g. public transport, non-motorised vehicle (NMV) or car). This research has two implications in supporting energy consumption studies, as discussed below.

**Identifying significant mode of transport** is the first implication. The ML modelling can reveal which modes affecting users' perception of accessibility and what their weights are. This capability can evaluate different transport infrastructure (e.g. public transport or NMV) and respective impact on the users' perception of accessibility. This also can reveal the potential opportunities for encouraging people to use public transport.

Furthermore, considering fuel consumption as a factor of the ML modelling provides the capability to investigate users' perception in utilising different modes of transport such as: private car; low fuel consumption mode (e.g. using public transport); or non-motorised vehicle (e.g. walk or use bike).

**Investigation of the improvement of the existing transport infrastructure** is the second implication of this thesis in the energy context to provide the capability to investigate the potential of the modification of a travel mode infrastructure. For example, if public transport was a significant factor, the model can report changes in its weight (e.g. coefficient in the ML model). The weight can be changed by improving public transport operation (e.g. increasing services and the quality) or by developing its infrastructure (e.g. increasing bus routes and stops). Since different areas (e.g. LLSOAs) have different demographic attributes, the feedback of public transport improvements may vary across the areas due to the variation in demographic characteristics. On the other hand, the ML model showed that different age groups had different perceptions of accessibility. Therefore, the same public transport improvement in two areas may have two different results (i.e. an area with more senior and retired people versus an area with young scholars around a university).

These abilities can be employed to study changes in the developing infrastructure for low fuel or non-motorised vehicles by monitoring users' perception changes. It can also be used in decision support tools to make better decisions in reducing fuel consumption.

### **8.5.3 Public Transport Behaviour**

Individuals' accessibility awareness could be investigated by its effects on users' perception. As discussed in the first questionnaire survey, awareness was one of the factors to encourage people to use public transport, while users' perception of accessibility can be changed according to their awareness. Public awareness about benefits of using public transport and non-motorised vehicle might be revealed as a coefficient of significant factors affecting users' perception of accessibility.

## **8.6 Applications**

Unlike achievements reported from this study, many studies report on tools that consider travel time, travel distance or travel cost as their main factors in accessing a destination. Tools such as Google Maps and Bing Maps are using these factors to find a suitable travel mode or offer options in travelling to a destination. In order to go to a destination, these tools usually provide several options for a journey, for example, to travel from 'The British Museum' to 'Imperial College' in London, they generate several options to travel (3 by car, 4 by public transport, 3 by foot and 3 by bike). Choosing one of these options is often an issue; and it can be difficult when the visitor is not familiar with the area especially when they do not want to travel by car.

Furthermore, it is often helpful to ask local people about their experiences and perceptions of travelling to a destination within their area. While the experiences of local people can benefit other users, but the users' perception may be different because of their preferences such as walking distance, safety of walking at night, the quality of available public transport. It would, therefore, be very useful if there was a tool to offer travel options based on the combined perceptions of both the user and local people. Such a tool would also be very valuable to organisations such as the NHS who need to make decisions based on their users' perception of accessibility.

Users' perceptions can be altered by changing their situation such as weather conditions, season, daylight or even the ground surface slope. A tool can be developed and improved based on different conditions and locations, to guide its users according to their perceptions via web-based applications or social network information (e.g. Google Maps or Bing Maps).

Based on a generic accessibility model, a multilevel model can be customised for every location where the required data are available. The users also can train the application by entering their priorities and perception on accessibility through some questions as well as leaving feedback scores for any experienced journey. Users' perception can be shared into a geodatabase by uploading the data via the application to enhance the general accessibility model of the area.

Finally, a mobile application can be developed linked to a web site. By using this tool, any online or offline user can benefit easy access to their destination according to their accessibility perceptions and all other local people experiences, providing not only '*shortest*' and '*fastest*', but also '*easiest*', '*safest*' or '*greenest*' access.

By developing such mobile application tool, many opportunities can be created in different transport market. The tool can be used as a personal tool or as a source for data mining. For example the NHS can benefit for updating and better understanding of users' travel behaviours in different areas to: compare performance between different travel modes in transferring healthcare facility users; get a quick feedback in response to a new located healthcare facility; identify future healthcare facility locations based on future demands; and encourage people to use non-motorised vehicles using users' current and future perception on accessibility.

## **8.7 Summary**

Findings of the literature review and the first questionnaire survey undertaken helped to explore the most important factors affecting accessibility. The results of the survey show that there are many individual and area-wide factors affecting accessibility. Importance and the priorities of these factors are different for different users. Although the survey

could reveal the factors, it was needed to identify the most important factors among many factors. It was also required to rank the significance of the factors through a scientific method to facilitate generalisation, therefore, the ML model is used and the model examined the importance of factors in two levels. The statistical modelling results showed that four factors (namely, travel distance, bus services, age and the destination choices) are the most significant factor for all participants of the second questionnaire survey. The coefficient of each factor revealed their negative or positive impact on users' perceptions of accessibility. The similarities and differences of the ML modelling, the first survey, and literature review are discussed in this chapter. Some weakness and strengths of ML modelling are also discussed.

Some benefits of considering users' perception are discussed in this chapter to help decision makers assess accessibility to healthcare facilities. It also suggests how this approach can monitor people's behaviour; and the potential of this thesis in encouraging people to use public transport or NMV to reduce carbon emissions and congestion to promote sustainable travel.

This chapter also introduces some implications of this thesis relating to: assessing accessibility as a score-based measurement system; employing a customer-oriented approach to assess accessibility; studying transport energy consumption; and monitoring public travel behaviour.

In order to obtain the users' perception and develop the ML modelling, some new applications are provided through new IT technologies, for instance, mobile applications and WEB tools. These technologies will provide opportunities to develop some applications relating to accessibility to healthcare facility.



## 9 CONCLUSION

### 9.1 Introduction

This chapter brings together the thesis and provides conclusions. It explains the ways which the thesis achieved its aim and objectives. This is followed by the limitations of this thesis are discussed in relation to the data and the ML modelling, followed by suggestions for further research and recommendations. Finally, the chapter discusses the contribution to knowledge.

### 9.2 Achieving the aim and objectives

This section discusses the findings of this research in relation to the aim and objectives of this thesis. The aim of this research was *to model user's perception of accessibility by focusing on both individual socio-economic and area-wide characteristics*. As such, the research intended to support the philosophy of providing fairer access to healthcare facilities to support future healthcare facility reconfigurations and developments.

Five objectives were defined to conduct this research in order to achieve the aim. These objectives were developed according to the research gaps identified by the literature review. Achievement of the five objectives are summarised and discussed below.

1. *To explore accessibility and transport issues associated with travelling to healthcare facilities.*

The results of the literature review (in Chapter 2) explained the need for this research considering related issues to health and transport. The literature review highlighted the three main study areas which needed to be considered in this research. They are transport, health and energy. The chapter also introduced three key important stakeholders of this research as the NHS, healthcare facility users and energy policy makers who have specific concerns to meet their criteria in assessing accessibility to healthcare facilities. These different points of view regarding accessibility were discussed in Chapter 2.

Since changes in the NHS system result in new reconfiguration or relocation of healthcare facilities, a review was undertaken relating to healthcare system reconfigurations and the effect of the changes on the users' accessibility.

The literature review also highlighted that the NHS is responsible for five per cent of all road traffic in England and about one percent of the total CO<sub>2</sub> emissions in England. The literature review also presented the direct effects of the CO<sub>2</sub> emissions on public health.

It was also understood that, distribution, accessibility and availability of healthcare services are unavoidably unequal since distance travelled and available modes of transport change over time. Also, the spatial distribution of population and demand for healthcare service require planning for accessing accessibility to healthcare facilities. Individuals are geographically scattered and have different age, gender, needs, socio economic status and deprivation characteristics. This affects their demand for healthcare, their ability to travel to obtain care services, and the modes of transport they are willing and able to use.

2. To investigate the potential of employing GIS and statistical methods in measuring and assessing transport accessibility to healthcare facilities.

Chapter 3 reviewed the available approaches and theories in assessing accessibility which have been used in previous theoretical and applied studies. The review highlighted the ability of GIS in integrating and analysing spatial and non-spatial data; and critiqued selected previous practical research and the developed tool. Studies have used statistical methods in assessing accessibility to healthcare facilities. Three major theoretical approaches and practical methods were discussed in Chapter 3. In order to obtain a better understanding of accessibility, this research integrated related factors by the use of GIS.

3. To determine important factors that affect accessibility to healthcare facilities.

In order to review the important factors, about 30 practical studies were selected and summarised in Chapter 3 to ascertain their important spatial and non-spatial factors in relation to accessing healthcare facilities. Furthermore, Chapter 6 presented the

important factors affecting accessibility which were identified by the first questionnaire survey undertaken. The factors also analysed by the ML linear regression model and the results are presented in Chapter 7.

*4. To develop a user-based accessibility model of healthcare facilities using statistical methods.*

Following the methodology stated in Chapter 4, this objective was achieved through examining different econometric models. Several ML models have incorporated two levels of variables to observe both individual level and area-wide level factors which were identified by the literature review and the first questionnaire survey. Two series of models were developed for all respondents and respondents with car ownership. Models for the respondents with car ownership showed that 6 to 12 per cent of the variation in the accessibility score was explained by the hierarchy data structure.

The multilevel model found four significant factors of users' perception of accessibility namely, travel distance, age groups, bus services and the destination choices. The best fitted ML model was then employed to develop an accessibility prediction model in order to predict accessibility for all LLSAOs within the study area. Finally, the hospitals were scored according to the users' perception considering the significant factors. The results of this work were presented in Chapter 7.

*5. To develop recommendations for assessing accessibility to healthcare facilities with respect to reconfiguration and relocation.*

Objective 5 was achieved by linking the previous four objectives at the final stage of the thesis. Chapters 8 and 9 provide a summary of the findings achieved throughout the objectives. Some suggestions and recommendations were discussed throughout the two chapters in order to assess and improve accessibility to healthcare facilities. The potential of generalizability of this research methodology were also discussed by introducing its implications and applications.

The suggestions for further research in Chapter 9 can help decision makers to provide fairer access to healthcare facilities for different purposes such as: employing the ML

modelling capabilities to develop a spatial decision support system; improving the model by considering more levels; and customising the model for different locations.

### **9.3 Limitations**

It is required to clarify limitations of this research which provide further areas of future research. These are mostly related to data and the ML modelling and discussed below.

#### **9.3.1 Data**

Questionnaire survey based research has some common limitations as choosing a sample size does not have a straightforward and definitive answer (Bryman, 2012). This thesis considered two middle-sized towns as its study areas. Therefore, further research for different size of town or city is required to investigate the effects of different factors on users' perception of accessibility. For example, since the majority of respondents of the first questionnaire survey were patients and visitors (89%), the survey may not be representative of staff needs.

Index of Multiple Deprivations (IMD) data used in the thesis were produced by the Social Disadvantage Research Centre at the University of Oxford. Seven grouped domains were combined together as an index, IMD, using following weights (Department for Communities and Local Government, 2010 ): Income (22.5%), Employment (22.5%); Health and Disability (13.5%); Education, Skills and Training (13.5%); Barriers to Housing and Services (9.3%); Crime (9.3%); and Living Environment (9.3%). Selecting these groups and their percentage may have some impact on the modelling results. Hence this process may affect the IMD factor to be an insignificant variable of the ML modelling.

Both questionnaire surveys would benefit from further research with larger datasets being modelled to identify more trends of users' perception of accessibility. In addition, developing these studies in other areas and countries may be able to identify further comparisons to take place to find more significant variables.

### 9.3.2 Econometric Models

In term of examining public transport or NMV (e.g. walking and cycling) data by the ML models, the number of respondents was low especially for cycling. Therefore, further data collection could help the model to identify the effects of whether the respondents are in a walking or cycling catchment area or not.

The ML modelling was developed based on the data from random respondents; as some age groups need more consideration to access healthcare facilities (e.g. seniors and children with ages 0–4), therefore, it may be needed to develop a specific model using their data. It may also be needed to model the data from the respondents who do not have access to a car (i.e. model for respondents without car ownership). Such a model could use a scoping survey method to identify a specific group perception on accessibility. A spatial filter analysis can also help to select suitable respondents for the ML modelling such as: the respondents who are living within the hospital catchment area of walking and cycling; and the respondents who can access a bus stop within a maximum 400m distance.

The main limitation of the ML modelling was sample size. Collecting larger datasets from more respondents who were using different travel modes (e.g. bus, bike and walk) can support the model in finding more significant factors. In a small town such as Loughborough which has good safety and security in all of its LLSOAs, it may not be possible to consider safety/security effectively on accessibility perception in comparison with big cities with different characteristics in safety/security.

Regarding the aim and objectives of this research, this research focused on transport issues related to access to healthcare facilities. Thus, the quality of care was not considered as a factor of the ML modelling. Considering attractiveness of the provided facilities and services is a way of measuring accessibility (Van Herzele, 2003), therefore, further research could potentially remove this limitation.

Individual factors and particularly the area-wide characteristics in the UK or in other countries may be different to Loughborough and its surrounding, for example, safety

and security factors may have a significant effect on users' perception of accessibility in big cities with different types of area rather than a safe and small town. Therefore, developing ML models with more respondents' data within different and bigger areas may find more significant factors which can affect the accessibility perception.

#### **9.4 Further Research**

Because of the novelty within this research, there is considerable potential for further development, for example, employing new kinds of factors may be able to provide some new study area such as considering quality of care of the healthcare facilities as an independent variable. Also, the advisability model can be used as an extension in other tools or software packages using the adopted research approach such a decision support system. Areas for further research are presented as follows:

- **Spatial Decision Support System (SDSS)**

Healthcare decision makers strongly consider the quality of available healthcare services in their catchment area. Travel time and distance can cause difficulties for them in providing care services especially when the medical need should be served regularly (Goodman and Wennberg 1999; Joseph and Phillips, 1984; and Haynes et al., 1999). Therefore, decision makers have to consider many situations and criteria rather than travel time or distance; they have to make a decision to provide their facilities in different conditions and even during different times.

As a result of this research, the ML modelling can integrate all spatial and non-spatial data using GIS techniques to suggest appropriate solutions relating to defined scenarios and situations. While the statistical modelling and GIS analyses are useful, decision makers need a system to make their decision and policy without undertaking such complex analytical jobs. A complex spatial and non-spatial assessment often have multiple and conflicting objectives for its solution, therefore, decision makers require a GIS based tool which will assist them in assessing the updated scenario (McLafferty, 2003).

This research has a potential to be developed as a decision support tool. The research methodology can be used to arrive at a formula to score any healthcare facilities with different significant factors effecting users' perception of accessibility. The decision support system (DSS) can have an online user interface to obtain the second questionnaire survey required data. The DSS input can be enhanced by linking to a geo-database including geo-referenced data, such as: National Census; Ordnance Survey and deprivation indices; accident data; bus routes and stops maps. This upgraded tool is a spatial decision support system (SDSS) tool. Figure 9-1 shows how a SDSS tool can be used among different criteria of different stakeholders.

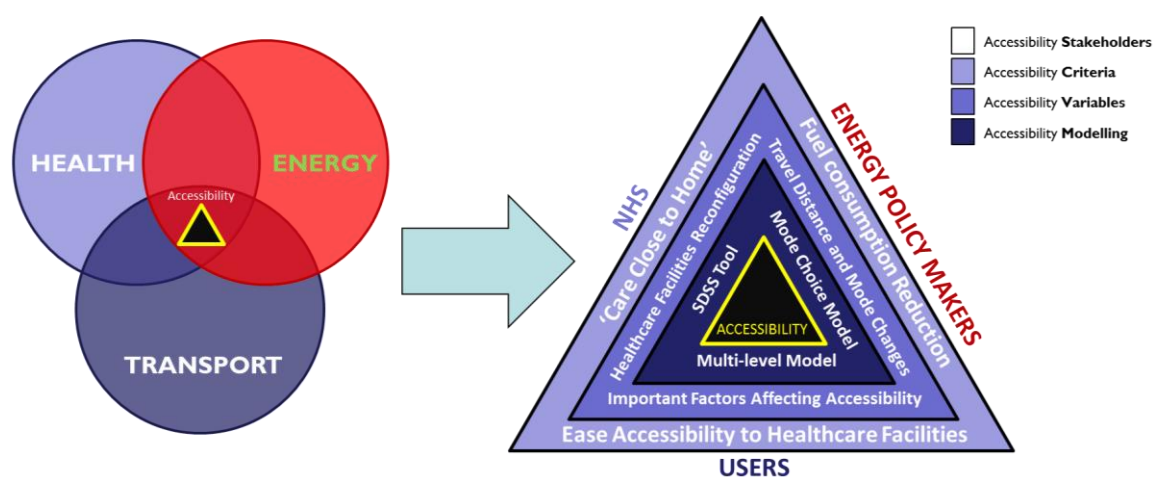


Figure 9-1: SDSS for NHS

Spatial decision support systems (SDSS) can integrate GIS advantages with a collection of methods to support and assess healthcare accessibility studies. A combination of a geo-database and database management system with data querying operation, can provide a set of GIS analytical tools and spatial interaction models by designing a user interface as a SDSS (Rushton, 2001). This system helps decision-makers to create questions, discover alternatives, and identify potential solutions in an interactive and computer based environment.

A SDSS can be used to plan and evaluate home-delivered services for future demographic forecasting, access routing, and optimal location modelling (Gorr et al., 2001; Cannon et al., 1998; Tanser and Wilkinson, 1999). Qualitative data from care

stakeholders about the care service demands can be incorporated in a SDSS (Sheppard et al., 1999).

The SDSS can be developed as a “top down” approach; it means developer and planners may choose the tools and data for the system and after that the users or decision makers will test and improve the system. While this approach allows researchers to develop the system, involving the decision makers and stakeholders throughout the development process leads the SDSS to be improved according to the type of data, analytic methods, querying tools and preparing a more user-friendly interface (McLafferty, 2003).

- **ML Modelling for more Levels and Areas**

As discussed in the Chapter 6, users’ preferences and priorities varied in accessing different sites. The destination choices were one of the significant factors in the ML modelling, therefore, there is a suggestion to develop further ML modelling considered by adding new levels such as: different levels of healthcare facilities (e.g. acute hospital and GP); different levels of urban areas (e.g. small town, middle-sized town and big cities); and different countries.

This research suggested the hypothesis that the users’ perception may increase or decrease by some factors affecting accessibility. Further research for other area and levels can test this hypothesis and propose further empirical evidence, which may finally provide a general formula for the relationship between users’ perception on accessibility and some significant factors. This would generalise the potential use of findings from this research. As the survey data collection and the road network information can be the main issues for generalising this research methodology, some solutions have already been proposed in Section 8.4 of the previous Chapter.

## **9.5 Recommendations**

This section provides some recommendations for the stakeholders of this research (Figure 9-2), which were introduced in section 2.1. The key stakeholders are: the **NHS** who are seeking to provide ‘care close to home’; the **Department of Health** and **Energy**



**Policy Makers** who are planning to reduce fuel consumption and carbon emissions; and **Users** who are seeking easy access to healthcare facilities; and the real decision makers as to whether to use a facility or not.

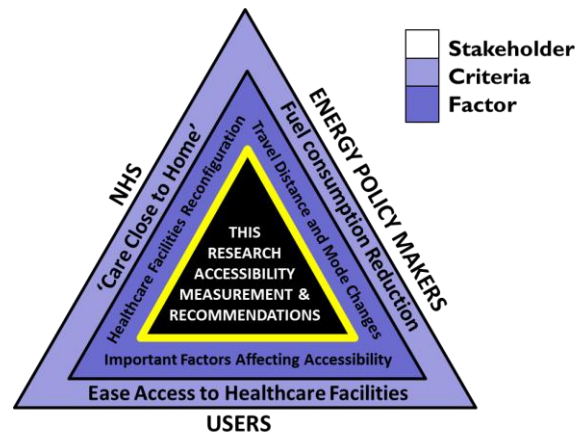


Figure 9-2: Key stakeholders

The proposed recommendation can be used for different scenarios such as: reconfiguration of healthcare facilities and services; assessing the current situation and future demands; site selection for new healthcare facilities; cost effectiveness for NHS stakeholders and investors; impact of service and infrastructure reconfiguration on energy consumption; public transport and non-motorised vehicle versus private car.

### 9.5.1 Recommendations for NHS

**Creating accessibility maps** is important when assessing accessibility to existing healthcare facilities and their future reconfiguration. People from different areas have different demands with respect to different levels of healthcare facilities; they have also different perceptions of accessibility in accessing the facilities from different area. It is, therefore, recommended to NHS to create specific accessibility maps for all healthcare facilities in the UK according to the user's perception of accessibility. It is also recommended to update the maps regularly as well as for future demands using forecasted census data. The NHS can update and enrich the accessibility models using its HES (Hospital Episode Statistics) data. Those user-based maps support NHS in making better decisions and customer-oriented policies as the maps are created using users'

perception and GIS techniques. Using those maps would improve the SDSS as discussed in the Section 9.4.

As explained in Chapter 3 (Section 3.6), SHAPE has been developed by the NHS for creating accessibility contour maps. Despite the software links to rich data sources (e.g. Hospital Episode Statistics and Census data), the only factor in measuring accessibility by SHAPE is travel time by 'car'. Therefore it is not a comprehensive approach in creating an accessibility map and needs to be enriched by employing the significant factors influencing accessibility to healthcare facilities.

**Creating catchment areas of healthcare facilities** is beneficial to the NHS. It can help the NHS to reduce any potential gaps or overlaps between the service areas. Therefore, it is recommended that the NHS define the user-based boundaries for the service areas of healthcare facilities. Determination of the boundaries (i.e. based on the users' perceptions) would support the NHS in creating a real world boundary. Since accessibility needs to be taken into account when considering issues around equity of health service and provision it is also recommended to the NHS to identify catchment area of different level of healthcare facilities (e.g. GPs, dentists and hospitals) in the form of different layers in GIS environment. Integration and analysis of the layers could benefit the NHS in providing further equity in serving accessible services.

**Improved appraisal of healthcare facilities reconfiguration** could be one of the advantages of using this research methodology. While the NHS intends to provide equal (or at least fair) access to healthcare facilities, the investors need to determine the cost efficiency of any new development to enhance the transparency of their investments in healthcare facilities' reconfiguration (Figure 9-3). Therefore, it is recommended that the NHS evaluates accessibility to any new reconfiguration of healthcare facilities and services by integrating primary and community care services (e.g. Local Improvement Finance Trust (LIFT)); or to getting support from the private sector to build, finance or operate a new healthcare facility (e.g. Private Funding Initiative (PFI)).

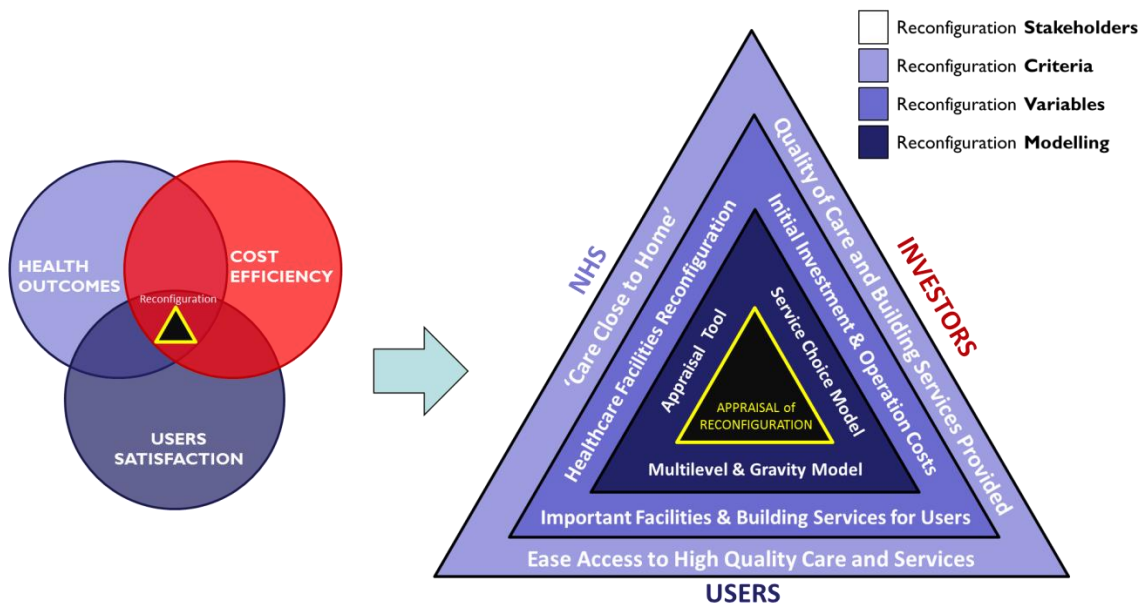


Figure 9-3: Appraisal of healthcare facilities reconfiguration

While in this research the suggestion was to retain the Walk in Centre NHS (WIC) instead of the Loughborough Community Hospital (LCH), the NHS Leicestershire County and Rutland (NHS LCR) endorsed the proposal to relocate the Loughborough Walk in Centre NHS (WIC) to the Loughborough Community Hospital (LCH).

Regarding the aim and objectives of this thesis, the research focused on transport issues related to access to healthcare facilities. Thus, the quality of care or the provided facilities of the destinations was not considered as a factor of this research modelling. Therefore some other factor rather than accessibility factors may be considered by the NHS LCR which can support their decision.

While the WIC is a better destination in terms of accessibility, the LCH would have a number of benefits, including quicker access to diagnostic tests as a 'one-stop health hub' which can provide the variety of services and as a core community hospital services. This means accessibility is one of important criteria and factors for the NHS Leicestershire County and Rutland (NHS LCR) in reconfiguring of healthcare facilities.

On the other hand, the destination choice (e.g. WIC and LCH) is one of the significant factors of this research which affect users' perception. Since the ML model showed that changing the destination from LCH to WIC reduces the users' perception of accessibility

by 6.5 units (on a scale of 0 to 100), this result can also support the NHS LCR decision. This means despite the obtained total score from the accessibility prediction model (i.e. WIC is more accessible compared to LCH), the respondents prefer LCH to WIC in terms of the destination attractions.

In order to assess the accessibility implications for healthcare facilities reconfiguration, it is recommended that the NHS creates accessibility maps before undertaking any new reconfiguration such as: relocating closer hospital and open new one; reconfiguring closer facility and use other hospital; relocating services from a big hospital to several community hospitals; resolving PCTs to GPs; and assessing location of GP services to integrate in several new GP.

An **Accessibility Rating System (ARS)** can be initiated by the NHS which is the largest single organisation in the UK. It is recommended that the NHS employs the ARS for all important healthcare facilities in the UK. This rating can help NHS to identify the poorest healthcare facility in terms of accessibility. It can also help the NHS strengthen healthcare facilities in encouraging people to access the facility by NMV or public transport. Since there is a relationship between public health and physical activities, it is recommended that the NHS expose the usage of NMV and public transport as important indicators of their ARS.

### **9.5.2 Recommendations for Energy Policy Makers**

Travel distance and the availability of public transport were the factors influencing users' perception of accessibility. These two factors have a direct relationship with fuel consumption of a journey. The NHS is the largest single organisation in the UK and is responsible for five per cent of all road traffic in England and travel accounts for 18 per cent of the NHS CO<sub>2</sub> emissions in England; therefore there is a considerable margin of reductions in CO<sub>2</sub> emissions specifically from NHS transport. This research achievement has the potential to provide some useful recommendations to the energy policy makers in reducing fuel consumption related to NHS transport.

On the other hand, most journeys to access healthcare facilities are short distances and 56 per cent of all journeys by car are less than five miles (DfT, 2007), therefore more people might prefer to use public transport or non-motorised transport. As mentioned in Chapter 2, Section 2.4, besides many criteria, the issues of accessibility to healthcare facility have been considered as an important assessment criteria for the Building Research Establishment's Environmental Assessment Method (BREEAM) rating (BREEAM, 2012); and the UK health authorities require assessing their healthcare facilities buildings to achieve the 'Tra' credit (BREEAM Healthcare, 2012). Some of the assessment criteria in transport section are: Tra 1, Provision of public transport; Tra2, Proximity to amenities; Tra 3, Cyclist facilities; Tra 4, Pedestrian and cyclist safety; Tra 5, Travel plan; Tra 6, Maximum car parking capacity; and Tra 7, Travel information point (BREEAM, 2012). All of these 'Tra' are going to assess the user's accessibility to a building. (BREEAM Transport, 2012; pp: 16). This shows the importance of considering users' interests and priorities as well as reducing the use of motorised transport.

**Revealing the most important mode of transport** helps the health and energy policy makers to understand individuals' preferences in using different travel modes to access different kinds of destination (e.g. healthcare, school, park, and business centre). A more integrated approach is needed between health and energy policy makers. Since people may utilise different modes of transport with respect to different travel purposes (e.g. business, holiday, or treatment), it is recommended that the policy makers use this research methodology in identifying the significant modes. It helps them to determine the fuel consumption of different significant modes of transport in relation to the usage of: private car; low fuel consumption modes (e.g. using public transport); and non-motorised vehicle (e.g. walking or using the bike). The energy policy makers can also understand the relationship between different travel purposes and selection of different travel modes (i.e. the fuel consumption of the mode) by people based on their perceptions.

**Encouraging people in using NMV and public transport** can be supported by understanding people's perception of accessibility. Since people behave based on their perceptions, therefore, it is recommended that the energy policy makers make their

decision based on the modelling of people's perceptions. This recommendation allows them to get real feedback by updating the model with a short and new set of survey data. It also helps them to identify the potential for improving a low/zero carbon emission's modes (i.e. public transport and NMV).

### **9.5.3 Recommendations for Users**

As suggested in the Section 8.6.1, developing a mobile application can help its users to find the easiest and safest access according to their perception. It is recommended to the users to share their perception of accessibility by using such future 'Mobile App'. The mobile application providers can also encourage the users to use the application by some attractive extensions such as: providing personal calorie consumption calculator and personal carbon footprint calculator.

## **9.6 Contributions to Knowledge**

Based on the literature review and exploring the previous practical research, the research identified some factors and issues which influence users' perceptions of accessibility to healthcare facilities. While some important factors were investigated in the first survey, this methodology could be generalised to identify important factors related to accessibility of healthcare facilities. The thesis has attempted to address this research gap by fitting a statistical multilevel model in order to identify the significant factors.

The findings of this research have added to the discussion over the relationship between the important factors affecting accessibility and the overall perception of accessibility. A number of contributions have been made to knowledge as summarised below.

1. Including users' perception of accessibility as a score-based measurement system for assessing accessibility.

This novel system brings advantages to assess accessibility beyond traditional measurement techniques. Rather than relying on travel distance or travel time, this approach provides a new score-based unit (on a scale of 0 to 100) to measure

accessibility. This measurement unit not only includes travel distance or travel time, but also contains other significant factors such as the perceptions of accessibility for different age groups and public transport provision in a score-based format. This introduces a new unified accessibility measure which incorporates important factors into a single unit.

2. Designing a methodology for using 'multilevel linear regression modelling' in assessing accessibility to healthcare facilities.

This research has linked different methods to develop a new methodology in assessing accessibility such as: undertaking quantitative and qualitative analyses to identify important factors; dealing with individual and area-wide factors by separating them into two levels; using GIS techniques to integrate different datasets; and examining econometric models to model the user's perception of accessibility by combining statistical and GIS analyses. This methodology has the potential to be generalised to related study areas for different destinations and for different purposes (e.g. access to hospital, shopping centres, or residential areas).

3. Designing an accessibility prediction model (APM) based on the ML model using GIS visualisation techniques.

The ML model has been used to provide a APM suitable for using in other areas (e.g. LLSOA). It can predict users' perceptions of accessibility to different destinations within a catchment area as data are updated (e.g. public transport development and residents age). The APM uses the significant factors affecting accessibility identified from the individual and the area characteristics.

4. Integrating different kinds of dataset using GIS analyses from variety of data sources.

This research selected many different significant and insignificant variables in two levels from a range of sources including: questionnaire surveys; National Census; Ordnance Survey and deprivation indices; accident data; bus routes and stops maps; frequency of bus services; road network maps; and UK Census Tract Boundaries data (i.e. LLSOA). All

of the data collection, cleansing and analysis processes can be used as a methodology to mash up required data for further or similar studies.



## 9.7 Main Conclusion

This chapter has provided a summary of the research achievements and limitations. The chapter also suggests further research and provides some recommendations for the key stakeholders of this research.

This research literature review revealed that assessing accessibility is more complex than just measuring travel distance or travel time. The assessment includes a wider set of factors relating to user's perceptions such as users' social backgrounds, their attitudes, their transport usage and area-wide factors. Since users' perception of accessibility can be altered over time due to changing expectations and available transport infrastructure, there is a need to develop a methodology in assessing accessibility to healthcare without dependency to any specific conditions such as: healthcare system; locations; available mode of transport; and individual and area-wide characteristics.

This research methodology presented that the user's perception of accessibility can be examined by employing multilevel statistical models to investigate the relationship between the accessibility score and individual socio-economic (e.g. age, gender, access to transport modes) and area-wide characteristics (e.g. income deprivation, public transport provision, safety and security). The methodology also showed that all important individual-level and area-level factors can be integrated in a GIS environment. The multilevel modelling could find some factors (e.g. travel distance, bus services, destination choices and age) as the most significant variables affecting users' perception of accessibility.

Collecting larger datasets from more respondents who are using different travel modes (e.g. bus, bike and walking) can support the model in finding more significant factors. Some factors such as safety and security and deprivation indices may be able to affect accessibility more significantly in big cities. Therefore developing the multilevel statistical models with more respondents' data within different and bigger area may find more significant factors which can influence users' perception of accessibility.

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## APPENDICES

### ***Appendix A: Publication, Presentation and Award***

Titidezh O, Quddus M, Ison S and Price A (2013) Modelling User Perception on Accessibility to Healthcare Facilities Using Statistical Methods and GIS, Transportation Research Board (TRB) 92nd Annual Meeting, Washington DC, USA.

Titidezh O, Quddus M, Ison S and Price A (2012) Modelling Transport Accessibility to Healthcare Facilities using Statistical Methods and GIS, 44th annual UTSG conference, The University of Aberdeen, Aberdeen, UK.

Titidezh O, Price A, Ison S, Quddus M A and Mills, G (2009) Accessibility Modelling for Healthcare Facilities Development: A Case of Reconfiguration Using GIS Tools, 2009 ESRI Health GIS Conference, Nashville, USA.

Ison S, Mills G, Price A, Quddus M A, Titidezh O and Adamu Z (2009) Loughborough and Hinckley Hospitals: Travel and Access Report, Loughborough University. [Report]

Astley P, Bolgar B, Mahadkar S, Mills G, Price A, Raftord N, Soriano B, Titidezh O (2009) PHIΦ: Planning Healthcare Infrastructure; Implementing the Next Stage Review Healthcare Infrastructure, Prince's Foundation for the Built Environment. [Report]

### ***Award and Prize***

**Winner of ESRI Young Scholars Award for Outstanding Doctoral Thesis Research**, Awarded by Environmental Systems Research Institute (Developer of ArcGIS), Selected by a university panel formed by Esri to present this research findings at 32nd Esri International User conference 2012, San Diego, California, USA.

**Winner of Poster Competition Prize, Loughborough University Research Conference**, Poster tile: "Care Close to Home: Appraisal of Healthcare Facilities Reconfiguration using GIS Tools", 2012, Loughborough University, Loughborough, UK.



**Abstract:**

**Modelling User Perception on Accessibility to Healthcare Facilities  
Using Statistical Methods and GIS**

*Omid Titidezh, Mohammed Quddus, Stephen Ison, Andrew Price*

Transport accessibility to healthcare facilities is a major issue in the United Kingdom, as recently demonstrated by the shift away from ‘providing healthcare in acute hospitals’ to ‘care closer to home’. However, it is not easy to measure transport accessibility since it is often highly subjective and deterministic. Common measures of accessibility focus on the creation of distance or travel time contours around a destination and devote less attention to individual differences such as users’ perception, their transport usage and area-wide factors.

The aim of this paper is to develop a user-based accessibility model by focusing on both individual transport usage (i.e. access to different transport modes and fuel consumption) and area-wide factors (e.g. transport network, public transport provision, safety/security and area deprivation). A questionnaire survey was carried out to measure users’ perceptions of the accessibility to various healthcare facilities. The responses are integrated with various datasets obtained from a range of secondary sources (e.g. National Census, Ordnance Survey, Deprivation Indices) using a GIS technique. A multilevel (i.e. individuals nested within local areas) mixed-effects statistical model is employed to develop a relationship between user perception on the accessibility and the factors influencing accessibility.

The initial results suggest that travel distance by car, number of available bus services, age and destinations affect accessibility to healthcare facilities. Based on the weighting of each of the factors, a range of policies can be developed that could lead to the reduction in health inequality in terms of fair access to healthcare provision.



**Abstract:**

**Modelling Transport Accessibility to Healthcare Facilities  
using Statistical Methods and GIS**

*Omid Titidezh, Mohammed Quddus, Stephen Ison, Andrew Price*

Transport accessibility to healthcare facilities is a priority issue in the United Kingdom and this has been recently demonstrated by the shift away from ‘providing healthcare in acute hospitals’ to moving care ‘close to home’. It is not easy to measure transport accessibility since it is often highly subjective and deterministic. Current approaches to measuring accessibility primarily focus on the creation of accessibility contours based on distance or travel time and therefore such methods ignore individual differences (users’ perception and their transport usage) and area-wide factors. This may result in health inequality with respect to accessibility to healthcare facilities.

The objective of this paper is, therefore, to develop a user-based accessibility model by focusing on both individual transport usage (i.e. access to different transport modes and fuel consumption) and area-wide factors (e.g. transport network, public transport provision, safety/security and area deprivation). A questionnaire survey was carried out to measure users’ perceptions of the accessibility to various healthcare facilities at Loughborough, Leicestershire. The responses from a total of 300 completed surveys are integrated with various datasets obtained from a range of secondary sources (e.g. Census, Ordnance Survey, Index of Multiple Deprivation) using a GIS technique. A multilevel (i.e. individuals nested within local areas) statistical model is employed to develop a relationship between user perception on the accessibility and the influencing factors affecting accessibility. The initial results suggest that area-wide factors such as income- and crime-indices along with the level of public transport provision, travel time by car, fuel consumption and the size of foot/bike catchments significantly affect accessibility to healthcare facilities. Based on the weighting of each of the factors, a range of policies can be developed that could lead to the reduction in health inequality in terms of fair access to health care provision.

**Abstract:**

**Accessibility Modelling for Healthcare Facilities Development:  
A Case of Reconfiguration Using GIS Tools**

*Omid Titidezh, Andrew Price, Grant Mills, Stephen Ison, Mohammed Quddus*

Before a reconfiguration of healthcare facilities or construction, it is important to consider accessibility and sustainability implications. Because of the increasing demands and expectations placed on health services, it is also necessary to study the impact of future growth in order to forecast and analyse.

The main aim of this study is to support easy and good access to the healthcare facilities in the East Midlands region of the UK using a GIS model of transport infrastructure and the healthcare facilities distribution. In the case study, GIS modelling of existing healthcare facilities and services has been undertaken accounting for transport and accessibility through an assessment. Evaluation of energy consumption and sustainable study was undertaken so as to support the strategic plan of healthcare facilities development according to human geography, population density, age and future growth. The best site locations were chosen according to travel time, neighbourhood, road network connectivity and mode of transport by creating contours of accessibility to healthcare facilities.


The three main scenarios identified during investigation were: the current situation; future demand; and future transport arrangements. The existing data set was analysed and more detailed information was provided via questionnaires and interviews. Predictions of the future population growth and demand for a typical location and the case study explored how future transport plans could impact accessibility to healthcare facilities.


The evaluation of existing healthcare facilities and their distribution accessibility maps were provided via the GIS model. The best location of healthcare facilities has been proposed according to the accessibility, urban planning guidelines and environmental impact assessment by CO2 emission studies.

The cases, methodology and findings of the investigation presented in this research will also be extendable and applicable to similar cases of healthcare services' reconfiguration, development and future plans.



[illegible]



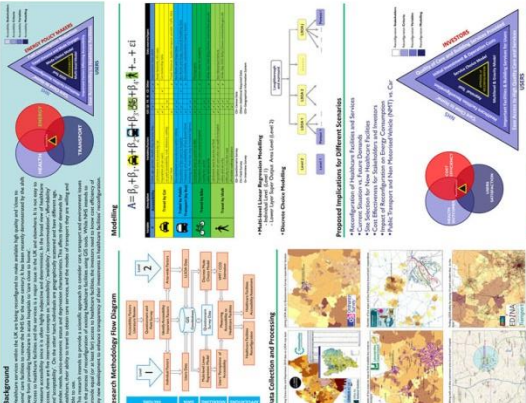


## ‘Care Close to Home’: Appraisal of Healthcare Facilities Reconfiguration using GIS Tools

### Background

Healthcare facilities are essential to the health and well-being of communities, providing a range of services from primary care to specialist treatment. However, the demand for healthcare services is increasing due to an ageing population, rising prevalence of chronic diseases, and changing patterns of health care delivery. This has led to a need to reassess the location, size, and configuration of healthcare facilities to ensure they can meet the needs of the community in a sustainable and efficient manner.

The purpose of this research is to develop a methodology for the appraisal of healthcare facilities reconfiguration using GIS tools. The methodology will involve the collection and analysis of data on healthcare facilities, population, and transport networks. The results of the appraisal will be used to inform decision-making on the reconfiguration of healthcare facilities, ensuring that they are accessible, efficient, and sustainable.



### Methodology Flow Diagram

```

graph TD
    A[Study Area] --> B[Data Collection and Preprocessing]
    B --> C[GIS Analysis]
    C --> D[Results and Recommendations]
    D --> E[Conclusion]
            
```

### Data Collection and Preprocessing

The data collection and preprocessing stage involves the gathering of raw data from various sources and its preparation for analysis. This includes tasks such as data cleaning, georeferencing, and projection.

Data Source	Data Type	Preprocessing Steps
Healthcare Facilities	Point Data	Georeferencing, Projection, Attribute Cleaning
Population	Area Data	Georeferencing, Projection, Attribute Cleaning
Transport Networks	Line Data	Georeferencing, Projection, Attribute Cleaning

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## Appendix B: First Questionnaire Survey



### Hinckley and Loughborough Locality: Travel and Access Survey

Dear resident and potential hospital user,

Following public consultation NHS Leicestershire County and Rutland has endorsed the proposal to relocate the Loughborough Walk in Centre to Loughborough Hospital, and the Hinckley and District Hospital to the Hinckley and Bosworth Community Hospital site.

During the public consultation a number of comments were received in relation to transport and access issues in Loughborough and Hinckley, associated with these proposals. In order to understand these issues fully we are now undertaking our survey in these areas.

The survey will finish by Friday 14 August and a final report will be produced based on our findings by Wednesday 30 September 2009. If we are able to make any recommendations of improvements to transport and accessibility to our community hospital sites these will be presented to, and considered by, the NHS LCR Trust Board and Leicestershire County Council for inclusion in future plans.

We hope that you will be able to take 10 minutes of your time to complete this important questionnaire and send it back to us using the enclosed prepaid envelope.

If you would prefer to complete this questionnaire electronically please access a web based questionnaire on: [www.lcr.nhs.uk](http://www.lcr.nhs.uk) or [www.leics.gov.uk](http://www.leics.gov.uk)

Thank you for your time and continued support in helping us to deliver better care closer to home.

Yours sincerely,

Liz Rowbotham  
Director of Quality  
NHS Leicestershire County and  
Rutland

Matthew Lugg  
Director  
Highways, Transportation & Waste  
Management  
Leicestershire County Council











## Hinckley and Loughborough Locality: Travel and Access Survey









This questionnaire aims to assess patients, staff and visitors existing experience and provide an opportunity for them to put forward suggestions for improving access and local transport to both Loughborough and Hinckley and Bosworth Community Hospital sites in the future.

### Section 1 – purpose and mode of travel

The following questions are about the purpose and way you presently travel to either Loughborough or Hinckley and Bosworth Community Hospital sites.

- 1) Which site are you completing this questionnaire for?  
(please tick only one)
- ☐ Loughborough      ☐ Hinckley
- 2) Over the past 12 months, how frequently have you travelled to Hinckley and Bosworth, Hinckley and District and Loughborough Community Hospitals or Loughborough Walk-in-Centre as either a patient, visitor or member of staff?  
(please tick one box in each row)
- |                  | Infrequently<br>(approx 0-5) | Frequently<br>(approx 6-20) | Very<br>Frequently<br>(approx 21+) |
|------------------|------------------------------|-----------------------------|------------------------------------|
| Patient          | <input type="checkbox"/>     | <input type="checkbox"/>    | <input type="checkbox"/>           |
| Visitor or carer | <input type="checkbox"/>     | <input type="checkbox"/>    | <input type="checkbox"/>           |
| Member of staff  | <input type="checkbox"/>     | <input type="checkbox"/>    | <input type="checkbox"/>           |
- Other, please state
- 
- 3) When making healthcare trips in the last 12 months, how often did you travel with a family or friend as a companion?
- ☐ Never      ☐ Sometimes      ☐ Always
- 4) What mode(s) of transport do you have access to? (tick more than one if appropriate)
- |   |   |   |   |   |   |  |   |
|---|---|---|---|---|---|--|---|
|  |  |  |  |  |  |  |  |
| Walk  | Cycle   | Motorbike   | Taxi / Friend   | Car   | Public Transport  | Ambulance  | Voluntary   |
| <input type="checkbox"/>  | <input type="checkbox"/>  | <input type="checkbox"/>  | <input type="checkbox"/>  | <input type="checkbox"/>  | <input type="checkbox"/>  | <input type="checkbox"/>   | <input type="checkbox"/>  |

- 5) Of the healthcare trips that you make to the following sites, what mode(s) of transport do you usually use?

								
	Walk	Cycle	motorbike	Taxi / Friend	Car	Public Transport	Ambulance	voluntary
Large Leicester hospitals (LRI, General and Glenfield)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Travel to your Dentist	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Travel to your GP	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>









## Section 2 - about individual sites

The following questions are about individual site locations. Please feel free to leave a non-relevant site blank. The following questions are about your experience of accessing the site.









### Hinckley and Bosworth Community Hospital Site

These questions relate to your experience of the Hinckley and Bosworth site and planned move of the GP Health Centre and Hinckley and District to the Hinckley and Bosworth Community site.

- 6) What mode(s) of transport do you usually use to travel to the following sites?

								
	Walk	Cycle	motorbike	Taxi / Friend	Car	Public Transport	Ambulance	Other/ voluntary
Hinckley and Bosworth Community Hospital, Ashby Road	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hinckley and District Hospital, Mount Road	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

- 7) What mode(s) of transport would you prefer to use to get to Hinckley and Bosworth Community Hospital? (tick more than one if appropriate)

							
Walk	Cycle	Motorbike	Taxi / Friend	Car	Public Transport	Ambulance	Voluntary
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please state why you do / do not use your preferred mode(s) of transport?









- 8) What do you consider to be the three main problems with accessing the Hinckley and Bosworth hospital site? (*by car, bus or walking and cycling*).

- 9) Please give details of your travel experiences to the Hinckley and Bosworth Community Hospital site (please giving specific details such as: time, cost, distance travelled by foot, quality of bus stops, number of bus changes, and bus route)?









### **Loughborough Community Hospital Site**

These questions relate to your experience of the Loughborough site and the planned move of the Walk in Centre to the Community Hospital site, Epinal Way.

- 10) What mode(s) of transport do you usually use to travel to the following sites?

								
Loughborough Hospital, Epinal Way	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Loughborough Walk In Centre, Baxter Gate for an appointment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Loughborough Walk In Centre, Baxter Gate in an emergency	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

- 11) What mode(s) of transport would you prefer to use to get to Loughborough Community Hospital? (tick more than one if appropriate)

							
Walk	Cycle	Motorbike	Taxi / Friend	Car	Public Transport	Ambulance	Voluntary
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please state why you do / do not use your preferred mode(s) of transport?

- 12) What do you consider to be the three main problems with accessing the Loughborough Community Hospital site? (*by car, bus or walking and cycling*)

- 13) Please give details of your travel experiences to the Loughborough Community Hospital site (giving specific details wherever possible of the: time, cost, distance travelled by foot, quality of bus stops, number of bus changes, and bus route)?



### Section 3 – further information

The following questions are about your general travel preferences and information needs for Loughborough or Hinckley and Bosworth Community Hospital sites.

- 14) Where do you most frequently travel from to access Community Hospital site(s)? *(Please tick only one)*
- |                          |                          |                          |                          |
|--------------------------|--------------------------|--------------------------|--------------------------|
| Home                     | Work                     | Leisure                  | Other                    |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Please state all or part of your home postcode?




Also, if this is not the postcode from which you most frequently travel, please state the alternative postcode?




- 15) Please rank the following items according to which has the highest importance for you when accessing the community hospital sites?

*(Please write your rank in the boxes provided where 1 is most important and 9 is least important. Please use all numbers 1 to 9)*

Rank

Travel time

Travel cost

Travel distance by foot

Quality of care provided to you

Building and facilities quality

Safe and secure street access

More services provided locally

Availability of public transport

Provision of car parking

- 16) How far can you walk to access a bus stop?

Less than 100 m (109 Yards)	100 - 200 m (219 Yards)	200 – 300 m (328 Yards)	300 – 400 m (437 Yards)	400 – 500 m (547 Yards)	More than 500 m (547 Yards)
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

- 17) Are you aware of the bus, walking, cycle routes which allow you to access Loughborough or Hinckley and Bosworth Community Hospitals?

Yes

☐

No

☐

- 18) If you were made more aware of what public transport is available, would you use it to travel to Loughborough or Hinckley and Bosworth Community Hospitals?

Yes      No      Maybe  
☐      ☐      ☐

If No, please state your reasons for this

- 19) Would you be willing to walk or bike to Loughborough or Hinckley and Bosworth Community Hospitals?

Yes      No      Maybe  
☐      ☐      ☐

If No, please state your reasons for this

- 20) Would you be willing to ask a friend or family member to drop-off and pick-up from Loughborough or Hinckley and Bosworth Community Hospitals?

Yes      No      Maybe  
☐      ☐      ☐

If No, please state your reasons for this

- 21) Would you be willing to use community / voluntary transports to drop-off and pick-up to Loughborough or Hinckley and Bosworth Community Hospitals?

Yes      No      Maybe  
☐      ☐      ☐

If No, please state your reasons for this

- 22) Please list your most important improvements for transport and accessibility to Loughborough or Hinckley and Bosworth Community Hospitals? *(if helpful, please refer back to question 9 or 13)*

23) How do you prefer to receive public transport information?

Web/  
Email

Tele-  
phone

Publicly  
Available  
Leaflets /  
Timetable

Posted  
Leaflets /  
Time-  
table

Text /  
Mobile

Appoint-  
ment  
Letter

☐☐☐☐☐☐

If other, please state?

24) What is your view on the range and availability of public transport information?

Good

☐

Fair

☐

Poor

☐

25) How would you improve public transport information?

### Background Information (Optional)

#### What is your age range?

- |                                  |                                  |
|----------------------------------|----------------------------------|
| <input type="checkbox"/> 16 – 19 | <input type="checkbox"/> 20 – 29 |
| <input type="checkbox"/> 30 – 39 | <input type="checkbox"/> 40 – 49 |
| <input type="checkbox"/> 50 – 59 | <input type="checkbox"/> 60 – 69 |
| <input type="checkbox"/> 70 – 79 | <input type="checkbox"/> 80+     |

#### The Disability Discrimination Act 1995

defines disability as: 'A physical or mental impairment which has a substantial and long term adverse effect on the ability to carry out normal day-to-day activities.' Do you consider yourself to be:

- |                   |                          |
|-------------------|--------------------------|
| Disabled          | <input type="checkbox"/> |
| Non Disabled      | <input type="checkbox"/> |
| Prefer not to say | <input type="checkbox"/> |

- ☐ Hearing impaired
  - ☐ Learning Disability
  - ☐ Long term condition
  - ☐ Physical impairment
  - ☐ Visual and Hearing impairment
  - ☐ Visual impairment
  - ☐ Wheelchair user
  - ☐ Mental Health
  - ☐ Any other, please write below
- 

#### What do you consider your ethnicity to be?

- ☐ Asian or Asian British
  - ☐ Black or Black British
  - ☐ Chinese
  - ☐ Mixed Heritage
  - ☐ White
  - ☐ Other ethnicities, please write below
- 

#### What is your gender?

- |  |                                 |                                      |
|--|---------------------------------|--------------------------------------|
| <input type="checkbox"/> Male              | <input type="checkbox"/> Female | <input type="checkbox"/> Transgender |
| <input type="checkbox"/> Prefer not to say |                                 |                                      |

#### What is your sexual orientation?

- ☐ Bisexual
- ☐ Heterosexual
- ☐ Gay
- ☐ Lesbian
- ☐ Prefer not to say

#### Preferred written/spoken language?

- ☐ How many adults, including yourself, are there in your household (18 or over)?
- ☐ How many children are there in your household (under 18)?
- ☐ How many cars are there in your household?

Please state the number of members of your household that will have access to a car in the situations below:

- ☐ During the day (8.30am – 5.30pm) in an emergency
- ☐ During the day (8.30am – 5.30pm) for a pre-booked appointment or for a drop-in session
- ☐ Out of hours (before 8.30am and after 5.30pm)

If relevant, please state any other information that you may feel is relevant

## Appendix C: Second Questionnaire Survey

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### ACCESSIBILITY SURVEY

No:

Please let us know this number if you want to withdraw your answers

Dear Respondent,

I am a PhD student at Loughborough University researching in the area of transport and accessibility. Accessibility is ease of access to your destination.

Your response to this survey is very important in furthering my studies.

Thank you very much for spending a few minutes of your time to complete this questionnaire.

ORIGIN

OVERALL ACCESSIBILITY & PERCEPTION

1. Please consider '**Loughborough Community Hospital**' on Epinal way as your '**destination**' for this questionnaire survey.

2. How did you access to this destination? (tick more than one if appropriate)

☐ Car ☐ Bus ☐ Bike ☐ Walk

3. Where did you start your current journey? ☐ Home ☐ Work ☐ Other

4. Would you please provide **FULL POSTCODE** of the origin of your journey?

5. Please choose an **overall accessibility perception** between your '**origin**' and this '**destination**':

- ☐ Very Poor  
☐ Poor  
☐ Neither Good nor Poor  
☐ Good  
☐ Very Good

6. On a similar question, please give an **overall accessibility score** for your '**origin**' and this '**destination**' between **0** to **100**

(**0** = not accessible at all, **100** = ideally accessible).

TO THIS  
DESTINATION:

7. Please rank the following **1** to **8** according to which has the highest importance for you when accessing your destination? (**1** for the **MOST important** and **8** for the **LEAST important**)

- ☐ Travel Time by Car  
☐ Frequency and Reliability of Bus  
☐ Fuel Consumption  
☐ Access by Bike  
☐ Access on Foot  
☐ Proximity to a Bus Stop  
☐ Road Accident and Crime  
☐ Bus Fare

8. Do you have access to a car? ☐ Yes ☐ No

9. What is your **age** range? *(Optional)*

- |                                  |                                  |
|----------------------------------|----------------------------------|
| <input type="checkbox"/> 16 – 19 | <input type="checkbox"/> 20 – 29 |
| <input type="checkbox"/> 30 – 39 | <input type="checkbox"/> 40 – 49 |
| <input type="checkbox"/> 50 – 59 | <input type="checkbox"/> 60 – 69 |
| <input type="checkbox"/> 70 – 79 | <input type="checkbox"/> 80+     |

10. Do you consider yourself to be: *(Optional)*

- ☐ Disabled
 ☐ Non Disabled
 ☐ Prefer not to say

**The Disability Discrimination Act 1995** defines disability as: 'A physical or mental impairment which has a substantial and long term adverse effect on the ability to carry out normal day-to-day activities.'

11. What do you consider your **ethnicity** to be? *(Optional)*

- ☐ Asian or Asian British  
☐ Black or Black British  
☐ Chinese  
☐ Mixed Heritage  
☐ White  
☐ Other ethnicities, please write: \_\_\_\_\_

12. What is your **gender**? *(Optional)*

- ☐ Male
 ☐ Female
 ☐ Transgender
 ☐ Prefer not to say

13. What is your total **annual income** of all people living in your household before tax and other deductions? *(Optional)*

- |  |  |
|--|--|
| <input type="checkbox"/> £14,999 and under | <input type="checkbox"/> £75,000 - £99,999   |
| <input type="checkbox"/> £15,000 - £24,999 | <input type="checkbox"/> £100,000 - £149,999 |
| <input type="checkbox"/> £25,000 - £49,999 | <input type="checkbox"/> £150,000 - £199,999 |
| <input type="checkbox"/> £50,000 - £74,999 | <input type="checkbox"/> £200,000 and over   |

Thank you very much for completing this survey


**Omid Titidezh**, PhD Student  
 Loughborough University  
 Email: o.titidezh@lboro.ac.uk

Online Pilot Survey using Bristol Online Survey (www.survey.bris.ac.uk):

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Accessibility\_Survey



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Note that once you have clicked on the CONTINUE button your answers are submitted and you can not return to review or amend that page

YOUR DESTINATION

1. Which one of the following hospitals have you recently visited?  
(Please choose one as your 'destination' for this questionnaire survey):

☐ Loughborough NHS Walk-in Center Hospital  
☐ Loughborough Community Hospital on Epinal Way

YOUR ORIGIN

2. How did/will you access to/from this destination? (tick more than one if appropriate)  
(select all that apply)

☐ Car ☐ Bus ☐ Bike ☐ Walk

3. Where did you start your current journey?

☐ Home ☐ Work ☐ Other

4. Would you please provide FULL POSTCODE of the origin of your journey?

OVERALL ACCESSIBILITY

5. Please choose an overall accessibility perception between your 'origin' and this 'destination' :

☐ Very Poor  
☐ Poor  
☐ Neither Good nor Poor  
☐ Good  
☐ Very Good

6. On a similar question, please give an overall accessibility score for your 'origin' to this 'destination' between 0 to 100  
(0 = not accessible at all; 100 = ideally accessible).

7. Please rank the following 1 to 8 according to which has the highest importance for you when accessing your destination? (1 for the MOST important and 8 for the LEAST important)


a. Travel Time by Car	<input type="text"/>
b. Frequency and Reliability of Bus	<input type="text"/>
c. Fuel Consumption	<input type="text"/>
d. Access by Bike	<input type="text"/>
e. Access on Foot	<input type="text"/>
f. Proximity to a Bus Stop	<input type="text"/>
g. Road Accident and Crime	<input type="text"/>
h. Bus Fare	<input type="text"/>

Continue >

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Accessibility\_Survey



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BACKGROUND INFORMATION

8. Do you have access to a car?

☐ Yes ☐ No

9. What is your age range? (Optional)

☐ 16 - 19 ☐ 20 - 29 ☐ 30 - 39 ☐ 40 - 49 ☐ 50 - 59 ☐ 60 - 69 ☐ 70 - 79 ☐ 80+

10. The Disability Discrimination Act 1995 defines disability as: 'A physical or mental impairment which has a substantial and long term adverse effect on the ability to carry out normal day-to-day activities'.  
Do you consider yourself to be: (Optional)

☐ Disabled ☐ Non Disabled ☐ Prefer not to say

11. What do you consider your ethnicity to be? (Optional)

☐ Asian or Asian British ☐ Black or Black British ☐ Chinese ☐ Mixed Heritage ☐ White  
☐ Other (please specify):

12. What is your gender? (Optional)

☐ Male ☐ Female ☐ Transgender ☐ Prefer not to say

13. What is your total annual income of all people living in your household before tax and other deductions? (Optional)

☐ £14,999 and under ☐ £15,000 - £24,999 ☐ £25,000 - £49,999 ☐ £50,000 - £74,999 ☐ £75,000 - £99,999 ☐ £100,000 - £149,999 ☐ £150,000 - £199,999 ☐ £200,000 and over  
☐ Other (please specify):

Continue >

Survey testing only  
Check Answers & Continue >

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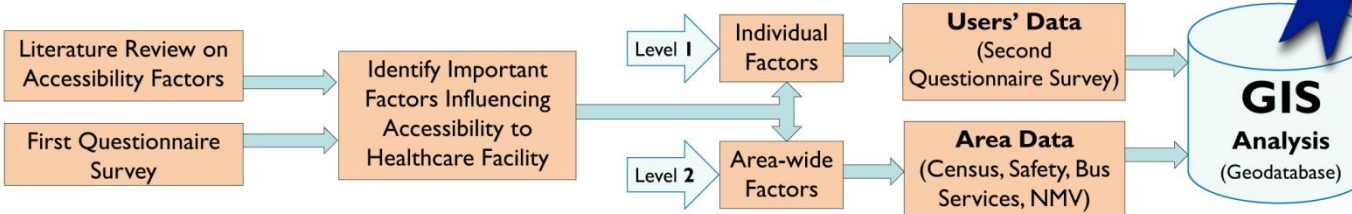


ACCESSIBILITY FACTORS

DATA INTEGRATION

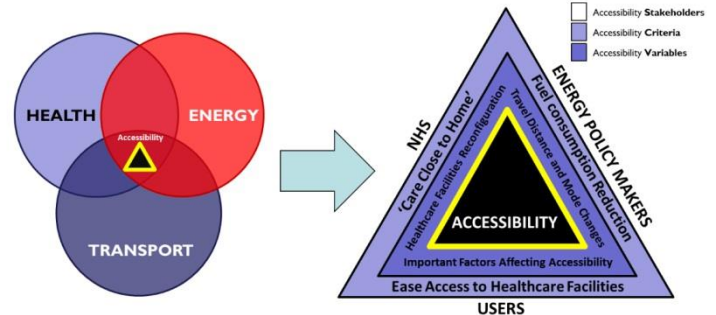
MULTILEVEL MODELING

PREDICTION MODEL

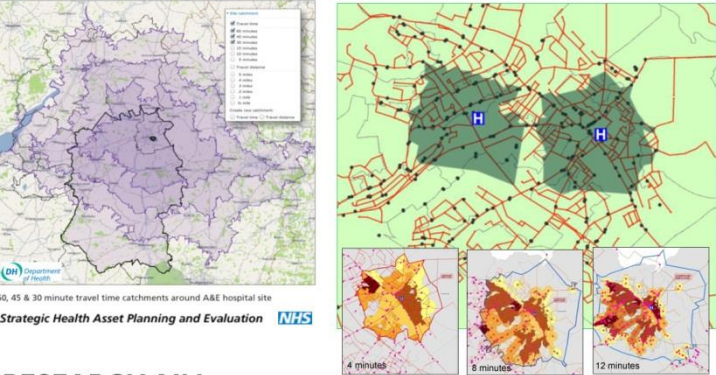


INTRODUCTION

Transport accessibility to healthcare facilities is a major issue in the United Kingdom, as recently demonstrated by the shift away from 'providing healthcare in acute hospitals' to 'care closer to home'. However, it is not easy to measure transport accessibility since it is often highly subjective and deterministic.



Common measures of accessibility focus on the creation of distance or travel time contours around a destination and devote less attention to individual differences such as users' perception, their transport usage and area-wide factors including income deprivation, safety and security. Failure to account for such factors may result in imperfect decision making in terms of healthcare relocation and reconfiguration.



RESEARCH AIM

The aim of this research is to develop a user-based accessibility model by focusing on both individual transport usage (i.e. access to different transport modes and fuel consumption) and area-wide factors (e.g. transport network, public transport provision, safety/security and area deprivation).

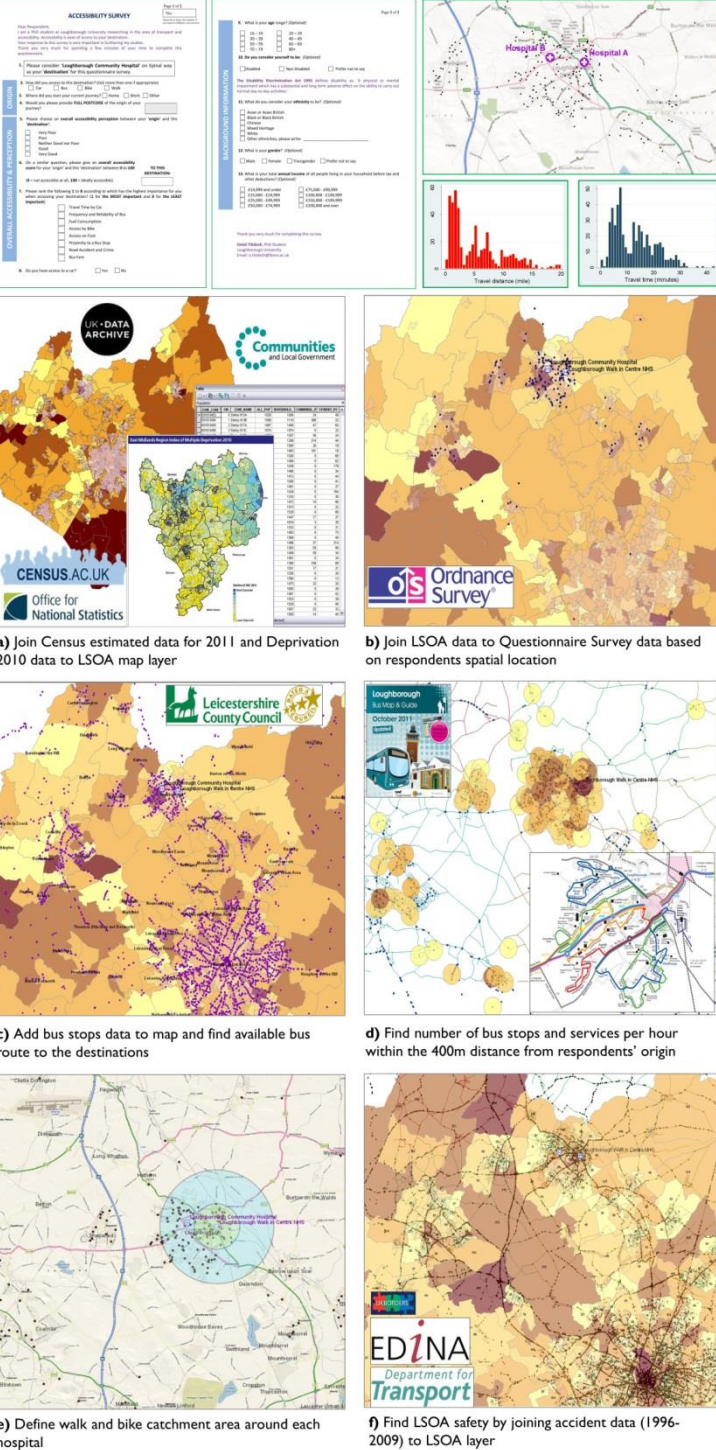
$$A = \beta_0 + \beta_1 \cdot \text{Car} + \beta_2 \cdot \text{Bus} + \beta_3 \cdot \text{Bike} + \beta_4 \cdot \text{Walk} + \dots + \epsilon_i$$

Variable	Description	Variables/factors	GIS	QS	FS	IS	CD	Other	Data sources/types
A	Accessibility	LSOA, age, gender, Health Dep, Income Dep, Population of car users, Car catchment area to access by Car, car park (availability, cost, distance, safety), Travel Time	✓	✓	✓	✓	✓	✓	Deprivation Data 2010, Road Network, HES data, Car ownership data
Car	Travel by Car	Bus catchment area (within 500m), Population of bus users to hospital, Frequency and availability of bus travel (time), Walking dist. from bus stop to hospital (Egress)	✓	✓	✓	✓	✓	✓	Travel Distance, Spatio-temporal variable Traffic data
Bus	Travel by Public Transport (by Bus)	Catchment area to access by Bike, Population of bike users around hospital, Facility for cycling, safety and security	✓	✓	✓	✓	✓	✓	Photography, Census data for disability
Bike	Travel by Bike	Catchment area to access on foot, Population of users who can walk to hospital, safety and security, Difficulty to Cross the road, Affordable walking distance	✓	✓	✓	✓	✓	✓	LSOA Dep 2010 (http://www.communities.gov.uk), Non Motorised Vehicle, LSOAs Dep 2010 (http://www.communities.gov.uk)
Walk	Travel by Walk								

QS= Questionnaire Survey  
FS= Field Survey  
IS= Interview Survey  
CD= Census Data  
Other= Additional Required Data  
GIS= Geographical Information System

DATA COLLECTION

A questionnaire survey was carried out to measure users' perceptions of the accessibility to various healthcare facilities. The responses are integrated with various datasets obtained from a range of secondary sources (e.g. National Census, Ordnance Survey, Deprivation Indices) using a GIS technique.



STATISTICAL MODELING

A multilevel (i.e. individuals nested within local areas) mixed-effects statistical model is employed to develop a relationship between user perception on the accessibility and the factors influencing accessibility.

**Multilevel Linear Regression Modelling**

$A = \beta_0 + \beta_1 \cdot \text{Travel Distance/Time by Car} + \beta_2 \cdot \text{Availability of Public Transport} + \beta_3 \cdot \text{Age Groups} + \beta_4 \cdot \text{Destination} + \beta_5 \cdot \text{Deprivation Indices} + \beta_6 \cdot \text{Safety and Security} + \beta_7 \cdot \text{Walk and Bike Catchment Area} + \beta_8 \cdot \dots + \epsilon_i$

$Y_{ij} = \beta_{0j} + \beta_{1j} X_{ij} + e_{ij}$

$Y_{ij}$  = Dependent variable representing the level of accessibility score of person  $i$  in area  $j$   
 $X$  = Person-level independent variable  
 $e$  = The person-level residual that is independent across observations

$A$  = A user perception of accessibility to a healthcare facility  
 $\beta$  = Factors (weights) affecting accessibility parameters  
 $\epsilon_i$  = Error term (unobserved factor)

$Y_{ij} = \gamma_{00} + \gamma_{01}Z + \gamma_{10}X + \gamma_{11}XZ + u_{0j} + u_{1j}X + e_{ij}$

$\gamma_{00}$  = Overall mean accessibility score (per person) across areas  
 $\gamma_{11}$  = Coefficient for the cross-level interaction term  
 $Z$  = Area-level independent variable  
 $u_{0j}$  = Effect of area  $j$  on the accessibility score  
 $u_{1j}$  = Area-specific random slope for the person-level variable

**Level 1 – Individual Variables**

- Age, Gender, Ethnicity, Income, Disability, Car Ownership, Travel Time, Travel Mode, Travel Distance, Fuel Consumption

**Level 2 – Area Variables**

- Safety, Security, Availability of Public Transport, IMD: Index of Multiple Deprivation, Barriers to Housing and Services, Health and Disability, Living Environment

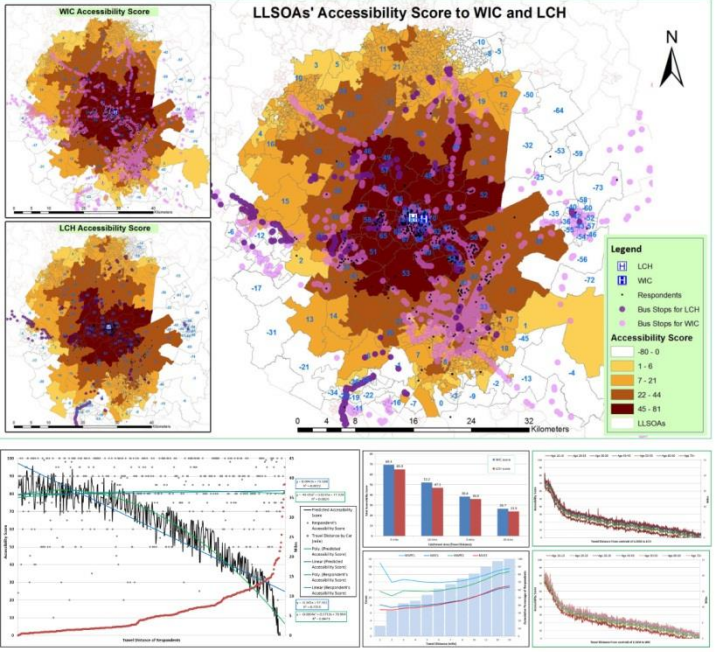
RESULT

The results suggest that travel distance by car, number of available bus services, age and destinations were the most significant variables affecting users' perception of accessibility to healthcare facilities.

Dependent variable = Overall accessibility perception	Model 1: For All Respondents	Model 2: Respondents with Car Ownership
<b>Level 1: respondent-level variables</b>		
Travel distance (miles)	Coefficient: -3.6448, t-stat: -2.45	Coefficient: -3.9780, t-stat: -2.58
Number of available bus services per hour within the 500m distance from origin/home	0.1122, 1.21	0.1754, 1.68
Age groups:		
16 - 19 (reference)	0.0000	0.0000
20 - 29	1.0321, 0.25	6.1554, 1.17
30 - 39	4.9453, 1.14	8.9680, 1.66
40 - 49	6.3053, 1.49	10.9695, 2.07
50 - 59	4.2479, 0.97	11.1209, 2.07
60 - 69	7.6979, 1.81	10.3783, 1.95
70 and over	7.0318, 1.61	11.5231, 2.13
Gender (male = 1; female = 0)	0.3367, 0.2	0.0714, 0.04
Mode choice:		
Walk (reference)	0.0000	0.0000
Car	-1.3159, -0.56	-3.2363, -1.32
Bus	-7.3536, -1.56	-6.3965, -1.17
Whether the respondent from the walking catchment (Yes=1; No=0)	-1.9507, -0.9	-0.4462, -0.18
Destinations (WC=1; LH=0)	-5.5950, -2.62	-6.4823, -2.93
Intercept	77.9138, 16.62	75.9458, 13.17
<b>Level 2: area-level variables</b>		
Index of multiple deprivation (IMD) score	0.1178, 1.43	0.1153, 1.23
Variance of Intercept	7.4110, 0.66	17.1375, 1.09
Variance of Residual	310.93, 13.82	267.88, 11.61
Statistics		
Number of observations	480	396
Number of groups (i.e. LLSOA)	152	146
Intra-class correlation (ICC)	0.0233	0.0601
Pseudo R-square	0.05	0.05
AIC (Akaike information criterion)	4161.94	3394.08
BIC (Bayesian information criterion)	4232.89	3461.76
LL(B), Log-likelihood (restricted) at convergence	-2063.97	-1680.04
LL(0) Null Log-likelihood	-2173.94	-1766.52

ACCESSIBILITY PREDICTION MODEL

In order to see which healthcare facility is more accessible, calibrated multilevel models along with number of people within the catchment area were then employed to predict the overall accessibility score related to a healthcare facility.



APPLICATIONS

By developing a Web tool or Mobile Application form this research methodology and findings, user perceptions can be obtained from different situation (e.g. weather conditions, season, daylight or ground surface slope). These technologies will provide opportunities to develop some applications relating to accessibility to healthcare facility.

CONCLUSION

Based on the model results, a range of policies can be developed that could lead to the reduction in health inequality in terms of fair access to healthcare provision. Also it would be valuable to organisations that need to make decisions based on their users' perceptions who are the real decision makers as to whether to use a facility or not. Collecting larger datasets from more respondents who are using different travel modes (e.g. bus, bike and walk) can support the model in finding more significant factors. Deprivation, Safety and Security indices may be able to affect accessibility more significantly in big cities with different types of area in terms of different deprivation. Therefore developing multilevel statistical models with more respondents' data within different and bigger area may find more significant factors which can affect accessibility perception. This research approach has been able to develop more precise policy based on users' perceptions as users are the real decision makers whether to use a healthcare facility or not.