Accessibility Modelling in Planning Practice: The Impact of Planned Transport Infrastructure on Accessibility Patterns in Edinburgh, UK

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Submitted for the degree of Doctor of Philosophy

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February 2015

ABSTRACT

Although many models/tools have recently been developed to measure spatial accessibility, many of these tools are still restricted to academic studies and have barely been applied in the world of planning practice due to several reasons including the complexity or inadequacy of the methodological approaches involved. Within this context, the research undertaken is motivated by the need to translate the concept of accessibility into a practical and useful tool for practitioners and policy makers. The research identifies several omissions in existing accessibility tools that can be considered as potentially important limitations for some purposes in transport and land-use planning. It also investigates the key features that characterise the usefulness of accessibility tools in planning practice. These findings have been used to develop the GIS-based accessibility tool for this research – SNAPTA (Spatial Network Analysis of Public Transport Accessibility) – which attempts to offer better usability and responds to a number of the omissions identified in existing accessibility tools.

SNAPTA has been applied to a pilot study in Edinburgh city with the main aim of analysing the contribution of the planned transport interventions to improved accessibility by public transport and distributional benefits for urban services and activities in the city. This research case study presents the first attempt to analyse profoundly the accessibility impacts of possible combinations of implementing future phases of the Edinburgh Tram and the Edinburgh South Suburban Railway (ESSR). The findings provide a better insight into the spatial equity and accessibility levels in Edinburgh, demonstrating the significance of introducing non-radial public transport routes to the city network. A key output of the analysis suggests that the first part of Edinburgh Tram, delivered in summer 2014, would bring a very limited improvement to the accessibility of population across Edinburgh Council’s area. On the other hand, the empirical evidence of the study shows that ESSR can play a significant role, bringing a greater benefit for accessibility than any other combination of tram lines. A workshop organised to test SNAPTA in a virtually real exercise enabled expert assessment of the usefulness, robustness and applicability of the tool. The research concludes that SNAPTA offers a useful alternative that can be used in decision-making to inform strategic planning processes for future urban growth and urban structure framed around the integration of land-use with strong public transport accessibility.

To my wife Talei, and to the memory of my father

ACKNOWLEDGEMENTS

First and foremost, my deepest gratitude goes to my primary supervisor, Angela Hull, for her expertise, invaluable feedback and consistent support. Without her excellent insights, this research would not have been possible. I would also like to express my thanks to my second supervisor, Glen Bramley, for his valued input and advice.

My sincere appreciation goes to the Syrian Ministry of Higher Education and Damascus University, Syria, for providing me with a scholarship so that I could carry out this research. Furthermore, I would like to mention the European Cooperation in Science and Technology (COST), which broadened my horizons by giving me the opportunity to participate in training schools for junior researchers and a short-term scientific mission, and allowing me to network with peers all over Europe, all of which contributed to the completion of my research.

I would also like to extend heartfelt thanks to David Watkins for his valuable assistance with data collection; the City of Edinburgh Council – in particular Alistair Harvey – for answering my questions; Lothian Buses – in particular Ian McIntyre – for providing me with data on bus networks; and to Derek Halden for his insightful advice.

Finally, I would like to thank my family in Syria, in particular my late father, and my parents-in-law in the UK for their unwavering support. My deepest appreciation goes to my wife, love and best friend Talei Lakeland, for always being there and for helping me with the proofreading of this thesis.

ACADEMIC REGISTRY
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School/PGI:	School of Energy, Geoscience, Infrastructure and Society		
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TABLE OF CONTENTS

GLOSSARY

CBD	Central Business District
CEC	City of Edinburgh Council
COST	European Cooperation in Science and Technology
DETR	Department of the Environment, Transport and the Regions
DfT	Department for Transport (UK Government)
DMRB	Design Manual for Roads and Bridges
ESSR	Edinburgh South Suburban Railway
GIS	Geographic Information System
GROS	General Register Office for Scotland
LTS	Local Transport Strategy
NHS	National Health Service
NRS	National Records of Scotland
OS	Ordnance Survey
ONS	Office for National Statistics
PATAP	Public and Accessible Transport Action Plan
RTS	Regional Transport Strategy
SEStran	South East Scotland's Regional Transport Partnership
SEU	Social Exclusion Unit
SNS	Scottish Neighbourhood Statistics
STAG	Scottish Transport Appraisal Guidance
TIE	Transport Initiatives Edinburgh
TMfS	Transport Model for Scotland

LIST OF PUBLICATIONS

Journal publications

Karou, S. and Hull, A.D. (2014) ‘Accessibility modelling: predicting the impact of planned transport infrastructure on accessibility patterns in Edinburgh, UK’, *Journal of Transport Geography*, vol.35, pp.1-11.

Chapter in book

Karou, S. and Hull, A.D. (2012) ‘Accessibility Measures and Instruments’, in Hull, A.D., Silva, C. and Bertolini, L. (eds.). *COST Action TU1002 – Accessibility Instruments for Planning Practice*, Porto: COST Office, pp.1-19.

Conference proceedings

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Hull, A.D. and Karou, S. (2011) Analysis of the impact of change in transport delivery on accessibility: the case of Edinburgh public transport, paper presented to *the World Planning Schools Congress*, Perth, July 2011.

CHAPTER 1 – Introduction

1.1 Background

Urban transport is a vital element to the structure of urban life. The real target of transport is access (ICT, 1974; O'Sullivan et al., 2000). Nowadays, the case of being accessible or not being accessible seems to be the issue in transport planning. As living, working, recreating, and shopping are spatially separated activities, people need to travel in order to participate in these different activities. In an extremely dynamic globalised economy, sufficient access to dispersed resources (for example, suppliers, labour and consumers) is a critical circumstance for households and businesses in order to succeed or even only to survive (Straatemeier, 2008). In this context, concepts of the Compact City Policy in Europe and the New Urbanism in USA seek to reduce travel distances and car use since high-density and mix-used areas are believed to be accompanied by more non-motorised and shorter journeys (Van Acker et al., 2010).

Traditional transport planning usually ignores the essential role that infrastructure networks play in supplying an adequate access to different resources and pays more attention to the efficiency of the transport system itself (Straatemeier, 2008). The main elements that have been evaluated for good performance and efficiency are traffic condition, road quality, network coverage, and vehicle characteristics. Although a focus on travel-time saving, there has been little empirical research on the distribution of spatial opportunities at each area. The traditional perspective of transport planning as a fundamental technical capability based on the concept of "predict and provide" in order to improve mobility is not able to achieve the balance between supply and demand any more. In recent decades, transport planners and decision makers have argued that it is the right time for a shift in paradigm (i.e. a serious transformation in the way that a problem can be defined and solutions assessed) towards a new approach in urban transport planning (Dimitriou, 1992; Gifford, 2003; Litman, 2008). This has been motivated by the need of transport policy to meet the requirements of modern society by addressing explicitly wider societal goals such as social cohesion, economic growth and environmental protection which can be served or restricted by transport developments. Accessibility has been recognised by urban and transport planners as a potential alternative to provide the links between transport policy and these other policy areas.

Planning for accessibility is becoming a key component of transport policy in the UK. A recent change in British transport policy (DfT, 2004a; DfT, 2006) suggests that local transport authorities should develop their accessibility strategies. The process of developing the strategies is known as Accessibility Planning which defines goals and applies indicators to enhance access to main services for socially excluded groups.

The UK economy is changing rapidly and is expected to continue so as a result of the dynamics of the world economy. Looking forward, globalisation will continuously change the structure of the UK economy and by implication the demands on the transport system will alter. Large urban agglomerations are becoming considerable growth areas and it seems obvious that they will be the drivers of the UK growth in the coming few decades (ODPM, 2006).

This expected growth of urban agglomerations, and their catchments, seems to be impacted over the next years by growing migration and population. Where extra housing and services are required to underpin the ongoing success of a growing urban area, it is clear in some conditions new or improved transport connections will be required to provide potential area benefits (Eddington, 2006). The changing intensity of development at locations in the city-region affects travel demand and the performance of the transport system whilst city scale transportation investment alters the accessibility of different parts of the city-region (Chapin and Kaiser, 1979; O'Sullivan, 1980; Priemus et al., 2001; Himanen et al., 2005; Holl, 2006; Sultana, 2006; Banister and Hickman, 2007; NICHES, 2007). The dialectical relationship between transport services and spatial opportunities affect both accessibility and spatial equity, another concept closely linked to quality of life. Therefore, the achievement of spatial equity in the distribution of new services and the optimal allocation of resources for infrastructure facilities are a major concern to planners and decision makers who seek to achieve government policies for sustainable development (Tsou et al., 2005; Goulias, 2007).

As a result, the integration of land use and transport in planning the location of new housing and services and their transport requirements together is assuming importance and is widely recognised as an efficient tool to minimise personal costs and maximise the available benefits (e.g. Wegener and Fürst, 1999; Meyer and Miller, 2001; Priemus et al., 2001). As the concept of accessibility can provide a useful framework for that integration, the development of cost-effective policy making involving an accessibility strategy will be a significant integrating force to define a more sustainable approach for transport delivery (Bertolini et al., 2005).

Various researchers have related the level of accessibility of services and goods between supply and demand to the spatial distribution of economic activities and, consequently, to economic growth, land development and increased welfare (see Krugman, 1991; Bruinsma and Rietveld, 1998; Fujita et al., 1999; Vickerman et al, 1999). The more accessible the area is to different activities in a society, the larger its potential growth (Hansen, 1959). Thus, only by adopting the right policies in the right places, transport investments can improve accessibility and contribute to productivity and economic growth as a result (Eddington, 2006).

The role that public transport plays in connecting communities and neighbourhoods and the impact of transport investment on those same communities is acknowledged in local transport policies that seek, for example, 'To improve the transport choices households have available to reach a range of services' or 'To promote accessibility to everyday facilities for all, especially for those without a car' (Hull and Karou, 2011). The spatial growth of urban areas and the decentralization of employment and facilities have made it harder for people without access to a car to make the daily commute and to take advantage of distributed retail and leisure opportunities.

Considering all the above, maximising accessibility, along with minimising travel (particularly by private car), reducing social inequities and minimising the negative effects on the environment are becoming a necessary agenda in urban transport planning (Tolley and Turton, 1995; Handy and Niemeier, 1997; Polzin, 1999). Achieving this agenda needs a package of new instruments focusing on the policy design of land-use and transport strategies in a multi-actor environment to counterbalance the current relative plenty of instruments for investigating mobility problems and assessing alternative transport solutions (Hull, 2005; Bertolini et al., 2005).

1.2 Research Scope and Objectives

There has been a growth of interest in the concept of accessibility over the last decades, with many accessibility studies published in the academic press discussing how to measure accessibility and the contribution such decision support tools might have.

Recently, the development of accessibility tools has used a multitude of approaches to inform land use and transport decision-making (Karou and Hull, 2012). Therefore, translating the concept of accessibility into a practical planning tool stems from the need for powerful techniques to help planners and decision makers to deal with urban and transport management and provide better evaluation of the impacts of different schemes (or combinations of schemes) advanced by transport and land-use policies.

Although many accessibility tools have been recently developed and tested in scientific research (e.g. Gutiérrez and Gómez, 1999; Geurs and Ritsema van Eck, 2001; Halden, 2002; Yigitcanlar et al, 2007; Curtis and Scheurer, 2010), the usefulness and usability of accessibility tools in planning practice is a much less-developed area of study. Many tools are restricted to academic studies due to the complexity of their theoretical underpinnings which leads to a level of detail and complication that makes their output difficult for policy makers and practitioners to understand and interpret. Other tools have been considered inadequate for application and, therefore, abandoned due to several failures or limitations related to operational and methodological issues that make the tool either not sensitive to changes in both the transport system and the land-use system, or incapable of reflecting actual travel behaviour.

The Scottish Government perceives high accessibility as essential to economic growth and competitiveness through "providing access to markets and enhancing the attractiveness of cities as focal business locations and tourism" (Scottish Executive, 2004, p.18). Edinburgh's economy is forecast to play a big part in Scottish economic growth in the next 20 years (CEC, 2010a). The city is currently commencing a huge phase of residential, office and retail redevelopment. Continuing economic success has however created a number of challenges. With a substantial population projected to grow by over 59,000 between 2010 and 2030 (CEC, 2010a) and number of jobs expected to increase by 15% between 2000 and 2015 (CEC, 2007) as well as the forecast rise in the households' car ownership by 30% from 2000 and 2016 causing twice as much time to be lost due to congestion over the same period (TIE, 2004), the maintenance of connectivity and accessibility is one such challenge (Hull and Karou, 2011).

The City of Edinburgh Council (CEC) has defined a series of actions including the implementation of new public transport infrastructures to support the transport system and improve accessibility in the Council's area. The key projects coming to Edinburgh's network is the tram system with several phases and massive allocated budget, and the re-opening of the Edinburgh South Suburban Railway (ESSR) to passenger services. The expectation is to cut demand for road travel and to serve the new regeneration and growth areas while they develop by delivering a reliable and safe public transport service and, consequently, by improving their accessibility. The Public and Accessible Transport Action Plan (PATAP) 2013 - 2020 suggests that the target is to increase public transport's share of all their journeys by 2015 by 1.3%, and by 2020 by 2.3% compared to the Scottish Household Survey average of 2007-8 and 2009-10 of 19.1% (CEC, 2013a, p.25). Since such strategies present key sustainable transport ideas such as plans to boost transport and land-use integration and increase the reliance on public transport, the accessibility tool developed in this research provides an opportunity to deliver key elements of this strategy through estimating the accessibility impacts of policy proposals based on research evidence.

A number of previous studies of accessibility in the Edinburgh city-region examined the transport and land use effects of major new land use developments and looked at accessibility to the key hospitals and employment sites in the region. However, none of these studies nor the business cases for the tram and ESSR considered how these two major transport projects will contribute to improved accessibility and affect the relationships between local travel and activity choices within the Edinburgh Council's area. These latter issues are the subject of this research.

Based on the above discussion, the research addresses two main questions: 1) how to operationalise accessibility measures in order to build a useful decision-making support tool for the integration of transport and land-use policies, and 2) how to use such a tool to assist the City of Edinburgh Council in prioritising transport interventions according to their contribution to improved accessibility. To answer these questions, the following objectives have been formulated for this research:

1. To investigate the theoretical framework of the development of accessibility-based planning tools,
2. To identify the analysis omissions in existing accessibility tools that have been used in planning practice,
3. To identify how to develop a useful accessibility tool for application in practice,

4. To develop an accessibility tool that responds to a number of omissions identified in the second objective and meets the usefulness criteria drawn in the third objective, and
5. To test the tool through empirical study in the city of Edinburgh to identify the impact of the programmed infrastructure improvements of the tram system and Edinburgh South Suburban Railway (ESSR) on public transport accessibility patterns to different types of urban service and activity.

The research thus focuses on accessibility analysis addressing issues of spatial equity and transport disadvantage. It develops an accessibility tool – the Spatial Network Analysis of Public Transport Accessibility (SNAPTA) – which has responded to the need for academic research tools to be more practical and useful tools for the world of planning practice. The tool addresses a number of limitations identified in other tools and attempts to offer better usability, covering aspects of accessibility adequately without making it very difficult to operate, interpret and, consequently, apply in practice. It is intended to assist discussion and support decision-making by examining the efficiency of the public transport network and the spatial distribution of activities, particularly where government contexts call for more sustainable transport options to be developed. Therefore, the development of the accessibility tool in this research has been closely linked to the policy needs arising from the Edinburgh Local Transport Strategy (2007 – 2012) and subsequent reviews.

Therefore, by achieving the above objectives, the contribution of this research can be envisaged in two key areas. First, a contribution is made to science by addressing the knowledge gap in the development of accessibility models that are needed to serve as useful tools in planning practice. The research identifies the main criteria that characterise the usefulness and applicability value of accessibility tools and provides a framework of how modellers can use these criteria to retain theoretical depth in simplified approaches, making their tools more applicable to practice. Second, a contribution to planning practice in general by providing an example of how to create a practical and non-complex accessibility tool that satisfactorily incorporates the relevant dimensions of accessibility and is very able to adequately provide a clear picture of the relationship between transport and land-use. In addition to planning practice in general, the research contributes to accessibility analysis and its implications for policy making/change for the Edinburgh case.

1.3 Research Activities

The research has been conducted through three main stages. First, it starts with a literature review in search of the necessary background information, from the academic perspective, for the concept of accessibility in transport and urban planning and the theoretical framework of accessibility measurement. The review has also examined and compared the different tools used for accessibility analysis to identify the omissions in first wave of tool development. This part of the literature review has been produced through the participation in the COST Action[1] TU1002 – "Accessibility Instruments for Planning Practice" and published in the first report (Hull et al., 2012a). A further literature review has been carried out to investigate the different uses of accessibility tools in the decision-making process, and how to choose and develop useful and usable tools for application in planning practice.

The conclusions of the literature review have been reflected in the second stage of the research which is the construction of the accessibility tool - SNAPTA - within the GIS environment. A wide range of data sets including data on transport infrastructure and services, data on urban activities and land-use systems as well as socio-demographic data have been collected from different sources either under licence from the relevant government or private organisations or from these organisations' websites. These data sets have been integrated into GIS for modelling accessibility in Edinburgh Council's area using a package of different accessibility measures.

In the third stage, the tool has been applied to a pilot study in the city of Edinburgh for both ex post and ex ante accessibility evaluation of public transport services. As a part of the COST Action, to test the tool in a virtually real exercise, a workshop with transport and land-use planners was organised to introduce the tool capabilities and discuss relevant outputs to the application to Edinburgh's network. A post workshop survey was completed by the participants to give feedback on the usability and usefulness of the tool for addressing accessibility issues in planning practice. The results of this survey have been reported to the COST Action and published in its second report (te Brömmelstroet et al., 2014). In addition, validity tests including accuracy and sensitivity analyses of the

[1] COST- the acronym for European Cooperation in Science and Technology- is the oldest and widest European intergovernmental network for cooperation in research. Established in 1971, COST is presently used by the scientific communities of 36 European countries to cooperate in common research projects supported by national funds. COST is based on networks, called COST Actions, centred around research projects in fields that are of interest to at least five COST countries. Source: http://www.cost.eu/

tool were carried out to ensure its suitability for the intended use. This comprises comparisons of SNAPTA findings against observed data and findings produced by similar accessibility tools that have been applied in Edinburgh. The sensitivity of SNAPTA's outputs to changes in the parameters' values and the land-use and transport systems has also been examined in order to validate its application in various situations (see Appendix A).

1.4 Structure of the Thesis

The thesis is written and presented in the order that the research has been carried out. Figure 1.1 illustrates the research framework and the structure of the work presented in this thesis. The present chapter introduces the background to the issue of accessibility planning and the motivation for this research. It also defines the research questions and objectives as well as an overview of the main activities.

Chapter 2 reviews the literature on the concept of accessibility and discusses its main components. It presents an overview of the current theories from the field on accessibility measures. The choices of the operational issues of accessibility measurement including specifications, calibration methods, and other relevant technical considerations are also discussed.

Chapter 3 provides an insight into the available themes or approaches to accessibility modelling by categorising the 'first wave' of accessibility tools developed. The chapter explains how the concept of accessibility is measured and incorporated in accessibility tools, and identifies the analysis omissions that can be seen in these tools.

Chapter 4 focuses more on the usability and usefulness of accessibility tools in planning practice. The chapter describes the different uses of tools in the planning decision-making process. It discusses how accessibility tools can best be selected and developed for application in practice and, as a result, concludes the criteria needed to reach a useful tool for planners and other stakeholders.

Chapter 5 deals with the development process of the accessibility tool – SNAPTA. It explains, based on the conclusions from the previous chapters, the theoretical background and underlying concepts that form the conceptual framework of the tool. The chapter describes the methodology and techniques used for modelling accessibility as well as the sources and types of data sets required for the application to the selected pilot study. In addition, it defines the users of the tool and what they can use it for, and discusses its potentials and limitations.

Chapter 6 introduces the Edinburgh Council area as a case study of the research reviewing the relevant transport and accessibility policies, and discussing the main findings of previous accessibility studies in the region. It explains the rationale for the major public transport infrastructure programmed for the city and defines different scenarios of the possible completion of these infrastructures in order to be assessed in the SNAPTA analysis of accessibility. The chapter analyses the research's potential impact on the current and future policy and practice, and highlights how SNAPTA can contribute to the discussion on accessibility planning and how it can be used for future assessment of the transport vision and land-use and transport integration in Edinburgh.

Chapter 7 presents and discusses the results of the empirical study in Edinburgh focusing on the accessibility analysis of the public transport network for each scenario and the consequent absolute and relative improvement in accessibility to a particular activity or service. It continues with a discussion on how successful the SNAPTA tool has been to evaluate accessibility, the contribution gained through the analysis to the vision for Edinburgh transport and what the results mean in the UK transport context. The chapter also reports on the feedback provided by experts through the COST Action workshop, addressing the usability and usefulness of SNAPTA in planning practice.

Finally, Chapter 8 concludes the study, presenting the main findings and thesis' contribution to research. In addition, it outlines suggestions for further work.

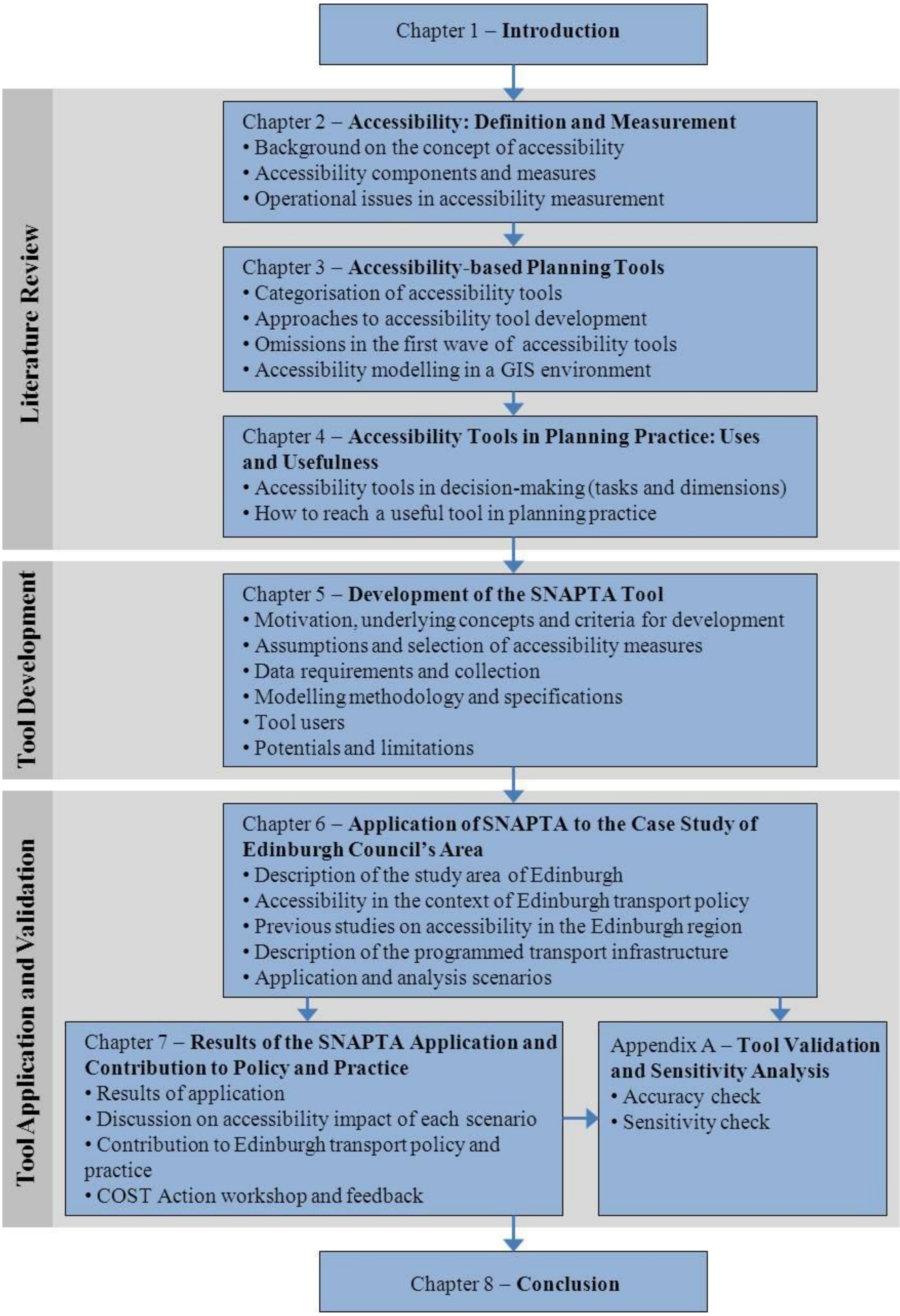

Figure 1.1: Research framework and thesis structure

CHAPTER 2 – Accessibility in Transport Planning: Definition and Measurement

2.1 Introduction

This chapter reviews the literature on the concept of accessibility within the context of transport and urban planning. It provides an insight into why the mobility-based approach as a part of traditional transport planning has failed to resolve transport problems, and why planning for accessibility has instead now become a priority for transport planners. The chapter identifies the main components of accessibility and presents an overview of the current theories from the field on accessibility measures and associated considerations. The chapter provides the basic information needed to understand the different dimensions of accessibility and how the concept can be measured as well as the relevant considerations that should be addressed. The knowledge obtained in this chapter is used later in this thesis (Chapter 5) to develop the accessibility tool of this research.

The structure of this chapter follows on from this. First, Section 2.2 presents various definitions of accessibility. This is followed by a section (2.3) discussing the reasons for the shift in traditional transport planning paradigm and the rise of accessibility as a planning concept. It also looks at the main differences between planning for accessibility and for mobility. Section 2.4 discusses accessibility components. Section 2.5 includes a description of different types of accessibility measures while Section 2.6 continues with a discussion on the advantages and disadvantages of these measures. Section 2.7 focuses on the main findings from the academic literature on the choices of operational issues believed to be important for the application of accessibility measures.

2.2 Definition of Accessibility

Accessibility is a broad concept. In the academic literature, it has been used with many definitions in several fields such as urban planning, transport planning, social planning, pedestrian planning and facility design, and marketing and geography (see Pirie, 1979; Jones, 1981; MuConsult, 1994; Envall, 2007). Accessibility can be considered as an aspect of people's quality of life, and also as an indicator of the built-up environment's potential for sustainability (Makrí, 2001). In general, accessibility is defined as the ease with which different activities, including public services and the needs of people, business and industry, can be reached through links provided by the transport system or communications technology.

Physical accessibility refers to the ability to reach a place despite having a physical impairment while mental accessibility expresses the ability to understand and handle a given area and associated facilities. In the fields of marketing and geography, accessibility refers to the relative ease of reaching a certain area or place (Litman, 2008). Social accessibility is defined in terms of having friends and a job, and being able to access work, meet people and take part in social activities (Makrí, 2001).

The accessibility concept is often used in planning the built environment, referring to landscape planning and the design of buildings and transport modes to express route and facility usability (HMSO, 1995; Folkesson, 2002). It emphasises the importance of creating a transport system that is able to accommodate the needs of all, including elderly and disabled people. In other words, accessibility refers here to the ability of disabled people to move and travel without help.

In transport planning, accessibility has been explained in a number of different ways. It is believed that Hansen (1959) produced the first significant scholarly work on the topic. Hansen (1959, p.73) defines accessibility as the "potential of opportunities for interaction", taking into account the distance between an origin and a destination as well as the value of, or number of, opportunities available at a destination. His definition views accessibility as the ability and desire of individuals to overcome the spatial separation between residential locations and surrounding services. Hansen (1959) distinguishes accessibility from mobility which is defined in his study as the potential for movement, the ability to get from one place to another. In Burns study (1979, p.391) accessibility is described as the "freedom of individuals to decide whether or not to participate in different activities" while in Ben-Akiva and Lerman study (1979, p.656) it is defined as the "benefits provided by a land-use/ transportation system".

Ingram (1971) made an important contribution to putting accessibility into a practical form by subdividing the concept into "relative" and "integral" accessibility. Relative accessibility was interpreted as the extent to which two locations are interconnected with each other while integral accessibility represents the extent to which one location is interconnected with all other locations in a given area.

Moseley (1979, p.182) has formulated an abstract/ schematic concept of accessibility, in which each component in that scheme affects accessibility, as follows:

People → Transport → Activities (at destinations)

People have a variety of activity needs, which can be satisfied through facilities offered at different destinations, with the transport system providing the connection between demand and supply. In this respect, de Jong and Ritsema van Eck (1996) argue that the concept of accessibility does not include just the transport connection between origin and destination and the ability of a group of individuals to travel, but also the purpose of the journey and characteristics of the activities found at the destination. In this view, accessibility can be understood as a relative concept. For example, what is accessible to young people within a particular walking distance is not necessarily accessible to old people and what is accessible by private car is not necessarily accessible by public transport. Also, what is a reasonable effort to travel to purchase furniture may not be reasonable in terms of grocery shopping. This is expressed in a more recent definition presented by Cascetta et al. (2013, p.118) which describes accessibility as "the ease in meeting one's needs in locations distributed over space for a subject located in a given area".

Handy and Niemeier (1997) defines accessibility by the spatial distribution of opportunities, the ease of reaching each opportunity, and its associated characteristics emphasising the importance of three elements: travel cost/time, travel choice and destination choice. It is notable that Handy and Niemeier make particular reference to patterns of land use and the nature of the transport system. Similarly, Derek Halden Consultancy (DHC) (Halden et al., 2000) characterises the understanding of accessibility based on three questions: 1) where or who is being considered (as accessibility is an attribute of locations or people); 2) what are the services and activities being reached; and 3) how are they being reached in terms of the factors that separate locations or people from the services including cost, time, distance, information, etc. Halden et al. (2000) made a further differentiation between the case of considering people in terms of "origin accessibility" and the case of considering service providers in terms of "destination accessibility". Origin accessibility is, therefore, defined as "the ease with which any individual or group of people can reach an opportunity or set of opportunities" while destination accessibility (also called catchment accessibility) is defined as "the ease with which a given destination can be reached from an origin or set of origins" (Halden et al., 2005, p.3).

Bhat et al. (2000, p.1) defines accessibility as a "measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time". In the same vein, the Social Exclusion Unit (2003, p.1) describes accessibility as an individual's ability to reach "key services at reasonable cost, in reasonable time and with reasonable ease". On the contrary, Geurs and Ritsema van Eck (2001, p.36) use the definition: "accessibility is the extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s)". Geurs and van Wee (2004, p.128) add further clarification to distinguish between the "access" and "accessibility" terms: "access is used when talking about a person's perspective, accessibility when using a location's perspective".

Bertolini et al. (2005, p.209) defines accessibility as "the amount and diversity of places of activity that can be reached within a given travel time and/or cost". To develop this definition, Bertolini et al. (2005) has used three widely supported assumptions about human behaviour (See Hägerstrand, 1970; Zahavi, 1974; Downes and Emmerson, 1985; Schafer and Victor, 1997; Wiel, 2002), as follows:

- Individuals mostly travel not just for the sake of it, but for an objective in order to take part in spatially disconnected activities such as working, living, shopping, etc.
- Individuals prefer to have as many choices as possible between a wide range of different activities
- Travel time, travel cost and less importantly travel distance restrict these options in terms of travel-to-work time/budget, total daily travel time/budget, etc.

Furthermore, Bertolini et al. (2005, p.212) suggests that accessibility has an efficiency dimension as well, presenting a definition of sustainable accessibility as accessibility "with as little as possible use of non-renewable, or difficult to renew, resources, including land and infrastructure".

In summary, the key distinction between most of the current definitions of accessibility within the transport planning context is that accessibility can be defined as an attribute of places (accessibility from) or an attribute of people (accessibility to). However, the key elements that are always included in accessibility definitions are the considered category of people or freight, the activity or service supply point and the availability of transport modes or service provision (Halden, 2002).

2.3 Why Consider Accessibility? Planning for Mobility vs. Planning for Accessibility

The social and economic welfare of people depends on the choices or opportunities available to them. The needs of people and businesses to reach activity opportunities which are not available at their location create the demand for travel (Halden et al., 2000).

Transport planning has traditionally focused on transport infrastructure looking in great depth at the movement patterns that connect people and places, with very little consideration of who will use the infrastructure or what opportunities are available at the destination location (Halden et al., 2000). The main focus of transport analysis was on transport demand. The general assumption was that transport supply could be maintained to meet the perceived demands of population. However, the capacity of network will be never improved at the adequate level required to keep up with ongoing increase in demand (Downs, 2004). Even it is possible to expand the current network, for environmental and financial reasons this decision is seen undesirable (Banister, 2002, 2005). It is well known that expanding the current and/or building a new network will increase the amount of traffic and the complexity of the movement pattern while it will not necessarily achieve a better level of connection and interaction between locations.

According to Levine and Garb (2002), the problem in traditional transport planning is that an extended transport network and an improved ability for movement might persuade services to disperse to outer locations, leading to a condition where more mobility is accompanied by more money and time spent in travel.

The uncertainty about the choice of future locational preferences of businesses and households makes predictive modelling of potential mobility patterns more and more problematic (Gifford, 2003; Bertolini, 2007). Furthermore, the analysis of the dynamics in spatial patterns and travel behaviour, stemming from the changes in the land use and the transport system, whilst being very important is often not considered in traditional transport models. However, those that do are often too complicated for decision makers not trained in the theory of these models (Gifford, 2003).

As a consequence, in recent years, increasing the mobility of people and goods by new investments in transport infrastructure is no longer a goal in itself. A major drawback of the concept of mobility (i.e. ease of the physical movement and the ability to get from one place to another), and a key rationale for restricting the use of this concept in policy goals that it is not obvious whether the goal is to persuade people into more or less travel, or whether more or fewer journeys is better (Jones, 1987). Today, transport planning requires more comprehensive analysis to assist decision makers to develop the best possible solutions to transport problems. Banister (2002) suggests that transport planning should address the needed connectivity of locations and improvements in the quality of life rather than forecasting the potential levels of congestion. Moreover, it should reflect and integrate the different objectives and views of all transport and land-use system stakeholders. Therefore, the need for new approaches based on integrated transport and land-use policies has become more and more necessary in order to ensure a strong link between transport supply and demand, and can be used to address wider social, economic and environmental objectives. Since accessibility as a planning concept provides the links between transport policy and these wider policy areas, the use of accessibility in transport planning practice has the potential to play a significant role in assisting planners and policy makers to define how their transport policy objectives can be achieved through practical policies (Halden et al., 2000).

In this respect, rather than satisfying mobility needs as a focus of traditional transport planning, the goal nowadays is to achieve good accessibility, providing a more efficient connection between the transport infrastructure and the spatial distribution of services without raising the negative impacts of mobility brought about by increased traffic (such as noise, congestion, air pollution, etc.). The main assumption is that an individual travels for a purpose to participate in particular activities (derived demand) and not for the sake of travel or just for fun (Makrí, 2001; Levine and Garb, 2002), which is more applicable to journeys made by motorised vehicles than those by walking or cycling. However, it is increasingly acknowledged that some leisure may not have a preconceived destination.

Ross (2000) argues that although mobility has significantly affected accessibility, it does not follow that better mobility always results in improved accessibility. Handy (2002) and Levine and Garb (2002) suggest that the increased ability to move can lead to better accessibility in the short term, but in the longer term this does not necessarily hold. They, independently, added that the achievement of good mobility is not enough or even a necessary circumstance for good accessibility since more travel, per se, would be seen as an indicator of poor accessibility. The authors state that it is possible to achieve good accessibility with poor mobility as long as the key services desired are located in the proximity. Levine and Garb (2002) conclude that increased mobility is required just to the extent that it improves accessibility.

In the light of the above-discussed problems of the traditional approach of transport planning as well as raising environmental and social concerns, the trend towards a shift in paradigm can be understood as a shift from a *mobility-oriented analysis* which assesses transport system performance in terms of quality and quantity of physical travel to an *accessibility-based analysis* which takes into account a wider range of factors and options (see Cervero, 1997 and Litman, 2008). This shift has considerable effects on transport planning. It reforms the definition of transport problems, the kind of solutions that can be implemented, and how proposed solutions are assessed. Mobility-based planning essentially addresses vehicle travel, and consequently the solutions focus on automobile-oriented transport improvement. The view of accessibility-based planning takes into account other aspects, and consequently different solutions are addressed considering more accessible land-use patterns, incentives to break travel behaviour, and improvement to alternative transport means (VTPI, 2006). In this context, Silva (2008) states that the paradigm of transport planning has been shifting from 'predict and provide' to 'predict and prevent' in accordance with the change of mobility problems and requisites.

However, a lot of present planning practices have a tendency to implement mobility analysis rather than accessibility. That can be seen in several cases such as the evaluation of transport system performance in terms of distance and travel speed, which tends towards faster modes and quantitative improvement rather than slower modes and qualitative improvements (Litman, 2007; Metz, 2008). On the other hand, many current practices recognise the advantages of a higher level of vehicle traffic and speed, but they often fail to identify the decline in walkability and the accessibility of locations. These types of planning practices can lead to decisions that raise mobility but decline accessibility on the whole (by cutting travel choices and encouraging urban expansion), and overlook other options to improve accessibility such as mobility alternatives and better accessible land-use development (Litman, 2008).

Table 2.1 compares the perspectives of mobility and accessibility approaches in transport planning. According to Cervero (2001), the key difference between planning for mobility and planning for accessibility is between planning for vehicles and planning for people and places. Cervero (2001) argues that accessibility analysis as a planning approach can compete with and complement the traditional focus of transport planning on mobility and ease of movement. The author suggests that the main reason for shifting the focus to accessibility is the negative impacts of too much traffic on environment as well as people’s desire to spend a longer time at their destinations and a shorter time travelling around.

Similarly, Curtis and Scheurer (2010) differentiate between planning for mobility and for accessibility, suggesting that the former approach (mobility) assumes that residents will obtain access to activities and facilities required to meet their daily needs through the transport network, based on a higher level of movement by car and without taking account of the land-use system. They claim that in the approach of planning for accessibility, there is a need to look at proximity to land-use opportunities as well as the transport system itself, forming a new way of thinking based on the integration of transport planning and land-use planning (Curtis and Scheurer, 2010).

Table 2.1: Comparison between planning for mobility and for accessibility

	Mobility approach	**Accessibility approach**
Definition	The potential for movement (ability of people and goods to move)	The potential for interaction (ability to obtain goods and services and take part in activities)
Objective	The ease to reach any location	The ease to reach opportunities, assuming that people travel for a purpose to participate in particular activities
Impacts on traffic	Improves the ability to move around and encourages the establishment of services dispersed in outer locations, which increases the amount of traffic and the complexity of the movement pattern	Improves the efficiency of transport system and the spatial distribution of opportunities in such a way which enables people to reach their desired destinations with the least possible amount of travel
Land-use consideration	Recognises that land use can affect travel choice	Recognises that land use and activity patterns have major impacts on transport and vice versa
Valuation of activities	No valuation of activities available at destinations	Explicit acknowledgement of the value derived from taking part in activities at destinations
Modes considered	Motorised modes only (car, truck and public transport)	Motorised modes, walking and cycling. Telecommunications can be also considered
Common indicators	Travel distance and speeds, road and transit Level of Service, cost per person-mile, travel convenience	Availability of transport choices, travel distance, time or cost per journey, distribution of opportunities, journey comfort and convenience, information provision
Common units of measurement	Cost per person-miles or kilometres for personal travel, and ton-miles or tonne-kilometres for freight travel	Journeys, opportunities and generalised cost[2]
Transport user benefits considered	Maximum personal and goods movement	Maximum transport choice, opportunities reachable, time saving and cost efficiency, journey quality, comfort and convenience
Environmental impacts	Good mobility has negative impacts brought about by increased traffic such as noise, congestion, air pollution, etc.	Good accessibility reduces the need for travel and therefore makes transport systems more sustainable.
Linkage with wider policy areas	Limited analysis of health and safety (crash rates), environmental and equity impacts	Provides the link between transport supply and wider policy areas including social equity (impacts on different user groups by mode, journey purpose and type of benefit), economy (economic efficiency and wider economic impacts) and environment (health impacts, CO2 impacts and quality of journey)
Resultant transport strategies	To develop transport improvement strategies that increase capacity, speeds and safety	To develop strategies that increase the efficiency of transport system and services distribution, and safety

Source: Author's own derived from Cervero (2001), Envall (2007) and Litman (2008)

[2] Generalised cost is described as the sum of the monetary and non-monetary costs of a journey in which non-monetary costs refer to the cost of travel time and the disutility of travel in general (e.g. inconvenience of interchange) (MVA Consultancy, 2009).

A number of key differences between accessibility and mobility approaches have been identified in the literature. First, unlike planning for mobility, as a result of the consideration of land use the concept of accessibility explicitly acknowledges the value that can be derived from taking part in an activity at a destination (Envall, 2007). The typical definition of mobility (the ease of moving around and getting to any location) makes little distinction between 'want' to reach a destination and 'need' to do so, and, therefore, planning for mobility does not make explicit valuation of activities available at destinations. On the other hand, accessibility can be used as a normative concept using a set of accessibility standards or indicators. An example of this are the core accessibility indicators (travel time thresholds) for different trip purposes defined by the Department for Transport (DfT) (2006, p.65) to guide the planning of public transport provision in Local Transport Plans in England and Wales (see Chapter 5, Section 5.8). This allows planners and decision makers to pre-define the type of activities and services to be considered important (e.g. SEU, 2003).

Another key difference between the two concepts is related to how mobility and accessibility respond to changes in land-use patterns (see Handy, 2002; Levine and Garb, 2002). Planning for accessibility has been seen to take into account land-use changes, particularly those which significantly affect travel behaviour and require people to travel for a relatively longer or shorter distance (or time) to pursue a desired activity (Levine and Garb, 2002), for example closure of the only local supermarket or opening the first GP practice in a given area. Moreover, changes to land-use patterns that can be more directly associated with transport network improvements are an important focus for planning approaches that seek to improve accessibility (Cervero, 2001; Litman, 2008). Therefore, the difference is that land-use strategies play a very small role in planning approaches that centre on mobility. In other words, the objectives of transport policy that are met by land-use changes brought by spatial and urban development policies are not often deducted from the objectives of mobility-based transport planning approach (Envall, 2007). If the objective of transport policy is to improve travel options, the use of accessibility analysis has the potential to find out whether this objective is being fulfilled (Halden et al., 2000). The analysis of the accessibility impacts of changes in land-use and activity patterns can be used by planners and decision makers to identify where transport improvements are needed to serve the new developments. An in-depth discussion on the application of accessibility analysis in planning decision-making is included in Chapter 4.

Another issue relevant to land use that the mobility approach does not deal with clearly, but which can be addressed in the accessibility-based planning approach, is the changes in land prices due to transport network improvements. According to urban economic theory, the construction of large transport infrastructure will increase land prices as a consequence of accessibility improvements. Higher land prices around transport infrastructure cause a higher density of urban development (Boarnet and Chalermpong, 2001). From the literature review by Boarnet and Haughwout (2000) on the effect of major road infrastructure construction on land use, it can be concluded that increased accessibility brought about by infrastructure improvements influences employment and population change, and increases land prices near major transport projects. A case study developed by Boarnet and Chalermpong (2001) identified that road construction improved accessibility and thus increased land prices, concluding that people are willing to pay for improved accessibility. Similarly, empirical evidence has also been found for the influences of public transport service improvements on the values of surrounding land (see Giuliano, 1989; Cervero and Landis, 1995). Therefore, based on the accessibility benefits that will be brought by a new transport infrastructure, planning for accessibility can be used to provide urban developers and service providers with an indication of the areas where land prices might increase.

Besides the link between land use and transport, planning for accessibility has been seen as a practical way to provide the links between transport supply and wider policy areas (DoE and DoT, 1995; DfT, 2006; Halden et al., 2000; SEU, 2003). Whilst planning for mobility take account of health and safety issues often in terms of crash rates only and offers a limited analysis of the environmental and equity impacts (Litman, 2008), accessibility considerations within the assessment framework of transport appraisal can play a significant role in meeting social, economic and environmental objectives (DETR, 2000a; Halden et al., 2000; Litman, 2008). As access to opportunities has the greatest impact on 'life-chances', such as work, healthcare and learning, lack of accessibility has been identified as a major part of the problems experienced by people facing social exclusion (SEU, 2003). The accessibility concept which supports an integrated view of transport and land use assesses the amount of available opportunities based on the existence of these opportunities and the provision of transport options that enable people to reach them within a certain travel time period. Planning for accessibility focuses on the level of transport choices and smooth connections for individuals and business between origins and destinations to ensure that urban developments are delivered in accessible locations (Halden, 2009). According to the Accessibility Planning Guidance (DfT, 2006), improved accessibility helps significantly to meet national and local agenda in other sectors, including: enhancing attendance and participation in education; enhancing health and reducing health inequalities; tackling social exclusion; improving opportunity and access to services in rural areas; raising the levels of participation in sport and culture; and promoting work as the best form of welfare. A consideration of health impacts can be carried out through an analysis of access to health care services, countryside, sport facilities, social support network and other opportunities affecting good health (DfT, 2006). Health impacts can be also considered by improved public transport accessibility through introducing new bus or rail services or making changes to the existing services which affect access to health or recreation facilities (Halden et al., 2000; SEU, 2003). Therefore, the accessibility approach ensures a clear and systematic process for identifying areas or population groups with accessibility problems and improves understanding of the constraints on access to opportunities. In addition, accessibility indices can be included within cost benefit analysis to address the economic efficiency and wider economic impacts of transport infrastructure and urban service developments (Halden et al., 2000; Geurs and Ritsema van Eck, 2001) (see Chapter 4 for a fuller discussion on how accessibility analysis can contribute to the social and economic objectives).

The mobility perspective defines transport problems in terms of barriers to the ease of movement, and therefore leads to transport strategies that increase the capacity and speed of motorised vehicle systems, including road and parking facility improvements, transit improvements, high-speed train, aviation and intermodal connections (Levine and Garb, 2002; Litman, 2008, 2011). Planning for mobility pays little attention to walking and cycling except where they provide an access to (or connection between) motorized modes, which represents a small part of person-miles (Litman, 2011). On the other hand, the accessibility approach takes account of all access options as potentially important, including motorized and non-motorized modes. Furthermore, accessibility is not necessarily restricted to the form of physical transport only. It can include mobility substitutes such as delivery services and telecommunications (Jones, 1987; Litman 2011). The importance of this feature of accessibility has the potential to grow since the number and quality of services that can be reached without being mobile has increased, for example internet banking (Enval, 2007). In this respect, the accessibility approach values modes according to their ability to meet users' needs, and does not necessarily support solutions based on faster modes or shorter trips if slower modes and longer trips ensure an adequate access.

Mobility can be assessed by using a number of indicators, including travel distance and speeds, road and transit Level of Service, cost per person-miles or kilometres for personal travel, and ton-miles or tonne-kilometres for freight travel (a ton of freight moved one mile/ kilometre) (Litman, 2008). These are typically measured based on travel surveys and traffic data. However, in recent years, new techniques have become available to evaluate mobility and multi-modal transport system performance, such as GPS tracking system and data on entry and exit transaction stored by smart travel cards (personal communication with Transport for London). With regard to accessibility measurement, the main indicators focus on travel distance, time or generalised cost per journey, availability of transport choices, and number of opportunities with a travel time (or distance) threshold in addition to other less common indicators that look at journey comfort and convenience and information provision (Makrí and Folkesson, 1999; Halden et al., 2000; Geurs and Wee, 2004). Section 2.5 below discusses in detail the different approaches to accessibility measurement.

In summary, planning for accessibility is a strategy which is different from the traditional transport planning paradigm in the way of how activity opportunities at destinations are valued and how changes in land-use patterns are dealt with. It has been developed from the idea or measure of how well a transport network performs (see for examples Buchanan, 1963; Ingram, 1971; Dallal, 1980) to a measure used to evaluate how well the combined transport networks and land use pattern serves people (see for examples Cervero, 1996; Levine and Garb, 2002; DfT, 2004a). Therefore, thoughts on accessibility planning have been developed within the context of concerns for enhancing the sustainability of urban areas and of reaching more sustainable transport outcomes (Curtis and Scheurer, 2010).

However, on the other hand, it could be argued that planning for mobility also has advantages. In determining policy responses, data on both accessibility and mobility might be needed. A research which focuses on the issue of transport-related social exclusion involving the case studies of Bristol, Nottingham and Oxfordshire has identified three criteria that are useful in identifying the degree of transport related social exclusion and highlighting appropriate policy responses. These are: the level of travel in the area as a whole (area mobility), the level of travel made by particular individuals or groups (individual mobility) and the overall accessibility of the area (Preston and Rajé, 2007). The study found that inclusion is associated with high levels of individual mobility and exclusion with low levels. In the conclusion, the authors emphasise that looking at the inter-relationships between accessibility and mobility is more rewarding than examining either in isolation.

Additionally, in recent transport studies there has been an increase in awareness that short and long term urban mobility decisions are made within social contexts (Abou-Zeid et al., 2013). For example, individual mode choice decisions are found to be better explainable by considering not only an individual's travel patterns, but also journeys and activities of other household members (see e.g. Pinjari and Bhat, 2011; Ronald et al., 2012). In this respect, for sustainable mobility planning, it is important to consider the impact of the network of social relations on various mobility related decisions, including long and medium term decisions (e.g. residential location, vehicle ownership and mode choice) and short term decisions (e.g. parking, driving, riding, and pedestrian crossing behaviours) (Abou-Zeid et al., 2013).

2.4 Accessibility Components

In the light of what has been discussed in the previous section on the differences between mobility and accessibility perspectives (Table 2.1), different components have been used to define accessibility in order to address the relevant considerations in transport planning and urban management (Section 2.3). In the literature, studies of accessibility have presented several ways to classify the main components of accessibility. According to Dalvi and Martin (1976, p19), evaluating accessibility involves three dimensions of equal importance: 1) individual's preferences and choice sets, 2) opportunities available and 3) the level of service the transport system provides in overcoming distances. Handy and Niemeier (1997) and Stanilov (2003) consider two main components of accessibility: the activity component and transport components. The activity component (or attraction or motivation) is related to the distribution of potential destinations, the magnitude, quality and character of activities, while the transport component (or impedance or resistance) is related to the spatial separation that individuals need to tackle in order to reach their activities. In other words, this component is described as the performance of the transport system, which is generally expressed in travel distance, time or cost.

Therefore, Handy and Niemeier (1997) identify four interrelated issues that need to be specified to measure accessibility, including: the degree and type of disaggregation, the definition of origins and destinations, the measurement of attractiveness (by the existence of a particular opportunity) and travel impedance. Furthermore, three types of disaggregation are recognised in their study: spatial, socio-economic and journey's purpose or type of activity. Reneland (1998) outlines four characteristics that should be defined to measure accessibility: origins and destinations, modes available, time of the day and the type of user (according to age, gender, physical ability, type of business, etc.). Halden et al. (2005, p29) discusses two main components for measuring accessibility: the calculation of the separation between origins and destinations using a specified set of modes, and the link of this measure of separation with land-use and population data to present accessibility indicators.

Besides transport and land-use (or activity) components, other studies (Burns, 1979; Kitamura and Kermanshah, 1984) have highlighted the importance of considering temporal component in measuring accessibility, arguing that transport and activity components may differ during the day. Geurs and Ritsema van Eck (2001) and Geurs and Wee (2004) consider four components for measuring accessibility: transport, activity, temporal and individual components. The temporal component reflects the availability of opportunities at different times of the day as well as the time available for people to take part in particular activities. The individual component is defined to reflect people's characteristics, including the needs (based on age, income, educational level, household situation, etc.), abilities (based on physical condition, availability of travel modes, etc.) and opportunities (based on income, travel budget, educational level, etc.). The author's argue that an accessibility measure should ideally consider all the four components. On the other hand, they recognise the difficulty of including all these components in a measure due to the high level of complexity which makes it very difficult to apply in practice (to be discussed in detail in Chapter 4).

It can be noticed that transport and land-use are components common to the classification adopted in all the accessibility studies above. Some studies consider individual characteristics (see Dalvi and Martin, 1976; Reneland, 1998; Geurs and Eck, 2001; Geurs and Wee, 2004) some of which include destination attractiveness as a part of the individual component (see Dalvi and Martin, 1976; Geurs and Eck, 2001; Geurs and Wee, 2004). On the other hand, Handy and Niemeier (1997) characterise destination attractiveness by both the quantity and location of different types of opportunities and break it down into its own characteristics. Temporal characteristics have been classified as a separate component of accessibility in Burns, 1979; Kitamura and Kermanshah, 1984; Reneland, 1998; Geurs and Eck, 2001; Geurs and Wee, 2004.

2.5 Accessibility Measures

It is clear that the different classification of accessibility components results in stress on different aspects of accessibility. Therefore, a range of different approaches to measuring accessibility have been identified in the literature (see Hansen, 1959; Pirie, 1979; Koenig, 1980; Handy and Niemeier, 1997; Makrí and Folkesson, 1999; Halden et al., 2000; Geurs and Eck, 2001; Geurs and Wee, 2004). In general, most of the accessibility measures known at present comprise at least two essential components: transport and activity components.

However, it is important to mention that there is no consistent terminology for describing types of accessibility measures (Envall, 2007). For example, the measure that Hansen (1959, p.73) developed and called a 'measurement of accessibility' has been referred to by different terms in later studies such as a gravity-based measure (Handy and Niemeier, 1997), potential accessibility measure (Geurs and Eck, 2001) and Hansen index (or measure) (Halden et al., 2000). Similarly, the contour measure (Jones, 1981; Geurs and Eck, 2001) is referred to as the isochronic measure (Koenig, 1980), cumulative opportunity measure (Handy and Niemeier, 1997), catchment measure (Halden et al., 2000) and threshold measure (DfT, 2004a). The utility approach as described in Koenig (1980) has been known as utility-based measure in both Handy and Niemeier (1997) and Geurs and Ritsema van Eck (2001) while it is described as value measure in Halden et al. (2000).

In the studies above, accessibility measures have been grouped in different ways. The categorisation defined by Geurs and Ritsema van Eck (2001) and Geurs and Wee (2004) is one of the most frequently referenced, and has therefore been used to structure the rest of this section. These authors group accessibility measures into four main categories: 1) infrastructure-based measures, 2) location-based measures, 3) person-based measures, and 4) utility-based measures.

Infrastructure-based measures analyse the performance or service level of transport infrastructure such as the average travel speed and congestion level on the road network. They have been considered in the national transport policy plans for some European countries (e.g. the UK, Germany, Spain and the Netherland) as an important indicator of the economic development of regions (Ympa, 2000). For example, congestion and total vehicle hours lost in congestion were used as acessibility indicators to evaluate the UK Transport 2010 policy plan (DETR, 2000b; Geurs and Ritsema van Eck, 2001). However, in several transport studies these types of measures have been seen from the traditional approach to transport planning (e.g. Ewing, 1993; Cervero et al., 1997). They do not take into account the land-use component, and are not very capable of dealing with temporal restrictions and individual characteristics (Geurs and Wee, 2004). Whilst the infrastructure-based measures help to identfy the level of transport services in an area, they fail to consider the opportunites at the desired destinations located away from this area (Geurs and Wee, 2004). In addition, issues related to how improved levels of transport services affect land-use patterns are not considered (Ewing, 1993).

Location-based measures describe the level of accessibility to spatially distributed activities. These measures have been split further into distance measures, contour measures, potential accessibility measures and the balancing factors of spatial interaction models. The distance measures (also called travel time or connectivity measures) are the simplest location-based measures, looking at the distance or travel time between two locations. The contour measures (also known as the isochronic measure, cumulative opportunities or proximity count) quantifies the number or size of opportunities reachable within a given travel time, distance or cost. Alternatively, it can be used to calculate the distance, time or cost required to access a fixed number of opportunities. The contour measures are sometimes used an indicator of equality of opportunity (Envall, 2007), for example to examine the proportion of households who have a GP practice within 30 minutes by public transport. Potential accessibility measures (also known as gravity-based measures) estimate the accessibility level in a zone to opportunities in all other zones by using Hansen's equation (1959) (see Chapter 5, Section 5.5 for a more in-depth discussion). The measure uses a distance decay function to reflect the diminishing influence of distant opportunities without imposing thresholds (also called cut-off values). In other words, opportunities are not considered to be equally accessible within a given distance, time or fixed cost. Instead, accessibility levels are considered to decay the longer the distance (or travel time or higher cost) is between the origin and opportunities.

In this regard, the impedance and decay function involved has a significant influence on the results of the accessibility measure. Therefore, the development of adequate impedance functions has been a key issue in several accessibility studies (see Geurs and Ritsema van Eck, 2001 for a detailed discussion of the different impedance and decay functions). However, it is difficult to establish that a particular function is capable of accurately reflecting actual travel behaviour.

The balancing factors (also called competition factors) of Wilson's constrained spatial interaction model (Wilson, 1970, 1971) are described as accessibility measures which have been modified to take into account the competition on supplied opportunities and the competition on demand (Williams and Senior, 1978). The constrained spatial interaction model involves one or two balancing factors as well as the magnitude of flow (e.g. journeys), the number of opportunities at origins and destination and the impedance function which reflects the friction imposed by the infrastructure connecting origins and destinations (Geurs and Ritsema van Eck, 2001). The value of the first balancing factor serves to ensure that the magnitude of flow (number of journeys) generated from the origin zone equals the number of opportunities (e.g. residents) at that zone. The value of the second factor ensures that the number of journeys ending at the destination zone equals the number of opportunities (e.g. jobs) in that zone (Geurs and Ritsema van Eck, 2001). The balancing factors can be used to analyse accessibility for opportunities where the effects of competition can be seen at both origins and destinations such as accessibility to jobs, where employees compete for jobs (destinations) and employers compete for employees (origins) (Geurs and Wee, 2004). Also they can be applied in the case when competition exists at origins only, but not destinations; for example supermarkets compete for customers but customers do not compete for supermarkets. Therefore, the balancing factors represent the competition of destinations available to the origin zone as perceived by the residents of this zone.

Person-based measures (also called space-time measures) are derived from the space-time geography first introduced by Hägerstrand (1970). In space-time geography, the land-use component and temporal component are given equal importance (Geurs and Ritsema van Eck, 2001). Using space-time prisms, these measures express the travelling patterns in space and time from the viewpoint of individuals. They examine accessibility at the individual level, analysing whether or how the participation of an individual (or household) in a particular activity can be achieved within the given time restrictions. In this context, space-time measures describe the feasibility of opportunities to an individual (Makrí and Folkesson, 1999), taking into account spatial and temporal constraints such as the availability or density of the transport system, and the opening times of facilities. In other words, the measures identify the potential areas of opportunities that can be reached and participated in considering given time restrictions (Dijst and Vidakovic, 1997; Geurs and Wee, 2004). Several models have been developed to analyse accessibility based on the principle of space-time geography. For example, the Contactability indicator developed by LVMT-IFSTTAR to examine the potential, for an individual in a location, for having face-to-face contact with someone else in a single or set of distant locations (Bertolini et al., 2012). The indicator measures travel times by public transport using a number of time constraints as accessibility criteria, including departure not earlier than 5am, return not later than 11pm and a minimum time period of 6 hours for a contact (Bertolini et al., 2012).

Finally, *utility-based measures,* which are derived from economic theory, describe accessibility based on the (economic) benefits that individuals gain from access to the spatially distributed opportunities (Geurs and Wee, 2004). The concept of utility-based measures addresses the decision to participate in one activity from a set of potential alternatives, all of which meet basically the same need (Greence and Liu, 1988; Geurs and Ritsema van Eck, 2001). These measures model travel behaviour based on the assumption that individuals seek to maximise their utility. Individuals assign a utility value to each destination choice (or a set of transport mode and destination choices) that they face, and select the alternative that achieves the highest utility value (Handy and Niemeier, 1997). However, since it is not possible to consider all the factors influencing the utility value associated with each alternative by a given individual, this utility can be estimated based on the sum of a non-random (deterministic) component and a random (stochastic) component (Koenig, 1980; Geurs and Ritsema van Eck, 2001). Utility-based measures take into account the attributes associated with each choice, reflecting the attractiveness of the destination, the travel impedance and cost to reach the destination, and the socio-economic characteristics of the individual or household (e.g. income and demographic variables) (Makrí and Folkesson, 1999). On the other hand, in more recent studies, the utility-based approach has been criticised as being unable to reflect accurately actual travel behaviour (e.g. Karash et al., 2008; Abou-Zeid et al., 2013). They argue that people do not always make their travel choices according to the associated utility, suggesting that there are other factors affecting travel patterns of individuals such as time saved by mode choice, the convenience and safety of journeys and the quality of the desired service/ activity at the potential destinations (Karash et al., 2008).

The literature reveals that different studies emphasise different components as being significant to include such as accessibility measures based on the individual (e.g. Koenig, 1980) or accessibility measures based on particular transport modes (e.g. Reneland et. al., 2004). Nevertheless, more comprehensive accessibility studies usually use a combination of different types of measures such as contour measures and potential accessibility measures (e.g. Cervero et al., 1997; Geurs and Ritsema van Eck, 2001). The justification is that different measures which focus on different aspects of accessibility planning and play different roles in policy and scheme appraisal can be complementary, giving a comprehensive picture of accessibility to support the decision-making. Inclusion of temporal constraints in accessibility measures seems a challenging question, for example the availability of opportunities at different times of the day or the allocation of cars between licensed drivers in the household at different times of the day (Morris et al. 1979; Geurs and van Wee, 2004). On the other hand, the availability of the new technology of GPS tracking and mobile data these days provides an efficient source for a wide range of travel behaviour data that could significantly improve the accuracy and ease the application of accessibility measures particularly at the individual level.

2.6 Advantages and Disadvantages of Accessibility Measures

Table 2.2 presents the main advantages and disadvantages of the different accessibility measures described in the earlier section. Infrastructure-based measures can be described as easy measures to apply and interpret by planners and policy makers since these measures involve the transport component only and are often applied using readily available data (Geurs and van Wee, 2004). However, being unable to consider the land-use component as well as temporal constraints and individual characteristics has been seen as a major drawback, which strongly affects the capability of this type of measure to capture key aspects of accessibility. Moreover, the exclusion of land use and activity patterns makes these measures incapable of examining the accessibility, economic and social impacts of transport and land-use change, for example how improved travel time (or speed) influences urban expansion, or how opening a new facility affects the accessibility level in the surrounding area.

Distance measures are the simplest accessibility measures. Nevertheless, their simplicity limits the application of this measure to the cases where the analysis considers journeys from only one origin with pre-defined location to one or set of destinations (e.g. travel time from a freight distribution centre to the rail network, ports, airports and several warehouses), or from one or set of origins to one given destination (e.g. travel time from all the zones of a city to a main hospital). Both distance and contour measures have been recognised as easy measures to apply (to different modes), understand and interpret to the public than any other accessibility measures (Handy and Niemeier, 1997; Geurs and Eck, 2001). Since no assumptions are made about an individual's perception of land-use, transport and their interaction, the distance and contour measures can be applied using readily available data. In this regard, the distance and contour measures fail to consider the spatial distribution of the demand for a particular opportunity as well as the capacity of available facilities (e.g. hospitals, schools, etc.). Both measures have the disadvantage of not taking into account the competition effects at origin and/or destination. Moreover, whilst the contour measure is able to consider the location and attractiveness of opportunities, the distance measure considers opportunities in terms of their spatial distribution only but not their attractiveness. Both measures cannot express the decrease in accessibility with distance (or time) to origin or destination. For example, for a 30 minute time threshold, the opportunity 29 minutes away are counted as equal to those located just one minute away. As a result of the arbitrary selection of travel time (or distance) threshold, the contour measure fails to consider opportunities which are located just outside the threshold area even by only few seconds. Moreover, due to the failure to take account of the decay of opportunities attractiveness and individuals' characteristics and preferences, this measure, according to Geurs and Ritsema van Eck (2001), does not provide an especially useful contribution to social and economic evaluations of land-use and transport changes.

The potential accessibility measure overcomes a main disadvantage of the contour measure (Table 2.2). The measure assesses the combined effect of the transport and land-use components, and includes assumptions about an individuals' perception of transport by using a distance decay function to reflect the diminishing influence of distant opportunities (Geurs and Wee, 2004). In addition, perception of land-use and activity patterns is also incorporated by weighting opportunities according to their attractiveness. However, a large concentration of opportunities within a zone (local accessibility) has a significant influence on the result of the accessibility analysis looking at the relationship between this zone and other zones in the modelled area. In comparison with the contour measure, the level of accessibility is influenced not only by the number, quality or size (economic or physical size) of opportunities, but also depends on their exact locations relative to the journey origin. Therefore, the use of a distance decay function provides the potential accessibility measure with a theoretical advantage over the contour measure. On the other hand, the calibration of this function is a highly controversial issue (see Section 2.7). The function has a significant influence on the results of the potential accessibility measure, and therefore needs to be selected with meticulous care (see Chapter 5, Section 5.4 for a discussion on how the distance decay function for the accessibility tool of this research has been selected). Although the potential accessibility measure can be easily computed using the available transport and land use data, the measure is more difficult to interpret and communicate with non-modellers as it combines land-use and transport elements. Unlike the results of distance measures (expressed in minutes/ hours, metres/ kilometres/ miles, etc.) and contour measures (expressed in values describing the number/ size of reachable opportunities), the results of potential accessibility measures are expressed in undefined units that are often presented in a set of indices (e.g. 1, 2, 3 and 4), reflecting the different levels of accessibility across the modelled area. Another disadvantage of potential accessibility measures is that temporal constraints are not included in the calculation of accessibility (e.g. time ranges for departures or arrivals of journeys and the availability of activities at different times of the day).

Regarding the balancing factors, the key advantage is that this type of measure copes with the exclusion of competition effects in the measures discussed above. Nevertheless, the balancing factors do not look at the individual component of accessibility. They are relatively complex and not easy to interpret and apply due to the iterative estimation procedure which incorporates both the locations of demand and supply weighted by a distance decay function (Geurs and Wee, 2004). The balancing factors are mutually dependent so that they need to be estimated by carrying out a process of calculation and repeating this process until a numerical equilibrium is reached (Geurs and Ritsema van Eck, 2001).

Space-time measures have the important theoretical advantage of considering all the accessibility components. Besides the transport and land-use components, individual characteristics and temporal constraints are also incorporated. However, unlike the balancing factors, person-based accessibility measures do not take account of competition effects. Their main shortcoming is related to the application difficulty. They require detailed individual activity-travel data such as data on individual's travel budget and time availability, which is often not available from standard travel surveys (Thill and Horowitz, 1997), and can be expensive and time consuming to collect. As a result of the requirements for a large amount of data, the application of space-time measures is typically limited to a relatively small geographical scale and specific population group (according to age, gender, income, car ownership, etc.), which make the results very difficult to aggregate in order to estimate accessibility values at a larger scale or for wider population groups. Space-time measures have been seen as potentially useful for social evaluations of land-use and/or transport changes as well as understanding walking and cycling infrastructure investment and issues of comfort and convenience involved in changing between transport modes. Nevertheless, these measures have the disadvantage of focusing on short-term behavioural responses, which is considered inadequate for the evaluation of major land-use and transport investments (Geurs and Wee, 2004).

Table 2.2: Main advantages and disadvantage of accessibility measures

Measure	Advantages	Disadvantages
Infrastructure-based measures	Easy measures to apply and interpret Data readily available	No consideration of land-use and activity patterns
Distance measures	Very straightforward to compute Easy to interpret and communicate Data readily available	Only for one relationship – between a set of origins to one destination only, or between one origin only to a set of destinations No distance decay No consideration of opportunity attractiveness No consideration of competition effects
Contour measures	Easy to interpret and communicate since the results are expressed as the number (or size) of reachable opportunities Sensitive to land-use changes at faraway destinations within the modelled area because there is no distance decay The size of population, number of jobs, floor space areas of retail, or any other reachable opportunity (within a specific cut-off travel time) can be expressed	No distance decay (all the opportunities located within the threshold time area are equally counted and not weighted by the distance) Arbitrary choice of accessibility boundaries (cut-off values). As a result not all the relationships between origins and desired opportunities are considered The opportunities which are located just outside the threshold time area even by only few seconds are neglected No consideration of competition effects
Potential accessibility measures	Gradual decay of accessibility with distance or time to origin or destination All relationships between origins and all possible destinations are considered so that not only the near opportunities but all desired opportunities are considered Combined effects of transport and land-use components are taken into account Modest data requirements	Self-potential (local accessibility within a zone) has a significant effect on accessibility values, particularly in zones with a big concentration of opportunities Assumes all individuals in the same location (or zone) have the same level of accessibility Less easy (than contour measure) to communicate and interpret by non-modellers because of decay function and expression of the results in an undefined unit Focuses on the spatial distribution of existing opportunities but not on the distribution of demand No consideration of individual's characteristics No consideration of competition effects The decay function and its associated parameters have a significant influence on accessibility values so that they must be selected with meticulous care

Table 2.2: Main advantages and disadvantage of accessibility measures – continued

Measure	Advantages	Disadvantages
balancing factors	Competition effects are considered	Not easily interpreted and communicated Relatively complex to compute No consideration of individual's characteristics
Space-time measures	Individual's characteristics are considered High level of individual-based disaggregation A detailed examination of the network including climate factors associated with the journey (e.g. comfort and convenience)	Requires a large amount of data which can be expensive and time consuming to collect. Therefore, the measure is more likely to be applied for a micro-scale analysis (e.g. neighbourhood studies) or small population group for which data collection is not too onerous Focuses on the demand side only (e.g. it takes account of the time availability of individuals but not that of activities) No consideration of competition effects
Utility-based measures	All accessibility components including transport, land-use, individual and temporal components are considered High level of individual-based disaggregation	Not easily interpreted and communicated. The measure should be explained using reference to relatively complex economic theories Not easy to compare different utility functions

Source: Author's own derived from Handy and Niemeier (1997), Geurs and Ritsema van Eck (2001), Geurs and Wee (2004) and Silva (2008)

The utility-based approach incorporates all the accessibility components apart from the temporal constraints. However, it enables the development of a space-time utility accessibility measure (see Miller, 1999; Silva, 2008) by taking account of the time available for activity participation, which implies the disadvantages of the person-based measures in terms of complexity and data availability. In general, the main shortcoming of utility-based measures lies in the difficult interpretability and communicability of the measures due to the connection with relatively complex economic theories of which most planners and decision makers are not familiar with (Koenig, 1980; Geurs and Ritsema van Eck, 2001). Clearly, a significant advantage is their potential applicability in economic assessment, identifying the impact of transport and/or land-use changes on individual benefits.

Based on the comparison of the accessibility measures discussed above (see Table 2.2), it can be concluded that the definition of how accessibility can be measured in land-use and transport planning varies according to the intended objectives. It is clear that different accessibility measures cover different dimensions of accessibility, and thus the choice of approach affects the results. In this regard, Handy and Niemeier (1997) and Makrí (2001) argue that there is no best approach to measuring accessibility. Different situations and objectives require different approaches. Therefore, it should be emphasised that approaches to measure accessibility need to be selected in awareness of the underlying assumptions of each approach (Guy, 1983; Kwan and Hong, 1998; Song, 1996). Later, Chapter 4 provides a detailed discussion of how to choose an appropriate accessibility approach for application in planning practice.

2.7 Important Choices for Accessibility Measurement

Regardless of the type of accessibility measure and the components involved, the results of accessibility measurement are also sensitive to number of issues in the relation to the specifications, calibration methods, and other technical considerations and fundamental assumptions underlying the applied approach in which the choice of these issues could limit the effectiveness of the whole analysis and have a strong influence on the result. The key issues which transport planners and modellers are required to make decisions when measuring accessibility can be summarised as follows:

- The definition of origins and destinations, and the nature of trips (i.e. multipurpose trips vs. single purpose trips);
- The definition of the level and type of data disaggregation;
- The definition of transport modes;
- The definition of geographical scale;
- The definition of boundaries of the study area;
- The choice of day of the week and time of day;
- The measurement of spatial separation;
- The measurement of opportunity attractiveness;
- The choice of value weightings to reflect the relative importance of different factors;
- The calibration of cut-off values (for contour measures);
- The calibration of decay distance function (for potential accessibility measures); and
- The calibration of destination choice (for utility measures).

It is important to make appropriate choices for the above operational issues in order to achieve an accurate reflection of actual travel behaviour. Inappropriate choices could lead to inappropriate conclusions. Figure 2.1 presents the main approaches to resolving these issues. The *definition of origins and destinations* is an important issue that must be given a special attention when an accessibility measure is developed. Handy and Niemeier (1997) recognised two main different types of trips that have been used in the literature: home-based trips and non-home-based trips. However, most modellers have focused only on home-based indicators which consider each origin as a household address.

In connection with the definition of origin and destination, issues related to *multipurpose trips and trip chaining* have been largely ignored. Trip complexity is growing; with journeys that increasingly combine trip chains. Rather than just travelling between home and work, individuals add in extra stops (to visit friends, go shopping, etc.) which is more common and more complex among car users than public transport users (Halden et al, 2005). A common assumption adopted in analysing accessibility is that all travel has a simple nature (Morris et. al., 1979; Jones et al., 2005), meaning that travel comprises only two separate stages; beginning at home, going to a single destination for a single purpose and then returning home. Handy and Niemeier (1997) suggest that the choice sets of destination opportunities in any accessibility study must reflect the actual choices available to each considered group (e.g. different socioeconomic groups have different needs and, consequently, different choices). In addition, the spatial and temporal limitations must be accounted for when choice sets of potential destinations are included in the modelling. However, Morris et al. (1979) argue that the consideration of all mode and destination choices for multi-stage journeys could weaken the behavioural veracity of most trip generation models due to the complexity in specification of purpose and mode in multi-stage journeys and the mutual effect of each stage on perceived accessibility related to previous and following stages. Another choice regarding the definition of origins and destinations has been discussed in Geurs and Ritsema van Eck (2001). It is based on the demarcation of nodes or regions across the whole study area to act as the potential origins and/or destinations. The authors discuss three ways to define the demarcation: (1) based on network nodes or centroids to represent cities or regions, (2) raster-based GIS technology, and (3) a combination of the previous two ways. In all these ways, the number of resulting nodes or regions relies on the disaggregation level used in the measurement (Silva, 2008).

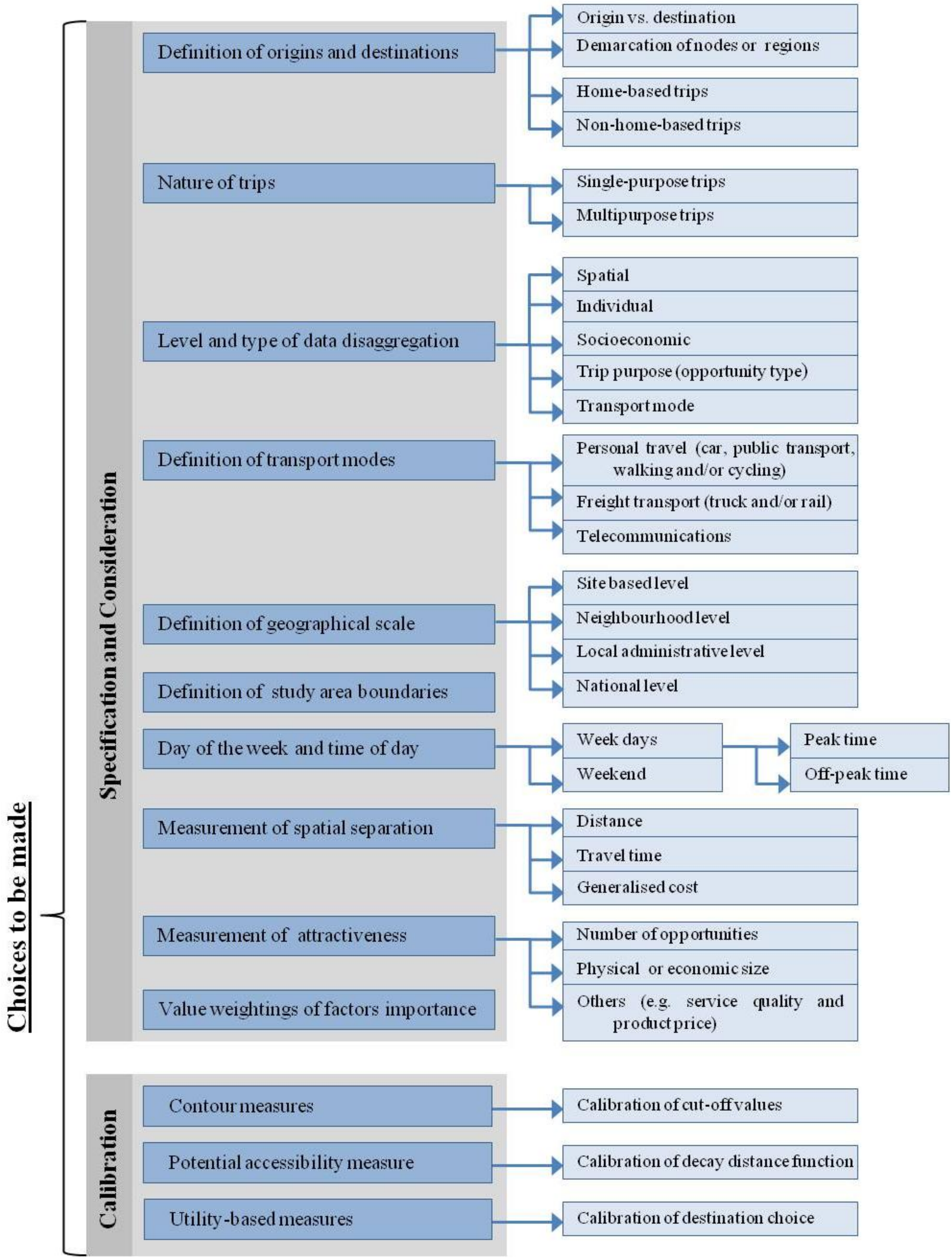

Figure 2.1: Choices of specification and calibration for accessibility measurement

Source: Author's own derived from Morris et al. (1979), Handy and Niemeier (1997), Geurs and Ritsema van Eck (2001), Silva (2008) and Halden (2009)

The *level and type of data disaggregation* is another important issue that has to be defined carefully since it has a great influence on the result of accessibility measurement. Generally, the disaggregation can be specified based on various dimensions such as spatial units, socioeconomic groups, trip purpose (or type of opportunity), transport modes, etc. (Handy and Niemeier, 1997; Silva, 2008). The spatial unit has been considered as the most essential dimension for disaggregation due to the spatial nature of accessibility (Handy and Niemeier, 1997). Concerning this dimension, disaggregation can be defined by zones where households and individuals are divided by proximity. One controversial assumption is that the choice of zoning system (i.e. the spatial division of the study area) has no impact on the estimation of accessibility. Based on micro-economic consumer choice theory, the individual perceives a set of available alternatives in which each alternative has a particular level of ordinal utility (Henderson and Quandt, 1971). In regard to this case, Morris et al. (1979) argue that the set of alternatives for destination choice is the set of zones. They point out that it is important that the individual perceives the spatial distribution of opportunities as this separate pattern of zones. However, Morris et al. adds that this is implausible apart from journeys for shopping purposes when the sought products are available only at very limited sites. In this respect, Dalvi and Martin (1976) and Geurs and Ritsema van Eck (2001) conclude that accessibility indices are sensitive to the type of zoning system applied.

Furthermore, data disaggregation can be defined separately by either household or individual. Handy and Niemeier (1997) state that the smaller the zone, the greater the disaggregation and, consequently, the more accurate the estimation of accessibility for households and individuals in the zone. Accessibility can also be measured for different socioeconomic groups according to age, gender, education, income, occupation, etc. With regard to disaggregation based on trip purpose, most of the accessibility studies have considered jobs as the only type of pursued opportunity, and for higher levels of disaggregation, distinction between work and non-work opportunities have been included. Transport mode is another disaggregation dimension that can be applied when a comparison of accessibility by mode is required. Disaggregation by mode can be useful for sustainability analysis by comparing accessibility by car with accessibility by public transport, walking and cycling. It is worth mentioning that although a higher disaggregation level leads to more accurate analysis, this could make the measure more difficult to operate and interpret. Silva (2008) argues that spatial disaggregation and node (or region) choice are extremely interdependent. In other words, higher spatial disaggregation decreases the impact of node choice on the results of accessibility measure. It is not surprising that this relation turns out to be vice versa; the less the spatial disaggregation, the higher the influence of node choice on the results validity.

The application of accessibility measures can be made at different *geographical scales*. However, the choice of geographical dimension should not be random. It needs to be made in order to produce the detail of results required for the intended objective of the study. In this regard, four administrative levels can be defined for accessibility measurement (Halden et al, 2005; Halden, 2009). First, there is the site based level – the level on which local urban and transport planners deal with accessibility during the permitting process for development proposals, such as for hospitals, schools and businesses to provide safe and good access for customers, staff and suppliers. Second, there is the neighbourhood level at which accessibility analysis can be used for urban space design and management to ensure access to local facilities such as food stores and bus stops (see Chapter 3, Space Syntax technique). The third level is the local administrative level particularly for local authorities, regional planning authorities, transport operators, passenger transport bodies and others. It is applied relatively often to decide how best to spend limited infrastructure funds to improve access to opportunities for businesses and residents. Fourth, the national level which is applied to make sure that the policy, funding and legislative framework assist in improving access for specific social groups or economic actors in line with government policy.

Besides the geographic dimension, the *definition of the study area boundaries* is another important choice for the reliability of analysis (Halden et al., 2000; Geurs and Ritsema van Eck, 2001). The decision to set up the artificial boundary could be crucial factor for the results of some accessibility measures such as cumulative opportunity measures in which the generated accessibility values for nodes or areas adjacent to the boundary are unnaturally low compared to the reset. Since no data is provided beyond the chosen boundary, the impact of the opportunities that are located just outside the modelled area, even by only few seconds, is neglected. That could undermine the accuracy of the measurement especially where these opportunities play a significant role in the public service in that area (e.g. hospital). Therefore, Silva (2008) discusses the fact that the size of the study area chosen to run an accessibility measure needs to be greater than the area defined for analysis. In this case, no areas in the analysis are affected by the artificial reduction in accessibility values due to boundary effects.

The *choice of transport mode* could be a general problem in trip generation models. That is due to the need to build separate indices for different modes such as car, public transport, cycling and walking for personal travel, truck and rail for freight transport. Morris et al. (1979) discuss that this requires some previous knowledge of the chosen mode regarding travel time, travel cost and fares, reliability, interchange options, and type of vehicle. In the sequential method of travel demand modelling, this knowledge becomes available only after the stage of trip distribution (destination choice). To deal with this situation, Vickerman (1974) and Burns and Golob (1976) have suggested a mode specific method for trip generation with giving a marked effect of car availability (defined at the time when the decision to travel, not to travel or to delay travelling is made). An interesting assumption is that the choice of destination and of mode is often assumed to be a simultaneous single decision. Morris et al. (1979) and Halden et al. (2005) recognise that in actual fact this choice expresses two separate choice functions that do not necessarily match a simultaneous single choice function. This assumption has been frequently made to avoid problems that might result from different behaviour models for destination and mode choice. The underlying base of the assumption is that the concept of accessibility is connected most naturally to a simultaneous perspective of travel and destination demand and choice, in which the combinations of mode and destination may be viewed to assess the accessibility to the home base of the trip. Morris et al. (1979) suggest that this perspective can be met by sequential choice models of mode and destination fairly easily for out-and-back home based trips.

Specification regarding *day of the week and time of day* when accessibility is considered must be also defined. Significant differences in transport and activity supply as well as people's demands might exist between week days and the weekend (e.g. access to jobs) and at different times of the day, for example peak time or off-peak time. Furthermore, the consideration of the accessibility impacts of seasonal variations might be also useful (see Halden, 2010).

The *measurement of spatial separation* (also called travel impedance) is another specification issue that needs to be addressed in measuring accessibility. The spatial separation represents one or more attributes of the links between areas that separate places and people from the opportunities (see accessibility components, Section 2.4). Distance, time or generalised transport cost are the most common indicators of spatial separation. Distance and time can be estimated based on straight-line distance or some modification of it (using a constant multiplier) (see Chapter 5, Section 5.7), or by using transport models to measure travel distance/ time based on the actual network. Field surveys can be conducted to collect information on actual travel times by car or public transport. Alternatively surveys of residents on their perceived travel time can be used (Handy and Niemeier, 1997). The travel time for a typical journey can be broken down into several components. For example, a car journey comprises walking to the parking place, car travel time, congestion time, finding a parking place near the desired destination and walking to the destination (Geurs and Ritsema van Eck, 2001). Regarding public transport, the journey comprises walking time to the closest access point (stop/ station), waiting time, in-vehicle travel time, interchange time (if applicable) and walking time to the destination. Many accessibility studies (see Koenig, 1980; Morris et al., 1979; Handy and Niemeier, 1997) recognise that distance as a measure of travel impedance has a less clear connection to the actual travel behaviour than travel time. When travel time is used, Handy and Niemeier (1997) emphasise that the impact of congestion on travel time needs to be considered by distinguishing between travel during peak times and travel during off-peak times.

Handy and Niemeier (1997) consider the use of generalised transport cost incorporating both monetary cost and non-monetary cost (time value) as an improvement over the use of travel time alone. Further, they suggest that differences in travel time and cost by mode need to be addressed. However, the estimation of non-monetary costs of a journey that refer to the cost of travel time and the disutility of travel in general (e.g. inconvenience of interchange) can be problematic, particularly when the same travel time value is applied to all travel, regardless of conditions, such as journey purpose, time of day, delay and discomfort (MVA Consultancy, 2009). In addition, the value of time and comfort might considerably vary from person to person according to the socio-economic characteristics and circumstances of an individual such as age, income, time availability, etc. Moreover, the prices of fuel and fares might change over short periods of time (Geurs and Ritsema van Eck, 2001), making the calculation of a journey's monetary cost not very practical. In addition to distance, time and cost, Geurs and Ritsema van Eck (2001) define travel 'effort' (or convenience) as an indicator of travel impedance that consists of several elements such as comfort, reliability, safety and the level of stress. Nevertheless, the authors recognise the difficulty of estimating and expressing some of these elements in quantitative terms.

The influence of the *attractiveness of opportunities* on travel patterns was found in theories of transport geography and transport economy (Karash et al., 2008). A study carried out by Naess (2002) that focuses on the traditional economic approach to understanding residential location concludes that the travel between different destinations is assumed to be influenced on the one hand by the reasons people may have for going to a place, and on the other hand by the discomfort involved when travelling to this location. In this regard, the author defines two elements that affect the destination choice: the attractiveness of locations and the spatial separation. Handy and Niemeier (1997) suggest that the attractiveness of opportunities can be estimated simply based on the number of reachable opportunities, or by using the opportunities' physical size (e.g. floor space area) or economic size (e.g. employment, turnover, etc.). In addition, several studies looking at shopping behaviour (e.g. Bucklin, 1967; Guy and Wrigley, 1987) show that the destination choice is influenced by a range of characteristics related to the quality and price of services and products available at the potential destinations. This finding suggests that such factors can be incorporated into the measurement of attractiveness (Handy and Niemeier, 1997).

Further attention should be also given to the choice of *value weightings of the relative importance* (or unimportance) of appropriate factors, such as journey convenience and safety, physical barriers, mode characteristics, service quality, etc. The weighting system chosen could have a significant influence on the results (Jones et al., 2005). It can be determined in advance by the modeller or through the calibration process which may also involve estimating the values of various constants and parameters in the measurement structure (Wegmann and Everett, 2008) (see the discussion below on the calibration methods for different accessibility measures). This is often accomplished with specialised statistical computer programs designed for just such purpose, or by using values of constants and parameters from models estimated for another location that is similar to the area being studied (Institute of Transportation Engineers, 1992). Verifying the values estimated for constants, parameters and weighting system is carried out through the validation process which seeks to demonstrate the ability of the accessibility measurement to replicate actual travel patterns. Validation is typically an iterative process linked to calibration (DfT, 1997; Wegmann and Everett, 2008). It requires comparing the measurement output to observed data to check whether they are in acceptable agreement. Alternatively, it can be carried out by comparing the output against other output generated by a similar model that is already successfully validated (against observed data) (Wegmann and Everett, 2008). A detailed discussion on the validation of the accessibility tool developed for this research is included in Appendix A.

In addition to the above-described fundamental issues and specifications, choices related to the calibration of the accessibility measures used and other relevant considerations need to be made. Several studies on measuring accessibility argue that all measures need to be calibrated, and the parameters used have to be selected and specified carefully to reach an accurate reflection of the actual travel behaviour (see Ingram, 1971; Morris et al., 1979; Handy and Niemeier, 1997; Geurs and Ritsema van Eck, 2001). In this context, Morris et al. (1979) point out that regardless of the nature and purpose of the intended application, the practical value of accessibility measures is based on the extent to which they reflect the actual travel behaviour and the perception of transport network users. Handy and Niemeier (1997) define that the aim of calibrating accessibility measures is to reflect the households' and the individual's perception of the travel and available destination choices. They add that the adopted calibration methods need to reveal the actual travel behaviour rather than the preferred behaviour which is not necessarily identical to the actual one. Therefore, it can be stated that the calibration is an important process to validate the soundness and accuracy of accessibility measures.

For the contour measures (cumulative opportunities measures), the *choice of cut-off values* (threshold travel distance, time or cost at which an opportunity is considered accessible) is the key element of the calibration. Although there is no a clear rule on how to choose this element, many studies used different cut-off values to calculate a series of accessibility measures (e.g. Voges and Naude, 1983; Witten et al., 2003). Handy and Niemeier (1997) suggest that using a bespoke travel survey to collect the frequency distributions of travel times or distances could give some indication of relevant cut-off values. Although these measures involve the most arbitrary calibration, some researchers argue that cut-off values should be selected to satisfy decision makers' and planners' perception of accessibility (see for example Geurs and Ritsema van Eck, 2001). According to the DfT (2006), for the definition of cut-off values, it is important to take account of other choices related to the purpose of the journey and transport mode considered. A study carried out by Jones et al. (2005) looking at accessibility by the local walking network shows that the choice of maximum acceptable walk times should take into account the age and physical condition of the social group considered since different social groups have different walk speeds.

For the potential accessibility measures (gravity-based measures), the calibration involves choosing or estimating a parameter value for the *distance decay function* (or impedance function*)* that reflects the importance of travel impedance in the destination choice (Handy and Niemeier, 1997). The choice of a suitable impedance function is fundamentally a technical issue. The literature does not provide a theoretical basis on how to choose the right function. The only adopted principle is to use a form that fits the available data. Using journey frequency, Ingram (1971) examines three functions for calibrating distance decay (reciprocal, negative exponential and Gaussian). The author concludes that a Gaussian function is more suitable than the others since it fits local data on trip length in minutes vs. trip frequency (Envall, 2007). According to the view of Handy and Niemeier (1997), the negative exponential function provides the closest connection with travel behaviour. Geurs and Ritsema van Eck (2001, p.146) define four main forms of impedance functions that are frequently used in accessibility studies: a negative power or reciprocal function, a negative exponential function, a modified version of the normal or Gaussian function, and a modified log-logistic function. These functions were estimated for the journey possibility by all modes and journey purposes together using data on travel time and journey frequency from the Dutch National Travel Survey. Geurs and Ritsema van Eck reach the conclusion that the log-logistic function shows the highest correlation with observed travel behaviour while the negative exponential function comes second. From the different studies above, it can be identified that there are several factors that should be considered for the calibration of the impedance function, including transport modes, journey purpose and frequency, and characteristics of the individual and the destination. Further, Envall (2007) suggests that the perception and valuation of the impedance function also depends to some degree on the span of journey lengths considered in the calibration process (i.e. regional or local accessibility) and the quality and availability of the empirical data.

For utility-based measures, Basmaciyan and Schmidt (1964) introduce the *calibration of destination choice* models as a principle for deriving these measures. In this regard, Handy and Niemeier (1997) define that the destination choice models are calibrated based on travel survey data in which each journey reflects a single choice, and the aspects of the choice including travel impedance and the characteristics of both the traveller and the destination are considered as explanatory variables in a utility function. This method allows the examination of different utility function arrangements to determine the one that best corresponds to the actual travel behaviour.

2.8 Conclusion

This chapter reviews the relevant literature in order to clarify how the concept of accessibility has been defined in transport planning and why it has become an issue to be considered by transport planners and decision-makers. The traditional approach of transport planning which focuses on mobility to improve transport system performance in terms of quality and quantity of physical travel has failed to accommodate the increasing demands of the population. Moreover, the environmental impacts associated with the increasing amount of traffic and the complexity of movement patterns together with raising social concerns have been key reasons for exerting pressure for transport policy changes. Planning for accessibility differs from the traditional transport planning paradigm in how opportunities at destinations are valued and how changes in land-use patterns are dealt with. It has been developed from the idea or measure of how well a transport network performs (see for examples Buchanan, 1963; Ingram, 1971; Dallal, 1980) to a measure used to evaluate how well the combined transport networks and land use patterns serve people (see for examples Cervero, 1996; Levine and Garb, 2002; DfT, 2004a). As an approach which provides links between transport supply and wider policy areas, planning for accessibility addresses the requirements of socially excluded groups and improves understanding of the different social, economic and environmental impacts of transport changes. Therefore, thoughts on accessibility have been developed within the context of concerns for enhancing the sustainability of urban areas and of reaching more sustainable transport outcomes (Curtis and Scheurer, 2010).

Several different approaches to measure accessibility have been found in the literature. In general, accessibility measures must incorporate at least land-use and transport components. Other components related to individual characteristics and temporal constraints might be also included. The review identified that accessibility measures can be categorised into infrastructure-based measures, location-based measures, person-based measures, and utility-based measures. Further, four types of location-based measures including distance measures, contour measures, potential accessibility measures and the balancing factors are presented in the chapter. Each of these measures has advantages and disadvantages, and captures different dimensions of accessibility with different levels of complexity.

Choices made concerning operational issues including specifications, calibration methods, and other technical considerations have been seen as vital to the accuracy of reflecting the actual travel behaviour and, as a result, the usefulness of the measurement results. Therefore, accessibility measures should be applied with a careful definition of these issues and can best be calibrated using actual travel data. Some authors stress the importance of reflecting the actual travel behaviour rather than the preferred behaviour which is not necessarily the same as the actual one (e.g. Handy and Niemeier, 1997). Other authors prefer to keep this issue open according to the study objective, for example Envall (2007) points out that measuring accessibility could be based on actual travel behaviour, preferred travel behaviour or equality of opportunities. The following chapter examines how accessibility measures have been converted to decision-making support tools to be used in planning practice.

CHAPTER 3 – Accessibility-based Planning Tools[3]

3.1 Introduction

The interest in the concept of accessibility, more recently, has broadened such that there is a multitude of approaches used in the consideration of the development of accessibility tools (also called accessibility models or instruments) and the contribution they could make to urban planning practice to inform land use and transport decision-making. Following the review of academic literature included in the previous chapter on accessibility measures, this chapter focuses on the common approaches to accessibility modelling and aims to understand the different types of available accessibility tools. To understand the antecedents of the available accessibility tools, the chapter seeks to categorise the older first wave of the tools that have been produced in the last two decades, providing insights on how these tools address problems of urban management and transport planning. This documentary review is limited to the accessibility-based planning tools in the English language academic press and seeks to explain early conceptualisations of accessibility and how the concept is measured and incorporated in the tool. It helps to identify the main omissions in the first wave of accessibility tools to set a template of issues that the more recently developed tools should address. The findings of this chapter together with the criteria for developing useful tools in planning practice (identified in Chapter 4) form the underlying concept for the development of the accessibility tool in this research (described in Chapter 5).

This chapter has the following structure: Section 3.2 uses the literature to categorise the available accessibility tools. Section 3.3 takes a more thematic approach to the categorisation of accessibility tools developed for urban planning practice, using some of the most common accessibility tools in Europe. The section explains the themes or approaches to accessibility, the concept(s) incorporated in the tool, what is measured, data requirement and output as well as other relevant considerations. Section 3.4 presents what can be seen as some of the omissions in the 'first wave' of accessibility tools that should be addressed by tool developers if accessibility tools are to have a wider application in urban and transport planning. Finally, Section 3.5 focuses on the recent

[3] An early version of his chapter was published in the first report of COST Action TU1002 "Accessibility Instruments for Planning Practice in Europe" (Karou and Hull, 2012).

technical developments in modelling accessibility within the Geographic Information System (GIS) environment.

3.2 Categorisation of Accessibility Tools

Since the concept of accessibility, as discussed in the previous chapter, focuses on the 'ease of reaching' a number of daily activities at different destinations, planning for accessibility is, therefore, interested in the ability of social groups to reach destinations where they can carry out a given activity as well as access the transport network (Bhat et al., 2000; SEU, 2003). This conceptualisation of how efficiently the spatial distribution of services and facilities is connected/ integrated with the transport infrastructure creates a new challenge for the developers of accessibility tools and land-use/ transport planners.

The review of the literature on accessibility studies in Chapter 2 concludes that in general three key elements have been commonly considered to characterise accessibility measures: (1) a defined geographical "origin" location or category of people or freight that is being considered for accessibility, (2) a set of relevant destinations that might be weighted by the size or quality of associated opportunities, and (3) a measure of spatial separation between (1) and (2) which is usually expressed in terms of time, distance or generalised cost. Some accessibility tools focus on origins or people, some on opportunities, and some on the connection.

Accessibility tools can be categorised in different ways. Several criteria have been used in the literature to categorise accessibility models as well as other types of models in the field of transport and land-use planning. The most commonly used criteria include: model's purpose, type of measure used (see the previous chapter, Section 2.5), mode considered, data requirements, responses modelled and impacts measured (see Spiekermann and Neubauer, 2002; Scottish Executive, 2003; TRL & University of Leeds, 2004; DHC, 2007). Regarding responses modelled, accessibility tools can be sensitive to various changes related to speeds/delays, route, mode, trip generations and (departure) times, trip distribution and destination, modal shift, changes in population and employment distributions (by zone), and changes in other factors represented in the tool. Accessibility tools can be categorised according to the type of impacts that they are capable of measuring. For example besides measuring the impact on accessibility, some tools can give indications of how changes in transport, land-use, temporal or individual components affect travel demand/ pattern, modal shift or distribution of population, jobs and other activities as well as environmental and health impacts such as emissions, noise and accidents.

Issues related to the tool capability and functionality have been often used as criteria to categorise tools available for modelling accessibility. In this regard, one of the most frequently referenced categorisations was introduced by the Scottish Government in the Scottish Transport Appraisal Guidance (STAG) (this document to be described later in Chapter 6). The Scottish Government bases their categorisation of tools on the purpose for which indicators of local accessibility have been developed: for example to assess cycling and walking, and/or the coverage of public transport network, (Scottish Executive, 2003). Therefore, three main categories have been defined: 1) tools analysing local accessibility by walking and cycling; 2) tools analysing transport network accessibility; and 3) models designed for some other purpose but which can be used in the derivation of accessibility indicators (Scottish Executive, 2003, B-22). In the same context, Derek Halden Consultancy (DHC) (2007) split the accessibility tools available globally into three similar categories based on functionality. First, local catchment tools that are used by service providers such as public transport operators and retailers. These tools help providers to plan suitably for residents/ customers to enable access to their facilities, using the analysis of the local population and output information on potential customers within the catchment area. The second category is that obtained from public transport or road journey planners. This type of tools usually focuses only on calculation of the time required to reach desired destinations. The third category includes land use and transport models which are more complex compared with the catchment or journey planning tools. These can incorporate information on different features such as the type of opportunity and traveller behaviour that can be linked with separate accessibility models to produce a better quality accessibility calculation. By combining the two above categorisations, this research uses the following three categories in the next section to illustrate the different approaches taken by tool developers in the first wave of accessibility tool development.

Category 1- *Accessibility tools analysing walk times to public transport services or to local facilities*. The tools of this category look at local accessibility by walking and/or cycling only. In these tools, public transport systems are classified according to types of destination served, frequency, mode, and time of day while local facilities are classified according to the associated function. Usually, the consideration of local walking and cycling opportunities is based on the distance which can be measured either by using the simplest form – the straight distance – or by using the actual network. The tools use distances to calculate travel times by setting speeds for appropriate walking and cycling speeds. Their outputs often express accessibility in terms of the time required to reach the closest opportunity of a particular type or in terms of the number of opportunities reached by walking or cycling for a certain time or distance thresholds. Some of these tools have the capability to weight accessibility levels according to the characteristics of reachable public transport facilities such as the frequency/ reliability of services available at those facilities (Scottish Executive, 2003). Other tools consider the physical characteristics of pedestrian routes (e.g. slopes) in the calculation of walk times.

Category 2 - *Accessibility tools analysing travel times using public transport systems and motorised vehicles through the motorway network*. In these tools, public transport networks are defined using journey planning techniques and destinations are expressed as opportunities, activities or places (e.g. city centres). Origins and destinations are represented as people and activities (or places). Travel times through the network are usually calculated based on routes between zones using journey planning algorithms or derived from other transport modelling (DHC, 2007). In the most highly developed form of this type of tool, not just travel time through networks is taken into account, but also the scheduling of transport services and activities at journey destinations within time windows can be considered. The main disadvantage of these tools is that the relationship between supply and demand is inadequately represented or not represented at all (Scottish Executive, 2003).

Category 3 – *Tools or models that are not specifically developed to measure accessibility that, however, involve the process of accessibility modelling*. These incorporate: demand models, land-use transport interaction models, and activity-based models. Most demand models can generate some form of accessibility index – mainly changes in accessibility levels for input to an economic appraisal. Using aggregated measures of travel time and cost, demand models can calculate accessibility indicators by linking transport and land-use data (usually using a logarithmic scale for the travel time/ cost and readily available data on the land uses and other activities available in each zone) (Scottish Executive, 2003; DHC, 2007). Land-use transport models describe the spatial interaction in terms of accessibility as a central process for spatial development. Activity-based models estimate behaviour based on accessibility to opportunities. This category includes four stage models used in conjunction with accessibility analysis processors such as the Transport Model for Scotland (TMfS).

3.3 Approaches to Accessibility Tool Development

This section compares the different approaches to accessibility tool development using the above-mentioned three-fold categorisation of tools. This categorisation is chosen in the research in order to illustrate the different approaches to accessibility modelling based on the functionality and the purposes that a tool has been developed for, using a combination of two key categorisations in the literature (see the previous section). Another reason for adopting this categorisation here is because it is consistent with the classifications articulated in the state of the art scientific literature (Handy and Niemeyer, 1997; Geurs and van Wee, 2006; Silva, 2008) and at the same time relates easily with the context in which practitioners apply ideas on accessibility. More importantly, the three categories used to structure this section reflect a better understanding of issues related to tool usability in planning practice (discussed in the next chapter) that form a basis for the development of the accessibility tool used in this research. Examples of accessibility tools from each category have been selected for the discussion below. The selected tools represent a number of other tools that have a similar functionality and, therefore, fall into the same category. As noted earlier, this English language review is heavily dependent on accessibility tools developed in the United Kingdom due to the lack of English materials on accessibility tools developed in non-English speaking countries.

3.3.1 Category 1 – Local accessibility by walking and cycling

This first category includes accessibility tools that examine the accessibility by walking and cycling to public transport services or to local facilities. Within this category are tools that measure access to the public transport network at a geographical point without measuring the separation or interaction between places. One example of this approach is Public Transport Accessibility Levels (PTAL) which has been developed by the London Borough of Hammersmith and Fulham. PTAL deals only with the origin or destination of a journey using a set formula to measure the intensity of public transport provision at different points (bus stop or train station) within easy walking distance of each area or site (Jones et al., 2005). This formula takes account of walk time to nearby public transport services, the number of services available, service reliability and average waiting time in order to score each location on a six-point scale (Halden et al. 2005). The main datasets required are the public transport network including locations of public transport stops, delineation of routes and schedule frequency in order produce the PTAL indices for different time periods of public transport service (Wu and Hine, 2003). The output of PTAL's analysis is expressed as a set of accessibility indices for a range of locations. It is classified into six-value ranges and spatially mapped, and then defined in terms of accessibility levels.

Another example of this category, which incorporates more robust measures of the perceived walk access times to bus stops and rail transport, is WALC (Weighted Access for Local Catchments) developed by the Transport Studies Group (TSG) at the University of Westminster. This is a walk access tool based on a very detailed representation of the local walking network, covering pedestrian only routes, alleyways and short cuts. WALC calculates walk access times for different groups of people taking account of a number of barriers associated with the local environment, including: local terrain (e.g. steep hills); the lack of provision of a shelter and seating at bus stops; low levels of street lighting; and difficulties in crossing busy roads because of heavy traffic volumes, speeding traffic, barriers (e.g. guard railing) preventing crossing at convenient points and lack of safe crossing points (Jones et al., 2005). It uses the contour measure based on different walk speeds and maximum acceptable walk times to different public transport nodes, and with regard to the concerns of various population groups. Weighted values for the above barriers such as lack of bus stop facilities and steep gradients (=>1:5) are used to produce the catchment areas. Several different types of data are required for calculating each catchment; these include: a road network including a detailed pedestrian network; the location of bus stops (and facilities available), crossing points, steep hills, lamp posts as well as lighting levels; the weighted perceptions of different population groups in regard to each of the barriers associated with walk access; and other relevant data related to traffic flow and pavement characteristics (Jones et al., 2005). When various weighting factors are applied to the pedestrian network and to certain railway stations or bus stops, catchment areas can be calculated and presented as maps. The analysis is able to produce three different types of catchment area for each of the socially disadvantaged groups considered, to/from selected railway stations and bus stops. These include: unadjusted walk catchments (no penalties); daytime penalties catchments; and night time penalties catchments (Jones et al., 2005).

Both the PTAL and WALC tools analyse access to local public transport facilities but they fail to look at the accessibility impact of the land-use pattern. The distribution of local services that are located within a given walking distance/time threshold is not considered. Whilst PTAL treats people as having similar accessibility needs, WALC considers a number of individual characteristics, showing how the catchment boundary would differ according to the mobility of the population group, for example different walking speeds for different age groups (Jones et al., 2005). By taking account of individual limitations and physical obstacles (e.g. local terrain, heavy traffic volumes, etc) WALC aims to demonstrate how the consideration of the actual hindrances to walking will change and shrink the shape of standard catchment areas. Also, the impact of factors related to the safety of journeys can be included in the analysis such as low levels of street lighting for walking during hours of darkness and absence of formal pedestrian crossing arrangements. On the other hand, PTAL fails to consider the influence of the safety and physical features of the pedestrian network on walking time and, as a result, on accessibility (Wu and Hine, 2003). However, PTAL is capable of taking account of the frequency of the public transport services available within the catchment area in order to weight accessibility values. Unlike WALC which can be operated by using the standard functions of ArcGIS, PTAL requires working on ACCMAP software to facilitate the production of accessibility indices.

3.3.2 Category 2 – Accessibility by motorised vehicles through the transport network

The tools of this category look at accessibility by public transport and/or car through the motorway network. One or more motorised modes are considered while the analysis of walk times to public transport services might also be incorporated in some tools. The journey planning technique is usually used to describe how origins and destinations are connected based on the best route (i.e. shortest time, distance, or lowest cost). One application that focuses on accessibility of the bus network is PTAM (Public Transport Accessibility Mapper) which was developed by West Yorkshire Passenger Transport Executive. PTAM is an integrated GIS-based accessibility mapping tool which is able to calculate both origin and destination-based indicators. The tool measures accessibility of a location or set of locations by calculating the total travel time by bus taking account of walking time (straight-line distance from and to bus stops), bus waiting time (estimated from service frequencies) and bus journey time (calculated from bus timetable database) (Halden et al., 2005). PTAM requires a range of data sets related to transport, activities and people, including: bus services databases (i.e. timetables, stops and routes); Ordnance Survey mapping illustrating road networks, and administrative boundaries; census statistics including many population characteristics; employment location characteristics; and facilities databases using information on the provision of retail, education, health, and leisure services (Jones et al., 2005). The output of PTAM can be presented as isochrones on an Ordnance Survey background or as tables including census statistics, employment statistics and lists of facilities associated with their attributes (Jones et al., 2005).

Another application that focuses on the bus network is SONATA (SOcial Needs And Transport Accessibility) which has been used by rural local authorities in the UK to address travel needs and prioritise their expenditure on rural public transport (DfT, 2000). SONATA is a technique that was developed by Steer Davies Gleave in the late 1980s to estimate travel needs and identify gaps in the transport network across a given area (Helm, 1999). It evaluates the extent to which the existing public transport services are able to meet people's travel needs based on trip profiles estimated from maximum travel times and duration of purpose, and also test the effect of service changes and define those services that are most significant in meeting these needs (Cumbria County Council, 2002). It assigns total travel needs to particular journey purposes according to percentages obtained from travel survey data (Titheridge, 2004). The model analyses the use of bus services for work, health, senior education, leisure and shopping purposes. By applying car ownership, population and other socio-economic factors, numbers of unmet journeys can be identified (Somerset County Council, 1997-2000). The key output of SONATA is a prediction about the proportion of travel needs produced by each area which are met by the public transport network. The output can be expressed in terms of need met/unmet for each journey purpose. A mapping system has been included to present the results on a geographical base. Additionally, SONATA is able to generate a report on the number of travel needs that are met by each separate public transport service (Steer Davies Gleave, 2004).

Some tools in this category can cover all the key components of journey time by public transport incorporating walking time, waiting time, in-vehicle time (actual not generalised/ weighted) and interchange time. An example of this type of tools is CAPITAL (CalculAtor for Public Transport Accessibility in London). CAPITAL measures accessibility based on the minimum of total travel time between two zones using any combination of public transport modes in Greater London (i.e. bus, underground, Docklands Light Railway and national rail) in addition to walk access times (by assuming an average walk speed of 5km/h) to the public transport network (London Transport, 1999). The CAPITAL tool combines information from Transport for London’s Planning and Development Geographical Information System (PDGIS) and its public transport assignment model (RAILPLAN) (Jones et al., 2005). It relies on the Ordnance Survey Centre Alignment of Roads (OSCAR) database as a source of the road network in Greater London, containing all the major and minor roads, which has some supplementary information on walk links. RAILPLAN represents links, stops and services together with route characteristics such as frequency and uses a multi-routing assignment algorithm. The analysis output is typically provided as shaded maps showing isochrones of journey travel times from and to a specific location, or set of locations using GIS mapping software. Furthermore, the output file can be also presented as a spreadsheet on which other types of analysis can be carried out (London Transport, 1999).

There are tools in this category that support multi-modal travel including public transport, car, cycling and walking. Two examples of this approach are TRANSAM (TRANSport Accessibility Modelling) and Accession. TRANSAM is an approach developed by Brown & Root to measure and quantify road network accessibility by competing travel modes and to analyse access changes as a result of network improvements and introducing new public transport services. It provides the ability to make a comparison of accessibility measures for cycle, walk and public transport networks or for a combination of these travel modes for a complete journey from origin to destination (Robbins, 1999). The calculation takes into account the walk time at the start and end of the public transport journey, the wait time at the bus stops and railway stations, and the on board travel time (Titheridge, 2004). Data sets have to be set up in GIS for TRANSAM. These include the car network with the associated speed-flow relationships and observed volumetric information for each link; the public transport network (i.e. bus and rail) with the service time tables; cycle and walk networks; network nodes reflecting bus stops and railway stations; points of interest or "focal" points on the network such as transport interchanges, centres of employment and key hospitals; and other relevant statistical data (Robbins, 1999). By running TRANSAM, travel time contours will be generated based on the lowest generalised cost route for a range of travel modes (e.g. rail, bus, car, cycle and car) from all network nodes to the destination node. As a result, GIS can demonstrate visually the extent of travel attainable for acceptable combinations of travel modes, highlighting the areas where levels of network accessibility are relatively low or high.

Accession is a travel access and travel time mapping package that was developed by MVA and Citilabs on behalf of the UK Department for Transport (Jones et al., 2005). It is built from a fully functional GIS with many features to help Local Authorities and their partners in: setting up strategic and action plans; the evolution and development of proposed actions; the prioritisation of resources; and the monitoring of accessibility strategies and action plans (DfT, 2004b). Accession supports multi-modal travel and flexible routed and demand responsive transport modes (DfT, 2004b). The tool measures accessibility to and from any point based on travel time, cost, distance or generalised cost through road and public transport networks (Titheridge, 2004). It is able to consider many origin and destination combinations in calculating accessibility and to generate different types of indicators (Halden et al., 2005). Accession offers a number of calculation methods: Threshold Hansen/ Gravity measure, Hansen/ Gravity Measure, Relative Hansen/ Gravity measure, Simple Utility or logsum measure or simple time-constrained accessibility (Citilabs, a). Access to local public transport is represented as a combination of walk time to a boarding point and the average wait time for a service. This can be calculated based on either the actual walk time or a straight-line walk time, while in-vehicle travel time is usually calculated based on scheduled arrival or departure times. The accessibility calculation can be carried out for specific catchment values of origins/ destinations, for selected modes, for particular routes/ services, and for particular days of the week and times of day (Titheridge, 2004). Other criteria can be also considered in the analysis, for example road speed, maximum speed, frequency, start and end times, and delays for wheelchairs (Citilabs, a). In order to measure accessibility, Accession requires a collection of data sets with regard to: public transport data (rail and bus) including boarding points and full timetables; the road network with the associated speed limits; walk and cycle links; and demographic and other data that can be disaggregated from census geography and other polygon systems onto origin points (Citilabs, a). The outputs can be presented as tables and various contours reflecting accessibility levels. Also, they can be exported for mapping or analysis in other packages.

The above-described tools that look at accessibility by motorised vehicles through the transport network are examples of a wider group (see Category 2 in Section 3.2) which includes other similar tools, such as ACCMAP (MVA), APTT (Halcrow) and ABRA

(Colin Buchanan and Partners). A comparison between the above tools identifies that the accessibility analysis of some of them is restricted to just one transport mode. For example, PTAM and SONATA analyse accessibility using the bus network only while the other tools (CAPITAL, TRANSAM and Accession) consider all the public transport modes available in the modelled area. PTAM, CAPITAL and SONATA use travel time to express spatial separation. TRANSAM and Accession rely on generalised cost, applying the same time value to all journeys regardless of purpose and time of day. Apart from SONATA, waiting time at the public transport access points is included in the accessibility calculation carried out by all the tools. However, unlike the tools of Category 1, using the actual pedestrian network to calculate walking distance to the public transport network is not considered in all these Category 2 tools. They instead use the straight-line distance to measure walking time to the public transport network. Some of the tools including PTAM and SONATA fail to consider the interchange options of public transport journeys. The consideration of journeys at different times of day and days of the week is possible in TRANSAM, Accession and PTAM and can be specified by the user. On the other hand, the accessibility calculation in CAPITAL and SONATA is restricted to travel during the morning peak period only during week days (Jones et al., 2005; Titheridge, 2004). In addition, issues related to journey scheduling such as target arrival or departure time or both, arrival or departure during a specified period, depart after, and arrive before can be defined in the Accession tool.

Regarding the calculation of in-vehicle travel time, SONATA relies on travel survey data taking account of maximum journey times (DfT, 2000). PTAM, TRANSAM and Accession use the timetables associated with public transport services while CAPITAL estimates travel time based on the average speeds associated with the road network. CAPITAL considers only the location of opportunities while the other tools express opportunities in terms of attractiveness, mainly population or number of jobs at the destination-location. Whilst PTAM, TRANSAM and Accession assume that the analysis outputs reflect accessibility levels of all people in the modelled area, different population groups can be considered in measuring accessibility in CAPITAL and SONATA. For example, CAPITAL uses standard representative values for walk speeds, thresholds, etc. (Jones et al., 2005), and SONATA employs a combination of local surveys and social indicators to measure travel needs for different groups (Titheridge, 2004). Nevertheless, all the above tools, in general, cannot help in predicting future changes in transport or land use since they are mainly sensitive to the supply side only (e.g. changes in routes, job distribution, etc.) while information on individuals' demands is hardly included. Although GIS techniques have been involved in the construction of all these accessibility tools, some of them cannot be operated and managed using only the standard features of GIS. TRANSAM requires a customised GIS (Robbins, 1999). Accession is not an open source model. It can only be run via specific software (Accession and Geomedia), which is considered as the model's main disadvantage (Yigitcanlar et al., 2007). All these tools lack the real time capability to update the data involved, such as changes in travel time due to traffic congestion, delay, road construction, maintenance or surfacing.

3.3.3 Category 3 – Models designed for another purpose incorporating accessibility

In this category there are models and tools that have not been developed specifically to measure accessibility that, however, incorporate some dimensions of accessibility modelling (e.g. GenMod, DELTA, MEPLAN, ACCALC, TMfS, ACCALC, SNAMUTS, Space Syntax, etc.). Included in this category as examples are two demand/ land-use – transport interaction models and a technique from urban space design.

GenMod

GenMod is a static multimodal transport model that was developed by the Transportation Planning Department of Amsterdam (DIVV) and the University of Amsterdam (te Brömmelstroet and Bertolini, 2008). It is basically a traditional four-step model based on household surveys and mobility counts. As a by-product, GenMod can be used for measuring accessibility as it calculates travel times between 933 zones within the Amsterdam region using extensive public and car transport networks.

GenMod has been used to show the land use – transport system consequences of land use/ transport alternatives, by calculating network consequences (e.g. level of service), network opportunities (e.g. for more efficient use) and the dynamics of indicators that show the change from a baseline scenario; for example potential accessibility (e.g. the number of people or jobs accessible from each zone within acceptable travel time) and sustainability (e.g. the number of people or jobs reachable within a straight-line distance) (te Brömmelstroet and Bertolini, 2008). In order to run the model, land-use data including the number of people or jobs held by zone, and road and public transport networks are required. The outputs of GenMod runs are presented as clear overviews of all the indicators used and spatial maps produced by GIS that help to define which land use –

transport system choices have a negative effect on the chosen indicators and which a positive one. These can be used to build a list of appropriate land use/ transport choices and strategies.

TMfS (Transport Model for Scotland)

TMfS is a strategic, multi-modal demand and assignment model which was developed by MVA Consultancy, with its land-use capability developed by David Simmonds Consultancy (Transport Scotland, a). The key objective of TMfS is to enable the Scottish Government and Local Authorities across Scotland to examine the impact of and/or interaction between major inter-urban road and public transport schemes and major transport policy options in forecast years (MVA, 2006). TMfS measures the implications of these schemes for accessibility and travel demand and, as a result, helps local authorities in prioritising and scheduling their transport interventions (Transport Scotland, a). Other objectives are to undertake economic, traffic and land-use assessments of proposed transport schemes and policies, and also to produce robust traffic forecasts on all trunk roads within the model area (Transport Scotland, b; MVA, 2006).

An accessibility analysis package is included as an add-on to the basic TMfS model. The analysis uses the output costs obtained from running the basic model along with several parameters specified by the user, and produces a number of accessibility measures. These measures can be for either destinations or origins, and can be weighted by demographic and socio-economic data related to each geographical zone such as the number in employment or the number of households (Transport Scotland, b). The model takes into account the main responses of transport network users to schemes or policies such as destination choice, mode choice, route choice, trip frequency and peak spreading. A wide range of data is required to run TMfS which is built using a system of zones and a transport network. The main data include (Transport Scotland, b): census and travel to work data; planning data forecasts on future development land allocations; national/regional economic and geo-demographic assumptions; public transport service data; road network details; and count data (traffic counts, public transport user counts, turning counts at junctions and car park surveys).

TMfS is a strategic regional model that generates a variety of outputs that can be used to evaluate policy initiatives or public transport and road infrastructure schemes as well as to predict changes in both transport and land use patterns over the model area. The key outputs available from TMfS are: operational analysis; accessibility analysis (performed by linking the operational analysis of the transport model with graphical and tabular analysis of land use changes); congestion mapping; accident analysis; environmental analysis; economic and financial assessment; sub-area analysis; and demographic and land-use predictions (Transport Scotland, b; MVA, 2006).

Unlike the accessibility tools in Categories 1 and 2 described earlier, both models TMfS and GenMod include information on travel demand that can be linked with transport supply to predict future scenarios in transport or land use. Access to cars per household can be considered in GenMod to identify areas where public transport improvements are required. TMfS has the capability to generate appraisal indicators relevant to economic and environmental impacts associated with the transport network and accessibility improvements (e.g. reduction in emissions due to changes in the journey length/ route) (MVA, 2006). GenMod gives an indication of the impact of accessibility changes on sustainability by identifying changes in the number of people or jobs reachable within a walking distance due to transport/ land-use interventions (te Brömmelstroet and Bertolini, 2008). Whilst GenMod models are able to represent the distributional impacts of strategies and measures per geographical area for all people, TMfS can be run to consider different population groups. Opportunities and activities at the destination have been included in these two models in which the number of these opportunities (e.g. number of jobs) is often used to express zone attractiveness. The above models consider accessibility by public transport or car. However, since TMfS was developed to be applied at a large geographical scale (regional/ national level), the calculation of walking time to bus stops or railway stations has not been considered for journeys carried out by public transport services. GenMod uses the straight-line distance to measure walking time to the nearest public transport access point (te Brömmelstroet and Bertolini, 2008). Issues related to interchange options and time/ day of journeys for accessibility modelling can be included in both models. Similar to the accessibility tools of Categories 1 and 2, TMfS and GenMod do not have the capability to update the data in real time.

Space Syntax

Space Syntax is a technique developed by Bill Hillier, Julienne Hanson and colleagues at the Bartlett, University College London that provides a spatial analysis of aspects and structure of space and helps to describe social activities and human behaviour from a spatial configuration perspective (Jiang et al., 2000). Space Syntax has been used to estimate the connectivity and, therefore, accessibility of architectural or urban spaces (i.e. buildings, open spaces, streets and cities) (Hillier, 1996). It is also able to define movement patterns and the degree of difficulty in mobility. Moreover, the tool can be used for other applications including land-use distribution, criminal activity, estate prices and other spatial related characteristics.

The main principle of Space Syntax is to model a spatial structure as a set of axial lines and calculate spatial indices of a space in order to estimate the relation between various parts of indoor or urban spaces (Jun et al., 2007). Axial lines are lines of unhindered movement used in measuring accessibility, and they are defined as the least number of longest straight lines. This is illustrated with a connectivity graph where axial lines are represented as nodes and line intersections as links, which reverses the terminology used in the traditional method (Abubakar and Aina, 2006). Three key measures using different configuration parameters can be applied in Space Syntax: 1) "connectivity" which computes the degree that each space (node) is directly linked to other spaces (nodes) in the connectivity graph, 2) "control" which computes the potential of any space to provide part of a route linking between any two spaces within a defined distance (modelling movement *through* spaces), and 3) "integration" which computes relative depth from any space to all other spaces (modelling movement *to* spaces) (Abubakar and Aina, 2006; Vaughan and Geddes, 2009).

Distances can be considered in Space Syntax by three different types of calculation. These include metric (shortest paths), topological (fewest turns' paths) and geometric (least angle change paths). For example, when *topological distance* is applied, the most accessible locations are not those closest to all other locations in terms of metric distance, but rather those in terms of number of changes of direction through the journey (Hillier et al., 2007). The topological method, also called depth-based accessibility, is considered more significant than the metric method since it assesses the complexity of routes within the modelled area (Rose and Stonor, 2009). Depth of one node from another can be directly estimated by calculating the number of turns (or steps) between two nodes, while the depth of a node (or a street) in a particular step distance is measured by the number of nodes that are separated from that node by the given number of steps (Jun et al., 2007). For accessibility modelling in Space Syntax, the transport network (public transport services, roads, cycle and/or walk routes) as well as the associated lengths of the network links are required to be built. The spatial indices derived from Space Syntax analysis reflect the extent to which a space (or node) is integrated and connected with other spaces (or nodes) in the modelled area (Jun et al., 2007). The output maps can be presented in several scales of colours showing the different range of accessibility values (Vaughan and Geddes, 2009).

Since the Space Syntax-based technique does not consider traditional travel costs such as travel time (Jun et al., 2007), the model has a key disadvantage to calculate the actual journey length compared with TMfS and GenMod and other accessibility tools from Categories 1 and 2 described above. In Space Syntax, interchange options and waiting time at public transport access points cannot be considered. It is not possible to apply different values or weights to the other journey components including walking to the public transport network and in-vehicle travel time. Also, distance decay cannot be applied. The model considers the spatial distribution of opportunities while their attractiveness cannot be described in the analysis. The model is not capable to represent travel demand or different characteristics of population groups. However, Space Syntax is able to consider the impact of several physical features of the network such as the number of connections and turns that separate origins from destinations (Hillier et al., 2007).

3.4 Technical Omissions in Accessibility Tools

This section discusses the main technical omissions identified in the available accessibility tools based on the review of different approaches adopted in the first wave of accessibility tool development. The discussion focuses on the different types of impacts and the analysis capabilities of the tools that fall into Categories 1 and 2 since these tools are designed to address particularly the accessibility issues, which is the case of the tool developed for this research (see Chapter 5). Table 3.1 outlines the main factors omitted in the existing accessibility tools that can be considered as potentially important limitations for some purposes in transport planning and urban management. The failure to consider these factors could limit the analysis capability of tools to examine some relevant impacts or to reflect accurately the actual travel behaviour. However, it is important to mention that it is not necessary that each accessibility tool should capture all the analysis capabilities/ factors mentioned in Table 3.1 since the different objectives of accessibility analysis require different considerations. Further, the more factors which are considered, the higher the degree of complexity and number of data requirements which significantly limits the practical applicability of a tool in planning practice (to be discussed in detail in the next chapter).

Some tools are not available as open source and might require bespoke software (e.g. Accession) or an external function to be integrated into the GIS environment (e.g. TRANSAM and PTAL) which might be expensive and needs a high level of expertise in operating the software. Most of the available approaches to modelling accessibility particularly those that fall into Categories 1 and 2 focus on transport and activities supply but do not represent demand. For example, tools from Category 2 that aim to identify areas where public transport investments are required cannot include data on access to private cars per household. Being restricted to only one transport mode is a common omission. For example, tools from Category 1 designed to study local accessibility are restricted to walking only and do not consider cycling. Also, tools from Category 2 which analyse accessibility by public transport can model the bus network only while other available public transport modes are neglected. Similarly, for the case of public transport run by different operators, some accessibility tools focus on the key operator(s) only. This results in an underestimation of the coverage of the public transport network and, consequently, leads to an inaccurate reflection of actual travel behaviour. Another omission is the failure to consider the walking time to public transport access points in some tools in Categories 2 and 3 that examine accessibility by public transport at the regional or local administrative scale. For reasons related to data requirement and complexity (see Chapter 4), many tools cannot consider accessibility for different population groups. Instead, they analyse accessibility for a homogenous population which is considered insufficient for some study purposes. For example, tools from Category 1 look at accessibility to local facilities but cannot be run to consider different walking speeds or distance thresholds for different areas and age groups.

Table 3.1: Omissions in available accessibility tools

Factor/ analysis capability	**Omissions**
Supply/ demand relationship	Most tools, Categories 1 and 2, focus on transport and activities supply while people's demands are often not represented.
Software requirements	Some existing accessibility tools are not available as open source and might require bespoke software or an external function to be integrated into the GIS environment.
Modes considered	Some tools only consider one transport mode and some other tools are restricted to just one public transport service operator.
Walking time	Some tools which look at accessibility by motorised vehicles at local administrative scale fail to consider walking time to public transport network. Most tools, particularly from categories 1 and 2 (see Section 3.3), fail to calculate actual walking distance, instead using the form of straight-line distance.
In-vehicle travel time	Some tools fail to calculate actual in-vehicle travel time based on travel survey or services timetable and instead rely on speed limits or the average speed associated with roads to estimate travel time.
Travel time value	Most tools that express spatial separation in terms of generalised cost apply the same travel time value to all travel, regardless of conditions, such as journey purpose, time of day, delay and discomfort.
Scheduling	Most tools fail to take into account target arrival or departure time or both, arrival or departure during a specified period, depart after, and arrive before.
Times of day and day of the week	Some tools fail to identify the accessibility impacts of travel at specific times of day (i.e. peak time or off-peak time) and on a specific day of the week (i.e. during weekday or the weekend).
Impact of physical features	Most tools fail to consider the impact of physical features on walking time (e.g. steep hills and topographic constraints, crossing streets with high traffic volume, etc.)
Interchange options	Some tools fail to consider interchange options of public transport journeys between different modes or even between different operators.
Population diversity	Most tools fail to represent accessibility for different population groups (e.g. public transport accessibility for those without access to private cars, and different walking speeds or distance thresholds to public transport or local facilities for different age groups).
Attractiveness of opportunities	Some tools focus on the location and number of opportunities only while they fail to consider their economic or physical attractiveness. Some other tools do not have the capability to account for the diminishing attractiveness of opportunities with the increase in spatial separation (i.e. travel time, distance or cost).

Table 3.1: Omissions in available accessibility tools – continued

Factor/ analysis capability	Omissions
Real time updates (impacts of congestion and construction)	Tools often fail to take account of real time updates due to traffic congestion, delay, road construction, maintenance or surfacing.
Vehicle characteristics	Most tools fail to consider the type and characteristics of vehicles which might significantly affect accessibility for a particular purpose of journey (e.g. a bus with luggage carrying capability for people travelling to an airport, and a bus with assigned space for a wheelchair users and/or a pushchair for those travelling with young children).
Quality and environment of journey	Most tools fail to take account of the accessibility impact of the quality and environment of journey such as the availability of rest points and shelter from weather; comfort of waiting areas and vehicles; attractiveness and aesthetics of walking routes; support services when travelling (e.g. catering); and assistance and helpfulness of public transport staff.
Safety and security	Most tools fail to consider the accessibility impacts of safety and security factors during the journey, including real and perceived safety whether outside or in the vehicle, speed limits, obstructions during hours of darkness (e.g. lack of street lighting), and availability of road crossing facilities.
Environmental impact	Most tools fail to give an indication of the environmental impact associated with the route/ mode choice such as emissions resulting from the journey.

Other omissions identified, to varying degrees, in the existing accessibility tools in all three categories are related to a number of factors regarding how people perceive accessibility. These include: the measurement of the straight line distance rather than of the actual walking distance; measurement of the in-vehicle travel time based on speed limits or average speeds associated with roads rather than using travel survey or services timetable; non-consideration of the influence of physical features on walking time (e.g. steep hills and topographic constraints, crossing streets with high traffic volume, etc.); non-consideration of the interchange options of public transport journeys between different modes or operators; non-consideration of the influence of travel at specific times of day (i.e. peak time or off-peak time) and on a specific day of the week (i.e. during weekday or the weekend); non-consideration of the local/ regional significance of opportunities; and non-consideration of the diminishing attractiveness of opportunities with the increase in spatial separation (i.e. travel time, distance or cost). The scheduling options of journeys made by motorised vehicles, including target arrival or departure time or both, arrival or departure during a specified period, depart after, and arrive before are often not provided in Categories 2 and 3 tools. Regarding tools that express spatial separation in terms of generalised cost, the same travel time value is applied to all travel, regardless of conditions, such as journey purpose, time of day, delay and discomfort. In addition, tools often fail to account of real time updates due to traffic congestion, delay, road construction, maintenance or surfacing.

Factors (believed to be less important) related to vehicle characteristics which might significantly affect accessibility for a particular purpose of journey are often not included in the existing tools of Categories 2 and 3. For example, a bus with luggage carrying capability for people travelling to an airport, and a bus with assigned space for a wheelchair users and/or a pushchair for those travelling with young children. Similarly, most tools fail to take account of the accessibility impact of the quality and environment of journey such as the availability of rest points and shelter from weather; comfort of waiting areas and vehicles; attractiveness and aesthetics of walking routes; support services when travelling (e.g. catering); and assistance and helpfulness of public transport staff. The influence of safety and security factors during the journey on the route choice and, therefore, on accessibility is also overlooked by the majority of available tools. This includes factors related to real and perceived safety whether outside or in the vehicle and speed limits for Categories 2 and 3 tools, and obstructions during hours of darkness (e.g. lack of street lighting), and availability of road crossing facilities for Category 1 tools. Also, accessibility tools, in general, particularly those developed mainly to address the accessibility issues (i.e. Categories 1 and 2) lack the capability to give an indication of the environmental impacts associated with the route/ mode choice such as emissions resulting from the journey.

3.5 Accessibility Modelling in a GIS Environment

As presented earlier in Section 3.3, the review of a number of the available accessibility tools shows that GIS has been widely used by leading transport model developers to build and manage their accessibility tools. With the rapid increase in computer power and availability of a wide range of electronic data sets, the dependence on GIS techniques for accessibility analysis has significantly risen in the last two decades. GIS is well-known for its capability to analyse, model and visualise geographical data such as transport and socio-economic data. It facilitates the utilisation of quantitative geographical approaches within a digital environment. A GIS map can incorporate many and various layers of information that are accompanied with a linked database and which can demonstrate them in innovative ways (Grid, 3-D, thematic maps, etc.) to ease data interpretation (Wu and Hine, 2003).

In the past, GIS users used to analyse accessibility by using "buffer" and "overlay" functions. The main disadvantage of these traditional functions was their inability to consider the transport network. Accessibility used to be measured based only on "crow-fly" or Euclidean distances rather than using actual distances on the network. All the locations within the computed buffer zones are equally weighted, meaning that the nearest location to the desired destination or service is as equivalent as the furthest one to the same destination (de Jong and Ritsema van Eck, 1996; Geertman et al., 2004).

In 1991, Geertman and Bosveld used potential measures based upon a real world transport network for the first time in GIS-based accessibility analysis (de Jong and Ritsema van Eck, 1996). The analysis overcame the drawbacks of "buffer" and "overlay" functions, dividing the study area into many hexagonal tiles that are equal in size.

The review of different approaches to accessibility tool development (Section 3.3) suggests that most of the current GIS-based accessibility analysis usually uses accessibility measures that are especially designed in a separate modelling programme with a direct or indirect link to the GIS database. An integrated GIS tool, ACCESS, was developed by Liu and Zhu, 2004, within the ArcView 3.2 offering flexible and interactive GIS environment that supports accessibility analysis for many planning and decision making applications on a whole urban area or region. Accessibility Analyst is another new ArcView extension which was also created by Liu and Zhu working with the other ArcView extensions such as Network Analyst, Spatial Analyst, Patch Analyst and 3D Analyst in order to run advanced potential models in addition to the usual potential and contour models.

Recently, a software package named Flowmap was developed at the Faculty of Geosciences of the Utrecht University in the Netherlands to analyse and display interaction or flow data between two different geographical locations (Utrecht University, 2011). Since most thematic mapping and GIS packages have little functionality for handling this type of information, Flowmap fills this gap in GIS packages by dealing with: 1) storage, visualisation and analysis of spatial flow patterns (e.g. trade flows and commuter journeys); 2) computing travel times, distances, or transport costs using a transport network map; and 3) modelling the market areas of current or programmed services. Flowmap presents some unique and practical graphical measures including catchment profile, location profile and proximity profile. All these abilities make Flowmap an efficient technique that can be integrated in planning support systems especially in terms of facility and service location planning (Geertman et al., 2003). However, since it is developed as an extension for a particular spatial analysis that is difficult to run in GIS packages, data management, network analysis and mapping functions in Flowmap are further behind those provided in GIS packages (Liu and Zhu, 2004).

Another interesting tool that can be linked to GIS to improve its analysis capability of transport modelling is ACCMAP, which is a trip access and travel time mapping package providing an accessibility calculation from and to any point using travel costs through highway and public transport networks (Citilabs, b). ACCMAP is able to show the impact of network changes on the transport system by overlaying accessibility mapping on any background map. It also facilitates the generation of PTAL indices for different time periods using public transport services (Wu and Hine, 2003). Lately, a considerable development has been executed in the ACCMAP package by MVA and Citilabs on behalf of the UK Department for Transport (DfT) to build a new tool named Accession, which is capable to produce different types of indicators and measure accessibility using many more origin and destination combinations (Citilabs, b) (see above Subsection 3.3.2). These recent developments in computing accessibility have the potential to make GIS-based tools more accessible to transport planners and practitioners. However, the current GIS tools do not support an explicit representation of the behavioural choices which would be required for a more detailed activity-based travel analysis (Hull, 2011).

3.6 Conclusion

The importance of using accessibility tools in planning practice has recently been rising in many countries. This chapter reviews the way in which accessibility tools have been categorised and applied in the literature, focusing on the conceptualisation of accessibility and the dimensions modelled in the tool. To illustrate the approaches used by tool developers a three-fold categorisation was used which matched well with the state of the art categorisations by leading tool developers and related to how accessibility is being articulated by practitioners. Examples of each category are demonstrated to illustrate the general issues and themes. The chapter concludes by presenting the main technical omissions that limit the analysis capabilities of accessibility tools for a wider application in urban and transport planning. However, the usefulness and usability of accessibility tools in planning practice rely not only on their analysis capabilities but also on other factors which are discussed in detail in the next chapter.

CHAPTER 4 – Accessibility Tools in Planning Practice: Uses and Usefulness

4.1 Introduction

There is a wide range of uses of accessibility tools in planning practice. Since Hansen introduced the concept of accessibility to the spatial planning field in 1959, many accessibility tools with different measures and considerations have been developed and implemented in various case studies. The previous chapter reviews the literature on accessibility-based planning tools explaining how the concept of accessibility is measured and incorporated in the tool using the descriptions of these tools in the academic press. This chapter focuses more on the usability and usefulness of accessibility tools in the transport and land-use planning practice. It seeks to provide a better understanding of how such tools can be used to support the decision-making process and why some tools are still research tools and can probably never be applied in practice.

This chapter has the following structure: Section 4.2 describes the different uses, types and dimensions of accessibility tools in the decision-making process for planning. It also discusses the various institutional ways to operate and manage these tools. Section 4.3 reviews and concludes the research agenda on how to reach appropriate and useful accessibility tools in planning practice.

4.2 Accessibility Tools in Decision-making

4.2.1 Roles and tasks in planning decision-making process

In parallel with the change in policy priorities in recent years, decision-making in the transport planning context has become more of a complicated process. One of the most important changes in attitudes towards accessibility that has been brought by the policy goals in recent planning guidelines is the potential for the links between transport and wider policy areas (see Accessibility Planning Guidance in the UK) (DfT, 2006). Accessibility tools are a practical way to provide these links between transport policy and wider social, economic and environmental objectives. Three areas in which accessibility tools can help in the assessment and delivery have been defined in the Accessibility Planning Guidance: land-use/ spatial planning and service delivery; equity and appraisal; and best value, joint working and effective service delivery. Therefore, translating the concept of accessibility into a practical planning tool stems from the need for powerful techniques to help planners and decision makers deal with some problems within the traditional transport planning approach (see Chapter 2) and provide better evaluation of the impacts of different schemes (or combinations of schemes) brought by transport and land-use policies.

In several studies the application of accessibility tools in planning practice has been addressed giving a focus on the economic and social evaluations (see Geurs and Ritsema van Eck, 2001; Keller et al., 2012). Several approaches can be used in the decision-making process to analyse the economic impacts of improved accessibility because of changes in the transport system and/or changes in the physical location of land uses. Based on the micro-economic welfare theory, accessibility tools can provide a link between accessibility and the concept of consumer surplus and consumer welfare (Vickerman et al., 1999; Geurs and Ritsema van Eck, 2001; Gutiérrez et al., 2010). For example, accessibility tools that involve utility-based accessibility measures can be used to model travel behaviour and the benefits for different users of a transport system. In this context, accessibility is expressed as the net benefit that individuals fulfil through accessing opportunities. Consumers' surplus can be interpreted as the difference between two accessibility scenarios (e.g. one reflecting a base situation and one reflecting a policy change). By using the compensating variation from economic theory, the resulting differences in utility can be converted to monetary units. Tools with contour measures and potential accessibility measures can be used as an indicator of the market area of companies and firms, which plays a significant role in determining regional economic production. A study carried out by Fürst et al. (1999; 2000) to examine the relationships between transport infrastructure improvements, accessibility and regional economic production at the European scale, suggests that potential accessibility measures have the highest correlation with GDP per capita.

The distribution of cost benefits among people and companies is seen as a major issue in the political decision-making process (Bruinsma and Rietveld, 1998). Therefore, the consideration of equality aspects has become more important in the recent economic evaluations of transport projects. Based on the concept of accessibility, the spatial distribution of activities and the efficiency of transport system define the level of access that people enjoy to all types of activities (e.g. jobs, health care, education, retail, leisure, etc.), and therefore, affect people's economic and social opportunities. In this respect, accessibility tools which rely on activity-based measures are useful to planners and policy makers to evaluate these social impacts of urban structure and transport schemes, identifying the number of opportunities reachable from a certain location (Geurs and Ritsema van Eck, 2001). This type of tool can provide a useful approach to analyse the changes in the level of access to opportunities that are brought by transport and land-use policy plans. Moreover, some of these tools can be used to assess the distribution of access to opportunities (i.e. equality of opportunities) among regions and social groups. In other words, they can be applied to identify which individuals or groups in particular areas benefit from changes in accessibility. In the literature, three aspects of equity have been examined by accessibility analysis, including: spatial equity – estimating accessibility to services and activities by geographical area (zone) (e.g. Gutiérrez and Gómez, 1999; Halden, 2002; Tsou et al., 2005); social equity – estimating accessibility for population groups categorised according to socio-demographic characteristics such as age, gender, an educational level, physical ability, etc (e.g. Domanski, 1979; Jones et al., 2005); and economic equity – estimating accessibility by income groups (e.g. Shen, 1998; Talen and Anselin, 1998). However, the choice of accessibility measure used in the tool as well as the type of aggregation of individuals to an average accessibility level for an area and/or population group implies a particular treatment of equity and also influences the conclusions (Geurs and Ritsema van Eck, 2001).

A study conducted by Halden et al. (2000) concerning accessibility analysis in Scotland suggests that two things have to be identified to understand the use of accessibility analysis in the transport and land-use planning process: the main decisions that the relevant organisation needs to make, and the available accessibility tools which are used to help make these decisions. In the planning context, the decision is a choice made between objectives that express the aspirations and aims of decision makers, or a choice between a number of procedures and actions that are oriented to achieve those objectives. Accessibility tools refer to analysis techniques and methods which can be used to identify problems or assess the impacts of different schemes or combinations of schemes in order to assist decision makers in making decisions on which should be implemented.

Typically, a decision in the planning process needs: an interaction of stakeholders and external experts, collecting information, and processing information (Cook, 2003). In Britain, the main stakeholder in the planning process at the local level is the Local Authority which includes elected politicians who have a political control over the different departments of the authority (e.g. those responsible for planning and transport). The officers of departments manage and perform the day-to-day tasks of local authority and give advice to the politicians. The degree of experience and technical skill of officers differs noticeably and depends on the availability of resources and, therefore, the size of the local authority (TRL & University of Leeds, 2004).

The ultimate output of a decision-making process is a plan of action/ strategy with supporting methodologies. According to Banfield (1959, 1973) and Friedmann (1998), planning and decision-making may involve a number of stages and tasks (see Figure 4.1). This includes: 1) analysing the situation and defining the problem, 2) setting up the aims and objectives, 3) defining and designing alternatives, 4) identifying, forecasting and assessing consequences and impacts of each alternative, 5) comparing the alternatives in terms of consequences in connection with sought objectives and other values, 6) producing planning proposals and recommendations, 7) making decision on action using the knowledge built through the previous stages and other knowledge, 8) implementing the decision through suitable institutions, and finally 9) receiving feedback and post-auditing. In three of these stages, accessibility tools can be used by planners and policy makers for various purposes playing different roles. Figure 4.1 shows the role that accessibility tools can play in the decision-making process.

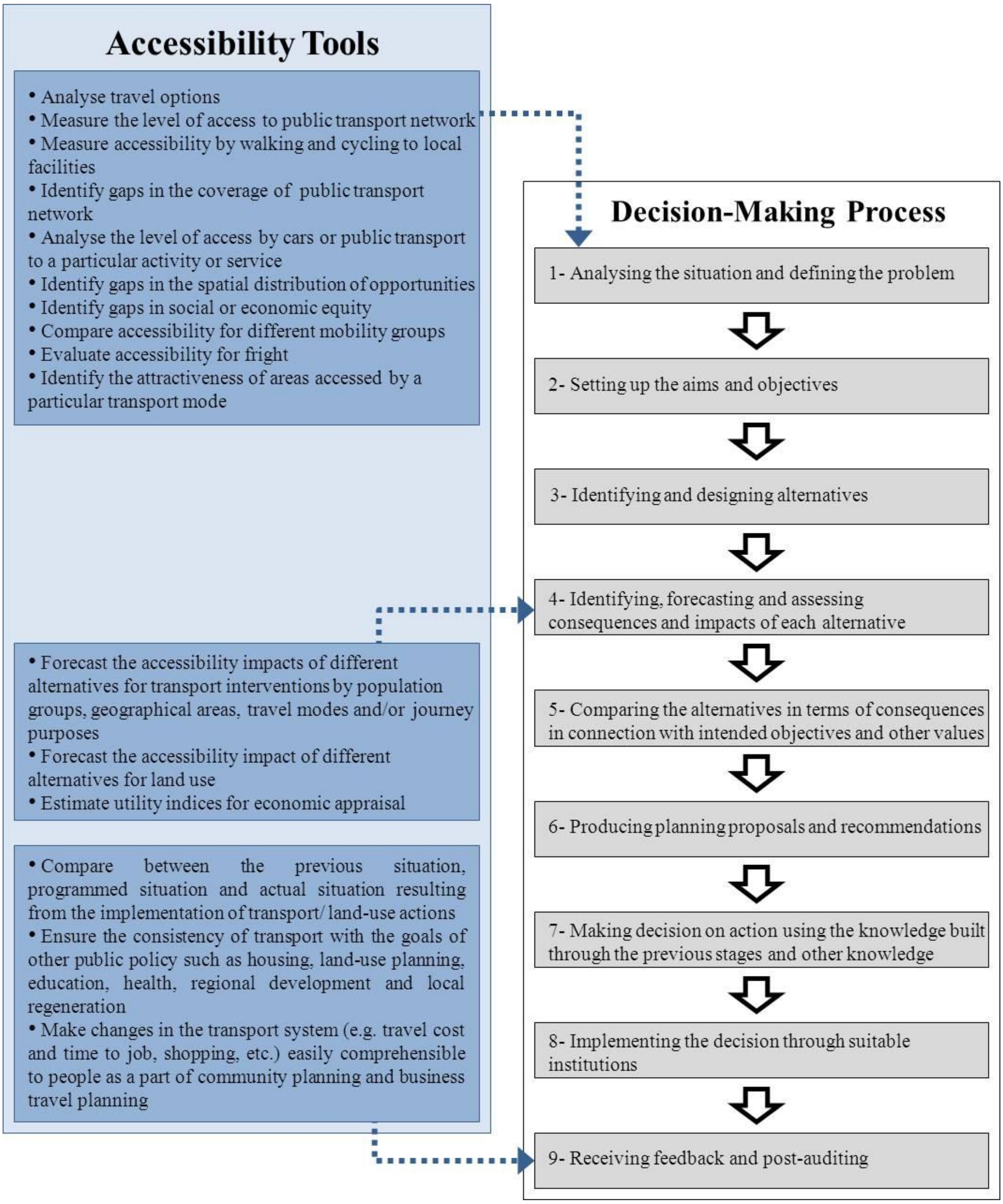

Figure 4.1: Role of accessibility tools in decision-making

Source: Author's own derived from Banfield (1959, 1973) and Friedmann (1998)

In the first stage of the decision-making process which involves *situation analysis and problem definition*, accessibility tools can be used to analyse the strengths and weaknesses of the integration of transport and land-use systems and examine the extent to which the existing transport policies succeed in meeting demands. They can aid in identifying the access level and travel options available to individuals/ households in certain locations; for example to measure the level of accessibility by walking to public transport network using given distance thresholds (e.g. 500 metres) for those which have no access to private cars. Another use is to identify which areas have a relatively poor accessibility by public transport to a particular type of activity or service in order to make a decision on where transport improvements should go. On the other hand, accessibility tools can be also applied in this stage of decision-making to help in identifying which type of activity is required to be opened/ relocated and where it should be located. This application involves an analysis of the efficiency and equity in the spatial distribution of opportunities, including local facilities that people in general intend to access by walking/ cycling (e.g. local supermarket and post office), or strategic destinations located within the region or the local authority area that people need to travel to by motorised vehicles (e.g. key employment sites, shopping centres, hospitals, education facilities, etc.). In the same context, accessibility tools can provide an overview of the attractiveness of areas accessed by a particular transport mode in order to identify the "hotspots" of activity (i.e. areas in which there is a relatively greater concentration of journey destinations carried out to pursue a certain activity) or locations where there are opportunities to locate a new business.

For the purpose of producing more sustainable transport schemes, planners and policy makers can use accessibility tools early in the process of decision-making to compare accessibility between different mobility groups, particularly accessibility by car versus accessibility by public transport, cycling and walking in order to study the impact of transport/ land-use schemes on modal shift. Additionally, an evaluation of accessibility for freight at the regional or national scale can be considered by accessibility tools in order to improve the economic efficiency of supply chains. The objective, in this case, is to influence logistics decisions towards patterns of activity that optimise social, commercial and environmental goals (Halden et al., 2000); for example tools can be used to identify potential sites for locating distribution or freight operator centres, taking account of access to the rail network, airports and ports.

In the stage of *assessing the impacts and consequences of different alternatives*, accessibility tools can be applied to make a prediction about the accessibility impacts of proposed transport interventions (e.g. running new public transport service, building new motorway, change to speed limit, change to interchange options, cost, quality and reliability, etc.) for the considered population group(s), geographical area(s), travel mode(s) and/or journey purpose(s) in order to explore whether these interventions would contribute to fulfilling the intended objectives and/or cause any undesirable consequences. Furthermore, some tools can predict the changes brought to the accessibility of people or areas due to land-use and activity interventions such as closing, opening or relocating a particular type of activity or service. Economic appraisal can be also carried out for several transport and/or land-use schemes using composite utility-based measures (Halden et al., 2000). Therefore, in this stage accessibility tools can help with the linkages between transport and other public policies, ensuring appropriate and clear consequences for the transport system that are caused by other areas of public policy decision making and service delivery.

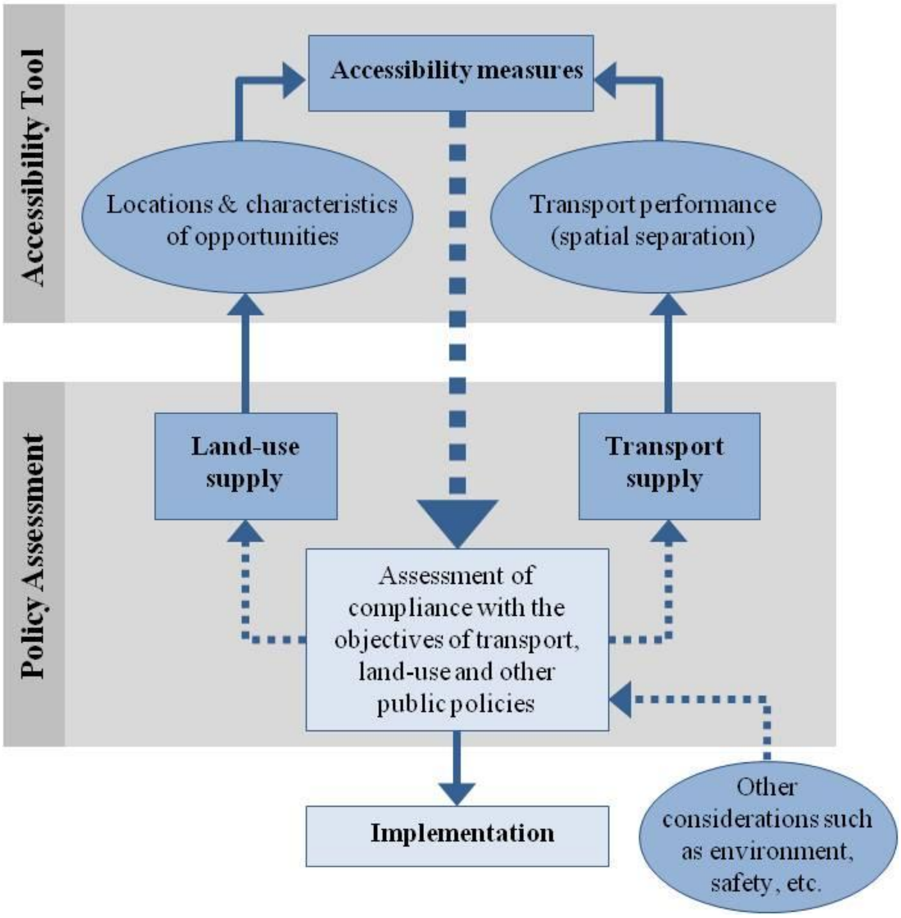

Figure 4.2: Accessibility tools in policy assessment

Source: Author's own derived from Halden et al. (2000)

In addition, accessibility tools can play a significant role in the stage of *feedback and post-auditing tasks* after delivering the action in order to ensure the consistency of transport objectives with the goals of other public policy area such as housing, land-use planning, education, health, regional development and local regeneration. Figure 4.2

shows how accessibility analysis can be incorporated within land-use and transport policy assessment. To find out whether the implemented action has achieved the intended objectives, planners and policy makers can use accessibility tools to compare between the previous situation, programmed situation and actual situation which is resulting from implementing the transport/ land-use interventions put forward in planning policy. As a part of community planning and business travel planning, using accessibility tools makes changes in the transport system (e.g. travel cost and time to job, shopping, etc.) easily comprehensible to people.

4.2.2 Classification, dimensions and operation

In connection with what has been discussed above, accessibility tools can be classified according to their tasks in decision-making system into four main groups (Keller et al., 2012): 1) passive decision support tools that assist the process of decision making, but is not able to bring out explicit decision suggestions or solutions; 2) active decision support tools that are able to bring out such decision suggestions or solutions; 3) cooperative decision support tools that allow the advisor or decision maker to complete, modify, or refine the decision suggestions provided by the system, before processing them back to the system for validation; and 4) decision support tools used in the ex-post evaluation of the decision impact. However, some accessibility tools can be classified under one or more of these groups. Table 4.1 presents the different tasks that might be associated with each group of decision support tools.

As discussed in Chapter 2 (Section 2.7), accessibility analysis can be carried out for four main administrative levels: site based level, neighbourhood level, local administrative level (local and regional authorities) and the national level. However, decisions based on accessibility analysis through the planning process can be generally arranged along three dimensions: strategic -, tactical - and operational dimensions (Keller et al., 2012). At the strategic dimension, long term decisions are usually made including decisions on how to contain the environmental and health problems caused by transport, which can be generic decisions seeking to cut emissions from transport and encouraging modal shift from car to public transport at the level of region or local authority area, or more specific decisions such as reducing congestion on main roads. Other decisions related to the national and regional transport strategy and development plan are considered strategic; for example improving the connection between a new airport or business development area with the surrounding region. Decisions at the tactical dimension are more medium term, and include proposals and alternatives to achieve what is already decided at the strategic dimension; for example, decisions on which bus route should be introduced to improve the access to a new development area. At the operational dimension, decisions have a more short term nature and focus on the actual implementation in such a way which maximises the benefit and minimises the negative effects; for example for a new bus route, decisions on the number and location of bus stops, frequency and bus characteristics (e.g. double-decker or single-decker bus) are often made at the operational dimension.

Table 4.1: Accessibility tools in decision-making – classification and tasks

Type of decision support tool	Tasks
Passive decision support tools	- To analyse the level of access by walking to public transport network - To analyse the level of access by walking/ cycling to local facilities - To identify gaps in the public transport network coverage - To analyse the level of access by cars or public transport to a particular activity or service - To identify gaps in the spatial equity in distribution of opportunities - To identify gaps in social or economic equity in access by a particular mode or to particular activities - To give an overview of the attractiveness of areas accessed by a particular transport mode - To evaluate accessibility for freight to influence logistics decisions - To compare accessibility between different mobility groups to study the impact of transport/ land-use schemes on modal shift. - To compare between the impacts and consequences of different alternatives for transport or land use - To describe accessibility as utility indices to be used in economic appraisal
Active decision support tools	- To decide on sites for locating residences, business, activities or services - To suggest which activity should be intensified, relocated or closed - To suggest which area requires an improvement to access to the public transport network - To suggest a potential public transport route or a path for new infrastructure - To decide on the most suitable alternative for transport or land use
Cooperative decision support tools	- The same above tasks of active decision support tool with the opportunity of modifying, refining or completing the decision suggestions provided by the system, before being processed for validation
Decision support tools used in the ex-post evaluation	- To compare between the previous situation, programmed situation and actual situation which is resulting from implementing the transport/ land-use interventions put forward in planning policy.

Considering all the above, a key reason for using accessibility tools is to boost the effectiveness of decision-making in planning practice by providing objective data on the impacts of decisions taking account of many economic and social factors. The results of accessibility tools are typically expressed in numerical values of output variables in tabular and/or graphical form accompanied by an expert commentary, which aims to help decision makers to understand the scientific analysis and provide them with a scientific advice rather than pre-empting the decision makers themselves.

However, in some cases the developers and/or operators of accessibility tools can be involved somehow in making decisions in planning practice. Three 'institutional' ways are commonly adopted to operate and manage accessibility tools (TRL & University of Leeds, 2004). In the first way, tools are developed, validated and applied by experts contracted to the decision makers. This has the advantage of taking the technical side completely out of the hands of decision-makers but has the disadvantage that decision-makers may not understand the tools and the underlying assumptions. Therefore, this way encourages an over dependence on the analytical method for planning and allows experts to have a lot of influence over the decision-making process. In the second case, external consultants develop a tool and provide it for decision makers to use it in-house (e.g. the transport department of a local authority). The advantage of this case is that decision-makers have hands-on access to the tool, allowing them to judge directly its weaknesses and strengths and use the tool freely whenever and however they want to. Besides the disadvantage of the high cost associated with this way, the lack of expertise that tool users may face when running the tool and interpreting its outputs is another major disadvantage here. Nevertheless, this can be avoided by appropriate training. In the third case, an accessibility tool is developed and run in-house by the decision-makers themselves. The main disadvantage is that local authorities, especially the smaller ones, may not have an adequate expertise to run the tool. Moreover, money and time restrictions are another problem which makes the option of outsourcing tool development more cost effective. In general, simple accessibility tools may be developed in this way while most of the complicated tools are developed as described in the first and second cases.

4.3 How to Ensure Accessibility Tools are Useful for Planning Practice

Many of the existing accessibility tools are still research tools and have not been used in planning practice due to the different reasons that restrict their application and make it very unlikely to be achieved in practice; for example the complexity of operation and interpretation, the high level of data collection, cost and manipulation, and other reasons related to the failure of the methodological approach and theoretical basis to consider some factors (see Chapter 3, Section 3.4). Therefore, there is a need for a move from research tools to more practical tools to be useful in planning practice. This section discusses in detail how to develop (or choose) a useful accessibility tool and improve its practical value in decision-making.

Whilst the application of accessibility tools has been regularly discussed and examined in scientific research (e.g. Gutiérrez and Gómez, 1999; Geurs and Ritsema van Eck, 2001; Halden, 2002; Curtis and Scheurer, 2010), their usefulness in planning practice is a much less-developed area of study. Several researchers have investigated how to choose an appropriate accessibility measure/ tool and evaluate the usefulness of its application in planning practice (e.g. Morris et al., 1979; Koenig 1980; Cervero et al., 1997; Handy and Niemeier, 1997; Reneland, 1998; Halden et al., 2000; Ross, 2000; Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004).

Most authors have recognised the ease of interpretation and understanding of modelling outputs as an important criterion to consider in the development of accessibility tools. Morris et al. (1979) define the primary differences in choosing appropriate accessibility measures/ tools for evaluation purposes in terms of two aspects: the level of disaggregation of population and opportunities, and the weight given to the ease of operation and interpretation of the involved measure. In their study, four general criteria are defined to help in the selection procedure of accessibility tools for evaluation: 1) the consideration of spatial separation (travel impedance) (see Chapter 2) which is responsive to changes in the performance of the transport system, 2) ability to reflect individuals behaviour and perception; 3) technical feasibility and operational simplicity and 4) ease of interpretation.

Other researchers also highlight the importance of developing accessibility tools that are easily interpretable and intelligible to decision makers and laymen. Koenig (1980) argue that accessibility tools should be suitable for a "dialogue" with the public, authorities, and non-experts. In parallel, Handy and Niemeier (1997) suggest that two key issues that should be considered in selecting accessibility measures are the cost of calculation and the simplicity of the procedure of interpreting and translating these measures into a useful form for decision-making. The authors argue that this can be achieved by using measures focusing on relative levels of accessibility (e.g. by using a simple ratio), which help to compare accessibility across different areas, time or both, rather than focusing on absolute levels of accessibility. Ross (2000) also discusses a number of principles that accessibility tools need to satisfy for useful application in practice. Being simple to use and understand is defined as a key principle.

Similarly, Geurs and Ritsema van Eck (2001) and Geurs and van Wee (2004) define interpretability as one of the main criteria to evaluate accessibility tools, stating that planners, policy makers and researchers should be able to understand and interpret the tool. They argue that the simplest activity-based measures are the easiest to interpret describing them as "common-sense" measures in which the outputs are presented in terms of travel time, distance or the total number of accessible opportunities. The potential accessibility measure is viewed as less easily interpreted. In other words, "more theoretically and methodologically sound accessibility measures are even more difficult to interpret" (Geurs and Ritsema van Eck, 2001, p.135). However, the authors suggest that showing the separate impacts of transport changes and land-use changes could improve the interpretability.

In connection with the ease of interpreting tools output, most accessibility studies (e.g. Cervero et al., 1997; Handy and Niemeier, 1997; Ross, 2000; Geurs and Ritsema van Eck, 2001) have focused on issues related to data requirements and costs as well as the level of data disaggregation. Ross (2000) states that accessibility tool "should be based on credible data" which is able to reflect accurately travel behaviour in the modelled area, and a "convincing and rational method of calculation" (Ross, 2000, p.3). Geurs and Ritsema van Eck (2001) discuss the importance of data need to tools usefulness, emphasising that the simplest measure obviously requires the least amount of data while the most complicated measures require larger amounts of data due to the disaggregate level of calculation. Therefore, they clarify that the difficulty of data collection for some measures, such as space-time accessibility measures, could make their applications impractical on the national level and only restricted to a relatively small area.

A study carried out by Cervero et al. (1997) considers the level and type of data disaggregation as an important criterion for good evaluation of accessibility. The study adds that a useful accessibility tool does not only describe opportunities as a lump sum but it does also look at the demand for these opportunities. For example, the measurement of accessibility to jobs should reflect the professional skills available across population (e.g. educational level, technical skills, etc.) compared to those required for the nearby jobs. In this context, Cervero et al. (1997) suggest that gravity-based and other measures need to take socio-economic characteristics of the population into larger consideration. The authors have come to the conclusion that when putting accessibility into operation as a performance measure, greater attention needs to be paid to setting up a clearer framework of objectives, articulated in relation to sustainability and social equity not only in regard to movement efficiencies. They suggest that taking various individual abilities and characteristics, such as physical ability and educational level, into consideration would give a more reliable description of the accessibility of different population groups.

Handy and Niemeier (1997) point out that “an accessibility measure is only appropriate as a performance measure if it is consistent with how residents perceive and evaluate their community” (p.1176). In this case, the measure reflects the main issues for residents in a particular place. For example, residents of relatively poor areas might perceive the cost and quality of services and products in a different way to those living in high-income areas. Although Handy and Niemeier consider the quality and cost of products in assessing the attractiveness in an area, they suggest that this would make the specification and calibration of accessibility measure more complicated (Handy and Niemeier, 1997).

Halden et al. (2000) recognise that for the purpose of practical application of all accessibility measures, the spatial separation functions, opportunity terms and size of the zones for addressing accessibility should be considered at a level of detail appropriate for the requirements of the particular objective(s) of application. To identify the use and views on accessibility analysis in Scotland, telephone surveys of 29 relevant organisations including local authorities, transport operators, developers and consultants have been conducted by Halden et al. (2000). Questions were asked about the main decisions which organisations had to make, and what approaches to accessibility analysis were applied to help in making these decisions. The study has concluded that practitioners in Scotland identify the need for: 1) simple accessibility analysis tools that help to support decisions on projects and polices; 2) analysis approaches that address the relationships between transport issues and wider polices especially land-use, economic development, education and health; 3) analysis that consider the needs of cyclists and walkers; and 4) consistent approaches that take into account accessibility by all travel modes. The authors argue that accessibility issues are viewed as a significant part of integrated transport policy to become an established part of the decision-making process but detailed guidance will be required if new tools to assess accessibility are developed.

In addition to interpretability and data need, Geurs and Ritsema van Eck (2001) focus on methodological soundness, which expresses the capability of tool to consider transport-, land use-, temporal- and individual characteristics. In a later study, Geurs and van Wee (2004) use four aspects, which to some extent are similar to those used in Geurs and Ritsema van Eck (2001), in order to assess the usefulness of accessibility measures in evaluation transport and land-use changes: theoretical basis, operationalisation, interpretability and communicability, and usability in economic and social evaluation. With regard to the theoretical basis aspect, Geurs and van Wee recognise that accessibility tools should be sensitive to changes in both the transport system and the land-use system. Also, they should reflect temporal restrictions of opportunities and consider the abilities, needs and opportunities of individuals. Although including all these elements in accessibility analysis would lead to a level of detail and complication that makes it very unlikely to apply in practice, the authors argue that it is important to be aware of the consequences of overlooking one or more of these elements. Operationalisation expresses “the ease with which the measure can be used in practice” (Geurs and van Wee, 2004, p.130). This can be in terms of ascertaining availability of data, techniques and models, and budget and time. Therefore, operationalisation is often in conflict with the elements of theoretical basis.

The term of ‘usability’ is used by Geurs and Ritsema van Eck (2001) and Geurs and van Wee (2004) to describe the tool’s ability to assess transport and land-use changes in the social and economic context. These authors discuss the usability of the different types of accessibility measures. They point out that infrastructure-based measures are easy to operate, interpret and communicate (see Chapter 2, Section 2.6), but because of the exclusion of land-use element this type of measures are not appropriate for economic and social evaluations of transport and land-use changes. They argue that accessibility tools relying on location-based measures and person-based accessibility measures are more usable for social evaluation and analysis of equity aspects while those involve utility-based measures are more appropriate when economic evaluation is needed. Distance measures and contour measures which are widely incorporated in accessibility tools are considered easy to calculate, interpret and communicate but less usable in evaluating social and economic impacts of transport and land-use changes (Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004). This is justified by the fact that all opportunities are viewed as equally desirable regardless of the type, size or quality of opportunities or the time availability of individuals due to their inability to consider individuals' characteristics and preferences as well as the extreme sensitivity to travel time changes and the failure to consider the attractiveness of opportunities (in the case of distance measures) and the decay of this attractiveness. The potential accessibility measure (or gravity-based measure) is considered as a social indicator for analysing the level of access to economic and social activities for different socio-economic groups (see Section 4.2). It also can be used as an input for spatial-economic evaluations of transport developments. Although the measure can be easily computed, its output is more difficult to interpret and communicate with the public compared with distance measures and contour measures (see Chapter 2, Section 2.6).

The findings of Geurs and van Wee study suggest that person-based measures (space-time measures) are potentially very useful for social evaluations of transport and/or land-use changes since characteristics and restrictions of individual are considered. However, as discussed in Chapter 2, the person-based measures have a serious disadvantage in relation to operationalisation and communicability due to the large amount of data required to run these measures. Therefore, the usability of tools which involve this type measures is usually restricted to a relatively small region and subset of population. The utility-based measures have been reported with a strong theoretical basis and, as a result, significant usability in economic evaluation. Nevertheless, the application of accessibility tools utility-based measures are often associated with the difficult interpretability and communicability, making them not easily understood by most planners and policy makers.

From this review, it can be derived that interpretability in general seems to be in conflict with usability. More complex tools aggregate more information with more sophisticated mathematical approaches, making them more difficult to operate and less easy to understand. In this regard, Geurs and Ritsema van Eck conclude that "there seems to be trade off between ‘common-sense’ interpretability and methodological soundness of the measure” (Geurs and Ritsema van Eck, 2001, p.138). This issue is also highlighted in Bertolini et al. (2005) emphasising that accessibility measure “must be consistent with the use and perceptions of residents, workers and visitors of an area, and it must be understandable to those taking part in the plan-making process” (Bertolini et al., 2005, p.210). In this respect, the authors define two aspects that characterise useful accessibility measures: ‘soundness’ – the consistency of the measure with the behaviour, and ‘plainness’ – the communicative qualities of the measure (Bertolini et al., 2005, p.218). This is confirmed later in the study of Straatemeier and Bertolini (2008) as one of the main findings from a number of accessibility planning workshops with practitioners from the Netherlands. The authors state that making accessibility analysis useful requires “finding the right balance between relevant perceptions of accessibility without sacrificing appropriate standards of rigor” (Straatemeier and Bertolini, 2008, p.10). Furthermore, they add that useful tools should be developed in close cooperation with practitioners. In the same context, to reach an ideal balance between usability and interpretability, Straatemeier et al. (2010) suggest that academic research in planning needs to adopt more experiential case-study design, meaning that academics and practitioners should cooperate to find “a balance between rigour and relevance” in order to create an approach which is based on knowledge theoretically and empirically sound and useful for applications in planning practice (Straatemeier et al., 2010, p.588)

In the first report of COST Action TU1002 (Hull et al, 2012a), the term of usability of an accessibility tool is described (differently to both Geurs and Ritsema van Eck, and Geurs and van Wee studies) as “a qualitative indicator of the extent to which an accessibility instrument is accepted and applied in planning or decision making process by its end-users” (Papa and Angiello, 2012, p.258). As a part of the second stage of the COST Action (te Brömmelstroet et al., 2014), a total of 17 workshop-based case studies involving different accessibility tools were carried out across Europe and Australia to explore how usable accessibility tools are in supporting urban planning practice, and how to improve their usability. The findings identify two types of problems that limit the usability of tools in planning practice: technical and resources problems, and political problems. The lack of familiarity of the planning organisations, in general, in Europe with accessibility tools is mentioned as an important barrier to using them. Furthermore, the unavailability of sufficient resources including money, time, data and modelling skills in many of these organisations is also reported as another barrier. Surveys were collected in the workshops show that accessibility tools are appropriate for analysing urban structure problems and supporting planning decisions. It is identified that existing tools have been seen useful for giving significant insight into planning problems while they seem to be less successful in providing insight into the land-use – transport relationship (te Brömmelstroet et al., 2014).

The COST Action findings also highlight the importance of visualisation and tool interface to be very useful for communicating accessibility and for forming a basis for discussion between urban/ transport planners and decision makers. The positive influence of geographical maps in the presentation of accessibility was reported by most practitioners and policy makers. Planners prefer to use maps to simplify the presentation of large amount of spatial data as well as to put the planning problem in its real-world place so that they can recognise locations and link accessibility to wider planning policies. On the other hand, the output of an accessibility analysis presented in the form of tables, numbers and graphs is often seen complex and needs a high level of expert knowledge to interpret (te Brömmelstroet et al., 2014). For improvement in usability, issues related to real-time capabilities were identified across the majority of workshops as the most-demanded feature missing in accessibility tools. In addition, the ability to model an area in detail with a high level of spatial and data disaggregation was recommended by practitioners in order to improve tools usability by achieving a closer reflection of reality.

In conclusion, it is clear that accessibility can be measured and evaluated in different approaches. It is vital to select an appropriate approach for the particular situation and objective since it is unachievable to develop an accessibility measure or tool for every conceivable application in practice. The discussion above reveals a number of issues that characterise the usefulness of accessibility tool in planning practice. In this research, it can be stated that a tool is useful for planners and decision-makers when:

- It offers a theoretical basis providing an adequate representation of accessibility elements that satisfies the application purpose, with a rational method of calculation.
- It considers an adequate level of data and spatial disaggregation.
- It is simply operated and oriented towards clear objectives.
- It is easily interpreted, understood and communicated with researchers, planners, and policy makers.

To some extent these characteristics show the potential of being in conflict with each other. Therefore, it is important to stress what has been discussed in several studies in the literature (see above) that a useful accessibility tool achieves an ideal balance between these characteristics with regard to the specific planning issue addressed, taking into consideration data requirements and the availability of financial and technical resources. The plausibility of accessibility measurement depends upon the robustness of behavioural foundations brought by the theoretical basis, the level and type of disaggregation and the practical restrictions of applied tool.

4.4 Conclusion

Accessibility tools can be used to address different problems and play several roles in different stages at different dimensions in decision-making process. These include the analysis of situation and definition of problem; identification, prediction and assessment of impacts and consequences for alternatives; and provision of feedback and post-auditing tasks. Although many scientific studies have described and applied accessibility tools as a decision support tool, the literature does not provide enough researches addressing the evaluation of the practical value and usefulness of applied tools. It is clear that many of existing tools are still research tools and have been abandoned by practitioners. While some tools are seen too complex and, thus, difficult to interpret and understand by non-modellers, the more simple tools have the risk of being unable to provide an adequately detailed picture of real-world planning issues, particularly those related to the complex nature of individuals' preferences and choice sets.

The review findings show that no fixed framework can be used to identify a set of appropriate measures for every single situation and use in practice. It is clear that none of the approaches developed to measure accessibility is able to satisfy the requirements for addressing all the urban and transport planning problems. Therefore, the choice of an accessibility tool for analysing planning problem and identifying their solutions needs to be linked with the definition of accessibility in the context of this particular problem, and the study's circumstances and objectives. Different circumstances and objectives require different analysis approach. Inappropriate choice of accessibility tool could guide to misleading decision and ineffective action/ policy. A recent study carried out by Curl et al. (2011) focusing on the practitioners' perspectives and experiences on using accessibility tools in England points out that local authorities need to have a clear definition of accessibility and clear objectives for Accessibility Planning.

The chapter concludes the research agenda on how to deliver useful tools in planning practice. Most studies recognised interpretability of accessibility tools as a key feature to consider in the development of useful tools in planning practice (e.g. Koenig, 1980; Handy and Niemeier, 1997; Geurs and van Wee, 2004). However, no information has been reported on how planners and policy makers perceive and interpret different tools and measures. The inclusion of a sufficient methodological substance is another essential criterion required to capture the relevant dimensions of planning issue. The ability of tools to process the analysis with an adequate data input and disaggregation must be also given attention in order to lead to robust solutions. Naturally, simple tools fall down on theoretical basis while tools with stronger theoretical and methodological substance are complex and hard to interpret and apply in practice. No clear description has been found in the literature that identifies the extent to which tools outputs need to correspond with the actual travel behaviour. However, it is important to mention that although some tools provide a strong theoretical basis, none completely cover all the relevant elements because the inclusion of the full set of theoretical and methodological elements would involve a high level of detail and complication that makes a tool very impractical. Therefore, several recent studies (e.g. Geurs and Ritsema van Eck, 2001; Bertolini et al., 2005; Silva, 2008, Straatemeier and Bertolini, 2008; Straatemeier et al., 2010) emphasise the need to find a trade-off between methodological accuracy and interpretability of accessibility tools in such a way which means tools are able to represent the urban and transport situation accurately enough whilst providing a common language for all involved stakeholders (urban, transport and environmental planners, politicians, transport operators, commercial developers, etc.). The knowledge obtained in this and previous chapters have been used for the development of the decision support accessibility tool of this research as presented in Chapter 5.

CHAPTER 5 – Research Methodology: Spatial Network Analysis of Public Transport Accessibility

5.1 Introduction

The materials presented in previous chapters reviewed the literature on accessibility-based planning tools providing a useful backdrop for a better understanding, from the academic perspective, of how the concept of accessibility and its different dimensions are measured and incorporated in the tool. The review discussed the different uses of accessibility tools in the decision-making process, and how to develop and choose a useful and appropriate tool for measuring accessibility in transport and land-use planning practice. This chapter presents the GIS-based accessibility tool developed for this research – Spatial Network Analysis of Public Transport Accessibility (SNAPTA), which has responded to the need for research tools to be more practical and useful tools for the world of planning practice.

The chapter is organised in eleven sections. Section 5.2 introduces the research issue and explains the underlying concepts forming the basis of the modelling approach taken in this research to model accessibility. Section 5.3 presents the criteria that are used to develop SNAPTA to reach a useful tool for planning practice. Section 5.4 describes the conceptual framework which combines the concept of accessibility measurement, the participation in activities by individuals and the public transport supply. Section 5.5 defines the basic assumptions that are made to formulate the tool framework. Section 5.6 presents the sources and types of data sets required to apply SNAPTA to the research case study. Section 5.7 describes the methodology of the modelling approach adopted in the tool, giving an explanation of how the different stages involved in measuring accessibility are carried out. Section 5.8 discusses the choices that need to be decided for the development of the case-specific SNAPTA for modelling Edinburgh Council's area. Section 5.9 identifies the different users of the tool while Section 5.10 focuses on its potentials and limitations.

5.2 Research Issue and Underlying Concept

Although several accessibility tools have been recently developed and tested in scientific research, many of these tools are still restricted to academic studies and have never been applied in practice. As discussed in the previous chapter, a main reason is the complexity of the theoretical underpinnings of some tools and the associated high level of data collection cost which leads to a level of detail and complication that makes them difficult to operate and interpret. On the other hand, some other tools have been seen to be too simple in such a way that they are not sensitive to changes in both the transport system and the land-use system or unable to reflect adequately the actual travel behaviour. In addition, the failure of some methodological approaches to consider a number of factors, which might be necessary to achieve the intended objectives of accessibility study, might limit the practical applicability of some tools for particular purposes (see Chapter 3, Table 3.1).

In this respect, this research aims to develop an accessibility tool, which responds to a number of methodological and operational omissions in existing tools and offers better usability by covering the relevant dimensions of accessibility adequately without making the tool very difficult to operate, interpret and, consequently, apply in practice.

Spatial Network Analysis of Public Transport Accessibility (SNAPTA) is an accessibility tool that has been designed in this research in the context of land-use and transport integration. It defines accessibility as the ease of getting to a particular area(s) or opportunity(s) using a particular transport mode at a reasonable cost and in reasonable time. The following definition can be used:

SNAPTA is a GIS-based accessibility tool relying on a package of different types of accessibility measures to calculate the spatial accessibility levels by different types of public transport modes to different types of opportunity using a high level of data disaggregation.

This definition highlights four fundamental aspects of the tool: 1) the production of geographically represented outputs, 2) the use of different types of accessibility measures based on different methodological approaches, 3) the consideration of different public transport travel options, 4) the consideration of the distribution of urban services and activities, and 5) a highly disaggregated analysis.

SNAPTA recognises that an accessible location benefits from a *proximity* to the public transport network, the *efficiency* of this network, and a good *interaction and connectivity* that the public transport network allows between this location and an opportunity or set of opportunities. In this respect, SNAPTA is able to analyse whether changes in the quality of these features of the transport system and land-use and activity system increase, or otherwise reduce, spatial accessibility across the modelled area. To measure successfully the accessibility of public transport and assess the change in this accessibility due to changes in transport and/or land-use system, the tool must consider all key dimensions that concern public transport journeys. It is commonly recognised that a single measure is unlikely to be able to cover all the relevant dimensions of accessibility (see Chapter 2). Therefore, the development of SNAPTA involves a combination of three location-based measures with different theoretical bases to capture different attributes and assess the urban interaction and connectivity of public transport networks in their land-use context. An in-depth discussion about the selection of these measures is included later in Section 5.4.

Table 5.1 outlines the omissions identified in existing accessibility tools (see Chapters 3 and 4) that SNAPTA seeks to address in order to provide practitioners with a useful approach to transport and land-use planning. Table 5.2 presents a comparison between SNAPTA and a number of existing accessibility tools representing the three categories for accessibility tool development that are discussed in Chapter 3. The tools are compared in terms of: accessibility components covered, accessibility measures used, calculation of spatial separation, trip purpose (type of opportunities), transport modes considered, geographical scale, data requirements, outputs, and the contribution to transport and land-use planning goals including public sector planning, private investor and individual goals. The way in which each of these issues is addressed in SNAPTA is discussed in detail later in this chapter and the next chapter. In comparison with the other accessibility tools from Category 2 that focus on accessibility by motorised vehicles, it can be noticed that SNAPTA considers a relatively wider range of readily available data sets (see the row on data requirements in Table 5.2). This allows the tool to respond to a number of the omissions identified in other existing tools (Table 5.1) with an adequate representation of transport and land-use elements. However, the tool is not intended to give a complete picture of accessibility. The challenge is not to argue that all the omissions addressed in this tool are neglected in other existing tools but it is more about delivering a practical tool that attempts to achieve a balance between the adequacy of methodological substance and data disaggregation on one hand and the ease of interpretation and operationalisation on the other hand (see Section 5.3).

Table 5.1: Omissions in current accessibility tools to be addressed in SNAPTA

Omissions in current tools (identified in Chapters 3 and 4)	Corrections provided by SNAPTA
Insufficient data approach which fails to reflect accurately the actual travel behaviour	High level of spatial disaggregation using a wide range of data sets including population, socio-economic, transport and land-use data (see Section 5.6)
Inadequate methodological approach relying on very simple accessibility measure	A combination of three different measures including distance measure, contour measure and potential accessibility measure, which are sensitive to changes in both transport and land-use and suitable to cover adequately the relevant dimensions of accessibility at a local administrative level (local authority or region level) (see Chapter 2)
High level of data requirements, cost and manipulation leading to a level of detail and complication	The accessibility measures selected for SNAPTA have modest data requirements. They do not require detailed individual activity-travel data and can be applied using readily available data (see Chapter 2, Section 2.6).
Not easy to be interpreted or communicated	The three measures selected are considered easy to interpret and understand by planners and policy makers (see Chapter 2). Moreover, the visualisation power of ArcGIS makes the tool outputs easily communicated even with the public (to be discussed later).
Restricted to only one transport mode and has no potential to include different types of modes	Consideration of all public transport modes in the modelled area including bus, railway and tram as well as the potential for considering car-based modes
Failure of some tools, particularly of those which analyse accessibility by motorised vehicles at local administrative scale, to consider the spatial separation between the origin and public transport network	Consideration of walking time required to access to the public transport network available within a certain time threshold
Failure to calculate actual walking distance and the dependence on the form of as-crow-flies distance instead	Using a reasonable value of constant multiplier for the straight-line distance in order to reach more accurate estimation of walking time (see Section 5.7)
Failure to consider interchange options between different transport modes or operators	Consideration of interchange time and options between all public transport services including those between different operators and modes
No consideration of the influence of travel at specific times of day and on specific days of the week on accessibility	Consideration of accessibility in peak time or off-peak time during weekday or the weekend
No consideration of traffic congestion	Consideration of the influence of traffic congestion on accessibility by calculating travel time based on the timetable associated with each service that already takes into account traffic delays because of congestion
No consideration of the accessibility impacts of physical features and obstacles	Consideration of the influence of slope and heavy traffic volume (i.e. crossing delays) on walking time
Failure to consider the significance of opportunities	Consideration of opportunities attractiveness based on the physical and economic size of urban activities and services
Failure to consider the diminishing influence of distant opportunities	By using the potential accessibility measure, SNAPTA considers the diminishing attractiveness of activities at destination with increasing travel time from the origin of journey.
The need for a bespoke and non open-source software which might be very expensive as well as non user friendly requiring high modelling skills or training due to the lack of expertise in dealing with this software	SNAPTA can be managed and operated using the standard functions of ArcGIS without requiring any bespoke software or external function to be integrated into GIS. However, working on the tool requires a good knowledge of GIS package including ArcCatalog and ArcMap.

SNAPTA is intended to assist discussion and support decision-making in examining the strengths and weaknesses of a land-use – public transport system and reaching solutions for planning problems, particularly where government contexts call for more sustainable transport options to be developed. Figure 5.1 illustrates how SNAPTA contributes to the decision-making process for planning (see Chapter 4, Section 4.2). The tool can be used by planners and policy makers to carry out a number of tasks for the stage of situation analysis and problem definition. It helps to identify 1) gaps in the coverage of public transport network, 2) efficiency of the distribution of services and activities, 3) gaps in the spatial equity of residents by highlighting the areas where people have a relatively poor or high level of accessibility compared with the others, 4) the strategic significance of public transport routes, and 5) the attractiveness of zones, or particular activity, accessed by public transport. The conclusions of these analyses help practitioners to define and formulate their planning objectives at strategic, tactical and operational dimensions (see Chapter 4, Section 4.2) for the local administrative level. In the stage of assessing alternatives, SNAPTA can be employed to analyse the accessibility impact of both changes in the land-use and activity system (e.g. service closure and relocation) and changes in the public transport system brought about by different interventions (e.g. new infrastructure or service, changes in service routes, changes in timetable or speed, and changes in interchange options). This can be applied for before-and-after analysis to compare the consequences and contribution of different alternatives to improved accessibility. The results can be linked with the pre-defined planning objectives in order to define a suitable transport and land-use policy and/or action. After implementing the decision, the outputs of SNAPTA can be used in the final stage of decision-making process for feedback and post-auditing tasks in order to ensure that the delivered policy/ action has achieved the intended objectives of transport and land-use policies as well as the consistency with the objectives of other public policies such as housing, education, health, regional development and environment. In this context, planners and decision-makers can use the SNAPTA analysis of the desired/ programmed situation to compare it with the previous situation and the actual one resulting from implementing the decision. A detailed discussion about the benefits of SNAPTA as a decision-making support tool in the context of this research case study is included in Chapters 6 and 7.

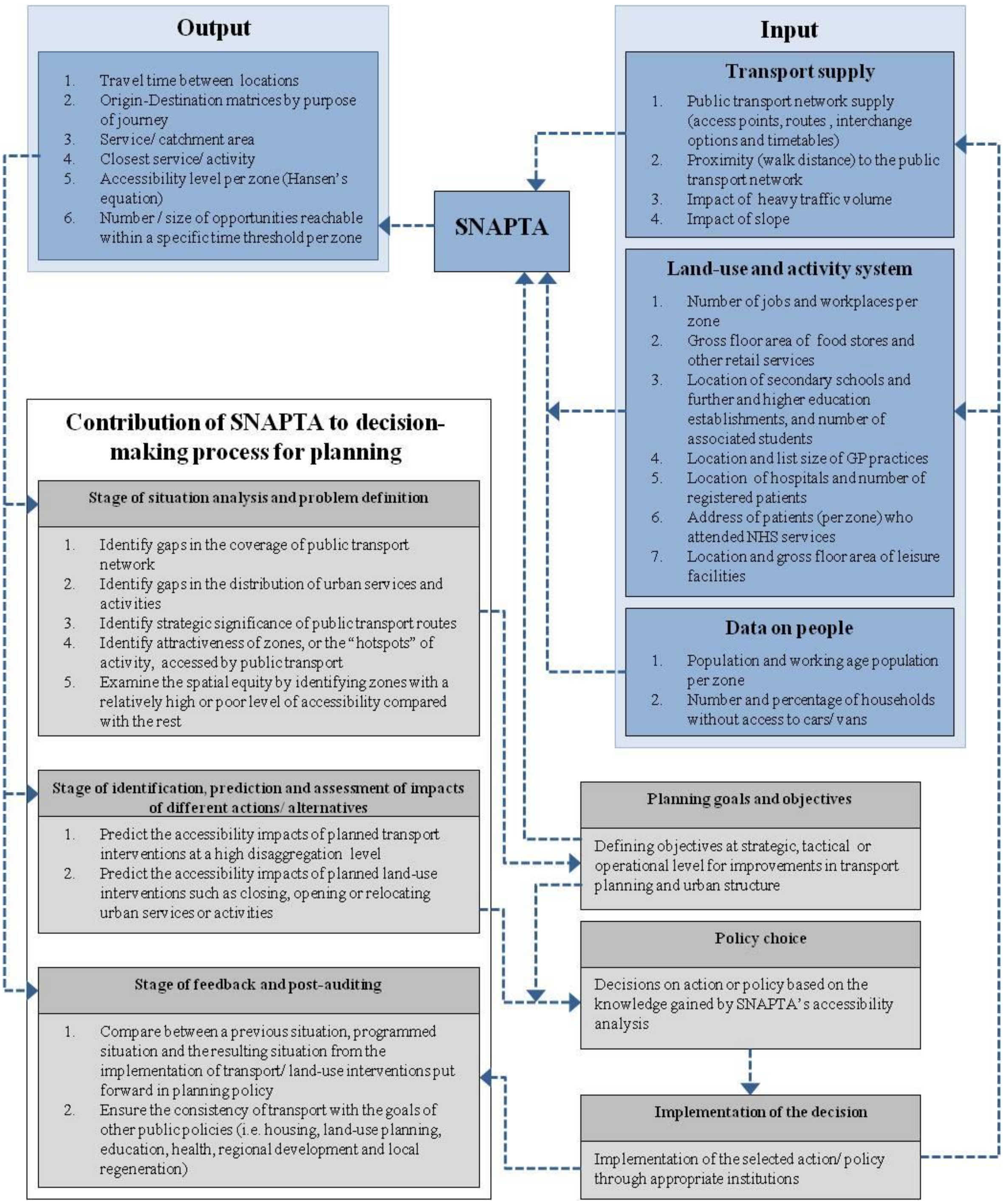

Figure 5.1 – SNAPTA in the decision–making process for planning

SNAPTA provides the methodology required to measure accessibility in accordance with the four ways that have been recommended by Ben-Akiva and Bonsall (2004) for research analytical tools to have more influence on public policy and, decision-making and planning process, as follows:

1) Increasing relevance – The tool addresses the concept of accessibility which is one of the most important issues in transport and urban planning (see DETR,

2000a; SEU, 2003; DfT, 2006). It is appropriate for current policy and based on an understanding of the present and future requirements of decision makers. It has been developed as an efficient and alternative approach to be used in real world planning decisions.

2) Improving the interface – The tool offers a transparent methodology that allows planners and decision makers to be involved in the calculation and analysis process. It helps the users to better understand the relationship between transport and land-use and how they affect each other. By using the tool they can identify problems in the urban structure by testing different alternatives look for scenarios to a planning solution.
3) Strengthening credibility – The tool has been developed taking into account the usefulness criteria identified in the literature review in order to create a robust and attractive product for decision makers and one which is not overly complex (see Section 5.3).
4) Effective dissemination – The tool outputs are easily communicated to planners, policy makers and members of the public in non-technical language. It is effective at visualising accessibility in maps which are sufficiently detailed, clear and easy to interpret and communicate even with the public (see expert assessment in Chapter 7).

The research tests the tool in the real world in planning practice by applying it to a case study of Edinburgh Council's area. Therefore, the development of SNAPTA has been closely linked to the appraisal of public transport interventions and the monitoring needs arising from the Edinburgh Local Transport Strategy (2007-2012) and subsequent reviews leading to a revised strategy (2014-2019) as well as other local and regional plans regarding transport vision and urban development (to be discussed in detail in Chapter 6). Since such strategies present key sustainable transport ideas such as plans to boost transport – land-use integration and increase the reliance on public transport, SNAPTA provides an opportunity to deliver key elements of this strategy so that vital decisions are based on evidence of the impacts on accessibility. For example, the tool can show which centres need to be improved or where to promote the public transport network based on the relevance of SNAPTA to decision making on the delivery of good accessibility and spatial equity in the distribution of opportunities (see Chapter 6, Section 6.6 for a fuller discussion on the relevant outputs from SNAPTA that help to do this). Chapter 6 examines the application of SNAPTA to the different transport scenarios or interventions envisaged in the Edinburgh Local Transport Strategy in order to identify their impact on spatial accessibility to different types of opportunities.

Table 5.2: Comparison between SNAPTA and examples of existing accessibility tools in planning practice

		Local access by walking/ cycling		Accessibility by motorised vehicles through the transport network							Models designed for another purpose incorporating accessibility		
		PTAL	**WALC**	**SNAPTA**	**SNAPTA** (further development)	**PTAM**	**CAPITAL**	**TRANSAM**	**SONATA**	**Accession**	**Space Syntax**	**GenMod**	**TMfS**
Accessibility components	Land-use			●	●	●	●	●	●	●	●	●	●
	Transport	●	●	●	●	●	●	●	●	●	●	●	●
	Temporal	●	●		●					●			●
	Individual		●						●				
	Other												
Accessibility measure traditions	Access to public transport services (public transport provision)	●	●										
	Spatial separation		●	●	●	●	●	●		●		●	
	Cumulative opportunity (contour)			●	●	●	●	●		●		●	
	Gravity-based (potential accessibility)			●	●					●		●	
	Time-space												
	Utility-based									●			
	Infrastructure-based												
	Network										●		
	Qualitative survey								●				●
	Other												
Estimation of travel time/ cost	Using speed limit/ average speeds on road network				●			●		●		●	
	Using scheduled journey times from public transport timetables			●	●	●	●	●		●		●	
	Walk time/distance on actual network		●				●	●		●	●		
	Walk time/distance based on as-the-crow-flies lines			●	●	●				●		●	
	Walk time weighted based on obstacles		●	●	●								
	Based on local survey data								●				●
	Based on outputs from other transport models						●						
	Other										●		
	Not applicable	●											

Table 5.2: Comparison between SNAPTA and examples of existing accessibility tools in planning practice – continued

		Local access by walking/ cycling		Accessibility by motorised vehicles through the transport network							Models designed for another purpose incorporating accessibility		
		PTAL	**WALC**	**SNAPTA**	**SNAPTA** (further development)	**PTAM**	**CAPITAL**	**TRANSAM**	**SONATA**	**Accession**	**Space Syntax**	**GenMod**	**TMfS**
Trip purposes/ opportunities	Any purpose (disaggregate) or all purposes (aggregate measure)					●	●			●	●		
	Work			●	●			●	●			●	●
	Healthcare			●	●			●	●				
	Education			●	●				●				
	Shopping			●	●				●				●
	Leisure			●	●								●
	Other												
	Not applicable	●	●										
Transport modes	Any mode										●		
	Public transport (only bus services)	●				●			●				
	Public transport (all modes)			●	●		●	●		●		●	●
	Car				●			●		●		●	●
	Walking		●	●	●	●	●	●		●		●	
	Cycling							●		●			
	Truck												●
	Other												
Geographical scale	Supra – national												
	National												●
	Supra – municipal/ regional				●					●		●	●
	Municipal	●	●	●	●	●	●	●	●	●	●	●	●
	Neighbourhood	●	●			●					●		
	Street	●	●								●		

Table 5.2: Comparison between SNAPTA and examples of existing accessibility tools in planning practice – continued

		Local access by walking/ cycling		Accessibility by motorised vehicles through the transport network							Models designed for another purpose incorporating accessibility		
		PTAL	**WALC**	**SNAPTA**	**SNAPTA** (further development)	**PTAM**	**CAPITAL**	**TRANSAM**	**SONATA**	**Accession**	**Space Syntax**	**GenMod**	**TMfS**
Data requirements	Population		●	●	●	●		●	●	●		●	●
	People characteristics (e.g. age, gender, income, education level, physical ability)		●		●	●			●				
	Rents/ land values										●		
	Opportunity locations database			●	●	●	●	●	●	●	●	●	●
	Number of jobs/ workplaces by location			●	●	●		●				●	●
	Data on patients in hospitals, GP and/or dentists			●	●								
	Data on students in universities, colleges and/or schools			●	●								
	Floor space area (e.g. commercial facilities)			●	●								
	Data on households without access to cars/ vans (car ownership)			●	●				●				
	Geographic database for road networks		●	●	●		●	●		●	●	●	●
	Data on speed				●			●		●		●	●
	Public transport network database (i.e. locations of bus stops, railway stations)	●	●	●	●	●	●	●	●	●	●	●	●
	Public transport routes and timetable			●	●	●	●	●		●			
	Frequency of public transport services	●				●				●			
	Pedestrian networks database	●	●					●			●		
	Cycle networks database							●			●		
	Data on traffic flows/ volumes		●	●	●								●
	Location of drop kerbs, crossing points, barriers, bollards, etc.		●										
	Local terrain and slope		●	●	●								
	Survey data (e.g. on journey length, journey quality, demand, etc.)								●			●	●
	Other		●								●		

Table 5.2: Comparison between SNAPTA and examples of existing accessibility tools in planning practice – continued

		Local access by walking/ cycling		Accessibility by motorised vehicles through the transport network							Models designed for another purpose incorporating accessibility		
		PTAL	**WALC**	**SNAPTA**	**SNAPTA** (further development)	**PTAM**	**CAPITAL**	**TRANSAM**	**SONATA**	**Accession**	**Space Syntax**	**GenMod**	**TMfS**
Outputs	List/ isochrones of journey times			●	●	●	●	●		●		●	●
	Population/ opportunities catchment indicators		●	●	●	●		●		●			●
	Output ranges/ classes (accessibility index)	●		●	●				●		●	●	
	Routing paths/ costs			●	●					●			●
	Flows												●
	Origin-destination based output			●	●	●	●	●		●	●		
	Link based output										●		●
	Pollution emissions												●
	Other												●
Contribution to planning goals (Hull et al., 2012b) – **Public sector planning goals**	To decide on the locations of residence/ activities/ services			●	●	●	●	●	●	●	●	●	
	To manage, encourage or reduce the use of a particular transport mode(s)	●	●	●	●			●	●	●			●
	To ensure economic equity			●	●			●		●		●	●
	To ensure social equity and cohesion	●	●		●	●			●				
	To stimulate economic development												●
	To ensure reduction of emission/ energy use							●					●
	Other			●	●								
Private investor goals	To locate business			●	●	●		●	●	●	●	●	●
	To invest in real estate			●	●				●				
	To develop public transport services (private operators)	●	●	●	●	●	●	●	●	●	●	●	●
	To develop freight supply chains (freight operations)												●
	Enhancing patronage levels through information and marketing – access to information												
	Other												
Individual goals	Choosing household location	●	●	●	●	●	●	●	●	●	●		●
	Choosing the best route to (a) particular activity(ies)			●	●		●	●		●			●
	Choosing the best mode(s) for (a) particular route(s)			●	●		●	●		●			
	Choosing the nearest activity(ies)			●	●	●	●	●		●		●	
	Other												

Source: Author's own derived from several sources

5.3 Usefulness of SNAPTA in Planning Practice

To ensure that SNAPTA is seen by practitioners to be a usable decision support tool, it has been developed with the consideration of the four usefulness criteria drawn from reviewing the literature on accessibility studies in Chapter 4. The first criterion focuses on the *Robustness of theoretical basis and methodology*. Reviewing the literature on accessibility measures and the relevant dimensions (provided in Chapter 2) shows that the widely used measures selected for SNAPTA (i.e. travel time/ distance measure, contour measure and potential accessibility measure) are able, to varying degrees, to demonstrate the relationship between transport and land use and to give a clear picture of accessibility levels at a local administrative scale (i.e. local authority or region). A survey was carried out through a local workshop in Edinburgh to collect experts' (transport and land-use planners) opinions on the ability of SNAPTA to do this (see Chapter 7 for the report on the expert assessment). The selection of different measures which rely on different approaches in assessing accessibility leads to a larger coverage of the aspects related to experience of travel by public transport. Moreover, the capability of SNAPTA to address a number of omissions in some current accessibility tools (Table 5.1) regarding data approach and disaggregation (see below), walking time calculation, interchange options and the impact of physical features boosts the confidence in the robustness of its modelling approach. The tool has been successfully validated against observed data which demonstrates its ability to replicate actual travel patterns (see Appendix A for validation and sensitivity analysis). Furthermore, the accuracy of SNAPTA's output can be checked through the different stages of modelling process for a limited geographical area before it is applied to different areas and repeated in further studies. The check can be carried out by calculating manually and individually the time of journey components and comparing the obtained values against their actual corresponding journey times (e.g. walking time to the nearest public transport access point and in-vehicle travel time between any two stops by a particular bus service).

Having an *adequate level of data disaggregation* is the second criterion considered in the development of SNAPTA. Although there is no clear approach presented in the literature to evaluating the adequacy of the data disaggregation used, as discussed in the previous chapter it is important for practitioners that the selected level of spatial and data disaggregation should be able to provide a sufficiently accurate reflection of the actual travel behaviour (te Brömmelstroet et al., 2014). In other words, a level which provides a detailed representation of accessibility conditions in reality that planners and policy makers can rely on to analyse planning problems and identify solutions satisfying the intended policy objectives and considered geographical scale. In this respect, SNAPTA uses the Scottish Census Data Zones which are the key small-area statistical geography in Scotland built up based on 2001 Census with population between 500 and 1000 residents each. Therefore, contextual data on population and socio-economic characteristics can be used at the highest available level of spatial disaggregation. In addition to the spatial disaggregation, the tool applies disaggregation by trip purposes (disaggregation of activities) taking into account six types of opportunities as the main destinations of public transport journeys. These include the central business district (CBD), employment, shopping (food stores and general retail services), education (secondary schools and further and higher education institutions); health and medical services (GP practices and hospitals), and leisure facilities. The consideration of this disaggregation and zoning system has been recognised by experts (transport and land-use planners) as an appropriate choice to adequately assess accessibility at the local administrative scale (for more details see expert assessment in Chapter 7). Although the tool is based on a high disaggregation level, it has modest data requirements. It does not require detailed individual activity-travel data and can be applied using readily available data.

Being *not complex to operate and simply oriented towards clear policy objectives* is another usefulness criterion that the tool seeks to meet. SNAPTA has been developed in a way that allows users to set up the calculation and orient it to produce results relevant to different stages of the decision-making process for planning (see Figure 5.1 above). Using ArcGIS, different calculation tasks with different objectives can be carried out in SNAPTA, including travel time between any two locations, catchment/ service area of a location (or set of locations), closest opportunity to a location (or set of locations), best route (i.e. shortest journey time) between any two locations, and origin-destination matrix between two sets of locations. On the other hand, these tasks are not too data hungry and over-complex in such a way which means they are misinterpreted. The methodology adopted is a transparent and easily understood technique, benefiting from the interactivity and interface characteristics of ArcGIS. As a part of further work, a manual will be produced and provided together with the tool in order to better understand how it works and aid the adjustment of the calculation methodology and associated parameters by practitioners. All the data involved in the modelling including population, socio-economic, transport and land-use data can be updated within the GIS environment in any stage of the calculation to fit the user requirements (e.g. introducing a new bus service or stop, opening a new facility, increasing the capacity of a school, changes in a service route or timetable, etc). They can be updated manually, which is straightforward and quick when it is needed for a relatively small number of changes. Moreover, SNAPTA can be managed and operated using the standard functions of ArcGIS without requiring any bespoke software or external function to be integrated into GIS. However, working on SNAPTA requires a good knowledge of ArcGIS package including ArcCatalog and ArcMap, particularly the functions of ArcGIS Network Analyst.

Ensuring SNAPTA is an *easily interpreted and communicated tool* is another significant issue that has been taken into account in the development stages. The distance measure and contour measure have been selected because these measures are considered as the simplest accessibility measures and easy to interpret and understand by planners and policy makers (see Chapter 2). The visualisation power of ArcGIS allows SNAPTA to present the outputs in sufficiently detailed and clear maps which are readily communicable to the public and non-experts. These maps help stakeholders to understand accessibility and the relevant planning issues in the context of the real world. For example, by using SNAPTA's maps planners and policy makers can easily realise the differences in the level of public transport accessibility to hospitals between the zones of the studied area. The maps can be presented in different colours or different shades of one colour in which each colour/ shade represents a different level of accessibility or of an absolute or relative (percentage) change in accessibility associated with a zone. Each colour on the map corresponds to a figure referring to a range of travel times (or changes in travel times) for the distance measure and number/ size of reachable opportunities (or changes in number/ size of reachable opportunities) for the contour measure. In the case of the potential accessibility measure, a clear index can be provided with the map to show the different levels of accessibility or of changes in accessibility (due to a transport/ land-use intervention) across the modelled area (see examples of the output maps in Chapter 7 and Appendices B, C and D). Therefore, the maps assist planners and policy makers to understand how well different scenarios of transport or urban development perform and affect the spatial distribution of accessibility that can be used as a basis for dialogue with all the stakeholders involved in order to make a decision and select a strategy.

5.4 Conceptual Framework and Selection of Accessibility Measures

The conceptual framework adopted in the SNAPTA tool for modelling the accessibility of public transport include 1) public transport supply, 2) location and attributes of activities, and 3) accessibility criteria and measurement. Figure 5.2 illustrates the concept of SNAPTA's framework. It shows the different elements and characteristics considered in SNAPTA that define the level of public transport supply available to the residents of each zone, and the type of opportunities that define the journeys destinations of residents travelling by public transport to participate in activities and services. To examine the strengths and weaknesses of the integration of these elements, three accessibility measures are incorporated in the conceptual framework.

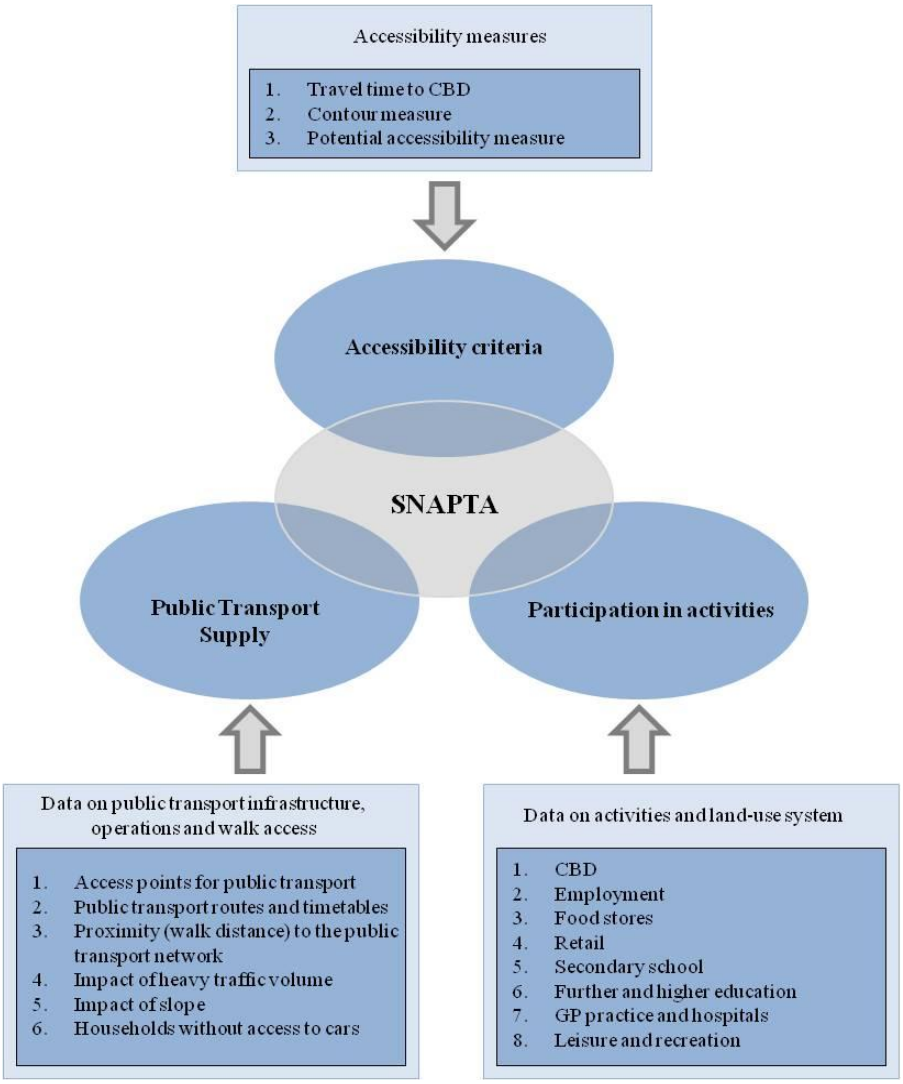

Figure 5.2 – SNAPTA's conceptual framework

Public transport supply incorporates the network, facilities and services of public transport including buses, tramways, railways, etc. that cover the whole of the area that is studied. The location of boarding points (i.e. bus and tram stops and railway stations), the timetables associated with each service and the availability of interchange options are used to compute in-vehicle travel time which is the main element of the calculation of spatial separation (travel impediment). The proximity of the residents of each zone to train stations and bus and tram stops are included in the calculation of spatial separation based on walking distance from zone centroid, taking into account the physical features that affect walking access to the public transport network (to be discussed in detail in Section 5.7).

The spatial distribution and attributes of activities and land uses (opportunities) are an essential element to be linked with the public transport supply within SNAPTA's framework in order to assess their accessibility. Using disaggregation by journey purpose, the tool considers travel to the main type of opportunities required to fulfil the needs of individuals who use public transport to reach these opportunities. Therefore choice of opportunity types and the consideration of their attributes depend on the intended objective of analysis. Regarding the spatial disaggregation of opportunities and land-use condition, as described above in Section 5.3, it has been carried out based on the Scottish Census Data Zones. In this respect, the tool assumes that all opportunities located in a zone are equally reachable from any location in the modelled area regardless of the size of the zone area (see Section 5.5 below for further discussion on the assumptions adopted for SNAPTA modelling approach).

Taking into account the adequacy of methodological substance as a key criterion for the tool's usefulness (described in the previous section), three measures with different theoretical bases and approaches are selected to calculate accessibility in SNAPTA. In regard to the ease of interpretation criterion, the measures selected, which belong to the activity-based measures (Chapter 2), have been considered, as discussed earlier, relatively easy to interpret and understand by planners and policy makers. They take into account the land use and transport characteristics of urban interactions and the availability of opportunities which can be accessed by public transport. These measures are:

1) *Travel time to city centre.* It is based on distance measure to calculate journey time by public transport between a zone (or set of zones) and the Central Business District (CBD). This measure is the simplest one in SNAPTA's package. It is straightforward to compute and its outputs are easily interpreted and communicated (see Chapter 2, Sections 2.5 and 2.6). It focuses on one relationship only (between each zone and the CBD), giving a quick indication of the spatial distribution of the level of accessibility to CBD across the modelled area with no consideration of the size and demand for the activities and services within that CBD. However, the measure can be applied to measure accessibility to any location not only to city centre.

2) *Contour measure*. The measure describes the total number or size of opportunities that can be reached by public transport within a specific travel time (cut-off value). The output can be expressed either by the quantity, capacity or floor space area of facilities and economic activities, making the measure simply interpreted (see Chapter 2, Sections 2.5 and 2.6). SNAPTA applies different cut-off values for travel time according to the selected trip purpose. These values have been defined by Department for Transport (DfT) (2006) as the core accessibility indicators that local authorities can use for the key public transport journey purposes (see Section 5.8).

3) *Potential accessibility measure.* This measure is a gravity-based measure that includes a transport component, mainly the travel time between zones, and a land-use component determined by the quantity or size of opportunities per destination zone. As described earlier in Chapter 2, a potential accessibility measure overcomes a main methodological disadvantage of a contour measure. It uses a distance decay function, reflecting the diminishing attractiveness of opportunities at a destination with increasing travel time from the origin of the journey. On the other hand, the expression of the measure outputs is in an undefined unit (i.e. a set of indices such 1, 2, 3, etc.), making it less easy than the other two previous measures to interpret and communicate with non-modellers. The potential accessibility for the residents of each origin zone (A_i) can be defined by using Hansen's equation (1959, p.74), as follows:

$$A_i = \sum_{J} a_j \,.\, f(t_{ij}) \qquad (1)$$

Where a_i is the attractiveness (i.e. quantity or size of opportunities) of destination zone *j*, t_{ij} is travel time, cost or distance from zone *i* to zone *j*, and $f(t_{ij})$ is an impedance function (distance decay function).

Several methods have been used to estimate impedance functions in accessibility studies (see Geurs and Ritsema van Eck (2001) for a detailed discussion). This research uses the negative exponential function as an impedance function that can be expressed in the following equation:

$$f(t_{ij}) = e^{-\beta . t_{ij}} \qquad (2)$$

Where β is a sensitivity parameter to travel time with a range of values between 0 and 1, reducing or increasing the effect of travel time changes. It determines the weighting of opportunities. The higher the value of β, the more heavily the readily accessible (nearby) opportunities are weighted (Hilber and Arendt, 2004), and the stronger the effect of travel time increase or decrease is applied. The lower the spatial disaggregation (or, hence, the larger the individual zone) and the bigger β the greater is the significance of the intrazonal potential (or internal accessibility) that is defined as the quantity or size of opportunities within a zone weighted by the average travel time within this zone. The relevant literature has adopted different values for β ranging from 0.5 at regional level (Simma et al., 2001) and 0.2 at nationwide level (Fröhlich and Axhausen, 2002; Hilber and Arendt, 2004) to 0.01 for Europe (Schürmann et al., 1997). However, for accessibility by public transport, some studies applies the negative exponential function with a low value for β regardless of the type of opportunities, for example the value of 0.01 was used by Boucq (2007) and 0.005 by Spiekermann and Wegnener (2007). The explanation is that public transport users are not very sensitive to a small variation of time. Since this research analyses accessibility at a local administrative level with a high spatial disaggregation (and relatively small zones) focusing on public transport only, the value of 0.1 is selected for β.

The selection of the measures above for SNAPTA provides a package of accessibility measures that can be used by practitioners and decision makers for different system queries. These measures have been widely used in the literature for diverse types of applications. They assess accessibility relying on different methodologies with different levels of complexity. Since each methodology is characterised by its own features to reflect various aspects of transport and land-use systems differently, the tool users can set up the measurement framework in a way that serves the circumstances and objectives of the different planning and policy issues. The fundamental difference between the three measures is that the travel time to city centre and contour measure focus on the separation between locations while the potential indicator focuses on the interaction between locations (Gutiérrez et al, 1996). The theoretical underpinnings of the potential accessibility measure are that the interactions between an origin and destination will decline with increasing distance and time but that interactions are positively associated with the amount of activity at each location (Hansen, 1959).

Using this package of measures, the tool is adequately sensitive to changes in both transport and land use at a local administrative level. It focuses on groups of people, and assumes that they have a set of social and economic activity needs to be met at different destinations, and that travel demand will be determined by the attractiveness of these locations and the quality of the transport infrastructure linking these places (Karou and Hull, 2014). Issues concerning the spatial equity of public facilities, the accessibility to workplaces, shops and other services by public transport, and the changes to accessibility brought about by new transport infrastructure or the re-location of public facilities can all be interrogated through the model. Furthermore, the use of these different measures in one tool provides an opportunity to tackle the methodological and operational disadvantages associated with each measure. For more detail, the advantages and disadvantages of the three measures are presented in Table 2.2 (Chapter 2).

5.5 Basic Assumptions

A number of assumptions have been considered in the formulation of SNAPTA's approach for accessibility modelling, taking into account the intended uses of the tool as well as issues related to the nature of selected measures, transport modes considered, level of spatial disaggregation and geographical dimension at which the tool is meant to be applied (to be discussed in Section 5.8). The following assumptions used in this research have been made in previous studies with similar circumstances and accepted in accessibility and transport modelling in practice (see Ali, 2000; Geurs and Ritsema van Eck, 2001; Halden, 2002; Holl, 2007; Yigitcanlar et al., 2007; Vandenbulcke et al., 2009).

1) All individuals in each zone are gathered at the centroid of their zone and have the same level of accessibility regardless of their different characteristics and travel demands (e.g. age, gender, income, physical ability, etc.) and different perception of the available opportunities. Similarly, all opportunities located in a zone are treated in the way in which all are placed at the centroid of that zone regardless of the size of zone area and how far their locations are from the centroid. As a result, internal journeys made to pursue opportunities within the same zone are neglected in SNAPTA's analysis. The level of spatial disaggregation strongly affects this assumption, which has been made to increase the practical applicability of the tool since detailed individual data would lead to a high level of complexity and data requirements particularly when it is required at a relatively large geographical dimension. However, for application at a local administrative level such as Edinburgh Council's area, which consists of 549 Data Zones (representing 549 origins/ destinations), using such an assumption does not limit the tool's capability to provide adequate information about accessibility problems and solutions. On the other hand, this makes the tool unsuitable for a micro-scale analysis (see Section 5.10 for potentials and limitations).

2) All travel incorporates only two separate stage journeys whatever the number of transfers involved in carrying out the journey; beginning at the origin-location, going to a single destination to take part in one or more activities and then returning to the origin-location. Therefore, the tool does not consider the case of a multi-stage journey that an individual makes for sequential activities. The key reason for this assumption is to not complicate the calculation process as a result of the large amount of journey possibilities that might be considered to satisfy different sequences of activities.

3) All opportunities that are located outside the selected boundary of modelled area have no influence on accessibility pattern whatever the significance of these opportunities in generating journeys from the area studied. This assumption has been widely made in accessibility analysis in practice since there is always a boundary to be defined for the modelled area. However, the boundary issue can be resolved by applying the tool to a wider area than the one required for analysis in such a way that includes those opportunities believed to have a significant impact on accessibility.

4) All public transport users are interested in travel time rather than geographical distance or fare cost. In other words, all individuals make their public transport journeys through the fastest routes (including the fastest interchange option) to reach their desired destinations. In SNAPTA, the spatial separation between locations is expressed in travel time. The estimation of generalised cost implies a much higher degree of complexity because it requires knowledge of fuel and operating costs, fare costs and monetary values of travel time, walk time and wait time as well as the need to express the convenience/ inconvenience of journey as a monetary cost. Moreover, it should be noticed that individuals view time value differently, and the prices of fuel and fares might change over short periods of time making the estimation of generalised cost less practical.

5) In the same context of the previous assumption, the tool assumes that people walk to the closest bus/ tram stop or train station (to their zones' centroid) at which the fastest public transport route running to their desired destination is available. The proximity to the public transport network is measured based on a straight-line distance multiplied by a constant derived from the urban structure of the studied area (see Section 5.7 for a further description).

5.6 Data Requirements and Collection

The construction of SNAPTA using GIS for application to the case study of Edinburgh transport network (discussed in Chapter 6) for accessibility modelling requires a wide range of secondary data sets collected from different sources. Due to the nature of the accessibility measures selected, the tool relies on data that are readily available at the Data Zone level, which ensures a high level of spatial disaggregation – a key criterion for the tool's usefulness (Section 5.3). Moreover, the fact that no detailed individual activity-travel data are required could ease the practical applicability and operation of SNAPTA – another criterion for the tool's usefulness – particularly for a large scale of urban area such as the administrative area of the City of Edinburgh Council. The boundaries of 549 Data Zones of Edinburgh Council's area, which are the key small-area statistical geography in Scotland based on 2011 Census, are obtained from Scottish Neighbourhood Statistics (SNS). The data required can be grouped into three categories: 1) data on people, 2) data on activities and land-use system, and 3) data on transport infrastructure and operations:

1) *Data on people*

- Population and households at Data Zone level – data obtained from data obtained from General Register Office for Scotland (GROS) Census 2011 (published every 10 years) (GROS, 2013)
- Working age population (i.e. the number of people who are from 16-64 years of age for men and from 16-59 for women) at Data Zone level (based on Scotland's Census 2011) – data obtained from GROS (2013)
- Number and percentage of households without access to cars or vans at Data Zone level (based on Scotland's Census 2011) – data obtained from National Records of Scotland (NRS) (2013)

2) *Data on activities and land-use system*

- Edinburgh CBD boundary (or the city centre ward) – data obtained from City of Edinburgh Council (CEC) (personal communication with CEC, 2011)
- Employment:
    i) Number of jobs available per industry sector at Data Zone level – data obtained from Office for National Statistics (ONS), Business Register and Employment Survey (BRES) 2009
    ii) Number of workplace units at Data Zone level – data obtained from ONS, Annual Business Inquiry (ABI) 2008
- Food stores: Location and floor space area of supermarkets for Scotland's large food retail chains estimated in 2009 at Data Zone level – data obtained from Pitney Bowes MapInfo Retail Locations (2010)
- Retail: Location and floor space area of all retail services (including food stores) at Data Zone level. The location of retail units were derived from Ordnance Survey Points of Interest 2007 edition and these point locations were used to match an enclosing building outline from buildings maps sourced from Ordnance Survey MasterMap 2010 in order to estimate the floor space data.
- Secondary schools: Location of secondary schools including state and private schools with the number of pupils registered in 2009/2010 – data obtained from CEC and sources related to private secondary schools in Edinburgh
- Further and higher education: Location of colleges and universities with the number of associated students registered in 2010/2011 – data obtained from Department for Education and sources related to education institutions in Edinburgh

- GP practices: Location of GP practice units with the associated list size in July 2011 – data obtained from National Health Service (NHS) Lothian
- Hospitals:
    i) Supply: Location of hospitals with number of outpatients, day patients, and inpatients registered in these hospitals in 2010 – data obtained from NHS Lothian
    ii) Demand: Number of patients who attended NHS Lothian services in 2010 at Intermediate Zone level – data obtained from NHS Lothian
- Leisure and recreation facilities: Location of leisure facilities including libraries, cinemas, sport facilities and parks at Data Zone level. The locations of these facilities were identified by using Ordnance Survey Points of Interest 2007.

3) Data on transport infrastructure, operations and walk access

- Locations of bus stops, tram stops, railway stations and other access points for public transport – data obtained from NaPTAN (National Public Transport Accessibility Network)
- Public transport routes and timetables regarding bus, tram and local train services which are run by different operators (Lothian Buses, FirstGroup Bus, E&M Horsburgh, Stagecoach Bus and Edinburgh Coach Lines) – data obtained from CEC, Lothian Buses and Traveline.
- Road networks – data obtained from Ordnance Survey (OS) MasterMap Integrated Transport Network (ITN)
- Ambient air quality – this includes data on the concentrations of NO2 (nitrogen dioxide) and PM10 (particles in the ambient air which are smaller than 10 micrometres across) at background locations 2002-2004. Ambient air quality at Data Zone level is used as a proxy for traffic volumes in roads to be considered as a factor delaying crossing. Data are obtained from Department for Environment, Food & Rural Affairs (Defra).
- Slope – this includes data on the variation in height values at Data Zone level showing the gradient in each zone as a physical feature that lengthens walking time to access the public transport network. The greater the variation in height values, the steeper the slope. Data are obtained from EDINA.

Some of the data above have to be prepared prior to model input in GIS. Using the timetables associated with bus/ tram stops, in-vehicle travel times between the consecutive stops need to be calculated for each public transport service in both directions. Also an estimation of weighting values of walking time based on the ambient air quality and slope data associated with each zone have to be carried out in advance of model input (see below Section 5.7 for more details). Some of the data collected on activities and land use are available per unit or establishment instead of per Data Zone, including data on secondary schools, further and higher education, GP practices and hospitals. In some cases, two or more establishments of the same type of activity are based in the same zone such as the Sighthill Campus of Napier University and Stevenson College. Therefore, data on activities including the number and size of these activities (e.g. number of students registered at each educational establishment) have to be aggregated over the geographical areas of Data Zones.

5.7 Methodology of Accessibility Modelling

This section discusses the construction of the accessibility-modelling framework of the SNAPTA tool. SNAPTA has been applied to the Edinburgh transport network (within CEC's area) to analyse 1) the spatial accessibility and equity in the distribution of urban services, 2) the impact that the planned transport infrastructure brought by CEC's Local Transport Strategy will have on spatial accessibility by public transport, and 3) the comparison between the different transport projects and the level of enhanced accessibility they produce. In this regard, the modelling approach involves the development of a number of scenarios that cover the key public transport projects planned for Edinburgh's network within the different time frames. This includes 1) the baseline year 2011 scenario, reflecting the situation of Edinburgh's transport network in 2011; 2) the year 2014 scenario, reflecting the network after the construction of the first part of Edinburgh Tram (see Chapter 6); and 3) longer term scenarios which consider different combinations of envisaged or planned transport projects for long-term development (see Chapter 7, Section 7.4). The projects examined in this study incorporate the construction of the tram system including all the proposed lines and re-opening of Edinburgh South Suburban Railway (ESSR). An in-depth description of these projects and Edinburgh transport system is provided later in Chapter 6.

The location and attributes of activity opportunities have been modelled in GIS (ARC/INFO). Land-use, demographic and socio-economic data (at Data Zone level) including the total number of jobs, the floor space area of retail services and recreation facilities, and the number of patients in health care centres and hospitals, have been obtained under licence from the relevant government organisations. The data on the number of students in secondary schools and universities, and number of leisure and recreation facilities have been obtained from these organisations' websites. Once the required data are collected for each zone, they are linked to the associated centroids of zones within the GIS database. Since the model assumes that all individuals are gathered in the centroids where their journeys start and end, the determination of centroids are re-calculated on the basis of population density rather than geometric centres to avoid assigning population on non-residential areas such as parks and large unoccupied lands. However, in this study the accessibility impact of new transport interventions has been isolated from changes in the land-use system by fixing the data on opportunities in such a way that each zone holds the values of baseline year data on population, employment, retail, health, education, and recreation in all the scenarios. Table 5.3 shows the relationship between SNAPTA's accessibility measures and the opportunities selected for the modelling framework.

Table 5.3: Overview of the relationship between the accessibility measures and opportunities

Type of opportunities		Accessibility Measures				
		Travel time to CBD	Contour measure			Potential accessibility measure $A_i = \sum_j a_j . f(t_{ij})$
			30mins cut-off	40mins cut-off	60mins cut-off	
Central Business District (CBD)		√	-	-	-	-
Population		-	√	-	√	-
Employment	Working age population	-	-	√	-	-
	Employees/ jobs	-	-	√	-	√
	Workplaces	-	-	√	-	-
Shopping	Food stores	-	√	-	-	√
	Retail services	-	-	√	-	√
Education	Secondary schools	- -	- -	√ -	- -	- √
	Further and higher education establishments	- -	- -	- -	√ -	- √
Health	GP Practice (supply)	- -	√ -	- -	- -	- √
	Hospitals (supply)	- -	- -	- -	√ -	- √
	Demand for health care services	-	√	-	√	-
Leisure and recreation		-	-	√	-	√

A digital multimodal transport network of bus services, tramways and ESSR railways has been built in GIS. The network is represented by links and nodes covering the whole area of study. The nodes are chosen on the network to correspond to bus and tram stops and railway stations across the modelled area. The links represent the connection between these nodes forming the routes of all public transport services considered. For each transport link in the GIS data base, tabular attributes of its type, length and the time needed to pass that link have been built. SNAPTA takes into account walk access time from the origin, waiting time, in-vehicle time, interchange time and walk time to the destination.

Walking time is calculated as a constant multiplied by the straight-line distance from the origin (i.e. the centroid of origin zone) to the nearest public transport stop, from the disembark stop to the interchange stop, and from the final disembark stop to the destination (i.e. the centroid of destination zone). The calculation considers access to public transport services and interchange where the distance to a stop (or between stops) does not exceed 500 metres, which is the maximum value of the range of 300-500 metres walk defined by the Scottish Transport Appraisal Guidance (STAG) (Scottish Executive, 2003) as indicative criteria for an acceptable walking distance to bus stops in urban areas. SNAPTA uses the value of 1.2 as a constant multiplier for the straight-line distance in Edinburgh Council's area. This value is typically applied by the City of Edinburgh Council as a reasonable multiplier (personal communication with CEC). It is estimated based on the network patterns of several example points around the study area with the 800 metres actual distance and 670 metres radius circles. Figure 5.3 shows the location of six example points which have been selected randomly to estimate the multiplier value. Once walking distances are estimated, the model uses a walk speed value of 3mph (or 4.83 kph) for average population to measure walking time (Jones et al., 2005 and Transport for London, 2010).

For the perceived walking time, the physical features that delay walk access from and to the public transport network in the beginning and end of journey are taken into account by estimating an extra walk time for each zone as a weighting value of walking time. This has been applied to slopes (e.g. for walking up a steep hill) and streets with heavy traffic volume which causes delay before crossing. Slope weights are calculated based on the variation in height values within each zone in which the greater the variation in height values, the larger the slope weight). Traffic volume weights are estimated using the concentrations of NO2 (nitrogen dioxide) and PM10 (particles in the ambient air which are smaller than 10 micrometres across) at background locations within zones. The total weighting value given to each zone is obtained by adding the slope weight up to 2 minutes to the traffic weight up to 2 minutes, meaning that the maximum extra walk time for each zone is 4 minutes. These limit values that have been imposed on the weighting factors for walking time are extrapolated from the results of surveys conducted by Jones et al. (2005) in parts of Keighley and Tower Hamlets in order to identify and quantify the importance of different obstacles that passengers might face between home and the bus stop or railway station, and at the bus stop itself. Based on the discussion above, SNAPTA estimates the perceived walking time as follows:

Perceived walking time = measurable walking time + slope weight + traffic volume weight

Wait time at the stop of origin or interchange stop is calculated based on the minimum average of scheduled waiting time for the selected public transport service. For example, in the case of accessibility by Edinburgh bus services in the morning peak time during week days, wait time is calculated using the scheduled waiting time for a service running every 10 minutes, since the most regular bus service in Edinburgh runs with a frequency of 6 buses per hour during in morning peak time. This makes the minimum average of scheduled waiting time 5 minutes (0.5 * 60/ frequency per hour) which is actually achieved by many public transport services in Edinburgh. However, the trip calculations could also be performed with minimum wait time at the stop of origin (zero minutes), which occurs when an individual walks to the stop at precisely the time a bus/ tram/ train arrives. Therefore, the walk access time from origin to public transport points is computed by adding the perceived walking time to the average of scheduled waiting time as follows:

Walk access time = perceived walking time + average scheduled waiting time

The in-vehicle travel time of the currently running public transport services is calculated based on the timetables associated with the bus and tram stops or railway stations during the morning peak times, which already takes into account delay on the roads because of traffic congestion. The timetables of proposed services, particularly those for long-term development, were not all available at the time of analysis. In this case, travel time has been estimated based on the average time that a currently running service requires to pass through the same route or through another route which has the same speed limit and similar traffic volume. For example, SNAPTA calculates the travel time in the future development lines of Edinburgh Tram (see Chapter 6) based on the timetable of the first phase of tram scheduled to run in summer of 2014.

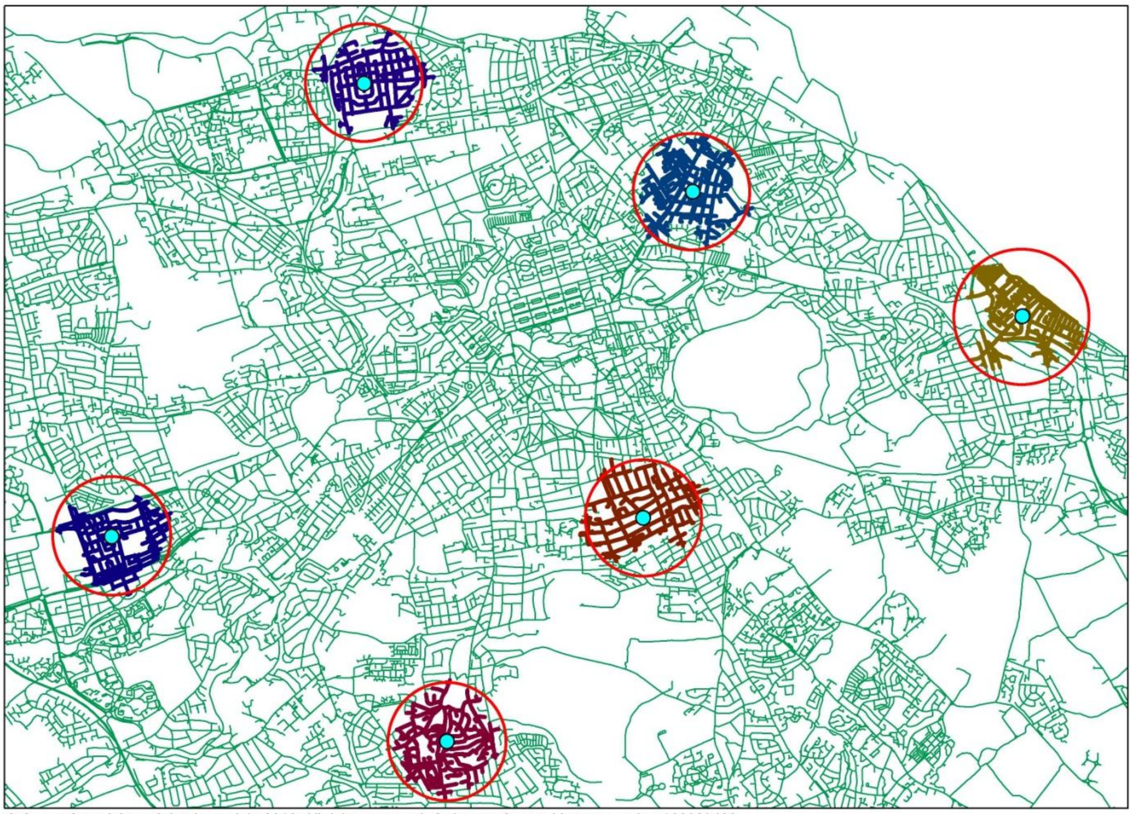

Figure 5.3 – Map showing how a multiplier of 1.2 is estimated (by CEC) based on a few example points around the city of Edinburgh with 800m actual distance and 670m radius circles.

Source: City of Edinburgh Council, Services for Communities.

Using the measure of travel time to city centre, accessibility is calculated based on the shortest public transport journey time (or the fastest possible route) during the morning peak hours (in week days) from the nearest node (bus stop, tram stop or railway station) in the network to the population-weighted centroid of each zone to the nearest node to the centroid of the CBD. The shortest possible journey time might be achieved by using one service only or through an interchange (one or more) between different services whether those services are provided by the same or different operators (i.e. Lothian Buses, FirstGroup Bus, E&M Horsburgh, Stagecoach Bus, Edinburgh Coach Lines) with the same or different transport mode (bus, tram or train).

The calculation of the potential accessibility measure is more complicated. It also involves the shortest possible journey times (as described above) between any two zones using public transport. This generates a number of relationships for each type of opportunity which is equal to the number of origins multiplied by the number of destinations. Creating an origin-destination (OD) Cost Matrix is the technique that has been used in GIS to carry out the calculation of the shortest journey times on the network between zones. Once the travel time is computed for each relationship, the potential accessibility for the residents of each origin zone is obtained by applying Hansen's equation (Section 5.4), which relates travel times with the values of opportunities attractiveness (see Section 5.8) in the destination zones using a distance decay function. A contour measure has been applied to measure the accessibility of the residents of each zone by calculating the number or size of the desired opportunities that can be reached by using public transport from that node in the network nearest to the origin zone centroid within the travel time threshold defined for the selected journey purpose (see Section 5.8 for further discussion on cut-off travel time values). Closest Facility is the GIS technique implemented to execute this measure.

Once the calculations have been carried out, a simulation of the spatial distribution of accessibility can be interpolated and mapped in the GIS environment based on the sum of accessibility values that are generated for each zone acting as origin-location. Values of the absolute and relative (percentage) changes in accessibility between the baseline scenario and the development scenarios are computed to find out and demonstrate the spatial variation in accessibility to a particular activity across the modelled area. Also, this allows a comparison of how the different measures incorporated in the tool capture the accessibility changes.

5.8 The Case-specific SNAPTA for Modelling Edinburgh Council's Area

There are a number of specifications and technical considerations that need to be decided when SNAPTA is applied to a particular area. It is important to make appropriate choices on these issues as they could have a significant influence on the analysis results and therefore on the policy decisions that might be made based on these results. Reviewing the literature on the main choices associated with the process of accessibility measurement and how they have been addressed by transport planners and modellers are presented in Chapter 2 (Section 2.7). However, this section discusses the choices required for the definition of the case-specific SNAPTA for the particular consideration of the Edinburgh case study. These choices can be summarised as follows:

1) Study area and boundaries
2) Spatial disaggregation level
3) Disaggregation of activities and the measurement of their attractiveness
4) Measurement of spatial separation (travel impedance)

5) Transport modes
6) Cut-off criteria
7) Impedance function (distance decay function) for potential accessibility measure
8) Day of the week and time of day
9) The physical features influencing walk access time

As will be described in the next chapter, the *study area* selected for this case study is Edinburgh with the consideration of the administrative boundary of the City of Edinburgh Council as the limit of the modelled area. The selection of this geographical limit is based on the fact that the area within this boundary is governed by the same local authority represented by CEC which is responsible for its residents and their accessibility requirements as well as transport and land-use policies. The focus of this case study lies on the significance of the future public transport infrastructure planned to the network of Edinburgh Council's area. This is the first detailed analysis to evaluate their impact on accessibility and ability to serve the new development areas around the city. Although SNAPTA in this research focuses on access to destinations within CEC's boundary only, similarly to other accessibility tools this has brought with it the disadvantage of not being able to consider the effect of activities and services that are located outside the boundary of the modelled area even by only few seconds; for example Queen Margaret University (located around 1 km away from the boundary of the Council's area in the south east of Edinburgh) and the opportunities for retail at Penicuik (south of Edinburgh) (see Chapter 6, Figure 6.1 for locations).

The use of Data Zones as the *spatial level for disaggregation* ensures highly disaggregated results, providing an adequate picture of accessibility patterns in Edinburgh that are appropriate for the purpose and nature of the study. With regard to the *disaggregation of activities* for this case study, as mentioned earlier, six different journey purposes have been considered in the analysis including the central business district (CBD), jobs, shopping, education, health and leisure. Journeys for shopping are analysed in two ways: general shopping taking account of all retail services and shopping for food only at supermarkets for Scotland's large food retail chains (see Chapter 7, Subsection 7.2.3 for the list of supermarket chains considered in the analysis). Furthermore, education opportunities are broken down into secondary schools and further and higher education institutions while two categories of health opportunities are considered: GP practices and hospitals. The *attractiveness of activities* has been measured by counting the opportunities considered at each destination-zone such as number of workplaces, schools, universities, GP practices, hospitals and leisure facilities. Also, it has been measured by using the economic size or occupancy of these opportunities including number of jobs, number of patients registered in health care centres and hospitals, and number of students in secondary schools and universities; or by calculating the physical size of facilities such as floor space area of supermarkets and other retail services in each zone. Table 5.4 presents the disaggregation of activity types and the measurement of their attractiveness for the case study of Edinburgh.

The shortest possible travel time has been used by SNAPTA to measure the *spatial separation* between areas which separate places and people from the opportunities. This comprises walk access time from the origin, waiting time, in-vehicle time, interchange time and walk time to the destination. For the case study of Edinburgh's network, the calculation of the travel time for each of these parts of the journey is described in Section 5.7. With regard to *transport modes*, all the public transport modes in Edinburgh including bus, tram and railway have been considered as well as walking from and to access points for public transport.

The *cut-off criteria* have been chosen using the core accessibility indicators identified by Department for Transport (DfT) (2006, p.65) for the key journey purposes for all Local Transport Plan areas based on the total travel time by public transport. This study applied a cut-off value of 30 minutes for travelling to food stores and GP practices. A length of 40 minutes is applied to journeys for the purposes of work, general shopping, secondary schools and leisure facilities while 60 minutes is used for travelling to hospital and further and higher education institutions. Table 5.3 (Section 5.7) shows these three cut-off values and the journey purposes to which they are assigned for the case study of Edinburgh. The variety in these cut-off values among different journey purposes can be explained by the fact that the choice of a supermarket and a GP practice is not as significant as the choice of leisure and education facilities (Witten et al., 2003). The cut-off time of a journey represents the total travel time acceptable to reach the desired destination, including all the journey components (i.e. walking time, waiting time, in-vehicle time and interchange time if applicable).

Table 5.4: Disaggregation of opportunities and the measurement of their attractiveness

Type of opportunity		Attributes of opportunity for the case study of Edinburgh
Central Business District (CBD)		N/A
Population		Population at Data Zone level using 2011 Census data Number and percentage of households without access to cars or vans using 2011 Census data
Employment	**Working age population**	Number of people who are from 16-64 years of age for men and from 16-59 for women using 2011 Census data
	Employees/ jobs	The total number of jobs per industry sector using Business Register and Employment Survey (BRES) 2009
	Workplaces	The total number of workplace units using Annual Business Inquiry (ABI) 2008
Retail	**Food shopping**	The total gross floor area of food stores (large supermarket chains) estimated in 2009
	Retail services	The total gross floor area of all retail services estimated in 2009
Education	**Secondary schools**	Number of secondary schools including state and private schools in 2011 Number of pupils registered in secondary schools in 2009/2010
	Further and higher education	Number of colleges and universities in 2011 Number of students registered in colleges and universities in 2010/2011
Health	**GP Practice (supply)**	Number of GP Practice units in 2011 GP Practice list size in July 2011
	Hospitals (supply)	Number of hospitals in 2011 Number of outpatients, day patients, and inpatients registered in Edinburgh's hospitals in 2010
	Demand for health care services	Number of patients (at Intermediate Zone level) who attended NHS Lothian services in 2010
Leisure & recreation		Number of leisure facilities including libraries, cinemas, sport facilities, parks, etc. in 2007

The *impedance function* reflecting the importance of spatial separation has been defined for the potential accessibility measure in the Edinburgh case study by using a negative exponential function which allocates a low value of 0.1 for the sensitivity parameter to travel time (ranging from 0 to 1). This is because the current modelling of SNAPTA considers public transport only at the local administrative scale for which users are not very sensitive to a small variation of time. Further information on the selected impedance function is provided in Section 5.4 above.

SNAPTA currently defines the *week day morning peak time* (7.00 am to 9.00 am) as the temporal focus. The morning commute time is regarded as the critical journey to work in the analysis of the accessibility potential of Edinburgh's public transport network. In addition to the speed and frequency of services, the time taken to access public transport is also important. Two *physical features delaying walk access* from and to public transport points in the beginning and end of journey are taken into account in this study including slope and traffic volume. An extra walk time (up to 4 minutes) for each zone is used as a weighting value of walking time and has been applied to slopes (i.e. walking up a steep hill) and streets with heavy traffic volume which causes delay before crossing (see Section 5.7 for more detailed discussion).

5.9 SNAPTA's Users

SNAPTA has been developed with an understanding of the potential users of the tool in the world of transport planning and urban structure (see Figure 5.4). The consideration of a local administrative level with the potential for expanding the modelled area to fit a regional level such as South East Scotland or Lothians area (see Chapter 6 for more detail) makes SNAPTA usable for local and regional authorities, which often have sufficient resources and skills to operate and apply the tool. Transport and planning authorities of a city or region can use SNAPTA's analysis to develop their policies and actions at strategic, tactical and operational dimensions in different stages of decision-making process (see the above discussion around Figure 5.1 in Section 5.2). Regional strategies related to the public transport connection of new residential settlements, distribution of key regional destinations (e.g. a business development area, hospital, airport, etc.) and accessibility impact of new infrastructure can be examined in SNAPTA. Once the regional strategy is defined, small scale strategies can be defined for specific conditions of each local authority in the region, and in accordance with the general regional strategy. Local planners can use SNAPTA for urban management, for example at a service operational dimension, when disaggregated by activity, to show the likely zonal impact of service closure and relocation, and to decide a new service location. Also, issues concerning traffic and public transport management can be addressed by the tool, taking into account the general regional strategy and local strategy. An in-depth description of how SNAPTA can be used to meet the transport and urban development objectives of CEC and the other relevant planning authorities is included in the next chapter.

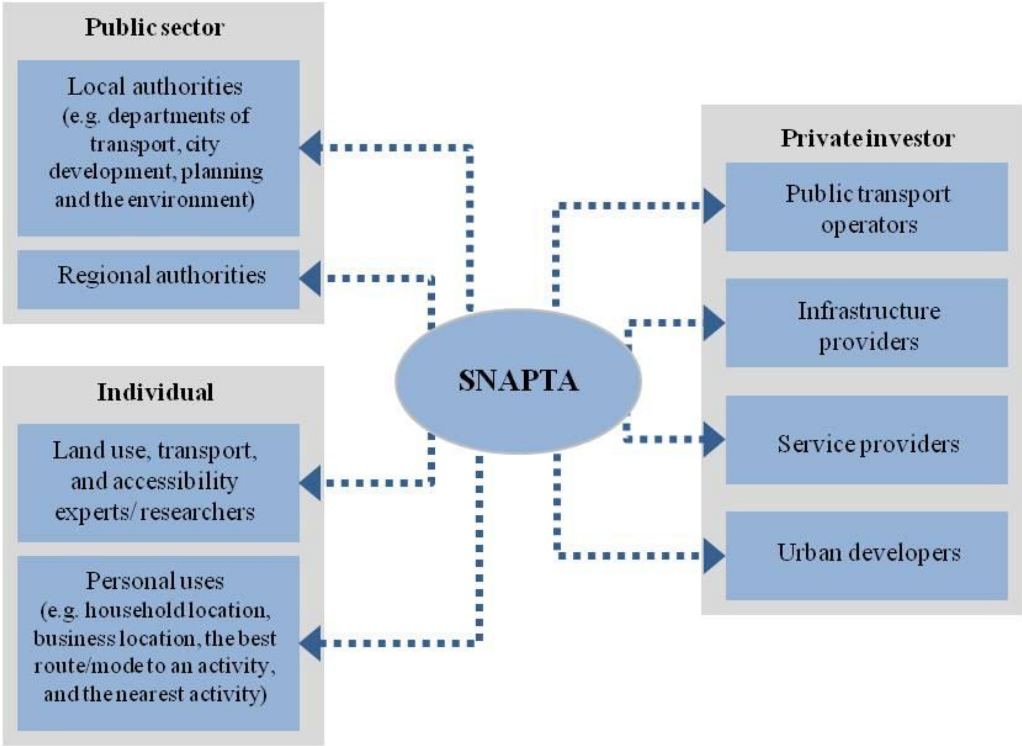

Figure 5.4 – Examples of potential stakeholders of SNAPTA

In addition to local and regional authorities, other stakeholders involved in planning decision-making can be considered as potential users of the tool. These include public transport operators (public or private sector operators) and private investors such as infrastructure and service providers and urban developers as well as land-use, transport and accessibility researchers. Public transport operators, who work as partners with local and regional authorities, can use SNAPTA to develop their strategies in co-operation with the other stakeholders for improving the provision and accessibility of their own transport services. Infrastructure and service providers are another important user of the tool, particularly at a strategic dimension. For example, they can use the tool to identify the attractiveness of locations or activities accessed by public transport in order to locate their business or invest in real estate. The decision can be made based on the gap in the provision of a particular service and the level of public transport accessibility to the desired location. Therefore, the tool can be used to identify a location that maximises the economic benefit of business by achieving a catchment area that makes this business reachable by public transport for the largest possible part of population (or particular group of population) within a time threshold. In the same context, the accessibility impacts of different alternatives of transport infrastructure can be assessed in SNAPTA to select an option that attracts additional investments and deliver further economic benefits. Since housing policy is a key driver of transport needs, urban developers can use the tool to plan together the location of new housing and its transport infrastructure requirements in order to maximise the available benefits. Furthermore, the tool can be used for individual goals; for example selecting household location, locating personal business, identifying the best route/ mode to reach a particular activity and identifying the nearest activity to a particular location. However, the use of SNAPTA by any of the above-mentioned potential users requires sufficient data resources as well as a good knowledge of ArcGIS package to carry out the analysis (see Section 5.3).

5.10 Potentials and Limitations

SNAPTA, as an accessibility tool developed to support decision-making for integrated land-use and transport policies, has potentials and limitations. As described earlier in Section 5.3, it offers significant potentials for better usability in planning practice through the consideration of the four usefulness criteria of accessibility tools: 1) having a robust theoretical basis and methodology, 2) using an adequate level of data disaggregation, 3) being not complex to operate, and 4) easily interpreted and communicated. In addition, SNAPTA also addresses a number of omissions identified in some existing accessibility tools (see Table 5.1), which could improve the soundness of the methodology and modelling approach adopted.

The tool is conceptually developed for a high disaggregation of land-use and transport attributes which provides a thorough understanding of accessibility patterns at a local administrative level. However, micro-scale aspects of accessibility such as urban design aspects are not considered. Therefore, despite the ability to produce the analysis and geographical representation of small scale variations of accessibility levels, SNAPTA provides a *limited local view of accessibility within zones*. It assumes that all individuals of each zone are gathered in the centroid of that zone and enjoy the same level of accessibility although they have different travel demands and may perceive the set of alternatives quite differently (see the basic assumptions presented in Section 5.5). On the other hand, the tool has the potential for expanding the local geographical scale considered to fit a regional level and, thus, to contribute to regional transport objectives. For the case study of this research (Edinburgh Council's area), the model expansion enables the local and regional authorities to analyse the accessibility and connection between the city and key destinations in the surrounding region, such as Queen Margaret

University in Musselburgh, St Johns Hospital in Livingston and Pitreavie Business Park in Dunfermline (see Chapter 6 for further details).

The choice of disaggregation level based on Data Zones that consist of geographical units with populations of between 500 and 1,000 household residents results in a *big difference in the spatial size of these units* depending on their population density. For example, in Edinburgh the areas of some zones in the west and south west of the city are very large compared with those in the centre because of their low population density. Therefore, for more accurate assignment of population on their residential areas, the centroids of large zones on the periphery of the urban area are re-calculated on the basis of population weights rather than geometric centres.

Another limitation regarding the level of data disaggregation is the difficulty of collecting *local data that are confidential at Data Zone level* such as the number of patients who live in each zone, and number of employees by industry in each zone. Nevertheless, some confidential data can be obtained under licence from government organisations while other data could only be given at lower level of disaggregation such as intermediate geographical zones which are at a statistical geography sitting between Data Zones and local authorities.

Similar to the other accessibility tools used currently in planning practice, SNAPTA is not able to consider the accessibility impact of *opportunities that are located just outside the boundary* of the modelled area. However, this could be tackled by choosing a study area that is wider than the area of analysis. The tool's inability to provide analysis of the *trip chaining* issue in which individuals go on a multi-stage trip for sequential activities is another limitation. The reason for ignoring trip chaining is to avoid the considerable increase in the complexity of accessibility analysis in such a way that could restrict the usability of the tool in practice (see the basic assumptions presented in Section 5.5).

Compared with other tools that use balancing factor measures, SNAPTA has the disadvantage of not considering the competition effects that can be seen at destinations. Unlike some other tools, SNAPTA does not look at the different types of job opportunities available at destinations. It only focuses on the total number of jobs in zones regardless of whether these jobs match the skills and qualifications of residents at origins.

A limitation can be identified in the calculation of walking time between the origin/ destination and the public transport network that is carried out using the crow-fly distance rather than the actual pedestrian network. However, the tool seeks to optimise the simulation of actual walking behaviour by using a reasonable value of constant multiplier (1.2 for the case study of Edinburgh) for the straight-line distance which is estimated based on the network patterns of several example points around the study area (see Section 5.7).

Also, the use of only one walk speed (3 mph) for the average person might limit SNAPTA's application for a purpose of comparing the accessibility of different population groups. This is due to the variation in actual walk speeds among people according to the different individuals' characteristics that might influence their walk abilities such as age, gender and mobility condition. On the other hand, the tool considers the physical features associated with each zone in the modelled area, taking account of slope and traffic volume (for crossing the road) as factors that delay walk access (see Section 5.7).

Another limitation is the tool's inability to calculate the real interchange time and waiting time at public transport access points. The calculation is restricted to either the minimum average of scheduled waiting time for a public transport service or the minimum waiting time (i.e. zero minutes) based on the assumption that an individual walks to the stop at precisely the time a bus/ tram/ train arrives.

The current tool does not look at the factors central to understanding modal choice which include cultural attitudes to specific transport modes, quality and environment of journeys, and factors associated with gender, age, income, physical ability and the number of hours spent working that influence travel behaviour. Because of SNAPTA's current consideration of demand data, as described in Section 5.6, the analysis is able to consider accessibility for all people, working-age people, people without access to cars/ vans, or people who attended health care services for consultations or treatments (at Intermediate Zone level). However, with a further development the tool has the potential to include other population characteristics reflecting different socio-economic groups in order to ensure that social exclusion issues are fully considered.

SNAPTA has been basically developed with a focus on public transport network only. Being restricted to public transport modes is considered as a potentially serious limitation for some purposes, giving only part of the picture. For example, to assess the sustainability impact of transport infrastructure, a forecast for modal shift arising from changed relative accessibility of different modes, especially from private cars to public transport, is required. Nevertheless, the tool has the potential to include car-based modes as well by offering the ability to build the road network taking into account the driving directions, and estimate the travel time based on the average speeds or speed limits associated with roads. In a similar approach to the one used to measure the accessibility of public transport, the tool can measure accessibility by car using the same package of measures. Travel time can be calculated based on the shortest journey time from the nearest point in the road network (where parking a car is permitted) to the population-weighted centroid of origin zone to the nearest parking point to the centroid of destination zone. Walk time from the centroid of a zone to the closest parking point on the road network can be estimated using the approach described in Section 5.7.

The tool also offers a good level of adaptability in a way which allows users to choose their method of measuring accessibility, and leaves several aspects to be defined for each context of application in order to satisfy its circumstances and objectives. The incorporation of three accessibility measures that are methodologically different into the GIS environment, with a high disaggregation of land-use and transport conditions, has the advantage of flexibility in the way journey components (i.e. walking time, waiting time, interchange time and in-vehicle time) are estimated and opportunities attractiveness are considered. Moreover, as described earlier in this chapter, this can be applied and managed using the standard functions of ArcGIS without requiring any bespoke software or external function to be integrated into GIS.

Using a package of different measures provides planners and policy makers with different pictures of accessibility due to different representation of the relationship between transport and land use. Another key strength of using different measures is the advantage of tackling the methodological and operational limitations associated with each measure. For example, no distance decay is considered in the travel time to CBD measure and contour measure, meaning all the opportunities located within the selected time threshold are counted equally and not weighted by the distance, while the potential accessibility measure applies a gradual decay in the distance. The travel time measure takes account of one relationship between the zones defined as origin-locations of journeys and CBD. Similarly, the contour measure focuses only on relationships between origin-locations and those locations that can be reached within a specific cut-off travel time. The potential measure has the advantage of considering simultaneously all the possible relationships between all zones within the modelled area. On the other hand, the travel time and contour measures are considered easier to interpret and communicate with non-modellers. A fuller discussion of the advantages and disadvantages of each measure is included in Chapter 2.

5.11 Conclusion

This chapter presents the methodology and underlying concept of the accessibility tool developed for this research – SNAPTA. The tool has been developed with the consideration of the criteria derived from the literature review for delivering a useful accessibility tool for applications in planning practice. It seeks to reach a balance between the ease of interpretation and the adequacy of methodological approach and data disaggregation. SNAPTA addresses a number of omissions identified in some existing tools that boosts the soundness of its modelling approach.

The tool can be used by practitioners to carry out a number of tasks in planning decision-making. It helps to analyse the strengths and weaknesses in the coverage of public transport network and the spatial equity and distribution of urban activities. It also can examine the contribution of different scenarios of transport and/or land-use interventions to improved accessibility. Therefore, SNAPTA seeks to provide local and regional authorities with an alternative practical tool to inform decision-making processes for transport planning and urban structure framed around the integration of land use with strong public transport accessibility. In this respect, SNAPTA can serve as communicative tool for the different stakeholders involved in the planning decision-making process including transport and land-use planners, public transport operators, infrastructure and service providers, urban developers and politicians.

The conceptual framework of the tool incorporates the concept of accessibility measurement, the participation in activities by individuals and the public transport supply. Three measures with different theoretical bases have been selected to calculate accessibility in SNAPTA: travel time to city centre, contour measure and potential accessibility measure. The tool requires a wide range of data sets including population, socio-economic, transport and land-use data which are readily available data that can be collected at a high spatial disaggregation level from the relevant government organisations.

A number of specifications and technical considerations need to be decided when SNAPTA is applied in planning practice. For modelling Edinburgh Council's area as a case study of this research, the chapter provides a clear definition of several choices for the development of the case-specific SNAPTA. These include choices related to the study area and boundaries; spatial disaggregation level; disaggregation of activities and the measurement of their attractiveness; measurement of spatial separation; transport modes; cut-off criteria; impedance function for potential accessibility measure; day of the week and time of day; the physical features influencing walk access time; and estimation of waiting time. In this context, the next chapter continues with an in-depth discussion on the case study of Edinburgh and how SNAPTA can be used to address the relevant planning questions.

CHAPTER 6 – Application in the Context of Accessibility Policy in Edinburgh Council Area

6.1 Introduction

This chapter presents the research testbed which includes the case study and its application developed for testing the accessibility tool – SNAPTA – defined in Chapter 5. The case study provides an insight into the capabilities of SNAPTA as a decision-making support tool addressing the accessibility issues in an integrated approach to land-use and transport policies. This pilot study enables the assessment of the robustness and usefulness of the tool in planning practice. It also offers a case-specific insight which allows refining the conceptual framework of the tool.

The following section (Section 6.2) describes the case study area, justifying its choice and providing information on the associated urban development and other relevant statistics. Section 6.3 discusses how the accessibility issue is considered in the most current transport and urban structure policies in Edinburgh and the surrounding region. Section 6.4 presents an overview and discusses the main findings of three previous studies of accessibility analysis in the study city-region. Section 6.5 presents the rationale for the planned public transport infrastructure in the study area including the Edinburgh Tram and the South Suburban Railway. Section 6.6 discusses the main purposes of the application of SNAPTA to Edinburgh's area, and identifies how the tool can contribute to meeting the objectives of the transport and urban structure strategies for the city.

6.2 Background on the Case Study Area

The area of Edinburgh Council was selected as the case study for this research to apply the SNAPTA tool. Edinburgh is the capital of Scotland, the largest city by area and the second largest by population in the country. It is situated in the east coast of the central urban belt of Scotland with a total resident population of 495,360 people and an overall density of 18.97 persons per hectare (GROS – 2011 Census). The City of Edinburgh Council (CEC) governs one of Scotland's 32 local government council areas with an area of 259 km^2. The council area includes urban Edinburgh and a 30 square miles (78 km^2) rural area. Figure 6.1 indicates the locations of Edinburgh districts as well as those of the key employment sites and main hospitals within the Council area, which are mentioned later in this chapter and the next chapter.

Figure 6.1: Locations of Edinburgh districts, the key employment sites and the main hospitals within Edinburgh's Council area

Source: Google Maps

The policies in the land use plan and Edinburgh's geographical location (bounded by the Firth of Forth on two sides) have contained urban sprawl, through the imposition of a green belt around the urban area and the encouragement of development on brownfield sites (Hull and Karou, 2011). The congested city centre with inner area has retained its high density and business and services' centralisation. The highest average office rents are retained in the centre suggesting that the demand for offices is still centrally located (see Figure 6.2). However, economic development has recently more and more gravitated to locations outside the high density centre in West Edinburgh (i.e. South Gyle and Edinburgh Park) and North Edinburgh (i.e. Granton Waterfront and Leith Docks). Retail is more dispersed with a number of shopping destinations throughout the city including the Gyle, Fort Kinnaird (in Niddrie) and Ocean Terminal (in Leith) (see Figure 6.1 for their locations) that is clearly one of the key drivers for the change in employment and retailing distribution away from the centre towards the edge of the city. Nevertheless, on the basis of turnover, Princes Street (city centre) remains the main shopping area (CEC, 2008).

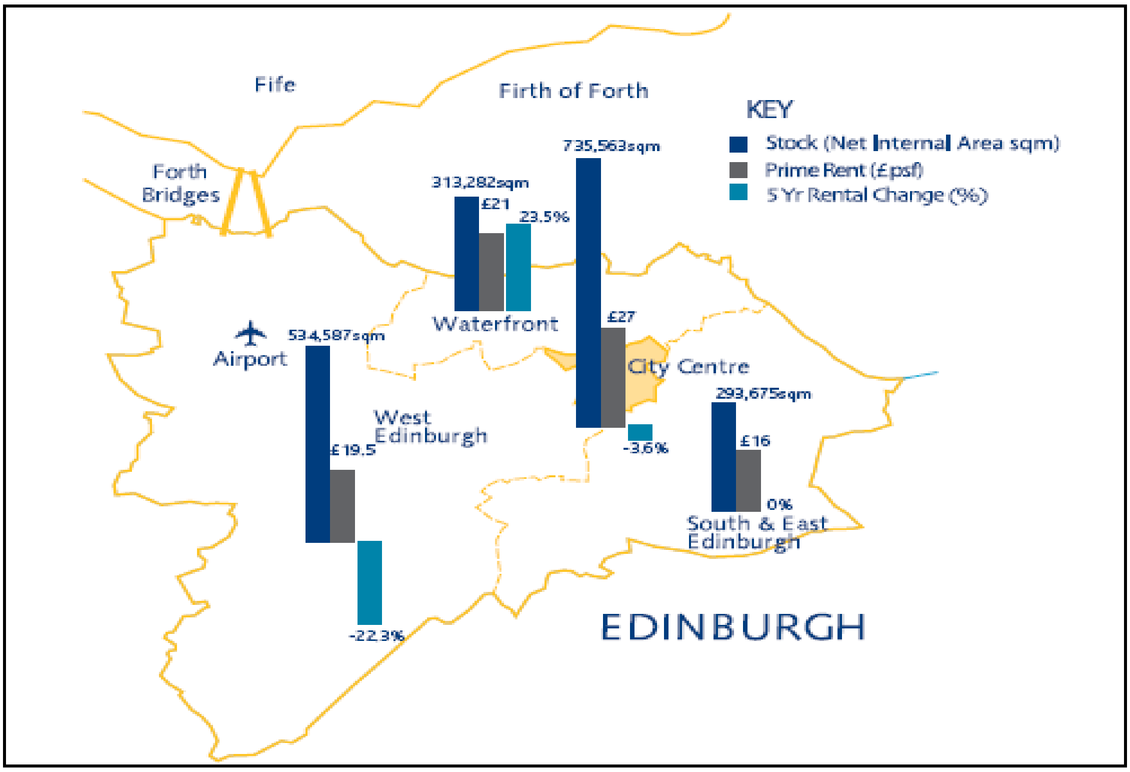

Figure 6.2: Office Locations in Edinburgh: 2007stock and rental values

Source: GVA Grimley (2007, p.8)

During the last decade, nearly 24,000 houses and 680,000m² of offices have been completed in Edinburgh (CEC, 2008). Currently, the city is commencing a huge phase of redevelopment. The four core development areas within the city identified in the Edinburgh and the Lothians Structure Plan 2015 are: the City Centre; Edinburgh Waterfront (North Edinburgh), covering Granton and Leith; Edinburgh Park, covering South Gyle and Sighthill; and Newbridge/ Kirkliston/ Ratho (CEC et al., 2004). Edinburgh Waterfront is set to provide an additional 25,800 new residential units and nearly 350,000m² of new office, retail and other commercial developments between 2006 and 2020, reflecting the growth in Edinburgh's economy and population. Significant new development is also predicted to be progressively built by 2020 in West Edinburgh with some 250,000m² of new office space (mostly at Edinburgh Park) and over 200,000m² of other commercial space (TIE, 2006). In addition there is yet unfinished redevelopment of the Old Royal Infirmary and Fountainbridge in the centre of Edinburgh. Figure 6.3 shows the location of housing and office developments programmed for completion between 2006 and 2015 based on outstanding consents and local plan allocations (CEC, 2008).

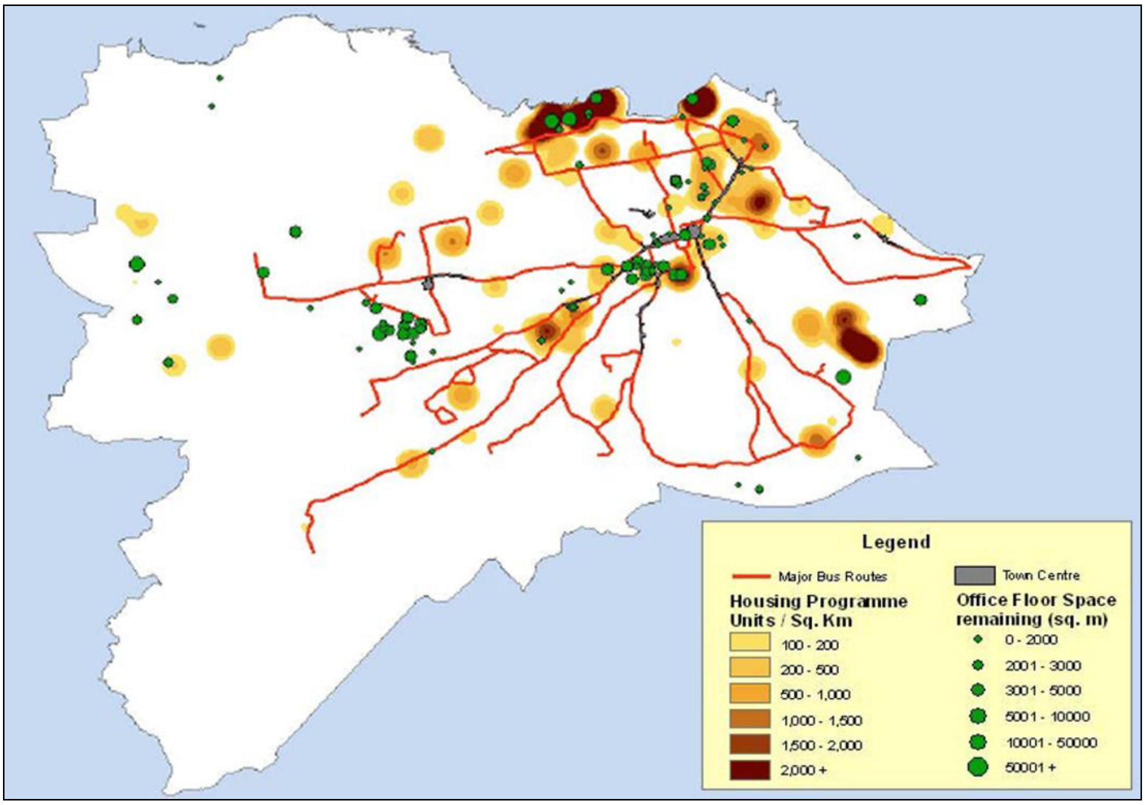

Figure 6.3: Location of housing and office developments programmed for completion by 2015

Source: City of Edinburgh Council planning records (2008)

Since the 1990s, travel in Edinburgh has grown, while traffic volumes have declined (i.e. more people, but fewer vehicles) resulting from increased public transport journeys (CEC, 2013a). Over the last decade, public transport accounted for around 3% more of Edinburgh residents' journeys; mainly due to more commuting by public transport (CEC, 2013a). According to the Annual Population Survey 2008, 68.5% of Edinburgh's workforce lives in the city; around 6% each in Midlothian, in West Lothian and in East Lothian, and 4.7% in Fife (ONS, 2008). It has hardly changed since 2001 (2001 Census), when 64,500 (24%) of the city's workforce commuted by bus, 11,200 (4%) by train (see Figure 6.4). Data published in the Public and Accessible Transport Action Plan (PATAP) 2013-2020 shows that the modal split for all journeys by CEC residents in 2009-2010 was 43% for cars, 35% for walking, 18% for public transport, 2% for cycling and 1% for "other" (CEC, 2013a, p.25). However, as a result of restrictive planning policies and the retention of the bus company in public ownership, Edinburgh has a relatively low modal baseline share for car travel (see Figure 6.5). Low modal share for car travel extends to destinations in central eastern wards, and drops off more quickly in the west. City centre destinations have by the far the lowest proportion of car trips with public transport achieving peak accessibility declining radially away from the centre to suburban areas where the private car is the main transport mode, although the influence of public transport corridors is clearly visible (Smith and Halden, 2005). The Gyle/ Edinburgh Park is a large scale business park on the western outskirts of the city, begun in the early 1990s, which has been highly successful in attracting the financial services industry (CEC, 2002). This is close to the city bypass and the Edinburgh airport at Ingliston and car accessibility is high with 70% of work trips made by car (Smith and Halden, 2005).

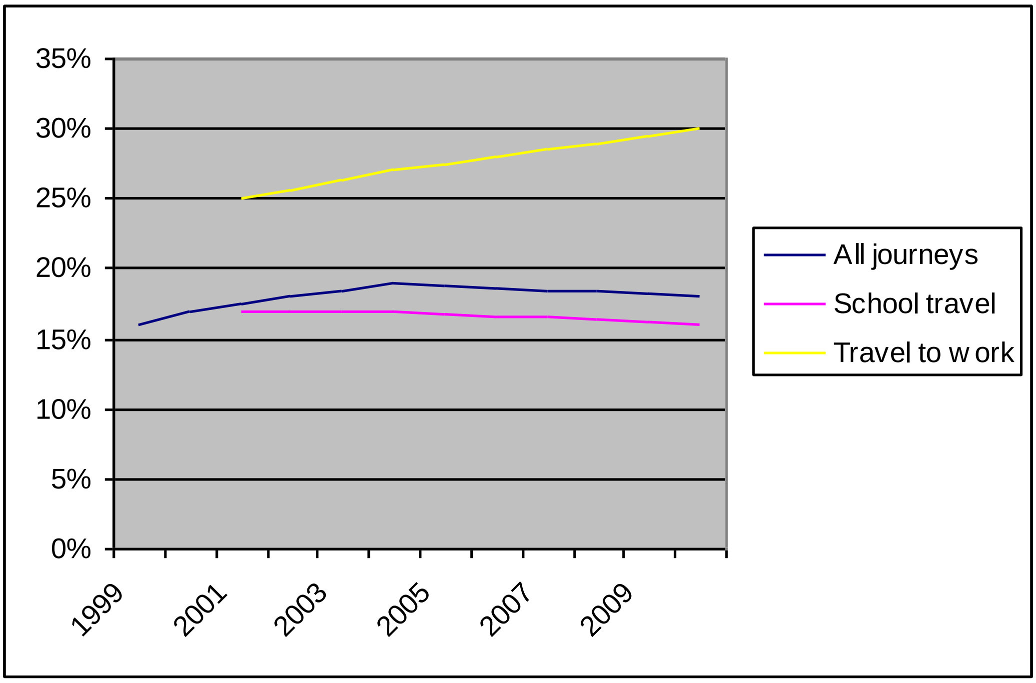

Figure 6.4: Edinburgh residents – public transport share of trips

Source: City of Edinburgh Council, 2013a

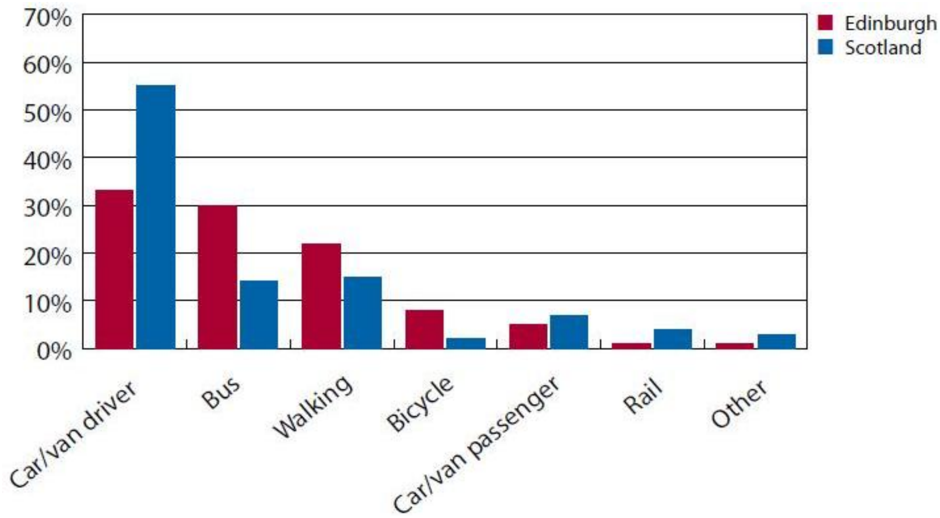

Figure 6.5: Adult residents' usual mode of travel to work/ education (2009)

Source: Scottish Household Survey (Scottish Government, 2010)

The anticipated introduction of the Tram in 2014 has been recognised by PATAP 2013-2020 as a major milestone. Modelling carried out by the Council predicts that in year 1, 27% of the tram passengers will be new to public transport, mainly having previously travelled by car, with a smaller number of new generated trips. As presented in Table 6.1, the modelling suggests that in 2015, the number of trips made on bus and tram will increase by 17% to reach 128 million; and it will become 145 million by 2020 (CEC, 2010b).

Table 6.1: Trips by bus and tram in Edinburgh

Trips in millions (* predicted)

	2006	2008	2010	2012	2015	2020
Bus	108	113	109	115*	123*	138*
Tram					5.1*	7.5*

Source: CEC, Business Case Update 2010

Rail trips in the ‘Edinburgh conurbation market’ are forecast to increase by 25 - 31% between 2009 and 2015; and 90 – 118% by 2024 (Network Rail, 2011). PATAP argued that to be consistent with the Council’s transport 2030 Vision, the Local Transport Strategy and the Active Travel Action Plan, public transport mode share should not grow by shifting pedestrians and cyclists onto buses and trains; it must gain market share from car travel (CEC, 2013a). Car/ van users acknowledge that they could use Edinburgh’s public transport. Its quality is widely recognised. However, Scottish Household Survey data suggests that nationally, car/ van commuters who could use public transport do not mainly because it ‘takes too long’ or there is ‘no direct route’ (CEC, 2013a).

Edinburgh’s population is projected to grow by over 59,000 between 2010 and 2030 (CEC, 2010a). As Edinburgh’s population grows, the demand for travel will increase. Population growth in the city region will also impact on levels of commuting into the city. Moreover, during the next 20 years, Edinburgh’s economy is forecast to play a big part in Scottish economic growth (CEC, 2010a). Given that the key sectors driving economic growth can change rapidly, a need has arisen for strong and flexible transport systems to support the economy regardless of dominant sectors or geographic areas of intense growth which will change over time (CEC, 2013b). Continuing economic success has however created a number of challenges. With a substantial population increase expected and "The number of jobs…….now expected to increase by 15% between 2000 and 2015" (CEC, 2007, p.14) as well as the forecast rise in the households' car ownership by 30% from 2000 and 2016 causing twice as much time to be lost due to congestion over the same period (TIE, 2004, p.2), the maintenance of connectivity and accessibility is one such challenge (Karou and Hull, 2014). Therefore, Transport 2030 Vision suggested that simply, by 2030, without action, the demand for travel from/to the city by private car will far exceed the current capacity. Real estate consultants fear that market actors are reluctant "to invest(ment) in a city perceived as expensive with a poor transport network" (GVA Grimley, 2007, p.4). Furthermore, an increasingly ageing population will bring with it the necessity to provide an inclusive transport system giving everyone access to the places they need to go (CEC, 2010a). Indeed, Transport Initiatives Edinburgh (TIE), the company formed by the City of Edinburgh Council to deliver the city's transport projects over a 15 year period, accepts "if the city's quality of life and continuing economic growth and success are to be sustained, there is a need to introduce measures to tackle increasing traffic congestion" (TIE, 2004, p.2). In this context, the City of Edinburgh Council and the relevant regional and national authorities have developed a number of strategies (to be discussed in detail in Section 6.3 below), which define a series of actions including the implementation of new public transport infrastructures and services to boost the transport system and improve accessibility in the Council area. The expectation is to cut demand for road travel and to serve the new growth areas while they are developing by delivering a reliable and safe public transport service and, consequently, by improving their accessibility.

6.3 Accessibility in the Context of Edinburgh Planning Policy

This section discusses how the accessibility issue is considered in the transport and spatial policies in Scotland with a focus on Edinburgh Council's area and the surrounding region. It provides a thorough update of the local and regional transport strategies for improving accessibility and the relevant guidance on urban development which the city of Edinburgh has to follow. Table 6.2 outlines the key strategies addressing the accessibility issue at the national and regional level that are developed by the relevant national and regional authorities, including the UK Government, Scottish Government (previously called Scottish Executive), SEStran (South East Scotland's Regional Transport Partnership) and the Lothians Councils. Table 6.3 presents the most recent local strategy documents issued by CEC. In the same context, Figure 6.6 illustrates the simplified relationship between the key transport strategies for Edinburgh.

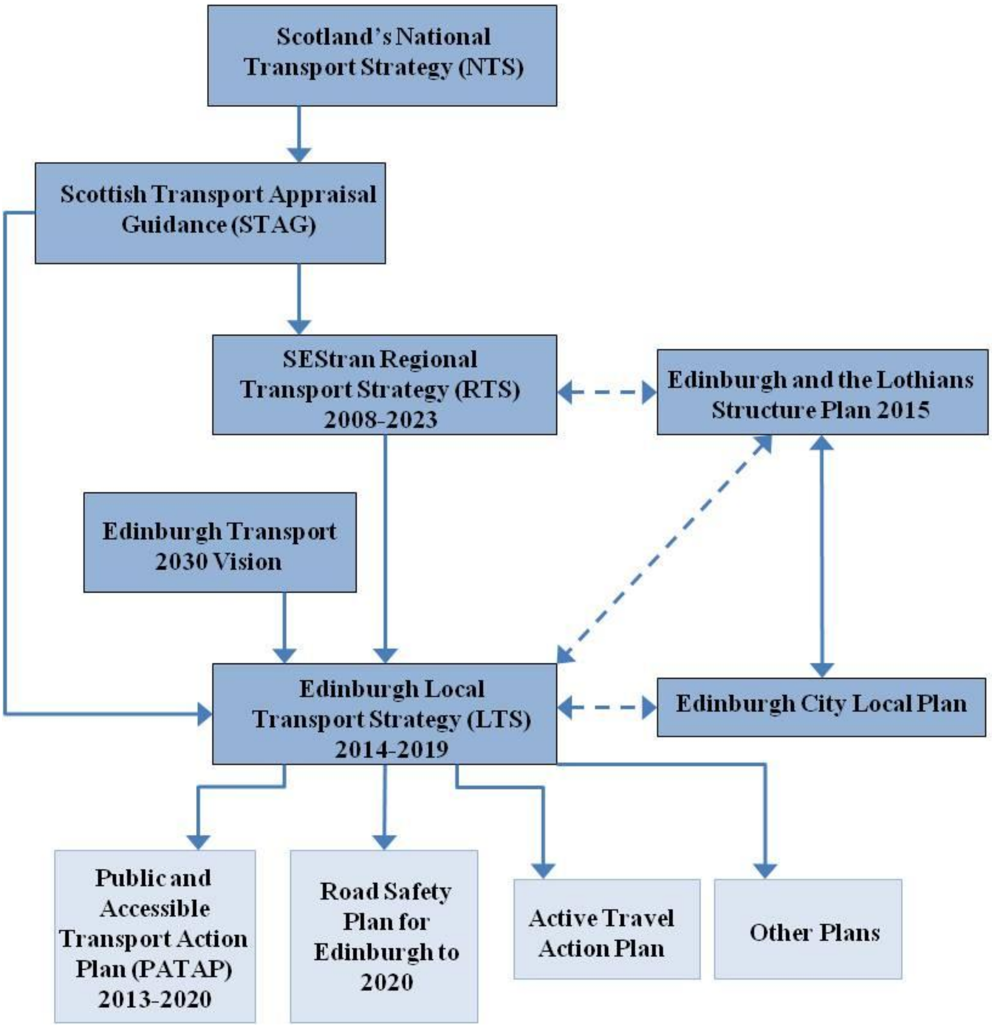

Figure 6.6: Simplified relationships between the key transport strategies for Edinburgh

Source: Author's own derived from SEStran (2008) and CEC (2013a)

Table 6.2: key strategy documents relevant to this research, issued by national and regional authorities

Author	Date	Title	Context
UK Government Social Exclusion Unit (SEU)	2003	Making the Connections: Final Report on Transport and Social Exclusion	The report examines the links between social exclusion, transport and the location of services. It is particularly focused on access to those opportunities that have the most impact on life-chances, such as work, learning and healthcare.
UK Government Department for Transport (DfT)	2004, 2006 (modified)	Guidance on Accessibility Planning in Local Transport Plans	The guidance presents an overview of the national and local policy context for accessibility, in transport and other sectors. It provides advice for local transport authorities on the recommended steps and measures for assessing accessibility. It addresses option appraisal of schemes and initiatives to improve accessibility as well as performance management framework for assessing progress in delivery against accessibility objectives and priorities.
The Scottish Executive	2004	Scotland's Transport Future: The Transport White Paper	The white paper sets out the Scottish Government vision for transport and its proposals represent a radical reform of transport delivery at national and regional levels across Scotland. The aim is to promote economic growth, social inclusion, health and protection of environment through a safe, integrated, effective and efficient transport system.
The Scottish Executive	2006	Scotland's National Transport Strategy (NTS)	The strategy maps out the long-term future for transport in Scotland for the first time. It outlines the long-term objectives, priorities and plans for integrated, modern, reliable and environmentally efficient transport choices.
The Scottish Executive (Government)	2003, 2008	Scottish Transport Appraisal Guidance (STAG)	The STAG contains guidance for local authorities and consultants on the appraisal of transport projects, policies, studies or schemes. It provides a framework to identify potential transport interventions.
SEStran	2008	Regional Transport Strategy (RTS) 2008-2023	The RTS provides a regional perspective on transport in Scotland. RTS set outs a framework for the future direction of investment in, and management of, transport in the SEStran area for the next 10-15 years. Two main aspects – the sustainable development of the area in a less car dependent manner, and the widening of access for all areas and groups – form the basis of the RTS. The document outlines the types of measures which will be implemented in the coming years, to deliver the transport system required for the successful future development of the SEStran's area.
City of Edinburgh Council, East Lothian Council, Midlothian Council and West Lothian Council	2004	Edinburgh and the Lothians Structure Plan 2015	The Edinburgh and the Lothians Structure Plan 2015 sets out the long-term vision for the development of land in Edinburgh and the Lothians. It centres on a land-use and transport strategy together with a set of policies which co-ordinate sustainable public and private investment with the protection of the environment. The structure plan provides the broad framework for local plans.

Table 6.3: key strategy documents relevant to this research, issued by CEC

Author	Date	Title	Context
City of Edinburgh Council	2007	Edinburgh Local Transport Strategy (LTS) 2007-2012	The LTS sets out the Council's aims and objectives for transport, and provides an overview of the Council's strategy. It summarises what has been done over the last few years. It sets out detailed policies for all aspects of transport, together with an action plan for managing and improving the city's transport over the period from 2007 to 2012.
City of Edinburgh Council	2010	Edinburgh City Local Plan	The Edinburgh City Local Plan sets out the Council's policies to guide development in the city and its proposals for specific sites. The Plan covers the whole of the urban area, and part of its rural, Green Belt fringe. The purpose of the Local Plan is to 1) provide a clear basis for determining planning applications, 2) allocate land to meet needs and targets set out in the Structure Plan, 3) provide a clear framework for regeneration strategies, and 4) provide support for wider strategies of the Council.
City of Edinburgh Council	2010	Edinburgh Transport 2030 Vision	The aim of this document is to establish a long term vision to guide the work of the City of Edinburgh Council City Development Transport Service over the next 20 years. It sits alongside the updated Local Transport Strategy for Edinburgh with a purpose to: 1) provide indicators as to how the Council's Transport Service is performing against a set of desired transport outcomes 2) demonstrate how the work of the Council's Transport Service contributes to the delivery of the Council's Single Outcome Agreement 3) set out other relevant transport related outcomes and indicators
City of Edinburgh Council	2010	Road Safety Plan for Edinburgh to 2020: Working towards Vision Zero	At the core of the Road Safety Plan is the goal that the Council and its partners will work towards Vision Zero; a road network where all users are safe from the risk of being killed or seriously injured. The plan sets out a range of interventions covering education, marketing, engineering and enforcement. Objectives were developed against which to assess the Plan's road safety interventions.
City of Edinburgh Council	2010	Active Travel Action Plan (ATAP)	The Active Travel Action Plan sets out short, medium and long term actions to encourage walking and cycling in Edinburgh over the period to 2020. It also includes ambitious targets to grow the proportion of trips made by bike to 10% of all journeys in the city and 15% of journeys to work.
City of Edinburgh Council	2013	Developing the New Local Transport Strategy: Issues for Review	The document identifies a set of transport related Issues for Review that need to be considered in formulating a new Local Transport Strategy for 2014-2019. The Council's Transport and Environment Committee authorised a stakeholder and public consultation on those issues.
City of Edinburgh Council	2013	Public and Accessible Transport Action Plan (PATAP) 2013-2020	The PATAP sets out a range of actions to enable and encourage people in Edinburgh to use public transport more often over the period to 2020. It aims to increase public transport's share of all trips in Edinburgh by 2020 by 2.3%.

Scottish Transport Appraisal Guidance (STAG) is a document produced by the Scottish Government to aid transport planners and decision-makers in the development of transport policies and projects (see Table 6.2). STAG, which was first issued in 2003 and updated later in 2008, is to be regarded as the key reference document for the appraisal of transport projects, policies, studies or schemes in Scotland (Scottish Executive, 2003). Accessibility and social inclusion is defined in STAG as one of the Government's five key policy objectives for transport, defining accessibility as "the ability of people and businesses to access goods, services, people and opportunities" (Scottish Executive, 2003, 10). This objective alongside environment, safety, economy and integration form the STAG criteria, providing a framework to ensure all potential impacts of transport/ land-use interventions are considered.

For transport appraisal, STAG suggests that the accessibility and social inclusion criterion should address two aspects: 'community accessibility' and 'comparative accessibility' (Scottish Executive, 2003; Scottish Government, 2008). Community accessibility includes a consideration of public transport network coverage and access to local services by walking and cycling. The guidance defines that the coverage of the transport system needs to be assessed in relation to key patterns of land use. Therefore the appraisal of public transport network coverage should look at the impact that transport proposals have on access to jobs, learning, health, shopping and other journey purposes of local significance (Scottish Executive, 2003). For access to local services, STAG discusses that it is necessary to define a small selection of local services which are frequently reached by walking and cycling (e.g. health centres, shops, post offices). It argues that if walking and cycling to public transport have not been considered under the public transport network coverage criterion they can be considered under local accessibility as for other local services. With regard to comparative accessibility, there are two main appraisal requirements to assess: 1) the distribution of impacts by people group (e.g. age, gender, etc.) and 2) the distribution of impacts by geographical area (e.g. areas of disadvantage and deprivation, development areas, urban areas, pre-urban areas, rural areas, etc.), clarifying that the choice of area of interest should be defined in relation to the particular policy objectives for these areas. In this context, STAG suggests that transport appraisals should rely on qualitative and quantitative assessment. It recognises the importance of using accessibility analysis as a powerful tool to ensure land-use and transport policy integration. To calculate accessibility to an appropriate level of accuracy for the needs of the STAG appraisals, the Scottish Government highlights three main dimensions to consider: the people groups to be included and the places, services and opportunities which they want to reach; the representation of the transport system; and the types of accessibility measure required (Scottish Executive, 2003, 10-4). However, STAG emphasises that practitioners should not begin the process of formulating transport planning objectives by considering only the national objectives, since this could diminish the importance of local objectives or the inclusion of issues which, for the transport planning context in question, are not relevant (Scottish Government, 2008).

Through the *National Transport Strategy* issued in 2006 (see Table 6.2), the Scottish Government defines that improving accessibility, connection and journey times are key strategic outcomes that local authorities must focus on to achieve the vision for transport in Scotland (Scottish Executive, 2006, p.2). These strategic outcomes would have wider benefits and would contribute to the delivery of a number of other key priorities including health improvement, social inclusion and regeneration. Improving connections and accessibility and other issues related to tackling congestion and integrating services and infrastructure have been considered vital to encourage individuals to make different choices about their preferred method of travel and enable individuals to become more economically active.

The Scottish Government perceives high accessibility as essential to economic growth and competitiveness through "providing access to markets and enhancing the attractiveness of cities as focal business locations and tourism" (Scottish Executive, 2004, p.18). Access to health and education is also seen critical. Evidence from across Scotland seems to indicate that although access to health and education by car is generally good, access through public transport is more varied and can be problematic. This has the potential to become worse as healthcare services are re-located to key sites across a particular region (Scottish Executive, 2006). Therefore, the Scottish Government in the National Transport Strategy emphasises that regional transport partnerships, local authorities and Health Boards should work together to address these issues with a view to maximising the contribution of the investment being made in transport services across a region. To measure progress in improving accessibility, connection and journey times, the Scottish Government suggests that regional and local authorities should regularly report on a range of monitoring indicators. These include congestion, average distance walked and cycled per person per year, carbon emissions from the transport sector; satisfaction of bus and rail passengers, walking time to nearest bus stop and frequency of bus service at nearest bus stop (for urban and rural areas), and access to key services (Scottish Executive, 2006).

The revised *SEStran Regional Transport Strategy (RTS)* for the South East of Scotland was approved by the Scottish Government on June 2008 to cover the period until 2023 (see Table 6.2). Improving accessibility for people with limited transport options, including those with mobility difficulties and/or with no access to a car, particularly in rural areas, is one of the key objectives of the strategy. To improve accessibility, SEStran defines four criteria to focus on: improving access to employment; improving access to health facilities; improving access to other services, such as retailing, leisure/social and education; and making public transport more affordable and socially inclusive (SEStran, 2008). Through accessibility modelling, the RTS has established a measure for residential access to employment for all areas of SEStran, at a detailed spatial level. Modelling can be used to measure the impact of public transport improvements on this accessibility measure. The target is to improve the access (by public transport) of the communities defined as most deprived by the Scottish Index of Multiple Deprivation (SIMD) to employment by an average of at least 10% (3% after five years, 10% after 15) (SEStran, 2008). A 'Hansen' access to employment indicator has been defined as the key measure for monitoring progress. The accessibility modelling undertaken in the RTS also allows an accurate picture to be built of communities with long travel times using public transport (defined in RTS as greater than 60 minutes) to hospital services. The target here is to reduce the proportion of zero-car households with poor access (more than 60 minutes travel by public transport) to defined key hospitals by 50% over the period of the RTS (by 2023) and 15% after the first five years. As for accessibility to other services, the RTS target is to reduce the proportion of zero-car households with poor access (more than 45 minutes travel by public transport) to defined further education colleges, job centres and regional shopping centres by 20% over the period of the RTS and 7% after the first five years. An annual accessibility mapping exercise using standard software and bus and rail timetable and Census information has been developed to measure progress against all the targets above.

Furthermore, SEStran RTS has linked its objective for improved accessibility with the Scottish Government's strategic objectives, particularly with making Scotland wealthier, smarter and healthier. It is believed that good accessibility would directly enable business and people to increase their wealth as well as allow wealth to be shared fairly. Improved accessibility contributes to smarter Scotland by expanding opportunities for the people of Scotland by nurturing throughout life-long learning and ensuring higher and more widely shared achievements. Also it contributes to a healthier society by ensuring better, faster access to health care (SEStran, 2008; SEStran, 2013). The proposed implementation strategy comprises of three themes based on a comprehensive set of policies and objectives: 1) region wide measures – those interventions affecting the whole of the SEStran area; 2) initiatives for specific areas and groups – mainly aimed at providing improved accessibility for various population groups in various locations; and 3) network based interventions – promoting comprehensive projects and initiatives to improve travel and reduce modal reliance on the car, along strategic travel corridors (SEStran, 2008).

Now SEStran has been using Accession for accessibility modelling. All authorities in SEStran area have been trained in the use of Accession and have access to the model through consultants MVA. The SEStran Accession model gives a graphic presentation of the accessibility of specific locations to other locations, including areas of employment, healthcare, education, retail and leisure, by various modes. One of the recent uses of Accession by SEStran, has been the assessment of various development locations identified in the formulation of the SESplan Strategic Development Plan, to test their relative accessibility to various facilities (SEStran, 2012). Further details on this study are included in Section 6.4 below.

At the level of Edinburgh Council's area, the *Edinburgh Local Transport Strategy (LTS) 2007-2012* (see Table 6.3) emphasises that the development and growth of the city-region has to be facilitated, and areas of new development, whether brownfield sites in and around the city or greenfield sites, must be well served by public transport if they are to be accessible and not generate excessive levels of car traffic causing congestion on the wider road network. The LTS vision for transport states that "the Council will seek to maximise people's ability to meet their day to day needs within short distances that can easily be undertaken without having to rely on a car. The city should develop and grow in a form that reduces the need to travel longer distances. Choice should be available for all journeys within the city" (CEC, 2007, p.19). In this respect, it is clear that accessibility lies at the heart of the transport vision for Edinburgh which defines it as "whether or not people can get to services and activities at a reasonable cost, in reasonable time and with reasonable ease" (CEC, 2007, p.82). The Council aims to promote good transport accessibility and connections within the city, between the city and the surrounding region, and between the city and major national and international economic centres. The strategy that has been pursued for many years is to provide travellers with choices making alternatives to car use as attractive as possible. A sequential approach, particularly in relation to travel within the city and the wider region, has been adopted by the Council: 1) to maximise the opportunities to meet travel needs on foot or by bicycle by promoting the location of places of employment, shops, and other centres of activity as close as possible to homes, and by making these modes as safe and convenient as possible; 2) where people do choose to make longer journeys, to provide good public transport choices to the maximum extent possible; and 3) where cars are chosen as the most appropriate means of travel, and where there is little alternative to road travel, for example for goods deliveries, to manage the road network as effectively as possible (CEC, 2007, p.21). The target is to ensure that car use is not chosen by more travellers than the road network can reasonably accommodate. Therefore, LTS aims to increase the proportion of journeys made by public transport and provide the required capacity to accommodate those who shift from private car to public transport. The introduction of the major projects now including tram and rail improvements (Section 6.5) seeks to enhance the quality, capacity and accessibility of public transport to provide a good alternative to car use for more people. SNAPTA have been applied in this research to examine the accessibility impacts of these projects (see Section 6.6). Table 6.4 presents a series of actions and arrangements that have been developed and implemented by the Council to attract people to public transport modes.

Table 6.4: Actions adopted in Edinburgh LTS 2007-2012 to attract people to public transport

Actions
- Completion of the programme of bus-bus interchanges, development of key interchange points between trams and buses, and the development of Haymarket as a major transport interchange for all public transport modes
- Continuing development of bus priority measures where appropriate, potentially in partnership with operators and others
- Extension of the One-Ticket integrated ticketing arrangement, and integration of tram ticketing with buses
- Implementation of Bustracker information at all significant bus stops in the city, and extension to other forms of information provision (for example internet and mobile phone SMS)
- Support for key shortfalls in the local bus network, with a particular emphasis on non-city centre services, evenings and weekends

Source: Edinburgh Local Transport Strategy (CEC, 2007, p.22)

According to the Local Transport Strategy for 2007-2012, by the end of its five year period in 2012, the Council's focus was to have trams running as the core of a modern transport system for the city as well as many of the rail projects are in place. For the longer term, LTS identifies two key projects that the Council sees as important and will promote their development through SEStran. These are the implementation of a tram line serving the South and South-East of the city; and a major investment in orbital public transport along the corridor of the City Bypass linking a number of major centres including the Airport, Edinburgh Park, Straiton and the Royal Infirmary (see Figure 6.1 for their locations). Both of these projects have been seen of regional significance, linking major population and employment centres in the Lothians into the wider transport network. In addition, it has been suggested that for the longer term scenario a consideration needs to be given to the connectivity needs for the economy 20 years ahead, and to the way in which the development of the city-region relates to transport infrastructure. In other words, the transport system needs to both influence and be influenced by the future location of homes and jobs (CEC, 2007, P.24).

In the beginning of 2013, the City of Edinburgh Council identified a set of transport related Issues for Review that need to be considered in formulating a new Local Transport Strategy for the next five years 2014-2019 (CEC, 2013b) (see Table 6.3). Supported bus services are a key issue highlighted by in the report. The report calls for maintaining supported bus services or enhancing bus services where commercial provision is non-existent or low frequency. The expectation is to maintain and enhance the extent and connectivity of the overall public transport network which could be extremely valuable link to the network for non-car users, low-income people, and those living in peripheral areas (e.g. rural west Edinburgh). The planned support tends to focus on: 1) orbital services; 2) connections to medical facilities; 3) services to smaller settlements such as Turnhouse and Ratho; 4) services in the early morning to allow shift workers to access to work; 5) evening and Sunday services on some routes (CEC, 2013b, P.10).

The new Local Transport Strategy also supports the provision of a modern and safe road network, contributing to the objectives of Road Safety Plan for Edinburgh to 2020 (2010d) (see Table 6.3). The Council introduces a proposal to extend 20mph speed limits to all residential areas (or to priority residential areas only). Similarly, for the outer suburbs of the city, there is also a proposal to implement a 30mph speed limit on all streets that are still with urban frontage (i.e. houses, businesses or shops) and keep a 40mph speed limit, with the exception of 20mph streets and some dual carriageways on the city outskirts (CEC, 2013b). However, when changes to speed limits are adopted, the Council recognises that there is a need to consider the effect on the accessibility of bus services on roads where buses might otherwise be able to exceed this speed.

Transport 2030 Vision is another document launched by CEC in 2010 to establish a clear long term vision to guide the work of the City Development Transport Service over the next 20 years (see Table 6.3). It sits alongside the updated Local Transport Strategy supporting the broad objectives of the city for the environment, accessibility, connectivity, social inclusion, health, and the economy. The Vision states that "by 2030, Edinburgh's transport system will be one of the greenest, healthiest and most accessible in northern Europe" (CEC, 2010a, p.2). Having an "accessible and connected transport system supporting the economy and providing access to employment, amenities and services" is identified as a main outcome against which achievement will be measured in 2030 (CEC, 2010a, p.5). Three indicators have been set up for this purpose: 1) working age population, resident in SEStran area, within 30 minutes public transport travel time from centres of employment; 2) accessibility of hospitals by public transport (population within 30 minutes public transport travel time), 8am-9am weekdays; 3) satisfaction with access by public transport. Table 6.5 presents the actions that have been considered to help the Council to deliver this outcome.

Table 6.5: Actions adopted in Transport 2030 Vision to deliver an accessible and connected transport system by 2030

Actions
- Increased public transport capacity including potential expansion of the tram network
- Quality transport interchanges
- Expansion of Park and Ride
- Better public transport connections to key destinations including Leith Docks, Edinburgh Park West Edinburgh and the Bioquarter
- Engagement with the freight sector to ensure the smooth flow of goods and services
- Engagement with the Edinburgh Chamber of Commerce Transport Group
- Engaging with local, regional and national partners to achieve the Council vision
- Improved cross-Forth services to Fife
- Proactive use of accessibility mapping and planning agreements to secure improved access to new development sites by all modes of travel
- Work with key visitor destinations in the city to improve accessibility by all modes of travel
- High speed rail to enhance connectivity

Source: CEC, Transport 2030 Vision (2010a)

Recently the *Public and Accessible Transport Action Plan (PATAP)* has been drawn up in 2013 to help in achieving the objectives of the Council's 2030 Vision by enabling and encouraging people in Edinburgh to use public transport more often (CEC, 2013a) (see Table 6.3). It suggests that the targets are a 17% increase in journeys on Lothian Buses and Tram between 2010 and 2015, 33% increase between 2010 and 2020. By rail, the target is that Haymarket grows from 4.1m users in 2010, to 5.5m in 2015, 6.5m in 2020; Waverley from 20m in 2010 to 26m in 2015, 30m in 2020. Therefore, the expectation is to increase public transport's share of all their journeys by 2015 by 1.3%, and by 2020 by 2.3% compared to the Scottish Household Survey average of 2007-8 and 2009-10 (19.1%) (CEC, 2013a, p.25). In this respect, PATAP contains a package of actions to improve public transport service and infrastructure delivery for the short, medium and long term. The actions address several issues regarding Active Travel Action Plan and Road Safety Plan, bus operations, bus infrastructure, rail, taxi and private hire car, community and accessible transport, Tram, and monitoring and review. For the purpose of improving public transport accessibility in Edinburgh, the Council defines a number of actions that are presented in Table 6.6.

Table 6.6: Actions adopted in PATAP 2013-2020 to improve public transport accessibility

Actions
- Produce a priority list of bus stops for improved access (i.e. routes to and from the stops) and implement a programme of improvements, with an initial target of 20 bus stops per year from 2012-2013 onwards.
- Review methodology for prioritising supported bus services.
- Identify weaknesses in reliability/access to jobs/access to hospitals/ frequency.
- Identify key interchange sites and actions (at key Tram stops, Bus Station, Waverley, Haymarket, Edinburgh Park and Edinburgh Gateway). Implement improvements, subject to funding.
- Identify funding for orbital bus services on the city bypass.
- Preserve and enhance good bus access across the city centre.
- Implement Phase 1a of Edinburgh Tram.
- Identify opportunities to enhance interchange between rail and Tram.
- Identify and address parking issues around Tram stops

Source: CEC, PATAP 2013-2020 (2013a, p.27-35)

In addition to the above transport policies, accessibility has been also a significant issue of interest for the spatial policies in Edinburgh and the surrounding region. The Edinburgh City Local Plan adopted by CEC (2010c) (see Table 6.3) defines a number of objectives to meet the transport requirements of new development in Edinburgh: 1) to minimise the distances people need to travel, 2) to maximise the accessibility of communities to jobs and essential services, and 3) to support the provision of necessary network infrastructure. The Local Plan supports the approach of delivering new urban development with high density since it is more likely than a low density suburb to meet the requirements of larger stores and generate a sufficient market for a local shop within walking distance. It is also more likely to provide sufficient patronage for a good and frequent bus service (CEC, 2010c).

The Scottish government raised a particular problem for people with no access to a private car, for whatever reason, stressing the importance of improving their ability to use the public transport system (Scottish Executive, 2006). In this regard, the Local Transport Strategy realises that growth in car ownership and use, and the changing locations of work, healthcare, education, shopping and other activities have made these activities less accessible to certain groups, exacerbating their social exclusion (CEC, 2007). Besides improving the coverage of public transport to provide the greatest potential benefits to most of these groups, the Edinburgh City Local Plan emphasises the importance of planning for accessibility to improve the interaction between land-use and transport planning, within the Council, in partnership with other agencies involved in development in the city, and at regional level. This ensures that developments have an appropriate mix of uses, and can be easily accessed by active travel and public transport (CEC, 2013b). Therefore, in the Edinburgh City Local Plan, planning for accessibility has been considered as an important approach to urban structure and spatial development to improve opportunities of participating in activities close to home. In other words, it helps to reduce the distance (or time) of journeys and even the need to travel, especially by car, to get to activities that people have to or wish to undertake, making travel on foot or by bicycle more realistic options in more cases (CEC, 2007, 2010c). A discussion on how SNAPTA can contribute to these spatial planning objectives is included in Section 6.6.

6.4 Overview of Previous Studies on Accessibility in the Edinburgh Region

This section presents an overview of three previous studies of accessibility, two of which have examined the transport and land use effects of major new land use developments in the Edinburgh city-region while the other focused on accessibility to the key hospitals and employment sites in SEStran area including Edinburgh Council's area. Derek Halden Consultancy (Halden, 2002) examined how the accessibility to jobs would change if a proportion (20%) of future development (development not already committed) was allocated according to different spatial strategies (e.g. green belt development; development of new settlements, etc). The option appraisal was carried out to inform the Structure Plan study for south east Scotland and used the Central Scotland Transport Model (CSTM) to extract the travel times between 45 zones (23 in Edinburgh) including the walk time, effective wait time, in vehicle time and boarding transfer penalties associated with public transport (Halden, 2002, p.315). The travel times were converted to form trip cost matrices for car available and non-car available trips using a weighted average of the resource values of time for work and non-work travel. Using land use data from 1997-99, accessibility indices were reported for the combinations of origins, destinations, time of day, people, trip purpose and mobility of greatest interest to policy development (Hull and Karou, 2011).

Halden (2002) found substantial disparities in accessibility for the population in affordable housing between the car available and non-car available zones in Edinburgh. The north west zones in Edinburgh (South Queensferry, Kirkliston, Balerno, Crammond/Davidsons Mains) had the "poorest non-car catchment accessibility of affordable housing in Edinburgh" (Halden, 2002, p.323), whilst the zones having more affordable housing in their catchments in central and southern Edinburgh provided good car available accessibility due to the proximity of the city bypass. Looking at the more strategic regional level, the study found that all of the development scenarios would increase accessibility by car by between 4% and 10% with the largest increases being felt to the east and south east of the city of Edinburgh (Smith and Halden, 2005). Development in the green belt would provide the most positive impacts in terms of regional accessibility for those living outside the city limits. Whilst the CEC policy to encourage continued development on brownfield sites in the city gave the highest degree of integration between land use and transport based on the lowest generalised minutes associated with travel (Smith and Halden, 2005).

David Simmonds Consultancy used a bespoke version of TELMoS (a later version of CSTM) to predict the impact of two major new strategic headquarters developments to the west of Edinburgh beyond the city bypass close to the airport (Bramley et al., 2011). It was assumed that the growth in employment from these developments opening in 2011 and 2021 respectively would reflect the expected growth in passenger numbers forecast to occur at the airport, which are forecast to grow from 6 million trips in 2001 to 17.8 million in 2021. A five sector zonal model was used to consider the effect of these developments on the transport system across Edinburgh (Hull and Karou, 2011). The model predicts that, without the additional office developments, congestion measured in terms of hours lost would increase fivefold between 2002 and 2021 in the West Edinburgh zone, covering the area to the west of the city and the airport. The impact of the two additional office developments by 2021 are a further increase in congestion of 32% in the West Edinburgh zone, 6% in Edinburgh City Centre and 11% across the rest of Edinburgh. Traffic increase across the study area would be of the order of 2-4%, with a 6% increase in the West Edinburgh zone by 2021 (Bramley et al., 2011).

A study carried out by MVA Consultancy (2008) in association with SEStran looked at accessibility to hospitals and employment in the region (i.e. SEStran's area), discussing what the SEStran model – Accession – can do to help local authorities to operate the model and develop accessibility work in their areas. The calculation of public transport accessibility was performed using the public transport data for all 8 of the SEStran Local Authorities plus Stirling and Dundee with the full ITN (Independent Transportation Network) road network (i.e. motorways, 'A' road, 'B' road, minor road, local road and private road publicly accessible) to measure the time taken travelling by public transport with walk access to the stop (maximum walk distance 800m) that can be calculated either as the crow flies or following a road network. Accession measures the travel time, by public transport, by calculating the time taken to walk, cycle or drive to the stop (depending on what method of access to the stop has been chosen), the 'in vehicle time' which is taken from the timetables as well as any interchange time (interchange is considered where the distance between stops is 500m).

The study examined the accessibility of the three main hospitals in Edinburgh including: the Edinburgh Royal Infirmary Hospital, Sick Kids Hospital and the Western General Hospital (see Figure 6.1 for their locations). According to the study's findings, the Sick Kids hospital has the highest number of households living within walking distance of it. Over 13,000 households live within walking distance of the Sick Kids Hospital. The Western General comes second followed by the Royal Infirmary. For accessibility by public transport, the number of households who could access the hospitals within 15 minutes and 30 minutes from the whole SEStran area has been considered in the analysis. The results showed that 125,146 households live within a 30minute public transport journey of the Edinburgh Royal Infirmary while 159,753 households for the Western General Hospital and 163,191 households for the Sick Kids Hospital (MVA Consultancy, 2008).

With regard to accessibility analysis to employment in Edinburgh, some sites were chosen as destination points: South Gyle Business Park; Victoria Quay, Central Edinburgh (Waverley Rail Station) and west of Edinburgh Ferry Road at Bae Systems building. Access times by public transport and by bus services only were given along with the number of households who could access the sites within 60 minutes and 30 minutes. The findings demonstrated that the area with access by public transport under 15minutes to South Gyle Business Park is relatively small reflecting the traffic congestion in the area or the lack of direct services to the area. Within 30 minutes during the morning peak hours, 6am – 9am 105,167 households can access South Gyle Business Park using public transport and 91,884 households using bus services only. Unsurprisingly, Central Edinburgh is the most accessible site for employment in SEStran's area with 230,558 households using all public transport modes and 220,763 households using bus only for 30minute journey while Ferry Road (Bae Systems building) is accessible to 169,263 households by public transport and to 168,432 households by bus only for the same cut-off travel time value (i.e. 30 minutes). As for access to Victoria Quay, no significant difference was shown between the number of households (129,643 households) which can access using all public transport modes and the number of those (129,634 households) which rely on the bus only to access the site within 30 minutes during the morning peak (MVA Consultancy, 2008).

Although the MVA study has not looked at the accessibility impact of policy change, the two other studies have identified two highly policy relevant considerations for CEC. Firstly, the public transport underperformance in the north western zone of the city towards the city bypass which particularly affects zones of affordable housing (Halden, 2002). Secondly, that the development in one area outside the city bypass has an impact, in terms of congestion, pollution and traffic levels throughout a much wider geographical area. However, neither of these two pieces of research looked at the impact of the Tram and Edinburgh South Suburban Railway (ESSR) on accessibility in Edinburgh, though the Halden study did assess the effect of a two cordon road toll (Hull and Karou, 2011).

6.5 The Rationale for the Edinburgh Tram and South Suburban Railway

The tram project was first mooted in the 1990's and received parliamentary accent in March 2006. In Edinburgh Local Transport Strategy 2007-2012, it is clear that the tram system is the main project coming up for Edinburgh's transport network (CEC, 2007). One of the key strengths of Edinburgh tram is the potential to build a fully integrated transport network of bus and tram system through interchange points, common ticketing and timetabling (TIE, 2007). Its construction has recently been completed, before which the completion date was deferred on numerous occasions due to legal action concerning the financial costs, disturbance and upheaval costs. Originally costed at £375 million in 2003, the budget was later increased to £545 million. In May 2011, it was revealed that £440 million had already been spent on the project (Scotsman, 2011). A report issued the following month estimated that the partial completion of the tram line from the airport to the city centre would cost £770 million (BBC, 2011a). A further report issued in August 2011 estimated that the final cost for the proposed line would be over £1 billion, including £228 million interest payments on a 30-year loan to cover the funding shortfall (BBC, 2011b).

The original 2001 proposal for Edinburgh Trams envisaged three routes across the city, Lines One, Two and Three (Figure 6.7); the first being a circular route running around the northern suburbs, with the other two forming radial lines running out to Newbridge in the west and to Newcraighall in the south east respectively (CEC, 2006). All lines would run through the city centre. After Line 3 was shelved, Lines One and Two were combined and split into three phases, with Phase 1 being further divided into Phase 1a and 1b (see Figure 6.8), as follows:

- Phase 1a; Newhaven to Edinburgh Airport
- Phase 1b; Haymarket to Granton Square
- Phase 2; Newhaven to Granton
- Phase 3; Edinburgh Airport to Newbridge

However, as a result of the suspension of work on Line Three due to lack of Scottish Parliamentary approval and later on Phases 1b, 2 and 3 due to lack of funding (CEC, 2011), in September 2011 only the construction of part of Phase 1a (a single line running from the airport to the city centre) is envisaged and effort has put into ensuring that this part comes to fruition.

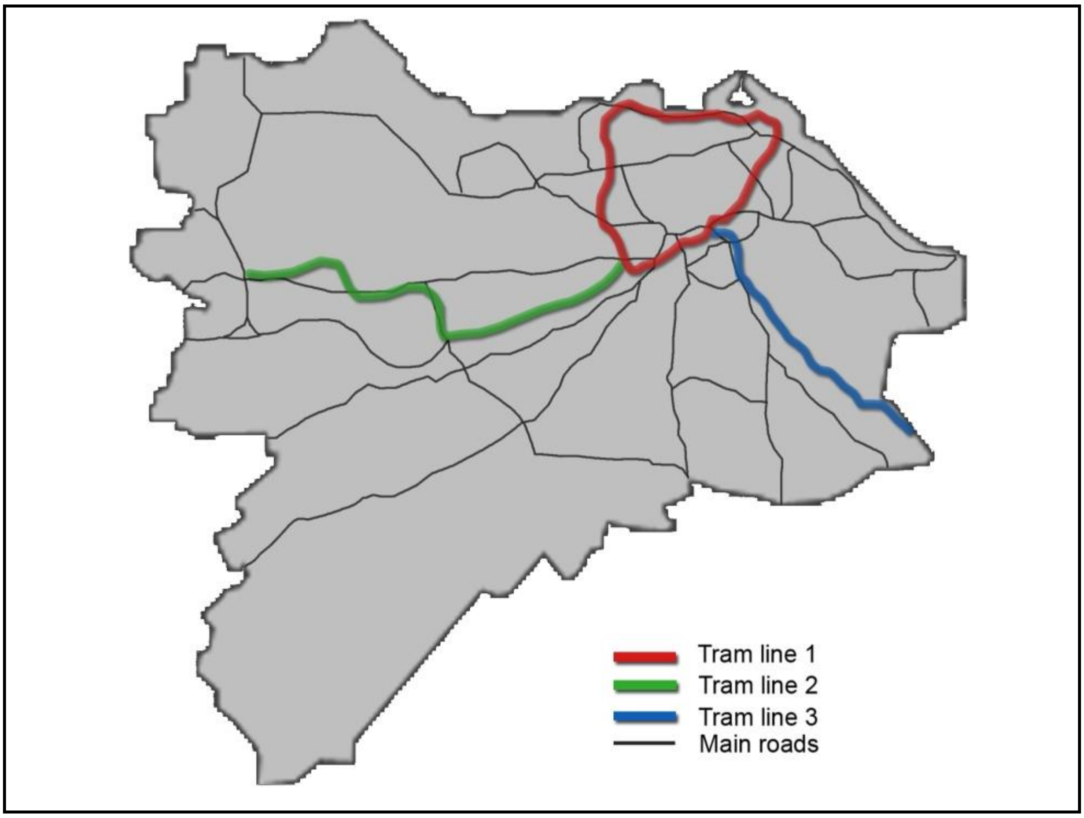

Figure 6.7: Edinburgh tram lines proposal (including all phases)

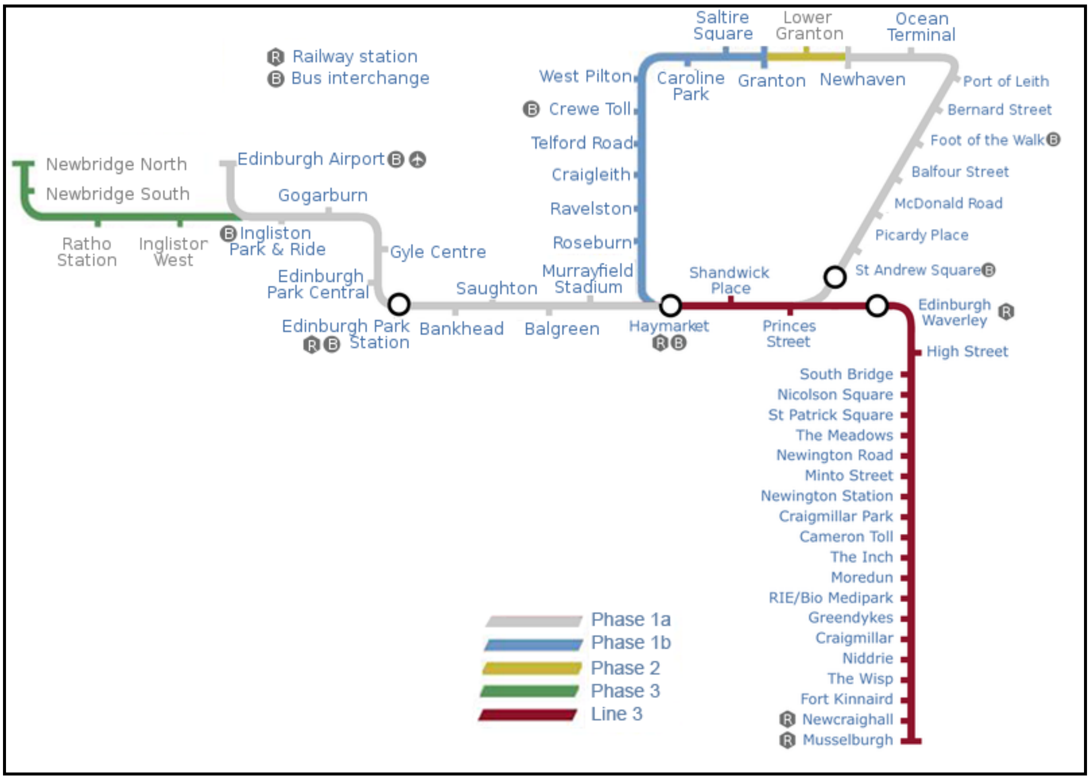

Figure 6.8: Edinburgh Tram Network

Source: www.edinburghtrams.com

Tram Phase 1a was given priority over all the other routes as West Edinburgh from the Gyle shopping centre to Newbridge has been identified by the Scottish Government as a national growth point. This part at 18.5km in length is, therefore, seen as vital to linking the 56 hectare development site at Leith through the West Edinburgh growth point to the airport and "in responding to the expected growth in travel demand" (TIE, 2007, p.41). Tram Phase 1a is being integrated with the bus network at five interchange stations with common ticketing and real-time information to serve as "the backbone for a comprehensive, higher quality public transport system to support the local economy and to help to create sustainable development" (TIE, 2007, p.8) through improving accessibility (TIE, 2007, p.32), "reduce(ing) traffic congestion and encourage(ing) modal shift" (TIE, 2007, p.33).

Tram Phase 1a provides an access to the city centre from the airport and the Ingliston Park and Ride site, particularly to key business parks, the redevelopment sites at Haymarket, Picardy Place, Port of Leith and Ocean Terminal. The twenty seven trams operating on Phase 1a have regenerative braking systems and are guided by an electric rail sharing road space with car vehicles with priority at junctions and segregated sections. Each tram is offering a capacity of 250 passengers and running at a frequency of

6 per hour initially between Edinburgh airport and Newhaven taking 45 minutes for the full journey. The frequency between Edinburgh airport and Haymarket will be 12 per hour when the Newhaven to Haymarket sections are completed (Phase 1b and 2).

Steer Davies Gleave undertook an *ex ante* evaluation of Tram Phases 1a and 1b to assess the value for money of the proposed tram using the Scottish Government's Scottish Transport Appraisal Guidance (STAG). The STAG appraises the welfare consequences of a project and takes account of the generalised social and environmental impacts alongside the economic impacts measured as travel time savings to car drivers and commuters. These are then monetised and presented as a benefit: cost ratio. The STAG appraisal compared the case for the trams with the 'do nothing' scenario. One of the assumptions of this was that "The Do-Something scenario includes a higher level of development along the tram corridor than in the Do-Minimum/Reference Case." (Steer Davies Gleave, 2006, p.108). Table 6.7 shows the estimated patronage demand for Tram Phases 1a and 1b.

Table 6.7: Predicted travel demand for public and private transport in 2011 and 2031

Scenario	Mode	2011 AM	2031 AM
Reference Case – Do Nothing	Public transport	94,993	135,845
	Private Car	114,303	140,042
	PT Share	45.4%	49.2%
Edinburgh Tram – Phases 1a and 1b	Public transport	97,183	139,753
	Private Car	113,918	139,753
	PT Share	46%	50%

Source: Adapted from Table 9.8 (Steer Davies Gleave, 2006, p.122)

Car ownership along much of the route is relatively low with the proportion of households without access to a car in Leith, Newhaven, Granton, Haymarket and Gorgie at over 50% (Steer Davies Gleave, 2006, p.6). These households already use public transport. The tram does not directly serve the North West areas of Edinburgh defined in the Halden (2002) study as having "poor non-car catchment accessibility" although feeder buses will link into the Ingliston and Edinburgh Park stations. The appraisal concludes that the "overall volume of movements in the 'with tram' case could potentially include a higher number of car trips than in the Do-Minimum even after the switch from car to tram has taken place." (Steer Davies Gleave, 2006, p.108). This higher number is assumed as a result of the higher development occurring alongside the tram route. This is likely to be particularly evident in the Leith redevelopment area. Private car use is predicted to grow with the tram from 113,918 in 2011 to 139,753 in 2031 (Steer Davies Gleave, 2006, p.15). Although "it is considered that the direct impact of the tram will be to reduce the overall level of car demand" (Steer Davies Gleave, 2006, p.125).

In regard to Edinburgh South Suburban Railway (ESSR), it is an existing double track railway line passing through the suburbs to the south of the city centre. It is used by freight traffic crossing the city, avoiding the central station areas. Campaigners have long argued that passenger services, which were withdrawn in 1962, should return as an important part of a sustainable and efficient transport system for Edinburgh. The City of Edinburgh Council has consistently recognised that the project could potentially assist in contributing to improved public transport in Edinburgh. The Council has funded a number of studies to consider the practicality and economics of the reopening of ESSR, including most recently a study by Atkins in 2004 to review the options and assess the feasibility of re-introducing passenger trains on the currently freight only line (CEC, 2008).

Journey to work data shows that the corridor around south central Edinburgh in which the ESSR runs has high levels of public transport use, particularly to the city centre, but also for many peripheral journeys further afield (CEC, 2008). It suggests that apart from the local trips and the trips to the city centre, journeys have been dispersed to a wide range of destinations, and the employment area in West Edinburgh has attracted considerable proportion of these journeys. A number of objectives have been defined by CEC (2008) and Transform Scotland (2007) for the ESSR project to contribute to the wider strategy of the region and city. These include transforming cross-city links; improving accessibility to designated employment growth areas; provide an important feeder to Waverley Station and the programmed new bus/tram/train interchange at Haymarket; making a significant shift in peak period journey-to-work trips from the car to public transport; enhancing the connections between the areas served by ESSR and other public transport modes (i.e. Edinburgh tram, the national rail network and bus services); ensuring access for all potential users to any new services or infrastructure; and minimising the environmental impacts of travel in the corridor of the railway (Transform Scotland, 2007; CEC, 2008).

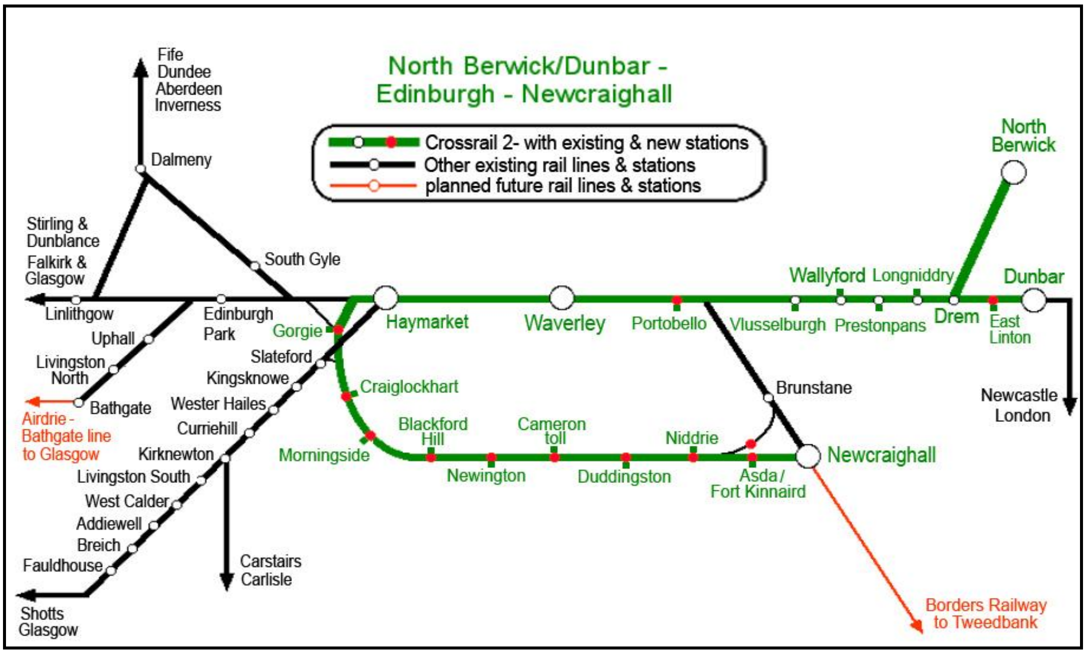

Figure 6.9: Edinburgh South Suburban Railway (ESSR) re-opening proposal

Source: TRANSform Scotland (2007, p.2)

The Atkins study (2004) examines a range of options for re-opening ESSR providing environmental, social and economic benefits at modest cost. It concludes that the most feasible option in the short- to medium-term would be to extend the existing North Berwick – Waverley/ Haymarket services to Niddrie (see Figure 6.9), with a capital cost estimated at £15 million (Atkins Transport Planning, 2004). In May 2008, a report issued by CEC estimates that the capital cost for this option including four stations is around £20 million and would be closer to £40 million in the case of eight stations (CEC, 2008). However, the Atkins report argues that the construction of Line Three of Edinburgh's proposed tram system to the south east of the city would clearly reduce demand levels and significantly erode the case for the scheme since it would compete with the locations of planned stations on the ESSR (Atkins Transport Planning, 2004).

For CEC, however, the extent to which the tram and ESSR will attract current and future car drivers to public transport is critical. Also pertinent is how they will contribute to improved accessibility and affect the relationships between local travel and activity choices. That which is not considered by the Steer Davies Gleave study, Business Case for tram, and Atkins report on ESSR is the subject of this research.

6.6 Application of SNAPTA for Transport and Land-use Planning in Edinburgh

This section addresses why and how the accessibility tool developed in this research has been used for the case study of Edinburgh. It discusses how the tool can contribute to the objectives and actions defined in the recent transport policy for Edinburgh that is described in Section 6.3 above. The choice of case study demonstrates the different ways in which SNAPTA can assist discussion and support decision-making in the planning for accessibility. SNAPTA has been applied to the Edinburgh transport network for three main different purposes.

First, the tool has been applied for a *before-and-after analysis of real-life network reconfigurations*. This is to identify the way in which accessibility changes across the whole area of Edinburgh Council after the completion of the significant public transport infrastructure of the tram and ESSR. The tool is used to compare changes in public transport access from the supply-side. The application also shows how land-use – transport integration can be clearly and visually communicated, and in so doing how SNAPTA outputs can be used to influence CEC's land-use – transport decisions. The reopening of ESSR and construction of the tram system in Edinburgh provided an opportunity to test the SNAPTA tool on a real-life by doing a before-and-after comparison of network performance and service levels. Edinburgh Tram is a highly controversial project. The project represents the largest investment in public transport infrastructure undertaken by the Scottish Government and CEC in Edinburgh in which the expected cost has risen sharply to exceed £1 billion, only to complete Phase 1a. In addition to the enormous financial cost, reasons concerning the continuous delay of completion date and the disturbance of local businesses who claim their income has been adversely affected by long-term road closures in the city centre since 2008 make it very criticized project (BBC, 2008; Scotsman, 2009). In this context, it is important to consider the tram in the application of SNAPTA in order to assess the associated improvements brought to accessibility in Edinburgh and identify if it was worth allocating such a large budget for this project. The SNAPTA analysis shows how patterns of accessibility by public transport change following the completion of the Edinburgh Tram or by reopening the ESSR. The analysis looks at accessibility impacts beyond the simple view of improvements located directly alongside the route of the new infrastructure itself. Since the tool examines the changes across the entire area of Edinburgh Council, it assesses the effect of network improvements in one corridor on the performance of network elements elsewhere in the area of study. Furthermore, the analysis identifies the way in which improvements to network accessibility offer a significant potential for improving land-use opportunities at locations with improved accessibility. In this way, the outputs prompt practitioners and decision-makers to rethink the land-use patterns in locations with high public transport accessibility.

The second purpose of applying SNAPTA to the Edinburgh network is the *evaluation and comparison between different future schemes (or scenarios) for land-use – transport integration*. By using the SNAPTA tool, a range of future scenarios regarding public transport infrastructure and service initiatives and corresponding land-use priorities can be studied, comparing the distributional impact of different transport policy and public expenditure in terms of accessibility. The tool is able to inform the strategic planning and decision-making process, allowing scenarios for future public transport networks and scenarios for future land-use patterns to be examined at a high disaggregation level. For example, in the case of Edinburgh Tram, the initial plan was to build three lines across the city (see section 6.4). Later Line Three was shelved and in September 2011 only the construction of part of Phase 1a is envisaged, with the development of additional phases of Lines One and Two shelved as well. For the assessment of future transport development scenarios when a fund is ensured to complete Line Three or another phase of Line One or Two, SNAPTA is applied to identify the significance of each scenario (or phase) in supporting public transport accessibility and land-use – transport integration. This assists the transport planners of CEC in arranging the list of priorities and making decisions on future infrastructure interventions

The Edinburgh Local Transport Strategy recognises the advantage of using accessibility measures for guiding locational policy and decision-making in order to ensure land-use and transport policy integration. In this respect, the strategy seeks to formulate the planning system in such a way which affects the distribution of housing, employment, shopping and leisure activities across the city. It does this by managing the redevelopment or change the existing land-use patterns, or by guiding the location and form of new development. The aim is to influence travel patterns in the medium to longer term to increase the proportion of journeys made by public transport and minimise the need to travel by car. To make decisions on which activity centre should have a particular role within the region area, SNAPTA is applied to Edinburgh network to provide a better understanding of which activity centres have the potential to perform well in terms of accessibility. The tool assists in defining which and where activity centres can best be opened, intensified or relocated. Therefore, SNAPTA as an interactive decision tool helps in the assessment of different scenarios for activities and land-use patterns framed around the accessibility of the public transport network and the accessibility of site.

Finally, the *evaluation of spatial equity* is the third purpose of the application of SNAPTA to Edinburgh's network. Since the facilities are spread over the whole area of the Edinburgh, it is not possible for all parts of the city to have equal access to all opportunities. However, the objective is to identify the main gaps in the distribution of urban activities and assess the efficiency and equity in the distribution of these activities in Edinburgh Council's area. SNAPTA focuses on the equal access to different opportunities including employment, shopping, education, health care and leisure regardless of an individual's need or financial circumstances. It examines the distribution of transport schemes effect on accessibility by geographical areas for different journey purposes. Therefore, the application of SNAPTA highlights the disadvantaged parts of Edinburgh's area where the residents have a relatively poor accessibility and need to travel for a longer time than those in other parts of the city to pursue the same amount or quality of a certain opportunity. This provides useful evidence on equity and adds value to both the strategic and local accessibility assessment, and the results can be used to support decision-making to tackle equity issues either by expanding or improving public transport infrastructure or by intensifying or opening an activity centre. However, it is difficult to tell whether the spatial distribution of activities in an area is equitable to the residents since each type of facilities possesses its own unique characteristics and satisfies particular needs. In addition, individuals have different needs and preferences (known as an attraction) for different types of activities that are difficult to define in the context of the whole urban area (e.g. the quality of a particular product/ service at activities). It is worth mentioning that the SNAPTA tool considers only spatial equity and does not look at social equity which focuses on the different needs, abilities and requirements for access based on particular characteristics of individual such as age, gender, income, household structure, educational level, disability or handicap.

Considering the above discussion on the main purposes for which SNAPTA has been applied to the case study of Edinburgh, it can be identified that the tool can be used to contribute, either directly or indirectly, to a number of the objectives of the CEC and SEStran transport strategies described in Section 6.3. In terms of *improved accessibility and connection*, SNAPTA can be used to address the following objectives defined for

Edinburgh transport: 1) to improve the interaction between land-use and transport planning; 2) to promote good transport accessibility and connections within the city; 3) to support the provision of necessary network infrastructure; 4) to improve public transport connections to key destinations including Leith Docks, Edinburgh Park West Edinburgh and the Bioquarter; 5) to improve access to employment; 6) to improve access to health and medical facilities; 7) to improve access to other services, such as retailing, leisure/social and education; 8) to improve accessibility of communities in smaller settlements such as Turnhouse and Ratho; and 9) to support improved local access to the airport with an emphasis on prioritising public transport (CEC, 2010a; CEC, 2013a; CEC, 2013b; SEStran, 2008). In this regard, the tool can be applied to provide the evidence to support some of the actions that the Council and SEStran have developed to address the above policy objectives. Table 6.8 outlines those actions that SNAPTA can help to deliver, showing the relevant evidence to each action.

Table 6.8: Examples of how SNAPTA can support CEC and SEStran actions to improve accessibility and connection in Edinburgh

Actions defined by CEC and SEStran	Evidences provided by SNAPTA
Proactive use of accessibility mapping and planning agreements to secure improved access to new development sites and key visitor destinations by public transport	Evidence on the accessibility impacts brought by different alternatives of public transport interventions such as a new bus service, alterations to a bus route, introducing a new bus/ tram stop or interchange option, etc.
Using accessibility analysis to identify where improvements to public transport should be targeted to provide the greatest potential benefits to most of community groups,	Evidence on the averages of the total travel times of the shortest public transport journeys that residents in each zone require to travel to all other zones (or to a set of locations/ opportunities) (see Chapter 7)
Identify weaknesses in accessibility to jobs and access to hospitals	Evidence on the spatial distribution (per zone) of the level of public transport accessibility to jobs and hospitals across the modelled area. This can be carried out by applying the contour measure or the potential accessibility measure (see Chapter 7)
Identify working age population within 30 minutes travel time by public transport from key centres of employment	Using the contour measure, evidence on the size of working-age population within the catchment area of the key employment sites in Edinburgh for different time thresholds (see Chapter 7)
Identify population within 30 minutes travel time by public transport from main hospitals	Using the contour measure, evidence on the size of population within the catchment area of the main hospitals in Edinburgh for different time thresholds (see Chapter 7)
Identify key interchange sites and opportunities to enhance interchange between rail and Tram	Evidence on the shortest public transport journeys, including the fastest interchange options, between a set of origin-locations and a destination (or a set of destinations). Identifying a set of origin-destination pairs between which people need to spend a relatively long time to travel by public transport. Analysis of the benefit brought to accessibility by different scenarios of introducing interchange points.

In addition, SNAPTA can be applied to help CEC in addressing a number of objectives for *supported bus services* in Edinburgh. These objectives include: 1) to preserve and enhance good bus access across the city centre; 2) to improve the extent and connectivity of the bus services and overall public transport network with a focus on non-car users, low-income people, and those living in peripheral areas; 3) to provide support for addressing the key shortfalls in the local bus network, with a particular emphasis on non-city centre services, evenings and weekends; 4) to improve access to Edinburgh Airport and build on the UK-leading Airlink bus service, with an emphasis on tram and bus; and 5) to ensure major investment in orbital bus services on the city bypass (CEC, 2010a; CEC, 2013a; CEC, 2013b). To achieve these objectives, the Council has identified a package of actions in which SNAPTA can play a helpful role in planning the bus services in Edinburgh and the surrounding region. The tool can make a contribution to three relevant measures introduced by CEC: 1) review methodology for prioritising supported bus services; 2) identifying the potential to provide feeder bus services to the tram, especially from settlements in the west of the Council area; and 3) identifying opportunities for orbital bus routes along the corridor of the City Bypass linking a number of major centres including the Airport, Edinburgh Park, Straiton, the Royal Infirmary, and Fort Kinnaird. In this context, SNAPTA can carry out analysis of accessibility by bus across the city, taking into account proximity to bus stops, the spatial coverage of bus network, attractiveness of activity centres accessed by bus, and the spatial equity in the distribution of opportunities (i.e. the ease of reach opportunities by bus from each zone). The analysis can provide transport planners with empirical evidence on the gaps in accessibility by bus. By linking this with data on the poorest zones in Edinburgh, where households are living on relatively low incomes without access (or with limited access) to a car, the Council's planners can identify where bus service support is needed with priority given to non-car users and low-income people (see Chapter 7).

The *potential expansion of the tram network* is another important issue that CEC considers to enhance the quality and increase the capacity of public transport by providing a good alternative to car use for more people. According to the New Local Transport Strategy 2014-2019 – Issues for Review (CEC, 2013b), once the delivery of the Edinburgh Tram (Phase 1a from the Airport to York Place) is completed, options for future lines will be examined. The implementation of another tram line and/or re-opening of ESSR to serve the South and South-East of the city is a potential option. As discussed earlier in this section, SNAPTA can be applied to examine and compare the accessibility impacts of a combination of different transport interventions. In this respect, the tool can play a significant role in assessing the major transport projects planned for Edinburgh's network (including the Tram and railway infrastructure) in terms of their contribution to improved accessibility by public transport (see Chapter 7). This provides the politicians in CEC with a better understanding of where transport improvements and investments should go, forming a basis for the decision-making.

For *safer roads*, the Council in the new Local Transport Strategy 2014-2019 has introduced several options to implement 20mph speed limits on residential streets (see Section 6.3 above). Similarly, the new strategy has brought a proposal to reduce the limit to 30mph in all streets in the outer suburbs of the city but still with houses or business frontage and retain a 40mph speed limit (e.g. parts of Telford Road, Comiston Road and Seafield Road). However, the effect on bus services due to the change in speed limit has been emphasised by the Council as something which needs to be considered (CEC, 2013b). In this context, SNAPTA can be used in the stage of the assessment of this reduction in the speed limit to identify the consequence for the accessibility of bus services on roads where buses might otherwise be able to exceed the new speed limit. Different timetables of the affected bus services would be considered in the analysis to find out the extent to which accessibility levels across the city, particularly in the areas served by these buses, have changed.

In addition to the transport strategies objectives discussed above, SNAPTA can also help in meeting objectives related to land-use strategy of both Edinburgh City Local Plan (CEC, 2010c) and the Lothians Structure Plan 2015, particularly the strategy that aims to support the *development of a sustainable city form* clustered around an enhanced public transport system. In this regard, the tool can be used to serve two main policy objectives: 1) to minimise journeys time/distance and even the need to travel, especially by car, to get to activities that people have to or wish to undertake; and 2) to increase the proportion of journeys made by public transport by 2015 by 1.3%, and by 2020 by 2.3% (compared to the Scottish Household Survey average of 2007-8 and 2009-10) (CEC, 2013a). By analysing the efficiency in the distribution of urban activities and coverage of the public transport network, SNAPTA provides an efficient way to identify development opportunities. Moreover, using a high level of spatial disaggregation enables the

Council’s planners to identify the most appropriate location (or zone) to locate a particular activity in such a way which meets the demand requirements for the biggest possible number of residents. This improves the opportunity for people to participate in activities close to home, reducing journey lengths and making travel on foot or by bicycle more realistic options in more cases.

6.7 Conclusion

This chapter presents the case study used in this research for the assessment of the SNAPTA potential as a decision-making support tool in planning practice. In order to test the tool in the real world, Edinburgh Council’s area was selected as a case study for several reasons. First, it is because of the currently important period of urban redevelopment that the city faces as a reflection of the growth in Edinburgh's economy and population, which is represented by four core development areas around the city incorporating residential, office, retail and other commercial development as identified in the Edinburgh and the Lothians Structure Plan 2015. Another reason is due to the significant schemes for delivering public transport improvements and new infrastructure presented by LTS, PATAP, Transport 2030 Vision and other relevant policy documents which introduce key projects including the highly controversial project of Edinburgh Tram with several phases and massive allocated budget, and re-opening ESSR. The aim of these schemes is to keep up with the growing needs of the city and serve the new communities and regeneration areas by ensuring reliable and sustainable alternatives to the car and improving public transport accessibility to employment and other services. In addition, no study has yet looked at the impact of the tram (at least phase 2, 3 and Line Three) and ESSR on accessibility in Edinburgh particularly in such a high level of detail and disaggregation.

In order to respond to the accessibility questions raised in the policy documents mentioned above, the research has defined three different purposes of applying SNAPTA to the Edinburgh case study including: a before-and-after analysis of real-life network reconfigurations; an evaluation and comparison between different future schemes for land-use – transport integration; and an evaluation of the spatial equity in the distribution of urban activities. The application goes deeper than the previous accessibility modelling studies in Edinburgh carried out by MVA, Derek Halden, David Simmonds and Steer Davies Gleave that were focused on demand/ supply relationships across a broad geographical coverage. By necessity, they provided little detail about locations (activities/ services) and individuals (customers). The current analysis of SNAPTA assesses the impact of Edinburgh Tram and ESSR and provides information about the changes in potential public transport accessibility between the 549 data zones of the Council's area. However, it cannot infer whether traveller's perceptions of the ease of reaching the facilities and services they require on a daily or weekly basis by public transport will also change. The next chapter discusses the results of the tool application to Edinburgh Council's area and the reflection on the policy objectives presented in this chapter.

CHAPTER 7 – Results of the Application and Contribution to Transport Policy and Practice

7.1 Introduction

This chapter presents and discusses SNAPTA's results for the empirical case study in Edinburgh focusing on the accessibility analysis of different public transport scenarios as well as the consequent absolute and relative change in accessibility to a particular activity or service. It continues with a discussion on what the findings mean in the context of the vision for Edinburgh transport and how it can contribute to transport and land-use planning decision-making. The chapter also reports on the COST Action workshop organised for testing SNAPTA and discusses the associated feedback provided by experts on the usability and usefulness of the tool in planning practice.

The next section (7.2) presents the accessibility analysis in the baseline year scenario of the case study. It discusses the findings of the use of three measures (travel time, contour measure and potential accessibility measure) to evaluate accessibility by public transport to ten different activity opportunities. Section 7.2 ends with a discussion on how these findings can be used for decision-making support to fulfil Edinburgh transport policy. Section 7.3 focuses on the changes in public transport accessibility due to the scheduled run of the first part of Tram Phase 1a in summer 2014. Section 7.4 addresses the impact of a number of longer-term development scenarios, describing the accessibility changes that will be brought about by different possible combinations of Edinburgh Tram and ESSR. Section 7.5 discusses the usefulness and practical applicability of SNAPTA through a virtual exercise delivered in a workshop in co-operation with transport and land-use planners as a part of the COST Action TU1002 "Accessibility Instruments for Planning Practice in Europe". The section continues with an explanation of the results of the experts' assessment presenting the main advantages and disadvantages of the tool.

7.2 Analysis of the Baseline Year 2011 State of Public Transport Accessibility

As mentioned before in the previous chapter, the development of SNAPTA has been closely linked to the policy needs arising from the Edinburgh Local Transport Strategy (2007 – 2012) and subsequent reviews. The tool can be run to produce huge amounts of information which can help in addressing various issues in transport and land use planning through different stages of the decision-making process. However, it is important to clarify what policy questions need to be answered and limit the analysis in this research to looking at them.

In this section, the use of SNAPTA for modelling the current state of accessibility has produced three main results: first the gaps in the coverage of the public transport network; second the spatial equity in the distribution of urban activities and services; and third the "hotspots" of a particular activity accessed by public transport (i.e. areas in which there is a relatively greater concentration of journey destinations carried out by public transport to pursue a certain activity). These results can be used to address a number of policy questions in transport and land-use planning, as follows:

- Which areas require their residents to travel excessively to pursue the same amount of particular activity when compared with other areas around the city?
- Where should public transport investment (i.e. infrastructure or service improvement) go to achieve better connection with locations of activity centres?
- Where should an activity centre be opened?

Answering the questions above for the case study of Edinburgh contributes to achieving a number of the objectives of SEStran and CEC transport strategy, which have been discussed in detail in Chapter 6. One of the key objectives is to support the interaction between land use and transport planning. In practice, this has been translated by the local and regional transport authorities into several objectives; for example improving access and public transport connections within the city and to the key employment destinations, health and medical facilities, and other services such as retailing, leisure and education as well as improving the accessibility of communities in smaller settlements in the Council's peripheral areas. Other objectives in which the analysis findings can play a significant role in the decision-making process is the provision of necessary network infrastructure, for example the support for key shortfalls in the local bus network and the introduction of new orbital bus services. In this respect the results help to identify where improvements to public transport should be targeted to provide the greatest potential benefits to most of people across the Council area.

7.2.1 Travel time

In this section, Figure 7.1 presents the spatial distribution of accessibility levels by public transport mode in Edinburgh according to the baseline scenario for the year 2011. It has been generated based on the calculation of the averages of the total travel times of the shortest public transport journeys (including walking time to and from public transport facilities and interchange time) that residents in each zone require to travel to all other zones during the morning peak hours. Since this result has been calculated with a focus on travel time only without a consideration of the location and size of urban activities, the coverage of the public transport network has been the key influence alongside the distribution and volume of the morning traffic in Edinburgh. Because of the radial form of the public transport network in the city (as described previously in Chapter 6), it is not surprising that the analysis of the current state of public transport journeys time suggests that the central area in Edinburgh, where people mostly use only one service to reach their destinations, enjoys the highest level of accessibility. Using the Scotland Census 2011, Table 7.1 shows the population and household numbers and percentages which are able to travel by public transport to all other zones within different ranges of average shortest journey times. Particularly significant are the higher percentages of households without access to motorised transport who live within those areas which have the highest accessibility by public transport. The findings indicate that the average shortest travel times of 548 journeys (549 Data Zones) that the majority of the population (over 80%) need to make to travel to all other zones range between 32 and 50 minutes. Just 3% of the population, which is equivalent to 15,453 people, require an average journey time of more than 60 minutes.

In a similar way to the above calculation of travel time, Figure 7.2 demonstrates accessibility levels by public transport to Edinburgh's Central Business District (CBD) using five ranges of the shortest journey time from each zone to the CBD. Although Edinburgh does not have a formally defined CBD (personal communication with CEC), this research considers the entire city centre ward (i.e. ward 11) (see Figure 7.2), which includes the main office district – the "Exchange District" – and the city centre retail core, as a broad definition of the CBD. The map shows that the residents in the south west of Edinburgh have the lowest level of accessibility to CBD with a travel time of up to 58 minutes. Table 7.2 focuses on population and households which can travel to the CBD within different ranges of journey times. It shows that just around 1% of the population (6,471) need to travel for more that 45 minutes to reach the central area while 30% need less than 15 minutes. As is the case with Table 7.1, Table 7.2 clearly demonstrates that the higher the level of accessibility by public transport, the higher the percentages of households without access to cars or vans.

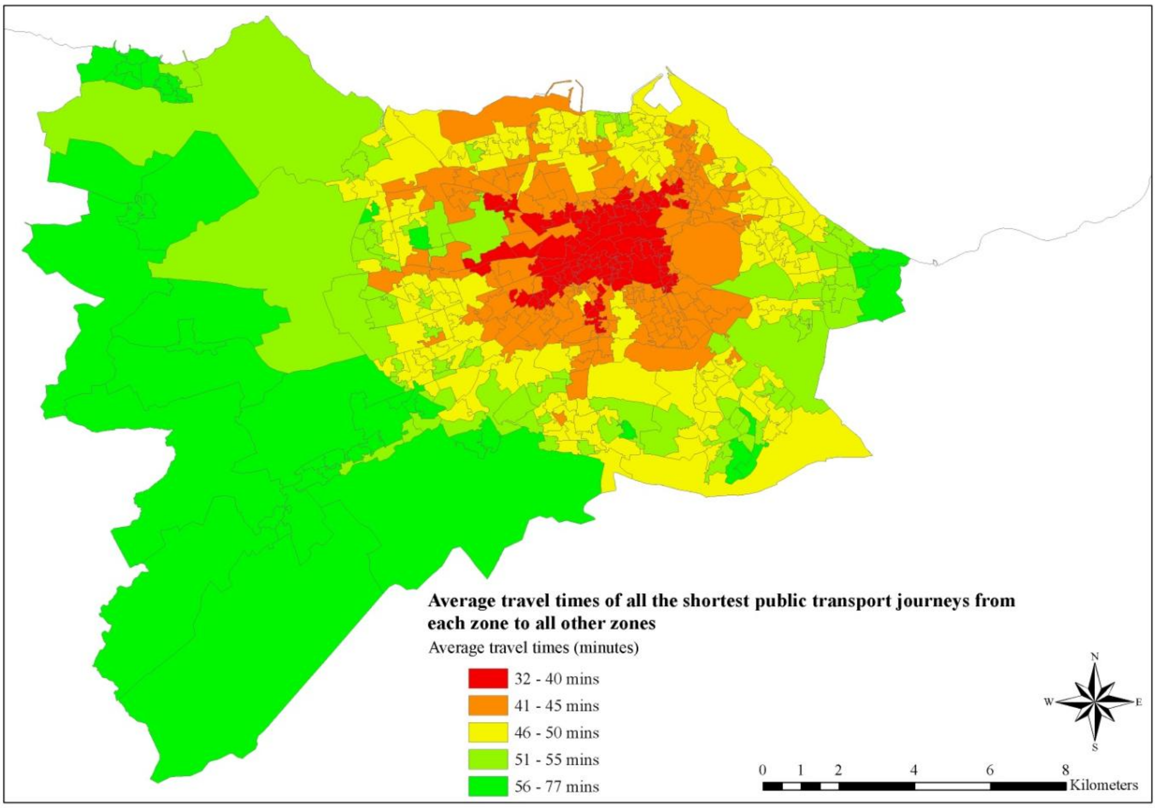

Figure 7.1: Baseline year 2011 scenario – Average travel times of all the shortest public transport journeys from each to all other zones

Table 7.1: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to travel to all other zones (by public transport) within different ranges of average shortest journey times

Average travel times of the shortest journeys to all zones	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
32 - 40 minutes	99,934	20%	45,338	23,648	52%
41 - 45 minutes	148,680	30%	68,761	29,033	42%
46 - 50 minutes	151,312	31%	69,370	25,737	37%
51 - 55 minutes	56,256	11%	24,388	7,995	33%
56 - 60 minutes	23,548	5%	8,950	1,656	19%
61 - 70 minutes	15,453	3%	6,259	975	16%

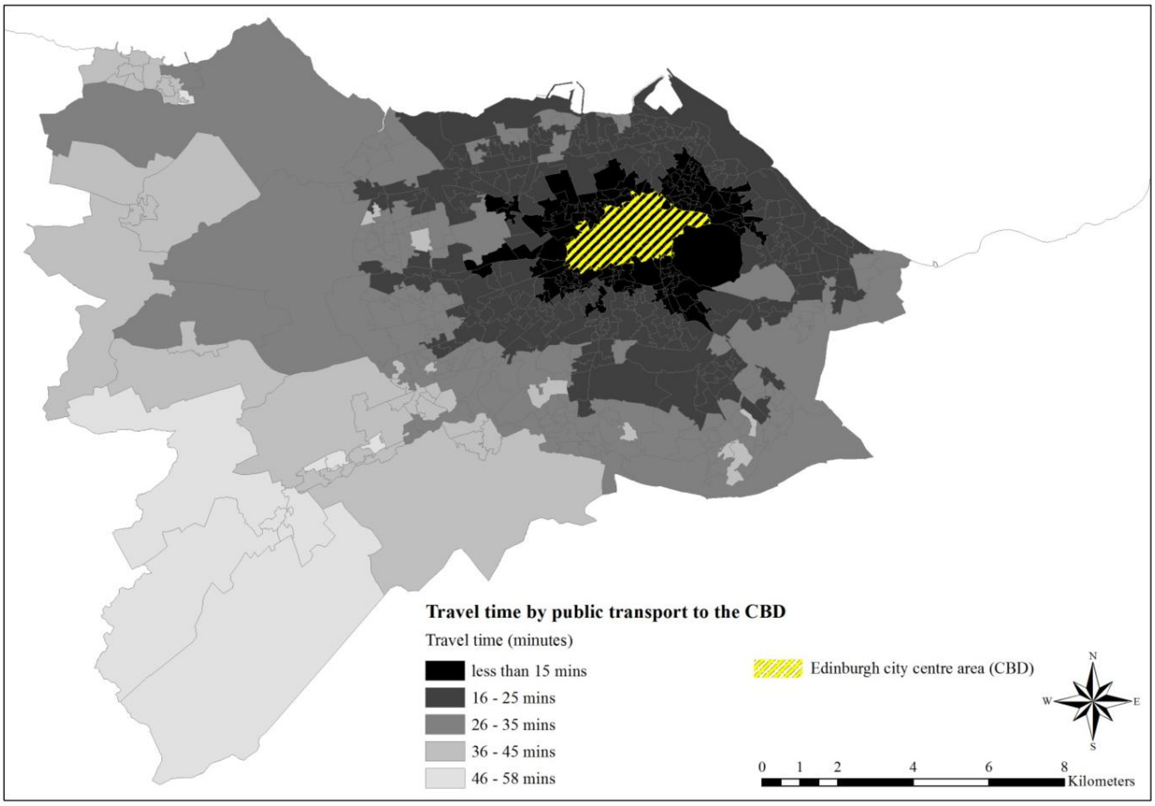

Figure 7.2: Baseline year 2011 scenario – Travel time by public transport to the CBD

Table 7.2: Population and households without access to cars or vans (based on Census 2011) which are able to travel to the CBD (by public transport) within different ranges of journey times

Travel times to the CBD	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
Less than 15 minutes	148,119	30%	68,229	35,502	52%
16 - 25 minutes	191,895	39%	88,291	33,217	38%
26 - 35 minutes	112,278	23%	49,432	16,579	34%
36 - 45 minutes	36,420	7%	14,421	3,314	23%
46 - 58 minutes	6,471	1%	2,693	432	16%

7.2.2 Accessibility to jobs

The use of a contour measure (described in Chapter 5, Section 5.4) for job accessibility analysis for the baseline year 2011 scenario shows considerable spatial variations in access to jobs that people can reach by travelling up to 40 minutes (see the discussion on cut-off criteria in Chapter 5, Section 5.8) using public transport. According to Figure 7.3, it is clear that the people in the central part of the city have the highest level of accessibility to jobs with up to 259,558 job opportunities reachable within 40 minutes travel time by public transport. This number continues to decline radially away from the centre to the suburban areas.

Using the potential accessibility measure (described in Chapter 5, Section 5.4) to quantify accessibility to jobs has produced a different spatial distribution of accessibility levels to the one obtained by the contour measure. Figure 7.4 shows five levels of potential accessibility in the case study area. Despite the similarity in classifying the city centre as the most accessible area to jobs, a notable difference can be recognised between the two results in the area of the major business park (i.e. Edinburgh Park, South Gyle, etc.) and Edinburgh Airport in the western periphery of the city where around 25,000 people are working according to the Business Register and Employment Survey (BRES) (ONS, 2009).

By linking the number of jobs that can be reached within 40 minutes with data on households without access to private cars or vans (see Table 7.3), it can be identified that the households with the lowest percentages of access to cars or vans are those which enjoy the best accessibility by public transport to jobs. Tables 7.4, 7.5 and 7.6 show the number of zones, the size of the working-age population and the percentages of households without access to cars or vans within the service areas of the key employment sites in Edinburgh for time limits of 30, 40 and 60 minutes respectively. These include four sites: Victoria Quay (Scottish Government), South Gyle (Edinburgh Park), Crewe Toll and City Centre (see Chapter 6, Figure 6.1 for their locations). The analysis indicates that South Gyle is the least accessible key employment site by public transport, with just 5% of the working-age population able to reach the site within 30 minutes. This percentage increases to 17% and 69% for 40 and 60 minutes respectively. On the other hand, the city centre is by far the most accessible site, with a service area covering 49% of working-age population for 30 minutes travel time, 82% for 40 minutes and almost the whole working-age population for 60 minutes. By comparing the accessibility of both sites Crewe Toll and Victoria Quay for different values of time limits, it can be noticed that Victoria Quay is more accessible to working-age population than Crewe Toll for 30 minutes travel times (22% for Victoria Quay and 16% for Crewe Toll) while Crewe Toll performs better for 40 and 60 minutes (42% and 86% respectively for Victoria Quay and 45% and 93% respectively for Crewe Toll).

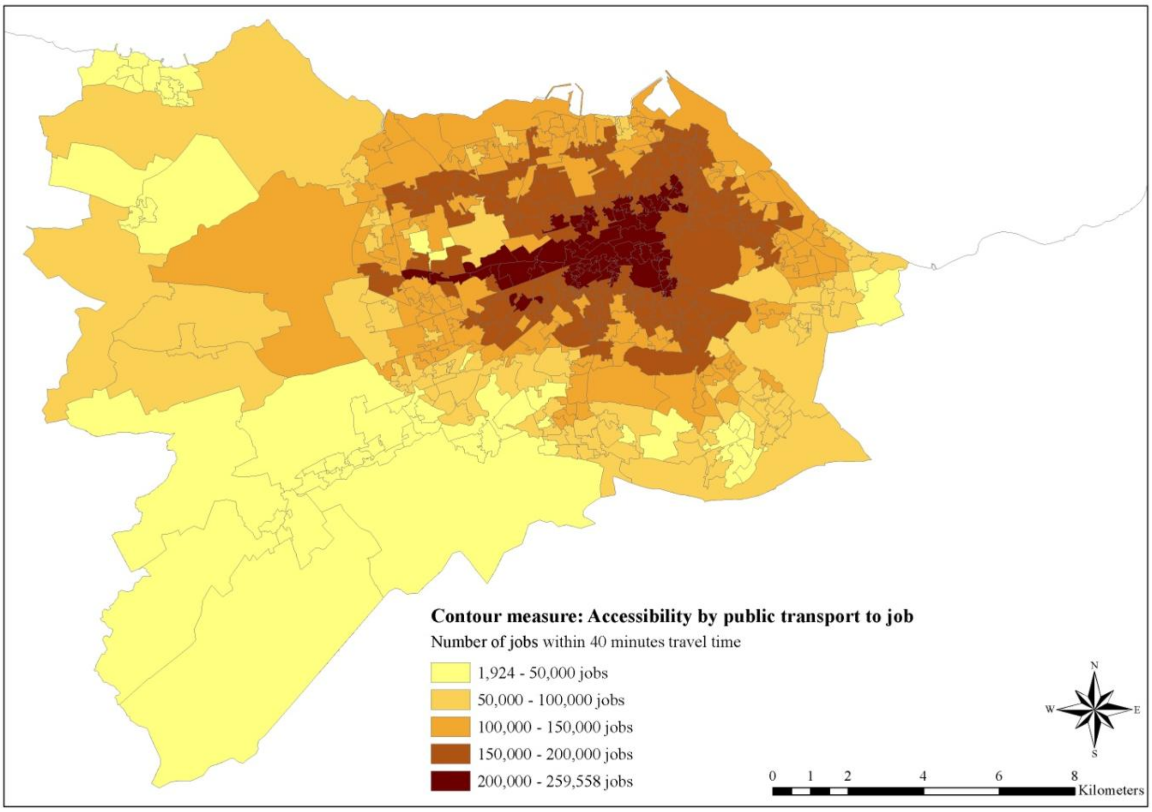

Figure 7.3: Baseline year 2011 scenario – Accessibility by public transport to jobs (contour measure)

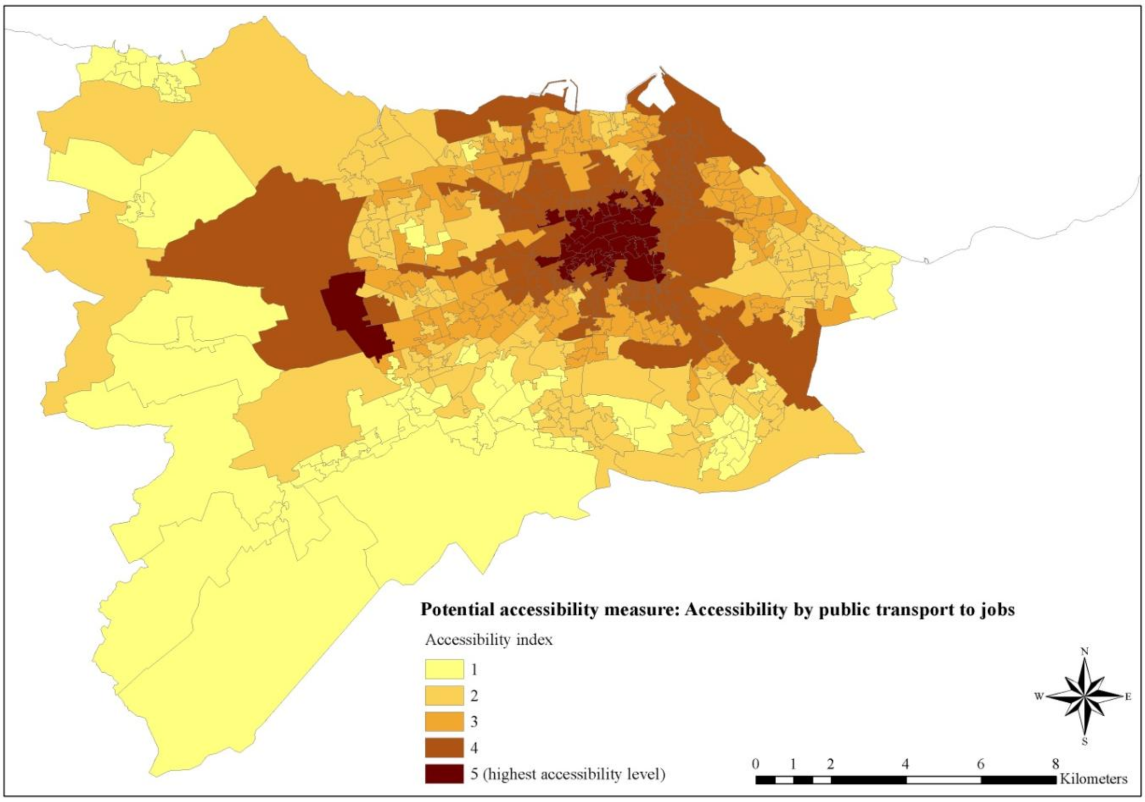

Figure 7.4: Baseline year 2011 scenario – Accessibility by public transport to jobs (potential accessibility measure)

Table 7.3: Working-age population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different numbers of job opportunities within 40 minutes' travel time by public transport

Number of jobs within 40 minutes' travel time	Working-age population	Percentage of working-age population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
1,924 - 10,000 jobs	3,724	1%	2,623	337	13%
10,000- 50,000 jobs	28,943	9%	18,039	3,723	21%
50,00 - 100,000 jobs	49,856	15%	35,617	12,371	35%
100,000 - 150,000 jobs	78,362	23%	56,633	20,369	36%
150,000 - 200,000 jobs	122,761	36%	80,023	35,953	45%
200,000 - 259,558 jobs	54,768	16%	30,131	16,291	54%

Table 7.4: Working-age population and households without access to cars or vans (based on Scotland Census 2011) within 30 minutes' travel time by public transport from the four key employment sites

Employment site	Number of zones	Working-age population 2011	% of working-age population	Number of households 2011	Households without access to cars or vans	% of households without access to cars or vans
Victoria Quay (Scottish Government)	102	73,445	22%	50,942	24,966	49%
South Gyle (Edinburgh Park)	31	16,259	5%	11,543	3,534	31%
Crewe Toll	86	52,594	16%	37,257	14,611	39%
City Centre	237	167,267	49%	103,342	49,369	48%

Table 7.5: Working-age population and households without access to cars or vans (based on Scotland Census 2011) within 40 minutes' travel time by public transport from the four key employment sites

Employment site	Number of zones	Working-age population 2011	% of working-age population	Number of households 2011	Households without access to cars or vans	% of households without access to cars or vans
Victoria Quay (Scottish Government)	200	141,242	42%	93,113	45,394	49%
South Gyle (Edinburgh Park)	103	57,427	17%	40,032	14,397	36%
Crewe Toll	223	153,820	45%	98,880	43,654	44%
City Centre	435	276,583	82%	181,938	77,809	43%

Table 7.6: Working-age population and households without access to cars or vans (based on Scotland Census 2011) within 60 minutes' travel time by public transport from the four key employment sites

Employment site	Number of zones	Working-age population 2011	% of working-age population	Number of households 2011	Households without access to cars or vans	% of households without access to cars or vans
Victoria Quay (Scottish Government)	457	290,000	86%	190,712	80,355	42%
South Gyle (Edinburgh Park)	368	233,932	69%	148,496	60,358	41%
Crewe Toll	505	313,300	93%	207,028	85,196	41%
City Centre	542	335,260	99%	220,762	88,705	40%

7.2.3 Accessibility to food stores and retail services

Modelling the accessibility for food shopping focuses on supermarkets and convenience stores for the country's large food retail chains only (i.e. Asda, Botterills, Co-operative Food store, Costcutter, KeyStore, Lidl, Local From Haddows, Londis, Marks & Spencer-Simply Food, McColl's, Morrisons, Sainsbury's, Sainsbury's-Local, Scotmid, Somerfield, SPAR, Tesco, Tesco-Express, Tesco-Metro, Waitrose, and Whistlestop Food & Wine). It uses data on the floor space area of these stores estimated in 2009 at Data Zone level which is the most current available data (at the date of SNAPTA construction). It is worth mentioning that the land-use pattern and accompanied floor space of food stores has slightly changed from 2009 due to opening number of large supermarkets such as Sainsbury's store in Longstone.

For the contour measure analysis, a value of 30 minutes has been applied as a cut-off travel time by public transport for food shopping. The result shows that residents of the city centre and the east area of Edinburgh have access to the largest floor space area of food stores with up to 261,400 square metres (see Figure 7.5). The application of the potential accessibility measure which does not consider a particular limit for travel time has produced an extremely spatially differentiated distribution of food shopping accessibility. Figure 7.6 interestingly shows that the city centre does not have the best accessibility by public transport to supermarkets and convenience stores. The consideration of distance decay across the whole study area with no use of a cut-off value has clearly a significant influence on the result. However, both the measures demonstrate that a very large area in the west of Edinburgh includes the worst performing zones for accessibility to food stores. Table 7.7 expresses the relationship between the levels of public transport accessibility to different ranges of supermarket floor space area and data on the associated sizes and percentages of population and households without access to cars or vans. It shows that 90% of Edinburgh's population can reach over 10,000 square metres of food stores within 30 minutes' travel time.

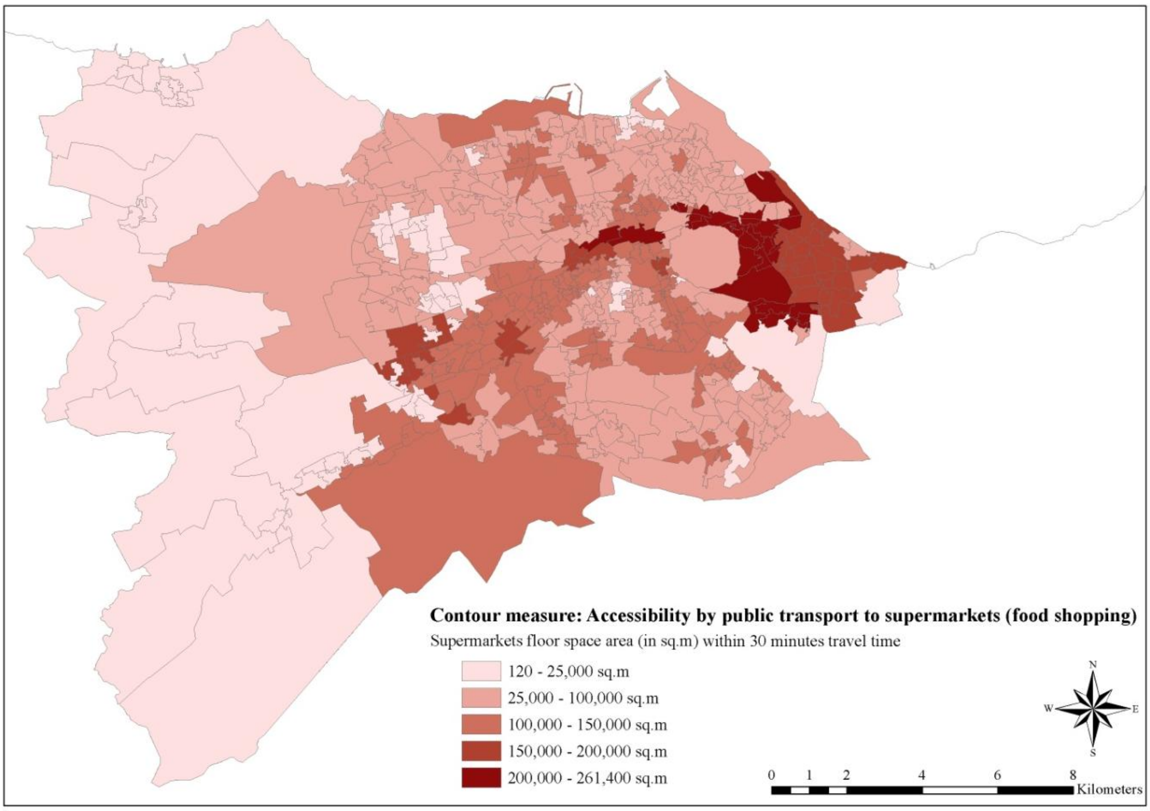

Figure 7.5: Baseline year 2011 scenario – Accessibility by public transport for food shopping (contour measure)

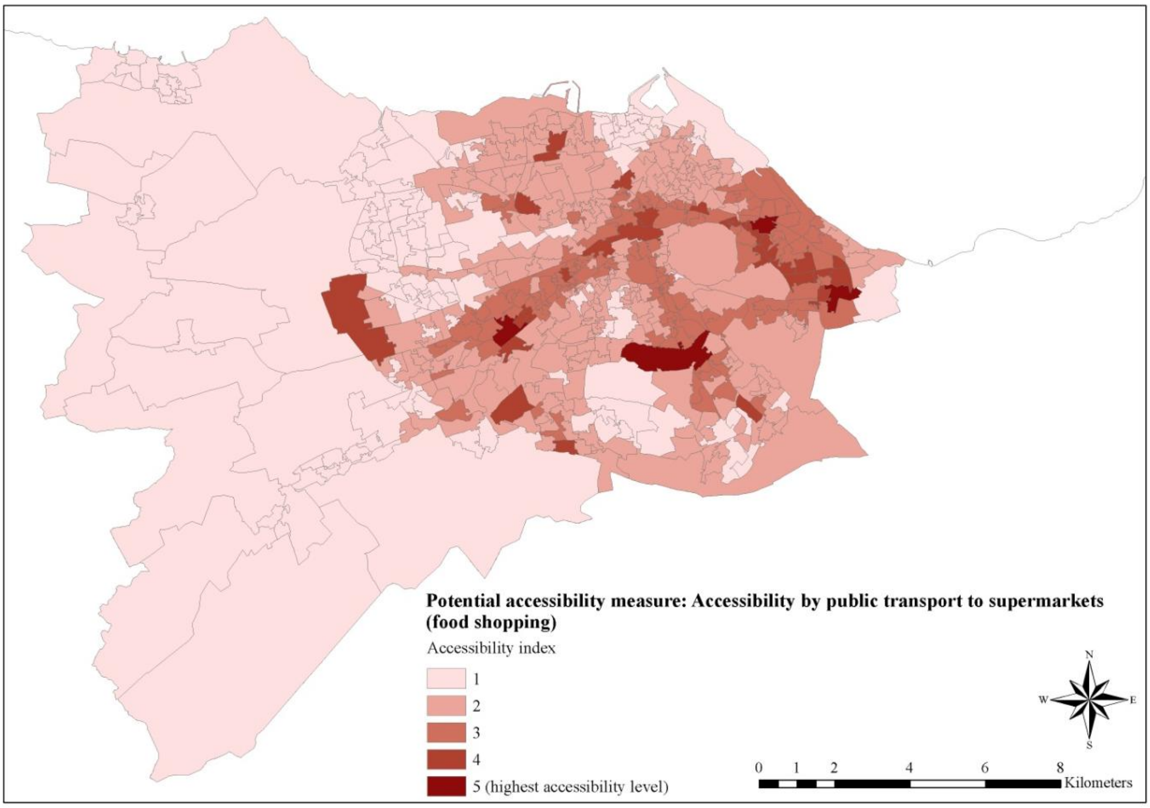

Figure 7.6: Baseline year 2011 scenario – Accessibility by public transport for food shopping (potential accessibility measure)

Table 7.7: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different ranges of supermarkets floor space area within 30 minutes' travel time by public transport

Supermarkets floor space area (in sq.m) within 30 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
120 - 10,000 sq.m	51,828	10%	21,542	5,631	26%
10,000 - 25,000 sq.m	12,994	3%	5,544	2,170	39%
25,000 - 50,000 sq.m	60,834	12%	26,720	7,737	29%
50,000 - 100,000 sq.m	166,711	34%	77,218	31,443	41%
100,000 - 150,000 sq.m	142,629	29%	64,188	29,688	46%
150,000 - 200,000 sq.m	34,543	7%	15,335	6,383	42%
200,000 - 261,400 sq.m	25,644	5%	12,519	5,992	48%

With regard to accessibility to all retail services, in general, including those for food shopping, Figure 7.7 and Figure 7.8 present the modelling results for the contour measure and potential accessibility measure respectively. The contour measure focuses on the total retail floor space area that people of each zone can reach by public transport. In contrast to the analysis of accessibility to food stores, a higher time threshold of 40 minutes has been applied since having a choice of supermarket is not as significant as that choice of other retail services. It is clear that the concentration of shopping streets and many of shopping centres in the area extending from the city centre to the south east has been highly reflected in the accessibility level of its residents with up to 2,933,200 square metres. Using the potential accessibility measure, this area of the city has been also classified as the best performing area. On the other hand, similar to accessibility to food stores, the two measures suggest that the vast majority of the population in the west and north of Edinburgh have the lowest accessibility level to retail services. Similarly to Table 7.7, Table 7.8 focuses on the relationship between the size and percentages of population as well as the number and percentages of households without access to cars or vans with the different ranges of retail floor space area that they can reach within 40 minutes travel time by public transport.

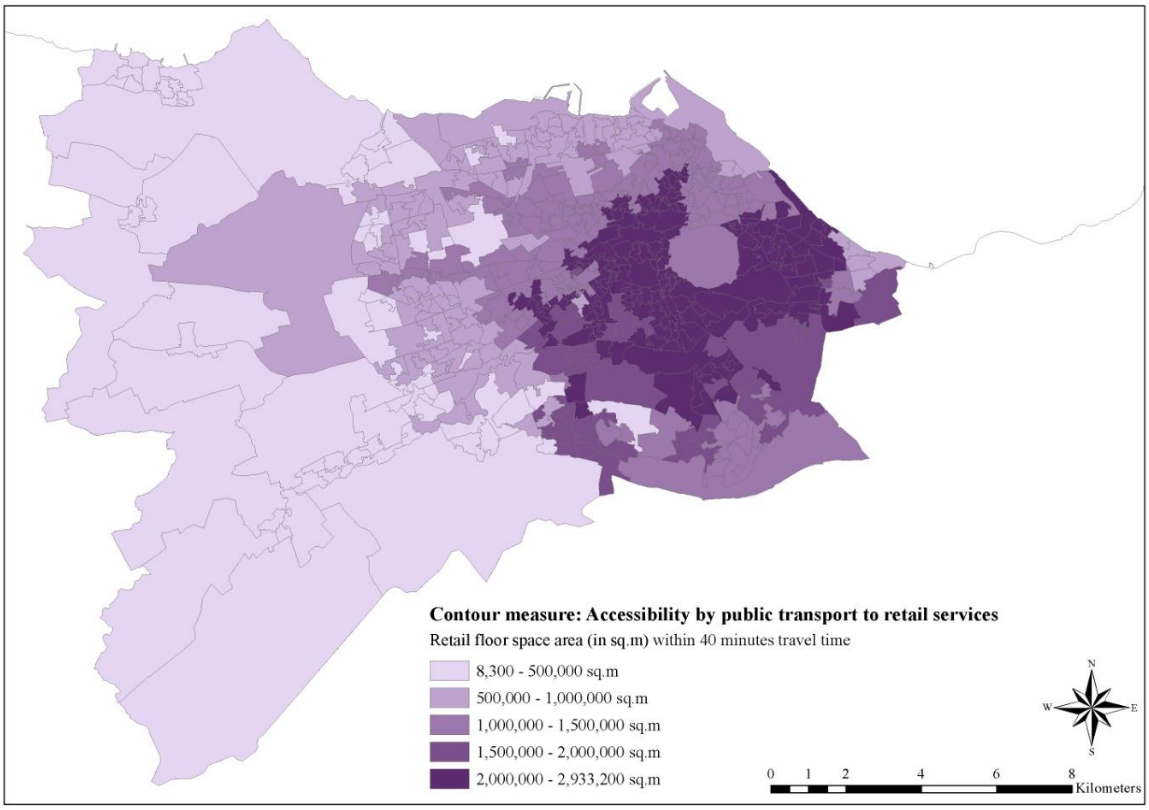

Figure 7.7: Baseline year 2011 scenario – Accessibility by public transport to retail services (contour measure)

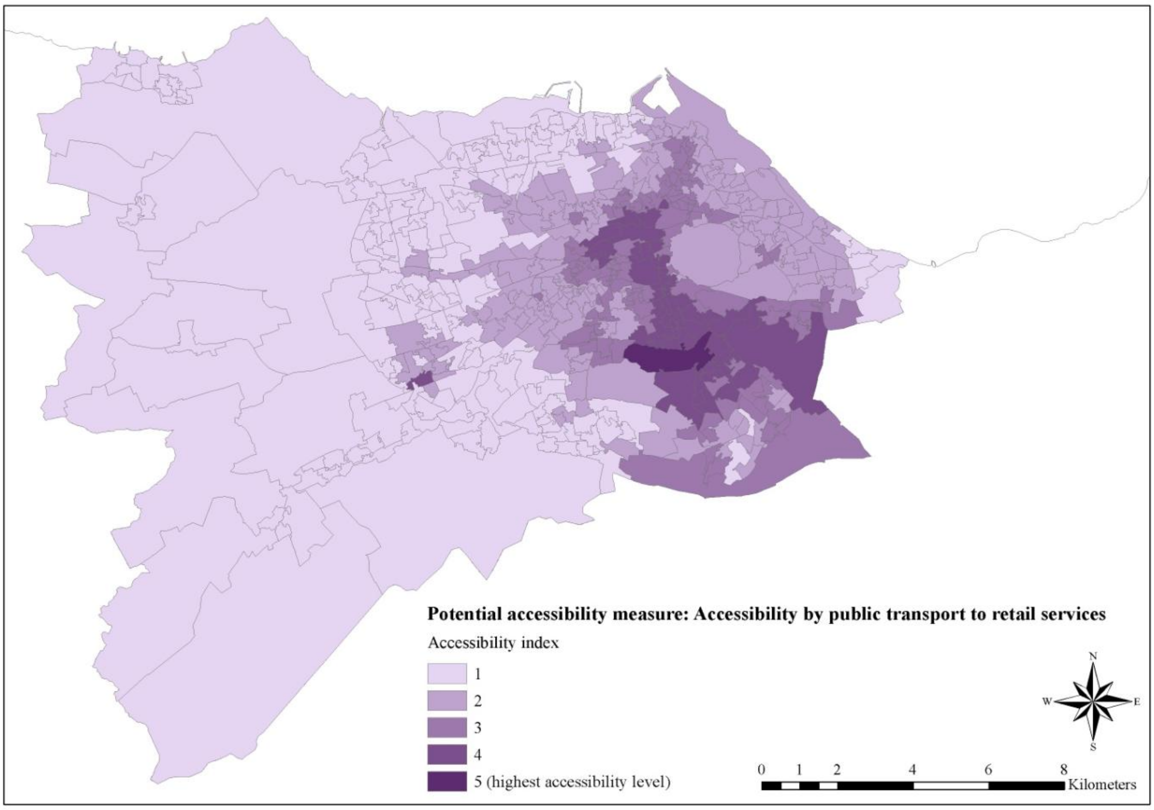

Figure 7.8: Baseline year 2011 scenario – Accessibility by public transport to retail services (potential accessibility measure)

Table 7.8: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different ranges of retail floor space area within 40 minutes' travel time by public transport

Retail floor space area (in sq.m) within 40 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
8,300 - 100,000 sq.m	13,094	2.5%	5,378	925	17%
100,000 - 500,000 sq.m	55,950	11%	23,016	5,925	26%
500,000 - 1,000,000 sq.m	102,978	21%	46,931	16,964	36%
1,000,000 - 1,500,000 sq.m	134,057	27%	66,149	29,267	44%
1,500,000 - 2,000,000 sq.m	42,512	8.5%	18,593	6,495	35%
2,000,000 - 2,500,000 sq.m	98,832	20%	43,358	18,844	43%
2,500,000 - 2,933,200 sq.m	47,760	10%	19,641	10,624	54%

7.2.4 Accessibility to education

For the journey purpose for secondary schools, a cut-off value of 40 minutes has been applied for the contour measure. The result shows that people who live in the central area have the best accessibility level with up to 28 secondary schools (out of a total 37 Council and independent schools across the city) within 40 minutes travel time by public transport (see Figure 7.9). When moving away from the centre, the number of accessible secondary schools within the same maximum travel time has decreased to the range of 2-5 schools only for the population in the most of the Council peripheral zones. Table 7.9 shows that the whole population in Edinburgh can reach at least two secondary schools when they travel for 40 minutes by public transport. Around 59% of the population can reach more than 10 secondary schools and 10% can reach over 20 schools within the same time threshold. The results also prove that the higher the number of schools accessed by public transport, the higher the percentages of households without access to cars or vans.

For the potential accessibility measure, instead of the number of secondary schools, the number of pupils registered in each school in 2009/2010 has been used as a gravity factor to measure the potential interaction between zones. It is interesting that the result presented in Figure 7.10 shows a more balanced distribution of the best performing zones. It illustrates that some of the peripheral zones, which have been classified as some of the worst performing zones using the contour measure analysis, have performed very well – providing their residents with a high level of accessibility compared with others in the central area. It is clear that the large number of pupils in some schools has influenced the result, noticeably increasing the accessibility level of zones where residents can reach these schools in a relatively short time (by public transport) compared with those who travel for the same time to reach other schools where much fewer pupils are registered.

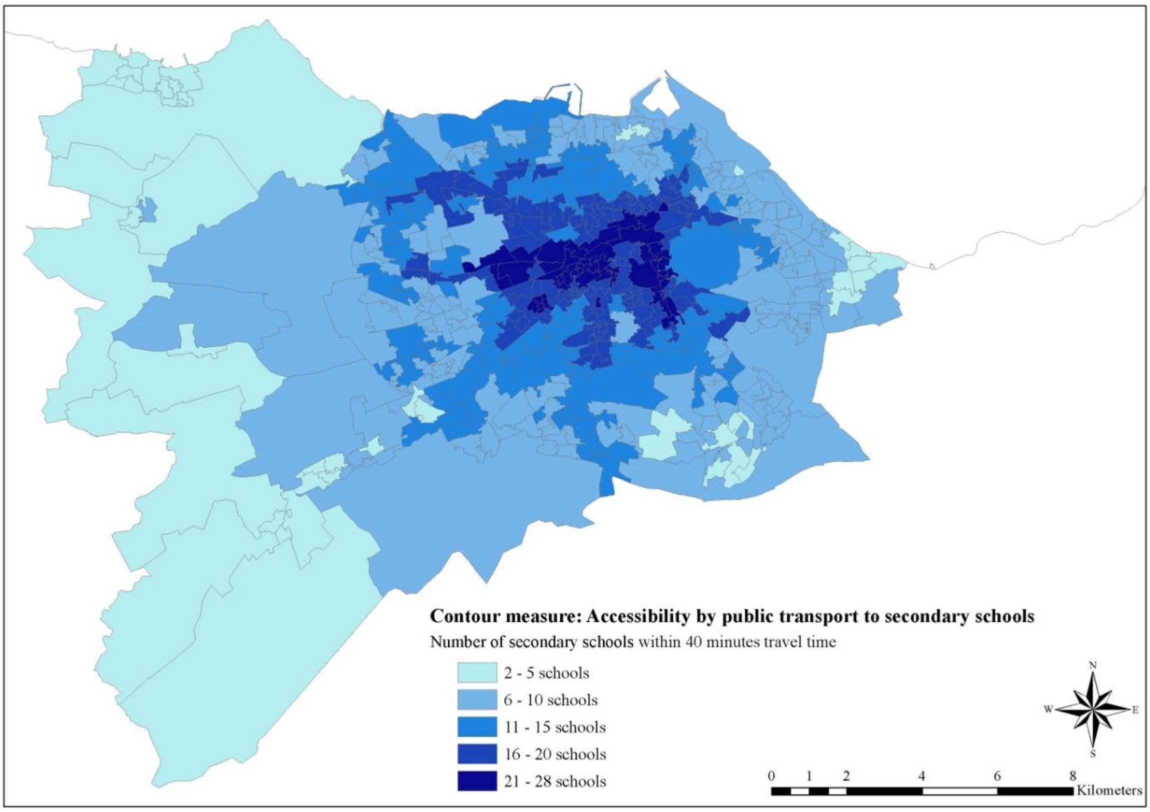

Figure 7.9: Baseline year 2011 scenario – Accessibility by public transport to secondary schools (contour measure)

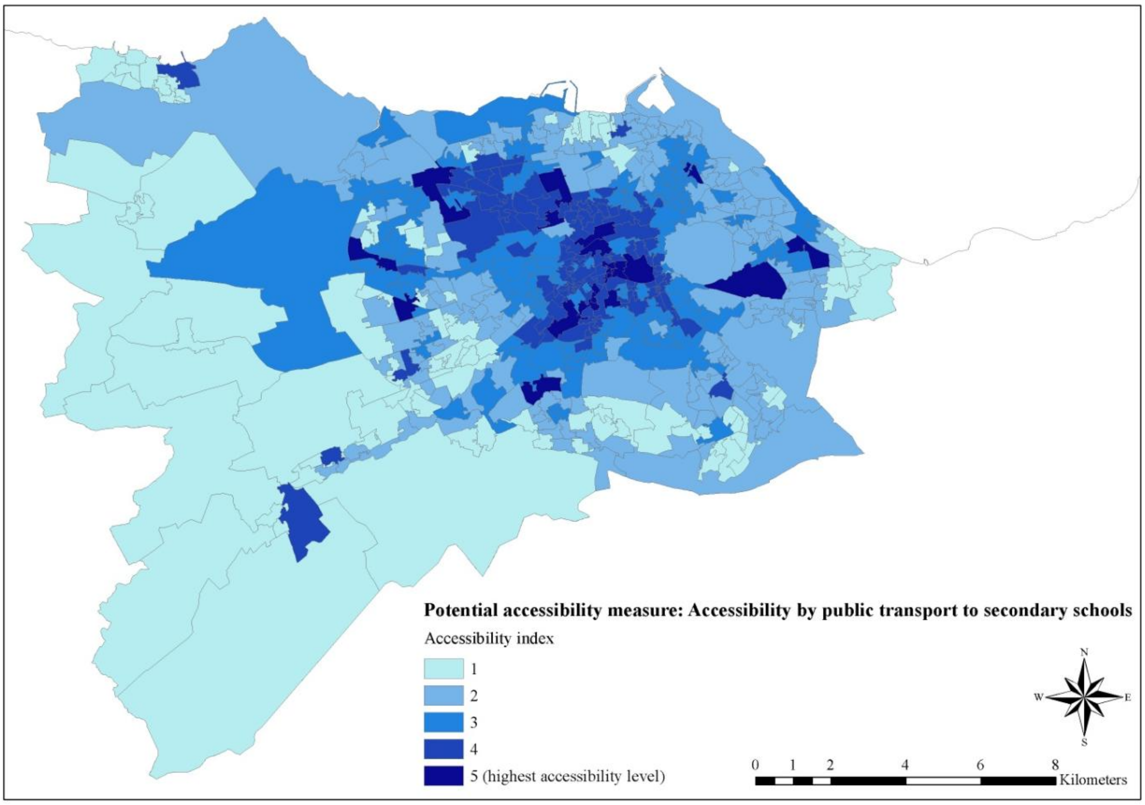

Figure 7.10: Baseline year 2011 scenario – Accessibility by public transport to secondary schools (potential accessibility measure)

Table 7.9: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different numbers of secondary schools within 40 minutes' travel time by public transport

Number of secondary schools within 40 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
2 - 5 schools	40,963	8%	16,871	3,448	20%
6 - 10 schools	161,091	33%	74,130	28,390	38%
11 - 15 schools	129,401	26%	59,016	22,310	38%
16 - 20 schools	113,726	23%	51,212	22,580	44%
21 - 28 schools	50,002	10%	21,837	12,316	56%

The analysis of the current state of accessibility to higher and further education facilities have also recorded two markedly different results. Six educational institutions have been considered in the analysis including: University of Edinburgh (10 scattered sites), Heriot-Watt University, Napier University (3 campuses), Stevenson College, Edinburgh's Telford College and Jewel and Esk Valley College, making a total of 17 sites. Since the Sighthill Campus of Napier University and Stevenson College are based in the same zone, accessibility has been measured to 16 zones only. However, it is important to mention that Queen Margaret University is not considered in the study because it is located just outside the Council's area.

In the case of the contour measure, the accessibility modelling has been carried out using a cut-off travel time value of 60 minutes. The result shows that within this maximum travel time the residents of most of the zones in the central and south east area are able to access all the above institutions' 17 sites by public transport while the residents of some zones in the west and south west of Edinburgh can reach 4 to 5 sites only (see Figure 7.11). Table 7.10 indicates that all 17 sites are accessible to 54% of Edinburgh's population (over 265,000) of which 45% of the households have no access to cars or vans. This percentage continues to decline with the drop in the level of public transport accessibility. Just 15-18% of the households of those which cannot reach more than 10 sites (less than 5% of the whole population) do not have access to private cars.

Similar to the analysis of accessibility to secondary schools, the measurement of potential accessibility to higher and further education facilities takes into account the number of on-campus students registered in Edinburgh's colleges and universities for the academic year 2009/2010. As a result, the zones which are home to a college/ university with a high concentration of students (i.e. Stevenson College and Napier University campus in Sighthill, Telford College in the north waterfront area, Edinburgh University's central campus and Heriot-Watt University campus in Riccarton) have gained the best level of potential accessibility by public transport (see Figure 7.12).

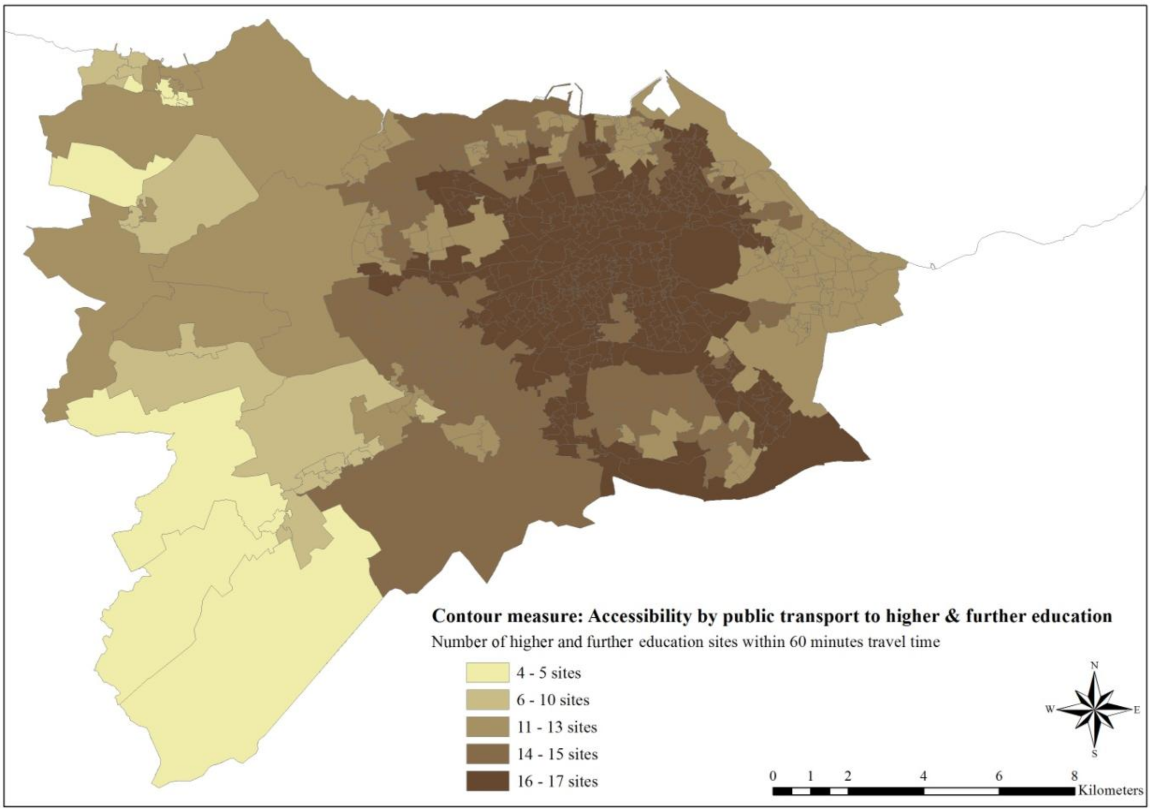

Figure 7.11: Baseline year 2011 scenario – Accessibility by public transport to higher and further education facilities (contour measure)

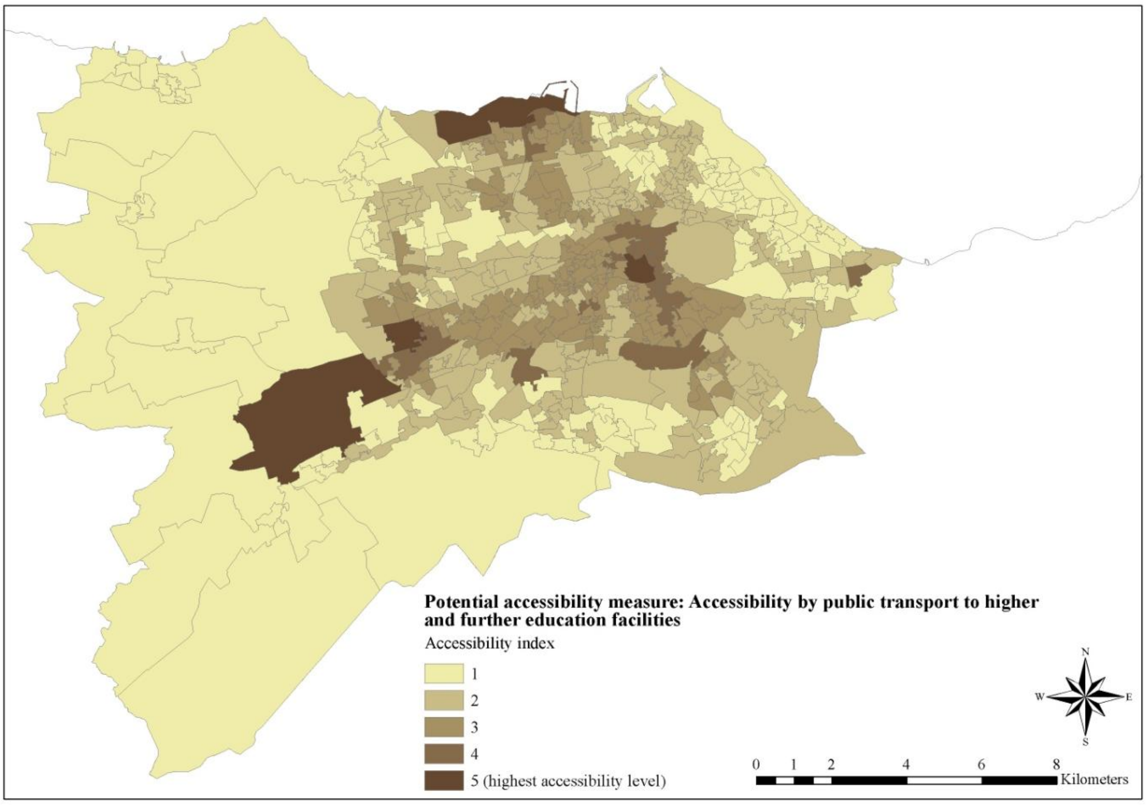

Figure 7.12: Baseline year 2011 scenario – Accessibility by public transport to higher and further education facilities (potential accessibility measure)

Table 7.10: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different numbers of higher and further education facilities within 60 minutes' travel time by public transport

Number of higher and further education sites within 60 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
4 - 5 sites	7,362	1.5%	2,913	423	15%
6 - 10 sites	16,115	3%	6,069	1,075	18%
11 - 13 sites	95,532	19%	43,228	14,362	33%
14 - 15 sites	111,134	22.5%	49,130	17,831	36%
16 - 17 sites	265,040	54%	121,726	55,353	45%

7.2.5 Accessibility to health and medical services

Accessibility to health and medical services has been modelled through two analyses: accessibility to GP services and accessibility to hospitals. The use of a contour measure for measuring accessibility by public transport to GP Practices relies on a cut-off value of 30 minutes which has been defined by DfT (2006, p.65) as the core accessibility indicator for this journey purpose for households without access to a car. The modelling demonstrates that almost all the population of Edinburgh fulfil the criteria of this indicator. The only exception is one zone along the west border of the Council area where the 1021 residents (equivalent to just 0.2% of the population according to the 2011 Census), need to travel for more than 30 minutes by public transport to pursue the closest GP (see Figure 7.13). Just 5% of the households in that zone do not have access to cars or vans (see Table 7.11). However, it is important to mention that this result might not reflect their actual accessibility to a GP since the analysis does not consider the nearby GP practices situated out of Edinburgh's Council area. On the other hand, the result shows that those who live in the centre have the best accessibility level with up to 38 GP practices. Over 81% of the population can reach 4-20 GP practices within 30 minutes. 18% of the households which can reach 1–3 GP practices are without access to cars. This percentage is 33% for 4-10 GPs, 44% for 11-20 GPs, 56% for 21-30 GPs and 66% for 31-38 GPs (see Table 7.11).

For the application of the potential accessibility measure, data obtained from NHS Lothian on the list size in July 2011 for each GP Practice unit in Edinburgh has been used as the attractiveness factor in the Hansen equation to weight the accessibility value. Therefore, the result of the accessibility distribution is very different to the one of the contour measure. Using five indices of accessibility level, the best performing zones are not all in the centre while those with the worst performance are mainly located in the peripheral area, particularly in the west, the south west and the north west of the city (see Figure 7.14).

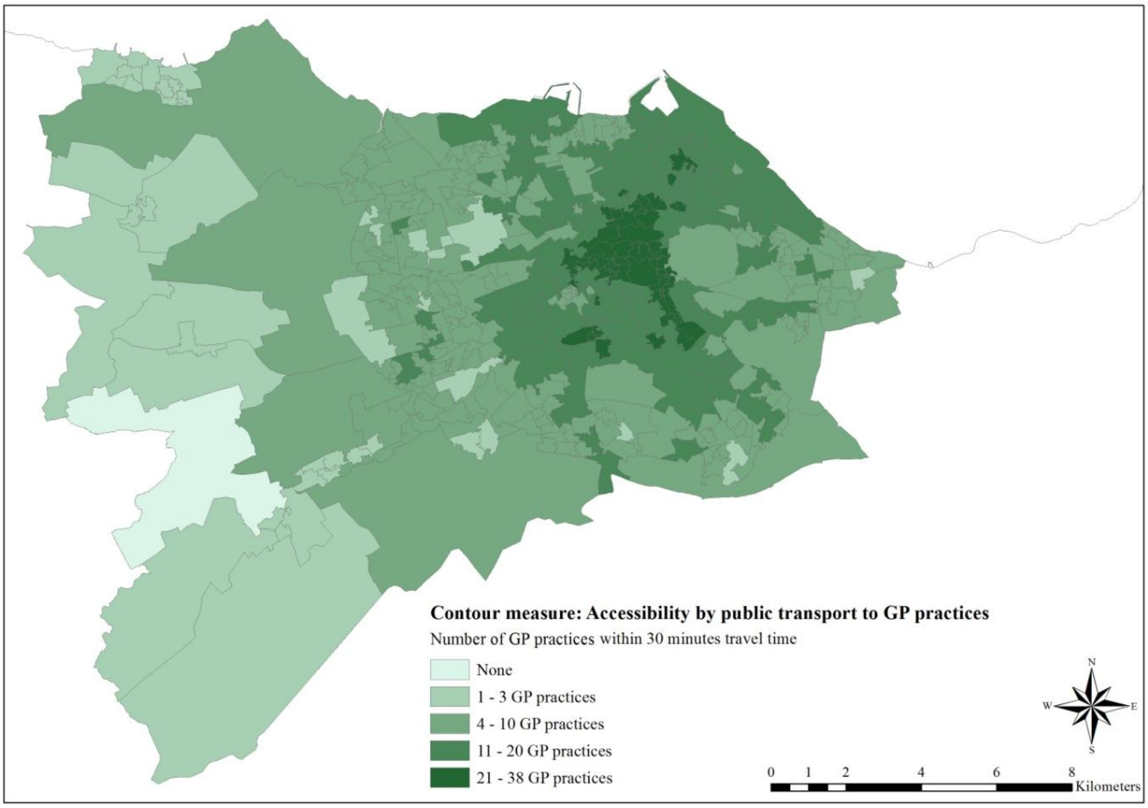

Figure 7.13: Baseline year 2011 scenario – Accessibility by public transport to GP practice services (contour accessibility)

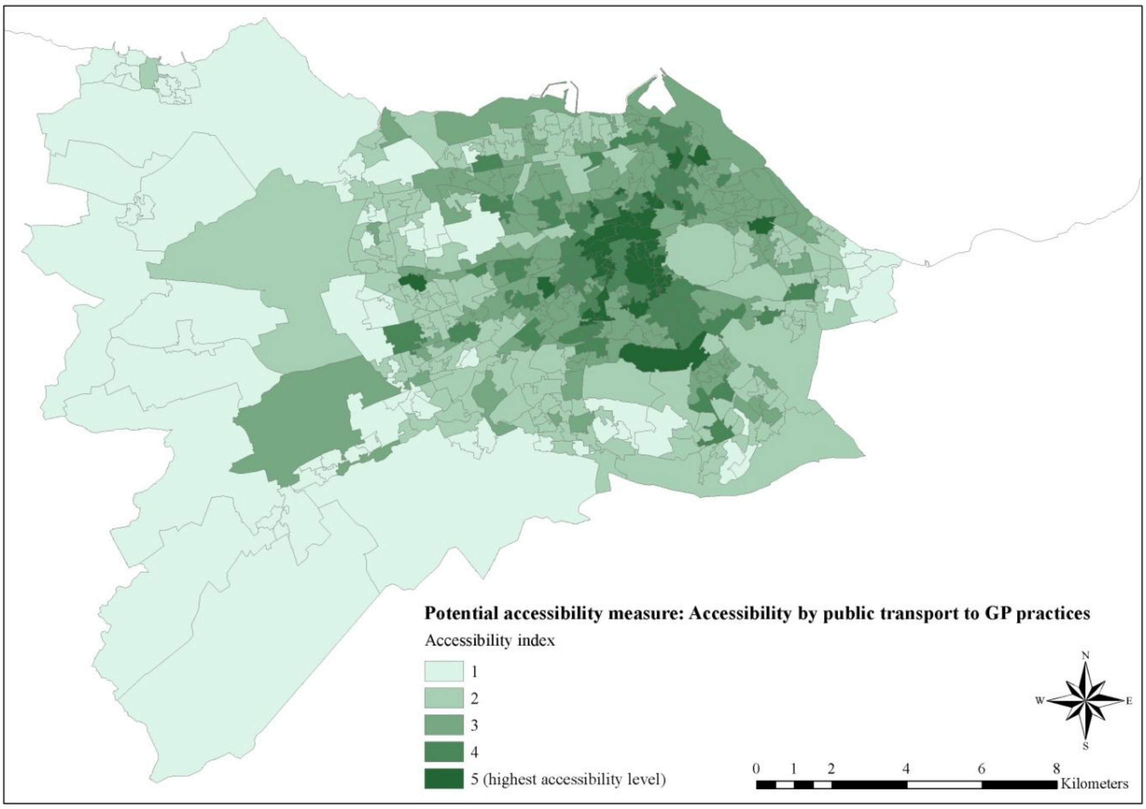

Figure 7.14: Baseline year 2011 scenario – Accessibility by public transport to GP practice services (potential accessibility measure)

Table 7.11: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different numbers of GP practices within 30 minutes' travel time by public transport

Number of GP practices within 30 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
None	1,021	0.2%	369	18	5%
1 - 3 GP practices	35,403	7%	14,629	2,585	18%
4 - 10 GP practices	177,399	36%	77,376	25,515	33%
11 - 20 GP practices	223,735	45.3%	106,154	46,940	44%
21 - 30 GP practices	50,287	10%	21,830	12,208	56%
31 - 38 GP practices	7,338	1.5%	2,708	1,778	66%

With regard to accessibility to hospitals, 15 hospitals within the Council area have been considered in the analysis. However, with two main hospitals only in Edinburgh: Royal Infirmary of Edinburgh and Western General Hospital, it is important to measure accessibility to them without the consideration of the others which are either specialised (e.g. Royal Hospital for Sick Children) or small and private hospitals. Therefore, the contour measure has been applied twice using 60 minutes cut-off value: first for all the hospitals and second taking into account the two main hospitals only. The result of the first application presented in Figure 7.15 illustrates a huge gap between the best and worst performing zones. The population of a large area of Edinburgh, particularly the centre, the south and the east, can access between 11 and 15 hospitals within 60 minutes travel by public transport. Nevertheless, the situation is very different in the west of Edinburgh especially in the south west where the people cannot reach any of these 15 hospitals when they travel by public transport for 60 minutes.

Concerning accessibility to the main hospitals only (see Chapter 6, Figure 6.1 for their locations), the analysis highlights that a number of zones in the west and the south west which are home to around 3% of the population are out of the 60 minutes service area of Royal Infirmary Hospital and Western General Hospital (see Figure 7.16). 14% of the population can reach at least one main hospital while 83% have the two main hospitals within their 60 minutes catchment area. However, just 14% of the households which cannot reach any of the two main hospitals by public transport (for 60 minutes time limit) do not have access to private cars while it is 29% for those which can reach one main hospital only and 42% for those which can reach the two main hospitals (see Table 7.12). Tables 7.13, 7.14 and 7.15 identify the number of zones, the size of population and the percentages of households without access to cars or vans within the service areas of each of the main hospitals for time limits of 30, 40 and 60 minutes respectively. They indicate that Western General Hospital is more accessible by public transport than Royal Infirmary Hospital. The calculation shows that the 30, 40 and 60 minutes service areas of Western General Hospital cover 16%, 45% and 95% of the population respectively while those of Royal Infirmary Hospital cover 12%, 25% and 86% for the same time limits.

For using the potential accessibility measure, SNAPTA takes into account the number of outpatients, day patients, and inpatients registered in 2010 in each of the 15 hospitals. The resulting distribution of spatial accessibility is very different from the distribution using the contour measure (see Figure 7.17). It shows that the residents of the corridor area that extends from the north to the south of Edinburgh linking between the sites of the two main hospitals as well as Lauriston Building, Princess Alexandra Eye Pavilion and Royal Hospital for Sick Children enjoy the highest level of accessibility to hospitals by public transport.

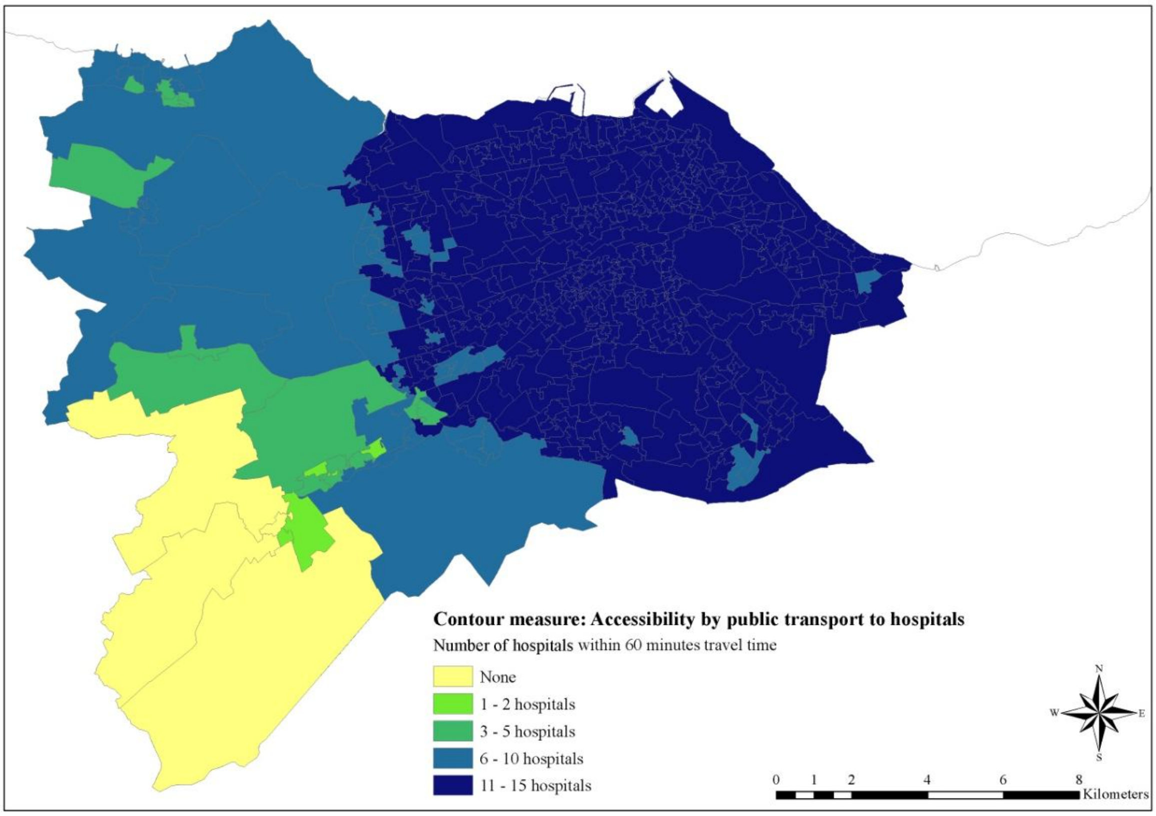

Figure 7.15: Baseline year 2011 scenario – Accessibility by public transport to all the hospitals (contour accessibility)

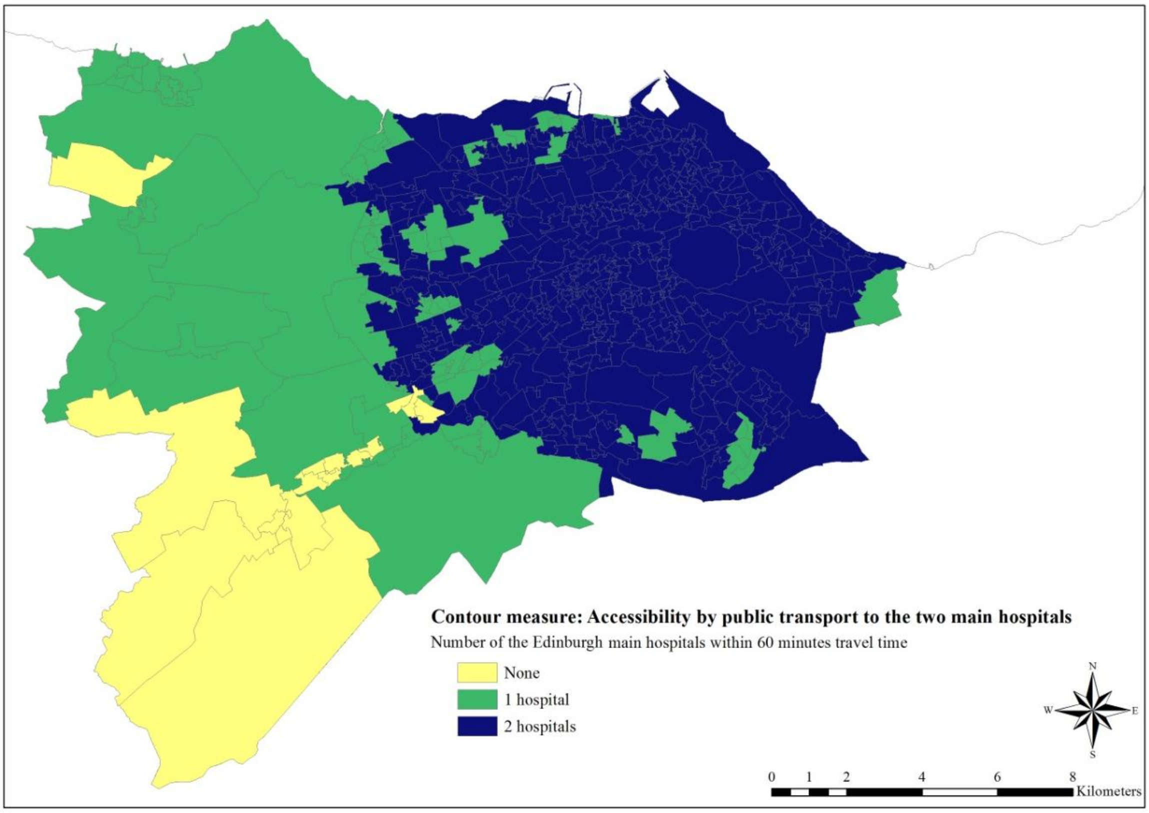

Figure 7.16: Baseline year 2011 scenario – Accessibility by public transport to the two main hospitals (contour accessibility)

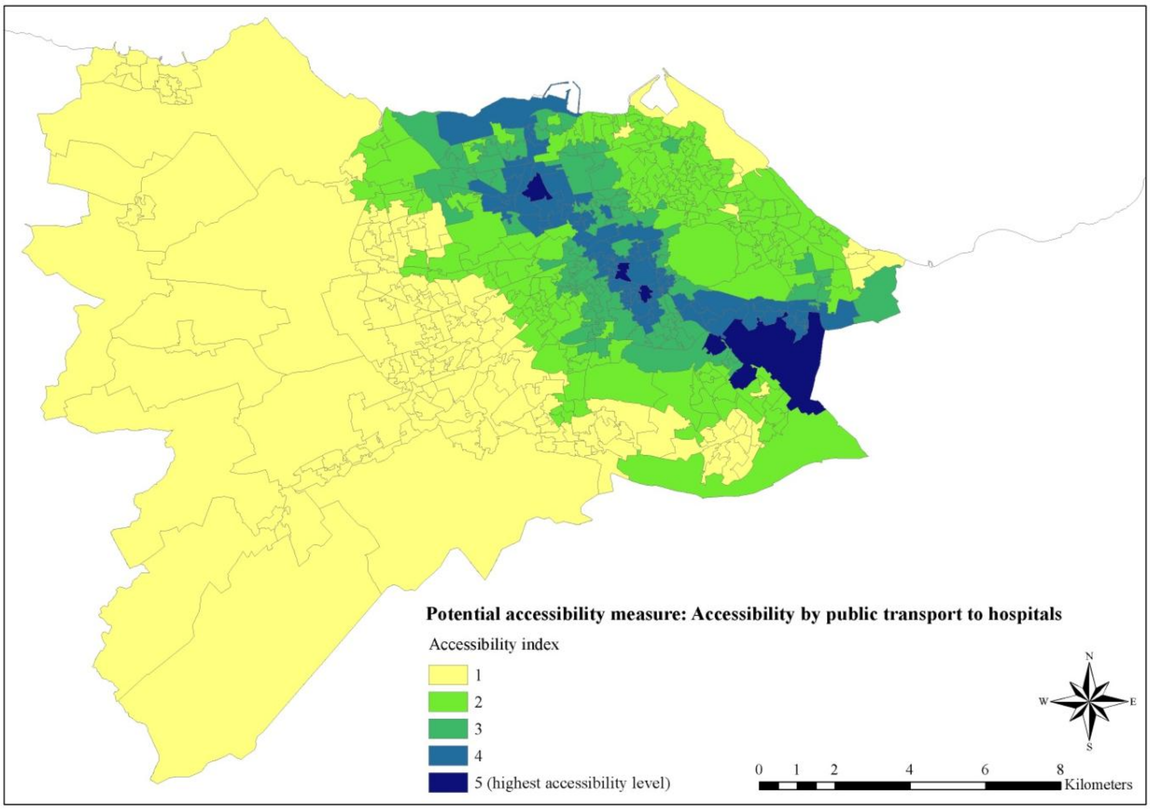

Figure 7.17: Baseline year 2011 scenario – Accessibility by public transport to all the hospitals (potential accessibility measure)

Table 7.12: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach Edinburgh's two main hospitals within 60 minutes' travel time by public transport

Number of the main hospitals within 60 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
None	13,050	3%	5,340	754	14%
One hospital	70,319	14%	29,797	8,694	29%
Two hospitals	411,814	83%	187,929	79,596	42%

Table 7.13: Population and households without access to cars or vans (based on Scotland Census 2011) within 30 minutes' travel time by public transport from the two main hospitals in Edinburgh

Hospital name	Number of zones	Population 2011	% of population	Number of households 2011	Households without access to cars or vans	% of households without access to cars or vans
Royal Infirmary Hospital	67	60,343	12%	25,158	11,944	47%
Western General Hospital	84	80,131	16%	36,528	14,431	40%

Table 7.14: Population and households without access to cars or vans (based on Scotland Census 2011) within 40 minutes' travel time by public transport from the two main hospitals in Edinburgh

Hospital name	Number of zones	Population 2011	% of population	Number of households 2011	Households without access to cars or vans	% of households without access to cars or vans
Royal Infirmary Hospital	140	124,868	25%	52,344	22,029	42%
Western General Hospital	238	223,229	45%	102,797	46,495	45%

Table 7.15: Population and households without access to cars or vans (based on Scotland Census 2011) within 60 minutes' travel time by public transport from the two main hospitals in Edinburgh

Hospital name	Number of zones	Population 2011	% of population	Number of households 2011	Households without access to cars or vans	% of households without access to cars or vans
Royal Infirmary Hospital	468	425,909	86%	192,957	80,492	42%
Western General Hospital	519	468,038	95%	212,698	87,394	41%

7.2.6 Accessibility to leisure and recreational facilities

To assess accessibility to leisure and recreational facilities, the application of SNAPTA takes into account the number and location of a wide range of opportunities across

Edinburgh, using the Ordnance Survey Points of Interest 2007 data (Ordnance Survey, 2007). This includes: theatres and concert halls; museums and art galleries; libraries; cinemas; casinos; country parks; amusement parks and arcades; theme and adventure parks; athletics facilities; bowling facilities; climbing facilities; golf courses and clubs; gymnasiums, sports halls and leisure centres; ice rinks; racecourses and greyhound tracks; shooting facilities; ski slopes; snooker and pool halls; sports grounds, stadia and pitches; squash courts; tennis facilities; swimming pools; and watersports.

Using the cut-off value of 40 minutes, the contour measure clearly shows that the highest accessibility level by public transport to the above leisure facilities is the central area of Edinburgh with up to 812 leisure and recreational activity centres (see Figure 7.18). This number declines radially away from the centre to the peripheral area with a range of 45 - 100 facilities in number of zones in the west of Edinburgh. Linking the ability to access different ranges of these facilities with data on population demonstrates that the vast majority of Edinburgh's population (around 95%) can reach within 40 minutes travel by public transport between 100 and 700 leisure facilities (see Table 7.16). In this part of the population, the percentage of households without access to cars ranges between 31% and 54% that is significantly higher than the percentage for those with generally poor public transport accessibility and who cannot reach more than 100 facilities (17% only). The use of the potential measure also demonstrates that the central area comprises the best performing zones, although the modelling does not illustrate a clear radial decrease in accessibility level from the centre (see Figure 7.19).

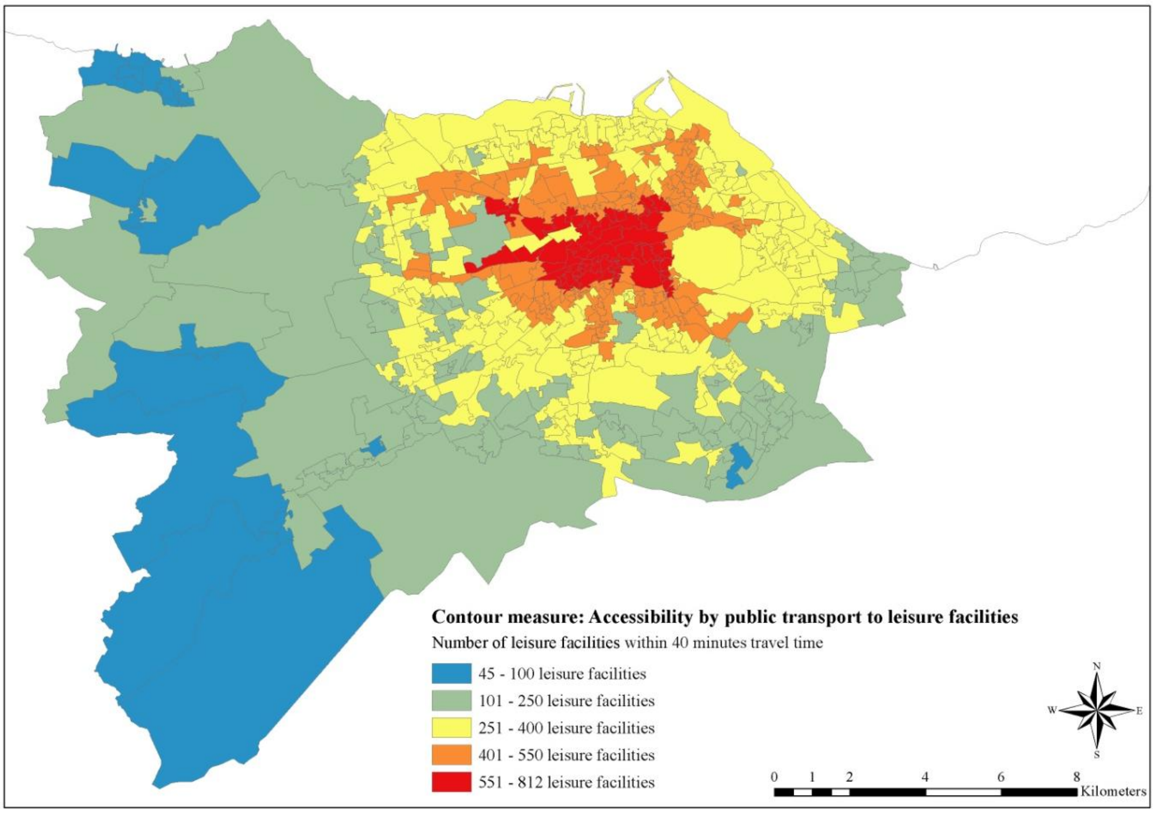

Figure 7.18: Baseline year 2011 scenario – Accessibility by public transport to leisure facilities (contour measure)

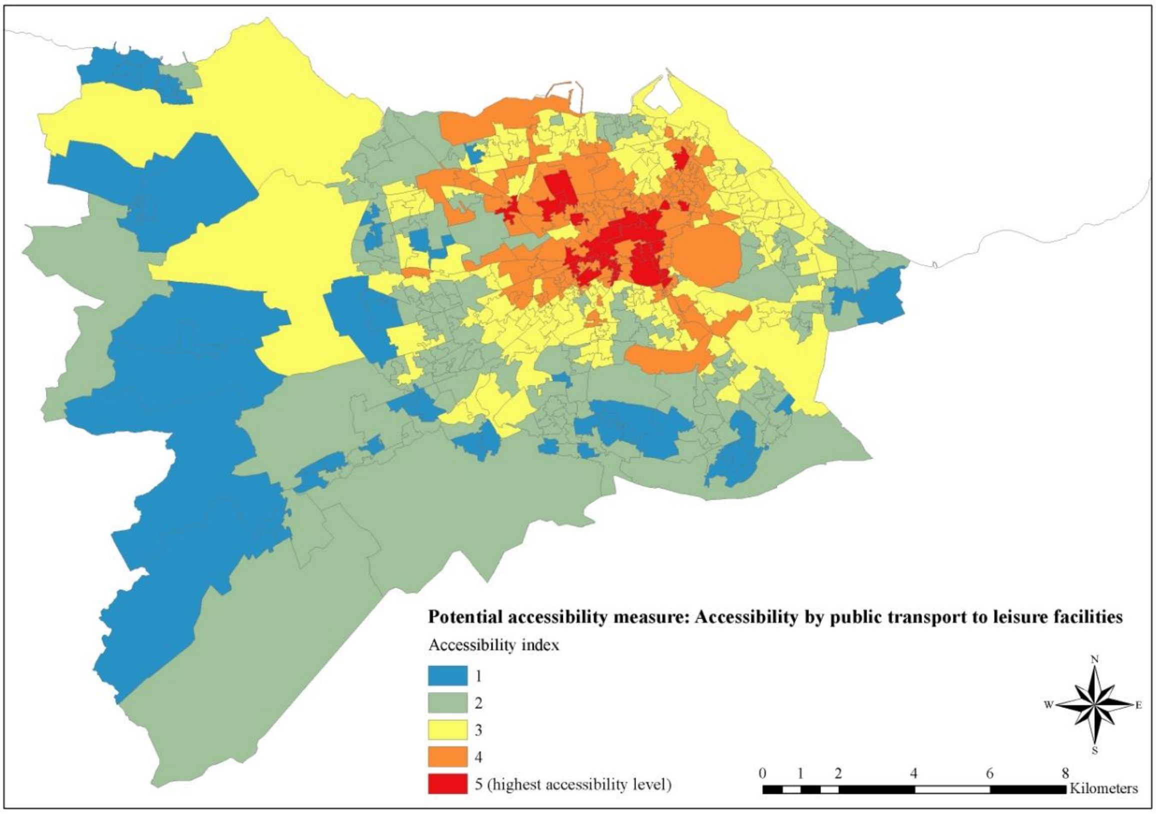

Figure 7.19: Baseline year 2011 scenario – Accessibility by public transport to leisure facilities (potential accessibility measure)

Table 7.16: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to reach different numbers of leisure facilities within 40 minutes' travel time by public transport

Number of leisure facilities within 40 minutes' travel time	Population	Percentage of population	Number of households	Households without access to cars or vans	Percentage of households without access to cars or vans
45 - 100 facilities	17,942	3.6%	7,375	1,276	17%
101 - 250 facilities	100,029	20%	42,120	13,055	31%
251 - 400 facilities	190,167	38.4%	87,539	32,659	37%
401 - 550 facilities	131,642	26.6%	61,954	29,099	47%
551 - 700 facilities	48,286	10%	21,246	11,489	54%
701 - 812 facilities	7,117	1.4%	2,832	1,466	52%

7.2.7 Reflection on Edinburgh transport policy

The above analysis has looked at the base year 2011 state of accessibility by public transport (i.e. local bus network) in Edinburgh for each data zone for a range of trip purposes. Such analysis provides an indication of how well transport and land use are integrated within the Council area. By using the travel time of the shortest public transport journeys, the lowest values indicate the highest degree of integration between land-use and transport because fewer generated minutes and/or lower cost are associated with travel (Halden, 2002).

Since the results of both the travel time measure and the contour measure rely heavily on the coverage of the public transport network, it is not surprising that the zones in the central area have the largest catchments of most of the urban activities by bus services while the zones on the periphery of Edinburgh, particularly in the west and the south west have the smallest catchments. This can be interpreted by the radial pattern of the current bus network and the concentration of jobs and wide range of activities in the central area. New jobs in the city centre will therefore have negative implications for accessibility distribution unless action is taken to enhance public transport from the peripheral areas. In this respect, the analysis findings provide evidence to underline the CEC plan in the new Local Transport Strategy for 2014 - 2019 for supporting orbital bus services, particularly on the city bypass, which appear to be important to improve the accessibility of the population in the peripheral areas and minimise their journey’s time to the centre.

The results of the potential accessibility measure show the interaction between each zone (as a journey origin) and all the others (as potential destinations) unlike the contour measure result which focuses on the opportunities only reachable within a maximum travel time. Given the difference in the distribution of spatial accessibility between the two measures, it becomes clear that, as the potential accessibility measure is not reliant on a specific cut-off value, and considers the influence of distance decay on accessibility (by giving more weight to the closer opportunities compared with those which require people to travel for longer), this has a significant influence on the calculation of accessibility. For example, the residents of two different zones who have access to the same number of job opportunities within the same travel time do not enjoy the same level of accessibility if they can only reach a certain number of these jobs within different travel time ranges. The choice of sensitivity parameter (*β)* value is crucial for reducing the extent to which the differences in travel time affect the obtained accessibility values (see Chapter 5 – Section 5.4 for more explanation). Moreover, the consideration of quantity or size of activity opportunities as an "attractiveness" of destination zones to weight the accessibility score when using the potential measure have also a considerable influence on accessibility values. Considering all the above, the potential accessibility measure shows that accessibility to a particular activity would significantly increase when more of these activities are concentrated on zones easily accessible by public transport. For example, this can be noticed in the case of accessibility to jobs in the zones of West Edinburgh Business Park where a relatively heavy concentration of workplaces and jobs are based in this location.

Taking into account the results of the three measures presented earlier in this chapter, the south west of Edinburgh is, in general, the most disadvantaged area in term of public transport accessibility to urban services, a long way behind the central area, which clearly benefits from the highest level of accessibility. In some cases the accessibility level in the best performing zones can be hundreds of times higher than in the worst performing areas. Therefore, the analysis findings can be used to identify the potential for new public transport route intervention. Figure 7.20 highlights the areas with generally the poorest public transport accessibility. The map also presents a recommended non-radial bus route which provides a service between the residential settlements in these disadvantaged areas (including Dalmeny, Queensferry, Newbridge, Kirkliston, Ratho, Kirknewton and Balerno) and the key employment site of South Gyle. It also allows many interchange points with other bus services running to the city centre, main hospitals and other activities across the city. In order to reach this recommendation for a new bus route, four different maps have been overlapped using GIS: 1) the averages of the shortest public transport journey times between zones (see Subsection 7.2.1), 2) percentages of households without access to cars or vans per zone, 3) locations of the key employment sites, and 4) the current network of local bus routes in Edinburgh. Based on these maps, a number of nodes on the network have been manually identified in order to form the potential corridor of a new non-radial bus route that links the areas with the poorest public transport accessibility levels with main destination sites.

Moreover, the application of SNAPTA can help to ensure that development locations are taken forward with good non-car available access from residential areas. A similar approach to that mentioned above has been used to build arguments in favour of policymaking. The obtained accessibility maps have been overlapped with the locations of the current key destinations as well as the future developments proposed by the Edinburgh City Local Plan. This highlights those areas that provide a sufficient level of access to new businesses and developments. On the other hand, by using the available data on demand as well as population and car ownership per zone, the areas with the relatively greatest needs for developments have been identified. It can be observed from the findings that the development in central Edinburgh would provide better accessibility for the whole population. However, additional increases in the concentration of activities in the centre would result in disadvantages to the spatial equity of the non-car users in the peripheral areas if public transport infrastructure and services remain unchanged.

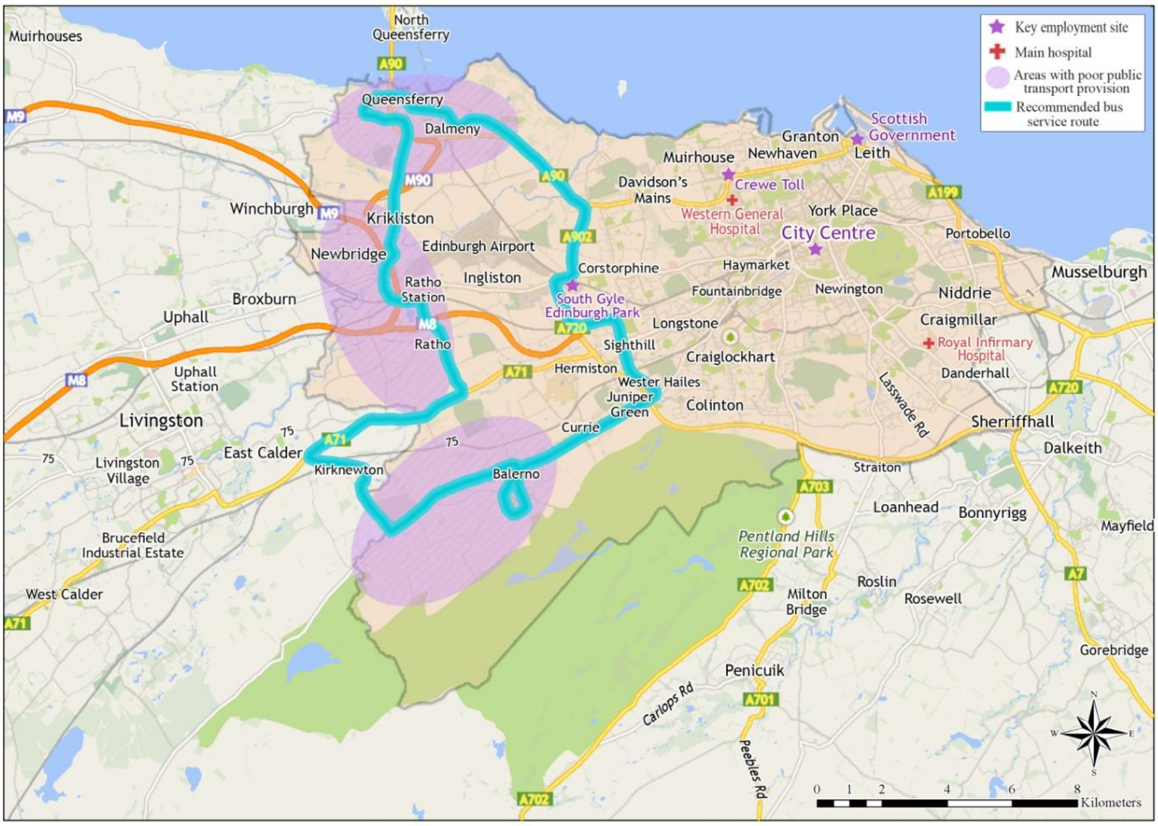

Figure 7.20: Recommendation for a non-radial bus route through the areas with the poorest public transport accessibility in Edinburgh

In this context, the analysis provides a useful evidence for CEC to support the business development in the key development areas of the Waterfront in north Edinburgh (i.e. Granton and Leith) and Newbridge/ Kirkliston/ Ratho in west Edinburgh as well as the additional job opportunities in the Edinburgh Bioquarter, located south of the Edinburgh Royal Infirmary, and the new business park – Shawfair Park – at Sherriffhall in south east Edinburgh (see Chapter 6, Figure 6.1 for their locations). The issue of employment growth and concentrations away from the centre, particularly on the relatively peripheral locations such as South Gyle/ Edinburgh Park has become a significant feature of the city and is likely to continue to grow in importance. This strengthens the argument for the sort of good non-radial/orbital public transport services linking between the east and west of the city in order to balance the city growth, improve access to employment and reduce the spatial inequity in accessibility across the city.

Although accessibility to food stores and retail services is significantly affected by access to a private car, the analysis provides a picture of the 'hotspots' for shopping activity accessed by public transport. It can be used by the Council together with large food retailers to identify locations for new opportunities for development with the maximum accessibility benefit. Proposals for new retail developments in the commercial heart of the city centre and in the Fountainbridge have been introduced in Edinburgh City Local Plan (CEC, 2010c). However the accessibility analysis suggests that the Local Plan proposals for additional shopping floor space and retail units on number of non-central sites including Wester Hailes, Hermiston Gait Centre, Granton Waterfront and Leith Waterfront would have more positive distributional benefits for shopping access for the population in the peripheral areas. The Council also has a number of proposals to rebuild four secondary schools on their existing sites to accommodate more students in order to serve the existing community and new housing (CEC, 2010c). Based on the potential accessibility analysis which considers the number of school students as an attractiveness factor, these replacement schools, particularly the two at Granton Waterfront and Portobello, would improve the potential accessibility of the residents of the zones that have a good connection with these schools by public transport.

In the same context, the Edinburgh City Local Plan's proposals for a series of open space and recreation areas (CEC, 2010c), particularly those that have arisen from the developments planned for Leith Waterfront and Craigmillar/ South East Wedge as well as the master plan for Scotland's National Showground and other related uses (e.g. hotels) in West Edinburgh can bring more balanced distribution of the spatial accessibility to leisure facilities across the city.

Besides the two new GP practices which are planned to be opened in Craigmillar in 2014 and Muirhouse in the north west of Edinburgh in 2016, additional new practices that will be developed according to population needs can improve accessibility. These are likely to be in areas with large planned housing developments proposed in the City of Edinburgh Local Plan, which may require the release of green belt land, and where currently there is no practice provision at all. According to personal communication with NHS Lothian in November 2013, potential areas are: Granton Waterfront, Leith docks area and South West Edinburgh (Edinburgh Garden District and others).

From an equity and social point of view, it is interesting that the results show a clear relationship between the level of public transport provision and accessibility in a zone and the proportion of households without access to cars in that zone. The analysis demonstrates this relationship for accessibility to different types of activities for different time thresholds. However, further research is required looking closely at this issue with focus on accessibility analysis for households living in the poorest zones on generally low incomes and without access (or with limited access) to a car.

The following section looks at the accessibility impact of the completion of the first part of Tram Phase 1a. Furthermore, the chapter continues by examining which combination of the future infrastructure of the tram system and the South Suburban Railway would contribute significantly to improved accessibility and allow more positive distributional benefits for activity opportunities.

7.3 Accessibility Impact of the First Part of Tram Phase 1a (Scenario B – 2014)

This section discusses the influence of the coming part of Tram Phase 1a, which is a single line scheduled to run in summer 2014 providing a service between Edinburgh Airport and York Place in the city centre, on the spatial distribution of accessibility to the urban services and activities mentioned earlier in this chapter. The analysis of public transport accessibility in 2014 after the consideration of the new major transport intervention has been carried out using the travel time measure, the contour measure and the potential accessibility measure. Both the absolute and relative (percentage) changes in the spatial distribution of public transport accessibility to the key services in Edinburgh between the baseline year 2011 scenario and the 2014 scenario has been calculated. In this chapter, only the output maps regarding the relative change in accessibility based on the travel time measure and the contour measure are presented while those of the potential accessibility measure are included in Appendix D.

The analysis demonstrates that, in general, the first part of Tram Phase 1a would have a little contribution to improved accessibility across Edinburgh. The residents of a few zones only located along the Phase 1a route will benefit from running the tram service in terms of reducing travel time and improving spatial accessibility to urban facilities. Regarding the average travel times of all the shortest public transport journeys from each zone to all other zones, the percentage decrease in travel time would be up to 8% for the most advantaged zones while the travel time to the CBD would decrease by up to 36% (around 11 minutes) (see Figures 7.21 and 7.22). The use of the contour and potential accessibility measures demonstrates that for the vast majority of Edinburgh's area, no improvements will be brought to accessibility. However, the calculation of changes in accessibility to job opportunities suggests an increase in number of the jobs that can be reached within 40 minutes travel time by public transport for the most of the zones along the corridor of the new infrastructure. Only two zones in the south of Corstorphine (between Saughton Road and Meadow Place Road) (see Chapter 6, Figure 6.1 for the location) will benefit by over 20% up to 29%, whereby their residents can reach an additional 35,642 job opportunities compared with the baseline year scenario, while most of the other advantaged zones will receive less than 5% improvement in accessibility to jobs (Figure 7.23). The use of the potential accessibility measure suggests a higher percentage increase in the index of accessibility to jobs up to 53% (see Appendix D). Although it is clear that the analysis shows a very geographically limited change in the percentage amount of the floor space area of food stores that can be reached within 30 minutes travel time, this amount would increase to a high level for the residents of two zones in south of Corstorphine by 403% and 6935% as a result of being able to reach an additional 7-8 large supermarkets with around 50,000 square metres overall (see Figure 7.24). The relative change that will be brought to accessibility to retail services (Figure 7.25) and leisure facilities (Figure 7.31) for the 40 minutes cut-off value has a wider geographical scale compared with accessibility for food shopping. Regarding education and health and medical services, the application of SNAPTA shows that, with very few exceptions, the first part of Tram Phase 1a for 2014 will not bring any improvement to the accessibility of population across Edinburgh Council's area (see Figures 7.26, 7.27, 7.28, 7.29 and 7.30). In light of the results discussed above, it appears necessary to carry out an accessibility assessment of the major transport infrastructure which has not been considered by CEC and TIE in the business case for the tram or any relevant study. Therefore, for long-term development, the next section of the chapter looks at the accessibility impact of seven possible scenarios of different combinations of the tram lines and ESSR.

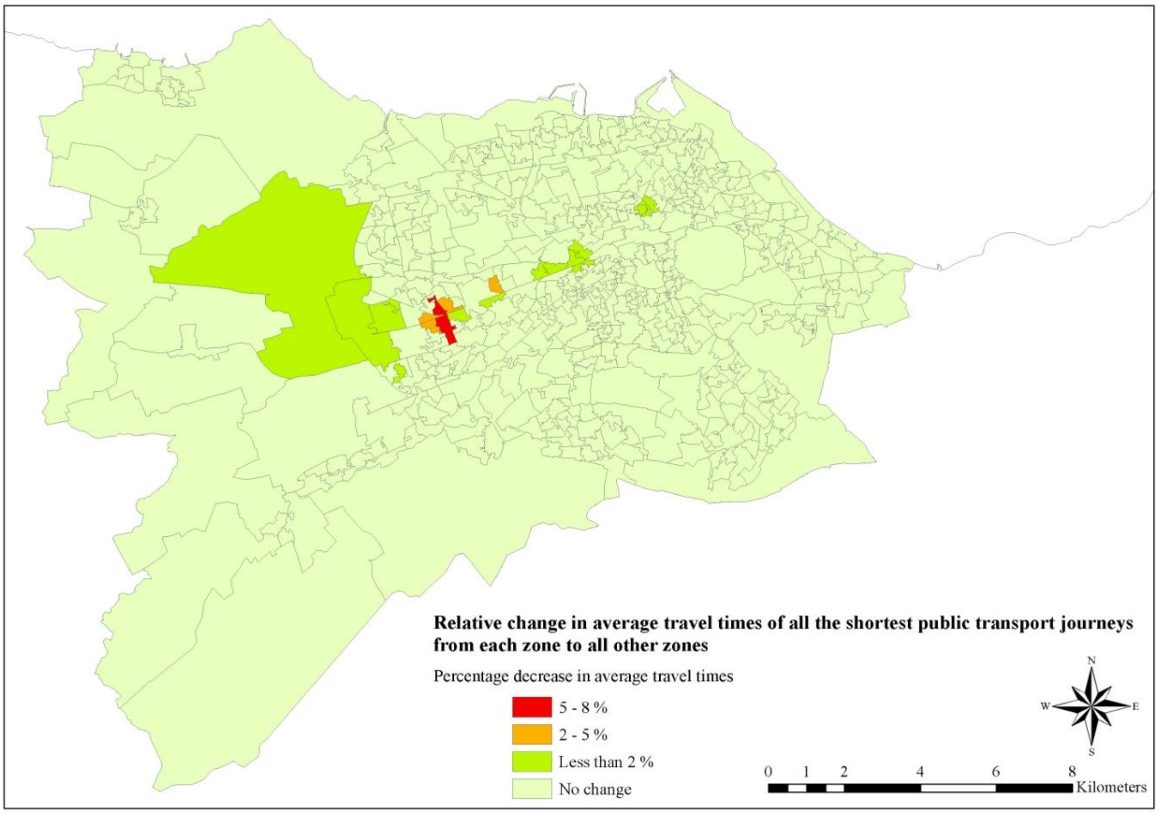

Figure 7.21: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and 2014 scenario

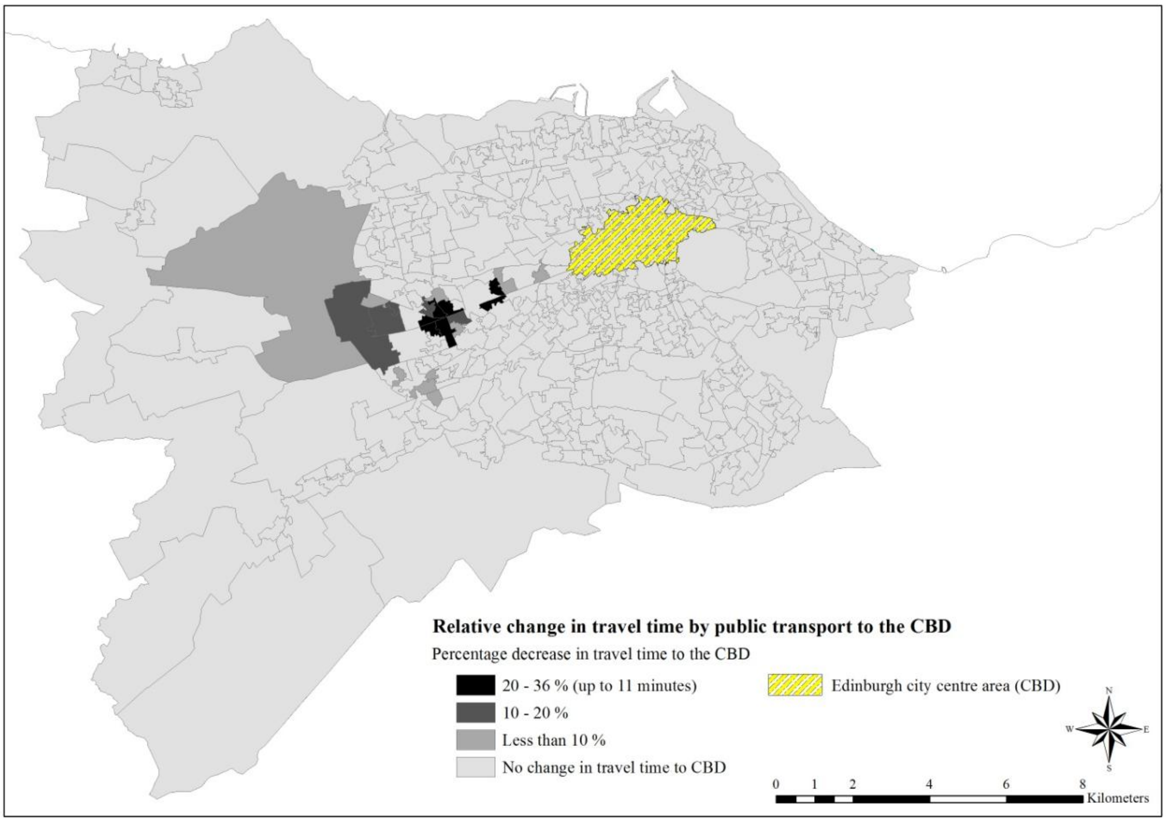

Figure 7.22: Relative change in travel time by public transport to the CBD between the baseline year 2011 scenario and 2014 scenario

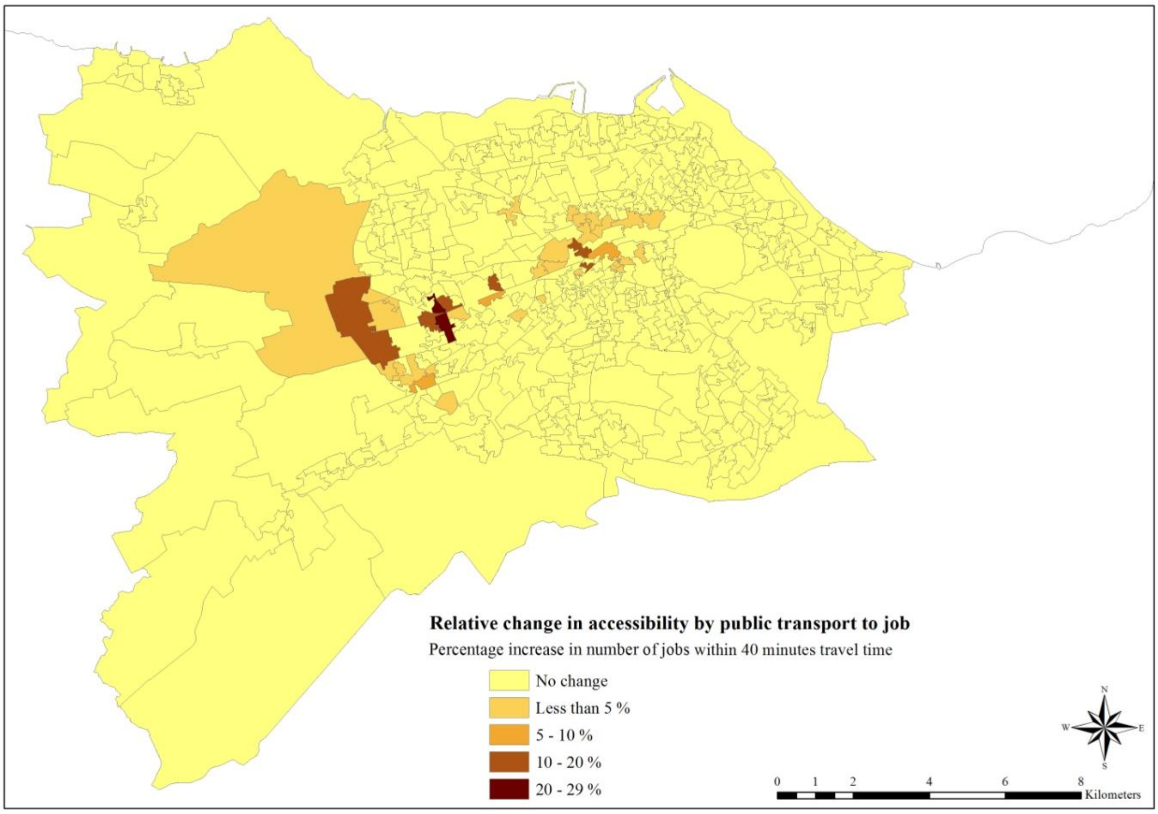

Figure 7.23: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and 2014 scenario, using the contour measure

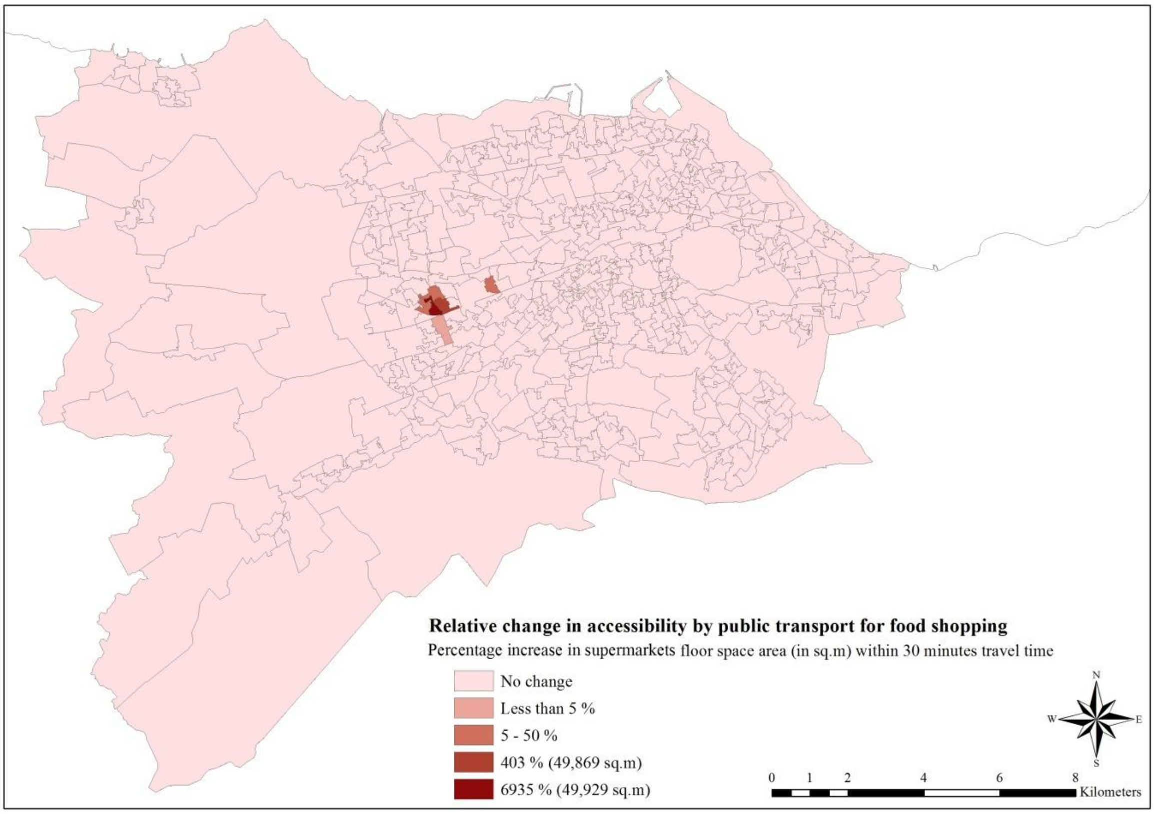

Figure 7.24: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and 2014 scenario, using the contour measure

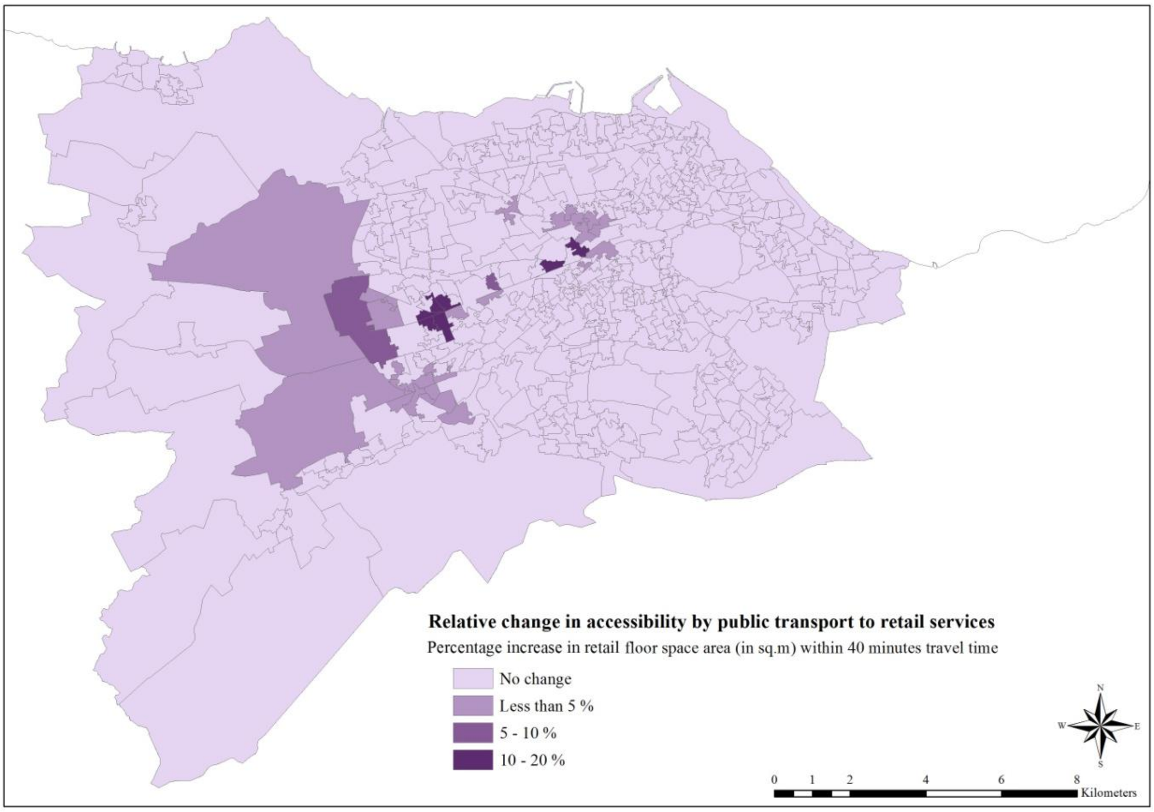

Figure 7.25: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and 2014 scenario, using the contour measure

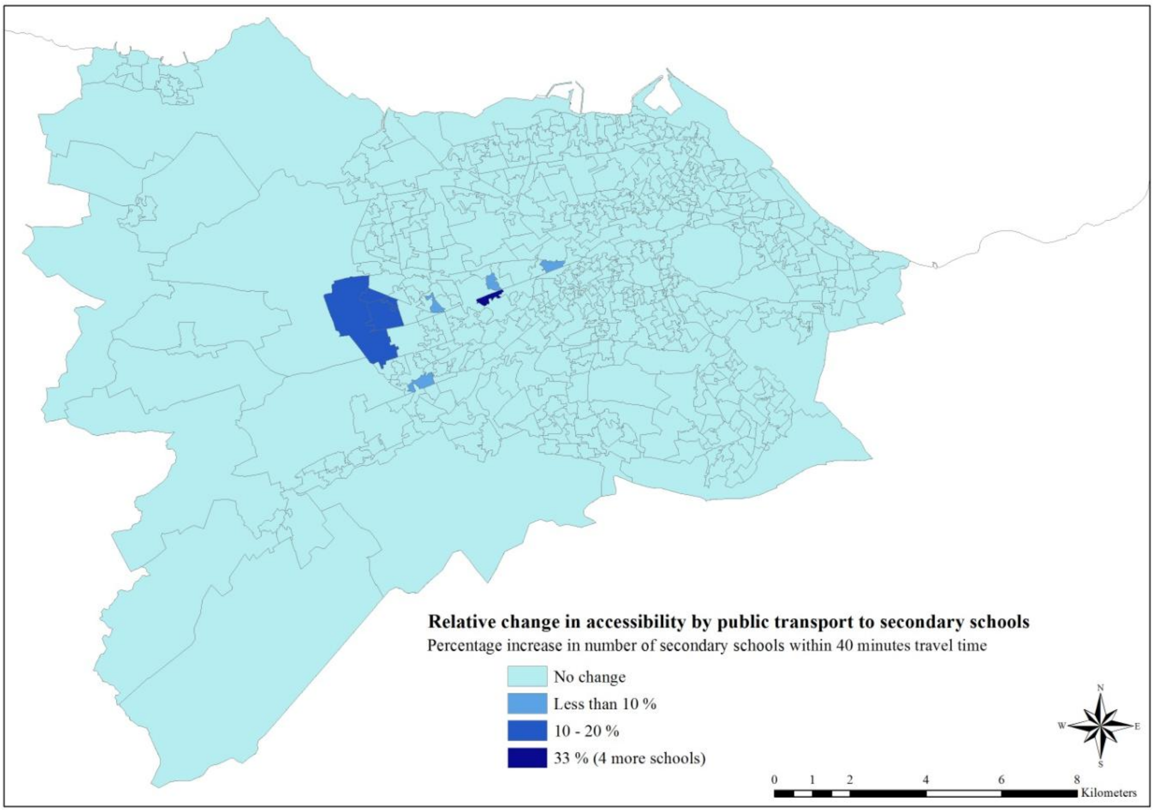

Figure 7.26: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and 2014 scenario, using the contour measure

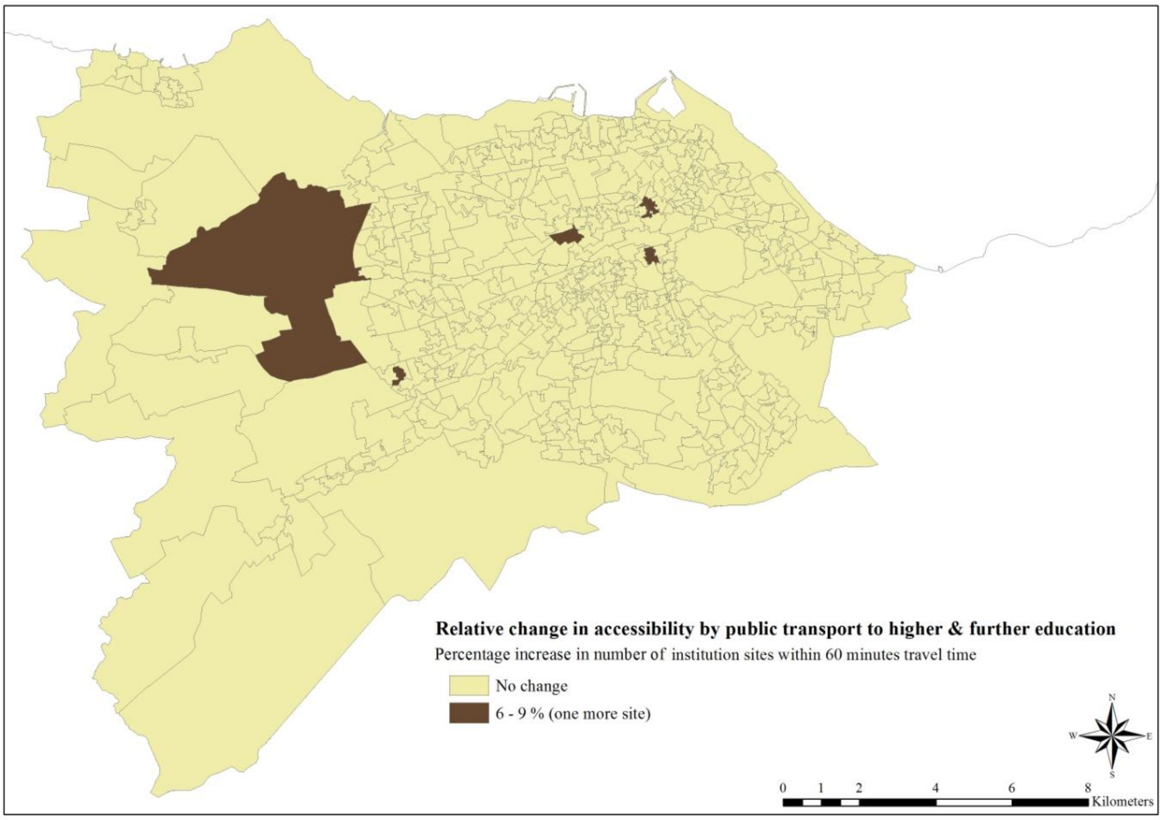

Figure 7.27: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and 2014 scenario, using the contour measure

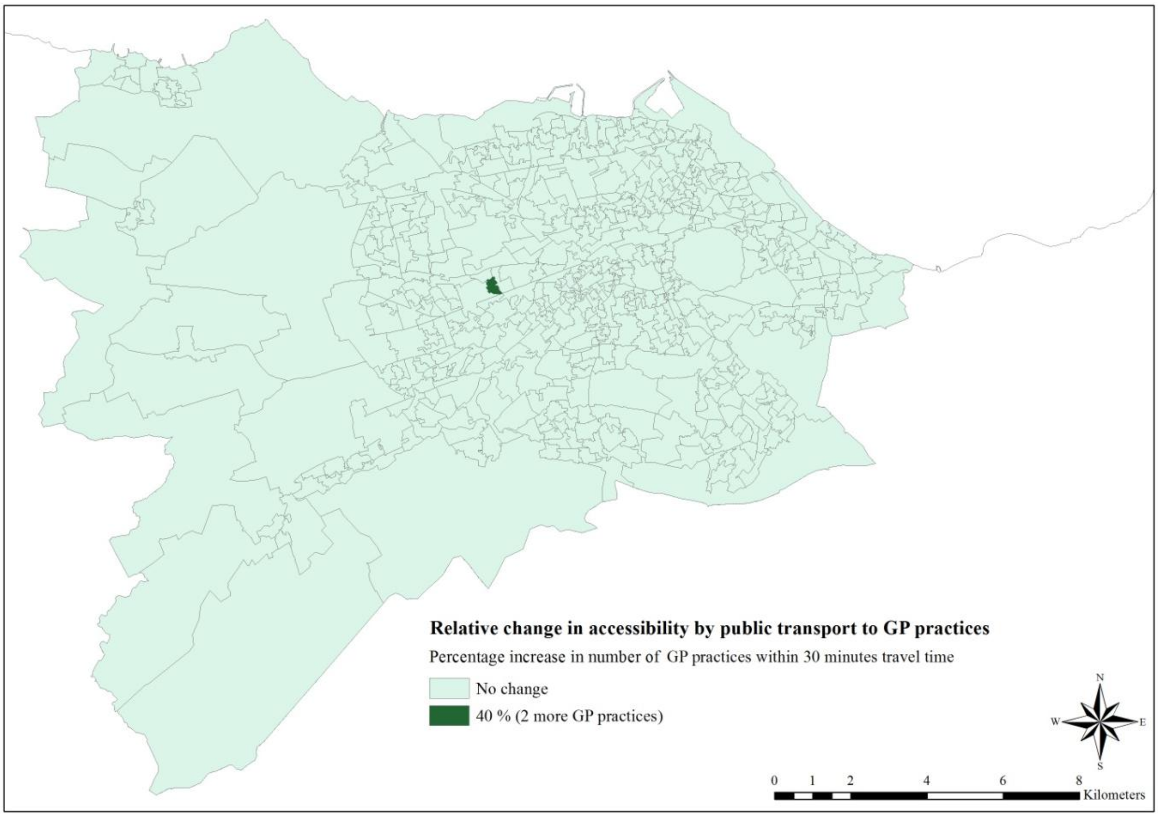

Figure 7.28: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and 2014 scenario, using the contour measure

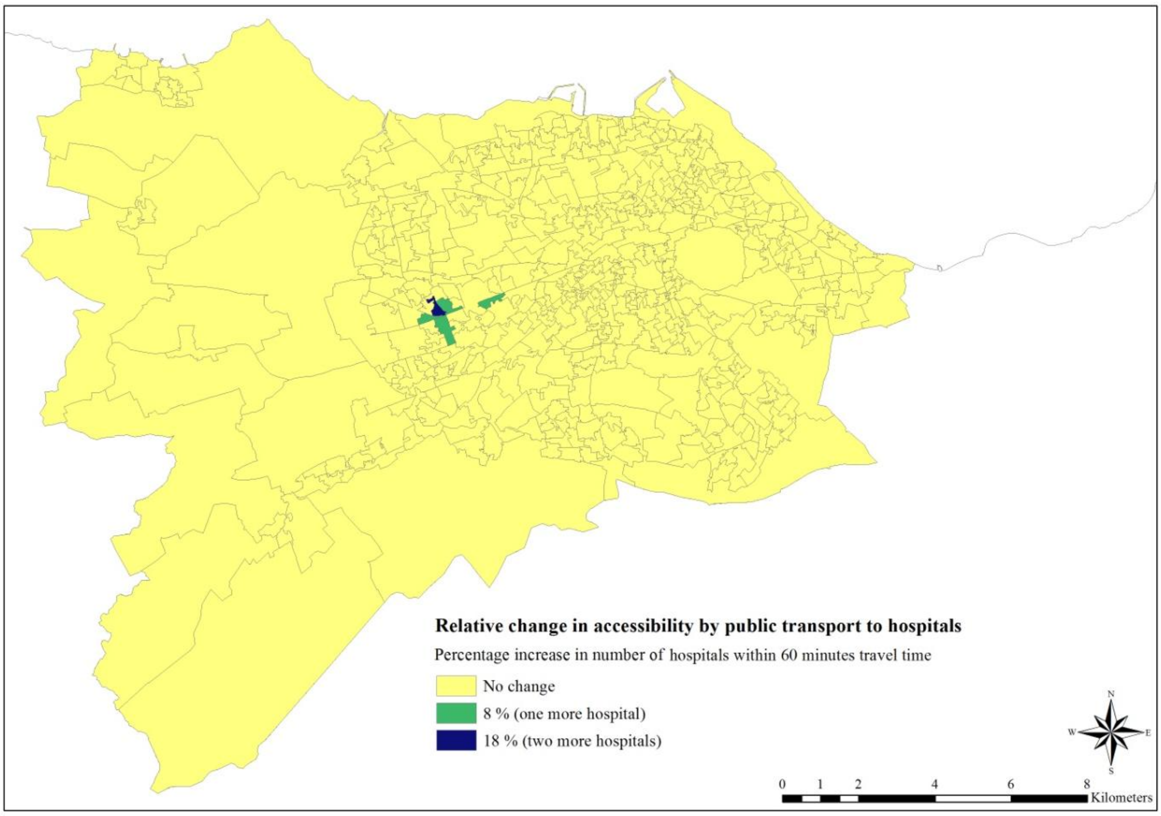

Figure 7.29: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and 2014 scenario, using the contour measure

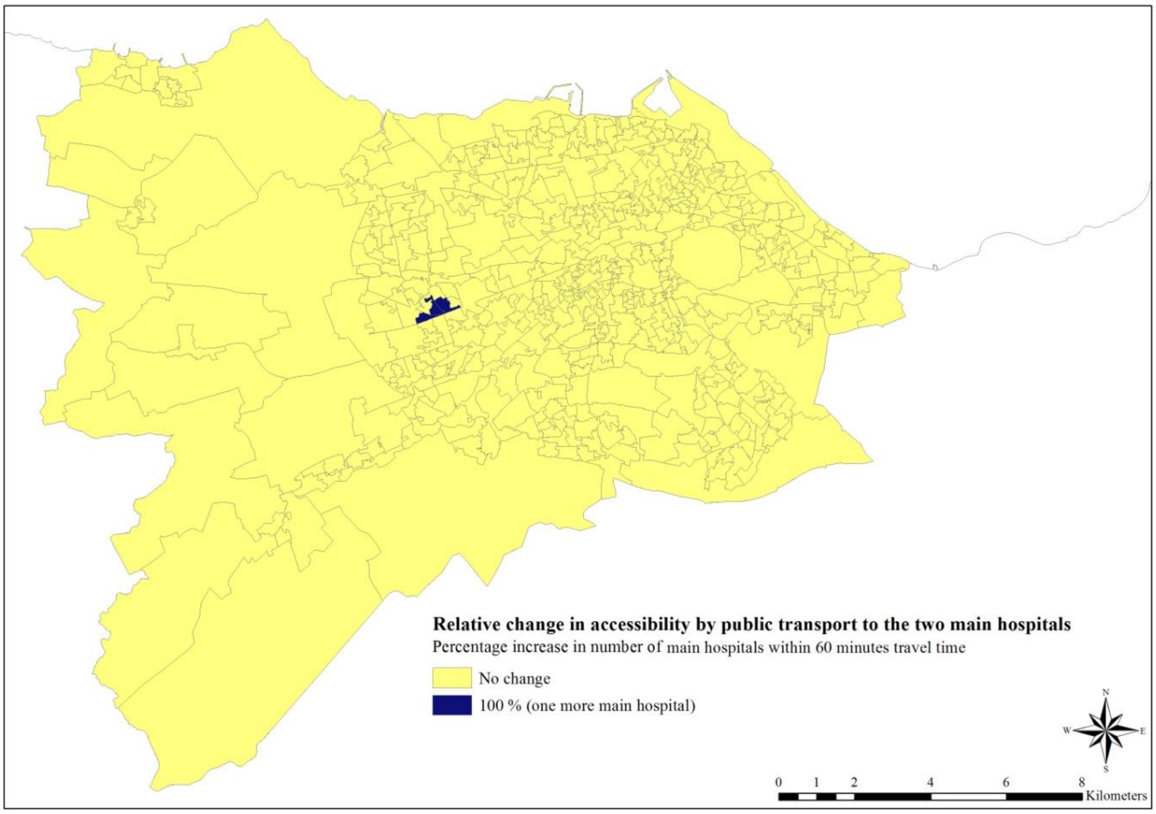

Figure 7.30: Relative change in accessibility by public transport to the two main hospitals between the baseline year 2011 scenario and 2014 scenario, using the contour measure

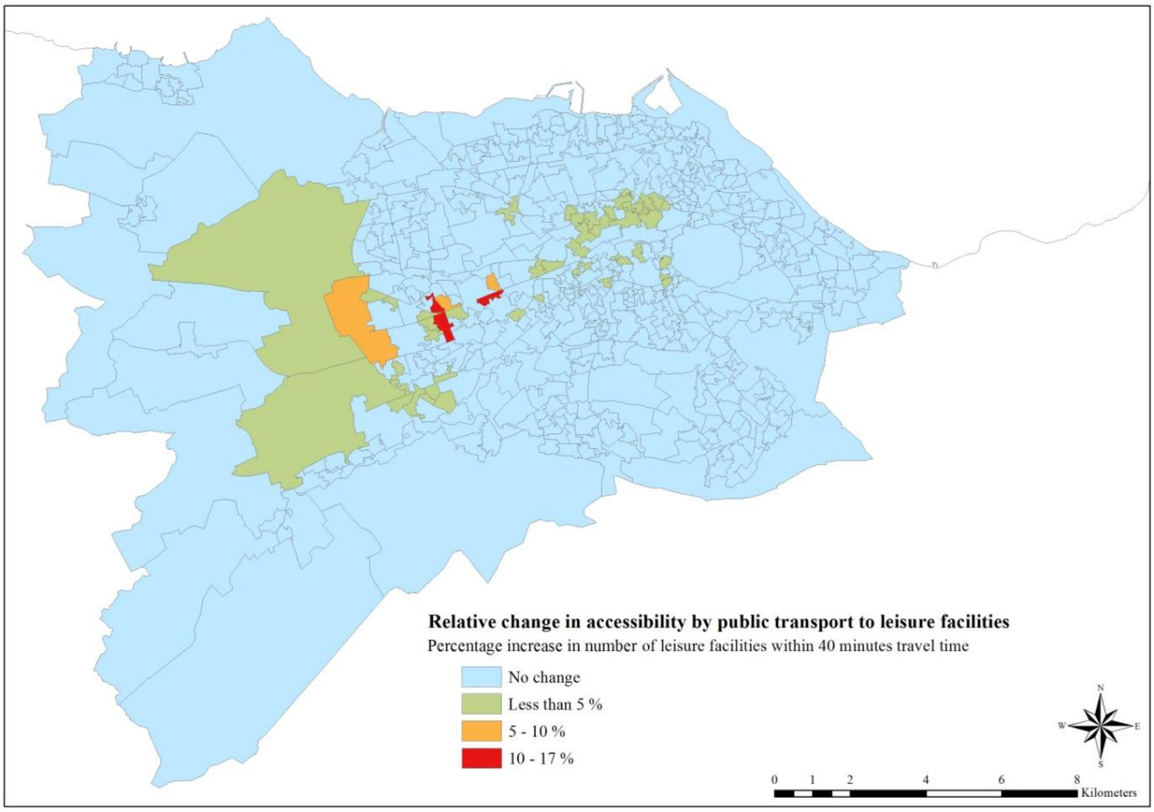

Figure 7.31: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and 2014 scenario, using the contour measure

7.4 Accessibility Analysis of the Future Development Scenarios

This section examines and compares a number of possible scenarios for completing the future phases of the tram and ESSR (see Figure 7.32) in terms of how significant their contribution will be to improved accessibility and distributional benefits for urban services in Edinburgh. The results can form the basis for a later discussion to assist the planners and decision makers of CEC in prioritising transport interventions and arranging developments in locations with high public transport accessibility. Therefore, seven scenarios have been selected for comparison, as follows:

- *Scenario C,* considering the local bus network of the baseline year 2011 and the whole line of Tram Phase 1a (from and to Newhaven and Edinburgh Airport via Haymarket)
- *Scenario D,* considering the local bus network of the baseline year 2011, the whole line of Tram Phase 1a, Tram Phases 1b (from and to Haymarket and Granton Square), and Tram Phase 2 (between Granton Square and Newhaven)
- *Scenario E,* considering the local bus network of the baseline year 2011, the whole line of Tram Phase 1a, and Tram Phase 3 (between Edinburgh Airport and Newbridge)

- *Scenario F*, considering the local bus network of the baseline year 2011, the whole line of Tram Phase 1a, and Tram Line Three (to South East Edinburgh)
- *Scenario G*, considering the local bus network of the baseline year 2011 and all the future tram lines of Edinburgh (i.e. the whole Phase 1a, Phase 1b, Phase2, Phase 3 and Line Three)
- *Scenario H*, considering the local bus network of the baseline year 2011, the whole line of Tram Phase 1a, and ESSR (between Waverley and Niddrie via Haymarket including eight stations)
- *Scenario I*, considering the local bus network of the baseline year 2011, all the tram lines (see Scenario G), and ESSR

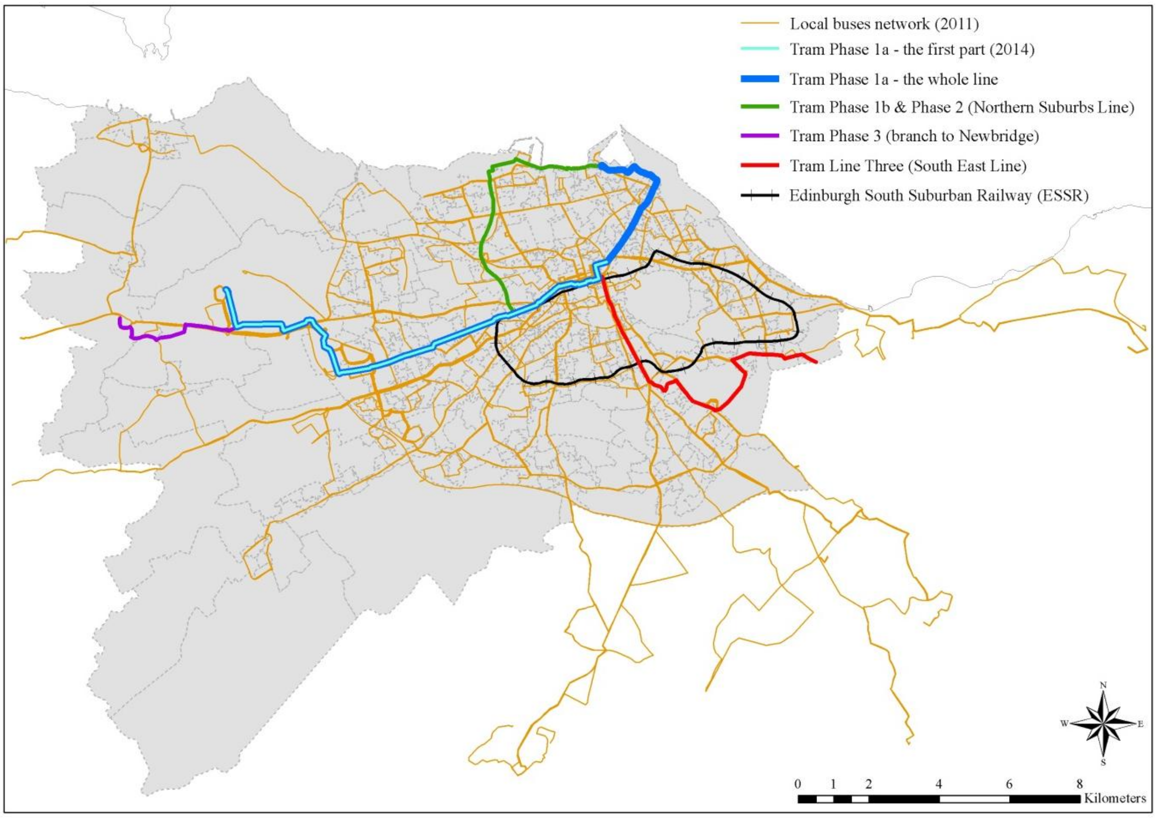

Figure 7.32: The baseline year's bus network and the proposed routes of all the tram lines and ESSR

It can be noticed that the completion of the whole Phase 1a is considered in all the above scenarios. This can be justified by the fact that considerable elements of the work on the second part of Phase 1a (from York place to Newhaven in the north of Edinburgh), including moving utility services out of the tramway route, has been already carried out since the original plan was to run the tram between Edinburgh Airport and Newhaven. With costs having risen leaving the Council with a shortfall of more than £200 million (BBC, 2011c), a decision has been made to cut the line to run only between the airport and York Place. Therefore, resuming the work to complete the second part of Phase 1a after the scheduled completion of the first part in 2014 seems to be much more likely than commencing the construction work of the other tram lines or ESSR (personal communication with CEC).

Due to space constraints, the output maps presented in this section focus only on the relative changes in job accessibility between the baseline year 2011 and the above future scenarios, which have been produced by using the potential accessibility measure. More maps showing the changes in accessibility to the other services and activities are presented in Appendices B, C and D. Regarding Scenario C, Figure 7.34 clearly demonstrates that the completion of the second part of Tram Phase 1a to provide a service along the whole Phase 1a route between Newhaven and Edinburgh Airport will not add a significant improvement to accessibility to jobs compared with the 2014 scenario (Figure 7.33). The accessibility of a few zones only along the route of the second part will increase by less than 5% in general. However, the contour measure has generated less positive findings suggesting that the increase in the number of reachable jobs within 40 minutes travel time will be geographically limited to two zones only by up to 5% (see Appendix C). Similarly, for the other services and activities, the analysis does not indicate any significant change that might be brought to their accessibility. Moreover, in some cases (e.g. accessibility to the main hospitals), the results suggest that the completion of the second part of Phase 1a will not have any influence on spatial accessibility at all.

The analysis demonstrates that the application of Scenario D which considers the completion of the whole Tram Phase 1a together with Phase 1b and Phase 2, forming a circuit in the north of Edinburgh (see Figure 7.32), will improve the level of job accessibility of the residents in a large part of the north suburbs by up to 25% (Figure 7.35). However, the maximum accessibility improvement (54%) will be still limited to few zones on the route of Phase 1a. Despite the variety between activities in the geographical scale of the accessibility impact of Scenario D, the potential accessibility measure shows that the accessibility level to the other services will also increase by up to 36% for food shopping and retail services, 16% for secondary schools, 23% for higher and further education facilities, 14% for GP practices, 43% for hospitals, and 24% for leisure facilities compared with the baseline year (see the relevant maps in Appendix D). It can be identified that the Northern Suburbs Line in Scenario D will not bring any improvement to accessibility to hospitals compared with Scenarios B and C. Interestingly, the project will lead to a higher level of public transport accessibility (by up to 5%) in some peripheral zones in the west of Edinburgh for leisure and higher and further education destinations. The calculation of the accessibility change for food shopping based on the contour measure, has produced another interesting finding indicating that the residents of a number of zones in the central area (in Haymarket) will be able to reach more than 32,000 extra square metres of supermarket floor space (compared with Scenarios B and C) within 30 minutes travel time which will increase their accessibility level by up to 114% (see Appendix C).

The accessibility analysis of Scenario E, which considers Tram Phase 3 as well as the completion of the whole Tram Phase 1a, demonstrates that Phase 3 – a small branch from Ingliston Park and Ride (south of the airport) to Newbridge North – will unsurprisingly make a very limited contribution to improved accessibility. Comparisons of the accessibility impact between Scenario C and Scenario E for different activity opportunities (see Figures 7.34 and 7.36 for job accessibility) show a relatively small difference. Tram Phase 3 will improve the accessibility of only one or two zones in Newbridge to jobs, retail, secondary schools and leisure facilities by up to 5% while the implementation of this infrastructure will not cause any change in accessibility to food stores, GP practices, hospitals and higher and further education facilities (see the maps in Appendices C and D).

The implementation of Scenario F which takes into account Tram Line Three together with the whole Phase 1a produces more significant consequences for future accessibility in Edinburgh. According to Figure 7.37 for percentage change in job accessibility, a considerable area in the south east of Edinburgh will benefit from the accessibility impact of Line Three by up to 5% with the exception of one zone only which will receive an increase in the accessibility index by up to 25%. Moreover, the result illustrates that the accessibility of two zones in Ratho (west of Edinburgh) will increase by up to 5% as well identifying that Line Three will have a more positive influence on job accessibility in the west of Edinburgh than Phase 3. The contour measure suggests that Line Three will generate a considerable increase (by up to 20%) in the number of job opportunities accessed by public transport within 40 minutes travel time. This will allow the residents of the most advantaged zones in the south east to reach over 12,000 additional jobs (up to 12,480 jobs) based in 131-141 workplaces (see the maps Appendix C). The most noticeable change has been identified in the spatial distribution of hospital accessibility in the east and south east of Edinburgh. It highlights an important increase in the accessibility index of up to approximately 242% influenced by the improvement brought by running Tram Line Three to the connection (i.e. travel time saving) with the Royal Infirmary hospital, which holds the highest level of attractiveness of the Edinburgh hospitals to the weighted accessibility values. Although no change will be brought to the amount of accessible supermarkets floor space from the south east for the 30 minutes cut-off time, the results demonstrate an increase of up to 25% (equivalent to an increase of about 372,500 square metres) in the floor space area of the retail services that can be reached within 40 minutes. The introduction of Line Three will also have a significant impact on the accessibility level in this part of the city to secondary schools (up to 20%) and leisure facilities (up to 17%) for a maximum travel time of 40 minutes (see the maps Appendices C and D). As for GP practices and higher and further education facilities, according to the contour measure, Line Three will barely make any difference to their accessibility for time limits of 30 and 60 minutes respectively while the gravity-based measure shows an improvement of up to 5% in a number of zones in south east Edinburgh.

Since Scenario G considers the completion of all the tram lines and phases included in Scenarios C, D, E and F, logically its accessibility impact is larger than the other above scenarios of tram combinations. The accessibility analysis indicates that the greatest benefits are recorded on the corridors of the new transport infrastructure in the west, north and the south east. The introduction of all the tram lines will bring about a reduction of up to 9% in the average travel times of the shortest public transport journeys from the zones in these areas to the others. The area along Phase 1a obtains the highest time saving to the city centre (up to 11 minutes) which is equivalent to an increase in accessibility of 20-36% (see the maps Appendix B). The map for relative change in accessibility to jobs (Figure 7,38) using the potential accessibility measure illustrates that a large part of Edinburgh will have better access to jobs by at least 5% compared with the baseline year 2011 scenario. A few zones will benefit the most from the future infrastructure with an increase of 25–54%. These percentage changes are smaller in the contour measure results when the travel time limit is fixed at 40 minutes, recording a maximum growth of 20-29% with an increase in the number of accessible jobs by up to 36,031 jobs.

Similarly to Scenario F, Scenario G will significantly raise the level of accessibility to hospitals (by up to 242% using the potential accessibility measure) in the south east and east of Edinburgh while no significant change will occur in the north of the city. The accessibility distribution of the other services and activities is also clearly affected by the introduction of the entire tram network, receiving different levels of relative changes particularly in the west, north and the south east of Edinburgh. Using the potential accessibility measure, the future infrastructure will bring accessibility improvements to the west of Edinburgh on the corridor of Phase 1a (with an increase of up to 36% for food shopping and retail services, 16% for secondary schools, 23% for higher and further education, 14% for GP practices and 24% for leisure facilities), the north (with an increase of up to 15% for food shopping and retail services, 10% for secondary schools, 8% for GP practices, 10% for higher and further education and 15% for leisure facilities) and the south east (with an increase of up to 36% for food shopping and retail services, 10% for secondary schools, 8% for GP practices, 10% for higher and further education and 15% for leisure facilities). Within a time limit of 30 minutes, a small geographical area extending from the corridor of Tram Phase 1a in the west to Haymarket in the city centre will obtain a considerable increase (of up to approximately 50,000 square metres) in the accessible floor space area of food stores, while the residents of only a few scattered zones will have access to higher number of GP practices with up to two practices (equivalent to an increase in accessibility of up to about 40%). On the other hand, the influence will be greater for the 40 minutes time limit. The residents of some zones on the corridor of Phase 1a and in the south east will be able to reach between 100,500 and 372,575 additional square metres of retail services (equivalent to an increase in accessibility of 13-25%), between 20 to 61 extra leisure facilities (equivalent to an increase of 10-17%) and up to 4 more secondary schools (equivalent to an increase of 10-33%) (see the relevant maps in Appendices C and D). With a time limit fixed at 60 minutes, which is a relatively high threshold for the dimension of this study area, it is not surprising that the accessibility benefits obtained at the local level are quite limited, since it was already possible in the baseline year 2011 scenario to reach most of activity opportunities of Edinburgh Council's area within 60 minutes travel time**.** In this respect, the greatest change in accessibility to hospitals and higher and further education facilities located within 60 minutes is recorded in a very small number of zones with an increase of one accessible site only for higher and further education and one or two sites for hospitals (with increases of 6-9% and 8-18% respectively). By comparison with Scenario B it can be observed that apart from the first part of Tram Phase 1a (between the city centre and the airport) none of the other future tram lines will make any difference to the number of accessible hospitals (either all hospitals or only the two main hospitals).

The consideration of ESSR in Scenario H shows a very clear effect on the accessibility distribution within Edinburgh. Interestingly, the results demonstrate that re-opening the railway, which runs in a loop for around 14 miles across the southern suburbs of the city (see Figure 7.32), will bring larger accessibility changes on a wider geographical scale compared with those brought by the future tram lines. The time saving generated by the combination of ESSR and the first part of Tram Phase 1a represents a reduction of up to 19% in the average travel times of the shortest journeys between most of the zones, which is 10% higher than the maximum time saving produced by the introduction of all the tram lines together in Scenario G (see the maps in Appendix B). The southern suburb's zones located around the infrastructure are those which benefit most from the infrastructure. The greater the distance from ESSR, the weaker the changes, but the gradient is steeper towards the city centre than outwards, which suggests that the benefits of ESSR tend to spread more towards the periphery than to the centre. The completion of ESSR will enable the majority of the people in the south west as well as those who are living in some zones around the infrastructure in the east of the city to save up to 8 minutes when they travel to the CBD, making their journey time shorter by up to 36% compared with the baseline scenario and the other tram development scenarios.

The map for the change in job accessibility (Figure 7.39) in Scenario H differs widely from those of the above scenarios. It is clearly perceptible that a large area of Edinburgh in the south and south west (the least accessible area based on the baseline year analysis discussed in Section 7.2) will obtain a substantial benefit with an increase of 5-25% in accessibility index while this benefit will be greater for a few small zones around the infrastructure with an increase of up to 83%. Accessibility for shopping will also significantly improve by putting ESSR into service for passengers. With the exception of the zones in the north and the north west of Edinburgh, the great majority of the residents of the Council area will benefit with increases of up to 69% for food shopping and 81% for shopping in general (33% and 45% higher than the maximum benefit brought to accessibility to food stores and retail services respectively in Scenario G). Similarly, the residents of most of Edinburgh's zones apart from those in the north part will enjoy better access to education with increases of up to 56% for secondary schools and 94% for higher and further education. The potential accessibility measure also demonstrates that

ESSR will raise the level of accessibility to GP practices and leisure facilities, particularly for the zones around the infrastructure, by up to 80% and 49% respectively. Regarding accessibility to hospitals, the results identify an important improvement in the accessibility level of the south west of Edinburgh with an increase of up to 50% while a number of zones on the corridor of ESSR will gain the greatest improvement by the infrastructure with an increase of 50-100% and of 279% in a single zone in the east of the city (see the maps in Appendices C and D).

On the other hand, in the contour measure, with a time limit fixed at 40 minutes, the changes in accessibility to jobs are larger than those recorded in the potential accessibility measure but they are limited to a smaller geographical area. An agglomeration of zones in the southern suburbs particularly in the Colinton and Craiglockhart areas will benefit with an increase in the number of accessible jobs of 14,894-61,713 jobs indicating an improvement in accessibility of 20-60%. The greatest benefit occurs in one zone in the south east with an increase of about 157% due to 67,277 additional jobs that can be reached within 40 minutes. For a cut-off travel value of 30 minutes, the contribution of ESSR to the increase in the accessible floor space area of food stores proves to be limited to the zones around the infrastructure corridor with an increase of up to 135,920 square metres (equivalent to an increase in accessibility of 213%). However, the greatest benefit for accessibility to food stores (within 30 minutes) identified in Scenario H is brought by the first part of Tram Phase 1a to two zones in south of Corstorphine by allowing their residents to reach around 50,000 extra square metres, raising their accessibility level to 403% and 6935%. The residents of ESSR corridor areas will be also able to reach extra GP practices (equivalent to an increase in accessibility of up to 73%) within the 30 minutes time limit. The effect of ESSR is greater when accessibility to retail services within the 40 minutes travel time is considered. A large area around the ESSR corridor will benefit with an increase in the accessible retail space floor areas by up to around 452,00 square metres (equivalent to an increase in accessibility of up to 50%). Furthermore, a number of zones around the infrastructure will gain the advantage of 1,128,500-1,484,500 extra accessible retail square metres (equivalent to an increase in accessibility of 75-212%) (see the relevant maps in Appendices C and D).

ESSR will also produce a clear change in number of the secondary schools and leisure facilities that can be reached from the southern suburbs' zones within 40 minutes with up to 9 additional schools and 249 additional leisure facilities causing increases in accessibility of up to 125% and 95% respectively. For a time limit of 60 minutes, the output maps (Appendix C) indicate wide and significant influence brought by the ESSR intervention, particularly to the peripheral zones in the east, the west and the south west of Edinburgh, compared with the tram scenarios discussed above. The number of accessible universities and colleges sites will increase by up to 5 sites, which is equivalent to an increase in accessibility of up to 45% (36% higher than the greatest increase brought in Scenario G). As mentioned earlier, the previous scenarios (i.e. B, C, D, E, F and G) show that, with an exception of small changes brought by the first part of Phase 1a, none of the tram interventions will have an effect on the number of hospitals that can be accessed within 60 minutes. In comparison with these scenarios, ESSR in Scenario H proves to have a relatively considerable influence on the level of accessibility to hospitals in number of zones, particularly on the south west of the infrastructure, with an increase of up to 56% as a consequence of being able to access 1-5 additional hospitals within 60 minutes (see the maps in Appendices C and D). Although ESSR does not improve the accessibility of those zones which already require their residents to travel for more than 60 minutes to reach one of the two main hospitals in Edinburgh (see Figure 7.16), it will make it possible for the people in a few zones in the south west of the infrastructure to reach, within 60 minutes, these two hospitals instead of just one.

Scenario I, which considers all the future transport infrastructure discussed in this study including all the tram lines as well as ESSR, unsurprisingly offers the greatest accessibility improvement compared with the all other scenarios above. By comparison with Scenario H, an additional time saving produced by Scenario I with a reduction of up to 5% in the average travel times of the shortest journeys from the zones in the north and south east to all other zones across the city (Appendix B). The relative change brought to job accessibility in Scenario I (see Figure 7.40) indicates an increase in the accessibility level of a large part in the north of the city by up to 25% benefiting from Tram Phases 1b and 2. In addition, some zones in the south east and west of Edinburgh will enjoy a higher level of accessibility by up to 5% due to the effect of Tram Line Three. Similarly, for accessibility to other services, the northern and the south eastern zones perform better in Scenario I than in Scenario H with increases in accessibility of up to 15% for food stores, retail and leisure facilities, 10% for GP practices and colleges/ universities, and 5% for secondary schools (see the maps in Appendices C and D). In the case of accessibility to hospitals, the calculation of accessibility changes highlights a key difference between the implementations of Scenario H and Scenario I, which identifies a significant benefit that will be brought by Tram Line Three to the Council south east area with an increase of 10-242% in accessibility to hospitals.

The differences between these two scenarios in the contour measure are somewhat less than those recorded above in the potential accessibility measure. The number of opportunities accessible from the north and south east areas within 40 minutes time will be higher in Scenario I than in Scenario H by up to 15,477 additional jobs, 374,800 additional retail square metres, 46 additional leisure facilities and one more school, which are equivalent to increases in accessibility of up to about 20%, 25%, 16% and 14% for jobs, retail, leisure facilities and secondary schools respectively). Finally, with regard to accessibility to food stores and GP practices within a 30 minute time limit and hospitals and higher/ further education facilities within a time limit of 60 minutes, the contour measure calculation shows either very limited differences or none at all between the contributions of Scenario H and Scenario I to improved accessibility (see the maps in Appendix C).

Based on what is discussed above in this section, the case study clearly shows that the first part of Tram Phase 1a (Scenario B) which is expected to run in 2014 will make a slight difference to accessibility in Edinburgh. Accessibility analysis has been carried out with 133 tests to evaluate seven possible combinations of tram and railway interventions within the Council area according to the absolute and relative benefit which they bring to spatial accessibility across the 549 modelled zones. Considerable differences have been identified between the impacts of the best and worst performing scenarios on accessibility to different opportunities. Predictably, Scenario I considering all the possible interventions is the one which brings the greatest benefit. The implementation of Scenario H interestingly proves to have a more significant contribution to improved accessibility, in general, than any other future tram scenario (which does not consider ESSR) including Scenario G which considers all the Edinburgh tram lines together. Scenario G, as it was logically expected, will produce greater accessibility impact than Scenarios C, D, E and F. Scenario C will bring the lowest accessibility benefit, and it was not surprising that Scenario E will add very limited benefit or none at all to what Scenario C already brings. On the other hand, it is not possible to define whether Scenario D or Scenario F will be better for Edinburgh without looking at the accessibility needs and priorities for each activity of the north and the south east residents, which are the main areas to benefit by Scenario D and Scenario F respectively.

Therefore, the empirical evidence in this research demonstrates that the completion of ESSR will have a greater redistributional impact on the spatial accessibility than any combination of tram lines. More peripheral areas beyond the EESR corridor will benefit most from this infrastructure improvement. Clearly, ESSR gains the advantage of the speed of railway travel which is not affected by traffic congestion and speed restrictions that the tram faces on roads, particularly in the central area. However, it is important to mention that the accessibility analysis carried out by SNAPTA does not consider the frequency of transport services, which is likely to be higher in the case of the tram than in the case of ESSR. The significant benefit of the circular ESSR should be recognised once it is seen more as a route between the South East sector and West Edinburgh rather than just another route into the centre, which emphasises the importance of introducing more non-radial/orbital public transport services in Edinburgh. Given that a large part of the infrastructure including stations and railway already exists and neither of the previous studies (i.e. SDG study, Business Case for tram, and Atkins report on ESSR) looked at the accessibility impact of the tram and ESSR, the quantitative accessibility approach in this study provides a potential basis for CEC discussion to rethink different priorities of future public transport interventions based on evidence of the accessibility impacts of changes in transport provision at a high level of spatial and data disaggregation of the land-use system.

Since the dimension of the case study of Edinburgh Council's area allows most of the population to reach a wide range of opportunities within a 60 minutes travel time by local buses, it can be stated that the improvements brought by the future infrastructure to the residents' accessibility to the opportunities within 60 minutes are not as significant as those for opportunities within 30 and 40 minutes. As land-use and socio-economic data do not exist for the future scenarios, the analysis of the changes in accessibility has been isolated from changes in population, land-use and other socio-economic development by fixing their data from the baseline year scenario, which was the most current data available in 2011. In addition, for the accessibility analysis of the future scenarios, the study does not consider any change in the bus network after the year 2011. Although it is likely that alterations will be made to the routes and/or timetables of some bus services in Edinburgh when the tram runs, no proposals for particular actions in case of new interventions have been defined yet (personal communication with Lothian Buses in 2013).

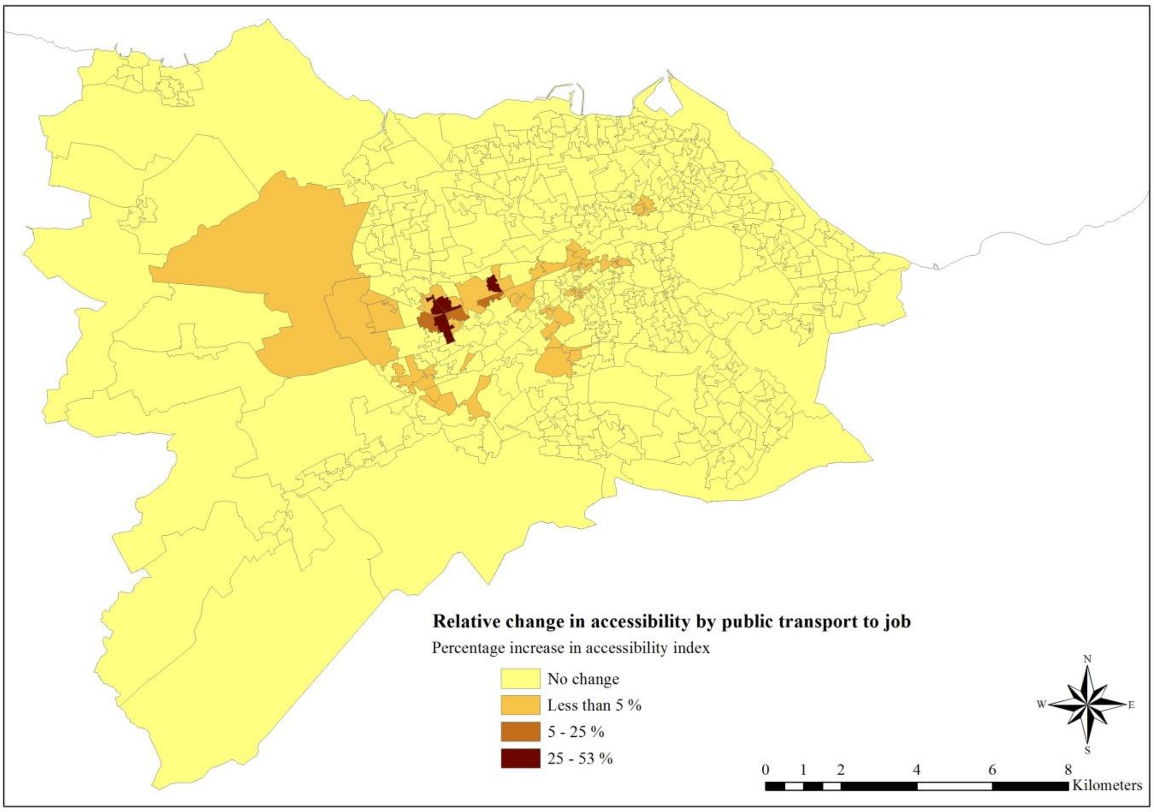

Figure 7.33: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

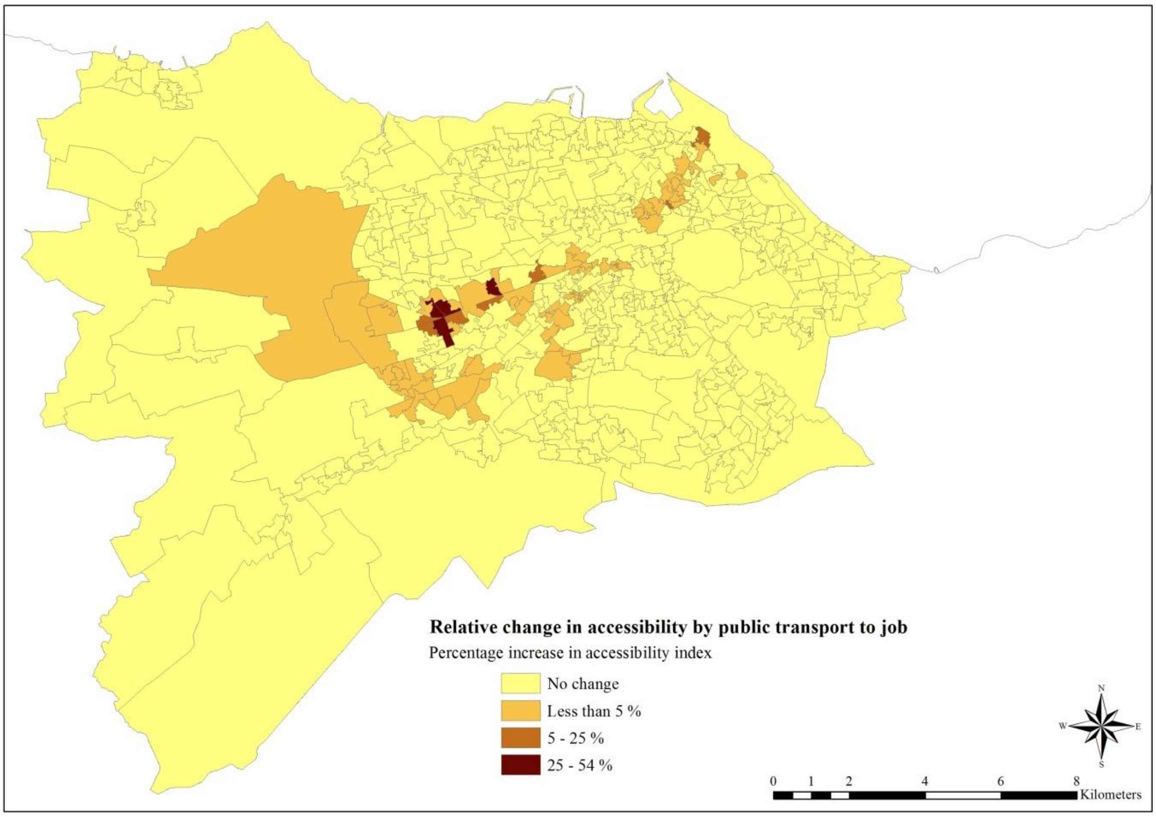

Figure 7.34: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

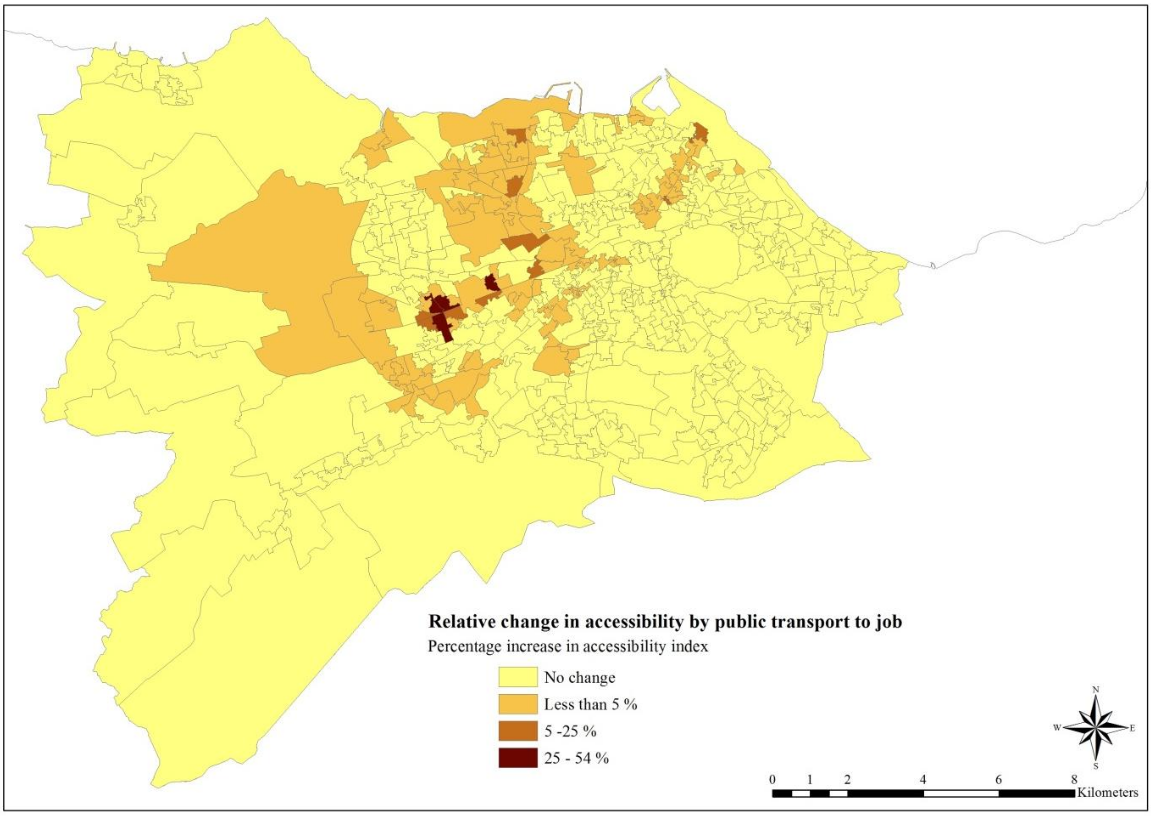

Figure 7.35: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

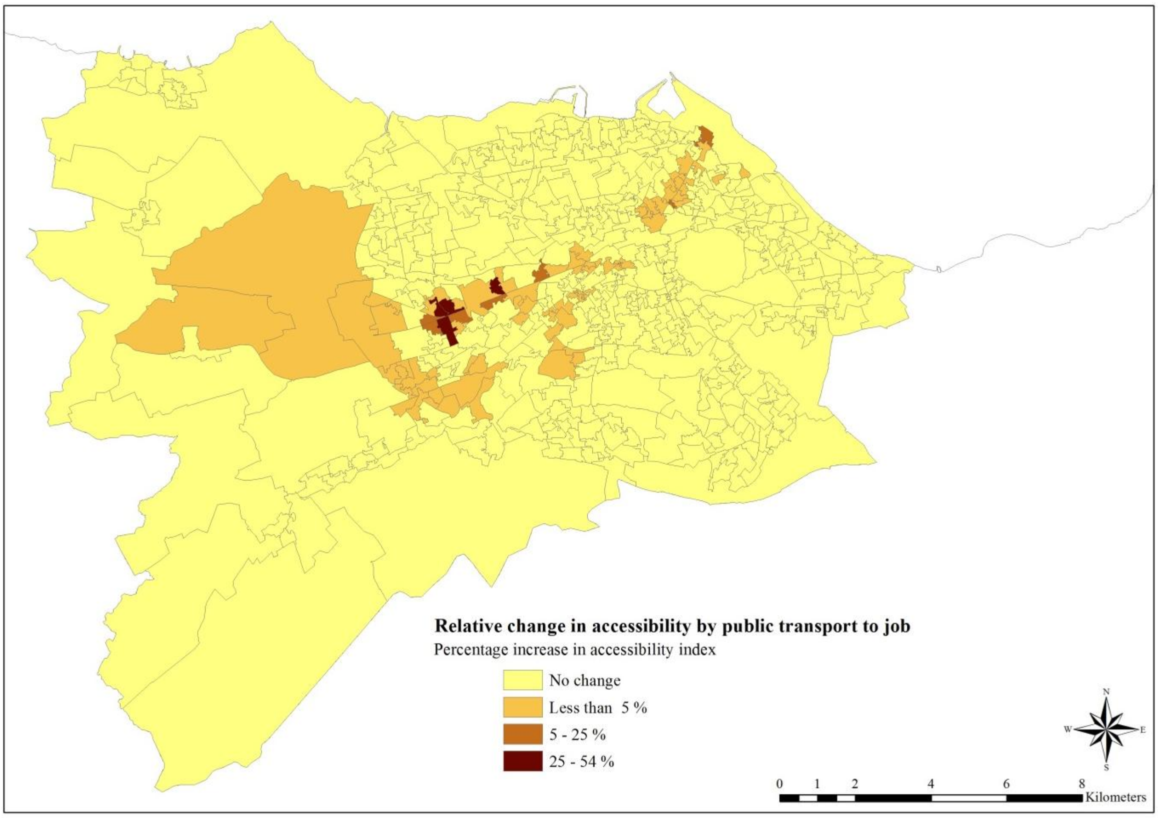

Figure 7.36: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

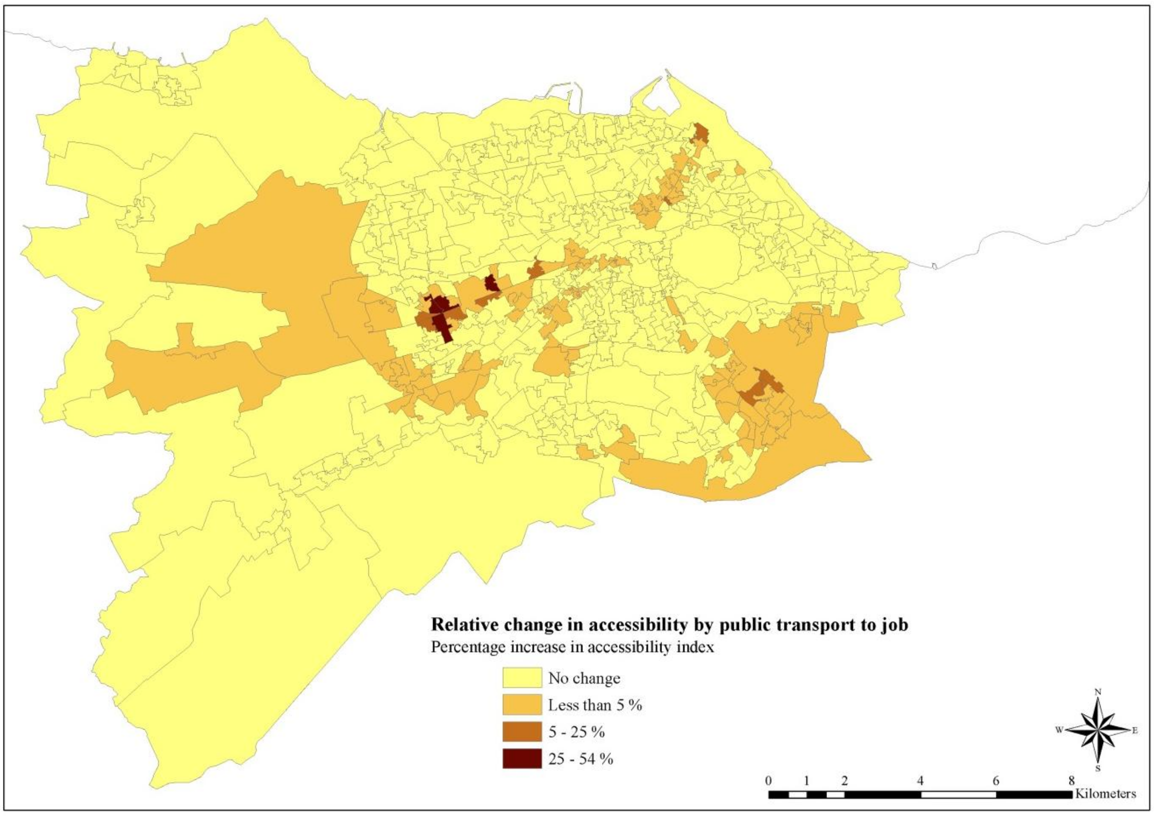

Figure 7.37: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

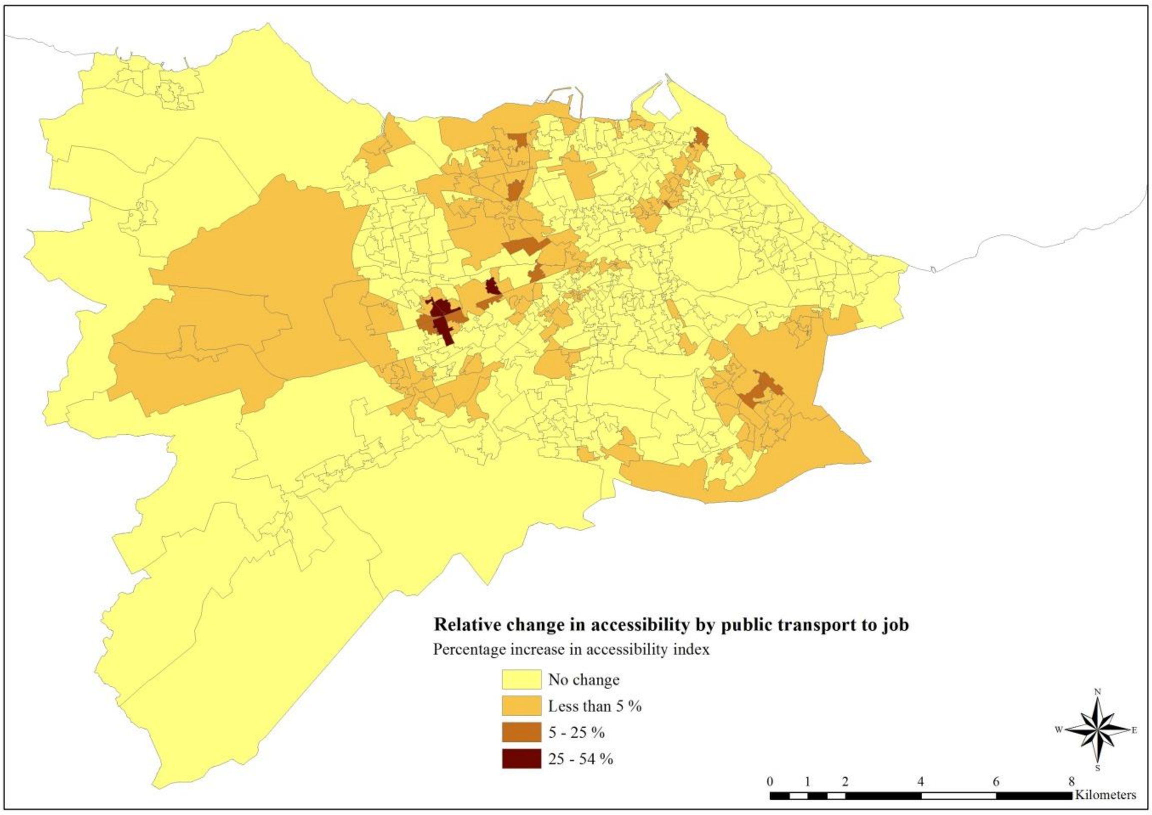

Figure 7.38: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

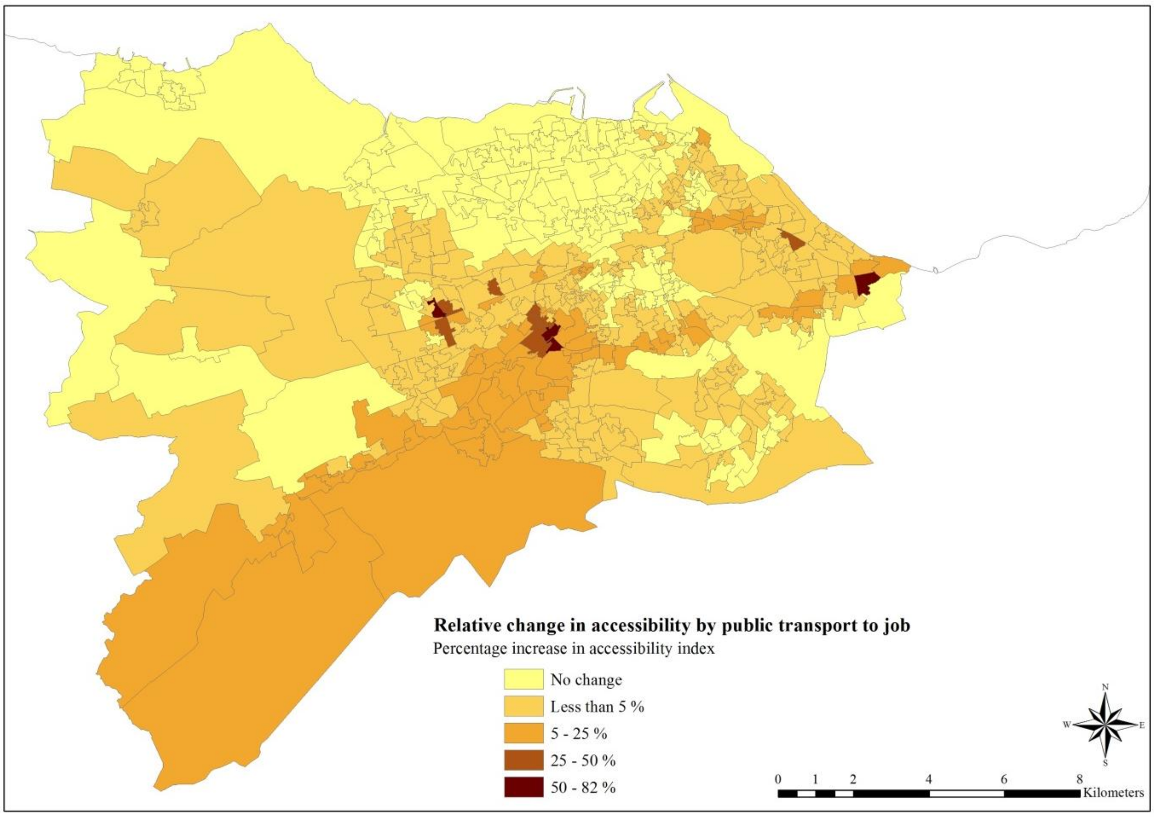

Figure 7.39: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

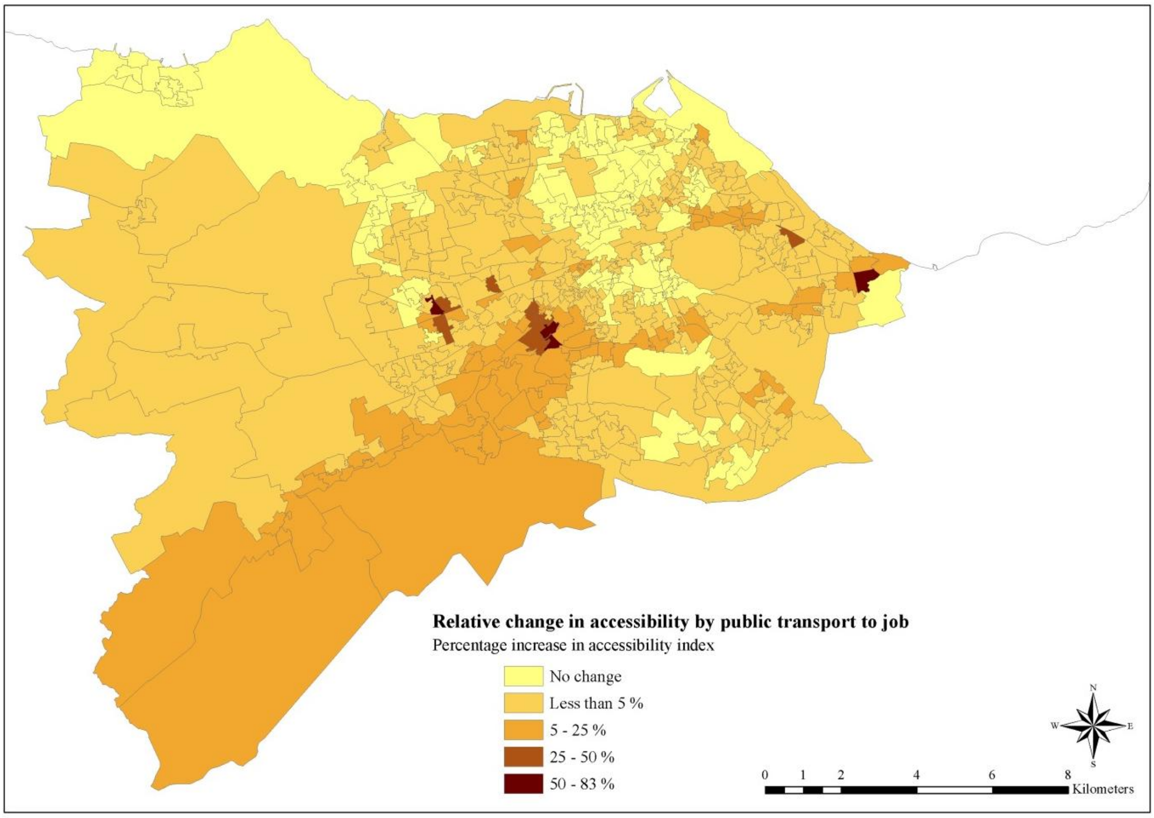

Figure 7.40: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

7.5 Expert Assessment (COST Action workshop)

As a part of the COST (European Cooperation in Science and Technology) TU1002 scientific programme "Accessibility Instruments for Planning Practice in Europe", the SNAPTA tool has been tested in a virtual exercise through a local workshop which took place in Edinburgh in June 2013. The aim was to discuss the usefulness of SNAPTA as a decision-making support tool as well as its usability and practical applicability by transport and land-use planners and politicians. The main results from this workshop were published in the second report of the COST Action (te Brömmelstroet et al., 2014).

A pre-workshop survey (see Appendix E) was sent to an interdisciplinary group of 13 people (7 land use planners, 6 transport planners) nominated by the Transport Planning and Policy Manager in the Services for Communities department in CEC. The surveys which were returned were mainly in agreement that the workshop should look at general transport issues and that SNAPTA should show how it can help in addressing these questions. Some of the nominees met to provide a collective answer to the questions. The following planning problem for CEC and indicators were agreed with CEC to address in the workshop: controlling climate change through sustainable transport with the indicators of mode share of sustainable travel modes, ensuring development is located in accessible locations and ensuring access to all key services.

The workshop was attended by 1) a land use planner from the Development Planning department in the City of Edinburgh Council, 2) an independent transport consultant from Derek Halden Consultancy who has experience in working on planning practical approaches to improve access for people to essential services, 3) the author of this thesis as the tool developer and 4) the moderator. All the participants have thorough knowledge of the concept of accessibility in planning and are familiar with the commonly used accessibility measures in practice.

The idea was to discuss how they used accessibility in their practice and to introduce a different tool for measuring accessibility. Therefore, it was important to engage participants who have been involved in some way in using an accessibility tool before. This provided an opportunity for a comparison with other accessibility tools helping the participants to identify the strengths and weaknesses of the SNAPTA tool. The planning team in City of Edinburgh Council has already used PTALs to assess the accessibility of new housing proposals as part of development management and as input to the land use development plan. The independent transport consultant has used the ACCALC tool to measure the accessibility of households in Edinburgh to grocery stores using the indicator of 400m to the stores.

In the workshop, after an explanation of the tool's conceptual framework, the modelling methodology and type of data used, the usefulness of SNAPTA as a decision-making support tool was discussed based on examples of the tool application to the public transport network across the 549 zones of the Edinburgh Council area. For the discussion a number of output maps were generated using three accessibility calculations: 1) the current status of accessibility by public transport to jobs and retail services produced by using the contour measure and the potential accessibility measure, 2) the service area of the new large Sainsbury's food store in Longstone where the residents can reach the store by local buses within 30 minutes cut-off travel time, and 3) the relative change in accessibility to jobs and retail services that will be brought about by the full construction of the infrastructure improvements of the tram system and ESSR. Issues concerning the usability and applicability of SNAPTA in planning practice including the specification of the main advantages and limitations were also discussed. Finally, general suggestions for the improvements that can be made to the tool were discussed.

Post-workshop surveys (see Appendix F) designed by the COST Action team were used to collect personal opinions on the ability of SNAPTA to effectively demonstrate the relationship between land-use and transport, and on its usefulness for identifying problems, selecting strategy/ alternatives and implementing a solution within the context of urban structure. Opinions on whether the concepts, calculations and assumptions used in SNAPTA are useful in real world planning decisions were also requested.

7.5.1 Main results

SNAPTA was in general very well accepted by the participants. There was a clear interest in the conceptual framework of the tool as well as its applications. The ability of the tool to provide an adequate representation of accessibility aspects and the relationship between transport and land-use elements made a good impression on participants. Not being totally reliant on the contour measure only, and using different accessibility measures, particularly the gravity-based measure which is not familiar to CEC transport modellers, was viewed as a useful approach to provide a different perspective on accessibility patterns. Furthermore, the use of these measures was not considered to be overly complex for practical applicability.

The potential interactivity of the tool was also referred to as a main advantage of its usability. All the participants agreed that the tool is effective at visualising the spatial distribution of accessibility as well as the changes that might be brought to this distribution due to changes in transport/ land-use system on this distribution. The output maps were described as sufficiently detailed, clear and easy to interpret and communicate. It was proven during the workshop that the SNAPTA maps can be used as an appropriate foundation for a discussion between experts and practitioners from different disciplines to analyse the situation and define planning problems. Moreover, the workshop highlighted the usefulness of output maps in the decision-making process by helping planners to assess different alternatives and inspiring them to develop transport/ land-use actions and strategies based on quantitative evidence of the impact on accessibility.

None of the participants disagreed with the key assumptions and specifications used in the accessibility modelling. The consideration of a high level of spatial and data disaggregation for land-use and activity system based on the Scottish Census Data Zones – the smallest geographical units in Scotland where most of the statistical data are available – was recognised as an appropriate choice to assess accessibility at the city level. On the other hand, the participants were aware of the disadvantages of this disaggregation system which features a large range in the size of zones according to population density.

The capability of the tool to generate results and visualise them in maps rapidly based on ad hoc enquiries was also considered to support its usability. Nevertheless, since the transport and land-use data used in the modelling can only be updated manually within the GIS environment, which is straightforward and quick when it is needed for a relatively small number of changes, suggestions were made regarding the real-time capabilities for a more efficient and time-saving method for updating data. Linking the tool with a program which automatically updates the data in real time was recommended as an improvement to the tool usability. However, this can be a realistic prospect when technical skills and software requirements are ensured. It is a very data hungry option and therefore is expensive when it is applied by bodies other than local authorities.

Additionally, being developed with a focus on public transport modes only was seen as a potential limitation for some purposes. Therefore, further development to consider car-based modes was also suggested to improve the usefulness of the tool. Finally, the fact that the tool was only developed to be applied at a local authority scale, with the advantage of potential regional expansion, was envisaged as a limitation of the micro-scale approach.

7.6 Conclusion

This chapter presents and discusses the results of the application of SNAPTA to the case study of Edinburgh city. The discussion focuses on SNAPTA's potential as a decision-making support tool for integrated land-use and transport policies. The results are presented in highly visual maps providing a clear picture of accessibility conditions across the study area. The accessibility analysis of the baseline scenario identifies the main gaps in the coverage of the public transport network in 2011 and addresses the spatial equity in the distribution of urban services and activities. Following the analysis of the 2014 scenario, a comparison between the accessibility impacts of seven longer term scenarios of different possible combinations of tram and ESSR interventions has been made. The findings form a basis for better understanding of where investments in public transport should go to provide the greatest accessibility distributional benefits for urban services in Edinburgh. Surprisingly, the results demonstrate that ESSR can play a significant role, bringing a greater benefit for accessibility than any of the other tram proposals. In this respect, this case study shows some of the capabilities of the SNAPTA tool providing an example of how it can be used as an alternative technique to support decision-making. It supplies insights of how practitioners and policy makers could apply the tool in planning for accessibility to make informed judgments on the success of land-use – public transport system and formulate strategic planning processes for future urban growth and development. Finally, the COST Action workshop for the expert assessment of the behaviour of SNAPTA shows a general belief in the usefulness and usability of the tool. The assessment confirms the visualization power of the tool and its capability to demonstrate the relationship between land-use and transport systems. Furthermore, the experts provided feedback on the main advantages and disadvantages of the tool defining the baseline for its improvement.

CHAPTER 8 – Conclusion

8.1 Research conclusions

Although many accessibility tools have recently been developed and tested in scientific research (e.g. Gutiérrez and Gómez, 1999; Geurs and Ritsema van Eck, 2001; Halden, 2002; Yigitcanlar et al., 2007; Curtis and Scheurer, 2010), the usefulness and usability of accessibility tools in planning practice are a much less-developed area of study. Based on the functionality and the purposes that an accessibility tool has been developed for, the research uses a three-fold categorisation of tools to illustrate the different approaches available to accessibility modelling. The three categories adopted are consistent with the classifications articulated in the state of the art scientific literature (Handy and Niemeyer, 1997; Geurs and van Wee, 2006; Silva, 2008) and relate easily with the context in which practitioners apply ideas on accessibility. These include: 1) tools analysing local accessibility by walking and cycling; 2) tools analysing accessibility by motorised vehicles through the transport network; and 3) models designed for another purpose incorporating accessibility.

The research has reviewed a number of accessibility tools that have been selected to represent other tools with a similar functionality (from the same category). The review provides an understanding of how the concept of accessibility is measured and incorporated in the tool, and identifies several technical omissions in existing accessibility tools that can be considered as potentially important limitations for some purposes in transport planning and urban management practice. Some tools are not available as open source and might require bespoke software or an external function to be integrated into the GIS environment which might be expensive and needs a high level of expertise in operating the software. Most of the available approaches to modelling accessibility focus on transport and activities supply but do not represent demand. Many tools cannot consider accessibility for different population groups but instead they analyse accessibility for a homogenous population, which is considered insufficient for some study purposes. For an analysis of accessibility by public transport, being restricted to only one transport mode and the failure to consider walking time to public transport access points (particularly at a regional or local administrative scale) are other common omissions. In addition, many of the existing tools have failed, in one way or another, to consider a number of issues in connection with how people perceive accessibility, including: the measurement of the straight-line distance rather than of the actual walking distance, and measurement of the in-vehicle travel time based on speed limits or average speeds associated with roads rather than using a travel survey or services timetable. Other omissions are related to the non-consideration of physical features (e.g. steep hills), interchange options (between different modes or operators), significance of opportunities at destinations, the diminishing influence of distant opportunities, and travel at specific times of day and on a specific day of the week. See Chapter 3 (Section 3.4) for a fuller discussion on omissions that might limit the analysis capability of tools to examine some relevant impacts or to reflect accurately the actual travel behaviour.

However, the research recognises that it is not necessary that each accessibility tool should capture all the above factors since the different objectives of accessibility analysis require different considerations. In this context, the research continues with an investigation into the usability and usefulness of accessibility tools in the transport and land-use planning practice (Chapter 4). The review shows that many tools are still restricted to academic studies and have never been applied in practice. This is due to the complexity of their theoretical underpinnings and the associated high level of data collection cost which leads to a level of detail and complication making the tools output difficult for policy makers and practitioners to understand and interpret (see Chapter 4). On the other hand, some other tools have been abandoned because they rely on very simple or inadequate methodological approaches that are not sensitive to changes in both the transport system and the land-use system or unable to reflect adequately the actual travel behaviour. In this respect, the review identifies four key features that characterise the usefulness of accessibility tools in planning practice: 1) the inclusion of a sufficient methodological substance to capture the relevant dimensions of the planning issue; 2) the ability to process the analysis with an adequate data input and level of disaggregation; 3) the ease of interpretation, understanding and communication with planners and policy makers; and 4) a low level of complexity to operate the tool and orient the analysis towards clear objectives.

The more theoretical and methodological elements are included, the higher the degree of complexity and number of data requirements – which significantly limits the interpretation and practical applicability of a tool in planning practice. Therefore, for accessibility tools development, it is important to reach a balance between methodological accuracy and interpretability (e.g. Geurs and Ritsema van Eck, 2001;

Bertolini et al., 2005; Silva, 2008, Straatemeier and Bertolini, 2008; Straatemeier et al., 2010). In other words, tools should provide an adequate representation of the urban and transport situation without making them more difficult to operate by practitioners or harder to understand by all involved stakeholders. Therefore, the tool's visualisation and interface capability, particularly in terms of using geographical maps for expressing the outputs, have been recognised as a very useful way for communicating accessibility and for forming a basis for discussion between urban/ transport planners and decision makers (te Brömmelstroet et al., 2014).

The knowledge obtained from reviewing the literature was used to form the underlying concept for the development of the decision support accessibility tool of this research as presented in Chapter 5. SNAPTA – Spatial Network Analysis of Public Transport Accessibility – is a GIS-based accessibility tool relying on a package of different types of accessibility measures to calculate the spatial accessibility levels by different types of public transport modes to different types of opportunity using a high level of data disaggregation. The tool incorporates three main elements – public transport supply, location and attributes of activities, and accessibility measurement. It attempts to offer better usability in planning practice through the consideration of the usefulness criteria drawn from reviewing the literature on accessibility studies.

The selection of three measures (travel time to CBD, the contour measure and the potential accessibility measure) rely on different approaches to assess the relationship between transport and land use, allowing different considerations of accessibility dimensions related to the experience of travel. This enhances the tool's applicability to a wider range of different planning problems/ questions. Also, it provides the opportunity for comparing the results of the different accessibility measures that could support the analysis conclusion on which actions or policies will be decided. However, the accessibility measures selected, particularly the distance and contour measures, are considered relatively simple and easy to interpret and understand by planners and policy makers (see Chapter 2).

Moreover, SNAPTA addresses a number of the omissions identified in some existing accessibility tools by: taking into account a sufficient data approach and disaggregation; using a reasonable value of constant multiplier for the straight-line distance in order to reach more accurate estimation of walking time; the consideration of interchange time and options between different public transport modes and operators; and the consideration of the influence of slope and heavy traffic volume (i.e. crossing delays) on walking time (see Chapter 5).

SNAPTA uses Data Zones – the key small-area statistical geography in Scotland – as a spatial level of data disaggregation which ensures the representation of contextual data on land-use, demographic and socio-economic characteristics at the highest available level of spatial disaggregation. Moreover, the tool does not require detailed individual activity-travel data and can be applied using a wide range of readily available data sets that can be obtained from the relevant government organisations. The calculation can be set up and oriented to produce results relevant to different stages of the decision-making process for planning, including: situation analysis and problem definition, assessing the impacts and consequences of different alternatives, and feedback and post-auditing tasks (see Chapter 5, Section 5.2). The methodology adopted is a transparent and easily understood technique, benefiting from the interactivity and interface characteristics of ArcGIS. The visualisation power of ArcGIS allows SNAPTA to present the outputs in sufficiently detailed and clear maps which are readily communicable to the public and non-experts. Moreover, the tool can be managed and operated using the standard functions of ArcGIS without requiring any bespoke software or external function to be integrated into GIS. Changes in transport and land-use elements involved in accessibility modelling can be executed within the GIS environment at any stage of the calculation to fit the user requirements.

Therefore, the research does not claim that SNAPTA is better than any other tool available in practice, or argue that it provides a complete picture of accessibility or that all the omissions addressed in SNAPTA are neglected in the other existing tools. The significance of the tool developed in this research is about providing practitioners with a practical alternative that offers an adequate methodological and data approach which is not complex to operate or interpret. With a further development the tool has the potential to include car-based modes and wider population characteristics reflecting different socio-economic groups (see Section 9.2 for future work).

In order to test the tool in the real world, Edinburgh Council's area, which is currently undergoing an important period of transport and urban development, was selected as the case study for the research. Therefore, the development of SNAPTA was closely linked to the policy needs arising from Edinburgh Local Transport Strategy (2007-2012) and subsequent reviews leading to a revised strategy (2014-2019) as well as other spatial and transport plans for the city of Edinburgh and the surrounding region (see Chapter 6). Three main purposes were defined for the application of SNAPTA to the case study of Edinburgh: 1) a before-and-after analysis of real-life network reconfiguration, 2) an evaluation and comparison between different scenarios of land-use – transport integration; and 3) an evaluation of efficiency and spatial equity in the distribution of urban activities. The tool was applied to analyse accessibility by public transport to different types of opportunity in 2011 – the baseline year of the study. This produced three main results: first, the gaps in the coverage of the local bus network; second, efficiency of the distribution of activities; and third, the "hotspots" of a particular activity accessed by public transport. The analysis addresses a number of policy questions and contributes to achieving several objectives of SEStran's and CEC's transport strategy (Chapter 6). It provides an indication of how well transport and land use are integrated within the Council area, identifying where public transport investment should go or new activity centres should be opened.

The results of the travel time and contour measures support the existing view that the central area of Edinburgh enjoys the highest level of accessibility by public transport to most of the urban activities, which highlights the influence of the radial pattern of the city bus network and the concentration of jobs and wide range of activities in the central area. The analysis also demonstrates that the periphery of the city, particularly the south west of the city is the most disadvantaged area in terms of accessibility (Chapter 7). This provides empirical evidence of the significance of introducing non-radial public transport routes which, together with information on households which do not have access to private cars, form a robust basis to advise the Council where public transport improvements should be implemented. In this context, a potential intervention for a new bus route was identified in this research in order to improve access to employment and reduce spatial inequity in accessibility across the city (see Chapter 7, Figure 7.20).

The use of the potential accessibility measure generated different results, to varying degrees (depending on the journey purpose considered), to those of the contour and travel time measures. The difference can be interpreted by the influence of the distance decay function which considers the diminishing attractiveness of distant opportunities that was used to weight the accessibility values. This identifies the zones in Edinburgh Council's area that are home to opportunities with a considerable physical/ economic size and with relatively easy access by public transport. For example, the zones of West Edinburgh Business Park where a large number of journeys have their destination due to the heavy concentration of job opportunities. Since the potential accessibility measure has not been used in the accessibility analysis carried out by CEC (personal communication with CEC), this study provides a new insight for a different perspective on accessibility patterns in Edinburgh, taking into account not only the distribution of activities but also the significance of these activities and their declining influence with increasing journey time. This, together with the use of Data Zone level for spatial disaggregation, shows that SNAPTA presents a clear picture of the distribution of activity hotspots accessed by public transport which helps CEC to make a decision on transport/ land-use interventions to balance the city growth and address the spatial equity issues. Moreover, it provides evidence to support the Local Plan proposals for the ongoing business development in the key development areas of the Waterfront in north Edinburgh and Newbridge/ Kirkliston/ Ratho in west Edinburgh as well as demonstrating the potential for new business parks such as Sherriffhall in the south east of Edinburgh (Chapter 7). The results indicate that in comparison with the new retail developments proposed in the city centre and in Fountainbridge, those planned to take place in a number of non-central sites including Wester Hailes, Hermiston Gait Centre, Granton Waterfront and Leith Waterfront will bring better distributional benefits for shopping access particularly for the residents of the areas with a relatively poor public transport accessibility. Such results improve the local authorities' understanding of the aspects of urban structure that influence accessibility patterns. The findings prove that SNAPTA is capable of addressing the spatial equity issue by identifying areas that do not succeed in being optimal and require their residents to travel excessively to pursue the same amount of facilities compared with other areas where travelling provides better time allocation. Therefore, it is believed that SNAPTA can be used by the CEC to play a significant role in deciding on where to locate future developments, particularly when social exclusion issues are considered and policy contexts call for more sustainable transport options to be developed.

A further analysis was carried out to identify the accessibility impacts of the major public transport infrastructure planned for Edinburgh's network (Chapter 7). A key output of the analysis of the first part of Tram Phase 1a, delivered in summer 2014, was the new evidence that there is very limited improvement brought to the accessibility of population across Edinburgh Council's area (Chapter 7). This emphasises the importance of carrying out an accessibility assessment of all the major transport infrastructure considered for the city. In this respect, SNAPTA was applied in this research to examine and compare the significance of a number of possible scenarios of completing future phases of the Edinburgh tram and the ESSR, in terms of their contribution to improved accessibility and distributional benefits for urban services in Edinburgh. Surprisingly, the results demonstrate that ESSR can play a significant role, bringing a greater benefit for accessibility than any of the other tram proposals (Chapter 7). Nevertheless, to be able to tell which scenario will bring the best benefit for Edinburgh, the accessibility requirements and priorities of the residents of each city area for each activity need to be considered. It is recommended that these new findings from this case study be taken into account through the preparation of medium and long term transport strategies that call for public transport actions based on evidence of the impact on accessibility in Edinburgh and the surrounding region. Therefore, the case study of this research proves that SNAPTA has a clear potential for application in real-life planning contexts. The tool is able to contribute to deliberations on changes to the public transport network, as a part of the local and/or regional authority transport strategy, by demonstrating the consequences of introducing a new transport infrastructure or service improvement for spatial accessibility across an urban area. It provides practitioners and policy makers with an efficient and useful alternative tool that can be used in decision-making to inform strategic planning processes for future urban growth and urban structure framed around the integration of land-use with strong public transport accessibility.

The author’s personal perception of SNAPTA’s capabilities was supported by experts’ opinions. Feedback on the usefulness and usability of the tool was given by transport and land-use planners through a workshop in co-operation with the COST Action TU1002 "Accessibility Instruments for Planning Practice in Europe" (Chapter 7, Section 7.5). The tool was in general very well accepted by the experts who participated in the workshop. There was a clear interest in the conceptual framework of the tool and its potential applications to Edinburgh’s network as a decision-making support technique. The ability of the tool to provide a good representation of the relationship between transport and land use at an adequate spatial disaggregation level was confirmed. The modelling approach and accessibility measures selected were not considered to be overly complex for practical applicability. The potential interactivity and visualization power of SNAPTA were seen as the main strengths. The output maps were considered appropriate to reflect accessibility conditions well at the local scale, providing interesting insights for policy assessment and decision-making purposes. Therefore, overall, the expert assessment revealed a general recognition of the robustness, usefulness and usability of SNAPTA as a decision-making support tool. On the other hand, limitations related to micro-scale analysis, non-consideration of car-based modes and the big difference in the size of zones associated with the spatial disaggregation system considered were identified (see Chapter 7, Section 7.5 for a fuller discussion). Further research into a real-time approach to data updates is still recommended to improve the tool in practical terms.

Using observed data (from the GPS tracking system of Lothian Buses) and output from a similar model used by CEC, the tool validation was undertaken in accordance with DMRB standards in order to ensure its suitability for the intended use (Appendix A). As a result, SNAPTA was successfully validated. The modelled journey times are in good agreement with the observed data. Also, it was concluded that the tool results are sensitive to changes in values of the modelling parameters as well as changes in the land-use and transport systems (Appendix A).

Finally, considering all the above, the main contributions of this study can be summarised in the following points:

Contribution to the science of accessibility modelling:

- Better understanding of the limitations of the application of accessibility tools/ models in the world of planning practice.
- Identification of the main criteria that characterise the usefulness and usability of accessibility tools.
- An attempt to bridge the knowledge gap between research and practice in the development of accessibility tools by providing an insight of how to consider the usefulness criteria in accessibility modelling in order to develop a tool that retains its theoretical robustness in a simplified approach.

Contribution to planning practice in general:

- Development of a new GIS-based accessibility tool, providing an example of how modellers can create a practical and non-complex decision-making support tool that satisfactorily incorporates the relevant dimensions of accessibility and is very able to adequately provide a clear picture of the relationship between transport and land-use.

Contribution to planning practice and policy making/ understanding in the Edinburgh case:

- Deeper analysis and a better understanding of the current spatial distribution of the level of public transport accessibility in Edinburgh Council's area to jobs, shopping, education, health care and leisure facilities, using three different accessibility measures and based on a wide range of data sets at a high level of spatial disaggregation.
- Identification of the potential for a new non-radial bus route in Edinburgh to improve the connection of areas that the analysis showed to have generally poor accessibility by public transport.
- Presentation of empirical evidence on the accessibility impact of the first part of Tram Phase 1a (scheduled for summer 2014) as well as on seven other scenarios of possible combinations of different major infrastructure proposed for longer-term development including Tram Phase 1a – second part, Tram Phase 1b, Tram Phase 2, Tram Phase 3, Tram Line Three and ESSR.

However, further contributions to both the Edinburgh case and planning practice in general can be achieved with future research. This mainly includes improvements to the capability of the tool developed in this research in order to reach a more efficient approach to accessibility modelling that could inspire modellers and practitioners with a higher level of integration between methodological adequacy and usability. Such improvements would also positively contribute to the quality of accessibility analysis in Edinburgh for a more robust basis for transport and land-use decision making as well as links with other policy areas. A detailed discussion on suggestions for future work is included in the next section.

8.2 Future Research

The research developed within this thesis opens new branches for future work and raises new questions. Considering the feedback given by experts and the lessons learnt from the case study, it is recommended to continue the development of SNAPTA to reach better usability and practical value. Tool enhancements can be achieved by further research on technical and operational features as well as analysis capabilities. The *calculation of waiting time* at public transport access points (e.g. bus/ tram stops or train stations) or for interchange should be improved in order to reflect the real waiting time more accurately instead of using the average scheduled waiting time at access points. In this regard, further research should be carried out to look at the potential *real-time capability* of the tool for a more efficient and time-saving approach to data input and update. Also, an approach needs to be developed to deal with the *accessibility representation of the relatively large zones* associated with Data Zone level. In other words, an approach which allows the accessibility level of the residents in a large zone to be represented by two or more values (depending on the size of the zone area) rather than assuming that all people in these zones enjoy the same level of accessibility.

To improve the analytical capability of SNAPTA, a number of issues should be considered for further development of the tool. *Car-based modes* need to be included in order to compare accessibility by public transport and by private cars to develop the required policy and actions. Another benefit is to address the sustainability impact of public transport intervention by identifying the potential modal shift from private car to public transport as a result of the changed relative accessibility of different modes. *Accessibility on foot to key local services* should be considered to support planning for sustainable accessibility, particularly in the central area. However, this requires consideration of the actual pedestrian network rather than using a constant multiplier for distances as the crow flies. In addition, for the analysis of local accessibility within zones, data on the exact locations of activities needs be included. In the same context, *different walk speeds* from and to public transport facilities should be considered to reflect the accessibility of different population groups according to age, gender or mobility condition rather than the average population. Also, further work is required to consider the *frequency of public transport services* as an additional factor in measuring accessibility. It would perhaps also be useful to investigate how to include the possibility of *two-stage trips* for a combination of two activities (e.g. jobs and shopping) in accessibility analysis without restricting the practical applicability of the tool. In addition, a *technical manual* will be produced and provided to practitioners together with the tool in order to better understand how it works and aid the adjustment of the calculation and relevant parameters. Although positive feedback was given by experts on the tool application to Edinburgh's area, it is important (in addition to working on all the above issues) to continue testing SNAPTA in other case studies and to seek the increased involvement of planners and policy makers in order to obtain more feedback for a better evaluation and, consequently, further improvement to the tool's usability. Following this it will finally be used within a real application in planning practice alongside a follow-up survey to monitor the practical success.

Regarding the case study of this research, one of the major problems facing public transport in Edinburgh is the need to change between buses (or buses and other modes) in the central area on many journeys and the slowness of bus movement through the central area, partly due to bus congestion at the stops. Therefore, it seems worth investigating how to develop any innovation which might speed up the changeover time and/or the time to transit the central area, and how much difference this would make. From an equity and social point of view, it would be useful to include questions on accessibility needs in future household surveys – carried out by the Council or another relevant organisation – to collect information related to the perceived importance of accessibility by public transport for a particular opportunity. The findings obtained can be used to develop empirical values per Data Zone reflecting household access needs. It would also be interesting to carry out an accessibility analysis for households living in the poorest Data Zones (e.g. 15%, 20% or 30%) and then examine the extent to which the implementation of transport strategies, particularly the combined ones, affects the accessibility of these areas. Since CEC has introduced a proposal of three options to support 20mph speed limits in residential areas in Edinburgh as part of the new Local Transport Strategy for the next five years 2014-2019 (CEC, 2013b) (Chapter 6, Section 6.3), there is a need to study the consequences for accessibility of the areas along roads where bus services might otherwise be able to exceed this speed. Additional studies also seem worthy in terms of accessibility by public transport: it would seem important to explore and consider the factors affecting modal choice which include cultural attitudes to specific transport modes, quality and environment of journeys, and factors associated with gender, age, income, physical ability and the number of hours spent working that influence travel behaviour.

APPENDIX A:

Tool Validation and Sensitivity Analysis

Introduction

In order to ascertain the adequacy of a new model's estimates for the intended use, it needs to be validated using observed data and the results compared against similar models. As a part of validation, this Appendix includes testing for the accuracy of the accessibility tool developed in this research using data collected from different sources. It also studies the sensitivity of the tool outputs to changes in the parameter values and the modelled land-use and transport systems. The next section discusses the validation methods adopted in this study and presents the results of both accuracy and sensitivity checks.

Validation

Validation is essential in ensuring that a transport model provides as accurate a presentation of the base year reality as possible. The Department for Transport sets various criteria to be met before a transport model can be said to be representing base year conditions to an acceptable standard. These criteria are set out in the Design Manual for Roads and Bridges (DMRB) (DfT, 1996) and comprise: 1) good comparison between observed and modelled traffic flow volumes on a number of selected links across the study area, and 2) good comparison between observed and modelled journey times for a number of routes through the study area. Since the modelling approach of accessibility tools, in general, does not look at traffic flow but focuses on travel time as the key spatial separation factor for accessibility measurement, the first DMRB criterion for validation is irrelevant to the case of SNAPTA. For this research, the validation process adopted establishes the credibility of the SNAPTA tool by demonstrating its ability to replicate actual traffic patterns. It has been undertaken using a combination of two types of checks: accuracy (or reasonableness) check and sensitivity check (Wegmann and Everett, 2008).

Accuracy check

The accuracy check assesses the quality of the information provided by SNAPTA and its adequacy for the purpose intended. It evaluates the tool in terms of acceptable levels of error, ability to perform according to theoretical and logical expectations, and consistency of tool results with the assumptions used in generating the results. The technique involves comparing the tool output against a set of other independent data and outputs produced by the accessibility tool of CEC which is based on Accession (see Chapters 3 and 6). Two comparisons of SNAPTA-modelled journey times against observed and modelled journey times which were obtained from different sources have been considered in the accuracy check.

First, a comparison of the SNAPTA-modelled journey times was carried out against actual (or observed) journey times between a number of pairs of bus stops throughout Edinburgh Council's area. Actual travel times of 20 journeys were obtained from the GPS tracking system of Lothian Buses – the main bus service operator in Edinburgh and the surrounding areas of Midlothian and East Lothian – based on journeys undertaken on Thursday 13 February 2014 during the morning peak time (nearest to 8.00am). Each of the pairings was selected to be on a journey that can be made using one bus service operated by Lothian Buses only, since no data for interchange points or for other components of the journey such as walk time to the nearest stop and waiting time is held by Lothian Buses (personal communication with Lothian Buses). Further checks were carried out to ensure that the choice of the best (i.e. fastest) routes in the model is sensible and corresponds to the observations.

It should be noted, however, that bus journey time comparisons can be made without the need to conduct actual surveys or use a GPS tracking system. Bus timetables are used as a proxy for the journey times through the road network and can be compared against the equivalent modelled journey times for the same bus services (MVA Consultancy, 2009). It is assumed that bus operators produce timetables with a strong understanding of congestion hotspots and peak vehicle requirements. As a result, if SNAPTA (which already relies on bus timetable data to measure travel time) is to be considered suitably robust, it would be expected that it would conform relatively closely to said timetables.

The second comparison checks modelled journey times produced by SNAPTA against those produced by the accessibility tool of CEC. It examines the outward and return journeys for a sample of 15 origin-destination pairs (i.e. centroids) throughout the study area, making the number of journeys 30 in total (see Figure A.1), taking into account journey components for both directions including walking time, waiting time, on-bus time and interchange time (if applicable).

In both comparisons above, the journey time validation has been carried out based on the DMRB criteria which requires the difference between the modelled and observed journey times to be within 15% (or 1 minute, if higher than 15% of the observed journey time) for at least 85% of routes tested (DfT, 1996). Tables A.1 and A.2 present the journey time validation results for the two comparisons.

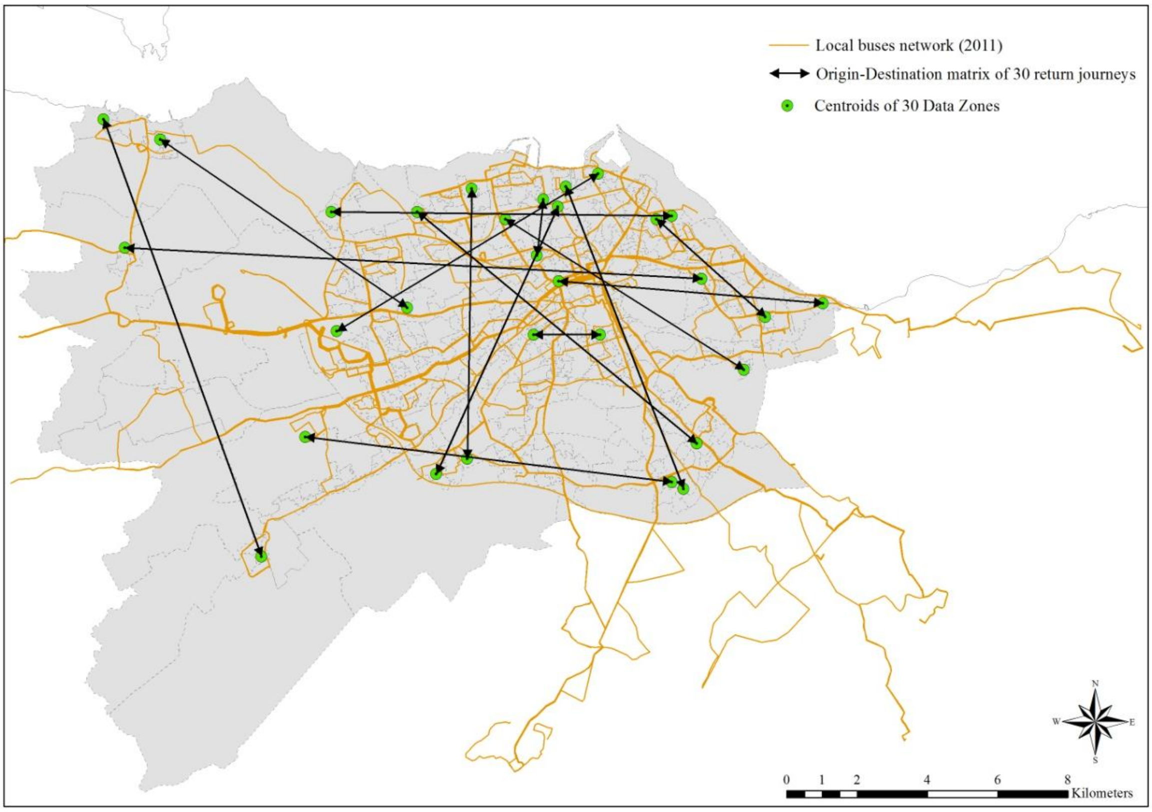

Figure A.1: Origin-Destination matrix of the 30 two-direction journeys tested throughout Edinburgh

Table A.1: SNAPTA model AM peak journey time validation

Bus route No.	Origin bus stop	Stop code	Destination bus stop	Stop code	Observed journey times (mins)	Modelled journey times (mins)	% Difference	Check (within 15% or 1 min)
1	Academy Park, Easter Rd	242010	Westfield Road, Westfield Rd	248700	38	34	-10.5%	Pass
8	Gypsy Brae, W Granton Rd	204950	Forth Street, Broughton St	206850	22	24	9.1%	Pass
10	Westgarth Avenue, Westgarth Ave	248510	Cables Wynd, Great Junction St	242380	50	49	-2%	Pass
11	Tollcross, Home St	243840	Southhouse Loan, Captain's Rd	209200	23	26	13%	Pass
15	Leopold Place, London Rd	207470	Seaview Terrace, Eastfield	210060	20	24	20%	Fail
19	Drumsheugh Place, Queensferry St	244750	Granton Crescent, Granton Crescent	245047	18	19	5.6%	Pass
21	Academy Street, Duke St	242000	Duart Crescent, Drum Brae S	202700	41	41	0%	Pass
24	Groathill Road S, Telford Rd	204420	Craigmillar cast, Old Dalkeith Rd	209560	62	58	-6.5%	Pass
25	Heriot Watt University	200260	Loganlea Crescent, Loganlea Dr	207847	69	68	-1.4%	Pass
26	Haymarket Station, Haymarket Terrace	246930	Clermiston View, Drum Brae Dr	247210	15	17	13.3%	Pass
30	Morrison Crescent, W Approach Rd	203045	Quarry Cottages, Newcraighall Rd	210250	38	34	-10.5%	Pass
32	Forester Park Ave, Meadow Place Rd	249070	Granton Park Ave, W Granton Rd	204890	29	31	6.9%	Pass
35	A8 at RBS Gogar, Glasgow Rd (A8)	202320	Sheriff Court, Chambers St	206400	65	60	-7.7%	Pass
37	Martello Court, Pennywell Gardens	204003	Kaimes, Burdiehouse Rd	209140	54	52	-3.7%	Pass
38	Kings Buildings, W Mains Rd	239800	Craigleith Hill, Craigleith Rd	204370	43	47	9.3%	Pass
42	Duddingston Park, Duddingston Rd	238930	Flora Stevenson, Comely Bank Rd	245210	51	55	7.8%	Pass
44	Newmills Road, Lanark Rd W	200100	Stoneyport, Lanark Rd	200870	19	17	-10.5%	Pass
45	Lauriston Terrace, Lauriston Pl	243730	Corslet Road, Riccarton Mains Rd	200240	37	41	10.8%	Pass
47	Waterfront Light, Waterfront Ave	250160	Clarendon Crescent, Queensferry Rd	204740	21	17	-19%	Fail
49	Summerside, Old Dalkeith Rd	327232	Lochend Park, Lochend Rd	207710	55	54	-1.8%	Pass
Number of routes considered								20
Number of SNAPTA journey times within 15% or one minute of observed journey times								18
Percentage of SNAPTA journey times within 15% or one minute of observed journey times								90%

Table A.2: Comparison of AM peak journey times on weekdays between SNAPTA model and CEC accessibility model

Origin Data Zone	Destination Data Zone	CEC model - journey times (mins)	SNAPTA - journey times (mins)	% Difference	Check (within 15% or one minute)
		Outward journeys			
S01001792	S01002337	71.94	83.61	16.2%	Fail
S01001803	S01002300	59.96	65.87	9.9%	Pass
S01001809	S01001844	54.45	54.92	0.9%	Pass
S01001851	S01002268	49.09	54.62	11.3%	Pass
S01001935	S01002256	50.24	53.12	5.7%	Pass
S01001954	S01002326	53.75	62.72	16.7%	Fail
S01002012	S01002013	26.86	30.79	14.6%	Pass
S01002062	S01002257	25.31	25.82	2%	Pass
S01002092	S01002331	39.95	43.54	9%	Pass
S01002128	S01002090	32.30	36.19	12.1%	Pass
S01002177	S01002283	23.69	26.62	12.4%	Pass
S01002213	S01002132	56.49	65.36	15.7%	Fail
S01002261	S01002260	51.75	55.40	7%	Pass
S01002269	S01001816	54.54	61.69	13.1%	Pass
S01002301	S01001860	56.40	62.47	10.8%	Pass
		Return journeys			
S01002337	S01001792	74.96	79.35	5.9%	Pass
S01002300	S01001803	56.33	63.74	13.1%	Pass
S01001844	S01001809	52.04	56.50	8.6%	Pass
S01002268	S01001851	48.13	55.02	14.3%	Pass
S01002256	S01001935	45.24	53.07	17.3%	Fail
S01002326	S01001954	54.02	62.61	15.9%	Fail
S01002013	S01002012	24.53	27.12	10.6	Pass
S01002257	S01002062	23.06	24.18	4.8%	Pass
S01002331	S01002092	37.42	41.39	10.6	Pass
S01002090	S01002128	33.94	38.90	14.6%	Pass
S01002283	S01002177	20.87	22.97	10.1%	Pass
S01002132	S01002213	56.87	62.66	10.2%	Pass
S01002260	S01002261	48.81	53.24	9.1%	Pass
S01001816	S01002269	56.50	62.84	11.2%	Pass
S01001860	S01002301	55.36	63.21	14.2%	Pass
Number of routes considered					30
Number of SNAPTA-modelled journey times within 15% or one minute of CEC model journey times					25
Percentage of SNAPTA-modelled journey times within 15% or one minute of CEC model journey times					83.33%

From Table A.1 it can be seen that the journey time validation meets the DMRB guidance in the comparison against Lothian Buses actual journey times. It shows a very good level of fit between observed and modelled journey times. 90% of the SNAPTA-modelled journey times pass the DMRB criteria, achieving a difference within 15% of observed times (see Table A.1). On the other hand, SNAPTA outputs do not meet the DMRB criteria when they are compared against modelled journey times produced by the Council accessibility tool. Table A.2 shows that 83.33% of the tool journey times pass the criteria for the 30 routes tested. It can be noticed in the comparison that all the listed SNAPTA journey times are longer than those of the CEC tool. This can be explained by the dependence of the two tools on different modelling approaches to calculating the time of journey components. The CEC accessibility tool calculates travel time by public transport, including walking, waiting and interchange time from any origin to any destination based on population weighted centroids of Data Zones. However, unlike SNAPTA, it does not consider the influence of slope and traffic volume which results in shorter walk times compared with SNAPTA. In this context, the journey time validation results suggest that, overall, SNAPTA reasonably represents the journey times in Edinburgh Council's area.

Furthermore, to test the tool for correct coding and programming, an additional check was undertaken by calculating manually and individually the component journey times between the set of origin-destination pairs defined in Figure A.1. The obtained values were checked against their corresponding journey time segments in the model. The journeys involved were broken down into stages to check the distances of links, time of travel through the links (according to the associated bus timetables), the calculation of walk distance, the slope and traffic volume weightings assigned for walking time within the zones involved, interchange time, and interchange options available at each bus stop.

Sensitivity check

As a part of validation, the sensitivity check comprises tests that monitor the responses of an accessibility tool to transport, land-use, socio-economic or political changes. Sensitivity is often expressed as the elasticity of a variable (Wegmann and Everett, 2008). Changing a value of one of the tool variables should identify the impact on the outputs. In this context, the sensitivity check adopted for SNAPTA has been carried out by making a number of changes in the modelling parameters and input and examining the associated impacts on accessibility values obtained.

The first sensitivity check involves not considering physical features in the calculation of accessibility by ignoring the influence of slope and traffic volume (see Chapter 5, Section 5.7) within a zone on walk time delay between the centroids and public transport facilities. This change was applied to test the consequence for journey times between the same set of pairings defined in the previous subsection (see Figure A.1). Table A.3 presents a comparison of journey times with and without considering the impact of physical features on walking. It can be seen that the modelled journey times are sensitive to the value of walking time weighting estimated for each zone based on the ambient air quality and the variation in height values. As it was logically expected, all the values of journey times in the case of considering the impact of physical features are greater than their corresponding values when the physical features are not considered. The result indicates that the time differences between the two cases do not exceed 8 minutes for the whole journey since 4 minutes is the limit imposed on the weighting value for walking time for each of the origin and destination zone (see Chapter 5, Section 5.7 for more details).

Moreover, this sensitivity analysis was applied to examine whether the calculation of catchment/service areas is sensitive to the value of walking time weighting. Table A.4 shows the size of working-age population within 30, 40 and 60 minutes' travel time by bus from the four key employment sites with and without considering the impact of physical constraints on walking time. It is clear from the table that the sizes of catchment areas and associated working-age population are always larger when no walking time weighting is taken into account in the calculation.

Table A.3: Comparison of SNAPTA journey times with and without considering the impact of physical constraints (i.e. slope and traffic volume) on walking time

Origin Data Zone	Destination Data Zone	Outward journeys times (mins)		Return journeys times (mins)	
		With consideration of physical constraints on walking	No consideration of physical constraints on walking	With consideration of physical constraints on walking	No consideration of physical constraints on walking
S01001792	S01002337	83.61	80.85	79.35	76.59
S01001803	S01002300	65.87	63.11	63.74	62.66
S01001809	S01001844	54.92	52.53	56.50	54.11
S01001851	S01002268	54.62	51.57	55.02	52.37
S01001935	S01002256	53.12	50.06	53.07	50.01
S01001954	S01002326	62.72	59.82	62.61	59.15
S01002012	S01002013	30.79	28.06	27.12	26.21
S01002062	S01002257	25.82	23.65	24.18	22.65
S01002092	S01002331	43.54	40.75	41.39	39.75
S01002128	S01002090	36.19	33.55	38.90	36.25
S01002177	S01002283	26.62	24.21	22.97	22.04
S01002213	S01002132	65.36	63.07	62.66	61.97
S01002261	S01002260	55.40	53.33	53.24	52.23
S01002269	S01001816	61.69	57.94	62.84	59.24
S01002301	S01001860	62.47	60.04	63.21	60.78

Table A.4: Working-age population (based on Scotland Census 2011) within 30, 40 and 60 minutes' travel time by public transport from the four key employment sites with and without considering the impact of physical constraints (i.e. slope and traffic volume) on walking time

Employment site	Working-age population within 30 minutes		Working-age population within 40 minutes		Working-age population within 60 minutes	
	With physical constraints	No physical constraints	With physical constraints	No physical constraints	With physical constraints	No physical constraints
Victoria Quay	73,445	92,373	141,242	168,654	290,000	303,688
South Gyle	16,259	28,647	57,427	83,273	233,932	265,983
Crewe Toll	52,594	77,090	153,820	196,259	313,300	325,915
City Centre	167,267	215,941	276,583	299,209	335,260	336,988

In addition, two further checks were undertaken to test SNAPTA sensitivity to changes in the transport and land-use systems in Edinburgh, which can be expressed as a policy validation. The first check involves recalculating average journey times of all the shortest bus journeys from each zone to all other zones after discounting Lothian Bus service number 22, which is one of the key and most frequent bus services in Edinburgh. This check aims to examine whether the size of population, households and those without access to cars associated with different ranges of average travel times by bus are sensitive to alterations in the transport network. From Table A.5, it can be noticed that without running the bus route number 22, the number of people with an average travel time (by public transport) of up to 45 minutes has declined while the result suggests that there are more people with 46-55 minutes average travel time. The other selectivity check focuses on the ability of the tool to respond to changes in land-use system by re-measuring the levels of public transport accessibility to main hospitals without considering Western General Hospital – one of the two main hospitals in Edinburgh – in the analysis. Levels of accessibility to main hospitals in the situation "without Western General Hospital" were calculated using the contour measure and compared to those of the "with Western General Hospital" situation in terms of the size of population and households without access to cars which are able to reach a main hospital within 30, 40 and 60 minutes' travel time by public transport. Table A.6 presents the results of the comparison which shows a significant decline in the size of groups living within a catchment area of at least one main hospital in Edinburgh. On the basis of the above analysis, it can be concluded that SNAPTA's outputs are sensitive to changes in transport and land-use systems

Table A.5: Population and households without access to cars or vans (based on Scotland Census 2011) which are able to travel to all other zones within different ranges of average shortest journey times (by bus) with and without considering bus service number 22

Average travel times of the shortest journeys to all zones	Population		Number of households		Households without access to cars or vans	
	With bus service number 22	Without bus service number 22	With bus service number 22	Without bus service number 22	With bus service number 22	Without bus service number 22
32 - 40 minutes	99,934	96,703	45,338	43,689	23,648	22,953
41 - 45 minutes	148,680	146,958	68,761	67,699	29,033	28,610
46 - 50 minutes	151,312	153,909	69,370	71,103	25,737	26,508
51 - 55 minutes	56,256	58,612	24,388	25,366	7,995	8,342
56 - 60 minutes	23,548	23,548	8,950	8,950	1,656	1,656
61 - 70 minutes	15,453	15,453	6,259	6,259	975	975

Table A.6: Population and households without access to cars or vans (based on Scotland Census 2011) within 30, 40 and 60 minutes travel from a main hospital, with and without considering the impact of Western General Hospital

Time threshold	Population		Number of households		Households without access to cars or vans	
	With Western General	Without Western General	With Western General	Without Western General	With Western General	Without Western General
30 minutes	139,526	60,343	61,266	25,158	26,071	11,944
40 minutes	312,603	124,868	140,460	52,344	59,899	22,029
60 minutes	482,133	425,909	217,726	192,957	88,290	80,492

Conclusion

The SNAPTA tool has been validated according to DMRB guidance to ensure its suitability for use. This appendix demonstrates that the tool has been successfully validated against observed journey times and supplemented by a comparison with journey time data produced by another accessibility tool, which together provide broad coverage across the transport network in Edinburgh Council's area. Generally the journey time comparison shows consistency between modelled and observed journey time profiles across the majority of the tested routes. In addition, a sensitivity analysis was carried out in order to validate the application of SNAPTA in various situations. The results show that accessibility values calculated are sensitive to changes in values of the modelling parameters as well as changes in the land-use and transport systems.

It should be noted, however, that deciding whether an accessibility tool is accurate and credible requires a clear definition of the purpose intended to allow one to judge a tool by its suitability for use. According to DMRB, the accuracy of any transport model cannot be expected to represent reality except within a given range or tolerance. Moreover, in most cases it is not necessary to go to great lengths to reduce that range and seek greater precision (DfT, 1997). Therefore, it is stated in DMRB that what is important is to ensure: 1) that the degree of accuracy is adequate for the decisions which need to be taken; 2) that the decision makers understand the quality of the information with which they are working; and 3) that they take the inherent uncertainties into account in reaching decisions (DfT, 1997). In this respect, taking into account the validation results in this appendix together with the objectives of the development and applications of SNAPTA (see Chapters 5 and 6), the author of this thesis is confident that the tool is sufficient in quality to represent real world conditions and is deemed a robust platform for accessibility measuring and forecasting within the study area.

APPENDIX B:

Additional Output Maps of Accessibility Changes between the Baseline Year 2011 and Future Scenarios – Travel Time Measure

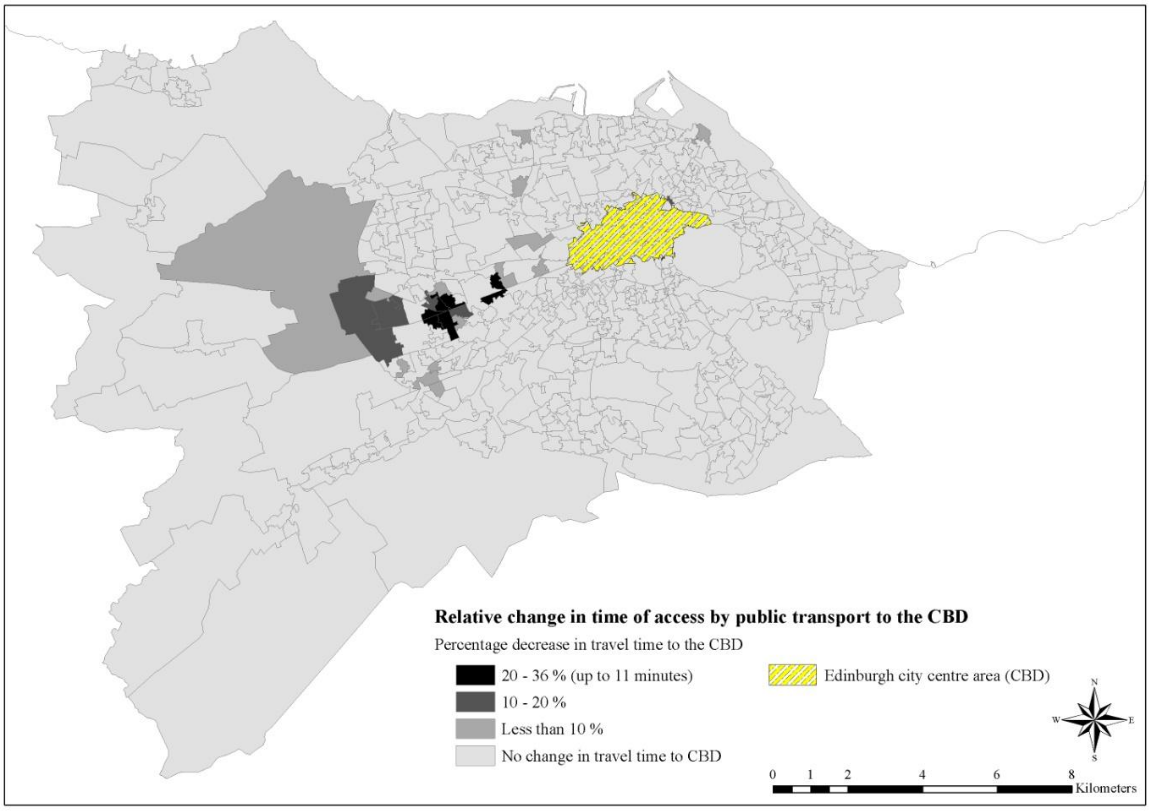

Figure B.1: Relative change in travel time by public transport to the CBD between the baseline year 2011 scenario and Scenario G

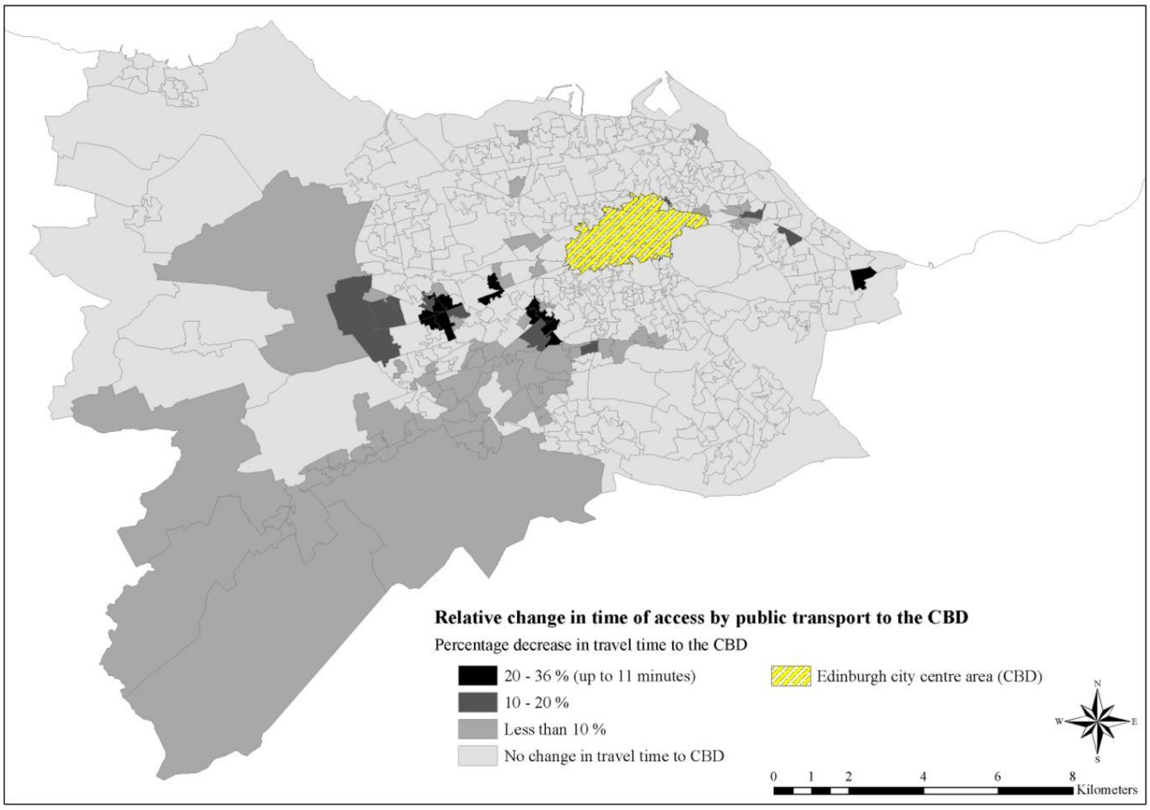

Figure B.2: Relative change in travel time by public transport to the CBD between the baseline year 2011 scenario and Scenario I

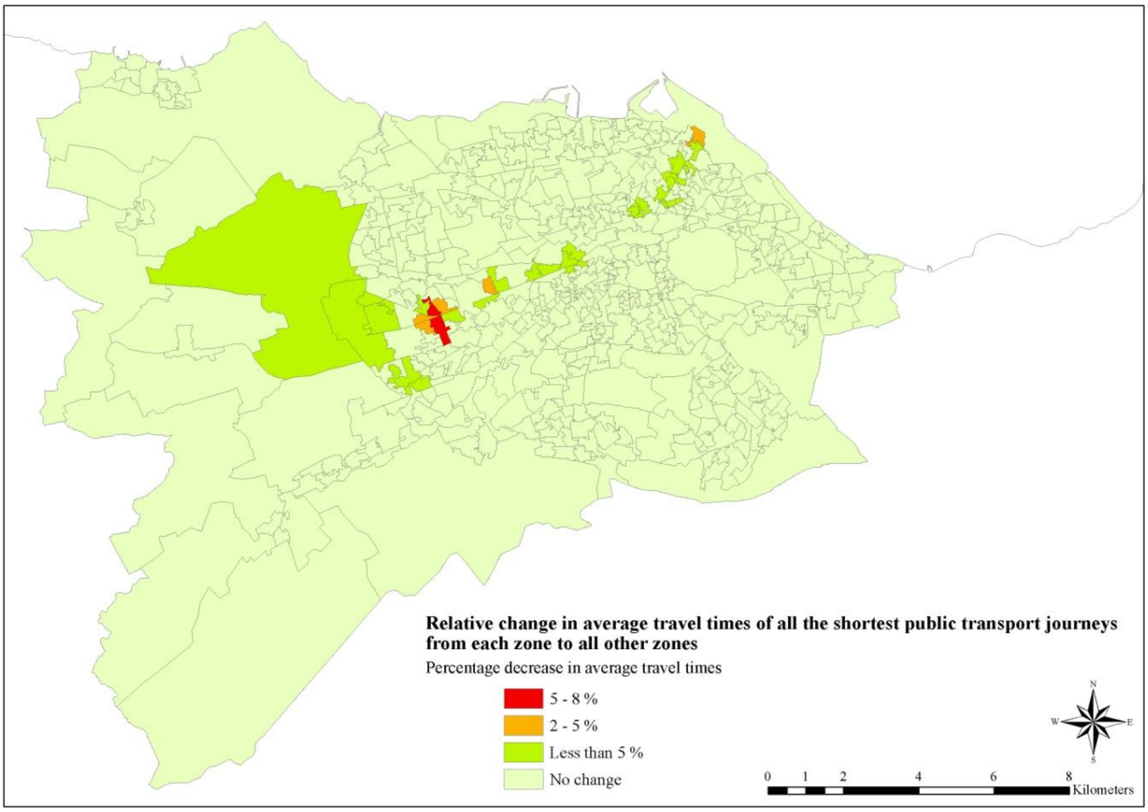

Figure B.3: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario C

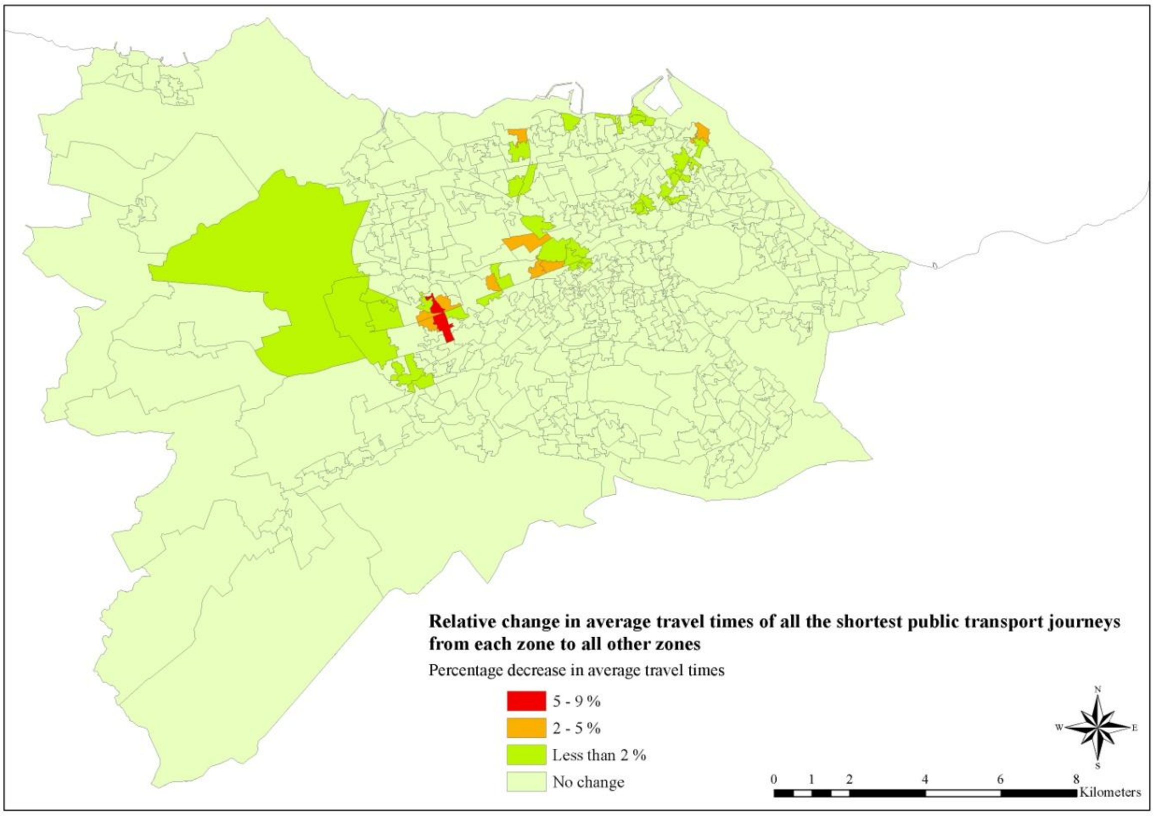

Figure B.4: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario D

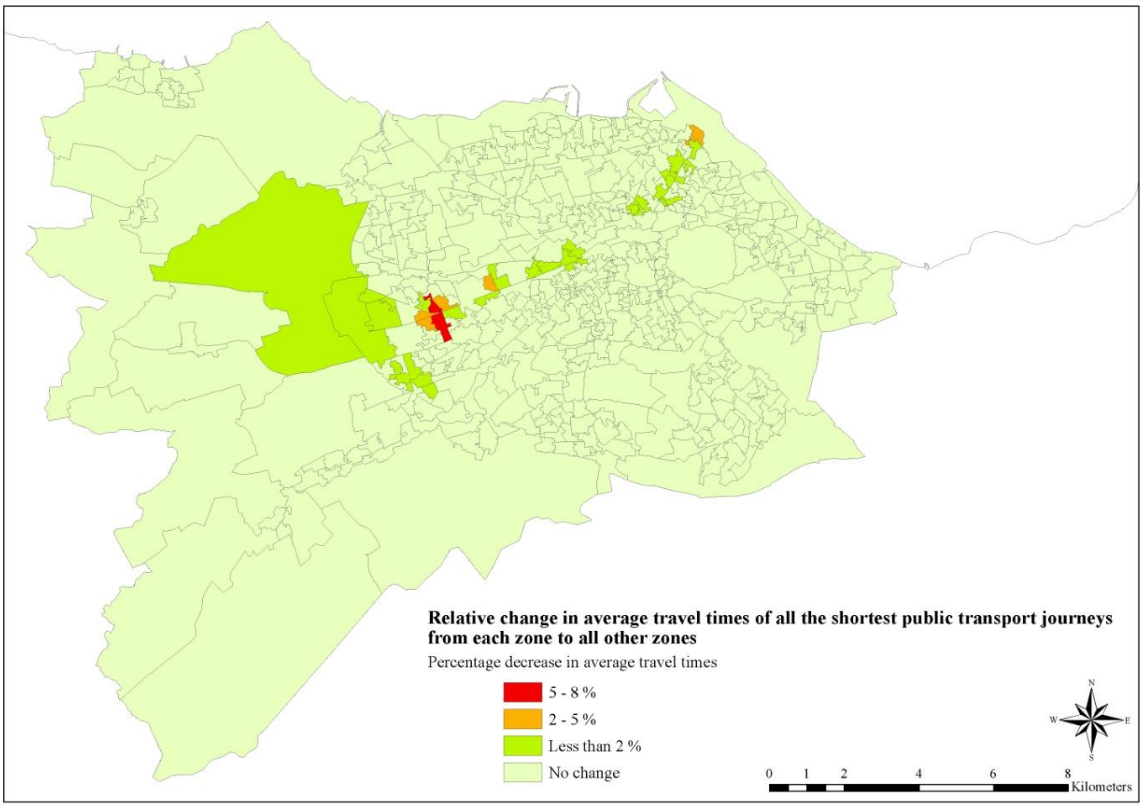

Figure B.5: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario E

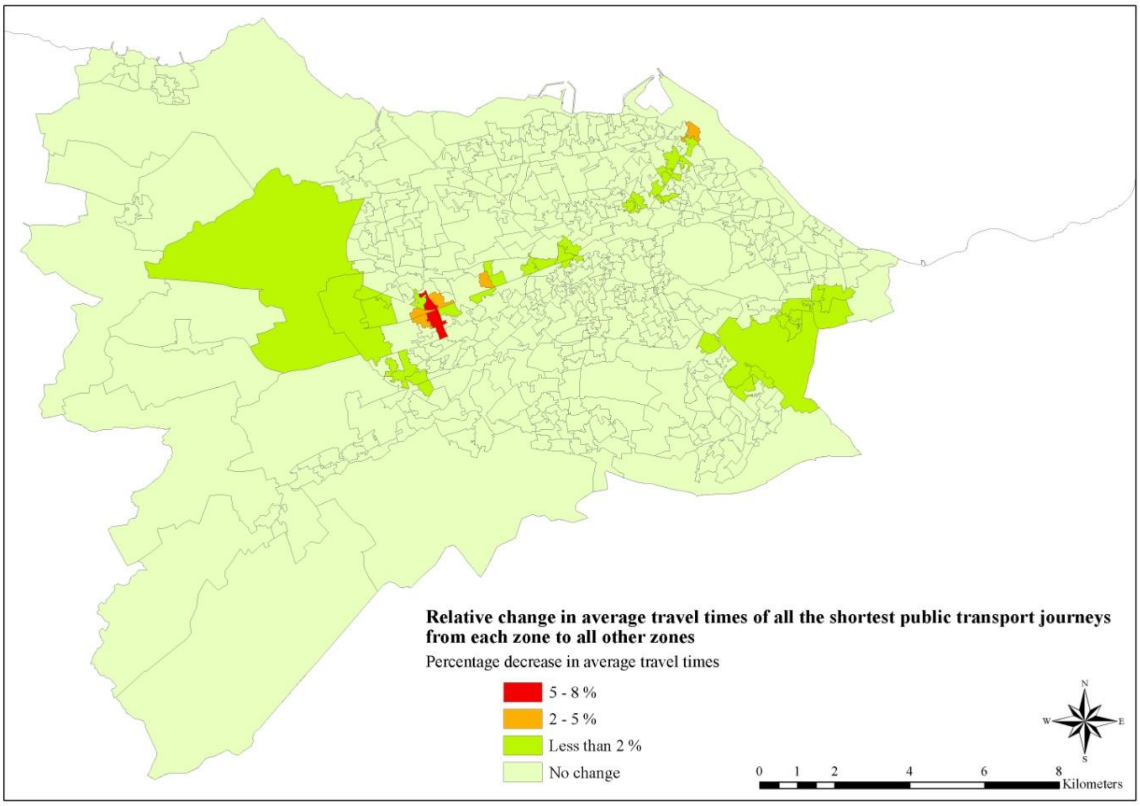

Figure B.6: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario F

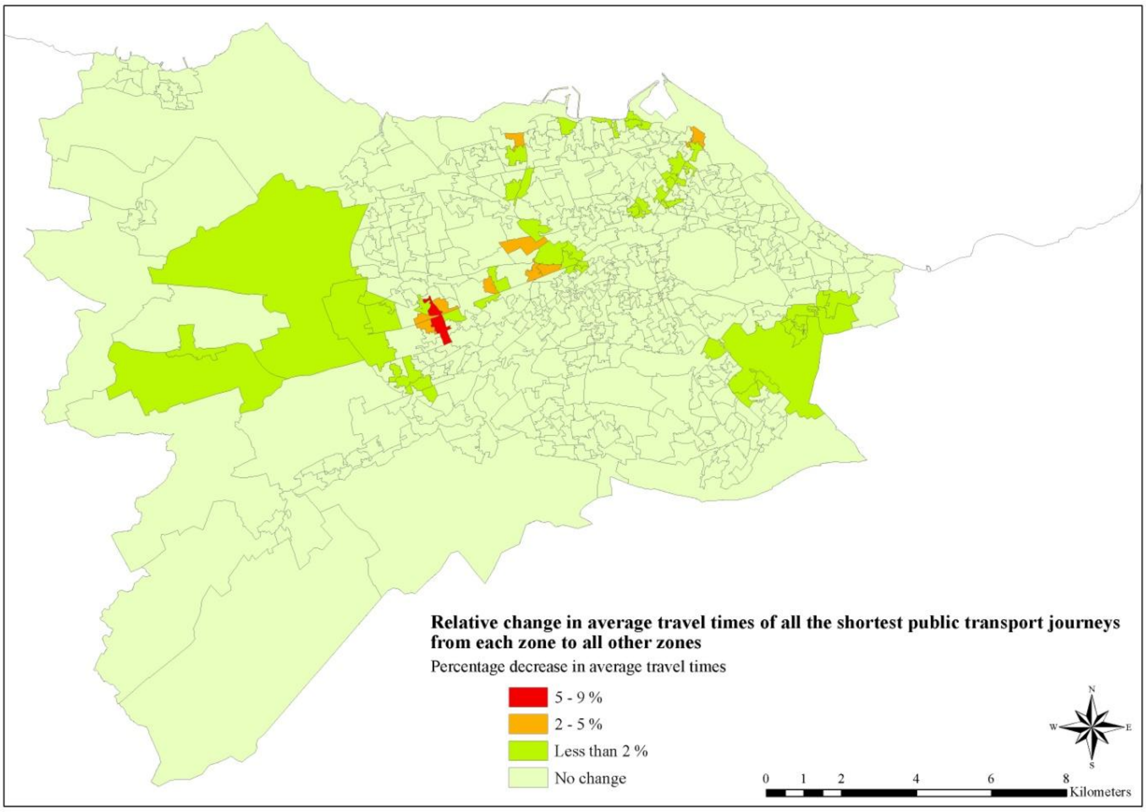

Figure B.7: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario G

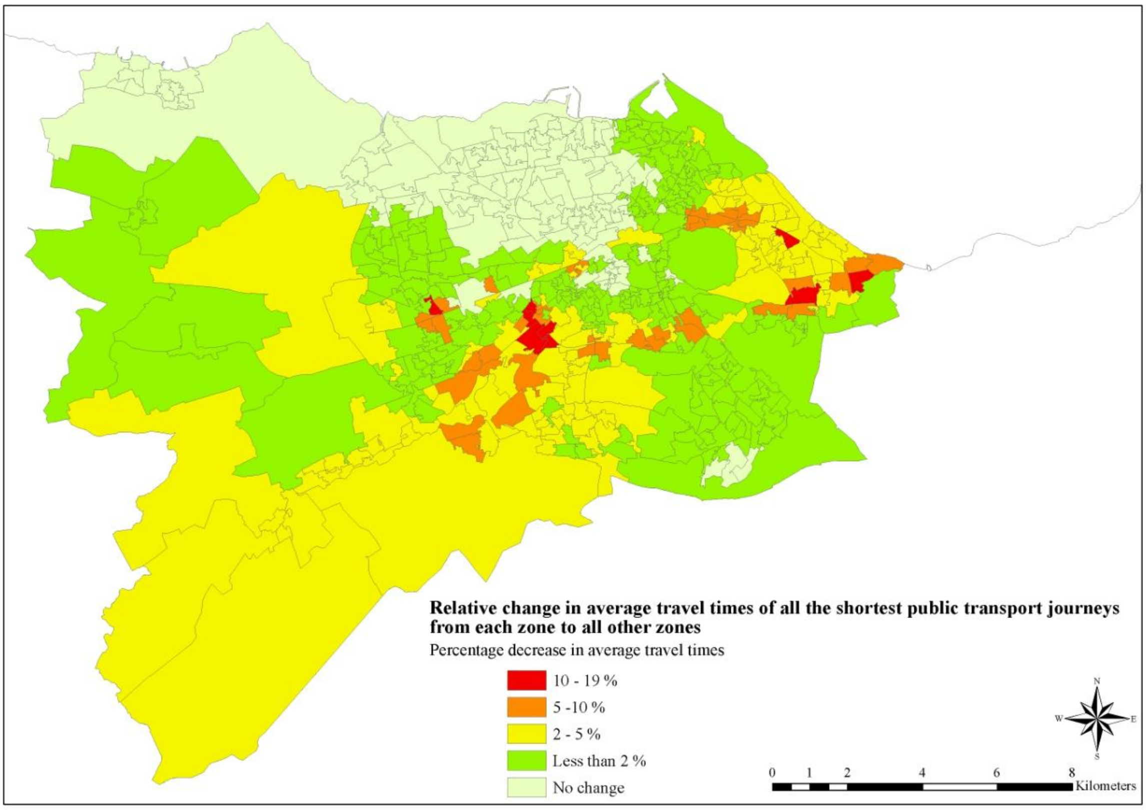

Figure B.8: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario H

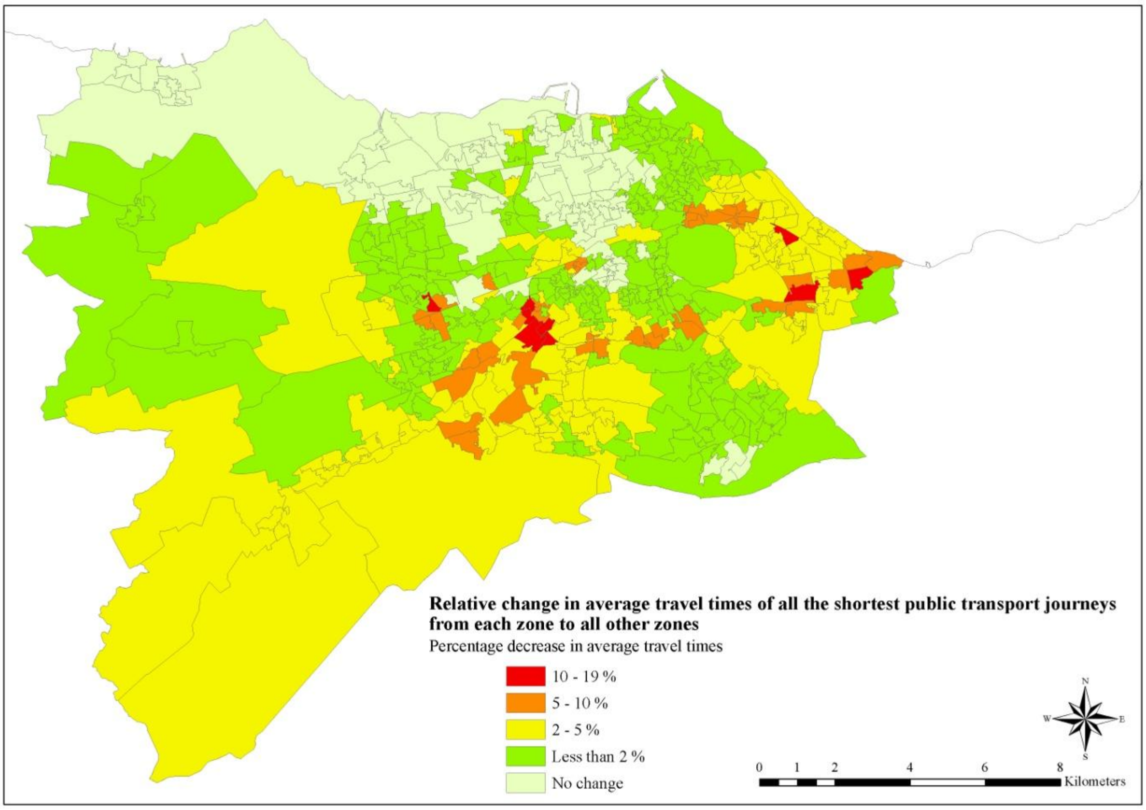

Figure B.9: Relative change in the average travel times of all the shortest public transport journeys (from each zone to all other zones) between the baseline year 2011 scenario and Scenario I

APPENDIX C:

Additional Output Maps of Accessibility Changes between the Baseline Year 2011 and Future Scenarios – Contour Measure

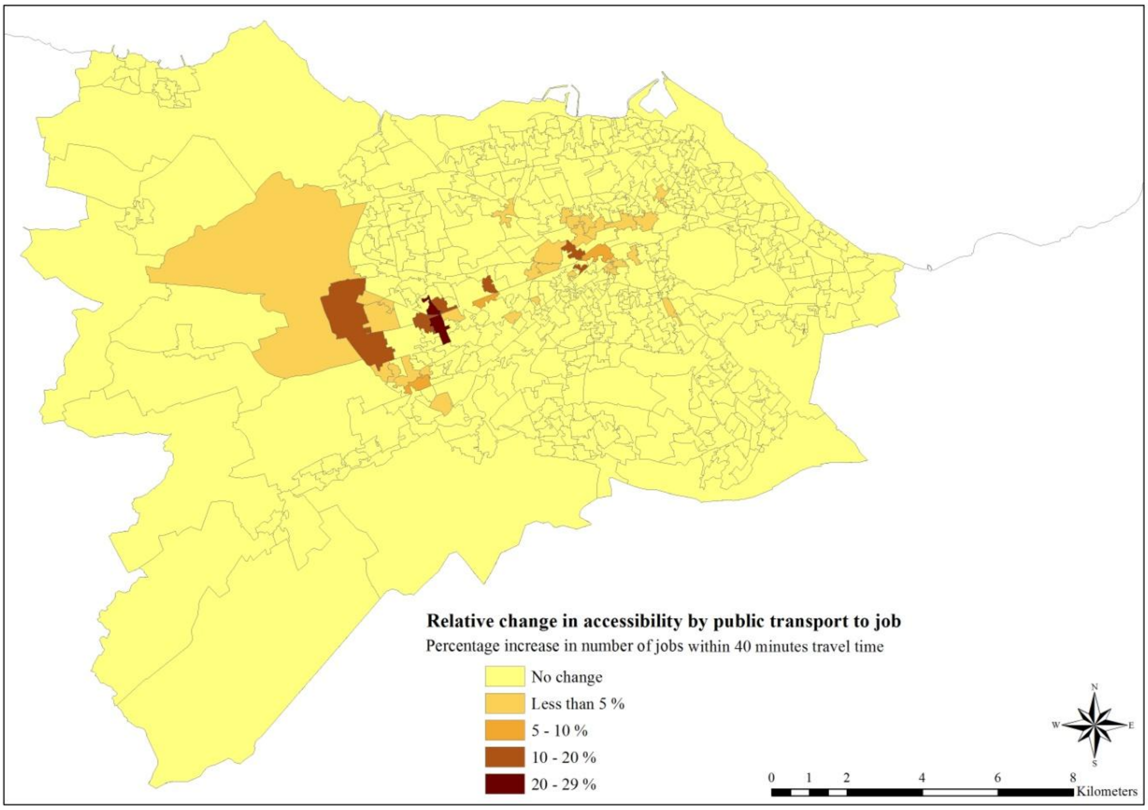

Figure C.1: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario C, using the contour measure

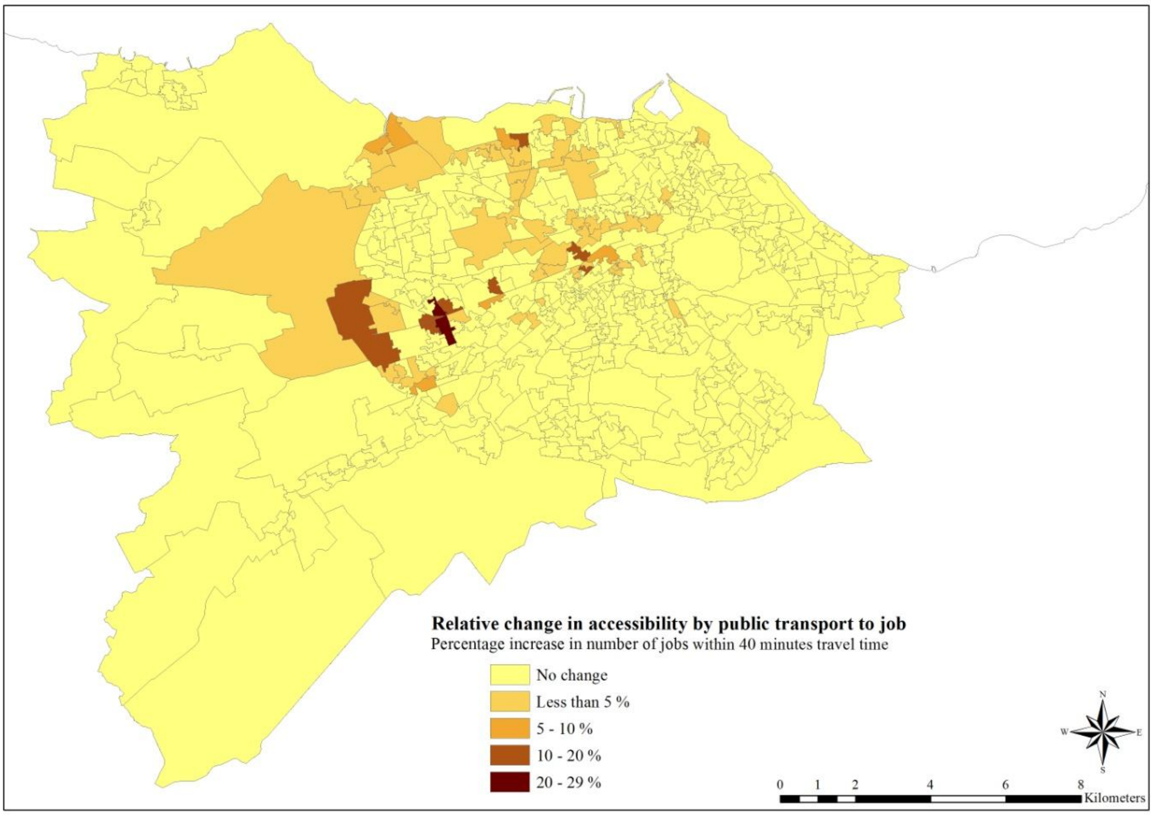

Figure C.2: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario D, using the contour measure

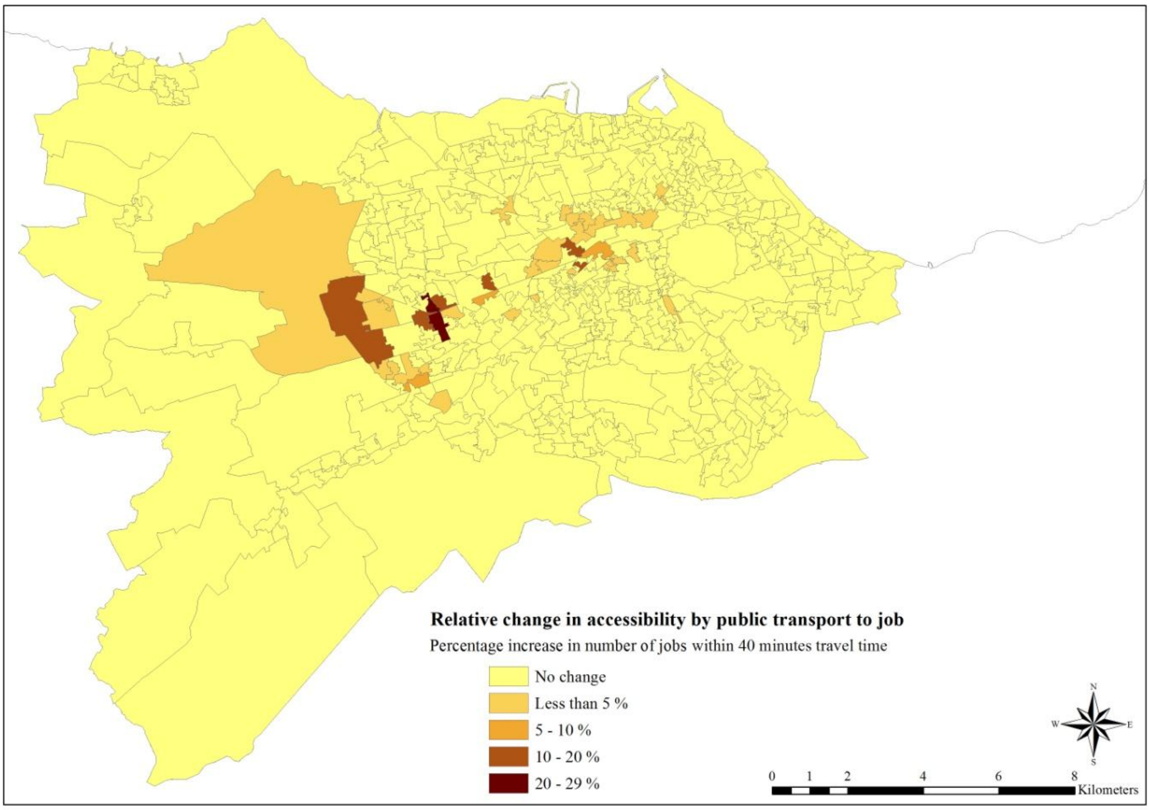

Figure C.3: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario E, using the contour measure

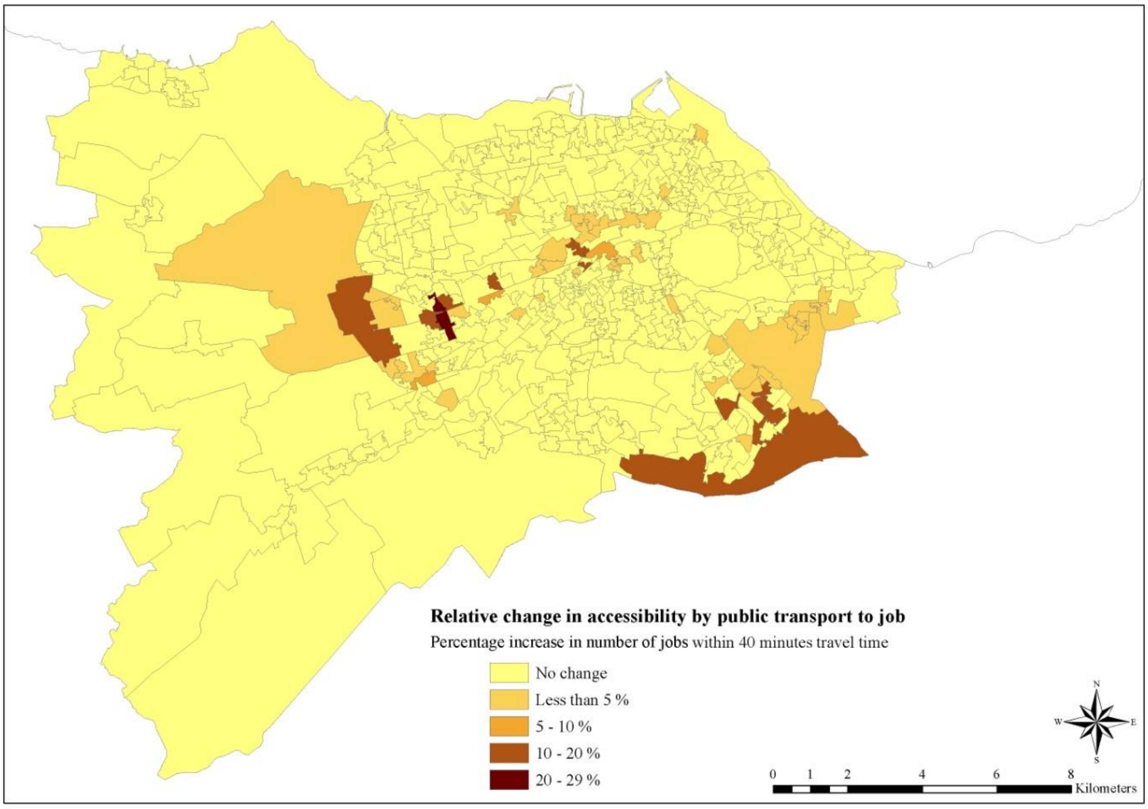

Figure C.4: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario F, using the contour measure

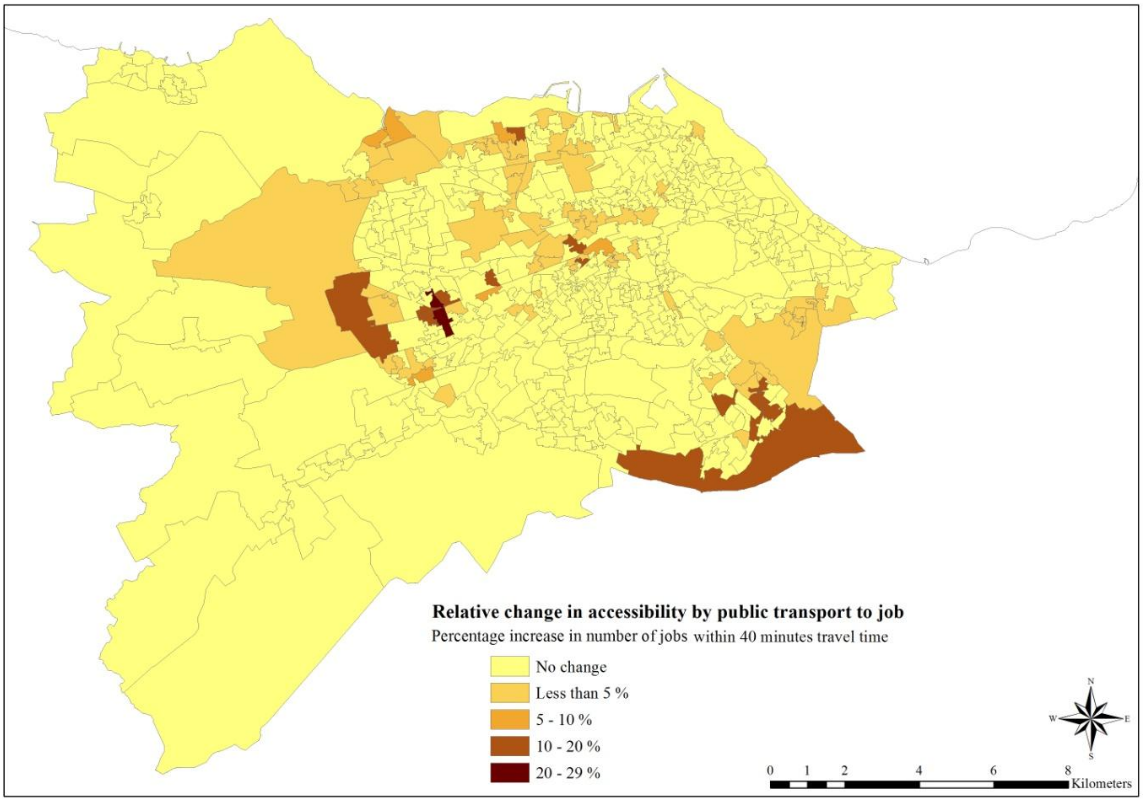

Figure C.5: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario G, using the contour measure

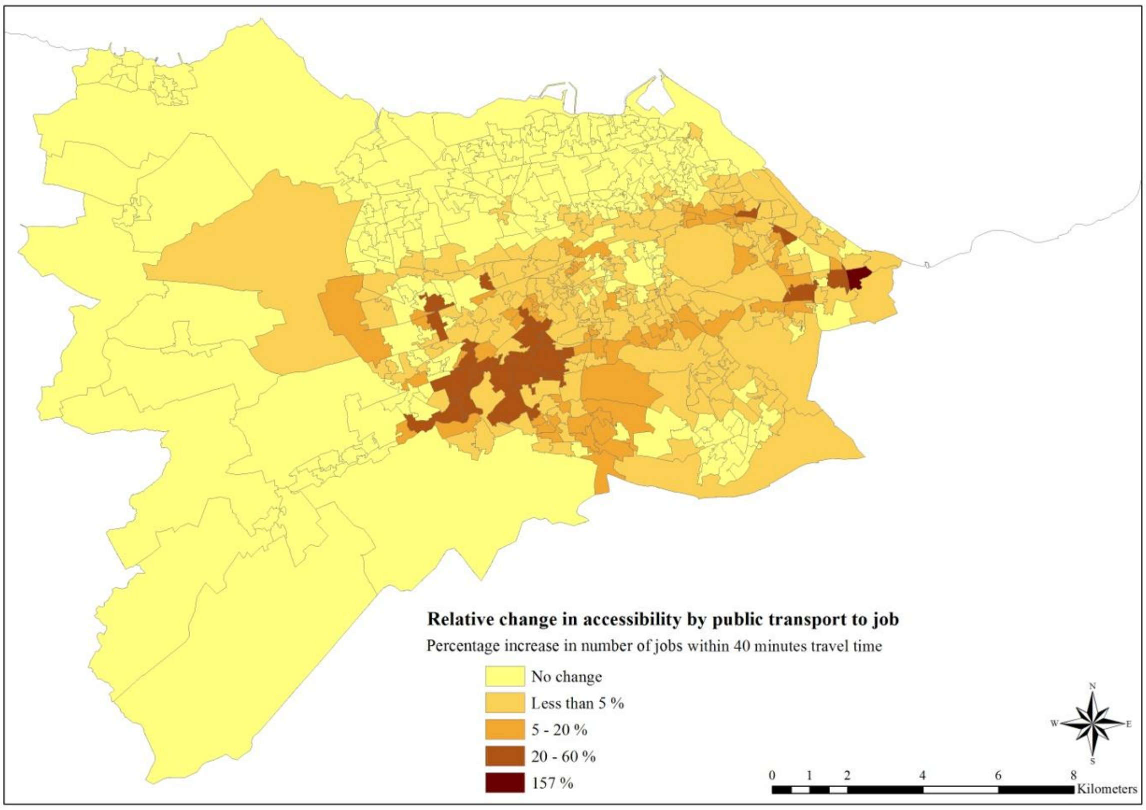

Figure C.6: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario H, using the contour measure

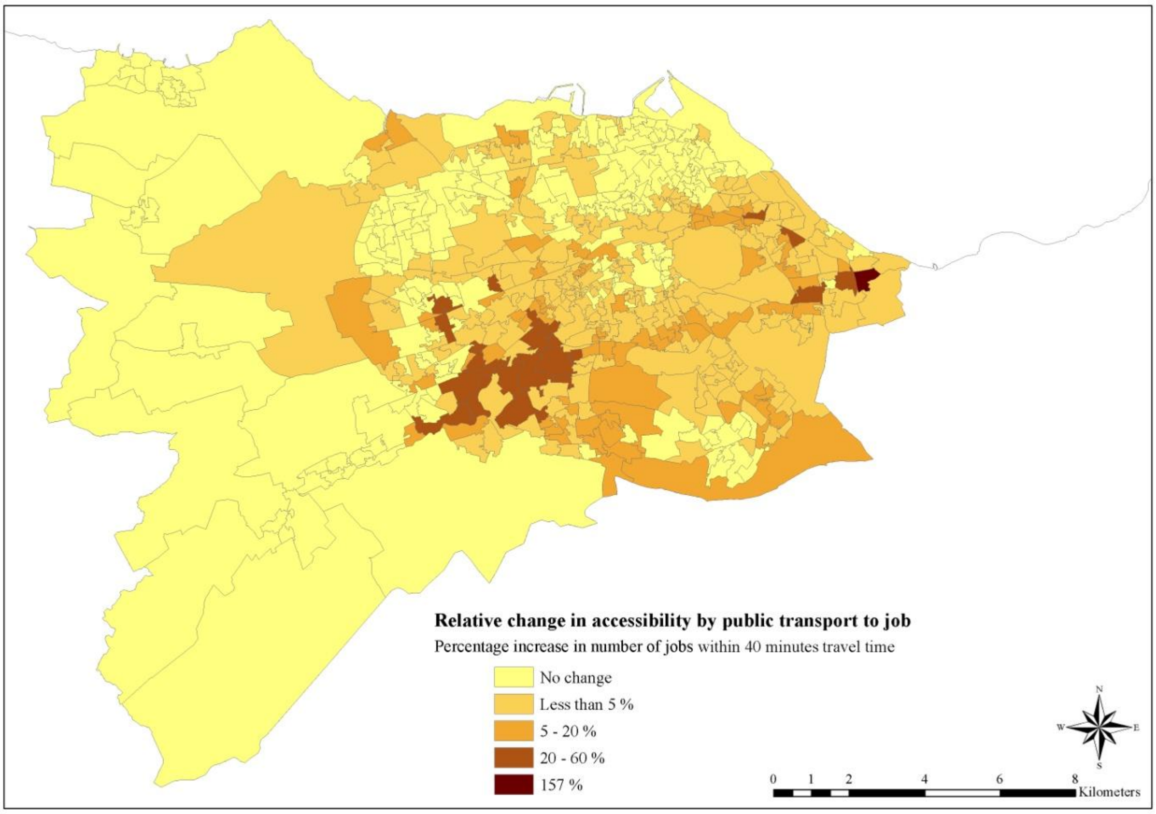

Figure C.7: Relative change in accessibility by public transport to jobs between the baseline year 2011 scenario and Scenario I, using the contour measure

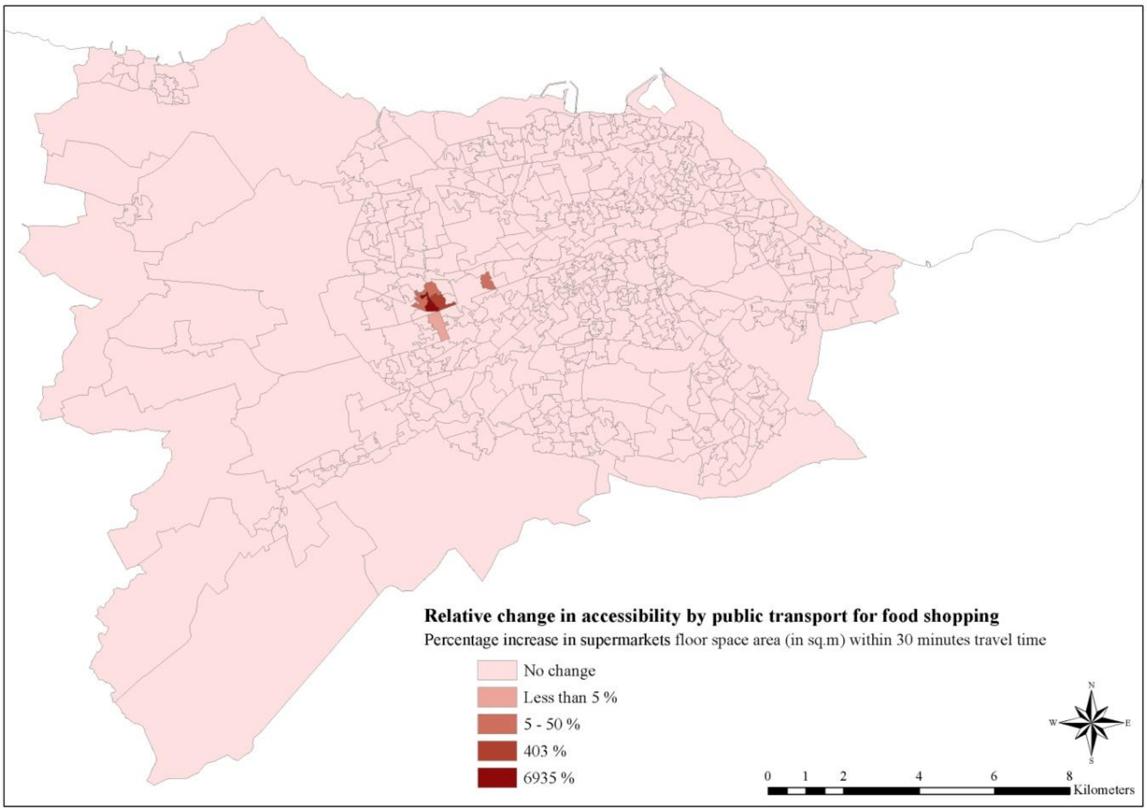

Figure C.8: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario C, using the contour measure

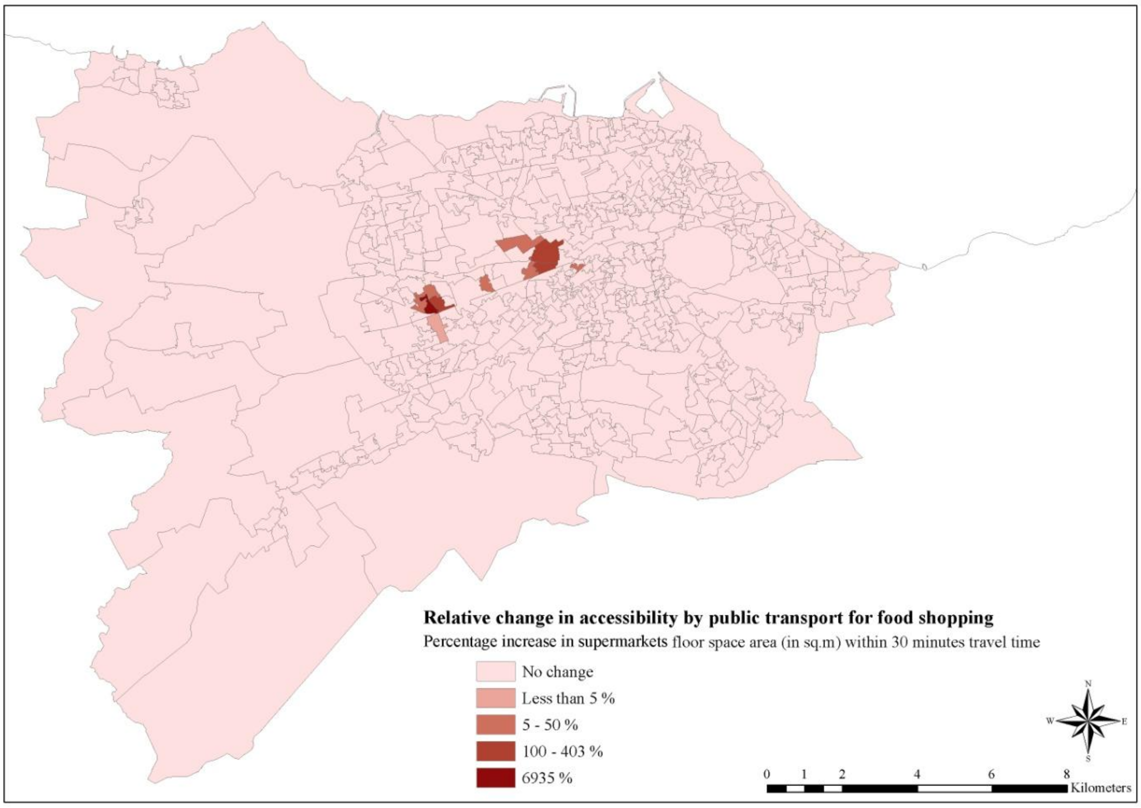

Figure C.9: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario D, using the contour measure

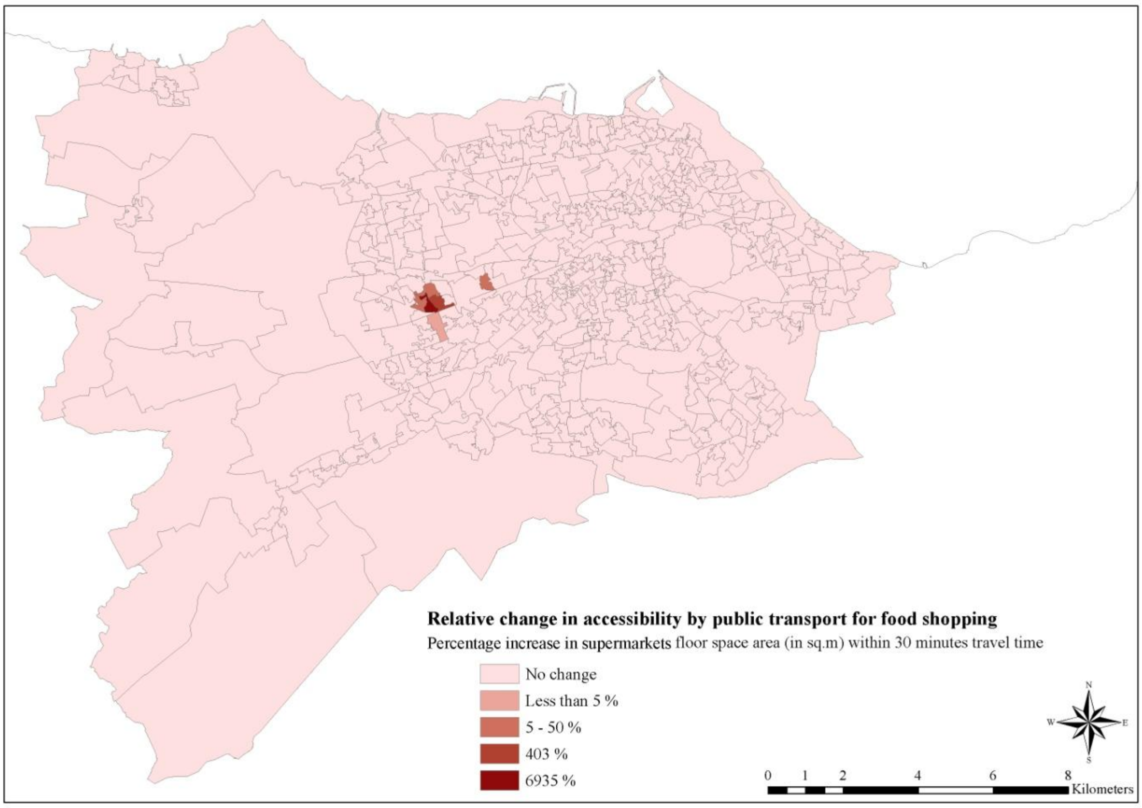

Figure C.10: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario E, using the contour measure

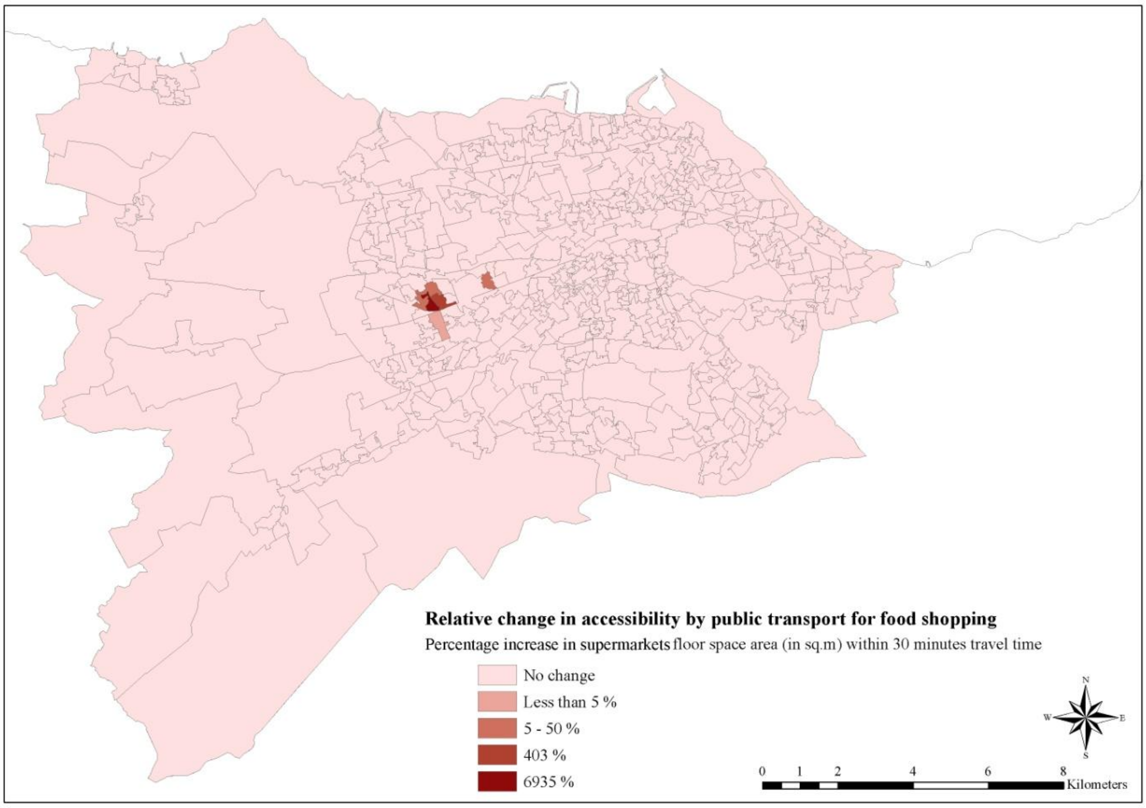

Figure C.11: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario F, using the contour measure

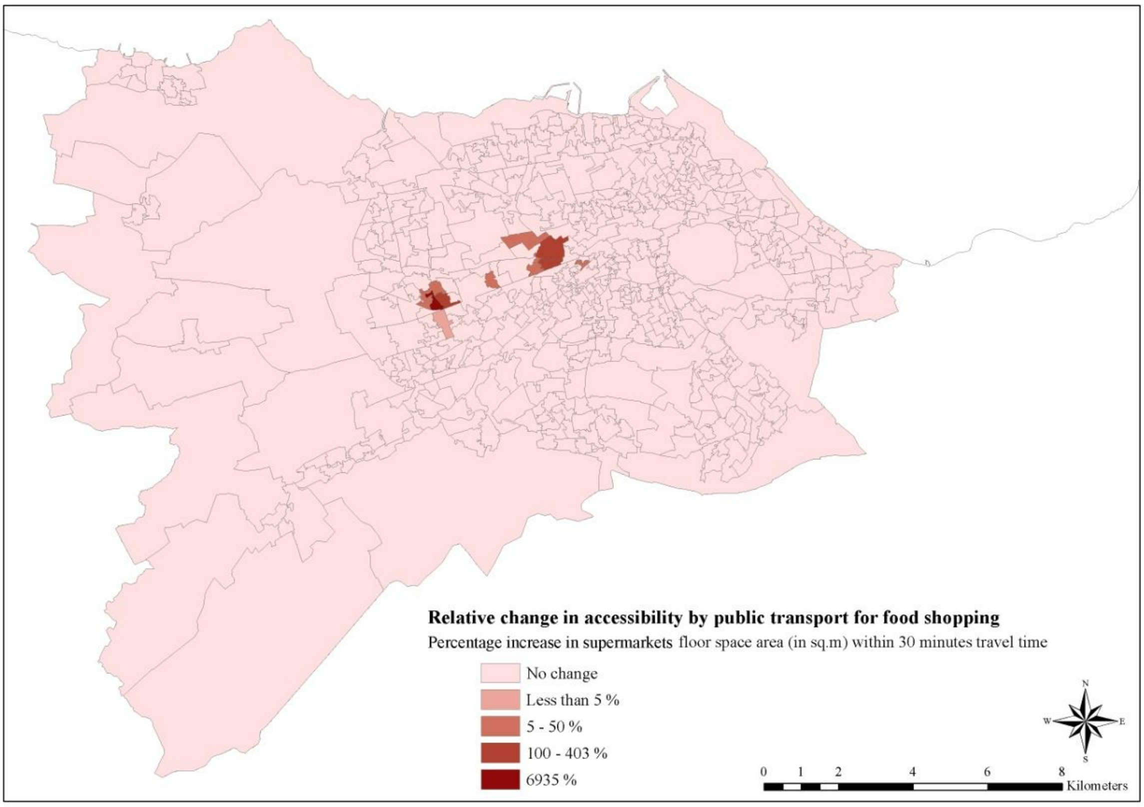

Figure C.12: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario G, using the contour measure

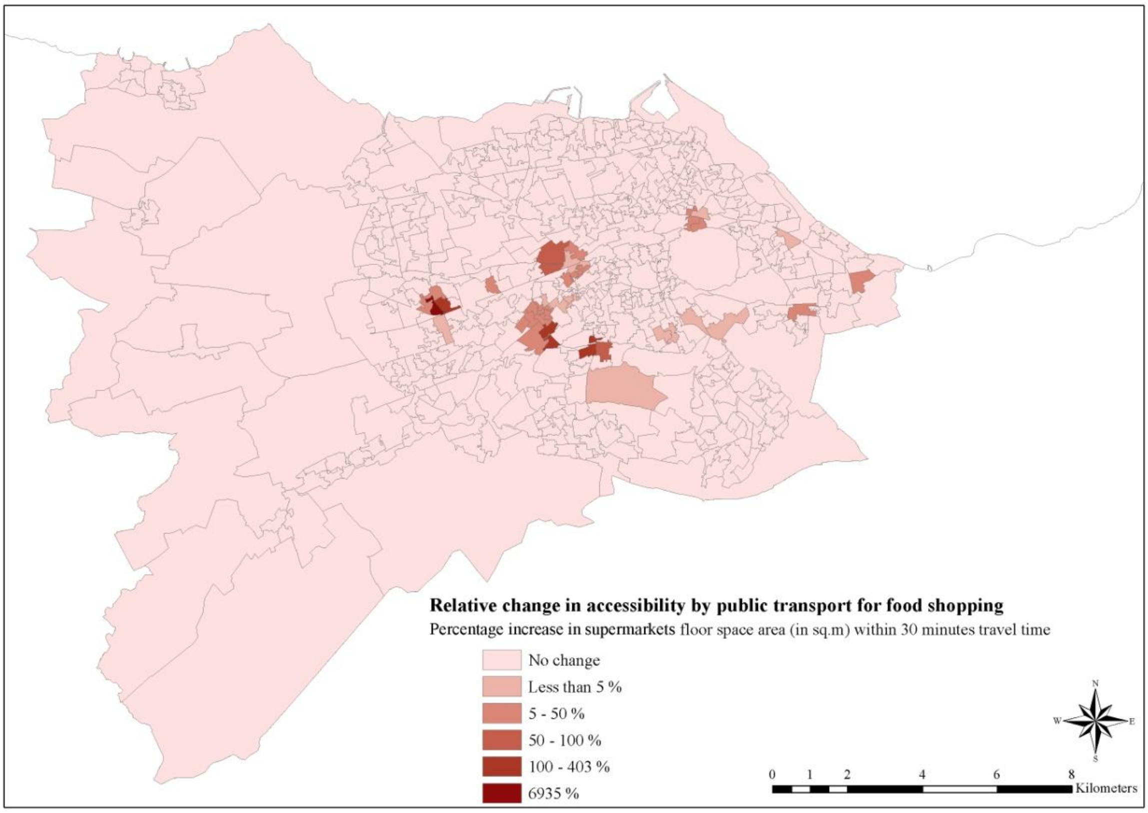

Figure C.13: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario H, using the contour measure

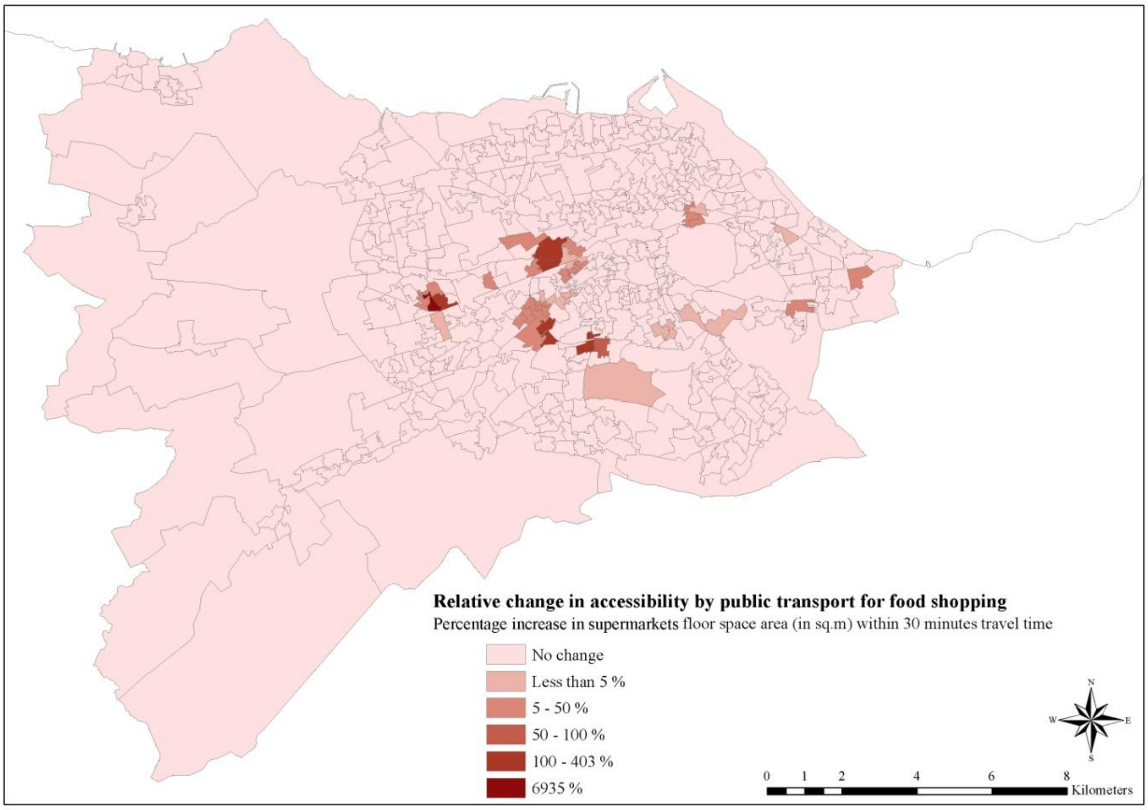

Figure C.14: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario I, using the contour measure

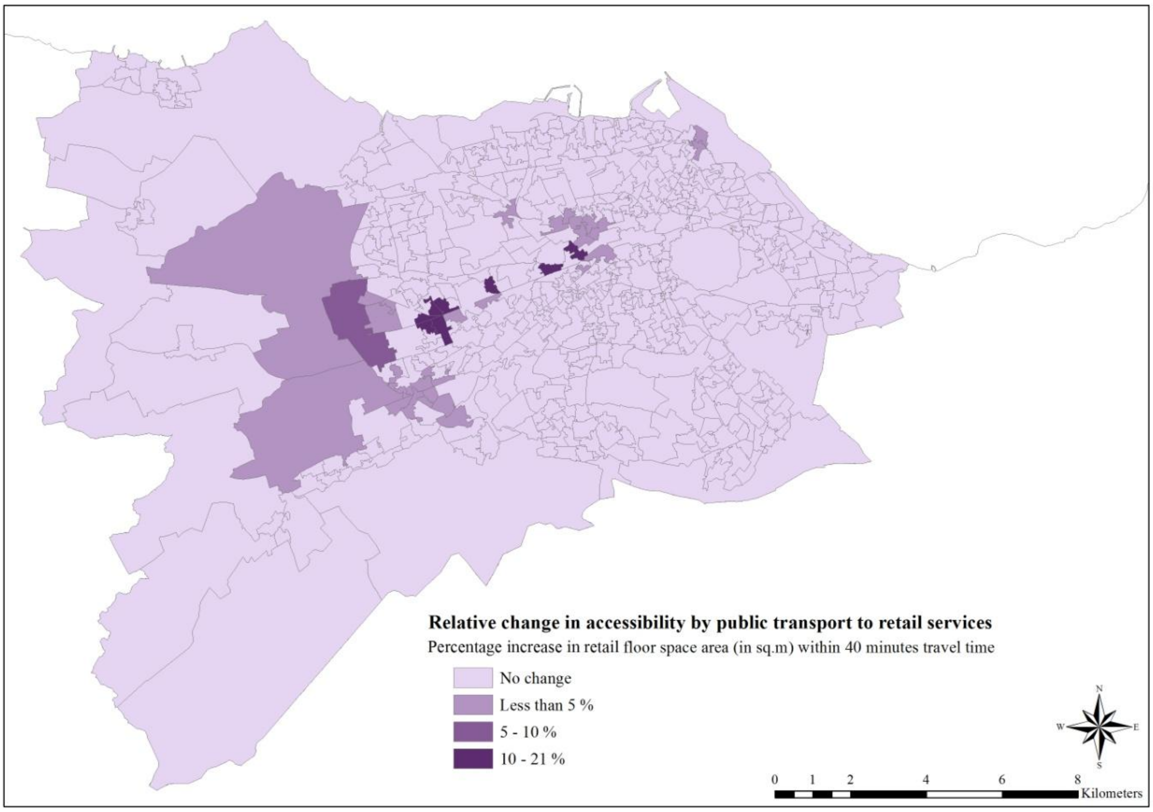

Figure C.15: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario C, using the contour measure

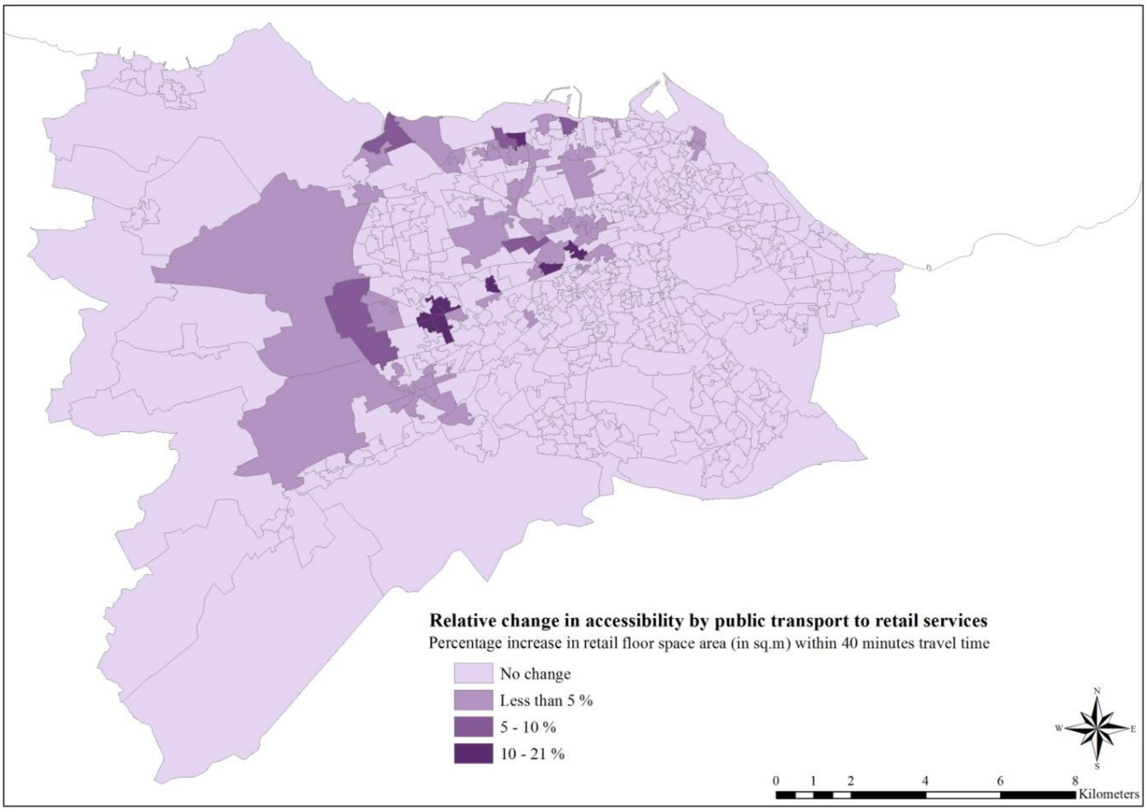

Figure C.16: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario D, using the contour measure

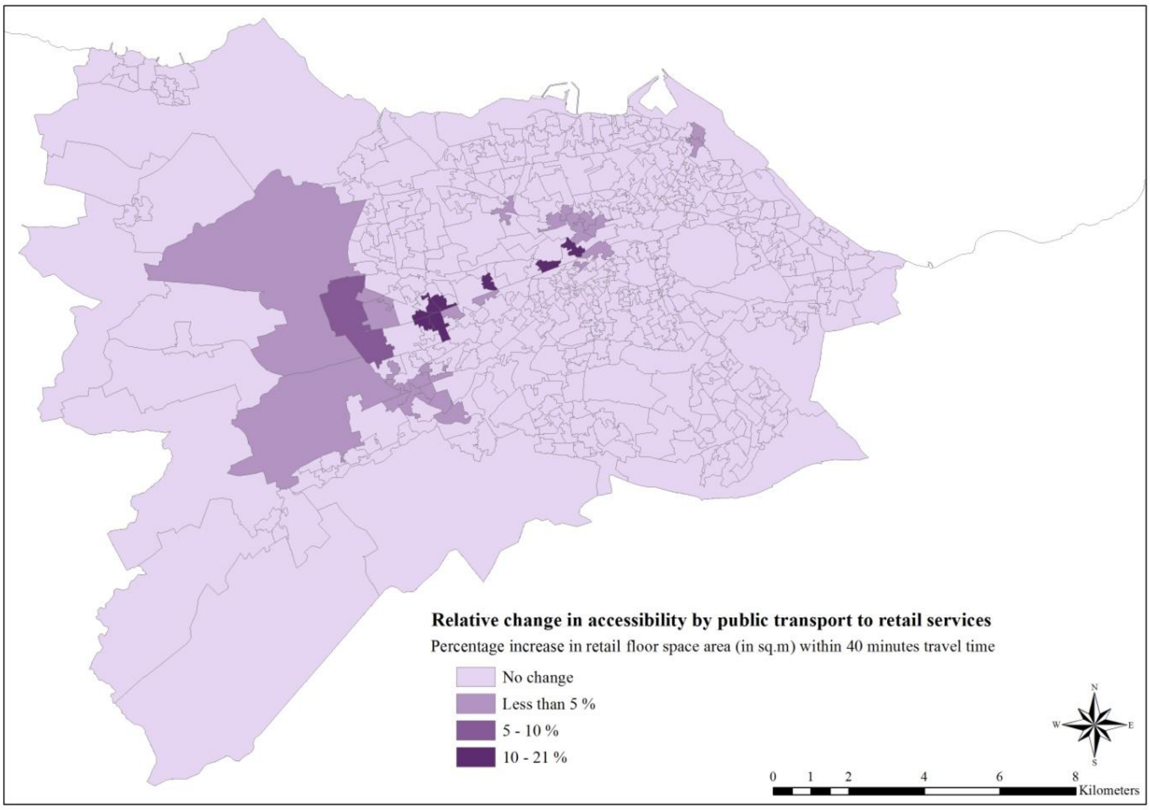

Figure C.17: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario E, using the contour measure

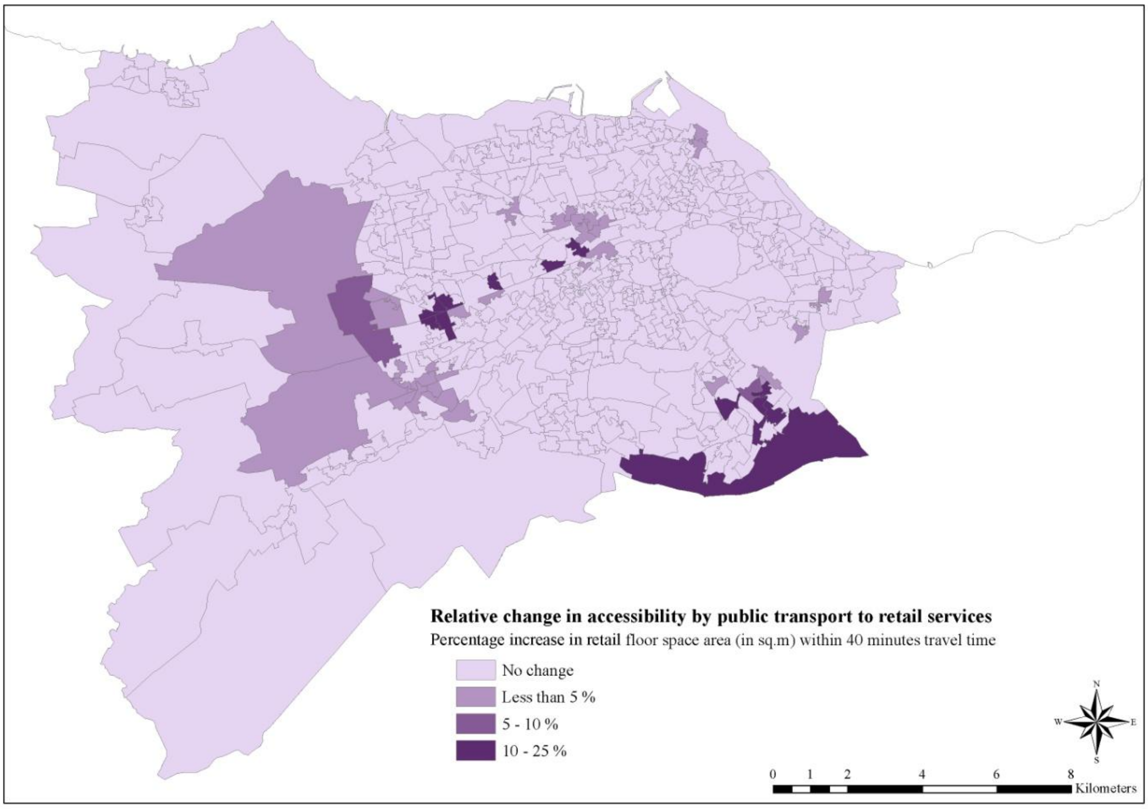

Figure C.18: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario F, using the contour measure

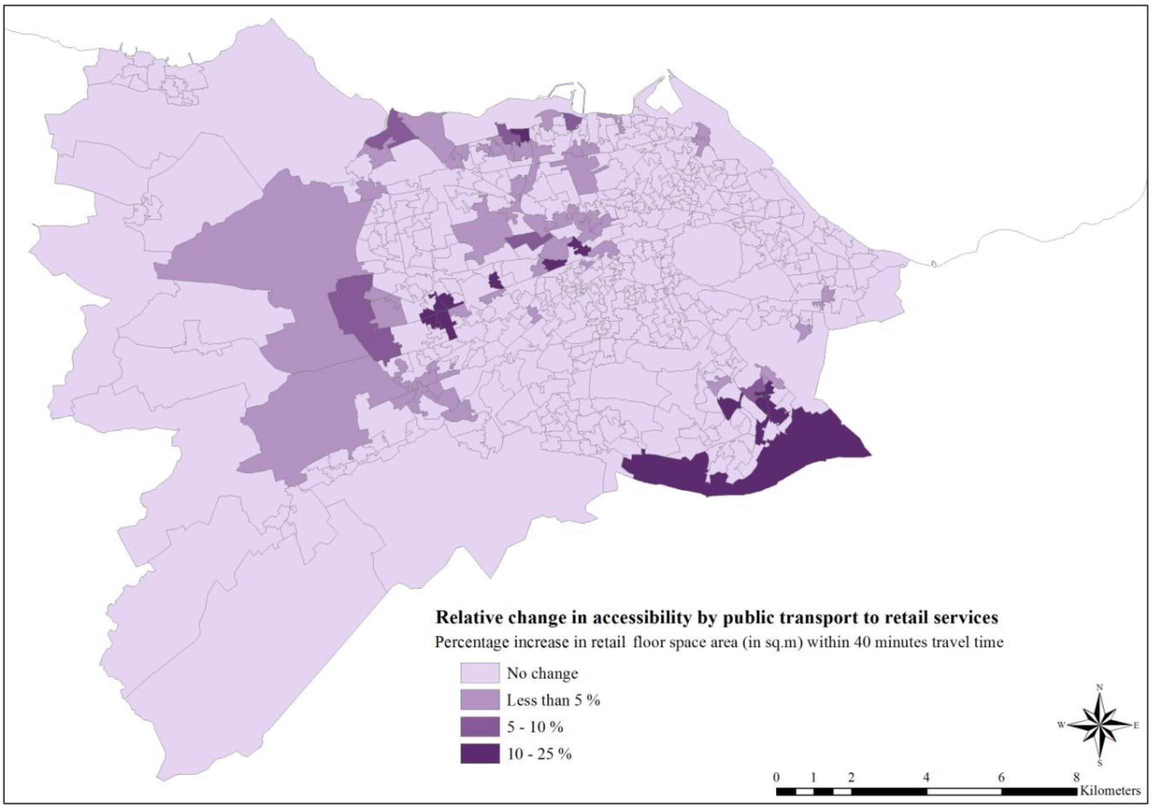

Figure C.19: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario G, using the contour measure

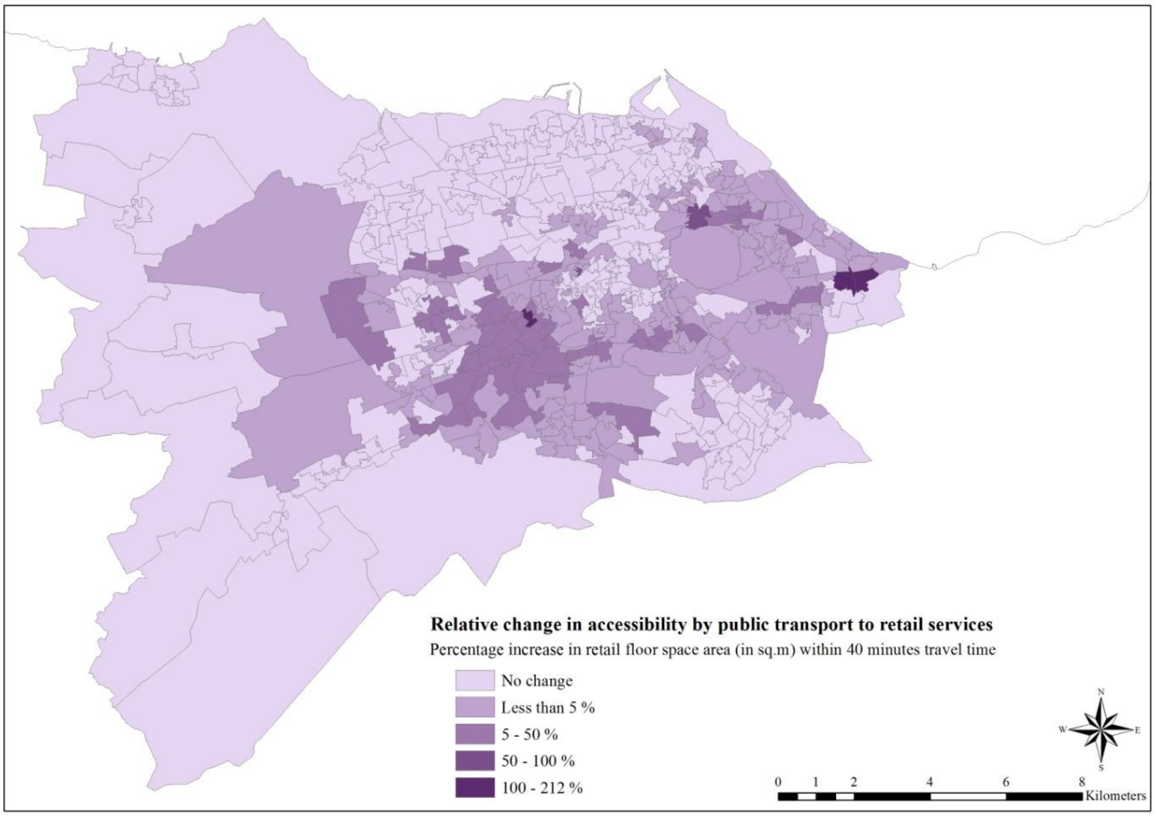

Figure C.20: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario H, using the contour measure

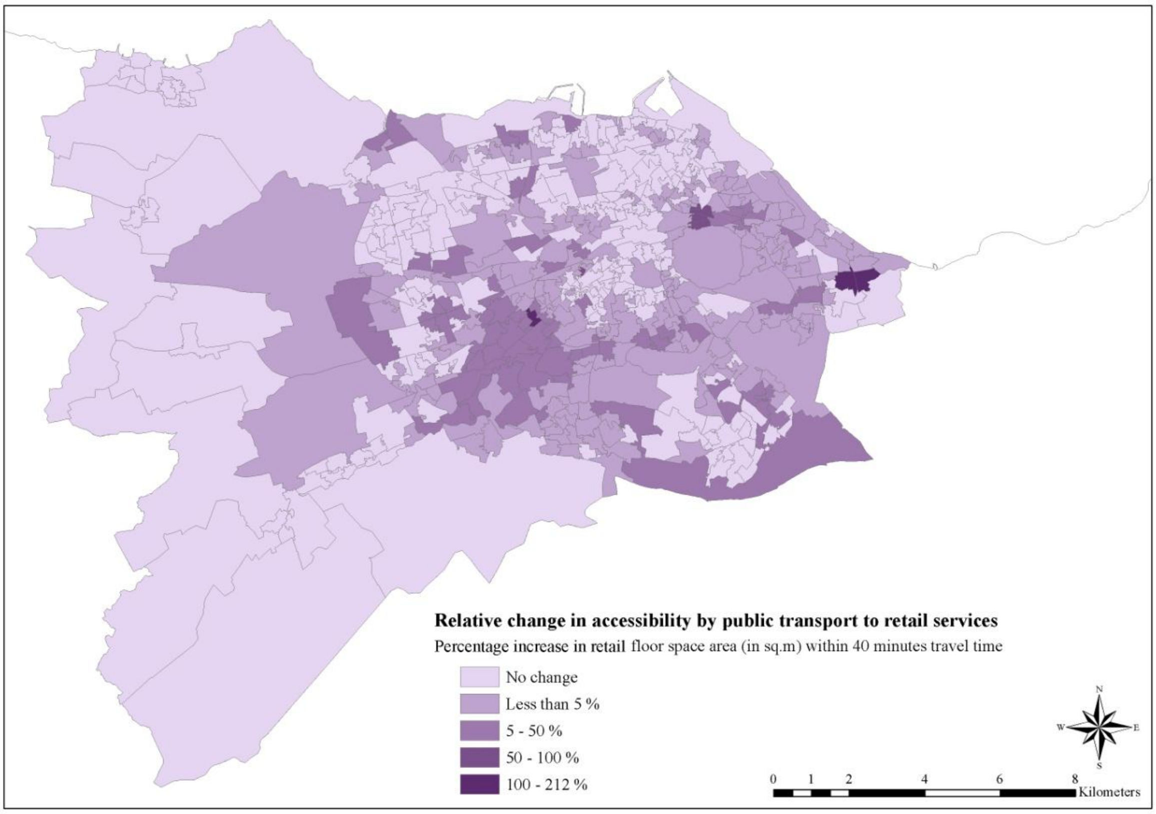

Figure C.21: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario I, using the contour measure

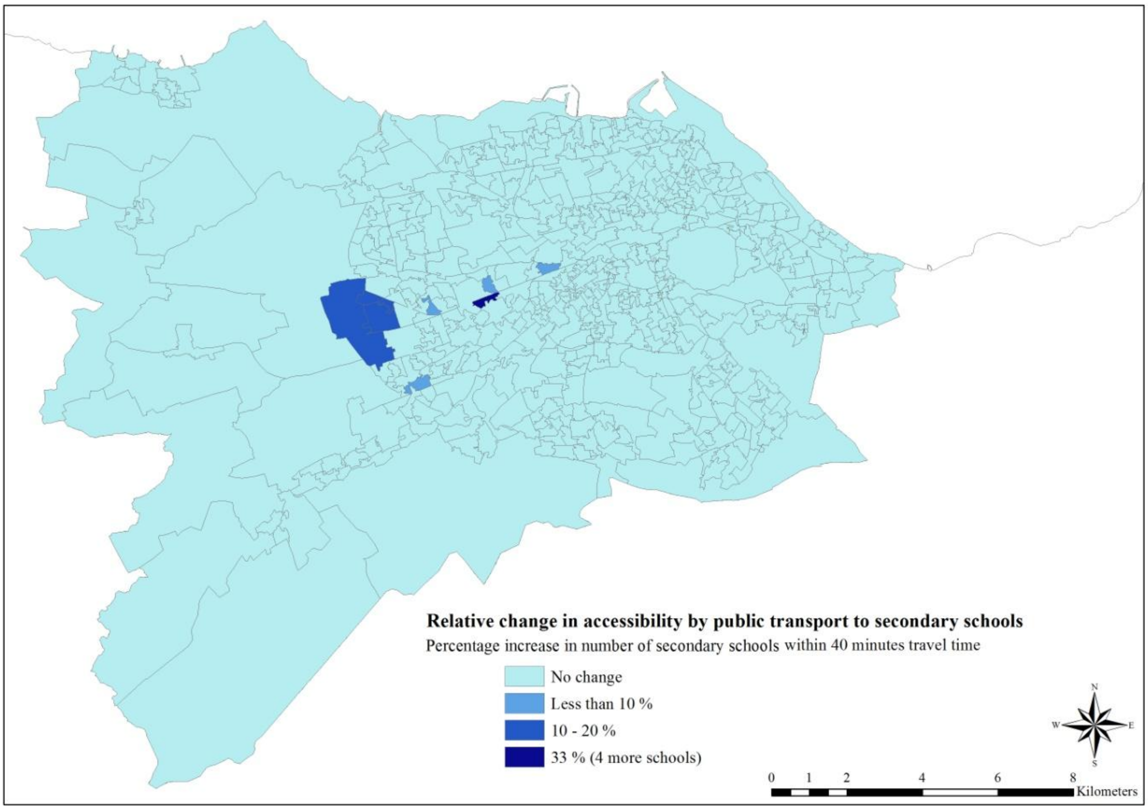

Figure C.22: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario C, using the contour measure

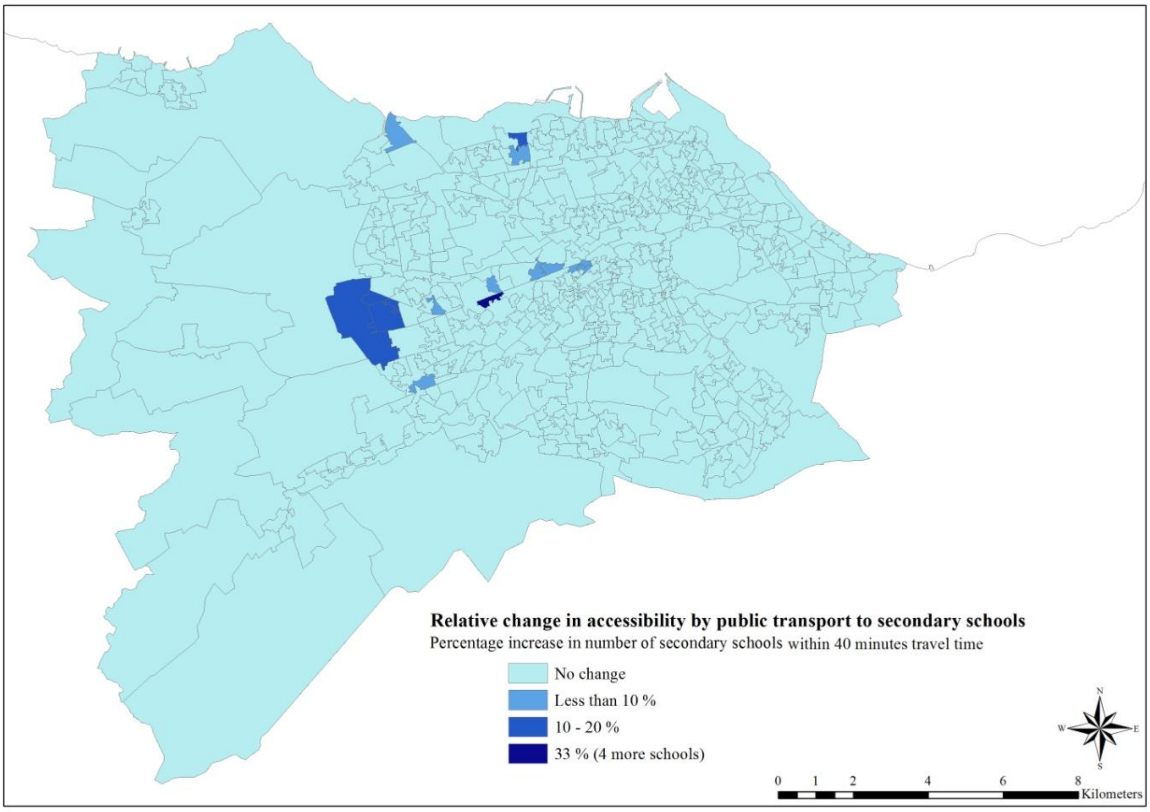

Figure C.23: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario D, using the contour measure

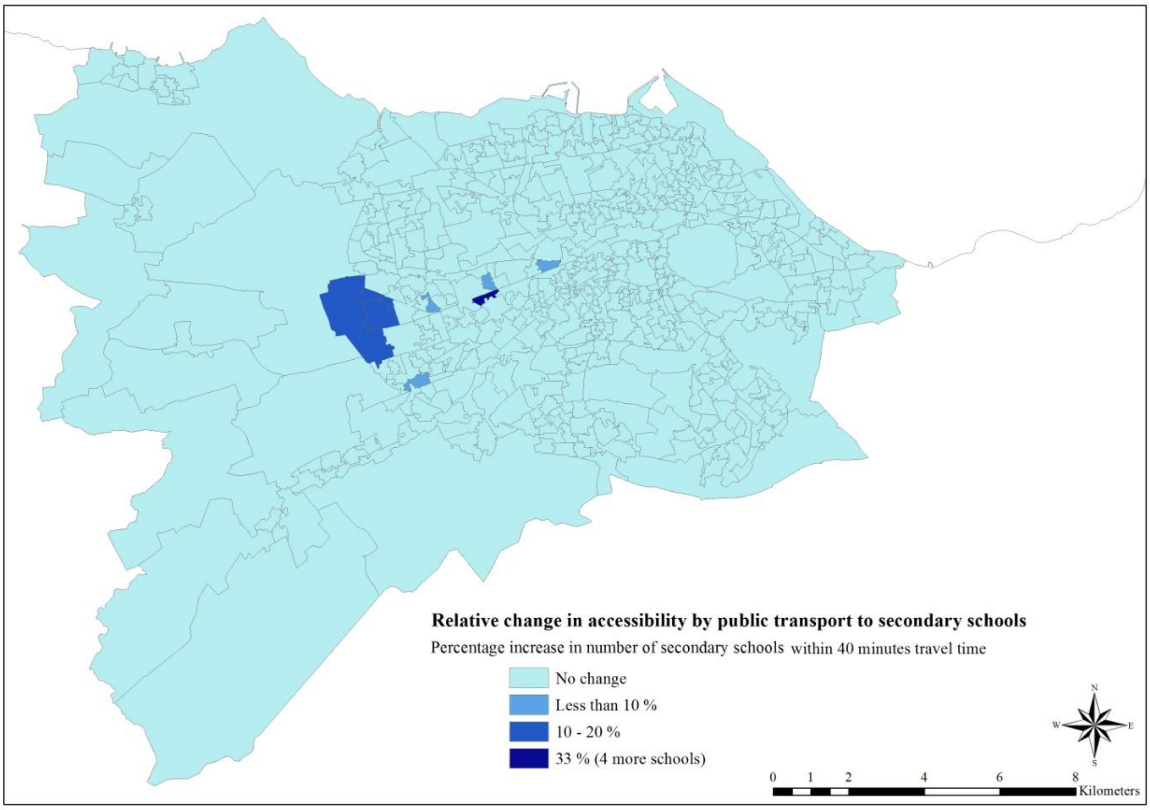

Figure C.24: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario E, using the contour measure

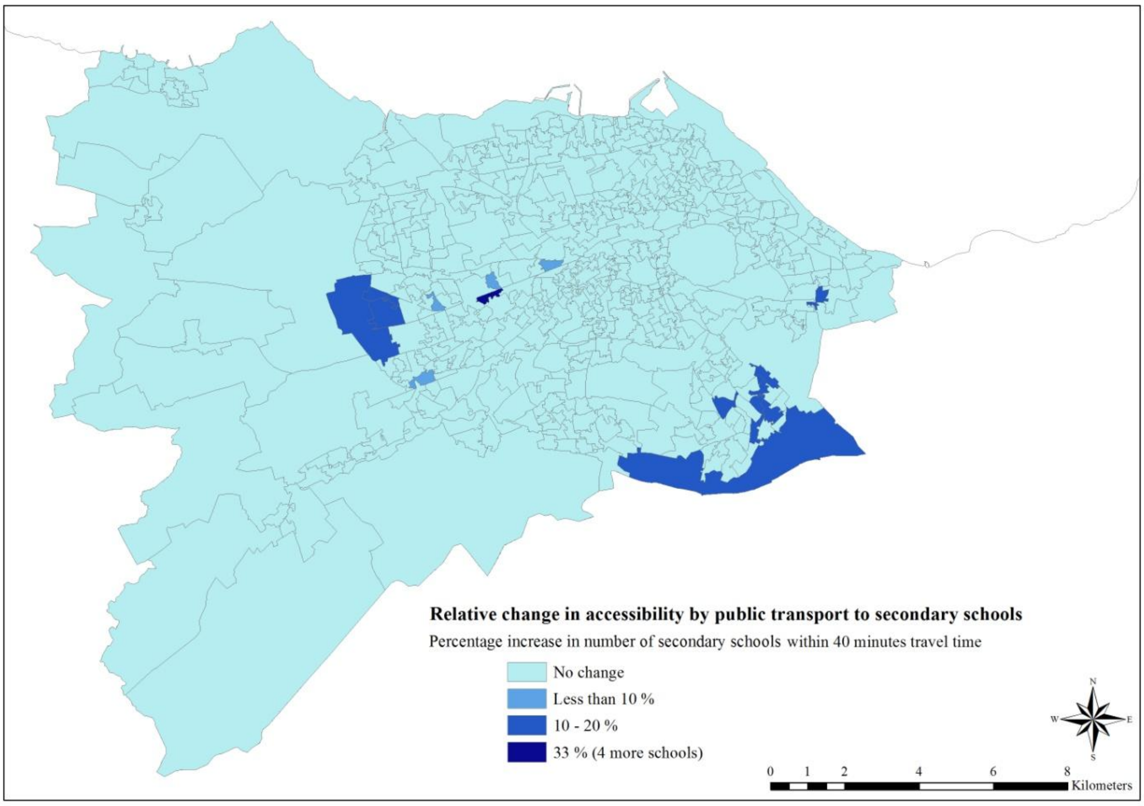

Figure C.25: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario F, using the contour measure

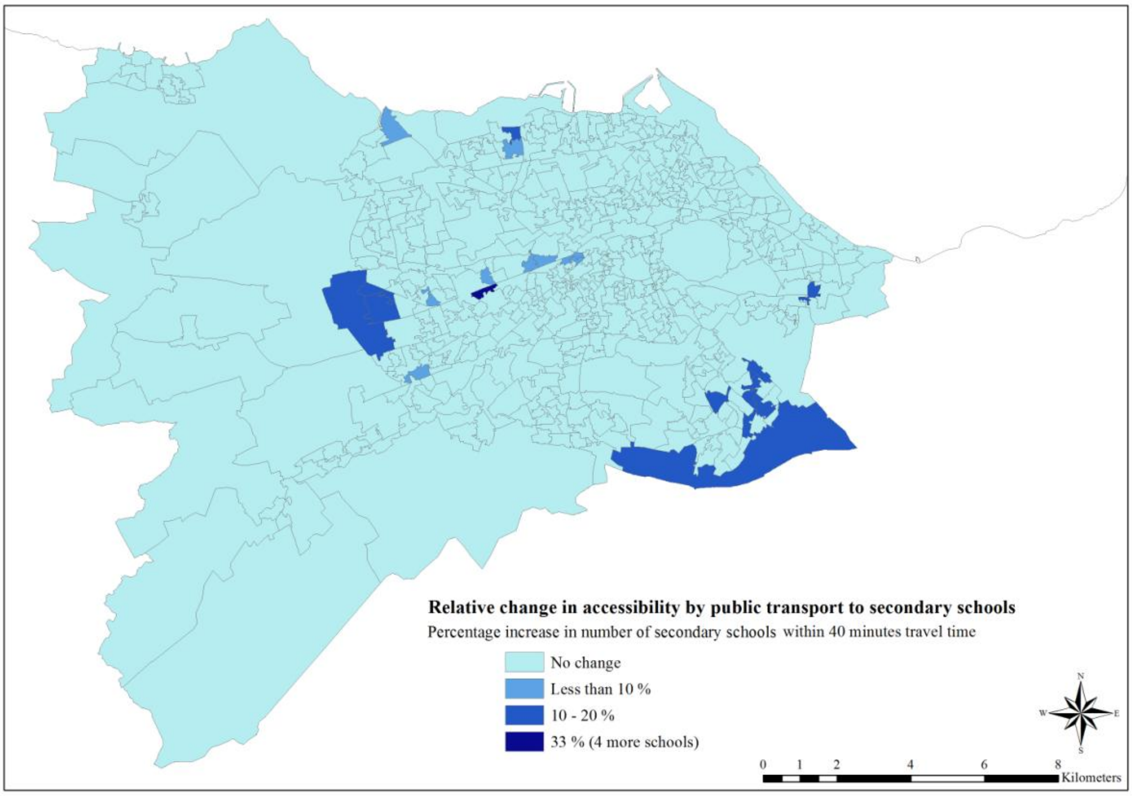

Figure C.26: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario G, using the contour measure

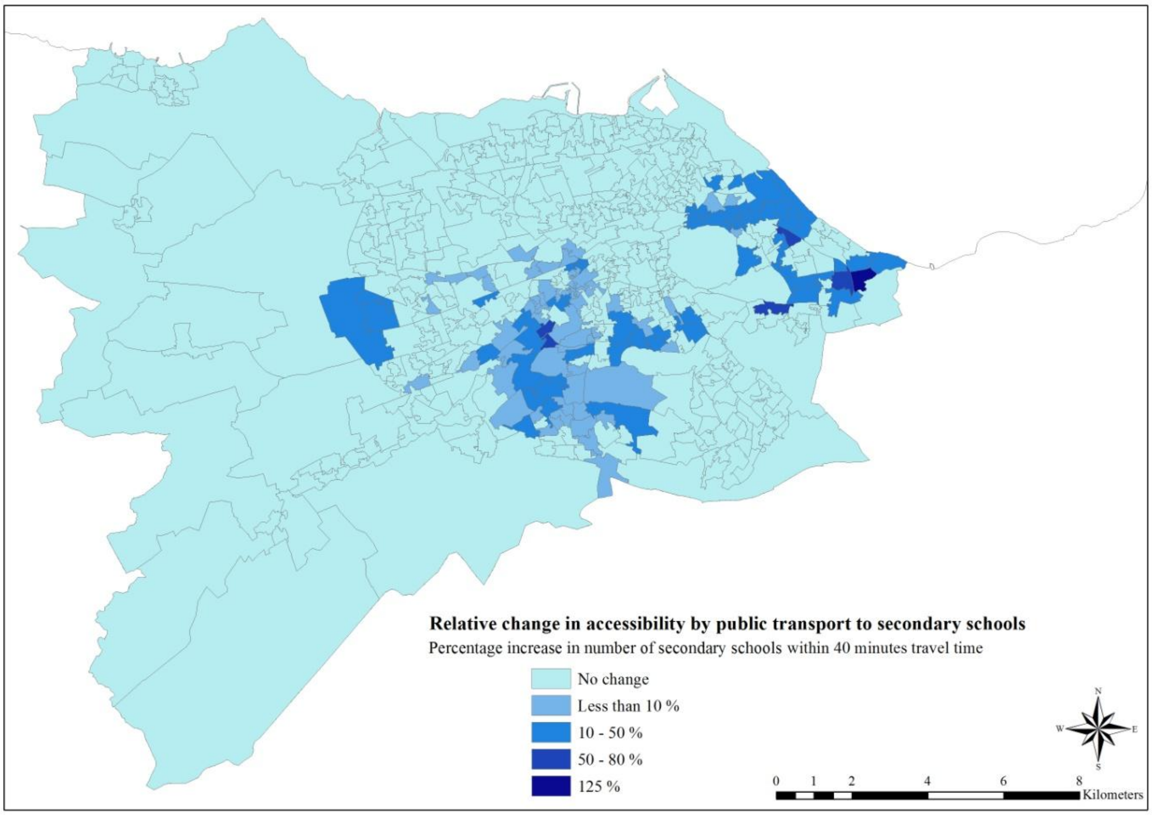

Figure C.27: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario H, using the contour measure

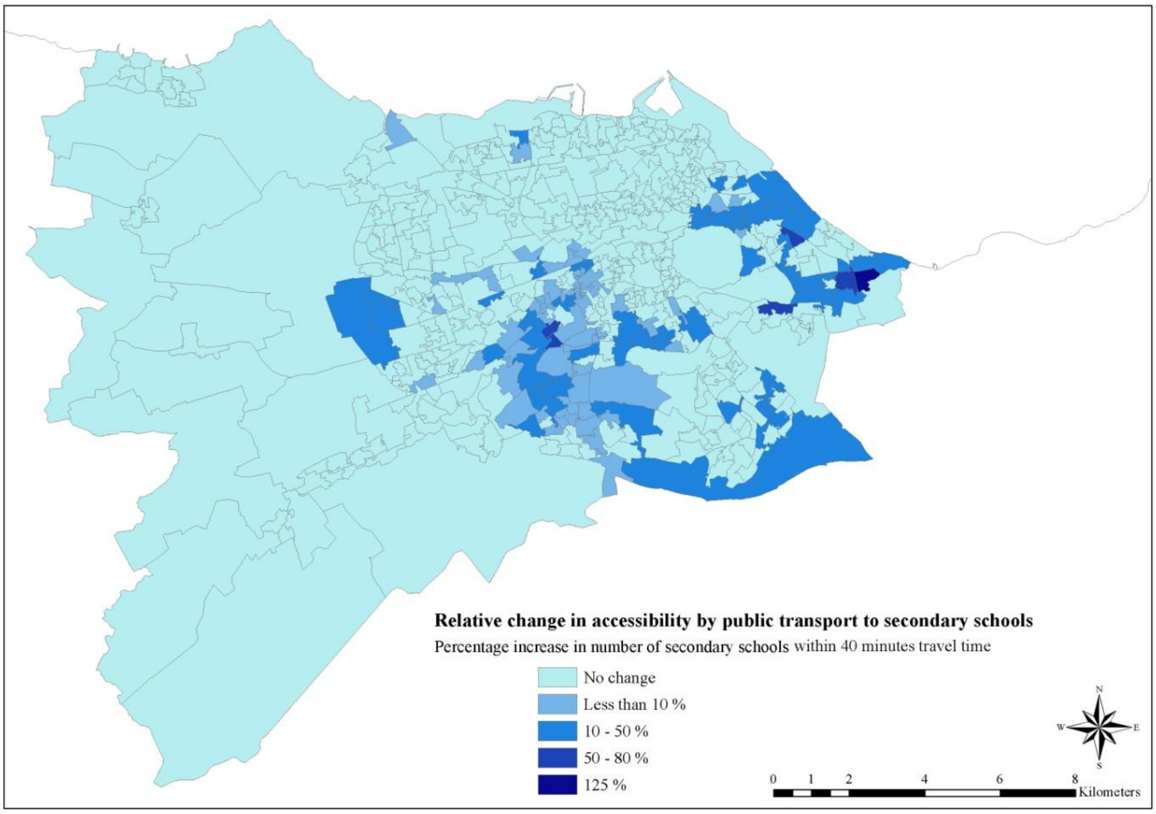

Figure C.28: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario I, using the contour measure

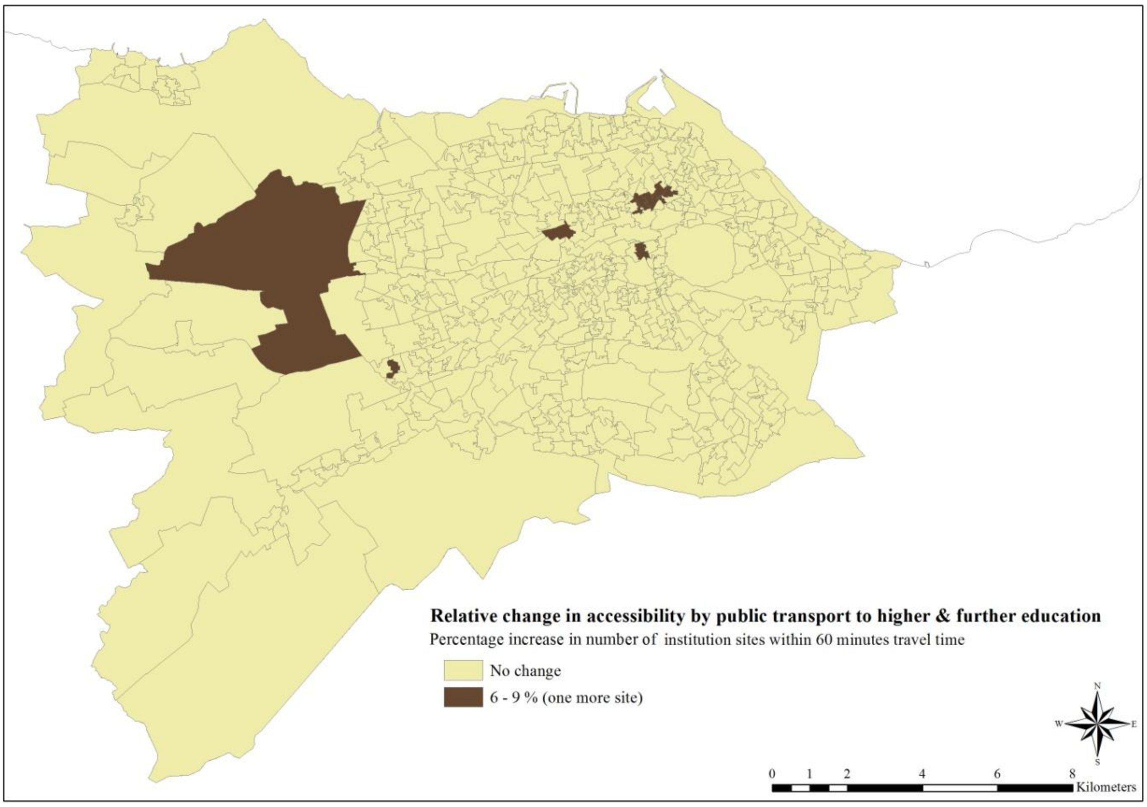

Figure C.29: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario C, using the contour measure

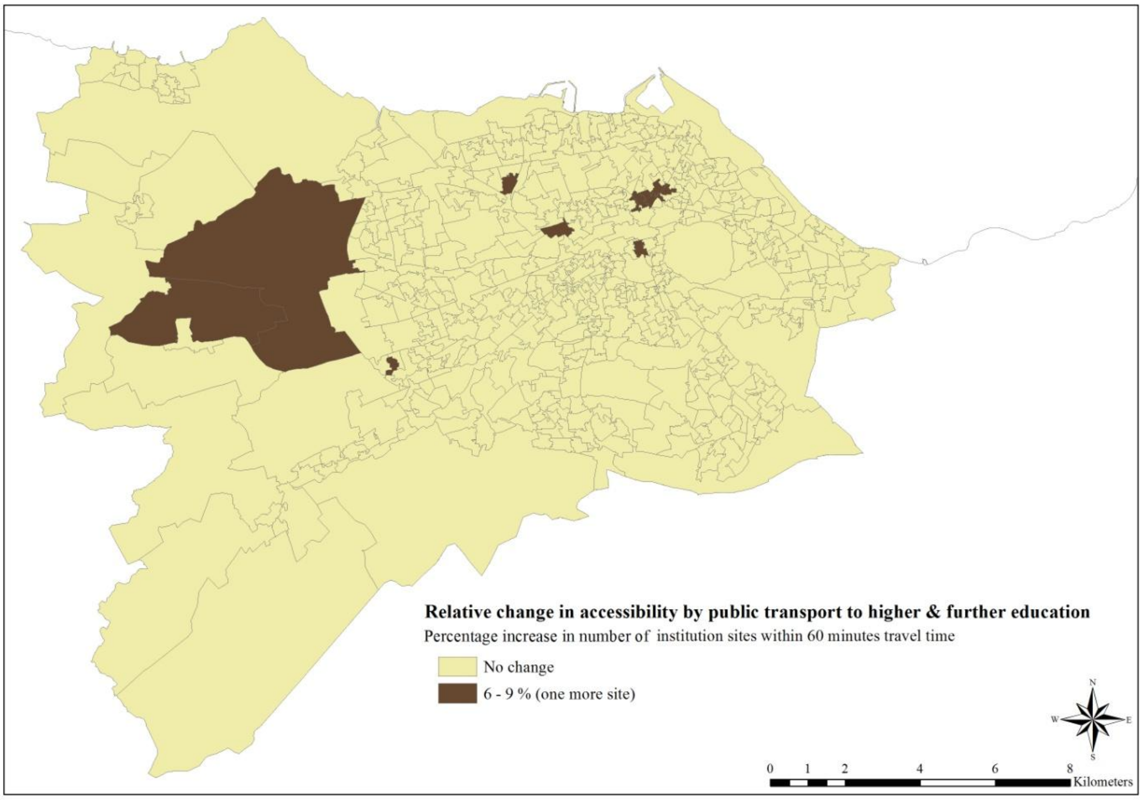

Figure C.30: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario D, using the contour measure

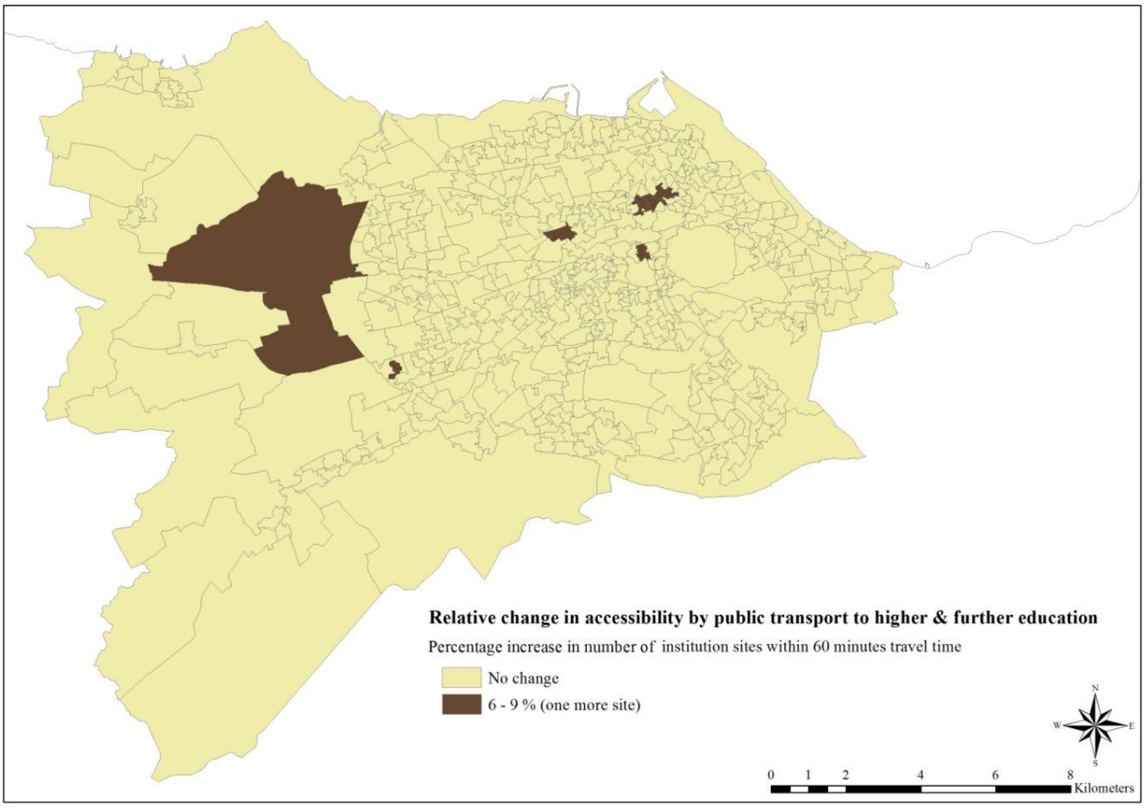

Figure C.31: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario E, using the contour measure

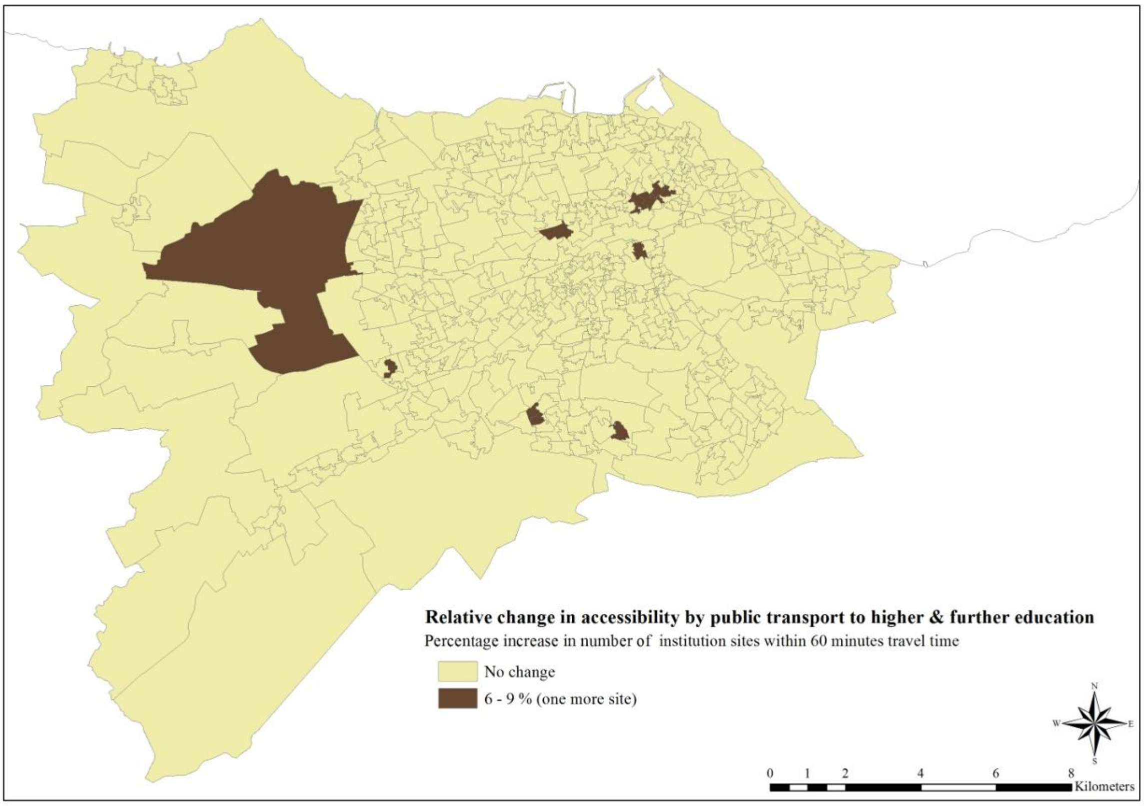

Figure C.32: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario F, using the contour measure

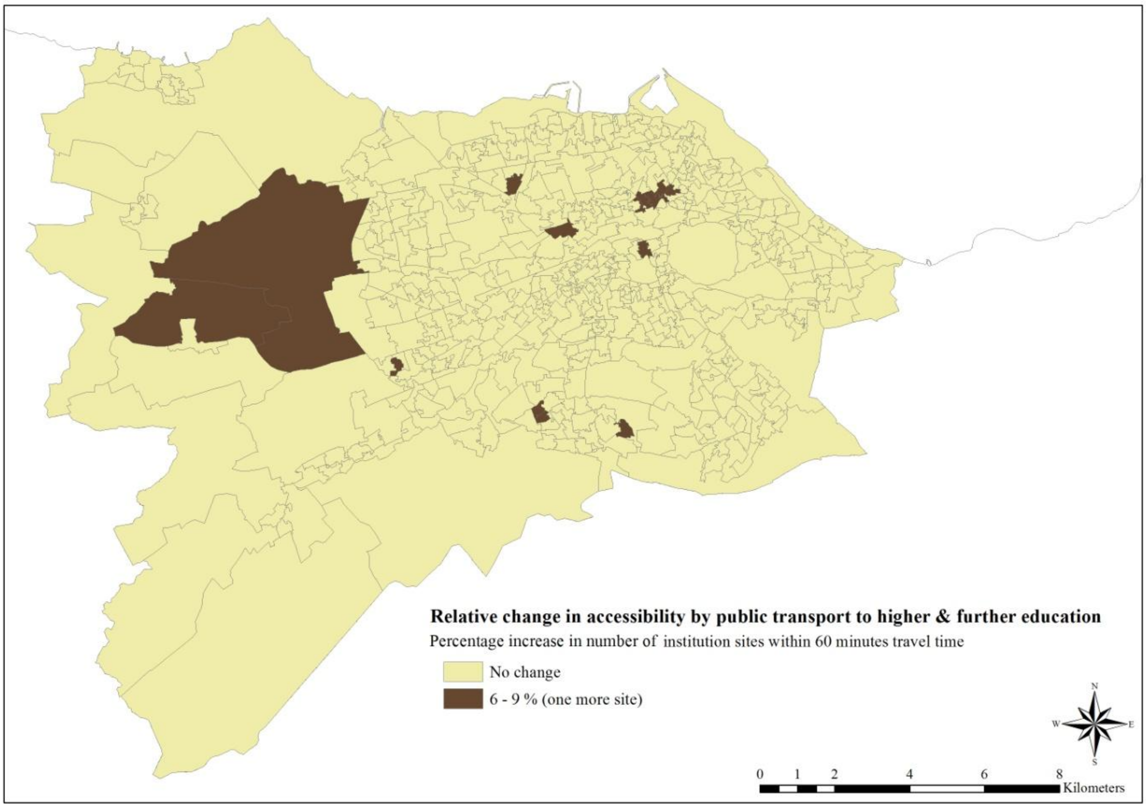

Figure C.33: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario G, using the contour measure

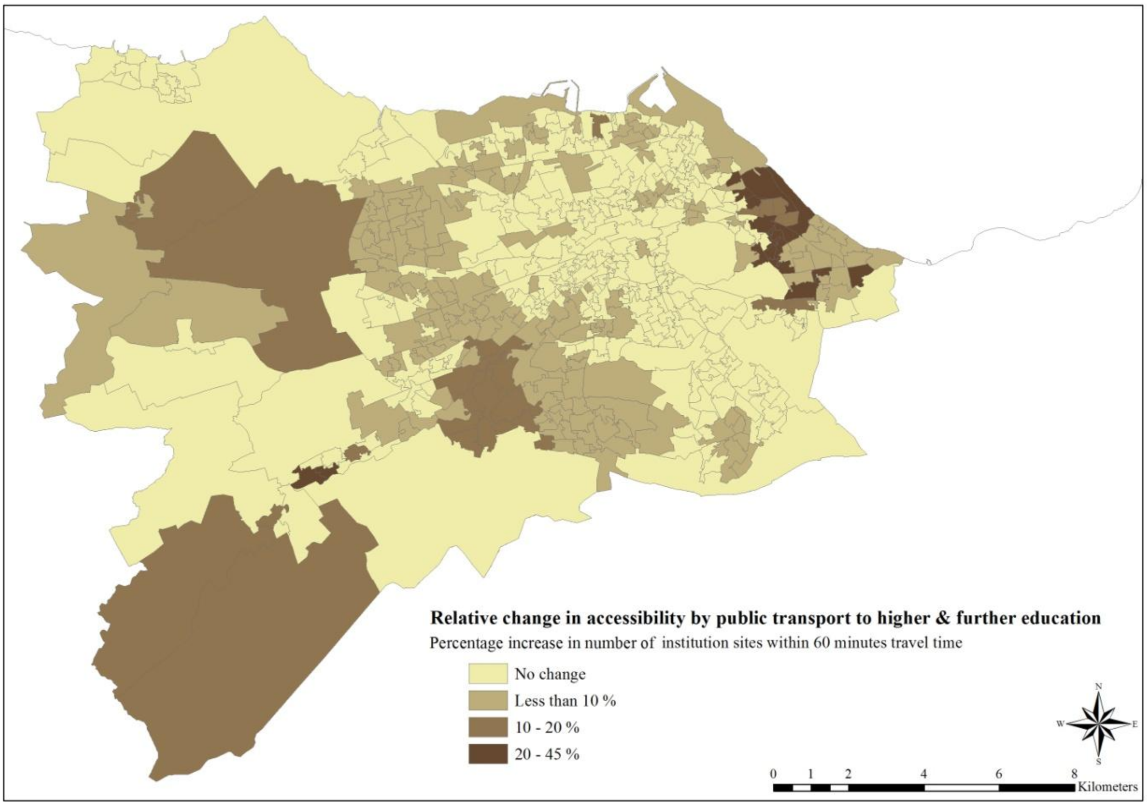

Figure C.34: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario H, using the contour measure

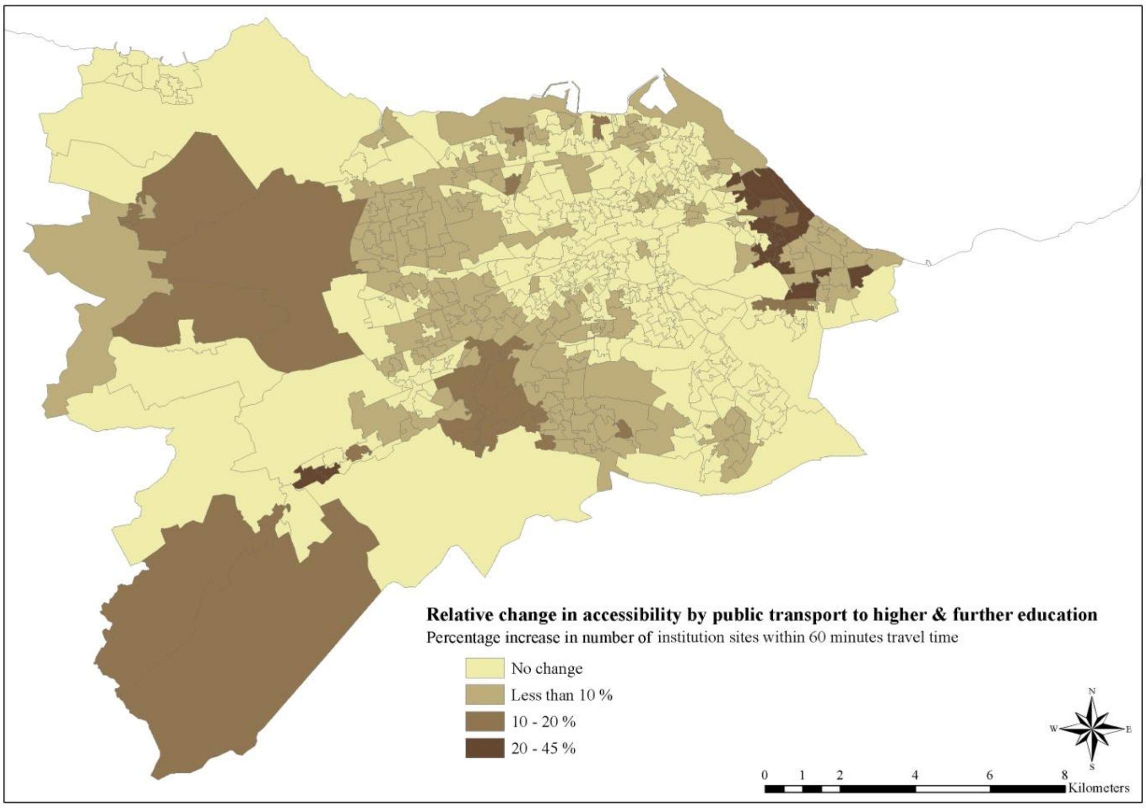

Figure C.35: Relative change in accessibility by public transport to higher & further education facilities between the baseline year 2011 scenario and Scenario I, using the contour measure

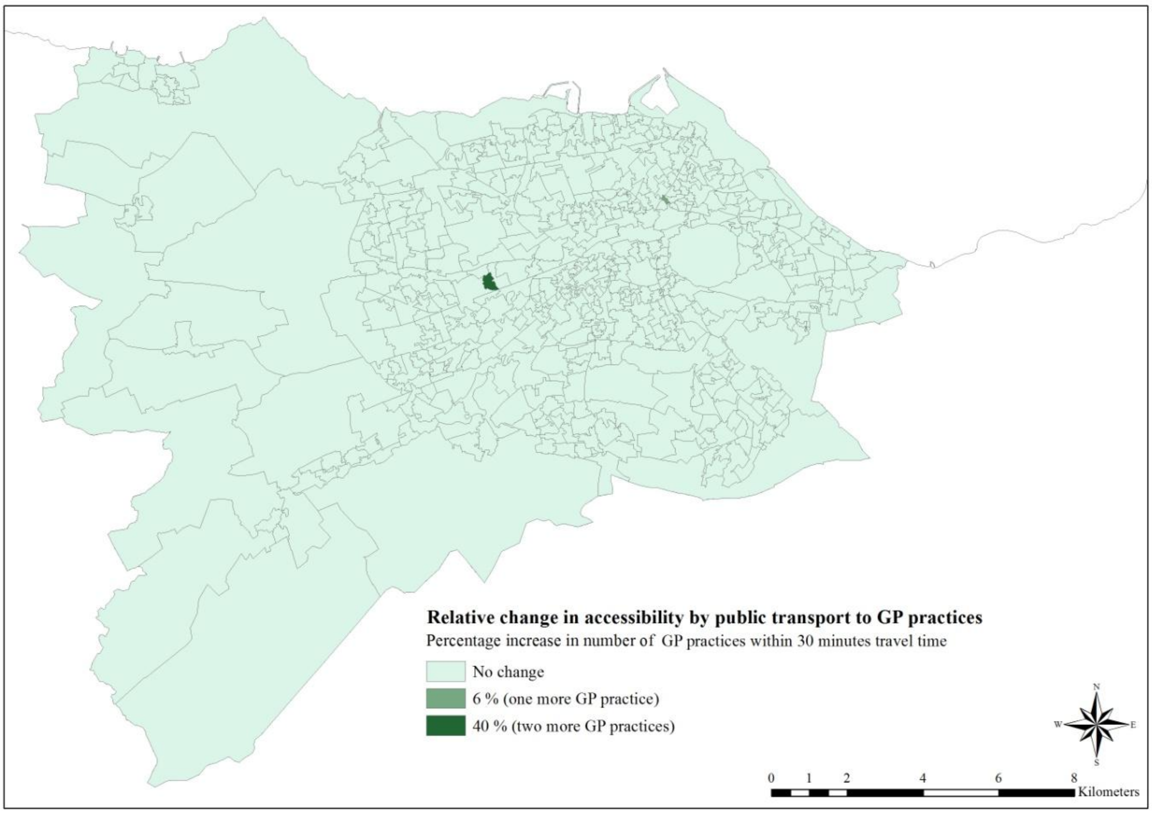

Figure C.36: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario C, using the contour measure

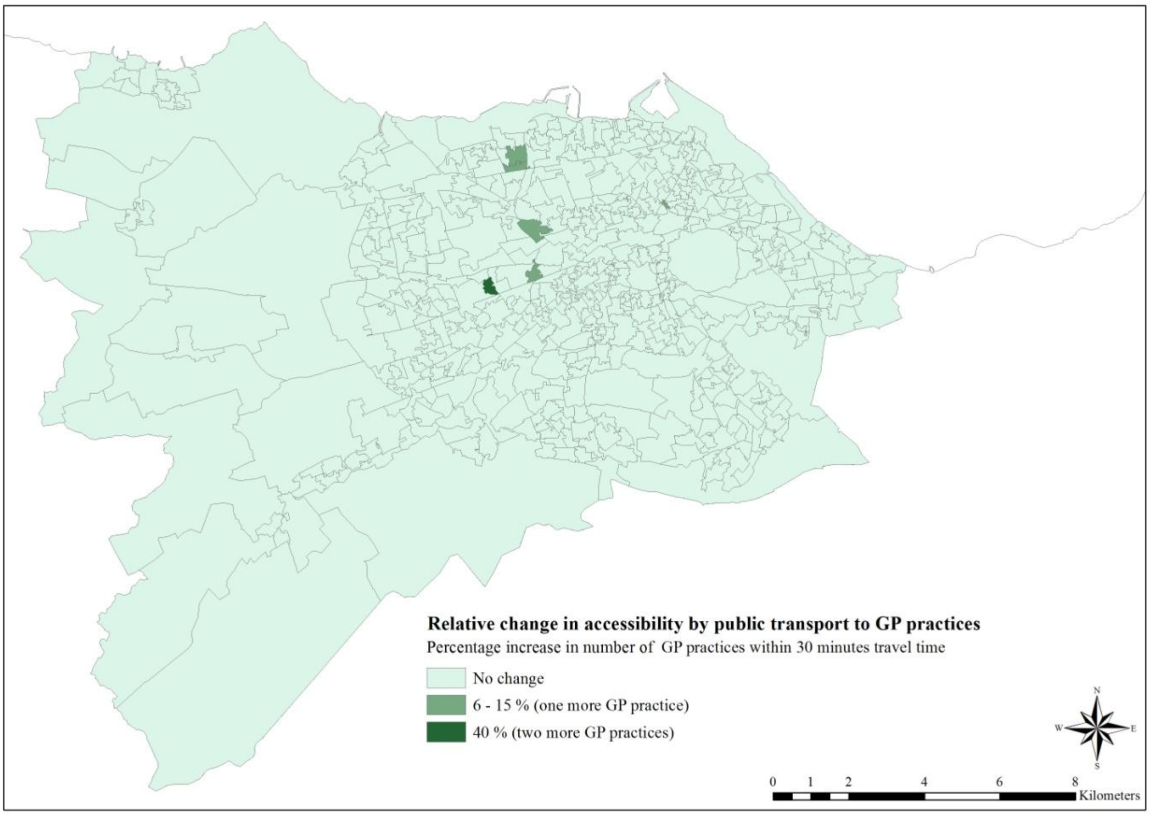

Figure C.37: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario D, using the contour measure

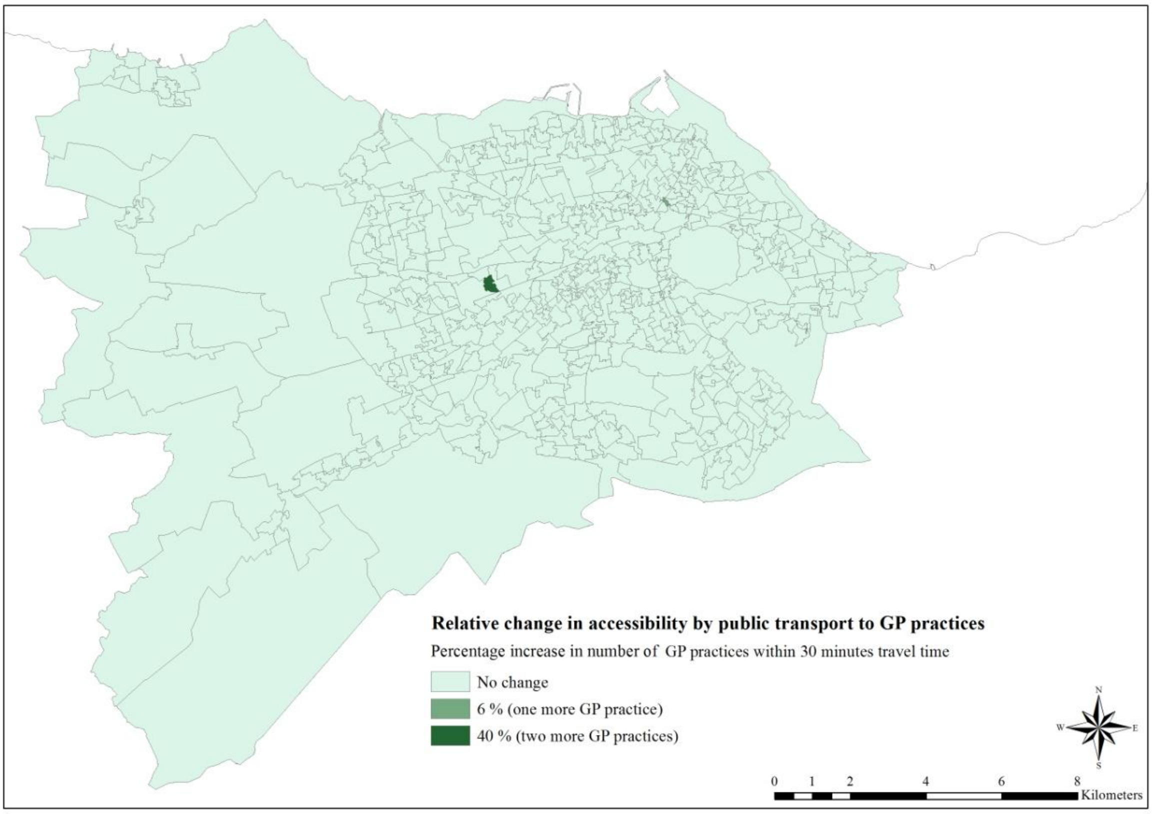

Figure C.38: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario E, using the contour measure

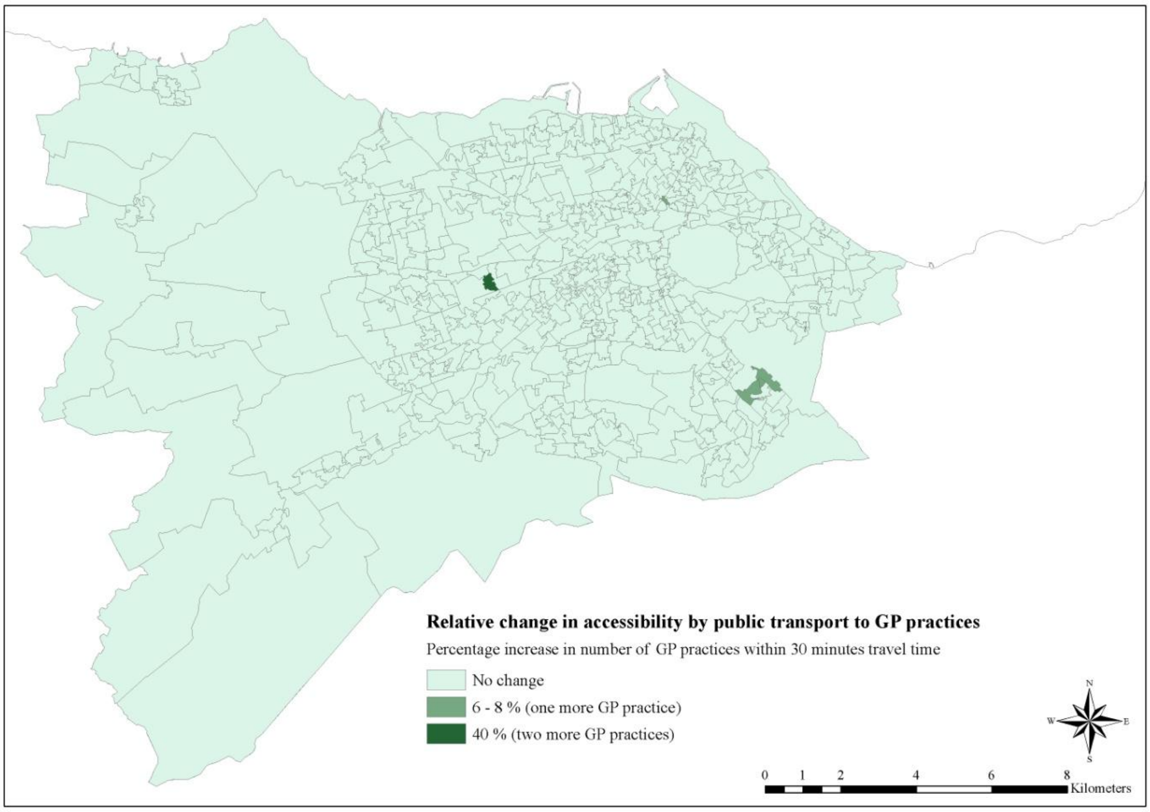

Figure C.39: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario F, using the contour measure

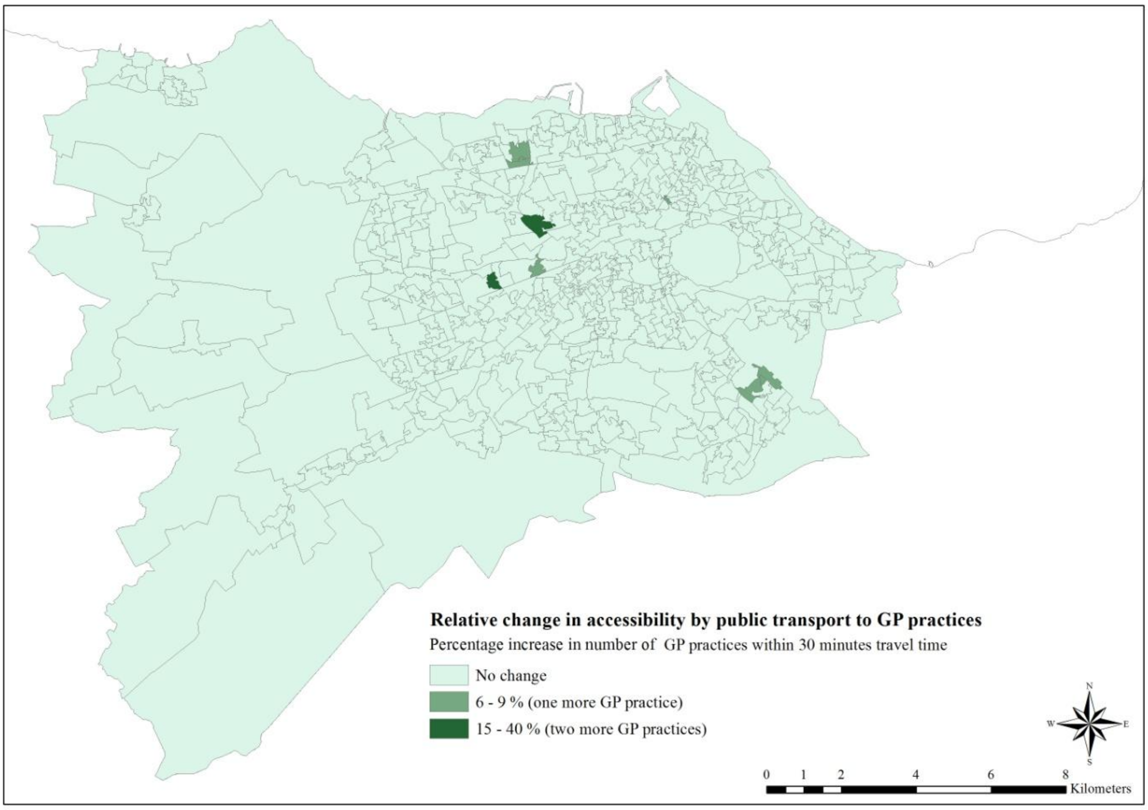

Figure C.40: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario G, using the contour measure

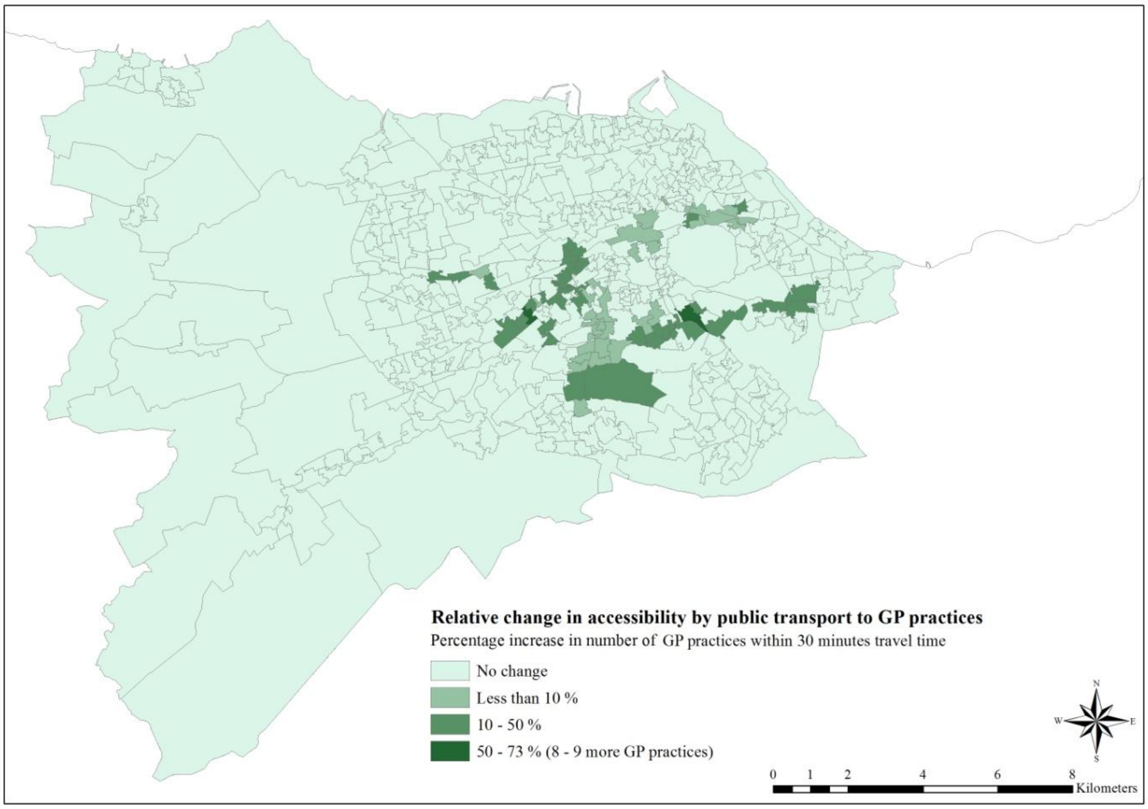

Figure C.41: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario H, using the contour measure

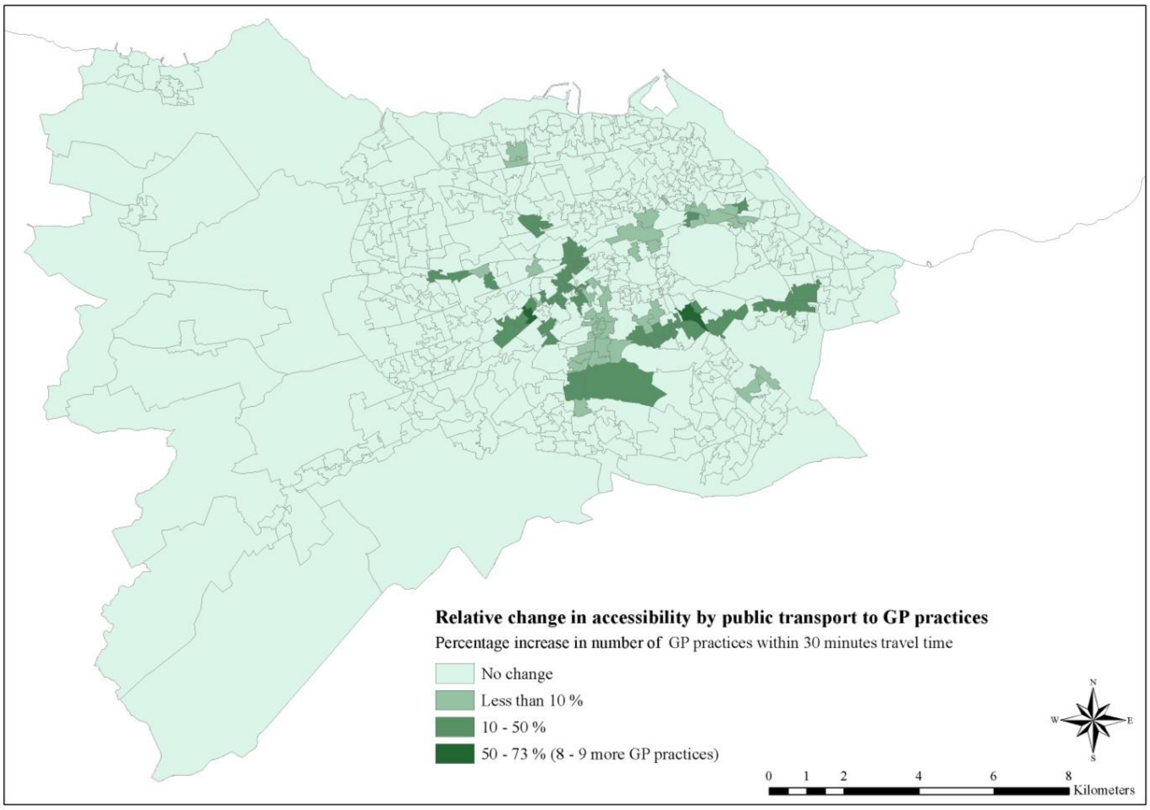

Figure C.42: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario I, using the contour measure

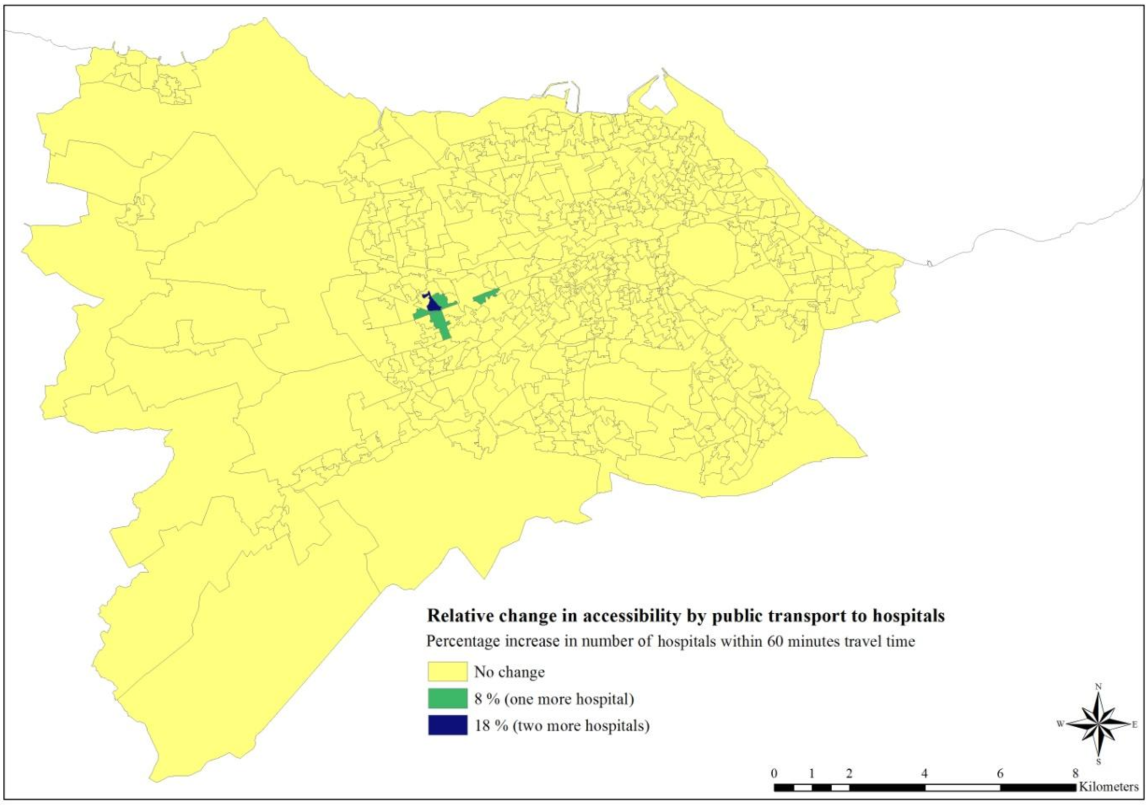

Figure C.43: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and Scenarios C, D, E, F and G, using the contour measure

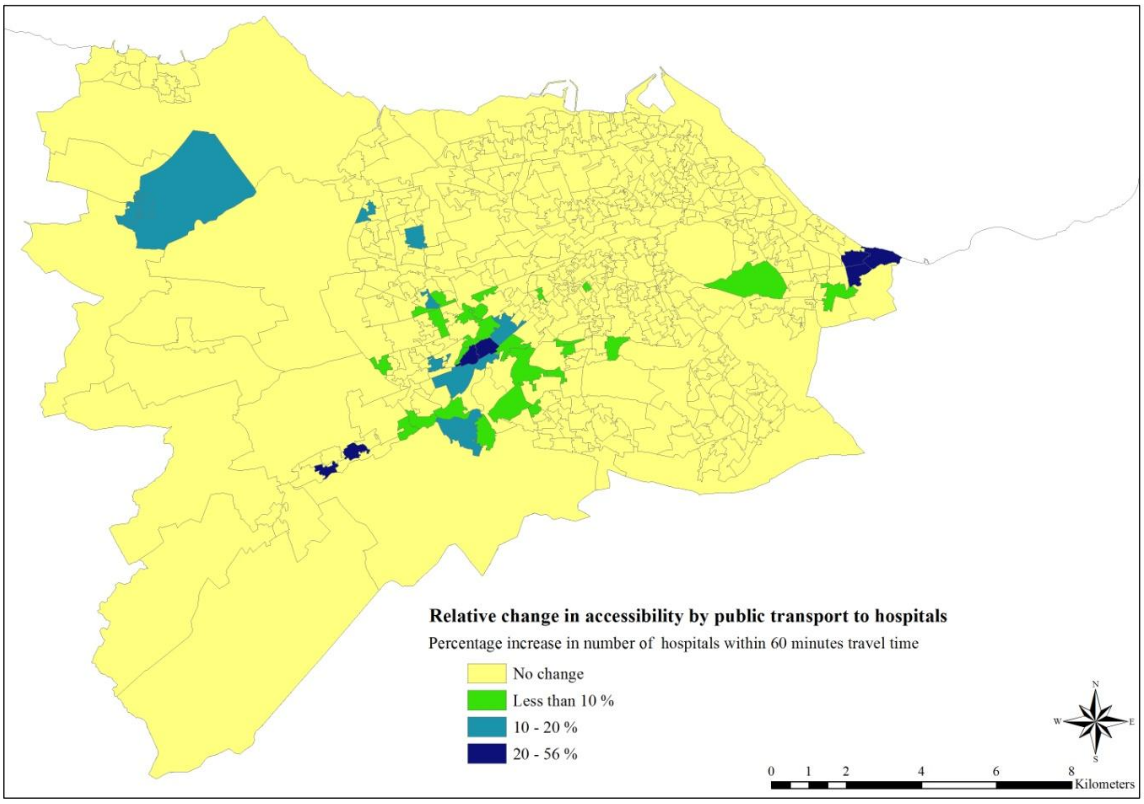

Figure C.44: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and Scenarios H and I, using the contour measure

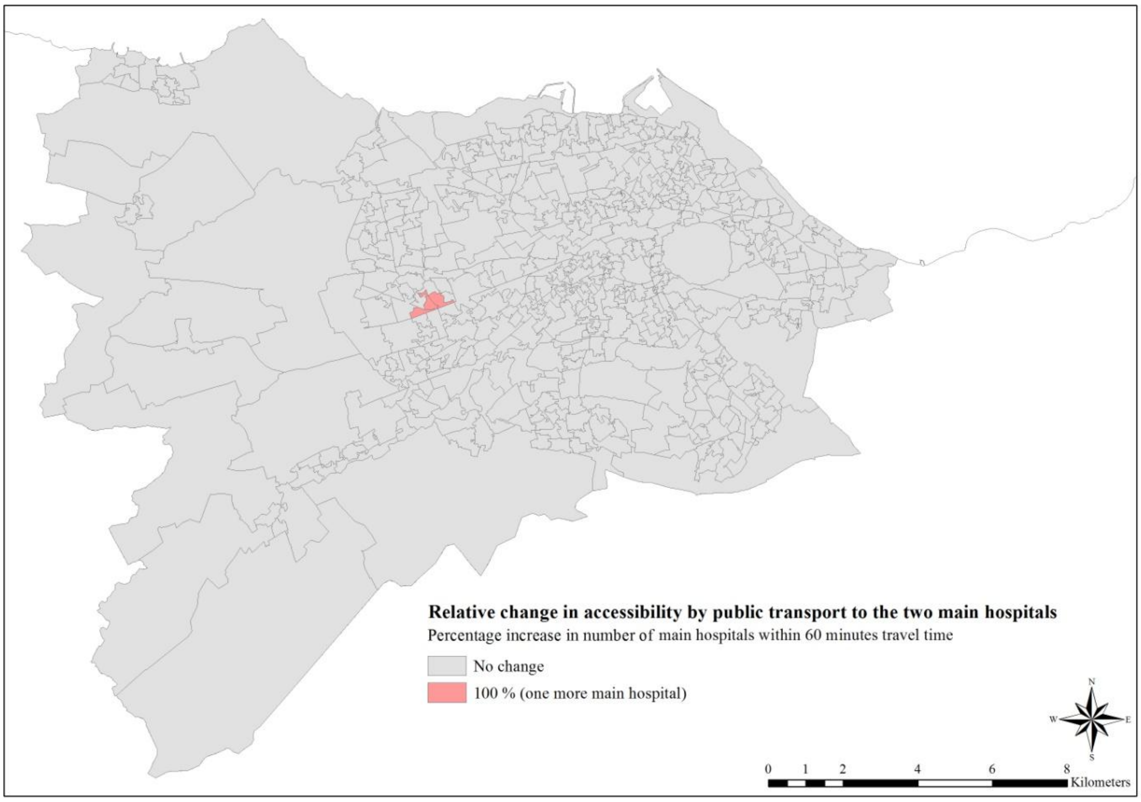

Figure C.45: Relative change in accessibility by public transport to the two main hospitals between the baseline year 2011 scenario and Scenarios C, D, E, F and G, using the contour measure

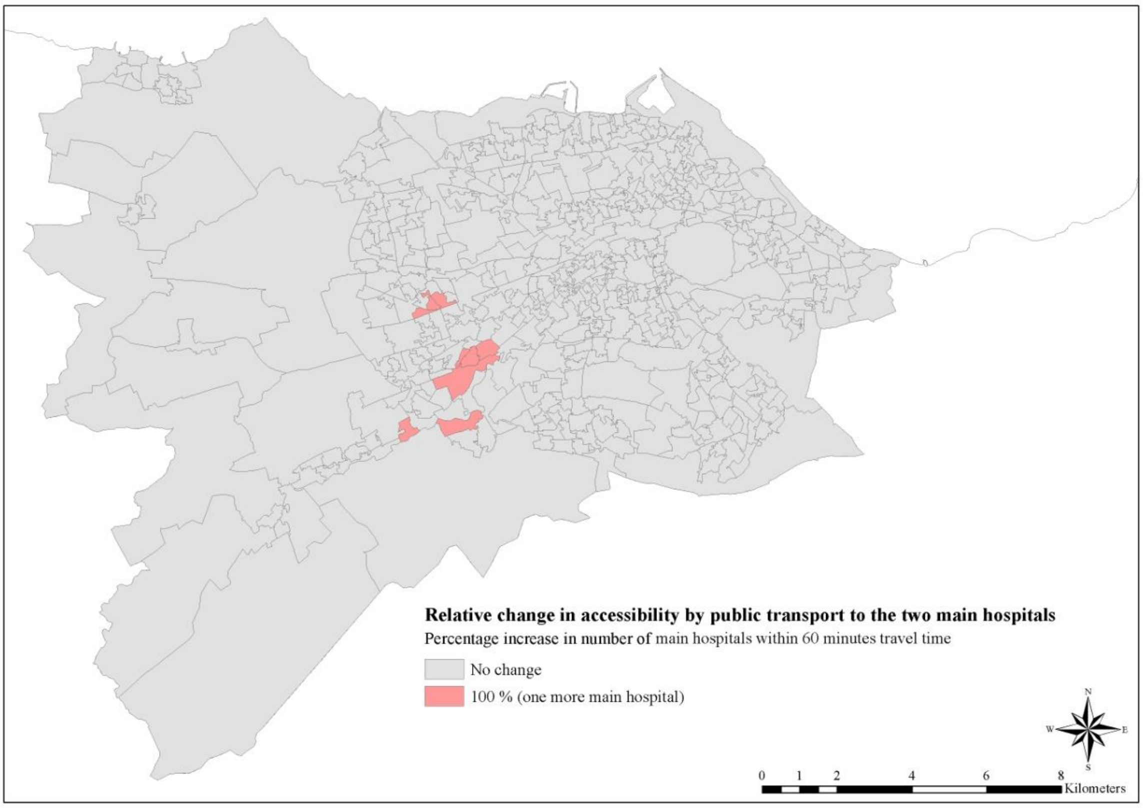

Figure C.46: Relative change in accessibility by public transport to the two main hospitals between the baseline year 2011 scenario and Scenarios H and I, using the contour measure

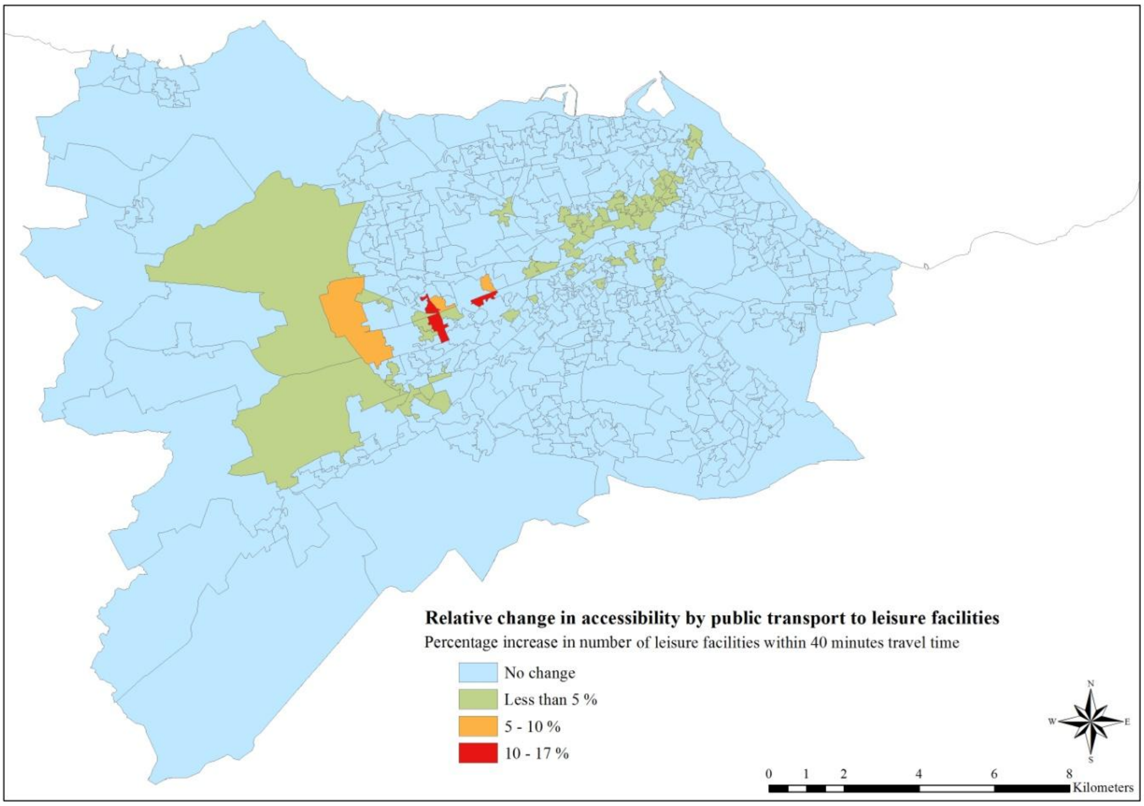

Figure C.47: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario C, using the contour measure

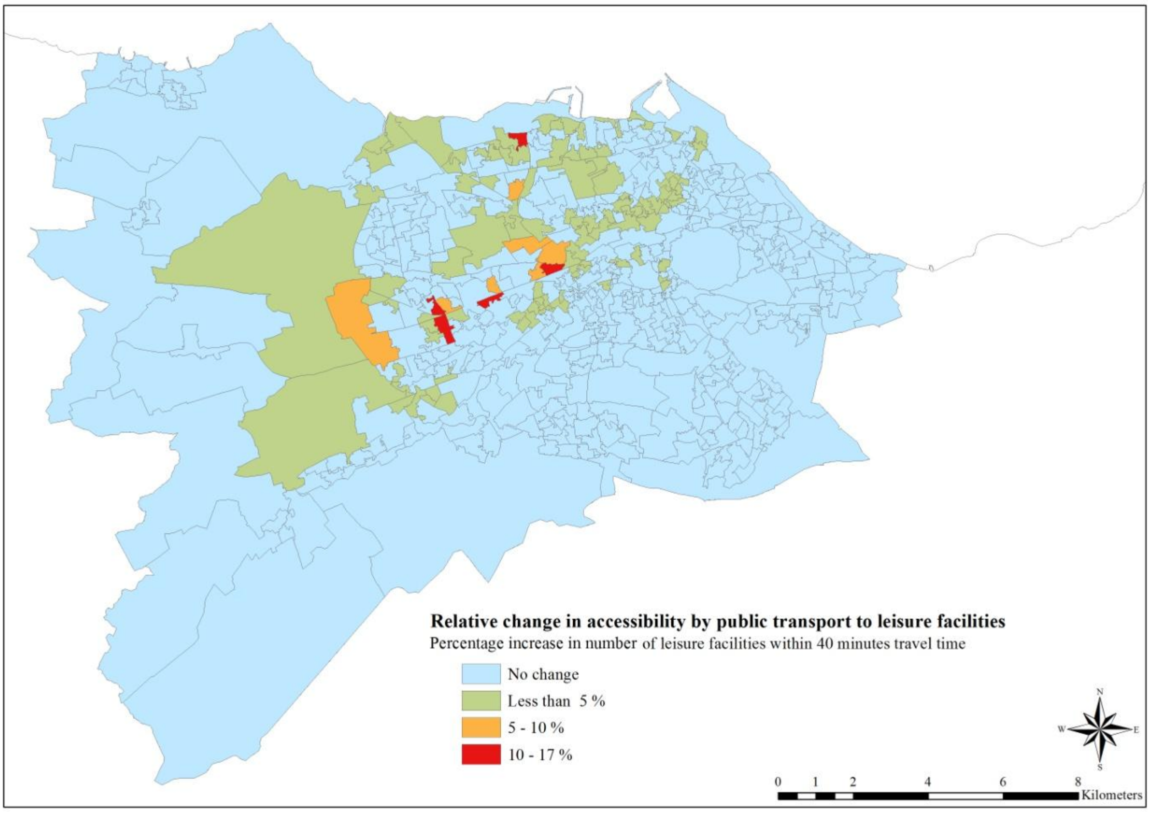

Figure C.48: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario D, using the contour measure

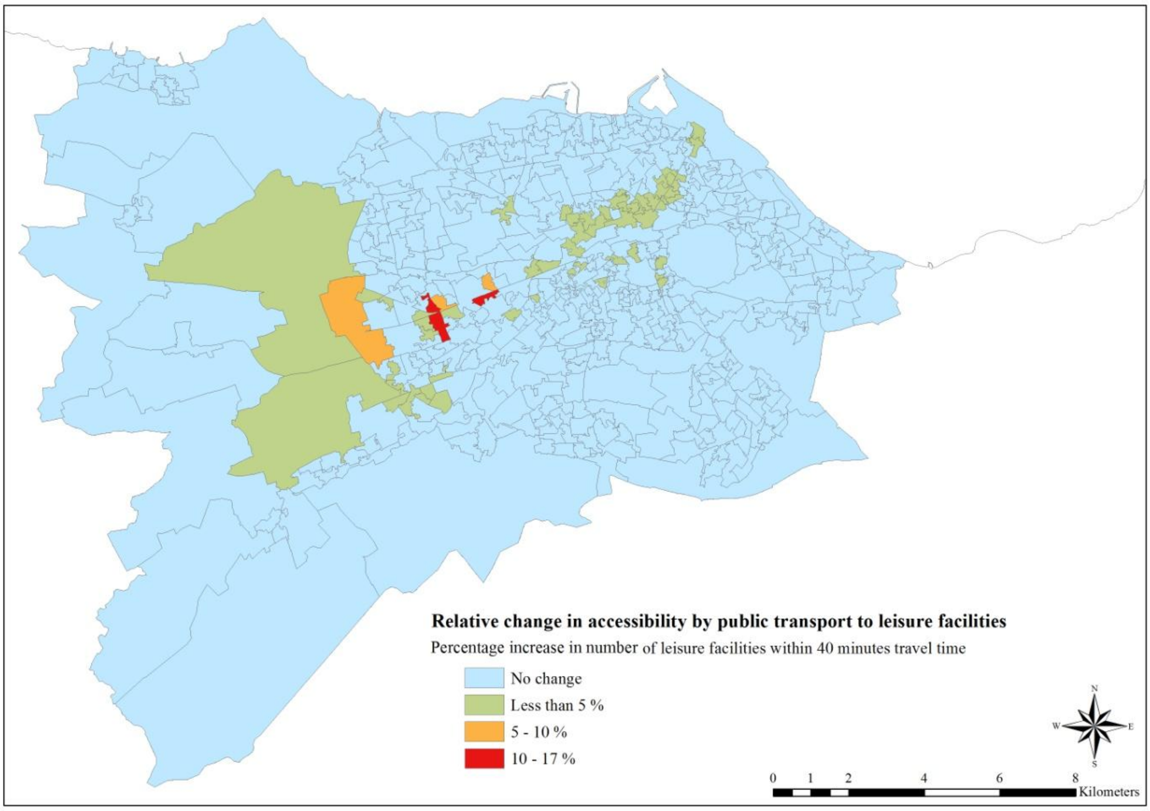

Figure C.49: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario E, using the contour measure

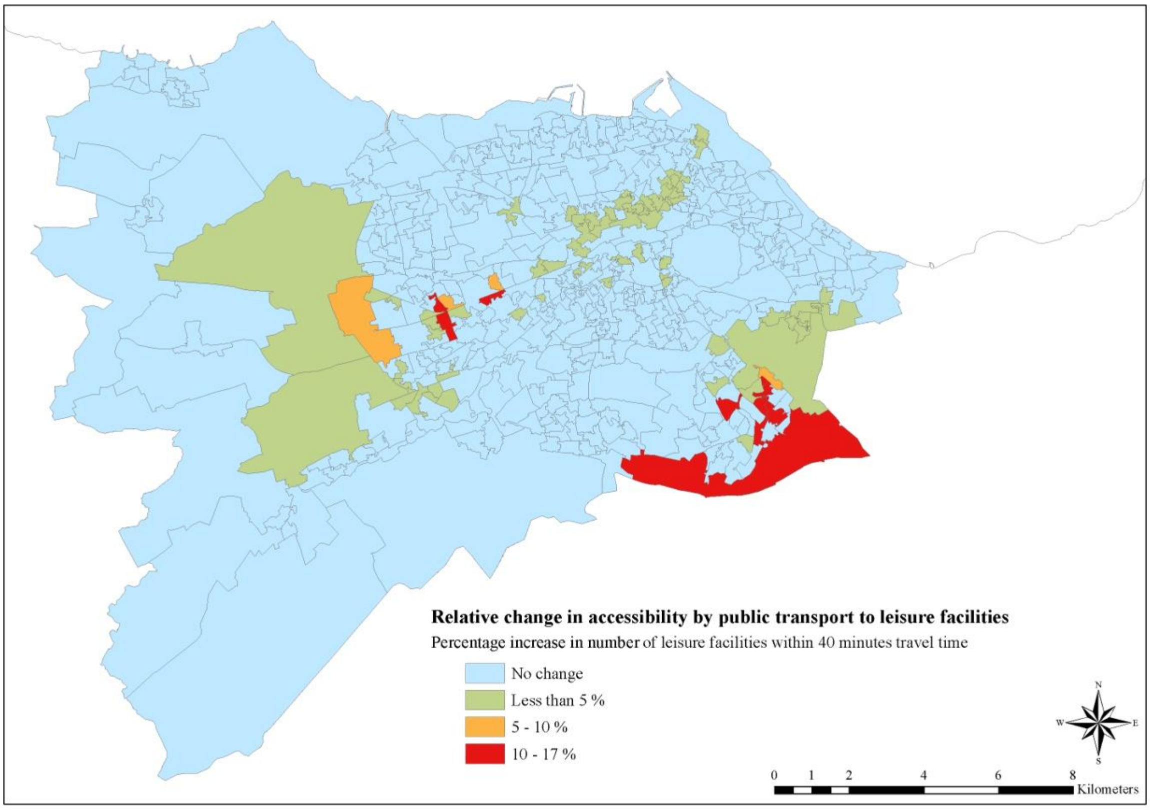

Figure C.50: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario F, using the contour measure

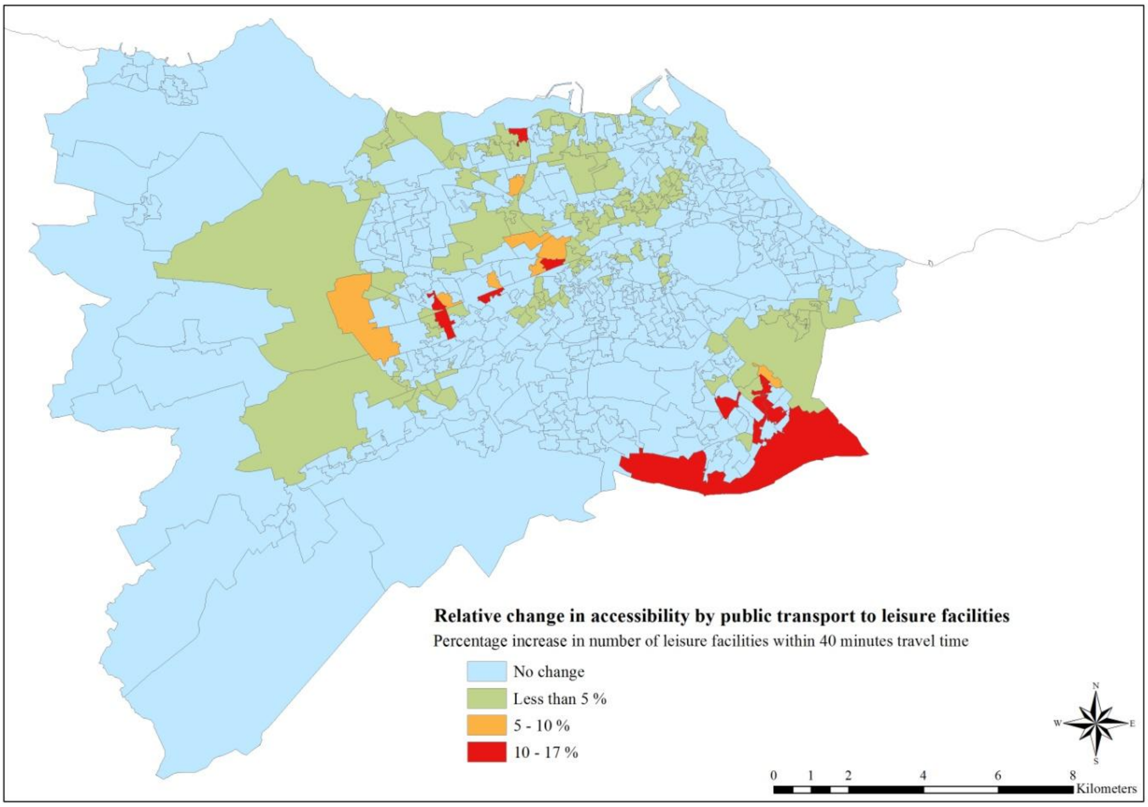

Figure C.51: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario G, using the contour measure

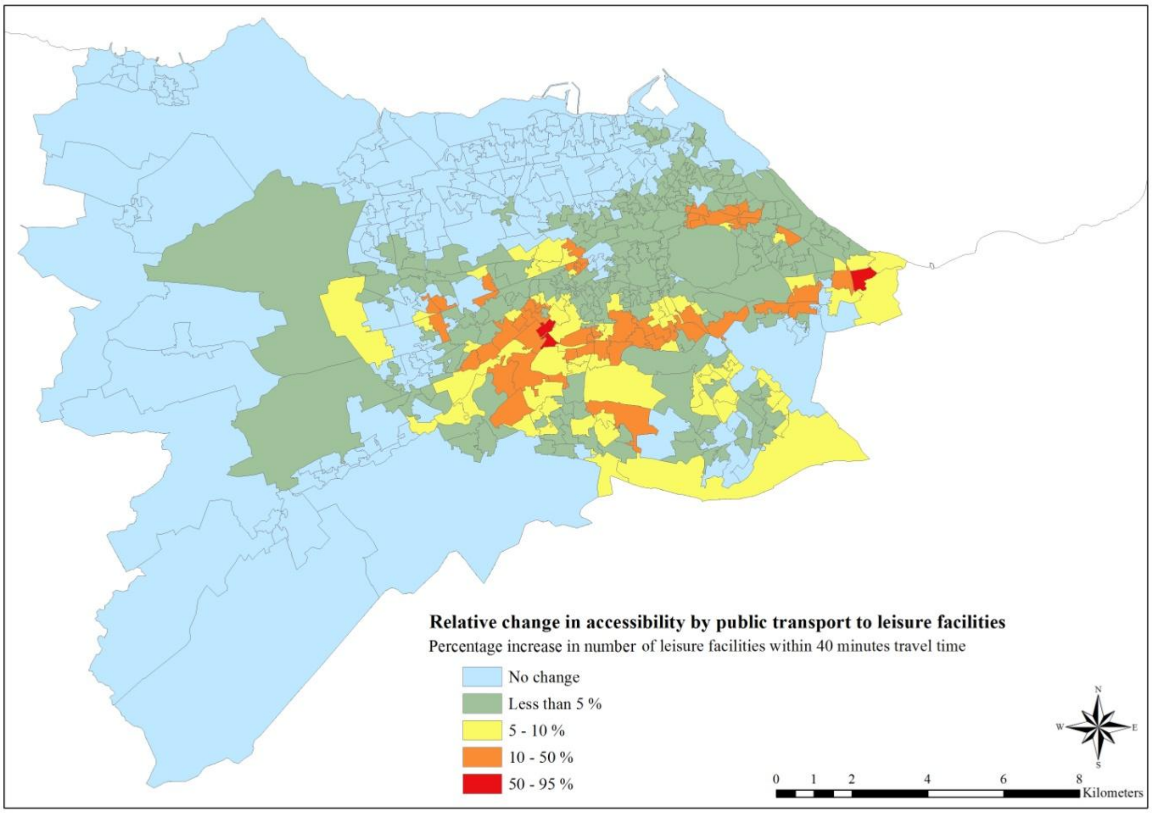

Figure C.52: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario H, using the contour measure

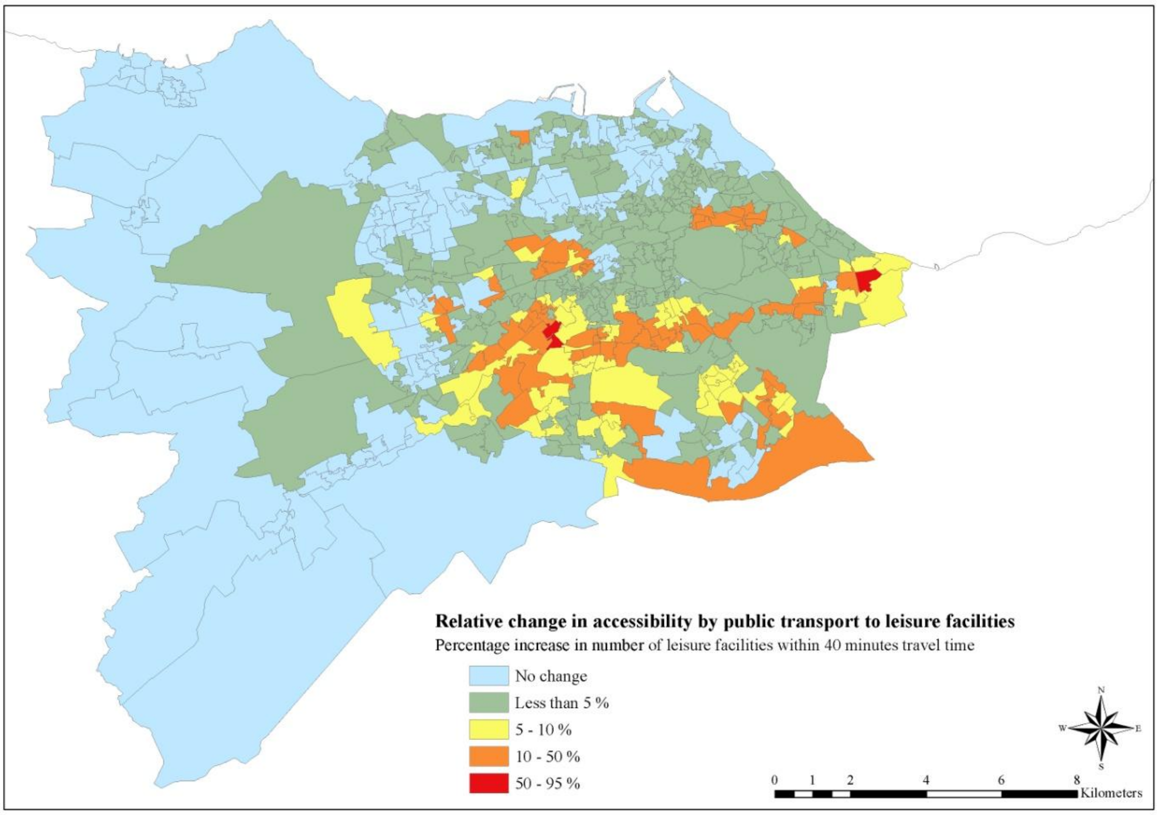

Figure C.53: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario I, using the contour measure

APPENDIX D:

Additional Output Maps of Accessibility Changes between the Baseline Year 2011 and Future Scenarios – Potential Accessibility Measure

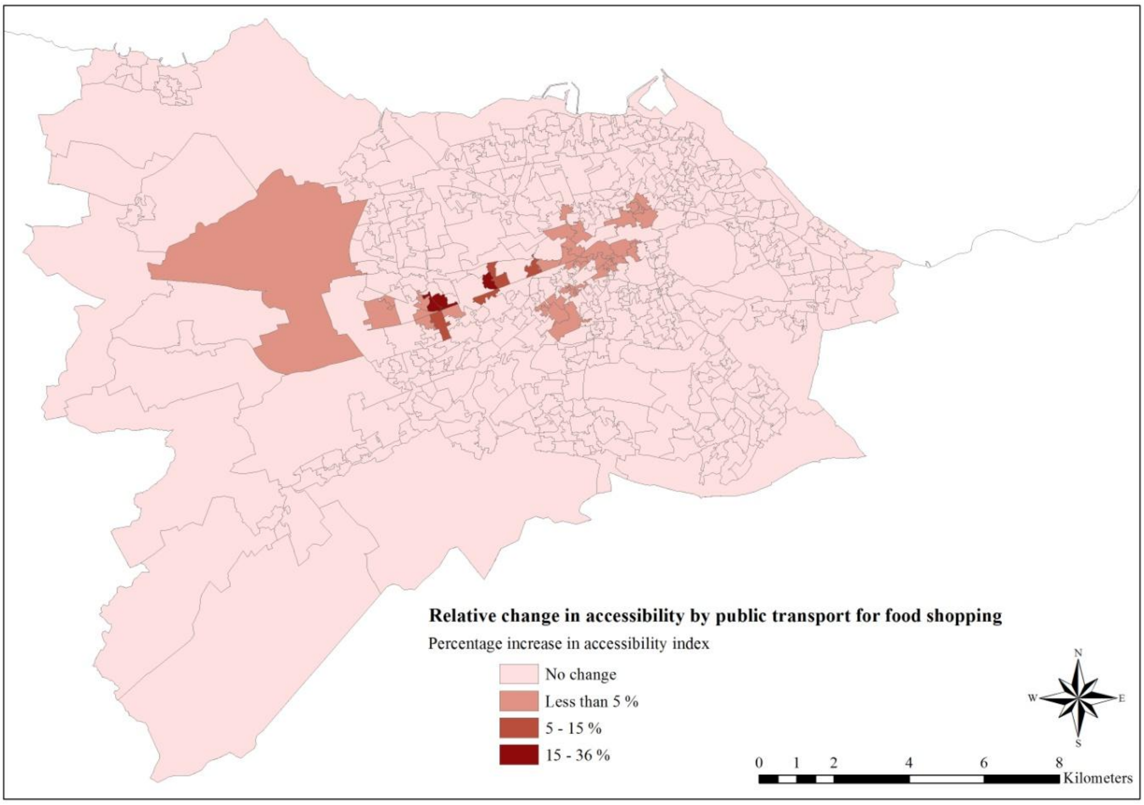

Figure D.1: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

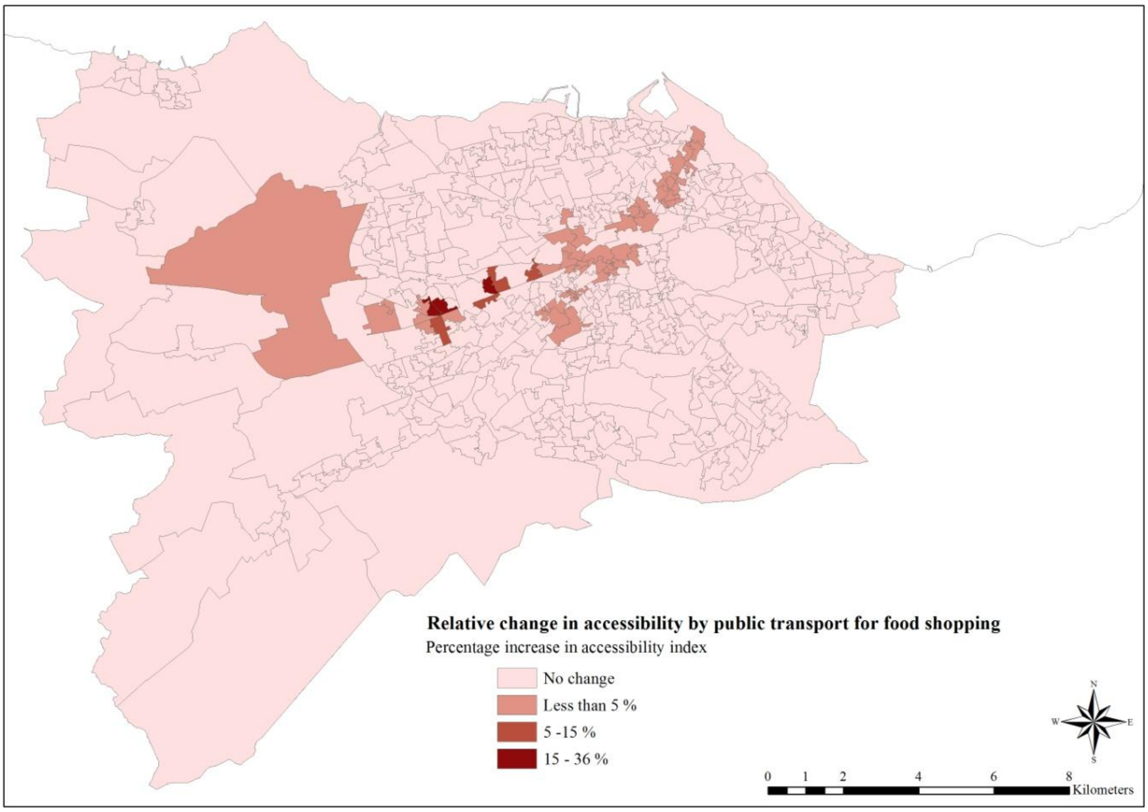

Figure D.2: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

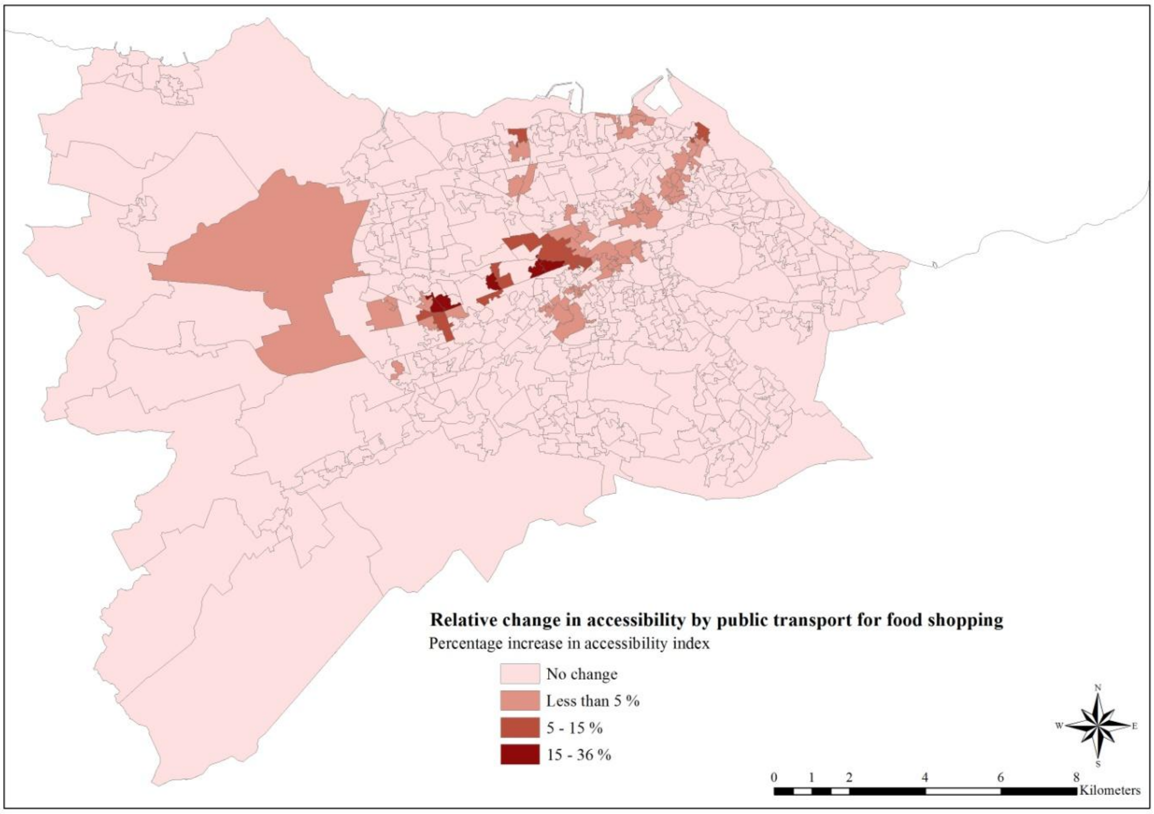

Figure D.3: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

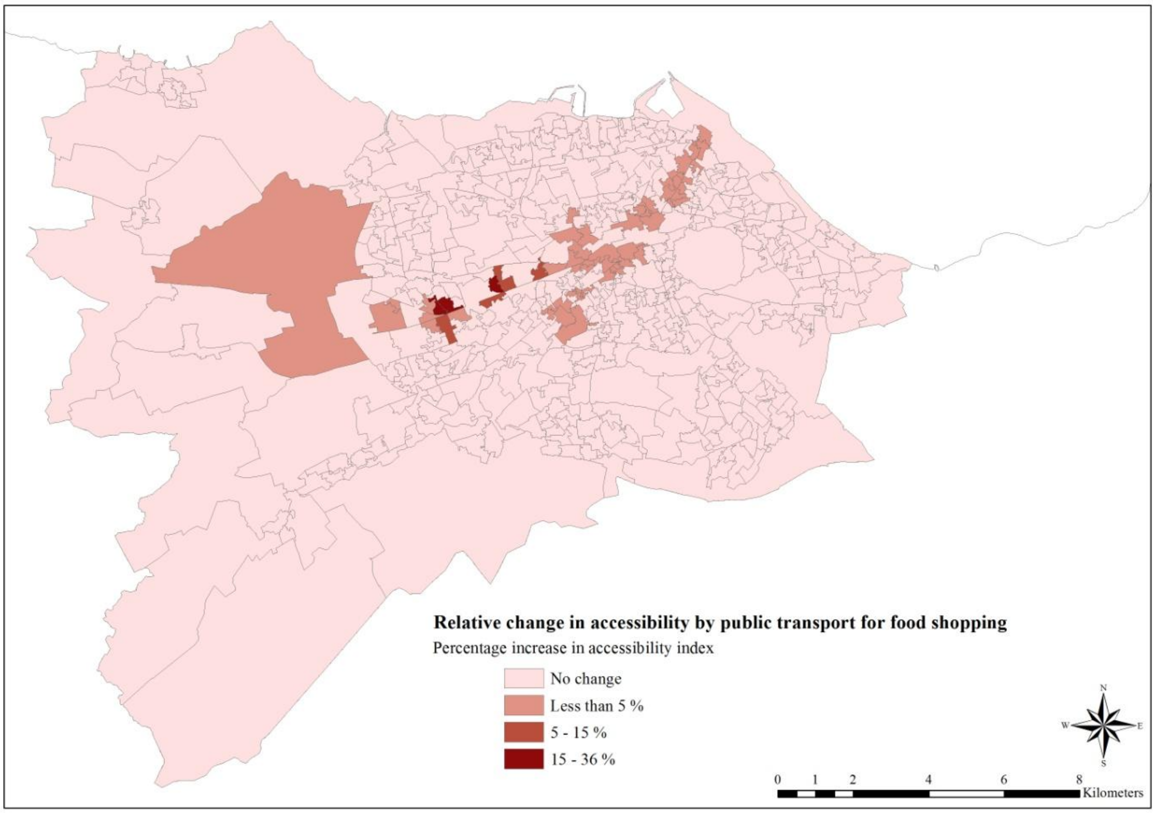

Figure D.4: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

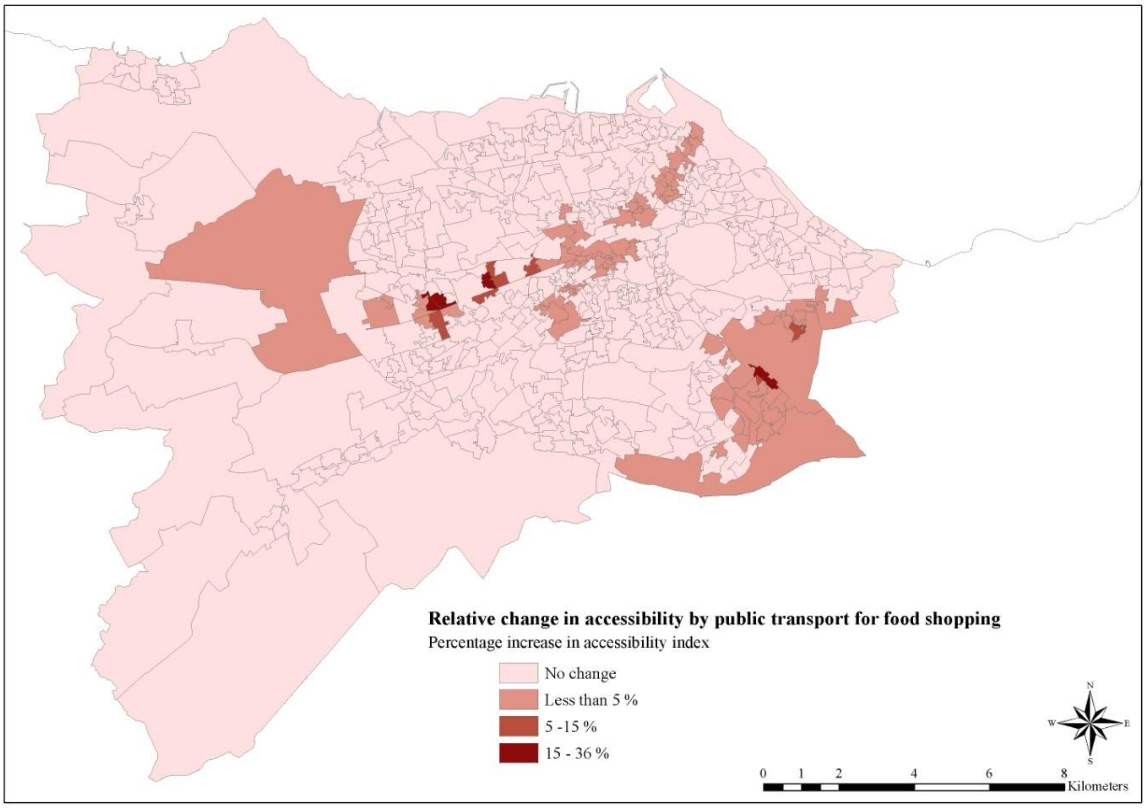

Figure D.5: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

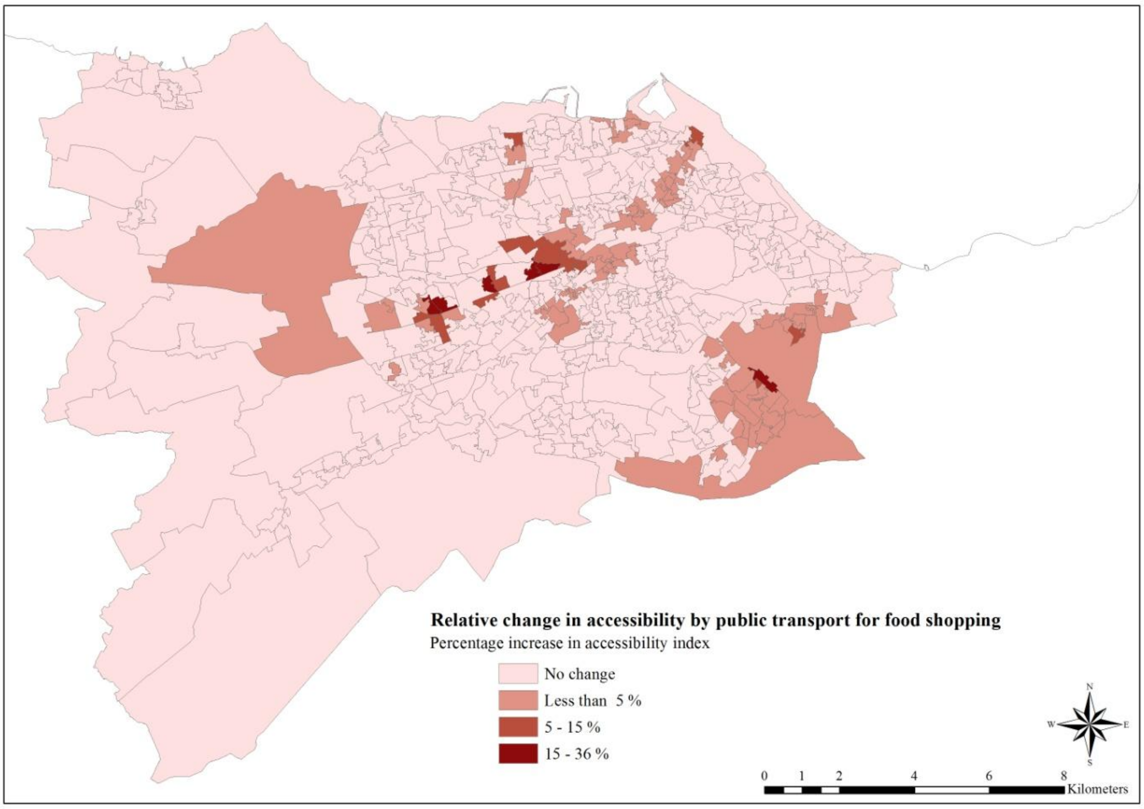

Figure D.6: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

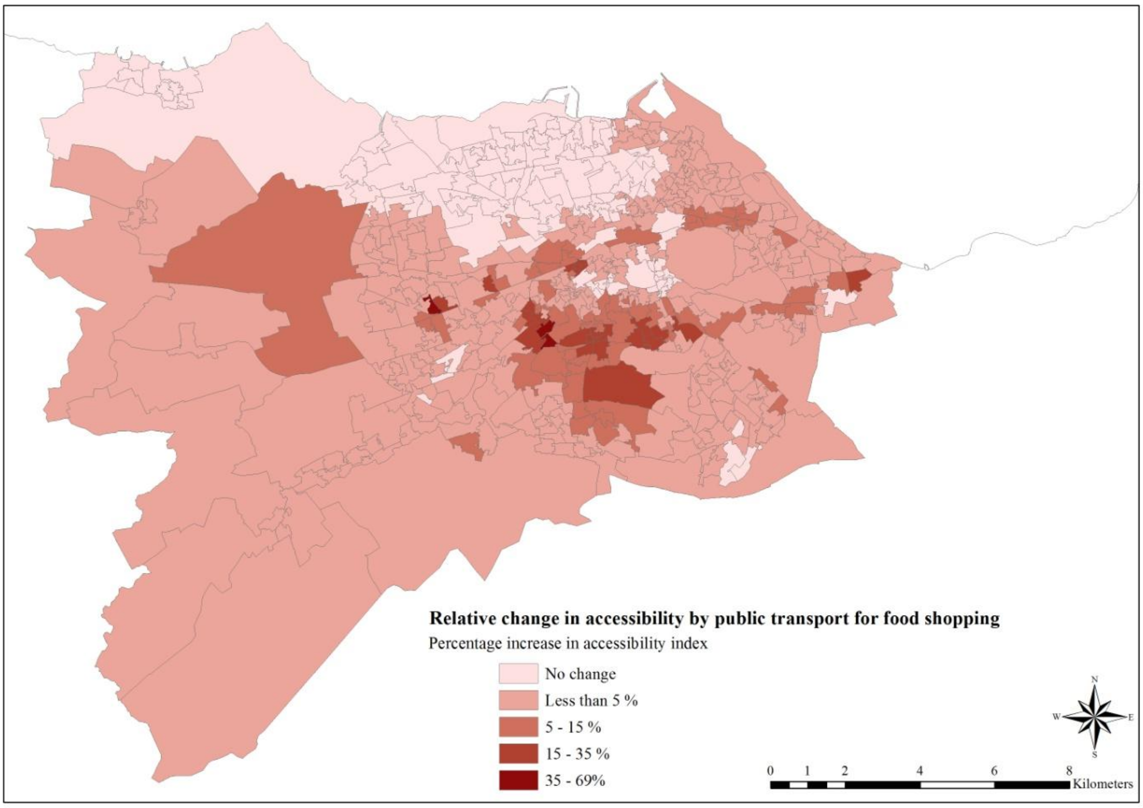

Figure D.7: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

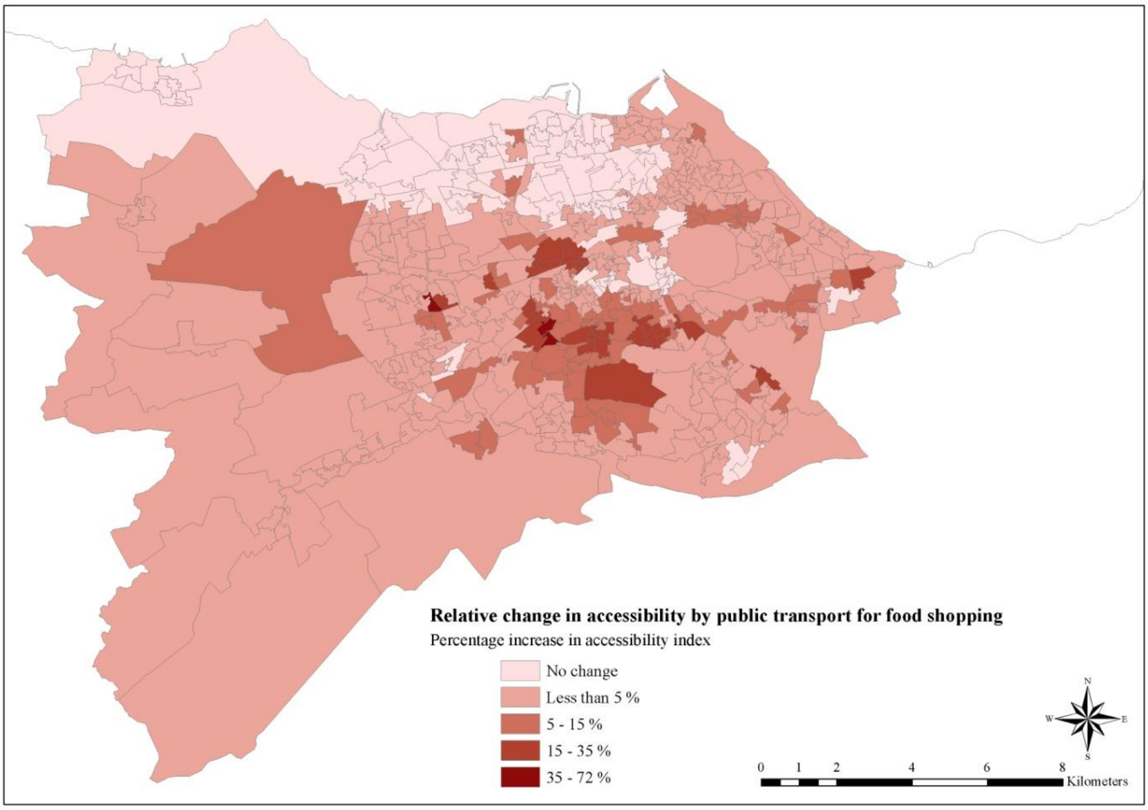

Figure D.8: Relative change in accessibility by public transport to food stores between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

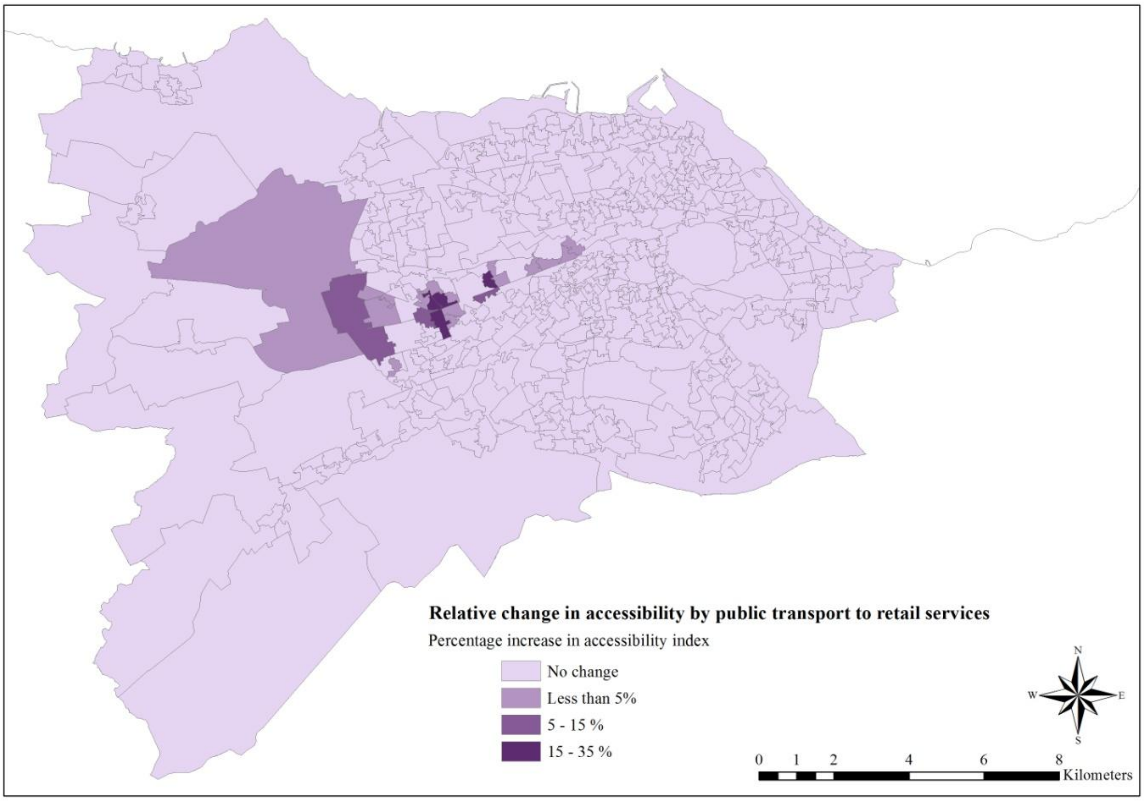

Figure D.9: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

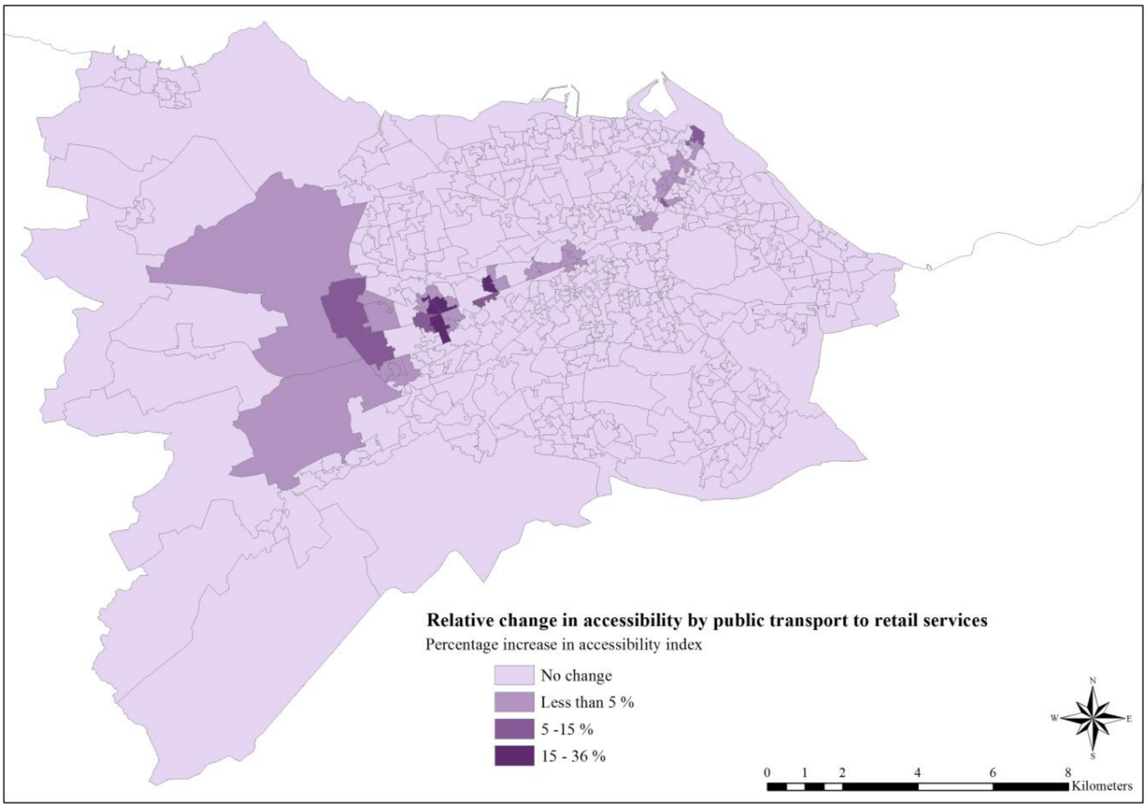

Figure D.10: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

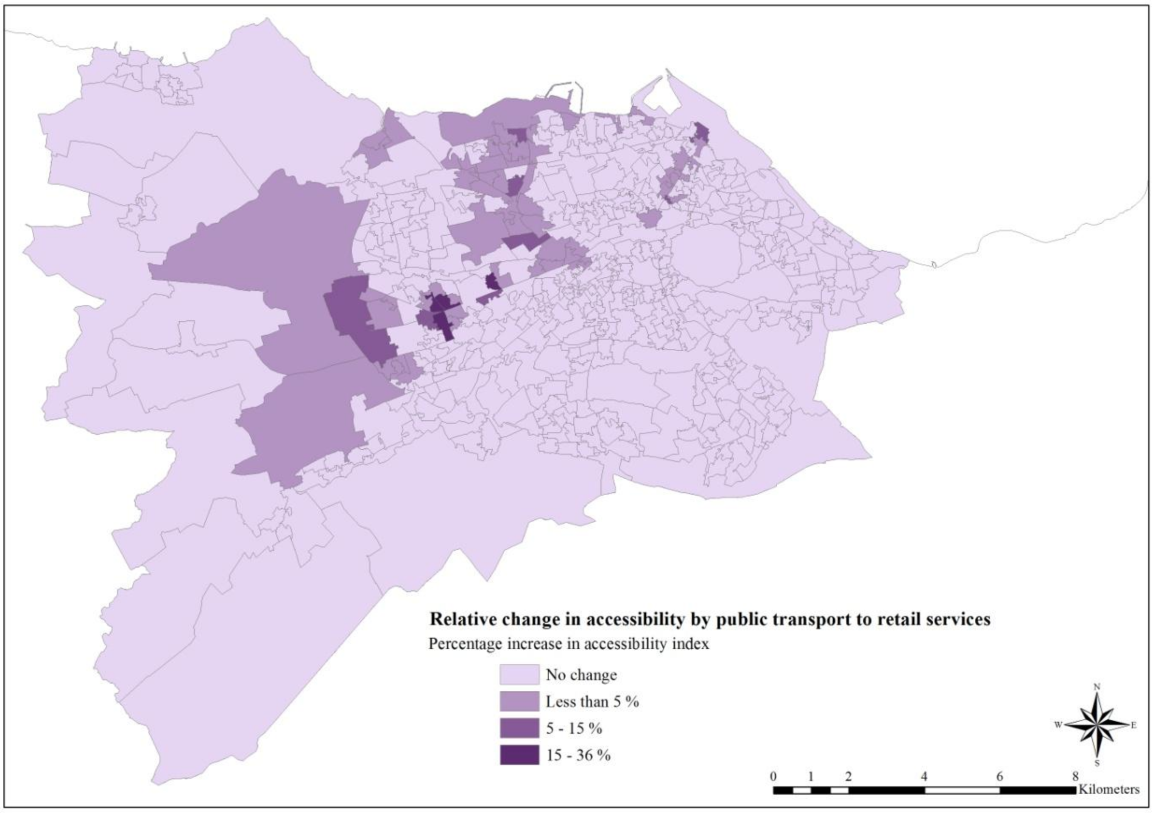

Figure D.11: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

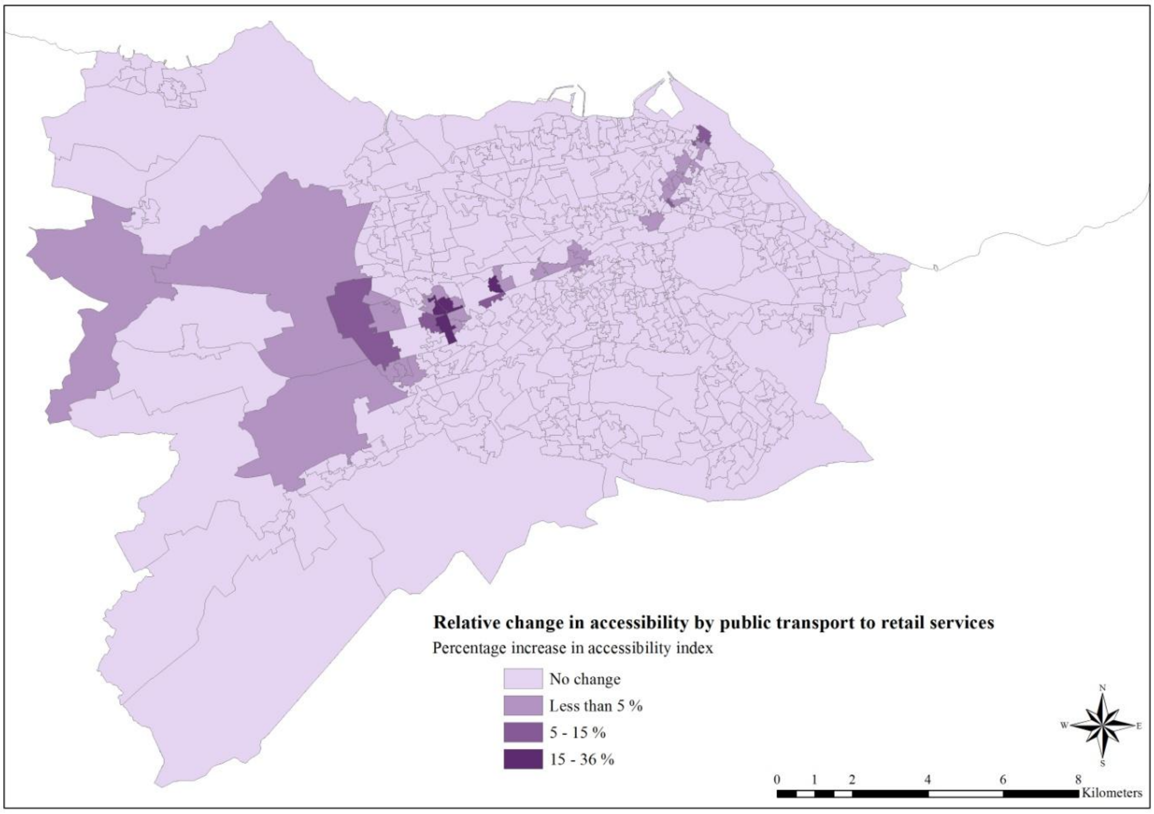

Figure D.12: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

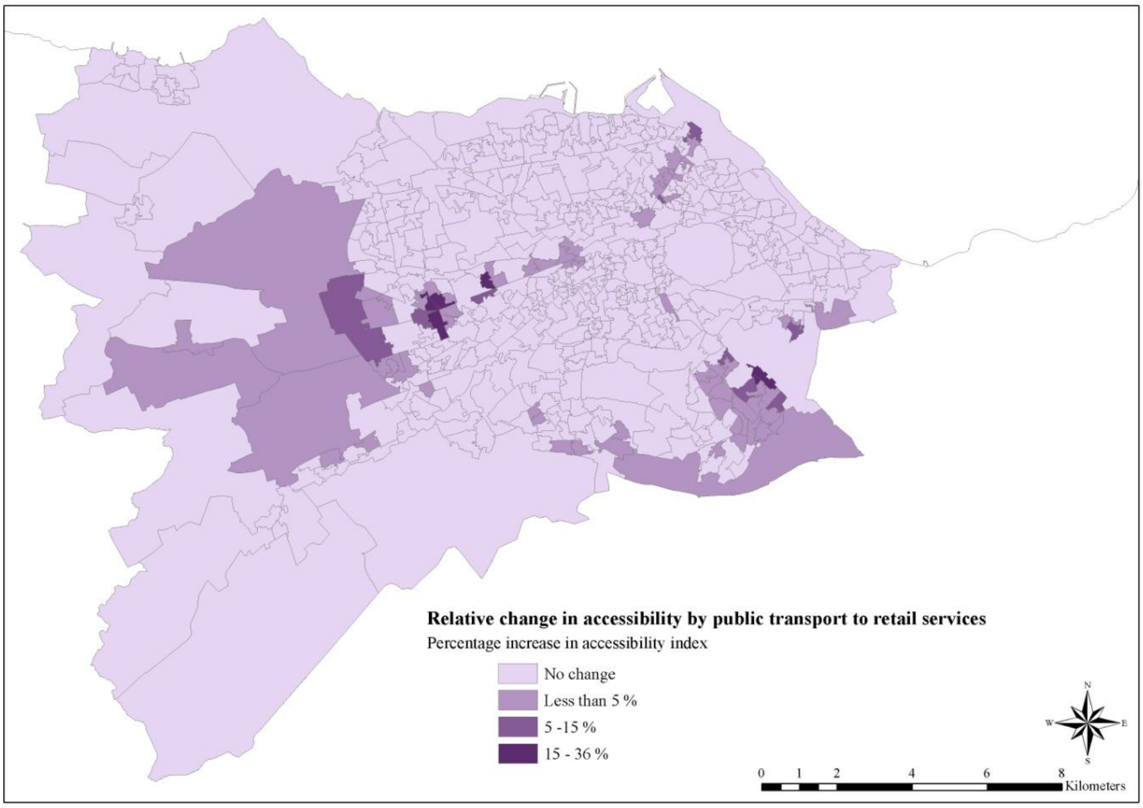

Figure D.13: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

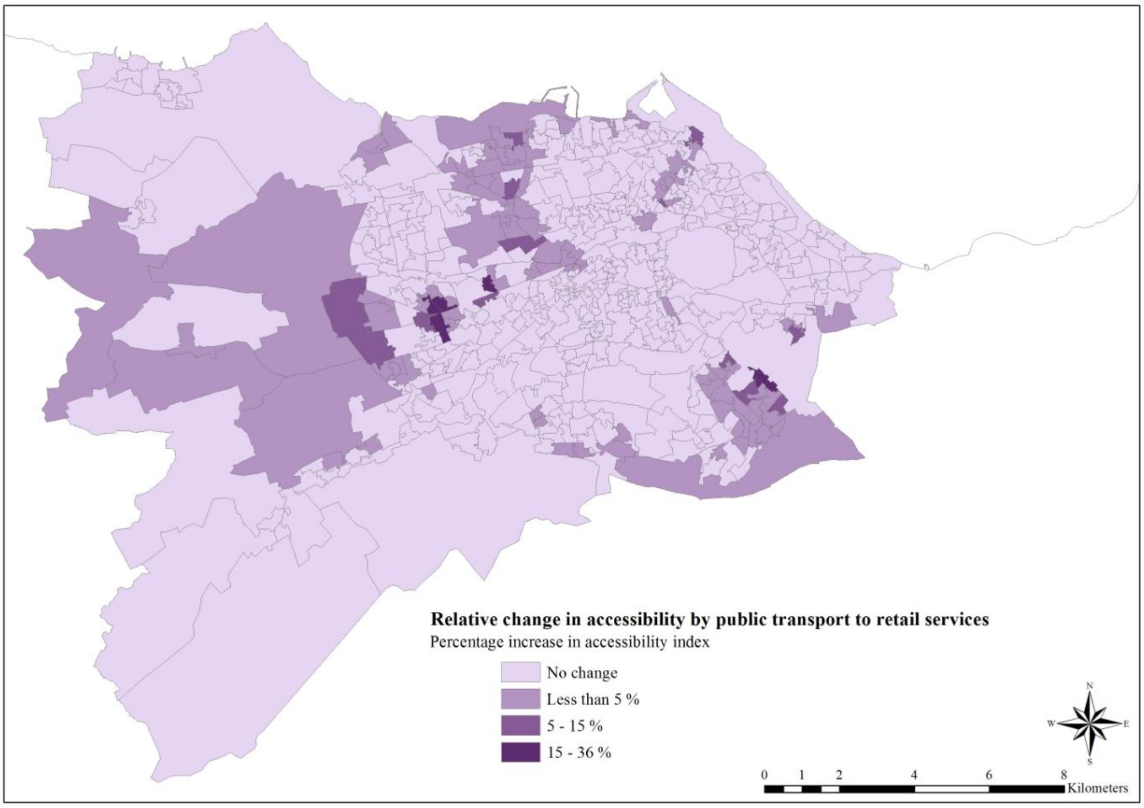

Figure D.14: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

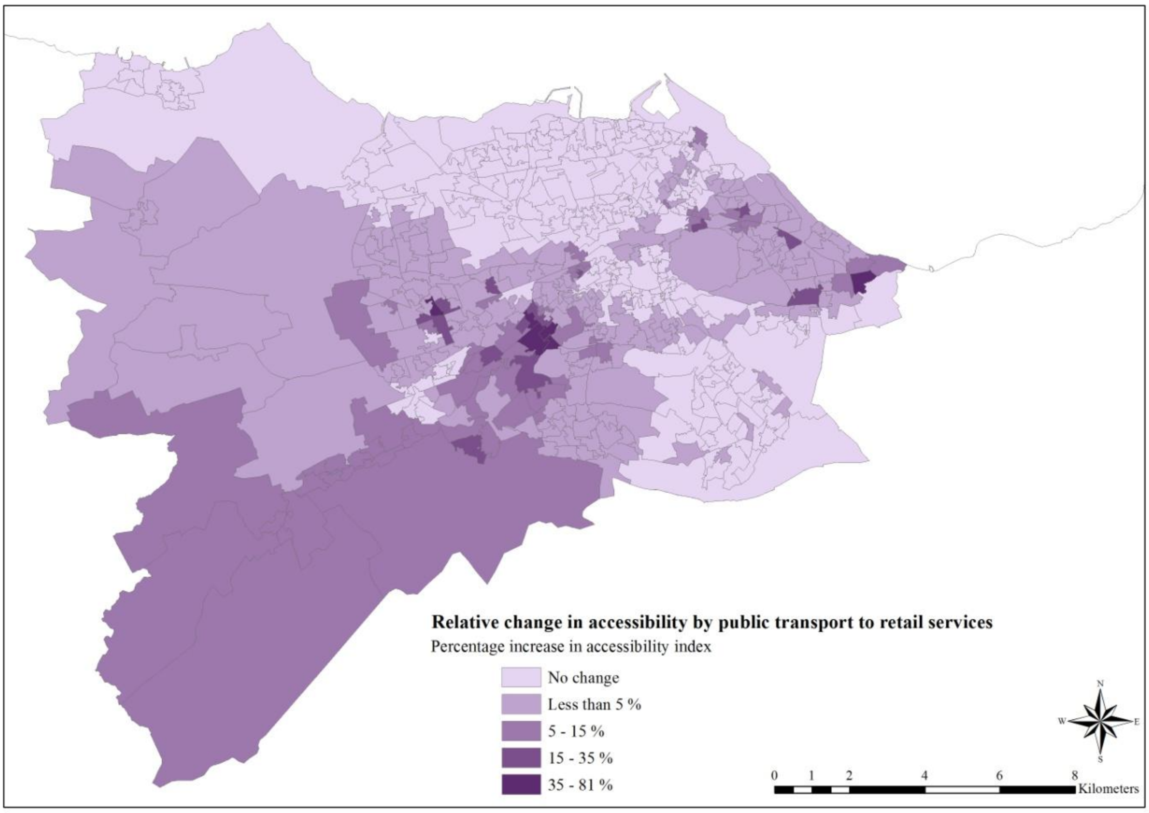

Figure D.15: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

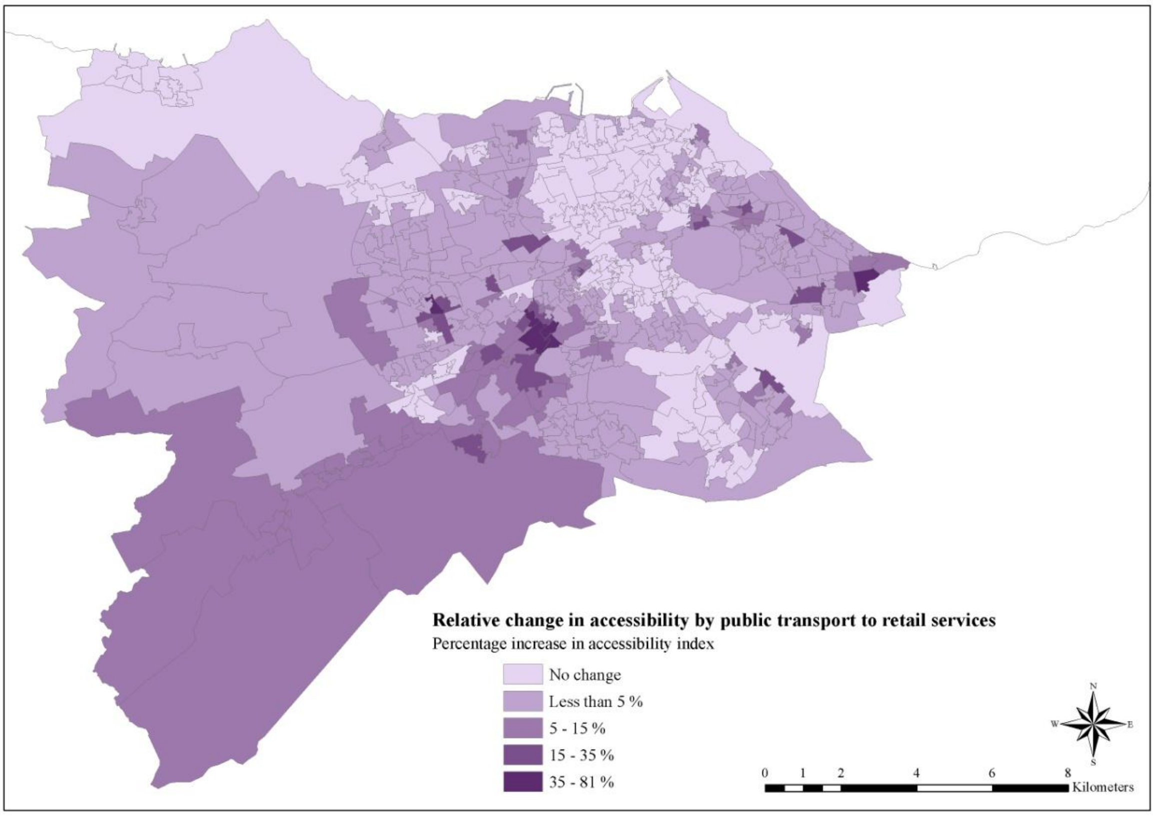

Figure D.16: Relative change in accessibility by public transport to retail services between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

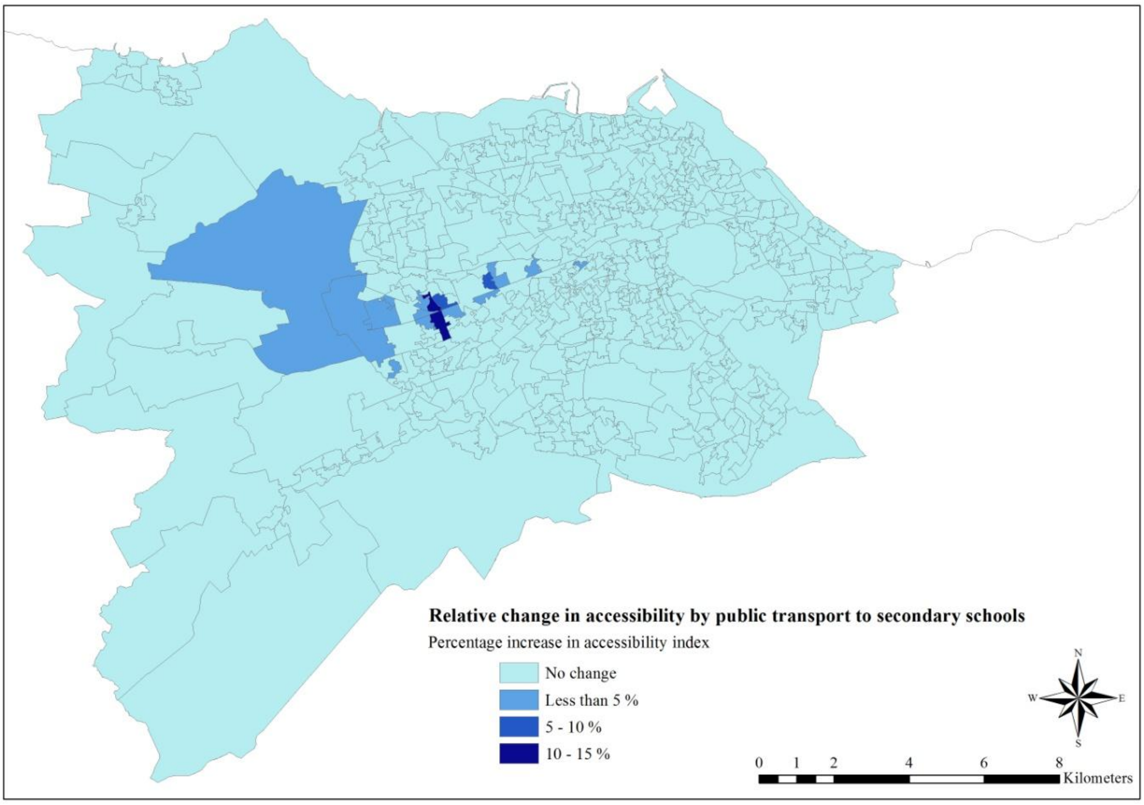

Figure D.17: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

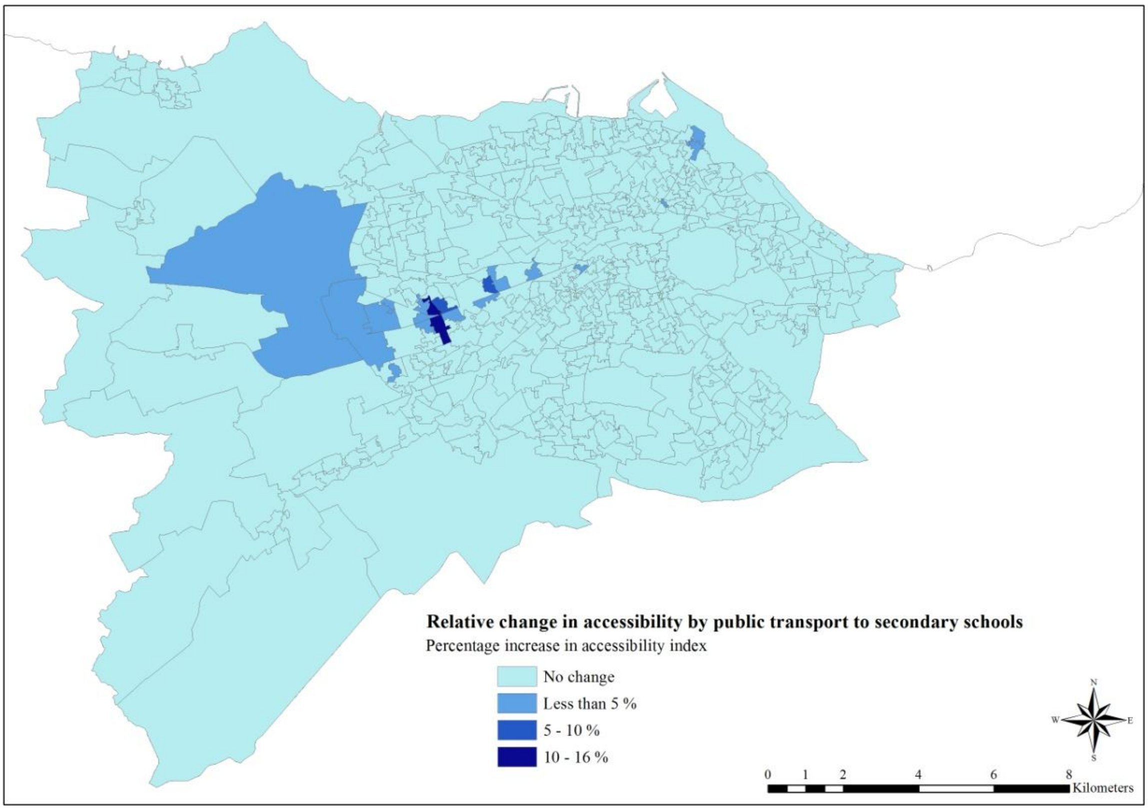

Figure D.18: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

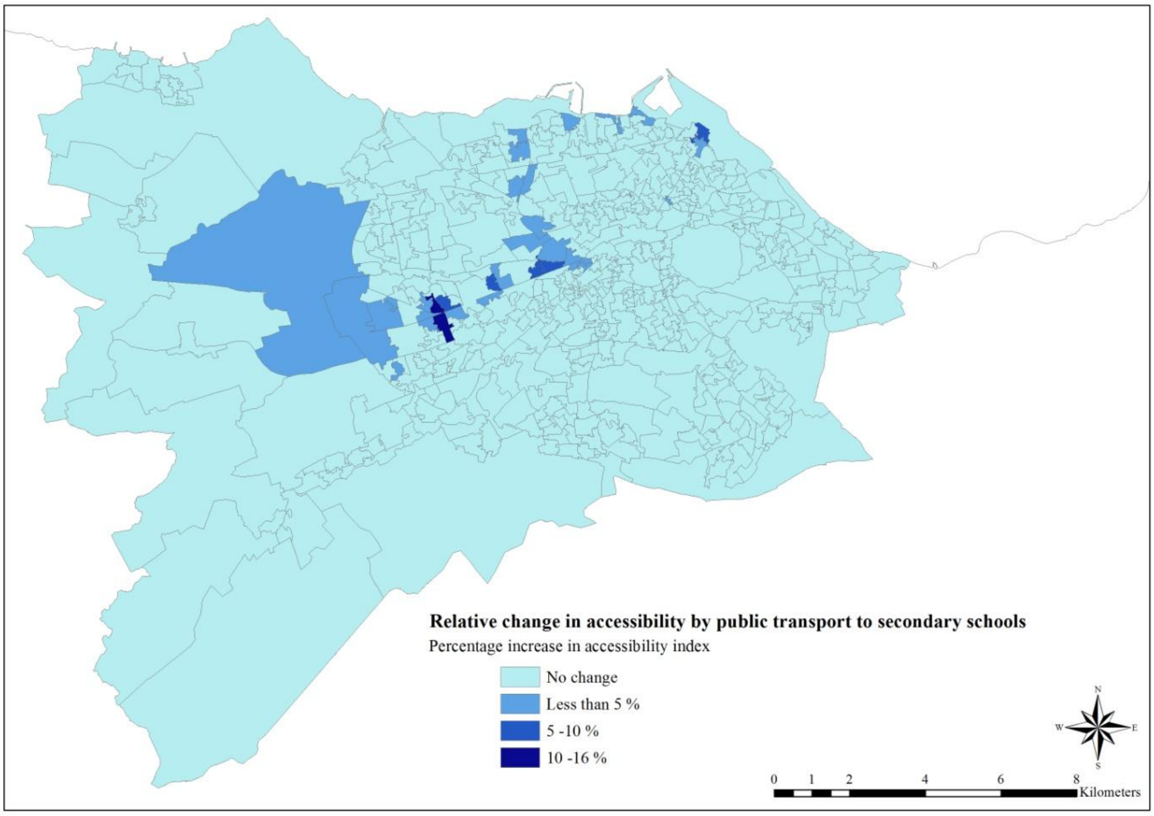

Figure D.19: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

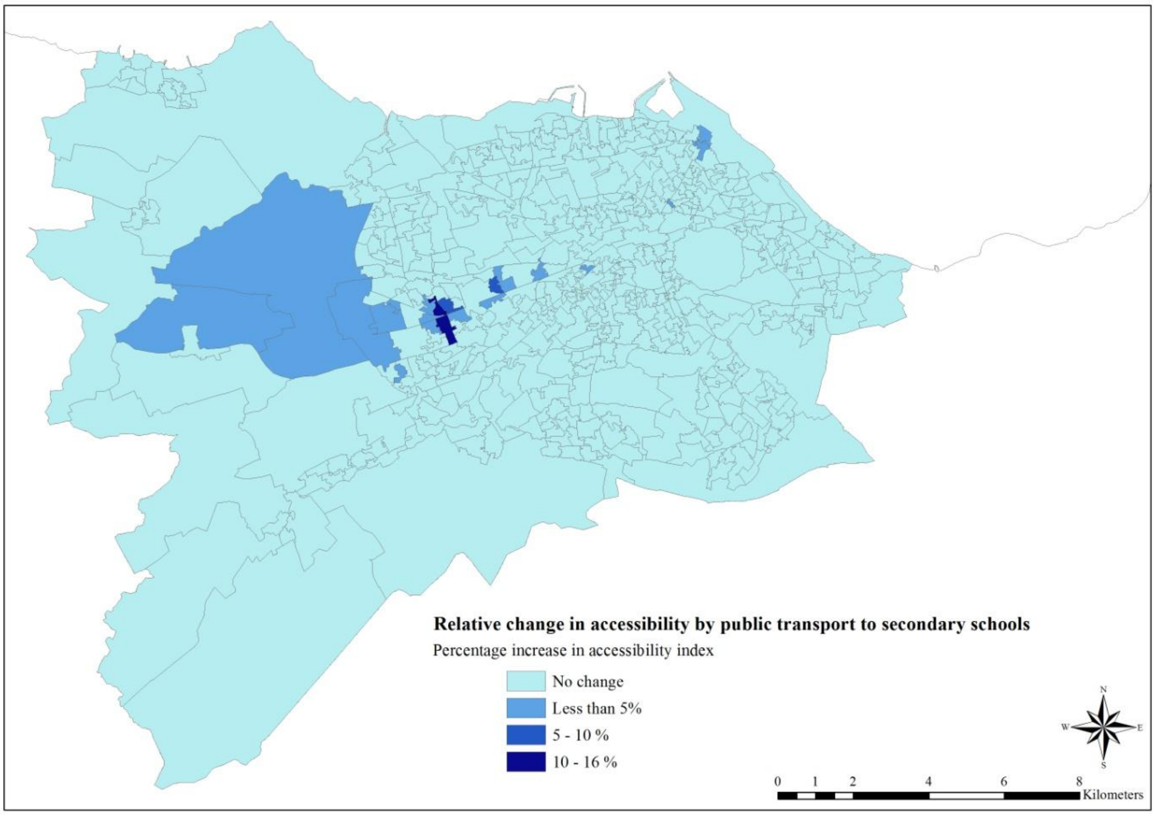

Figure D.20: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

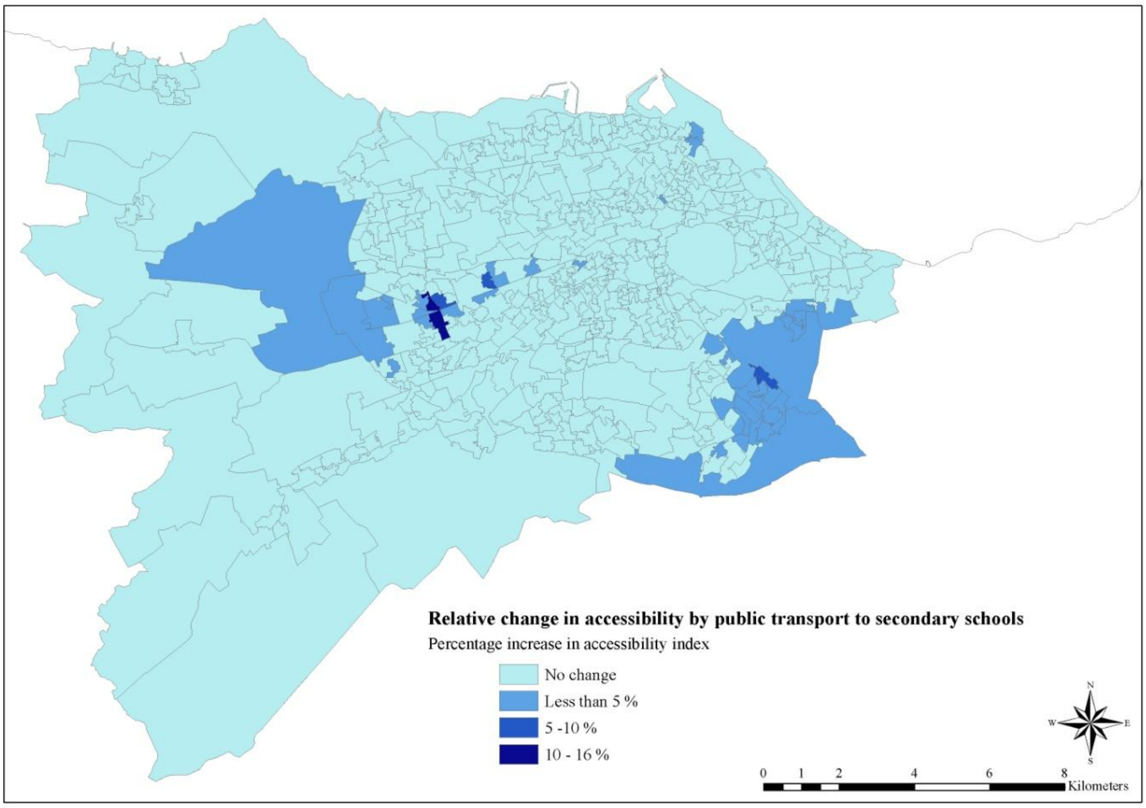

Figure D.21: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

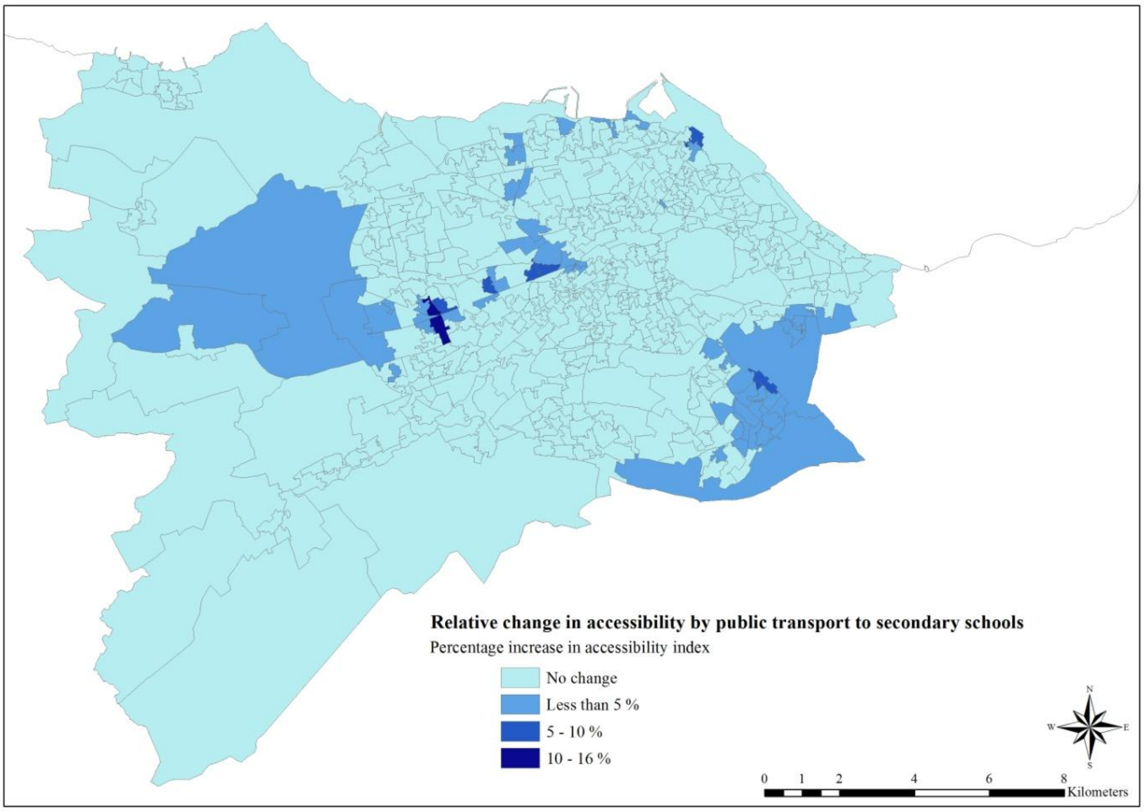

Figure D.22: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

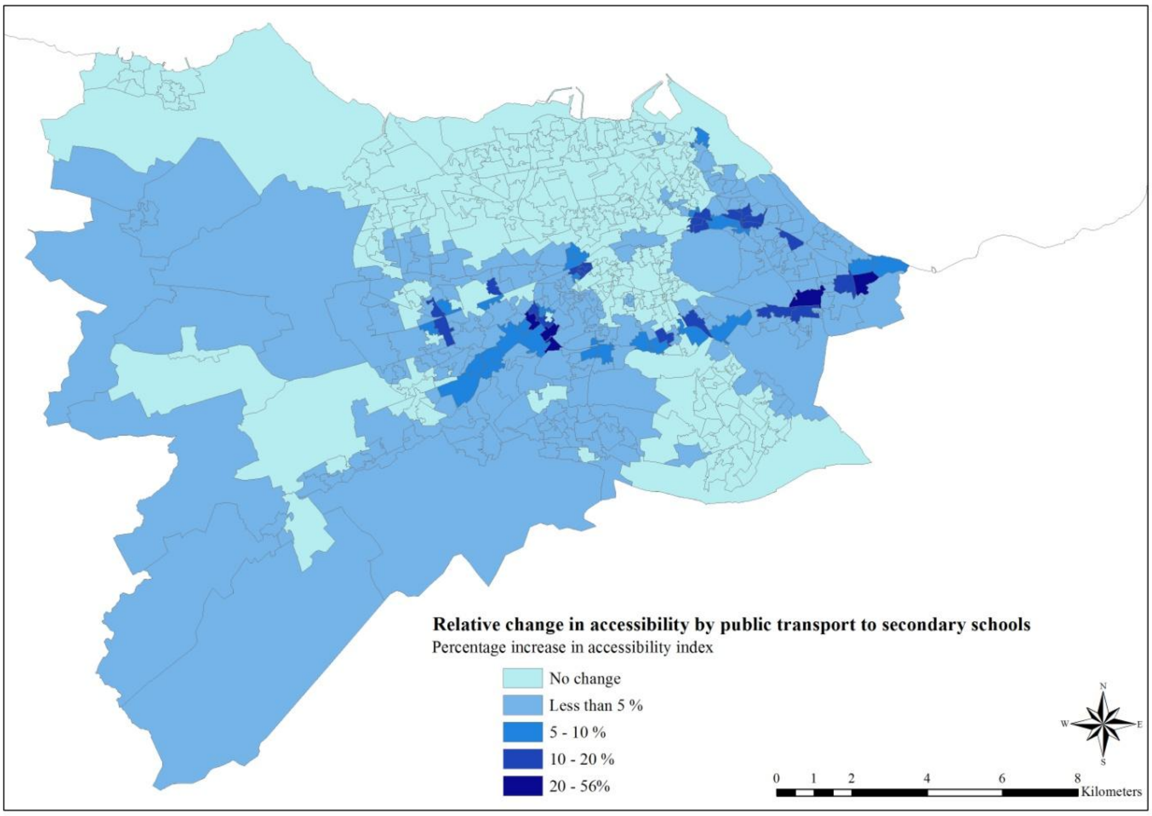

Figure D.23: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

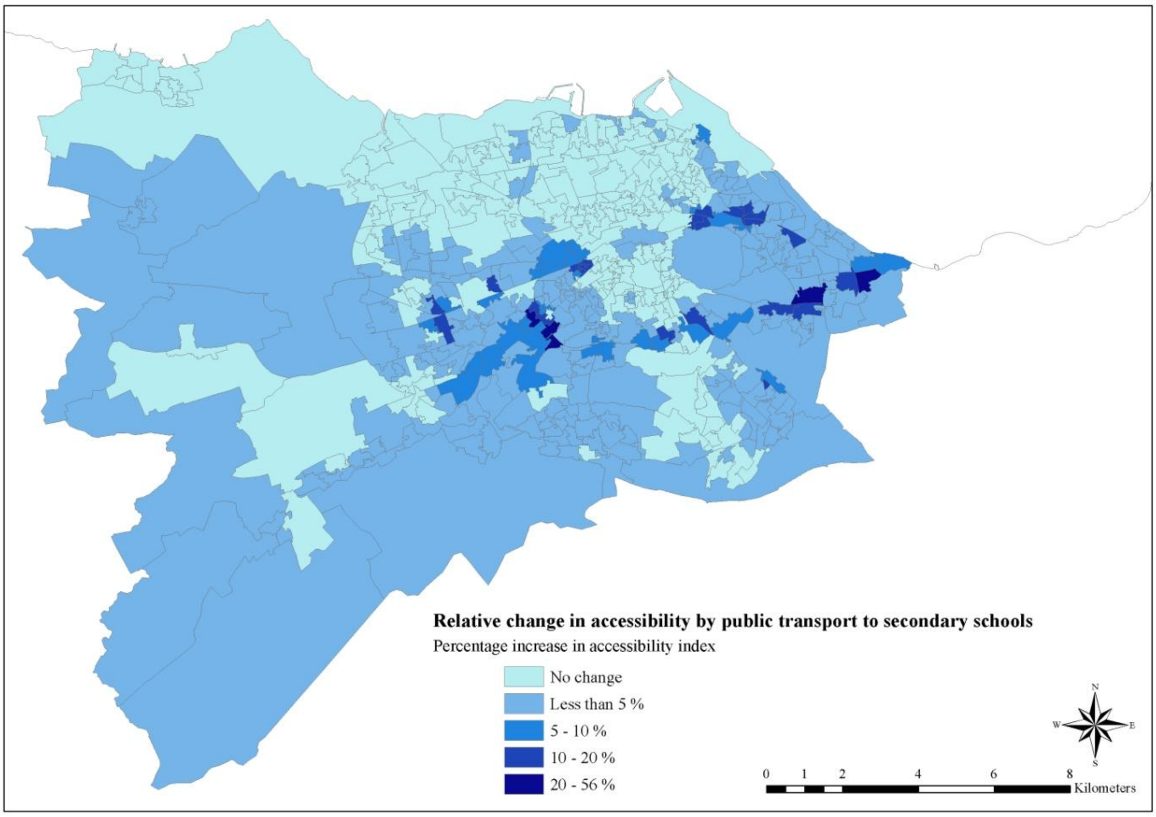

Figure D.24: Relative change in accessibility by public transport to secondary schools between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

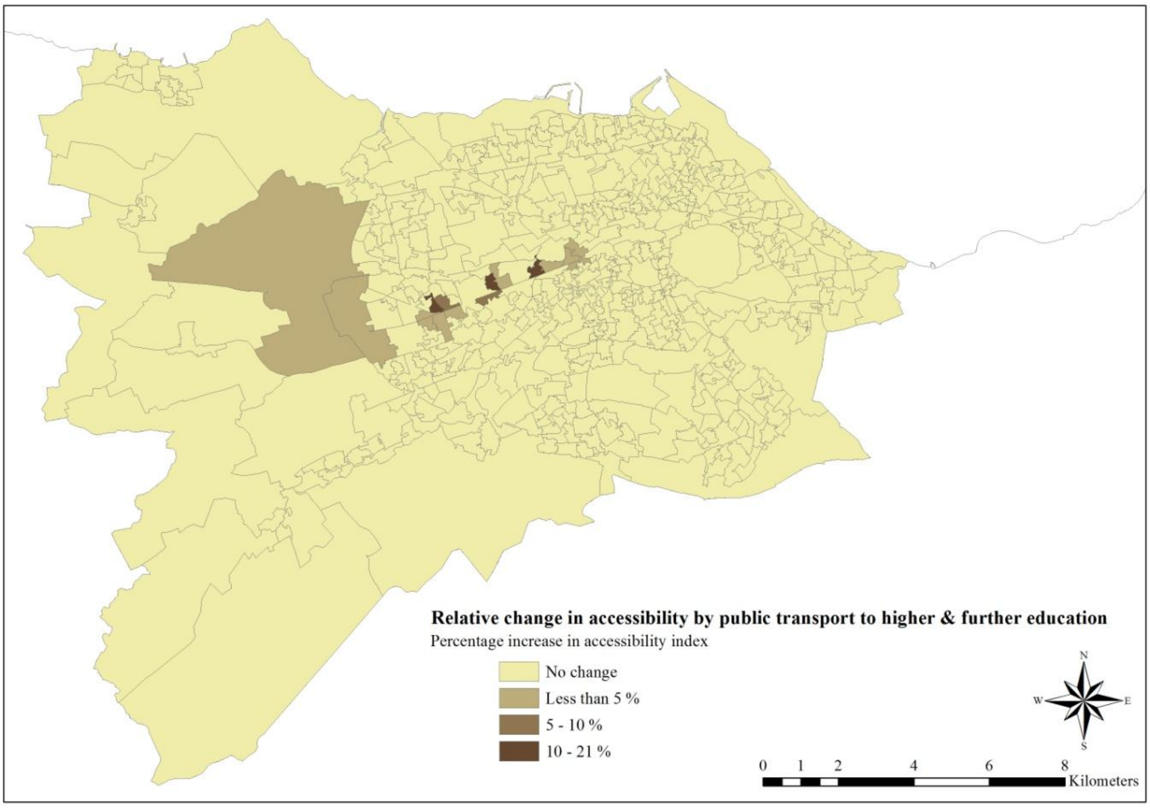

Figure D.25: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

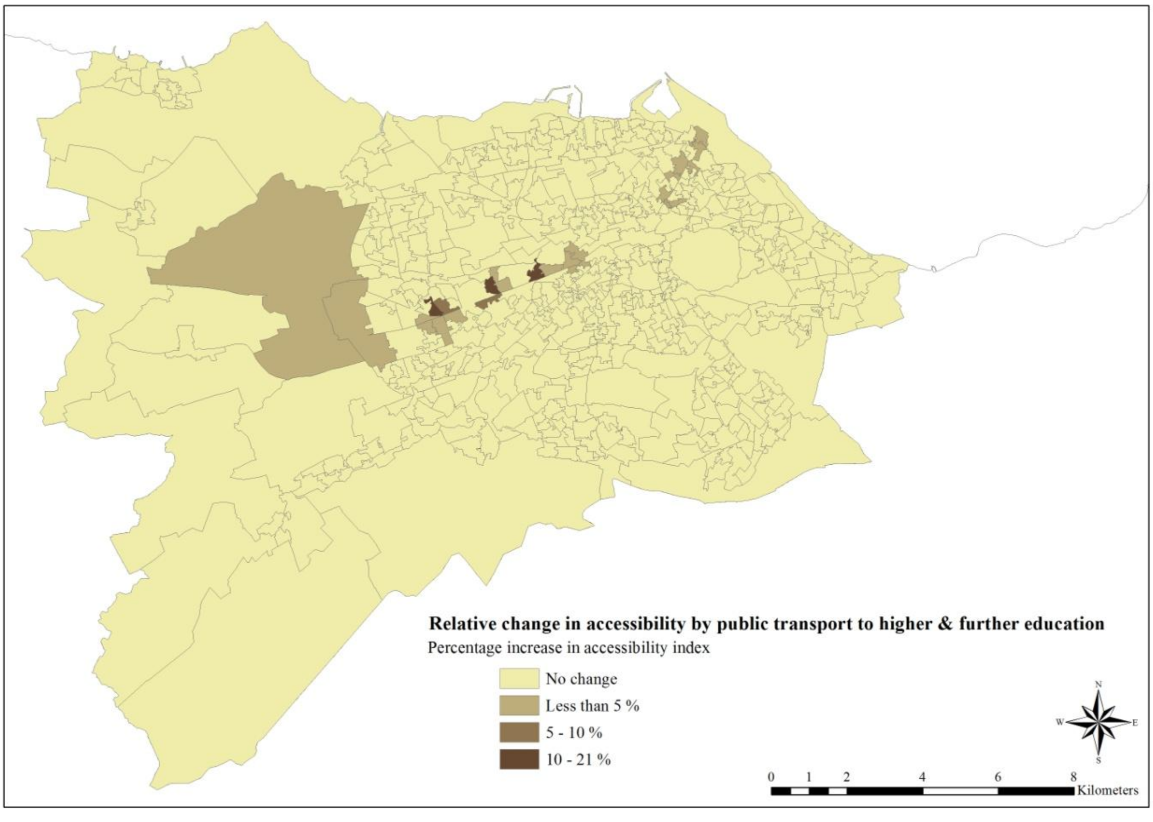

Figure D.26: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

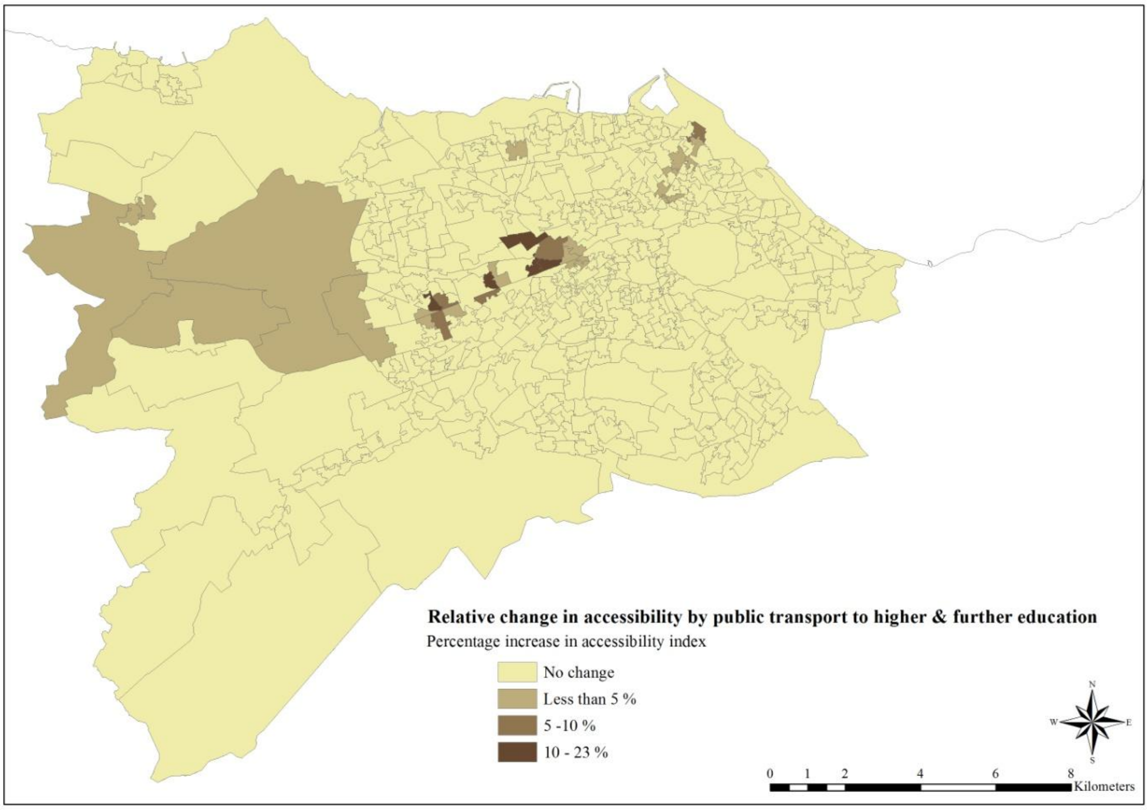

Figure D.27: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

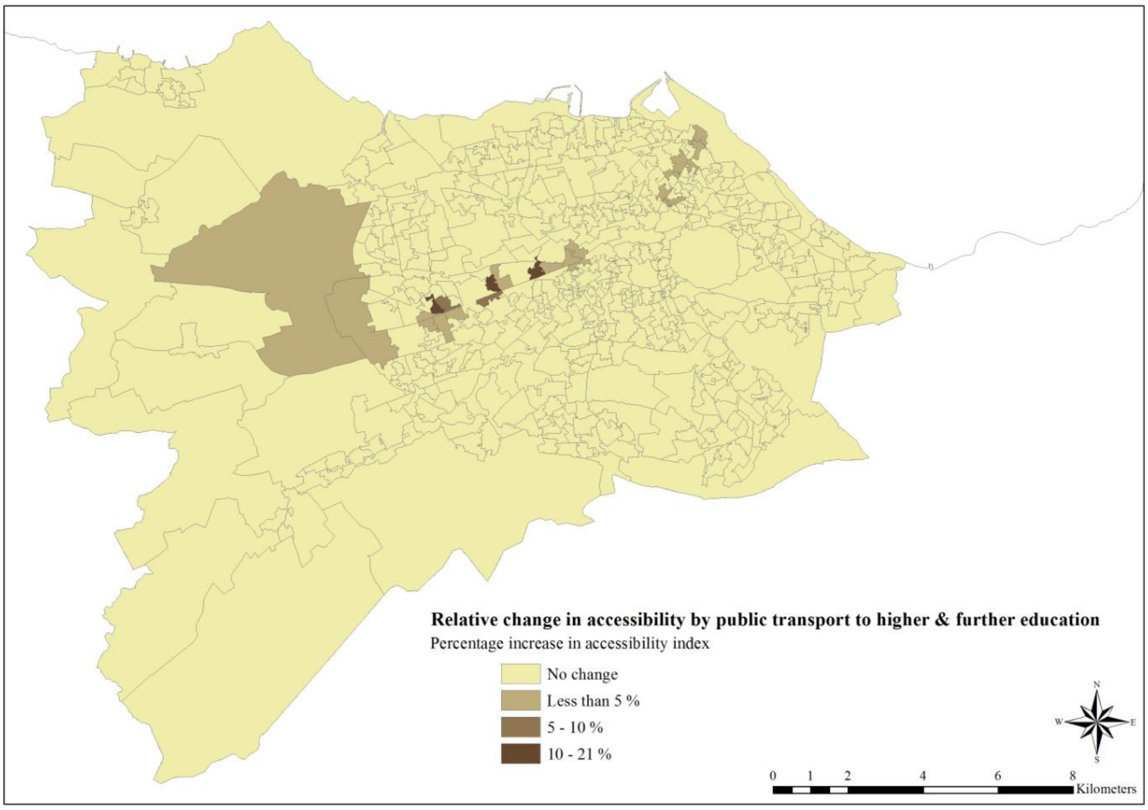

Figure D.28: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

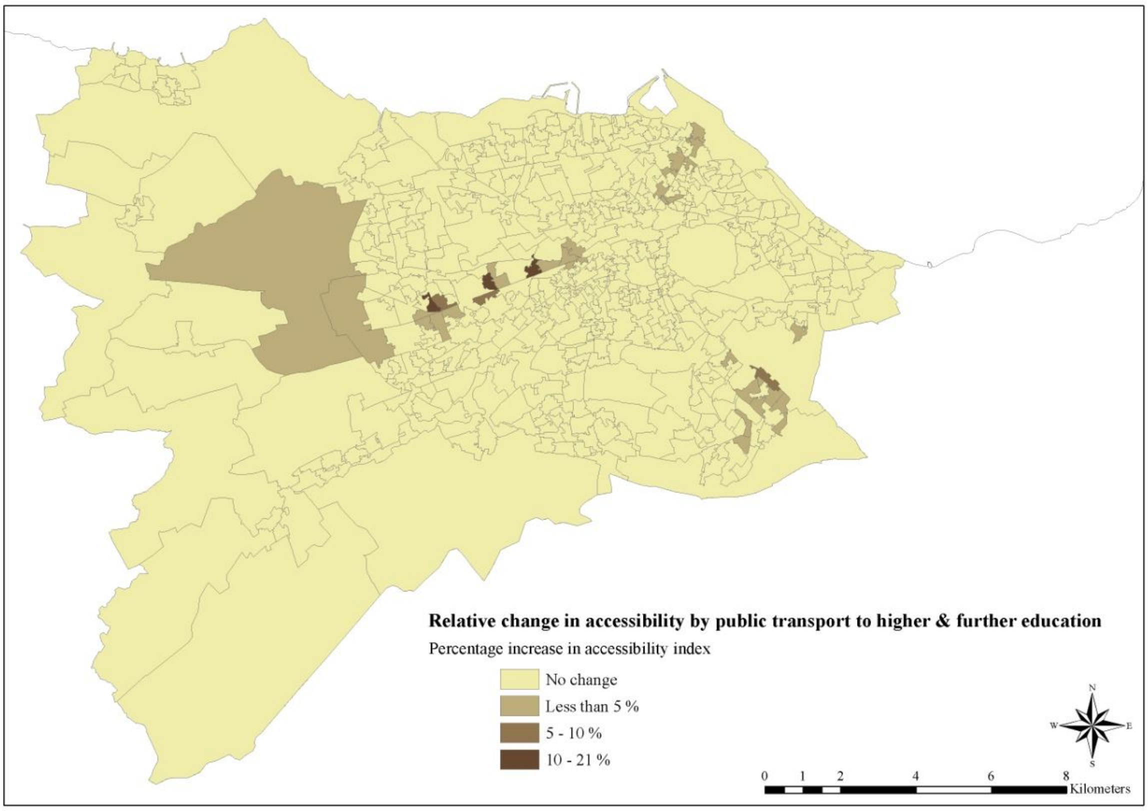

Figure D.29: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

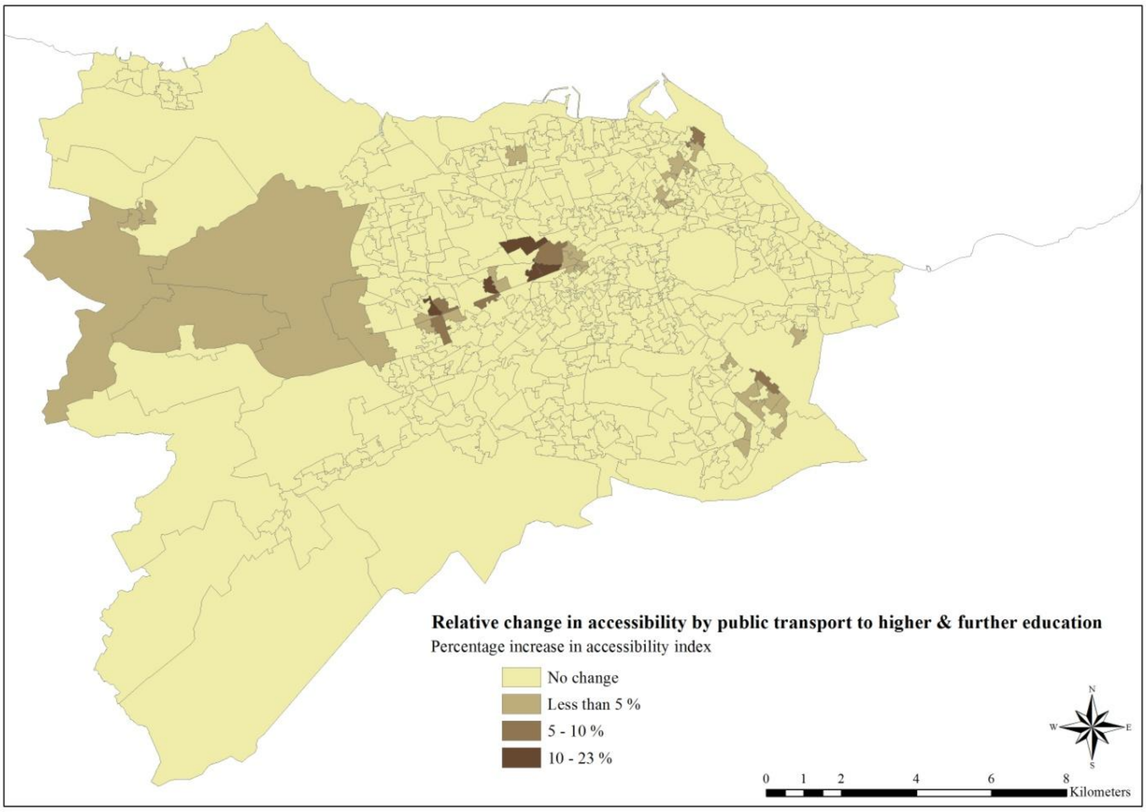

Figure D.30: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

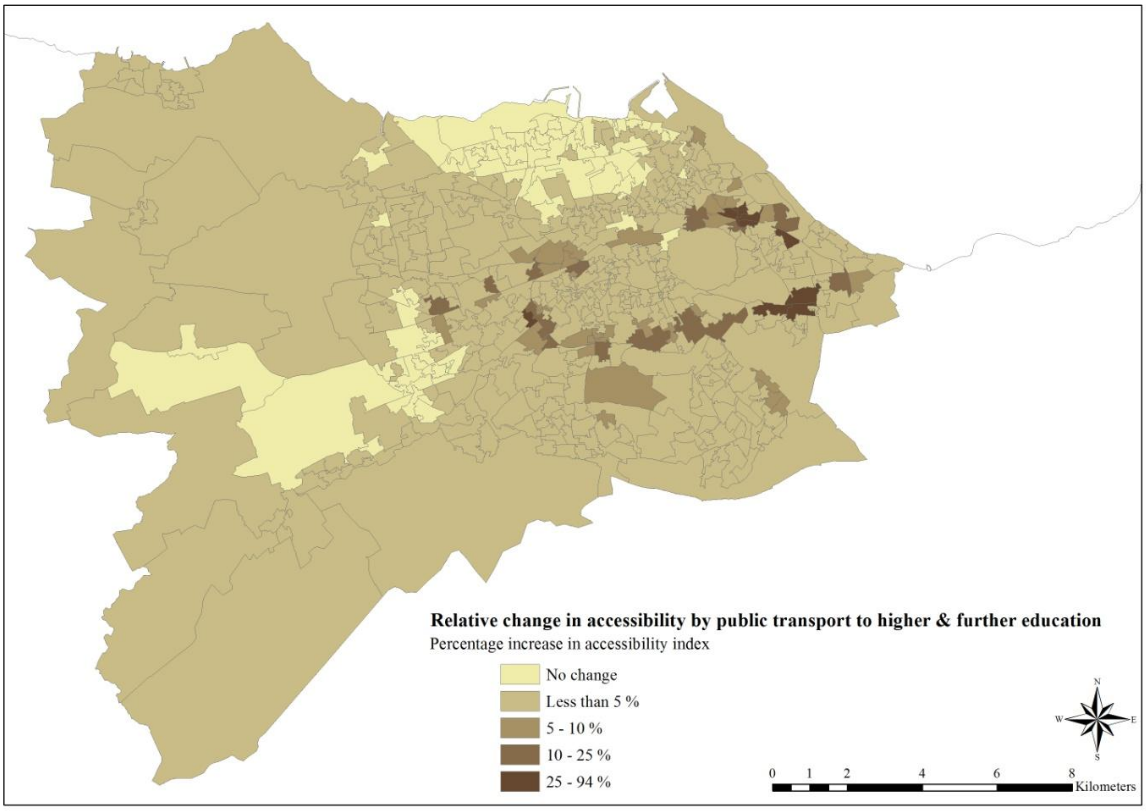

Figure D.31: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

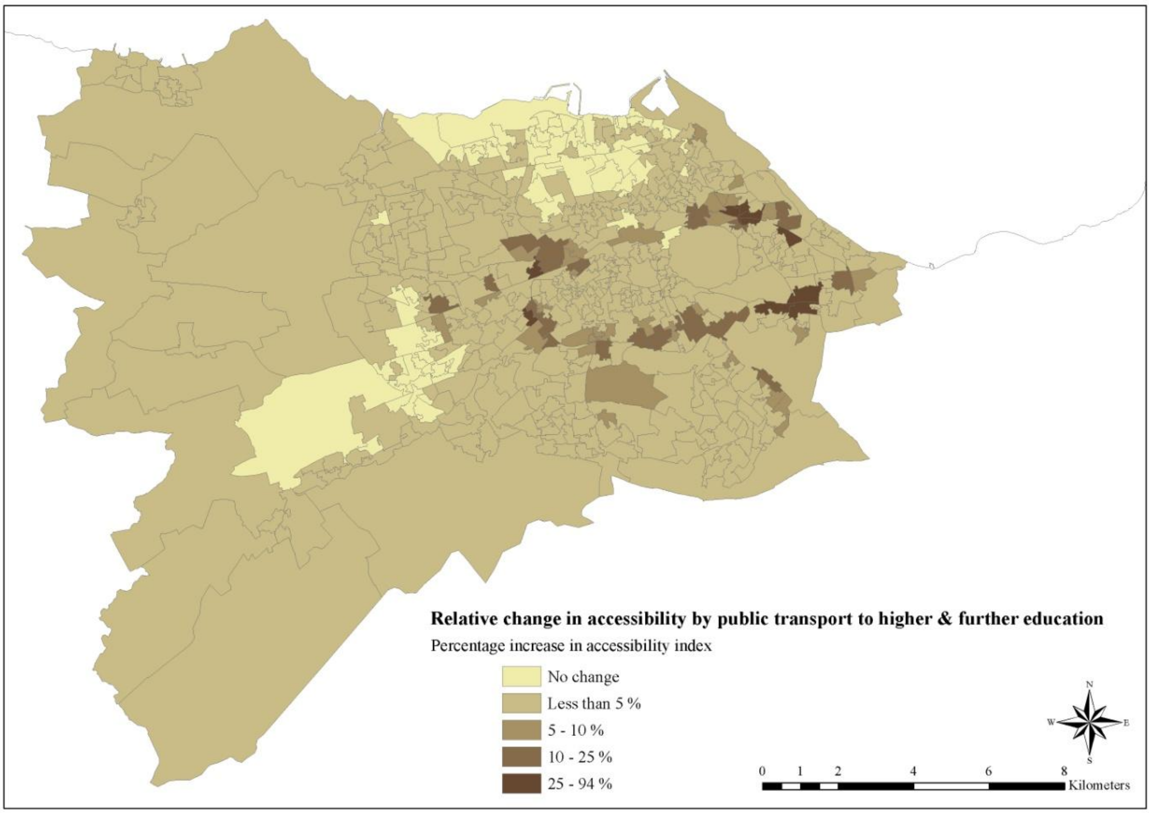

Figure D.32: Relative change in accessibility by public transport to higher & further education between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

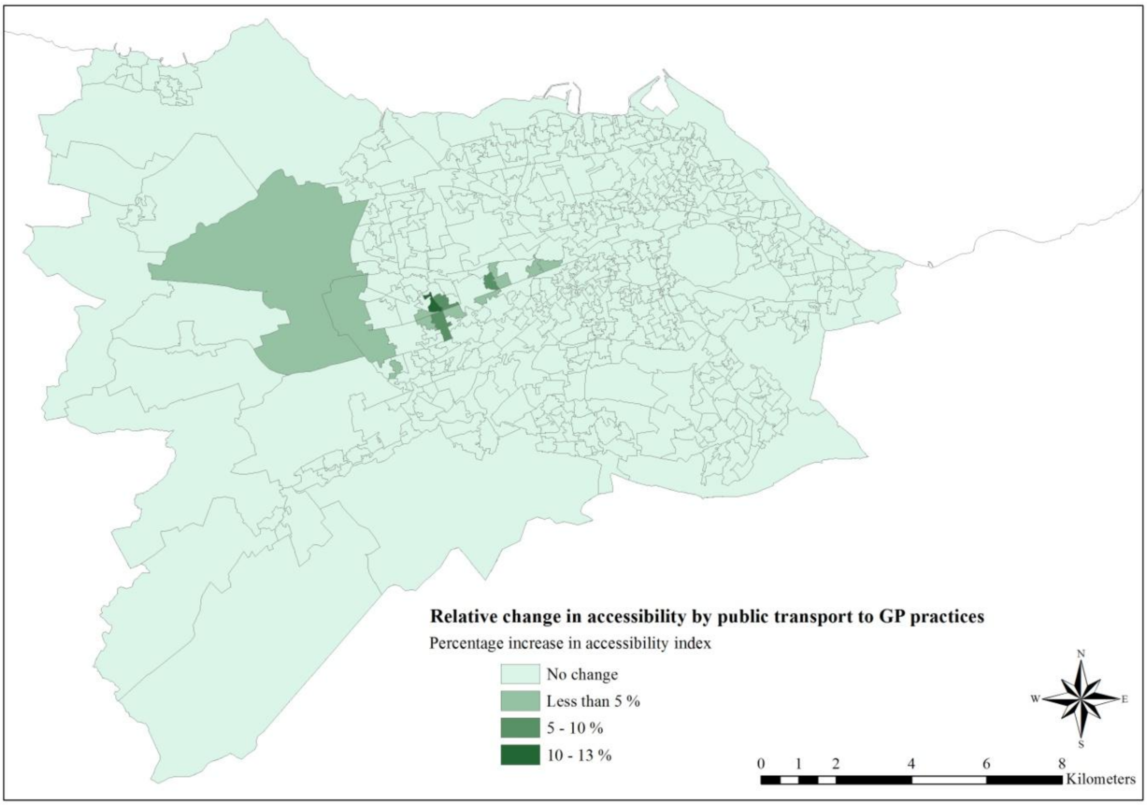

Figure D.33: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

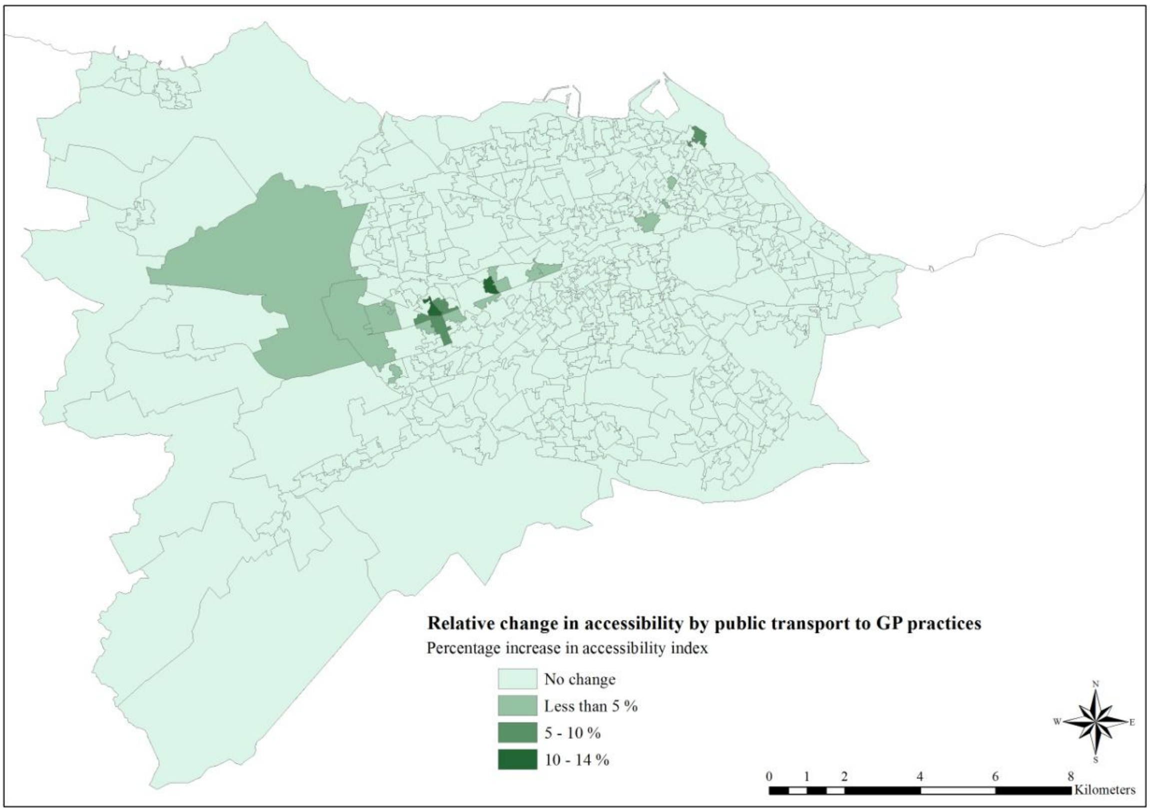

Figure D.34: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

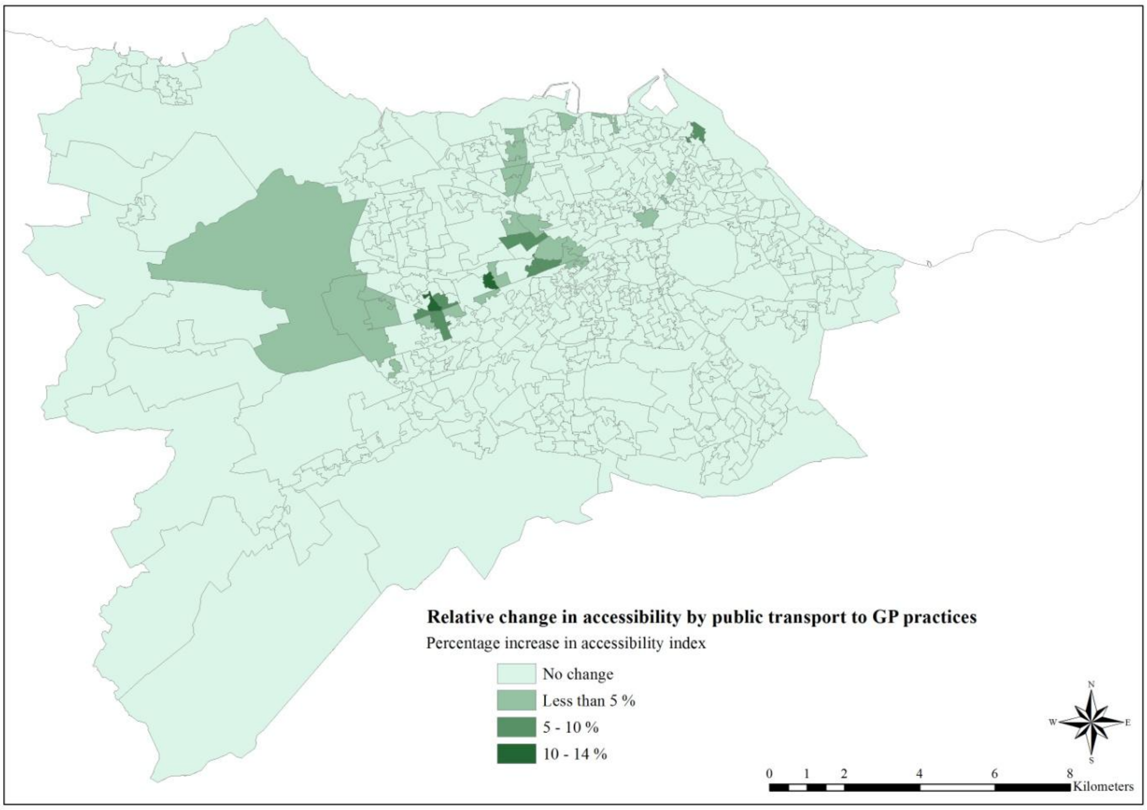

Figure D.35: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

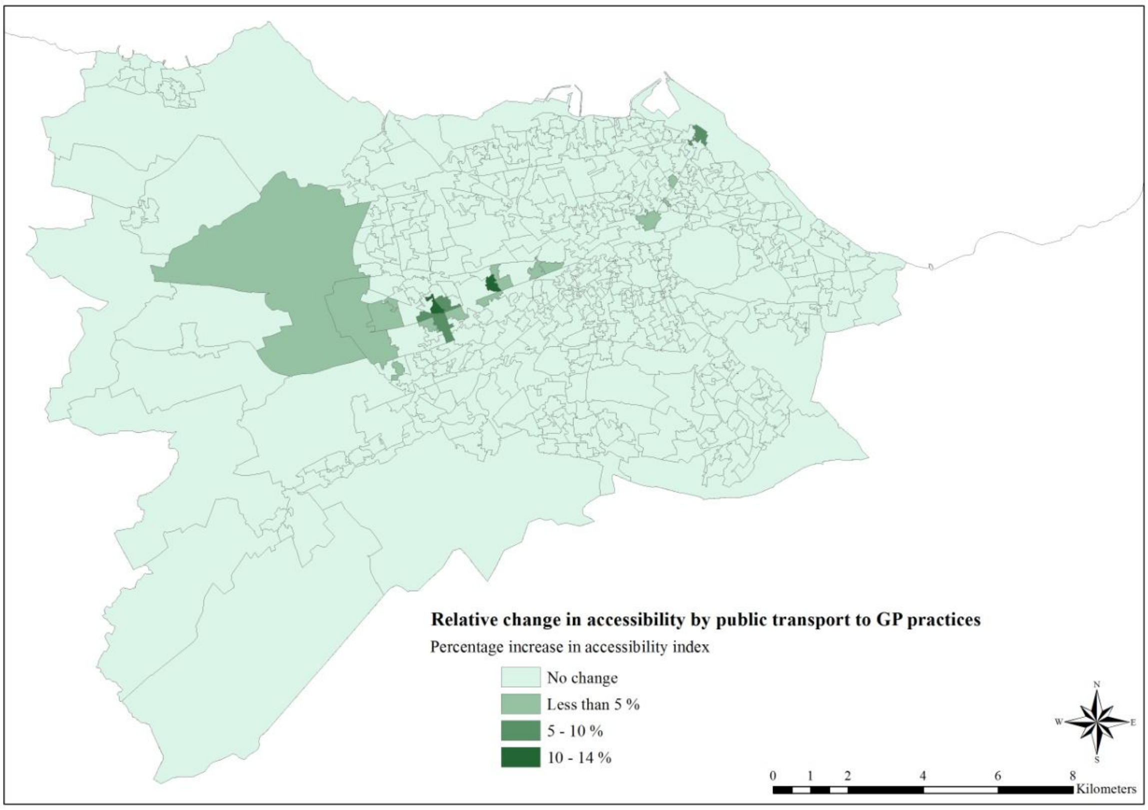

Figure D.36: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

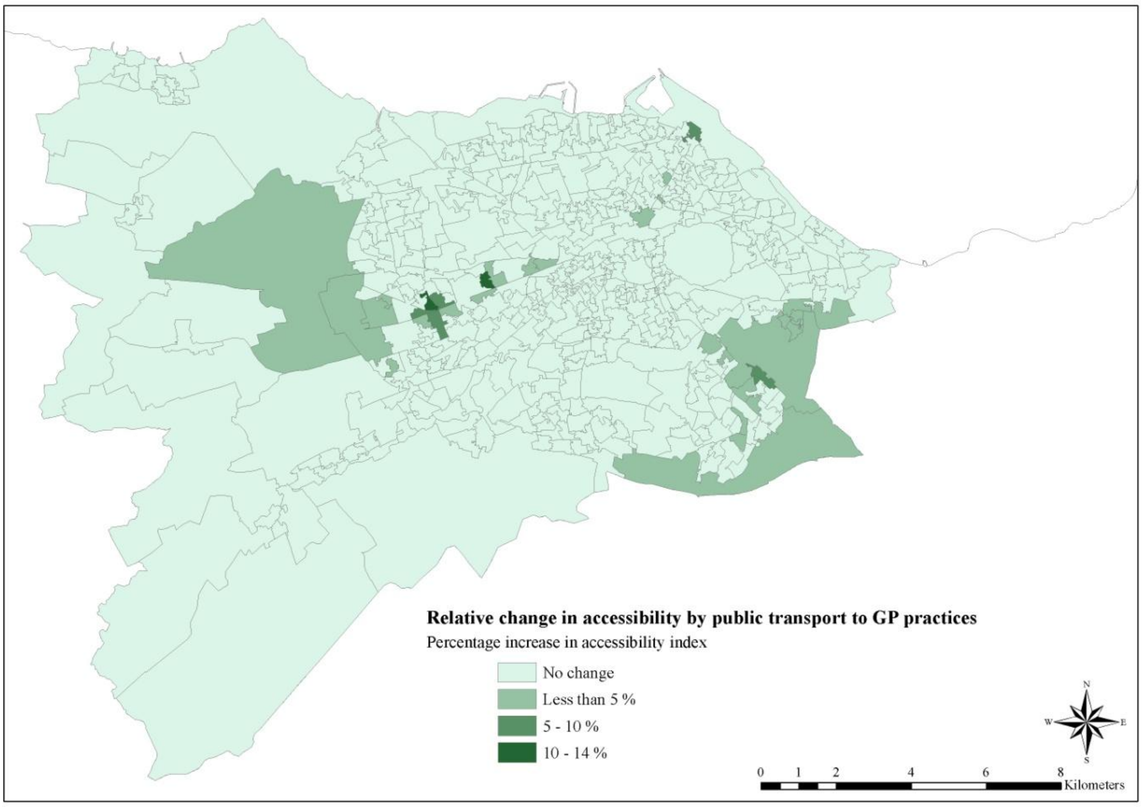

Figure D.37: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

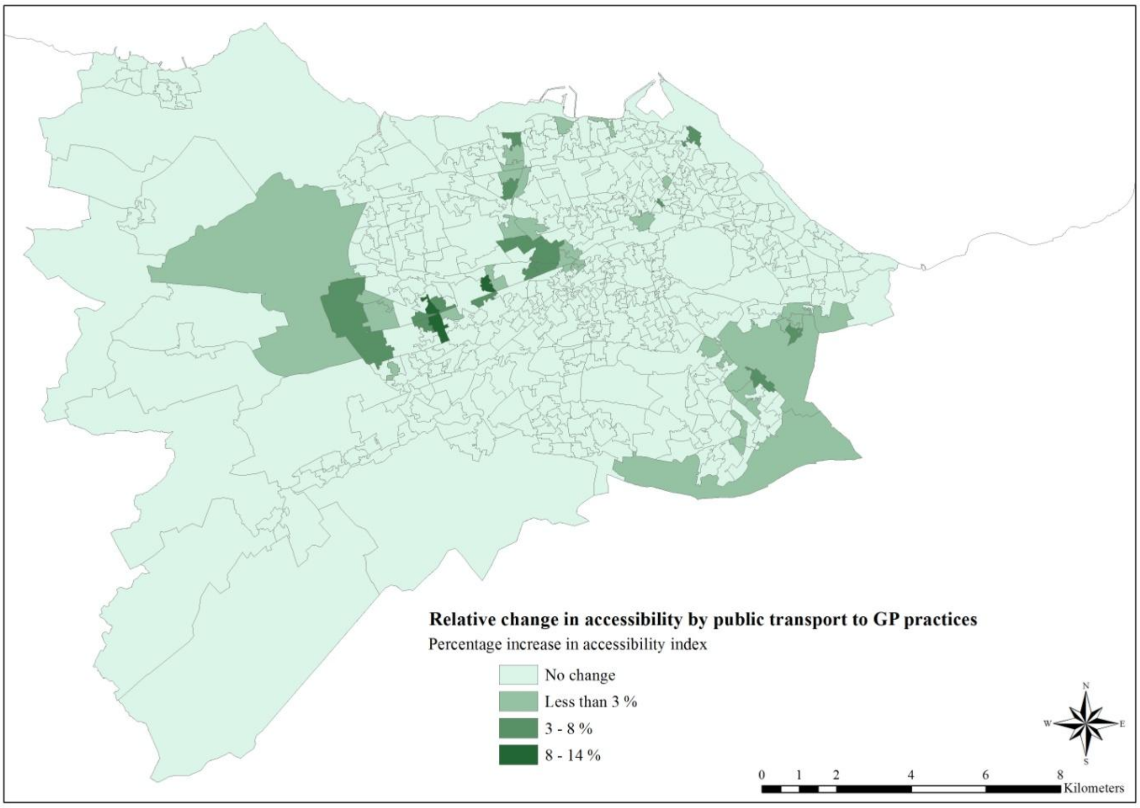

Figure D.38: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

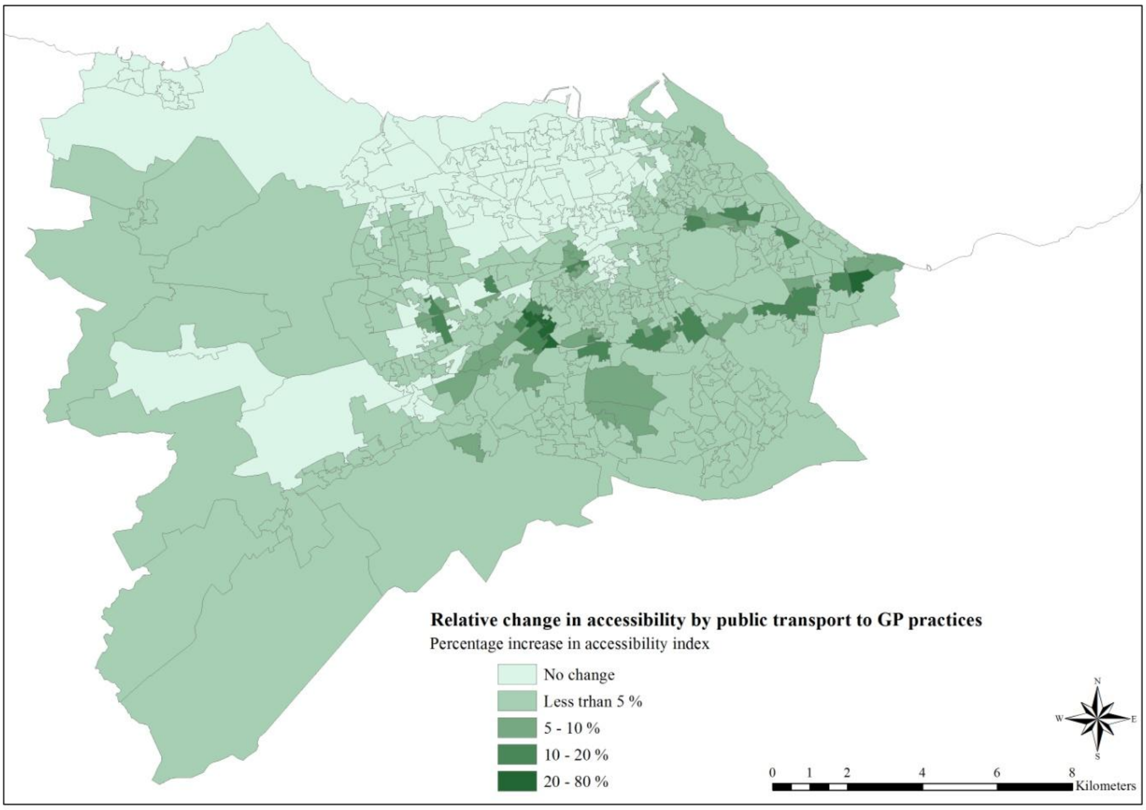

Figure D.39: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

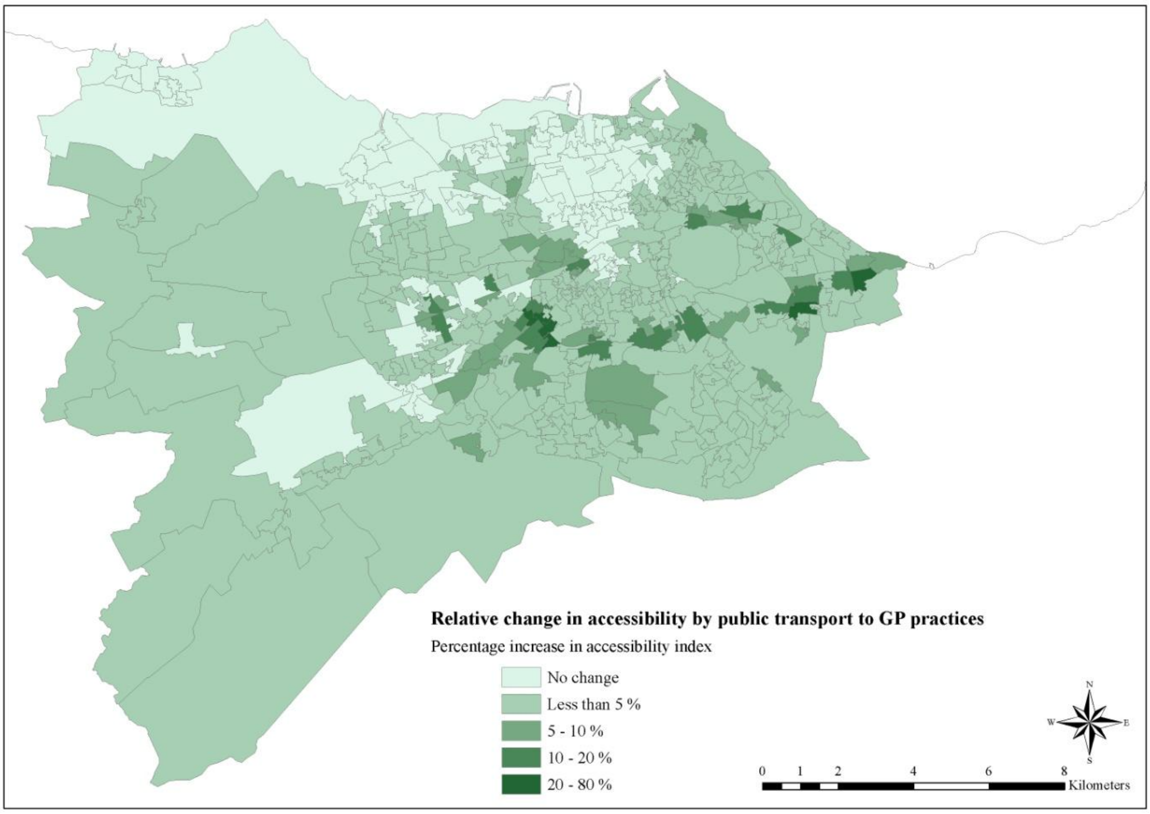

Figure D.40: Relative change in accessibility by public transport to GP practices between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

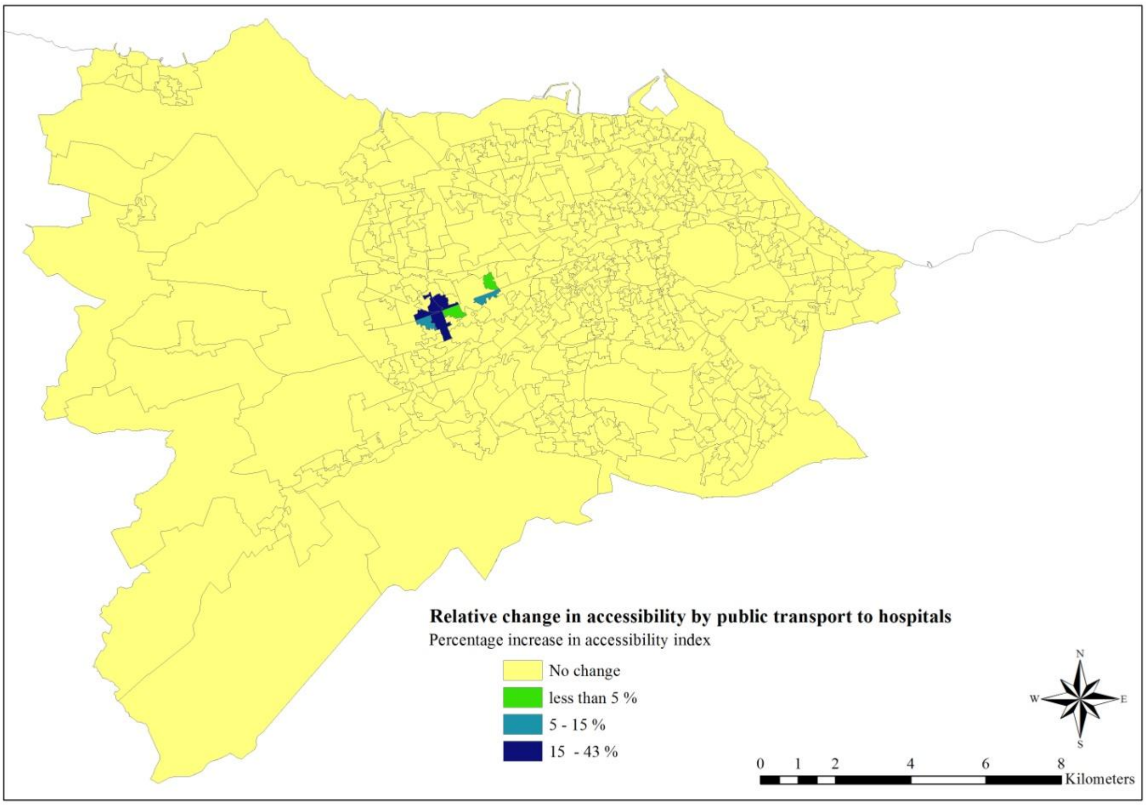

Figure D.41: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

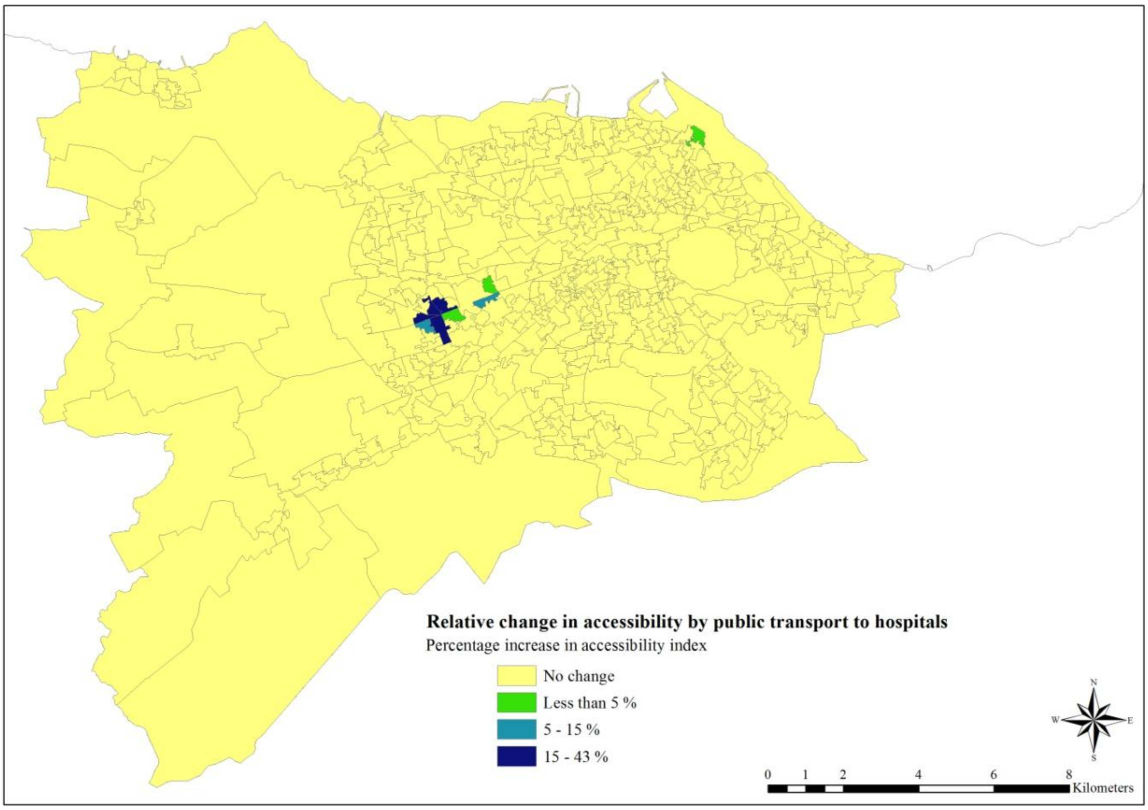

Figure D.42: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and Scenarios C, D and E, using the potential accessibility measure

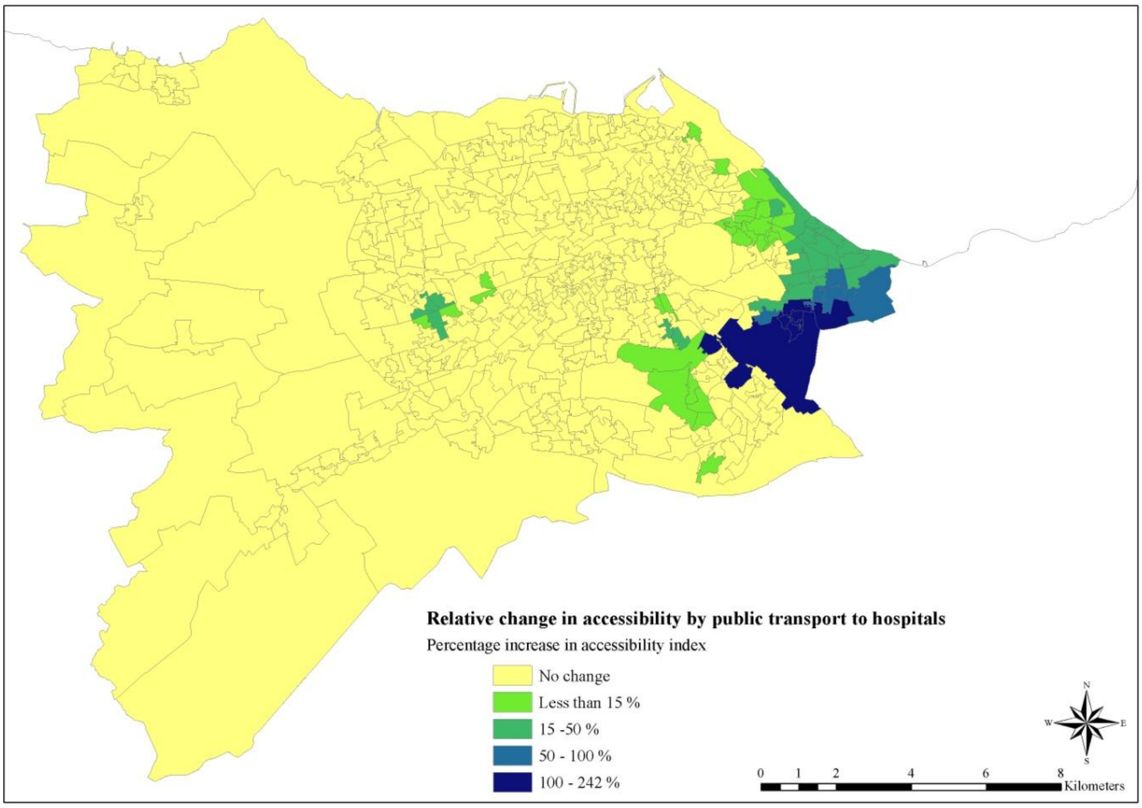

Figure D.43: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and Scenarios F and G, using the potential accessibility measure

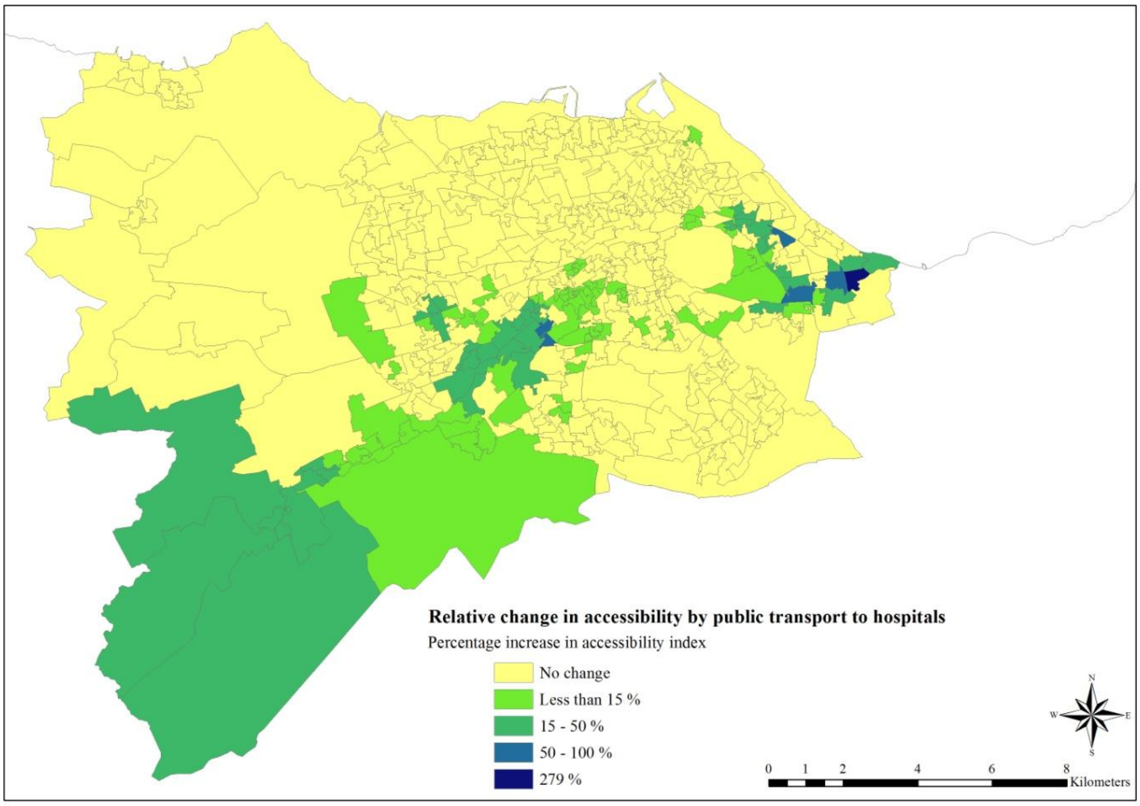

Figure D.44: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

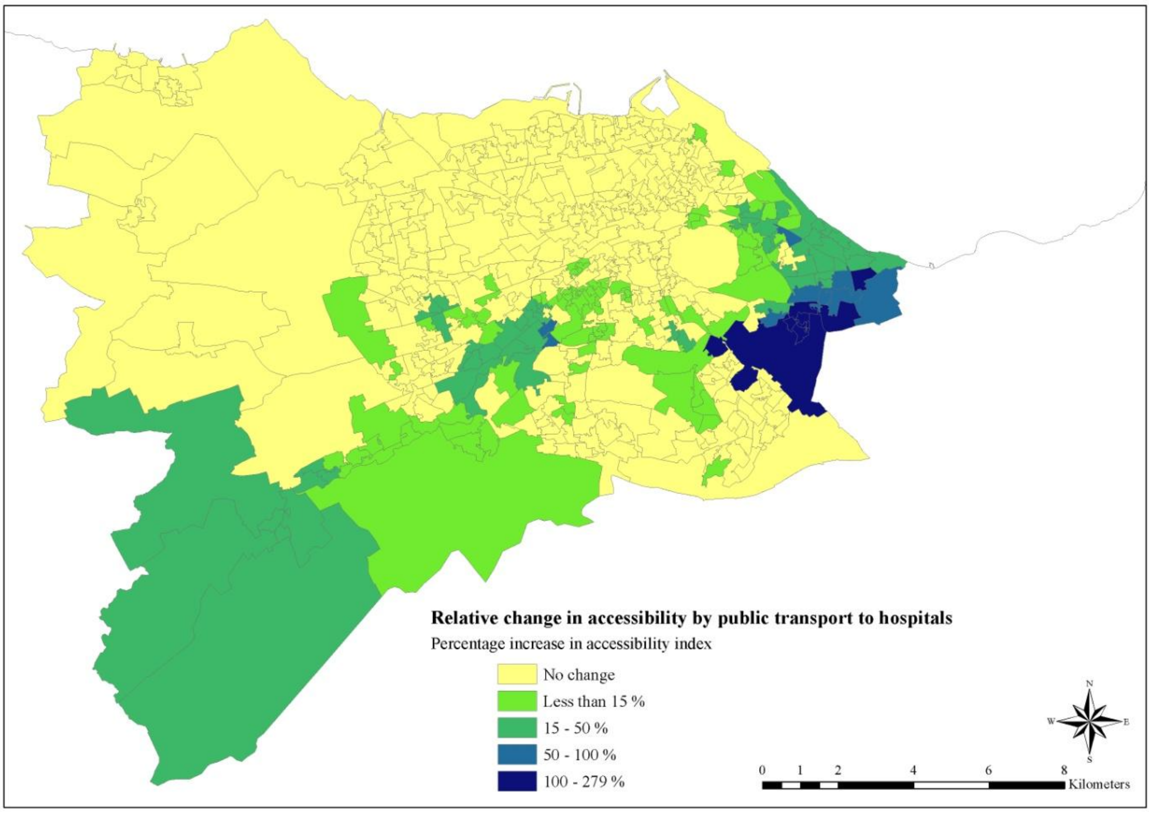

Figure D.45: Relative change in accessibility by public transport to all hospitals between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

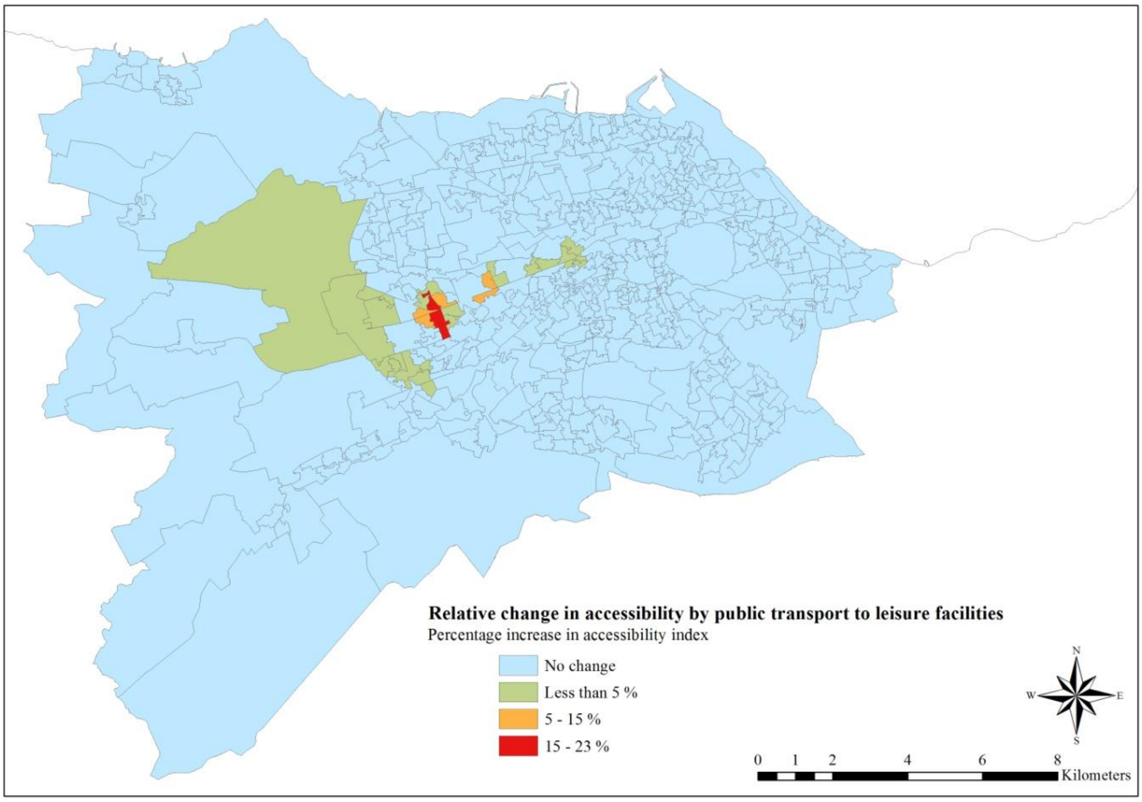

Figure D.46: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and 2014 scenario (Scenario B), using the potential accessibility measure

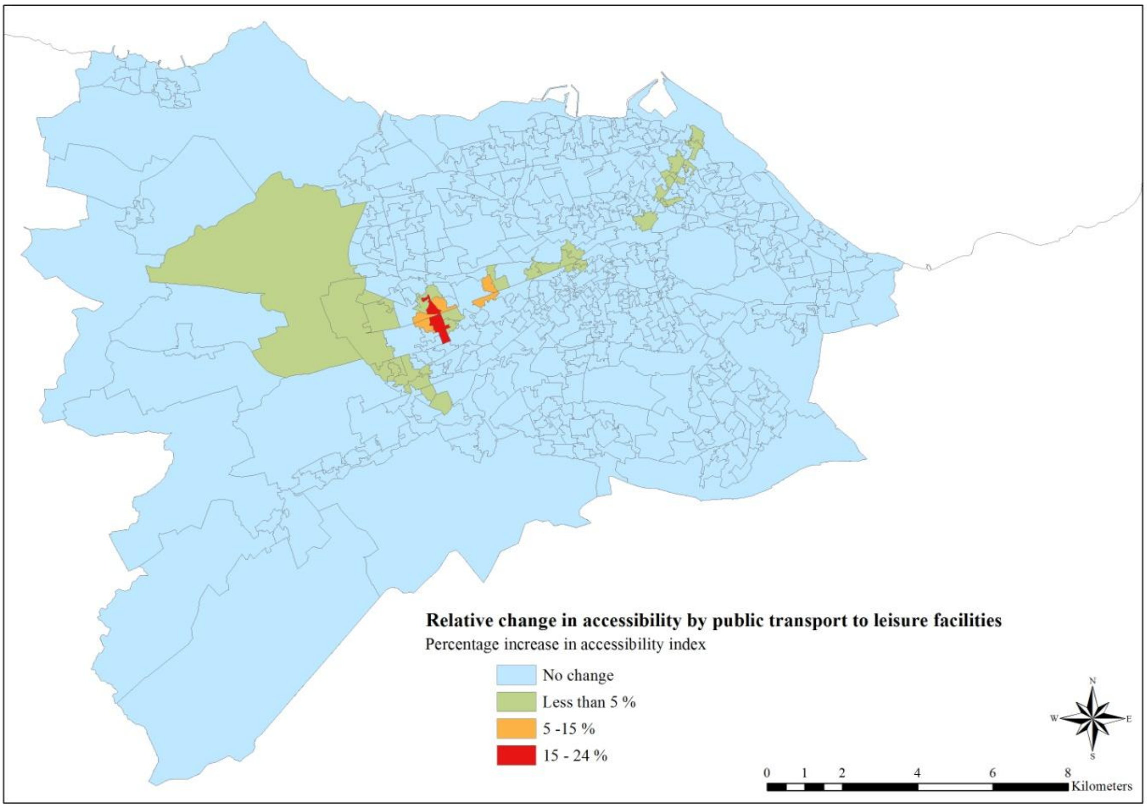

Figure D.47: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario C, using the potential accessibility measure

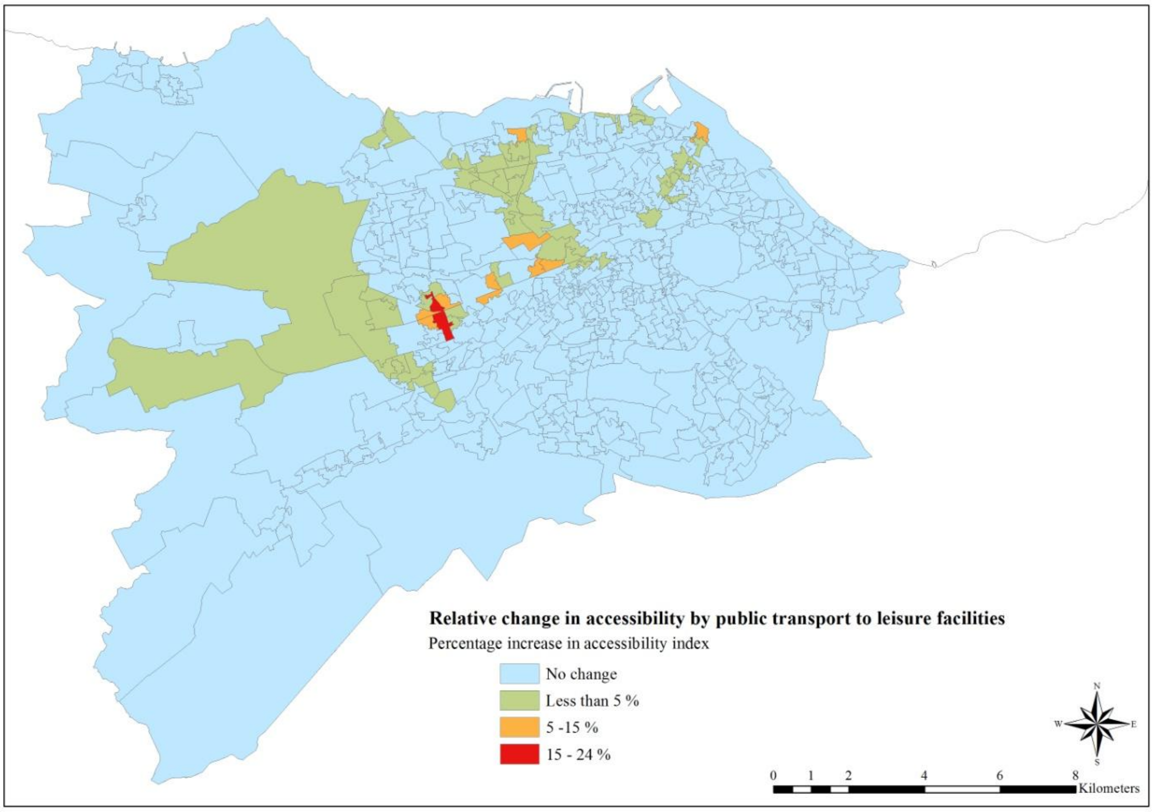

Figure D.48: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario D, using the potential accessibility measure

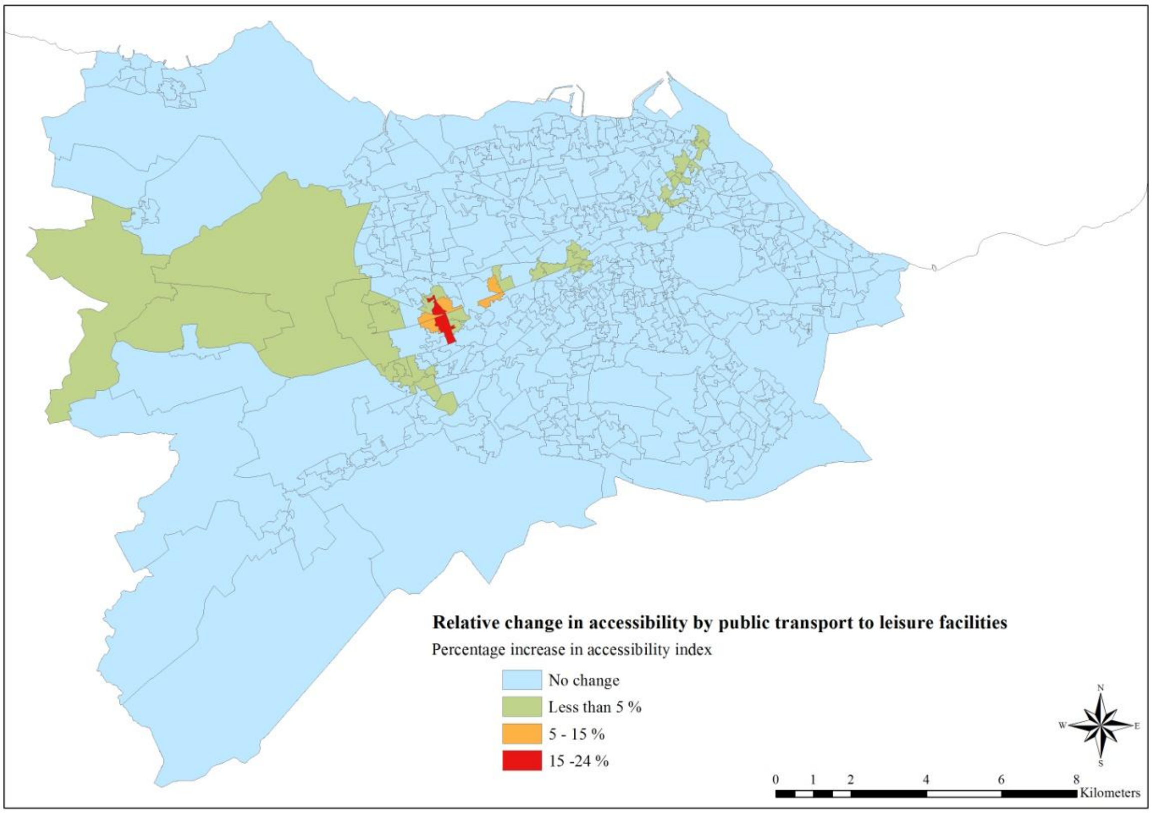

Figure D.49: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario E, using the potential accessibility measure

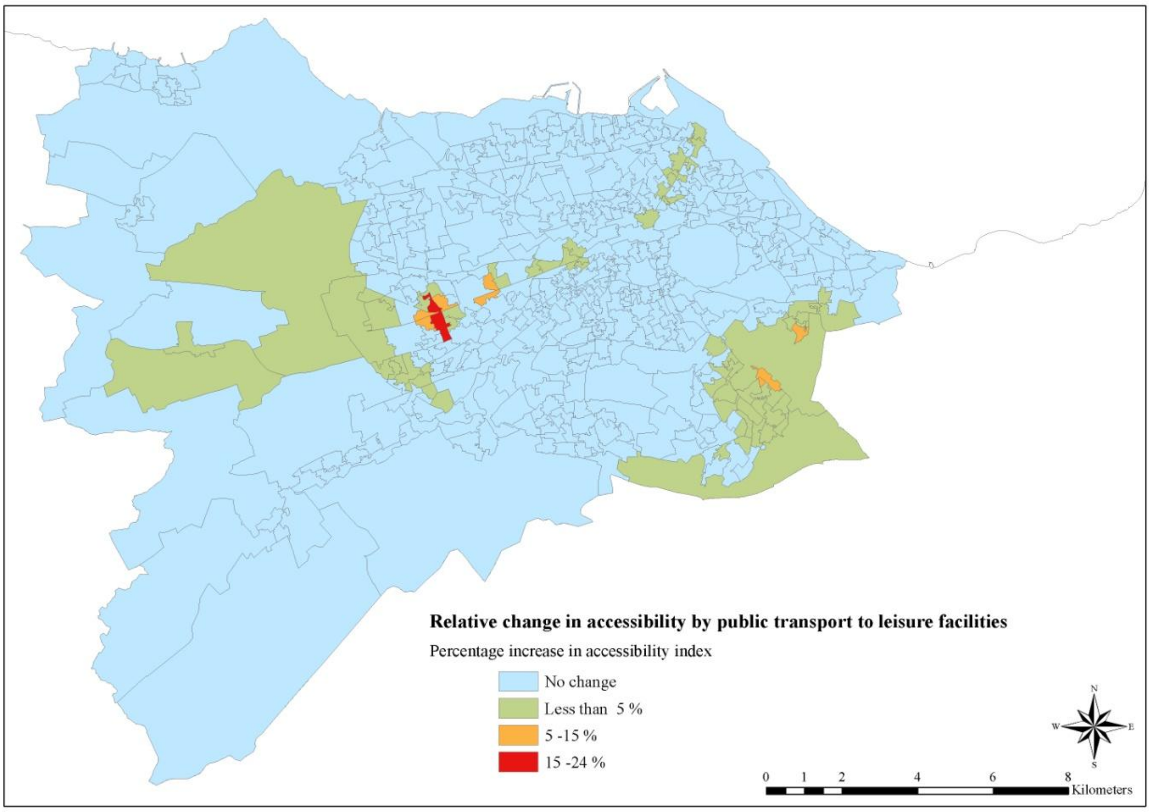

Figure D.50: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario F, using the potential accessibility measure

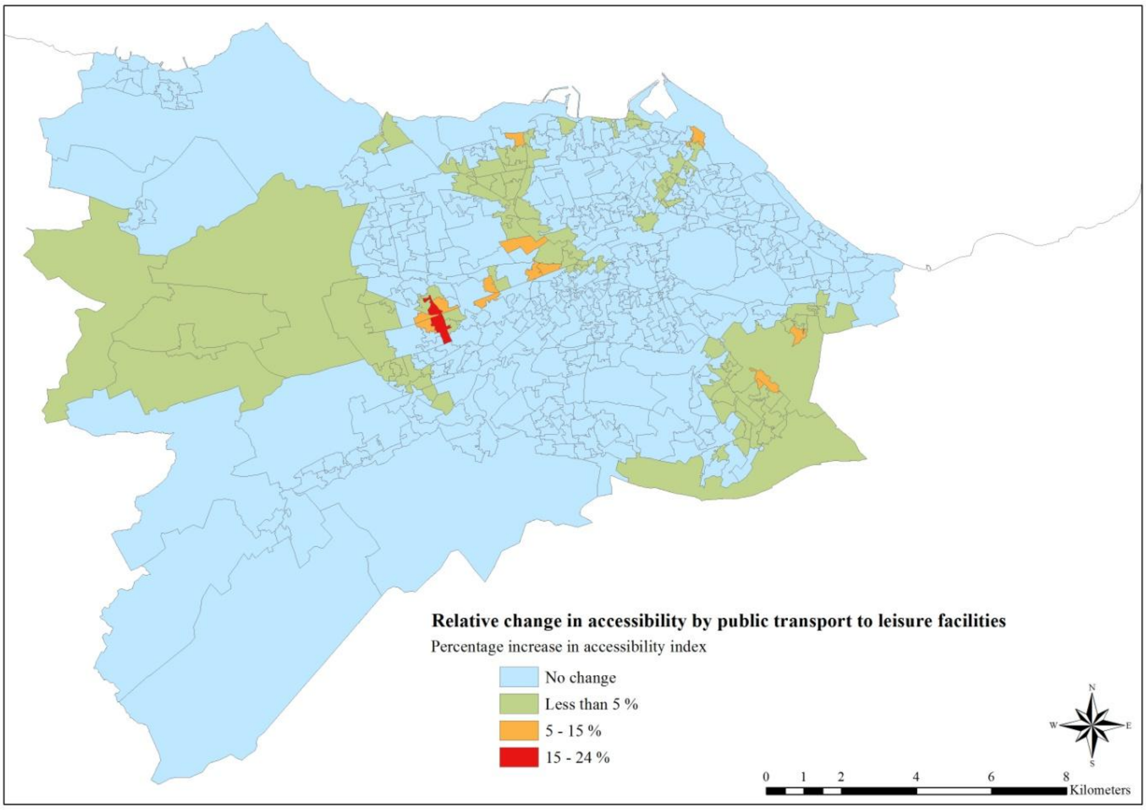

Figure D.51: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario G, using the potential accessibility measure

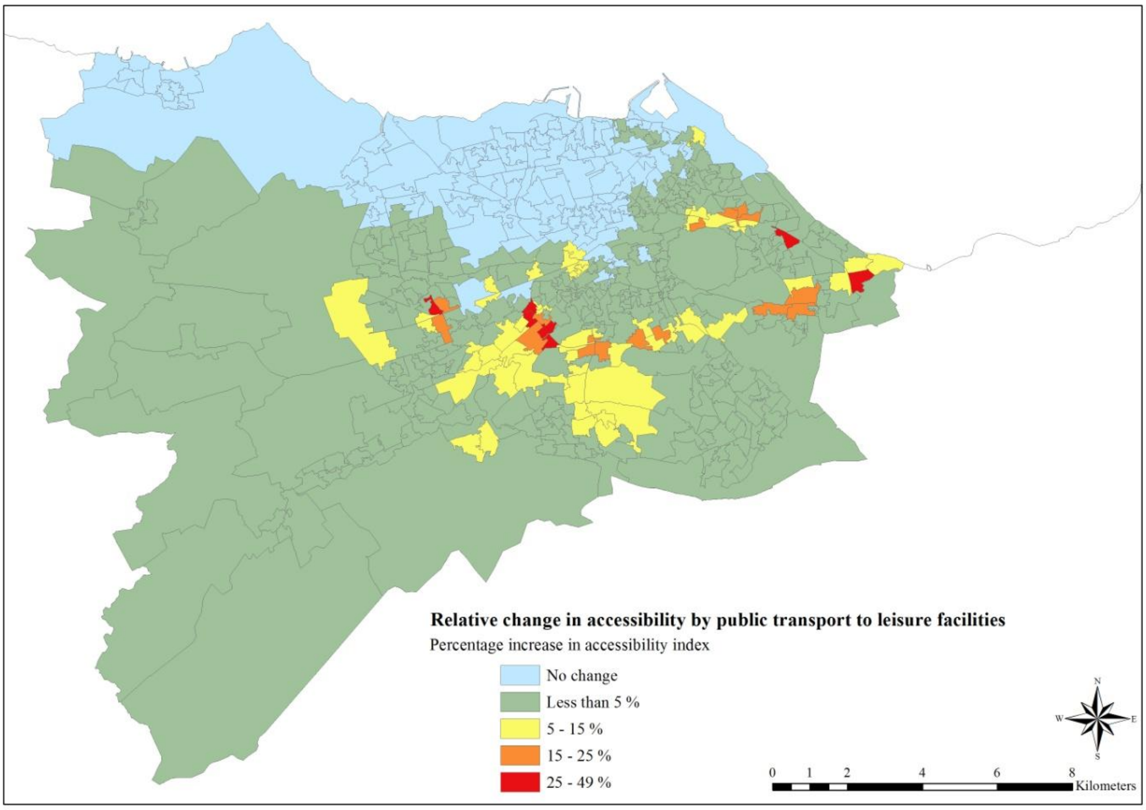

Figure D.52: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario H, using the potential accessibility measure

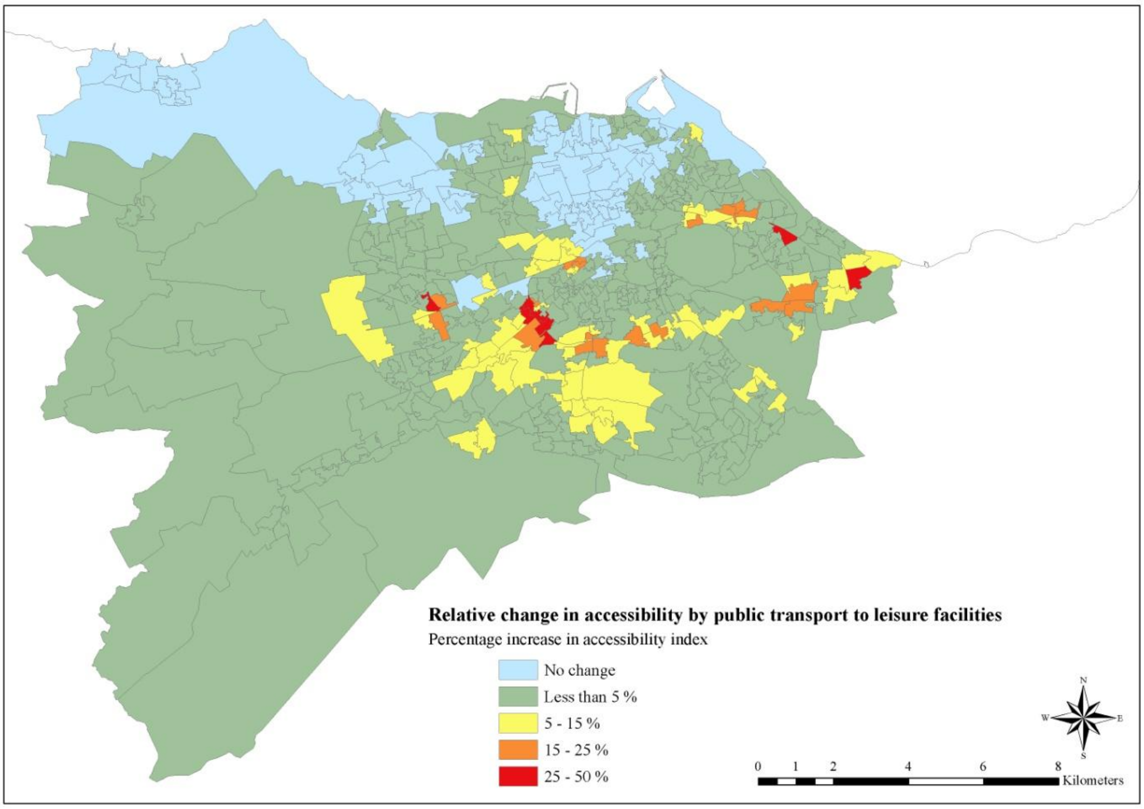

Figure D.53: Relative change in accessibility by public transport to leisure facilities between the baseline year 2011 scenario and Scenario I, using the potential accessibility measure

APPENDIX E:

Pre-workshop Survey

European Union COST Action TU 1002

"Accessibility instruments for planning practice in Europe"

You can find more information about this research here: http://www.accessibilityplanning.eu/

Thank you for agreeing to attend the Accessibility Workshop on DATE and LOCATION. By completing this 15 minute questionnaire before the workshop you are greatly assisting the team to understand the accessibility questions that are important for your profession and the job you currently have. The aim of the workshop is to understand how relevant the accessibility models we would like to test are to the policy and planning questions you face in your work.

ABOUT YOU AND YOUR ORGANISATION

Name: Email Address: @edinburgh.gov.uk

Organisation Name: The City of Edinburgh Council.

1. What type of planning does your organisation undertake? (Tick or place a cross next to more than one box if required)

- ☐ √ Strategic city planning
- ☐ Strategic road planning
- ☐ Strategic public transport planning
- ☐ Strategic land use planning
- ☐ Private vehicle network efficiency
- ☐ √ Public transport network efficiency
- ☐ √ Infrastructure provision
- ☐ √ Development assessment/statutory planning
- ☐ √ Non-motorised transport planning
- ☐ √ Local or Regional Economic Development

PEOPLE, TRAVEL AND LANDUSE

2. Thinking about People and Travel, name 3 important policy issues that your agency is working on in this respect?

    a) Increasing the mode share of sustainable travel modes for travel by Edinburgh residents.

    b) Containing the overall increase in vehicle – kilometres on all roads in Edinburgh.

    c) Reducing the number of people killed and injured in road traffic accidents.

3. In regards to the 3 policy issues you have listed above, what data, tools, or information makes you aware of these issues?

    a) Mode share data for local authority areas collected by the Scottish Household Survey.

b) Estimates on million vehicle – kilometres prepared by the Department for Transport and published in Scottish Transport Statistics.

c) Data from personal injury accidents in Scotland reported by the police using Stats 19 statistical returns.

4. When considering land use and transport systems, what data, tools, or information makes you aware of **development opportunities** within the city?

Proactive measures, such as the preparation of area Master Plans and Strategic and Local Development Plans. Reactive measures, such as planning applications and requests from potential developers.

5. How does your organisation match planning goals (e.g. increase access to labour force / locating residential development / locating employment centres) to transport modes?

Matching is done through the Local Transport Strategy policy of integrating land use planning and transport policies by ensuring that planning policies reflect the aims and objectives of the Local Transport Strategy and vice versa.

6. When thinking about different transport modes in your city, what kinds of opportunities do you think it's important for people to have access to?

Mode	Opportunity 1	Opportunity 2	Opportunity 3
Walking	Employment	Education	Retailing
Bicycle	Employment	Education	Retailing
Bus	Employment	Education	Retailing
Train	Employment	Education	Retailing
Tram	Employment	Education	Retailing
Metro	N/A	N/A	N/A
Taxi	Business	Leisure	Healthcare
Car	Retailing	Leisure	______
Truck	Distribution	Modal interchange	Construction

PLANNING AND DECISION MAKING

7. When preparing or assessing a plan*, what information does your organisation use to assess the efficiency of local and regional accessibility within the city? (* defined by user, please specify)

The Council's Transport 2030 Vision, which guides the work of staff in Transport, has an outcome 3, of an "Accessible and Connected" city. The information used to assess accessibility is:

a) Working age population, resident in SEStran area, within 30 minutes public transport travel time from centres of employment at City Centre, South Gyle Business Park, Victoria Quay, Leith and Ferry Road / Crewe Toll.
b) Accessibility of hospitals by public transport (population within 30 mins public transport travel time), 8am-9am weekdays. The hospitals are Edinburgh Royal Infirmary and the Western General.
c) Satisfaction with access by public transport. Households walking time < 6 mins to bus stop and frequency.

8. How are tools, or data outputs from tools selected for use in preparing or assessing a plan?

Data outputs were selected based on inputs available from reliable, independent information sources.

9. Where in the organisational hierarchy of your organisation are decisions made about accessibility? (E.g. Informal meetings with colleagues; a decision making committee; or by presenting tech reports to politicians).

Decisions on the type measures of accessibility are made at an officer level. The Council's Transport and Environment Committee approves an annual Transport Annual Report, which includes a measure of accessibility in terms of the outcome 3 of the Council's Transport 2030 Vision.

10. In your own words, how would you define Accessibility?

Accessibility is the ease with which desired destinations can be reached with the least generalised cost.

11. In your own words, how would you define Mobility?

Mobility is the ability to use a transport system to reach a desired destination, irrespective of distance.

European Union COST Action TU 1002

"Accessibility instruments for planning practice in Europe"

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Thank you for agreeing to attend the Accessibility Workshop on DATE and LOCATION. By completing this 15 minute questionnaire before the workshop you are greatly assisting the team to understand the accessibility questions that are important for your profession and the job you currently have. The aim of the workshop is to understand how relevant the accessibility models we would like to test are to the policy and planning questions you face in your work.

ABOUT YOU AND YOUR ORGANISATION

Name: Email Address: @edinburgh.gov.uk

Organisation Name: The City of Edinburgh Council (Development Planning).

1. What type of planning does your organisation undertake? (Tick or place a cross next to more than one box if required)

- ☐ √ Strategic city planning
- ☐ Strategic road planning
- ☐ Strategic public transport planning
- ☐ √ Strategic land use planning
- ☐ Private vehicle network efficiency
- ☐ Public transport network efficiency
- ☐ Infrastructure provision
- ☐ √ Development assessment/statutory planning
- ☐ Non-motorised transport planning
- ☐ Local or Regional Economic Development

PEOPLE, TRAVEL AND LANDUSE

2. Thinking about People and Travel, name 3 important policy issues that your agency is working on in this respect?

   a) Controlling climate change through promoting sustainable transport
   b) Ensuring development is located in accessible locations
   c) Ensuring access for all to key services

3. In regards to the 3 policy issues you have listed above, what data, tools, or information makes you aware of these issues?

   a) Census travel to work statistics
   b) Housing need/demand study, accessibility modelling of proposed new housing sites

c) Accessibility model of small proposals vs. existing service points (shops database, GP locations etc.)

4. When considering land use and transport systems, what data, tools, or information makes you aware of **development opportunities** within the city?

HNDA, Urban capacity study, Analysis of planning applications, PTAL mapping, Access to shopping centre/Supermarkets study.

5. How does your organisation match planning goals (e.g. increase access to labour force / locating residential development / locating employment centres) to transport modes?

Transport modelling (TMfS/TELMoS) / PTAL mapping / Census travel to work statistics

6. When thinking about different transport modes in your city, what kinds of opportunities do you think it's important for people to have access to?

Mode	Opportunity 1	Opportunity 2	Opportunity 3
Walking	Local shopping	GP	Public transport stop
Bicycle	Employment	Leisure	______
Bus	Employment	Large retail	Leisure
Train	Strategic employment	Large retail	______
Tram	______	______	______
Metro	______	______	______
Taxi	Retail	Leisure	______
Car	OOT shopping	Employment centre	______
Truck	Manufacturing	Retail	Distribution depots

PLANNING AND DECISION MAKING

7. When preparing or assessing a plan*, what information does your organisation use to assess the efficiency of local and regional accessibility within the city? (* defined by user, please specify)

(Local Development Plan / Strategic Development Plan) Accessibility analysis (Accession), PTAL mapping

8. How are tools, or data outputs from tools selected for use in preparing or assessing a plan?

We use what we have!

9. Where in the organisational hierarchy of your organisation are decisions made about accessibility? (E.g. Informal meetings with colleagues; a decision making committee; or by presenting tech reports to politicians).

At all levels from report authors, heads of service to committee ratification

10. In your own words, how would you define Accessibility?

Ease or speed of access between origins/destinations of interest via different modes of transport

11. In your own words, how would you define Mobility?

Ability to move to a desired location

European Union COST Action TU 1002

"Accessibility instruments for planning practice in Europe"

You can find more information about this research here: http://www.accessibilityplanning.eu/

Thank you for agreeing to attend the Accessibility Workshop on DATE and LOCATION. By completing this 15 minute questionnaire before the workshop you are greatly assisting the team to understand the accessibility questions that are important for your profession and the job you currently have. The aim of the workshop is to understand how relevant the accessibility models we would like to test are to the policy and planning questions you face in your work.

ABOUT YOU AND YOUR ORGANISATION

Name: Email Address: @dhc1.co.uk

Organisation Name: DHC

1. What type of planning does your organisation undertake? (Tick or place a cross next to more than one box if required)

- ☐ √ Strategic city planning
- ☐ √ Strategic road planning
- ☐ √ Strategic public transport planning
- ☐ √ Strategic land use planning
- ☐ √ Private vehicle network efficiency
- ☐ √ Public transport network efficiency
- ☐ √ Infrastructure provision
- ☐ √ Development assessment/statutory planning
- ☐ √ Non-motorised transport planning
- ☐ Local or Regional Economic Development

PEOPLE, TRAVEL AND LANDUSE

2. Thinking about People and Travel, name 3 important policy issues that your agency is working on in this respect?

   a) Analysis of what opportunities people can reach for local and national accessibility planning

   b) Analysis of the impact of land use planning proposals on access for people and businesses

   c) Transport appraisal of the impact of transport investment on access for people and businesses.

3. In regards to the 3 policy issues you have listed above, what data, tools, or information makes you aware of these issues?

   a) Electronic data on networks (PT networks/road networks), population data from household surveys and census, destination data from location of public and private businesses and services.

b) As above but combined with land use planning proposal details, and forecasts from land use transport interactions models.

c) As in (a) but combined with details of transport investment proposals, land use planning proposal details, and forecasts from land use transport interactions models

4. When considering land use and transport systems, what data, tools, or information makes you aware of **development opportunities** within the city?

Published development and transport plans showing land allocations and transport proposals.

5. How does your organisation match planning goals (e.g. increase access to labour force / locating residential development / locating employment centres) to transport modes?

In order to improve access it is necessary to make good use of capacity on all modes to ensure that systems can operate efficiently – this links above with demand models are important.

6. When thinking about different transport modes in your city, what kinds of opportunities do you think it's important for people to have access to?

Mode	Opportunity 1	Opportunity 2	Opportunity 3
Walking	Local food shops	Open space	Leisure/ sport facilities
Bicycle	Local food shops	Open space	Leisure/ sport facilities
Bus	Local food shops	Workplaces	Leisure/ sport facilities
Train	Town and city centres	Workplaces	Key trip attractors
Tram	Town centres	Workplaces	Leisure/ sport facilities
Metro	City centres	Workplaces	Key trip attractors
Taxi	Local food shops	Health providers	Night economy sites
Car	Local food shops	Workplaces	Leisure/ sport facilities
Truck	Local food shops	Workplaces	Leisure/ sport facilities

PLANNING AND DECISION MAKING

7. When preparing or assessing a plan*, what information does your organisation use to assess the efficiency of local and regional accessibility within the city? (* defined by user, please specify)

See response to question 2

8. How are tools, or data outputs from tools selected for use in preparing or assessing a plan?

See response to question 2

9. Where in the organisational hierarchy of your organisation are decisions made about accessibility? (E.g. Informal meetings with colleagues; a decision making committee; or by presenting tech reports to politicians).

Core business to improve accessibility

10. In your own words, how would you define Accessibility?

The ease of reaching opportunities and the ease by which opportunities can be reached

11. In your own words, how would you define Mobility?

The capability to move around

APPENDIX F:

Post-workshop Survey

Doc 03_COST Action TU 1002 - Accessibility instruments for planning practice in Europe
Post workshop survey

Dear colleague/workshop participant,

After completing the workshop, it is very important for us to understand your experience from your involvement in this process. In particular, we would like to know your views on how the workshop was organized, its results, the utility of the accessibility model and the potential barriers to adopt it in planning practice. The aim is to address the potential weaknesses in order to improve the experience of future colleagues who will participate in similar processes integrating research knowledge on accessibility tools in everyday planning practice.

You can find below a total of 42 items (16 about the session, 21 about the accessibility model and 5 about your profile) on which we would like to express your opinion on a 5-point scale. It will take no more than 10 minutes. Angela Hull is responsible for this survey, so If you need any clarification, please do not hesitate to ask her.

Thank you,
The COST project team

ABOUT THE SESSION

		Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not applicable
1	The session resulted in useful results					√	
2	I am confident that the group solution is correct			√			
3	I now have more insight into the processes that play a role in the problem				√		
4	My understanding of the opinions of the other participants about the problem has increased				√		
5	I will use insights from the session in my daily planning practice				√		
6	The process helped me interact with other participants and understand their ideas about the problem				√		
7	During the sessions we have developed a shared professional language			√			
8	We have reached a shared vision of the problem			√			
9	We have reached a shared vision on the goals			√			
10	We have reached a shared vision on the possible solutions			√			

11	I had a strong sense of being part of a group				√		
12	The session was time efficient				√		
13	I am satisfied with this session					√	
14	The results of the session are based on correct assumptions on the underlying system				√		
15	The session has given me insight into the possibilities that my organisation has in 'steering' the problem				√		
16	I will communicate the results of the meeting in front of other members of my organization					√	
	ABOUT THE ACCESSIBILITY TOOL /MODEL						
		Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**	**Not applicable**
17	My organization has the required computational skills to use the model “SNAPTA”					√	
18	Conflicting policies between agencies inhibits the use of accessibility models		√				
19	Model ‘SNAPTA’ would not likely be selected for use in planning decisions as my organization is not familiar with any (or other) accessibility models		√				
20	The results from model ‘SNAPTA’ are strongly related with the political commitment of my organization				√		
21	Accessibility models are relevant to my profession					√	
22	The culture of the organisation does not enable the use of accessibility models		√				

23	The organization serves the needs of multiple communities, and model ‘SNAPTA’ outputs would be useful to inform the debate				√		
24	There is little formal or informal incentive for cooperation between agencies on accessibility issues			√			
25	The precision of Model ‘SNAPTA’ would increase its cost				√		
26	Model ‘SNAPTA’ would be useful at generating and identifying problems				√		
27	Model ‘SNAPTA’ would be useful at selecting strategy/options for the urban structure				√		
28	Accessibility model outputs should be part of a learning process and not provide answers					√	
29	Model SNAPTA would be useful during implementation of an urban structure solution				√		
30	Model ‘SNAPTA’ offers new insights to planning problems			√			
31	Accessibility model output should be used to communicate urban structure concepts and ideas				√		
32	Model ‘SNAPTA’ have not demonstrated well the relationship between Land use and transport to be useful			√			
33	The concepts/ calculations/ assumptions used in Model ‘SNAPTA’ could be useful in real world planning decisions				√		

34	There are not sufficient resources in my organization (time/money) to complete accessibility modelling		√				
35	There are not sufficient resources in my organization (data/skills) to complete accessibility modelling		√				
36	Accessibility model outputs should be used to look for alternative scenarios to a planning solution				√		
37	Model 'SNAPTA' would be useful for analysis of urban structure problems				√		
	ABOUT YOU						
38	Name/Surname	39 Gender		Male √		Female	
40	Age		<30	31-45	45-60 √	>60	
41	Profession		Urban Planner √	Transport Planner	Architect	Other/state	
42	Organisation (Name & Sector): *City of Edinburgh Council*		Public Organisation √	Private Company	Freelance Consultant	NGO	Other/state

Doc 03_COST Action TU 1002 - Accessibility instruments for planning practice in Europe Post workshop survey
Dear colleague/workshop participant, After completing the workshop, it is very important for us to understand your experience from your involvement in this process. In particular, we would like to know your views on how the workshop was organized, its results, the utility of the accessibility model and the potential barriers to adopt it in planning practice. The aim is to address the potential weaknesses in order to improve the experience of future colleagues who will participate in similar processes integrating research knowledge on accessibility tools in everyday planning practice. You can find below a total of 42 items (16 about the session, 21 about the accessibility model and 5 about your profile) on which we would like to express your opinion on a 5-point scale. It will take no more than 10 minutes. Angela Hull is responsible for this survey, so If you need any clarification, please do not hesitate to ask her. Thank you, The COST project team

	ABOUT THE SESSION						
		Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**	**Not applicable**
1	The session resulted in useful results				√		
2	I am confident that the group solution is correct					√	
3	I now have more insight into the processes that play a role in the problem					√	
4	My understanding of the opinions of the other participants about the problem has increased					√	
5	I will use insights from the session in my daily planning practice				√		
6	The process helped me interact with other participants and understand their ideas about the problem				√		
7	During the sessions we have developed a shared professional language				√		
8	We have reached a shared vision of the problem			√			
9	We have reached a shared vision on the goals			√			

10	We have reached a shared vision on the possible solutions			√			
11	I had a strong sense of being part of a group			√			
12	The session was time efficient		√				
13	I am satisfied with this session			√			
14	The results of the session are based on correct assumptions on the underlying system						√
15	The session has given me insight into the possibilities that my organisation has in 'steering' the problem						√
16	I will communicate the results of the meeting in front of other members of my organization						√
	ABOUT THE ACCESSIBILITY TOOL /MODEL						
		Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**	**Not applicable**
17	My organization has the required computational skills to use the model “SNAPTA”				√		
18	Conflicting policies between agencies inhibits the use of accessibility models				√		
19	Model ‘SNAPTA’ would not likely be selected for use in planning decisions as my organization is not familiar with any (or other) accessibility models		√				
20	The results from model ‘SNAPTA’ are strongly related with the political commitment of my organization		√				
21	Accessibility models are relevant to my profession					√	

22	The culture of the organisation does not enable the use of accessibility models		√				
23	The organization serves the needs of multiple communities, and model 'SNAPTA' outputs would be useful to inform the debate				√		
24	There is little formal or informal incentive for cooperation between agencies on accessibility issues					√	
25	The precision of Model 'SNAPTA' would increase its cost						√
26	Model 'SNAPTA' would be useful at generating and identifying				√		
27	Model 'SNAPTA' would be useful at selecting strategy/options for the urban structure				√		
28	Accessibility model outputs should be part of a learning process and not provide answers					√	
29	Model SNAPTA would be useful during implementation of an urban structure solution			√			
30	Model 'SNAPTA' offers new insights to planning problems		√				
31	Accessibility model output should be used to communicate urban structure concepts and ideas				√		
32	Model 'SNAPTA' have not demonstrated well the relationship between Land use and transport to be useful		√				

33	The concepts/ calculations/ assumptions used in Model 'SNAPTA' could be useful in real world planning decisions				√		
34	There are not sufficient resources in my organization (time/money) to complete accessibility modelling			√			
35	There are not sufficient resources in my organization (data/skills) to complete accessibility modelling			√			
36	Accessibility model outputs should be used to look for alternative scenarios to a planning solution				√		
37	Model 'SNAPTA' would be useful for analysis of urban structure problems				√		
	ABOUT YOU						
38	Name/Surname	39 Gender		Male √		Female	
40	Age		<30	31-45	45-60 √	>60	
41	Profession		Urban Planner	Transport Planner √	Architect	Other/state	
42	Organisation (Name & Sector): *DHC*		Public Organisation	Private Company √	Freelance Consultant	NGO	Other/state

PUBLISHED JOURNAL PAPER

Journal of Transport Geography 35 (2014) 1–11

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Accessibility modelling: predicting the impact of planned transport infrastructure on accessibility patterns in Edinburgh, UK

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ARTICLE INFO

Keywords:
Accessibility
Transport planning
Spatial equity
Edinburgh Tram
Geographic Information System (GIS)

ABSTRACT

The achievement of good spatial accessibility and equity in the distribution of urban services is one of the supreme goals for urban planners. With Scottish Government backing, the City of Edinburgh Council (CEC) has started to construct a tram network to cater for the future needs of Scotland's capital city by providing an integrated transport solution using trams and buses. Spatial Network Analysis of Public Transport Accessibility (SNAPTA) which is a GIS-based accessibility model has been developed to measure the accessibility by public transport to different urban services and activities. The model responds to several limitations in other existing accessibility models in planning practice. It offers an alternative and practical tool to help planners and decision makers in examining the strengths and weaknesses of land use – transport integration. SNAPTA has been applied to a pilot study in Edinburgh city to identify the contribution of the infrastructure improvements of the tram system and Edinburgh South Suburban Railway (ESSR) to improved accessibility by public transport to six types of activity opportunities. This paper outlines the concept and methodology of the SNAPTA model, and presents the findings related to this pilot study with a focus on changes in potential accessibility to jobs between four different public transport network scenarios. The accessibility values so obtained help to identify the gaps in the coverage of the public transport network and the efficiency in the spatial distribution of urban services and activities. The findings focus on whether the planned transport infrastructures for Edinburgh will lead to better accessibility and reduced inequity (in terms of accessibility) across the city.

1. Introduction

Being able to reach the spatial opportunities in the city-region where you live without too much hassle is considered as one of the dimensions of quality of life in empirical studies of life quality (Bowling and Windsor, 2001; Leitmann, 1999; Roseland, 1997). The ability to access necessary services is a function of the range of transportation choices available and their travel time, safety, cost, and convenience as well as the internal structure of settlements and the spatial distribution of opportunities (Banister and Hickman, 2007; Forward, 2003). The efficient connection of the distributed infrastructure of services and facilities with the infrastructure for movement across city regions is a pressing issue for urban managers. The changing intensity of development at locations in the city-region affects travel demand and the performance of the transport system whilst city scale transportation investment alters the accessibility of different parts of the city-region (Banister and Hickman, 2007; Chapin and Kaiser, 1979; Himanen et al., 2005; Holl, 2006; NICHES, 2007; O'Sullivan, 1980; Priemus et al., 2001; Sultana, 2006). The dialectical relationship between transport services and spatial opportunities affect both accessibility and spatial equity, another concept closely linked to quality of life.

The role that public transport plays in connecting communities and neighbourhoods and the impact of transport investment on those same communities is acknowledged in local transport policies that seek, for example, 'To improve the transport choices households have available to reach a range of services' or 'To promote accessibility to everyday facilities for all, especially for those without a car' (Hull and Karou, 2011). The spatial growth of urban areas and the decentralization of employment and facilities have made it harder for people without access to a car to make the daily commute and to take advantage of distributed retail and leisure opportunities.

In this respect, there has been a growth of interest in the concept of accessibility over the last decades, with many accessibility studies published in the academic press discussing how to measure accessibility and the contribution such decision support tools might have. Recently, the development of accessibility models has used a multitude of approaches to inform land use and transport decision-making (Karou and Hull, 2012). Therefore, translating the concept of accessibility into a practical planning tool

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http://dx.doi.org/10.1016/j.jtrangeo.2014.01.002

stems from the need for powerful techniques to help planners and decision makers deal with urban and transport management and provide better evaluation of the impacts of different schemes (or combinations of schemes) advanced by transport and land-use policies.

This paper focuses on accessibility addressing issues of spatial equity and transport disadvantage through two objectives. The first objective is to develop an accessibility model – the Spatial Network Analysis of Public Transport Accessibility (SNAPTA) – which has responded to the need for academic research models to be more practical and useful models for the world of planning practice. The second objective is to test the model through empirical study in the city of Edinburgh based on *ex ante* evaluation of the new tram system and Edinburgh South Suburban Railway (ESSR) to compare between the accessibility impacts of different scenarios of the completion of these infrastructures.

The paper is organised in six sections. The introduction has identified transport accessibility as a key dimension of quality of life and a priority for sustainable urban management. This acknowledges the interaction between land use and intensity, individual travel behaviour and transport provision. The next section introduces the case study of Edinburgh. Section 3 discusses the rationale for the construction of the tram system and re-opening of ESSR. In Section 4, the conceptual framework and theoretical underpinning of the SNAPA model is presented. Section 5 focuses on the methodology of SNAPTA application to Edinburgh's network while the last two sections outline the findings and further developments in SNAPTA.

2. Case study of Edinburgh

The city of Edinburgh is situated in the central urban belt of Scotland with an overall density of 37.65 persons per hectare (2001 census). The policies in the land use plan and Edinburgh's geographical location (bordered by the Firth of Forth on two sides) have contained urban sprawl, through the imposition of a green belt around the urban area and the encouragement of development on brownfield sites.

Edinburgh's population is projected to grow by over 59,000 between 2010 and 2030 (CEC, 2010). As Edinburgh's population grows, the demand for travel will increase. Population growth in the city region will also impact on levels of commuting into the city. Moreover, during the next 20 years, Edinburgh's economy is forecast to play a big part in Scottish economic growth (CEC, 2010). The city is currently commencing a huge phase of redevelopment. Edinburgh Waterfront is set to provide an additional 25,800 new residential units and nearly 350,000 m of new office, retail and other commercial developments between 2006 and 2020. Significant new development is also predicted to be progressively built by 2020 in West Edinburgh with some 250,000 m of new office space and over 200,000 m of other commercial space (TIE, 2006). Fig. 1 shows the location of housing and office developments programmed for completion between 2006 and 2015 based on outstanding consents and local plan allocations (CEC, 2008).

Continuing economic success has however created a number of challenges. With a substantial population increase expected and "The number of jobs……now expected to increase by 15% between 2000 and 2015" (CEC, 2007, p. 14) as well as the forecast rise in household car ownership by 30% from 2000 and 2016 causing twice as much time to be lost due to congestion over the same period (TIE, 2004, p. 2), the maintenance of connectivity and accessibility is one such challenge (Hull and Karou, 2011). The Transport 2030 Vision argues that, by 2030, without action, the demand for travel from/to the city by private car will far exceed the current capacity (CEC, 2010).

The City of Edinburgh Council has defined a series of actions including the implementation of new public transport infrastructures such as the tram system and ESSR to boost the transport system and improve accessibility in the Council's area. The expectation is to cut demand for road travel and to serve the new growth areas while they develop by delivering a reliable and safe public transport service and, consequently, by improving their accessibility. The Public and Accessible Transport Action Plan (PATAP) 2013–2020 suggests that the target is to increase public transport's share of all their journeys by 2015 by 1.3%, and by 2020 by 2.3%

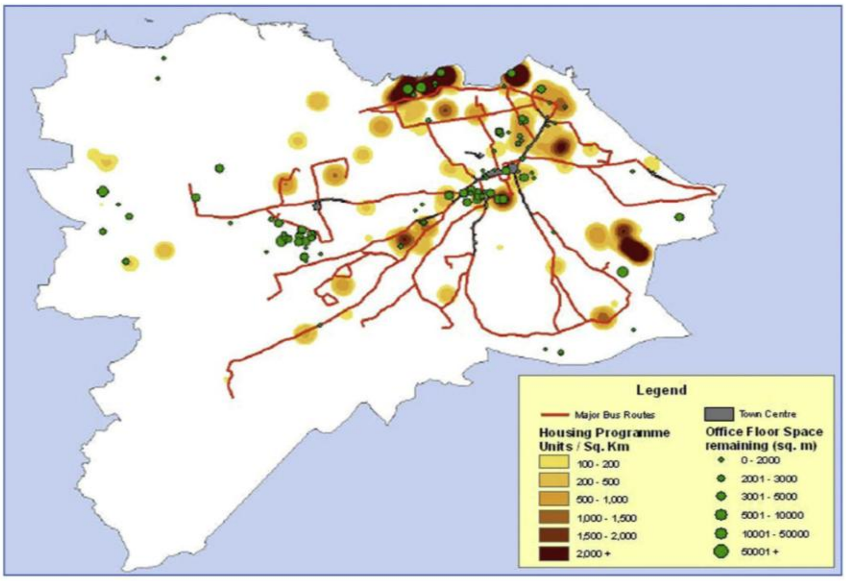

Fig. 1. Location of housing and office developments programmed for completion by 2015. *Source:* City of Edinburgh Council planning records (2008).

compared to the average attained between 2007–2008 and 2009–2010 (19.1%) (CEC, 2013a, p. 25).

The Scottish Government perceives high accessibility as essential to economic growth and competitiveness through "providing access to markets and enhancing the attractiveness of cities as focal business locations and tourism" (Scottish Executive, 2004, p. 18). In the National Transport Plan, accessibility is linked to improving journey times and connections and to the quality and affordability of public transport choices (Scottish Executive, 2006a, p. 2). Accessibility is translated into the Edinburgh Local Transport Strategy as "whether or not people can get to services and activities at a reasonable cost, in reasonable time and with reasonable ease" (CEC, 2007, p. 82).

A study carried out by MVA Consultancy (2008) in association with SEStran (South East Scotland's Regional Transport Partnership) used Accession model to look at accessibility to the key hospitals and employment sites in the region. The study focused on the calculation of travel times using walking, cycling, car and public transport before the construction of Edinburgh Tram. Two other previous studies of accessibility, before the development of the tram and ESSR, examined the transport and land use effects of major new land use developments in the Edinburgh city-region. Derek Halden Consultancy (2002) examined how accessibility to jobs would change if a proportion (20%) of future development (development not already committed) was allocated according to different spatial strategies (e.g. green belt development; development of new settlements, etc.). David Simmonds Consultancy used a bespoke version of TELMoS to predict the impact of two major new strategic headquarters developments to the west of Edinburgh beyond the city bypass close to the airport (Bramley et al., 2011). These two studies have identified two highly policy-relevant considerations for CEC. Firstly, the public transport underperformance in the north western zone of the city towards the city bypass which particularly affects zones of affordable housing (Halden, 2002). Secondly, that the development in one area outside the city bypass has an impact, in terms of congestion, pollution and traffic levels throughout a much wider geographical area.

3. The rationale for the Edinburgh Tram and South Suburban Railway

The Edinburgh Tram was first mooted in the 1990s and received parliamentary assent in March 2006. The Edinburgh Local Transport Strategy 2007–2012 defines the tram scheme as the key project coming to Edinburgh's transport network, emphasising that the Council is committed to implementing the project to strengthen the city public transport system. The Local Strategy argues that for the Edinburgh Tram to be successful and attract people, it will require full integration with existing bus services (i.e. through common ticketing, interchange points and timetabling), and with the fabric of the city (CEC, 2007). It is intended that Tram ticketing will be integrated with Lothian Buses covering day and season tickets. However, full ticket integration, e.g. where any bus service feeding into the tram provides a simple through ticket even for single journeys, cannot currently be delivered due to legislative restriction (CEC, 2013b).

The tram, which is being delivered by Transport Initiatives Edinburgh (TIE) – a company formed by CEC, is currently under construction with the completion date having been deferred on numerous occasions due to legal action concerning the financial costs, disturbance and upheaval costs.

The original 2001 proposal for Edinburgh Trams envisaged three lines across the city; the first being a circular route running around the northern suburbs, with the other two forming radial lines running out to Newbridge in the west and to Newcraighall in the south east respectively (CEC, 2006). All lines would run through the city centre. After Line Three was shelved, Lines One and Two were combined and split into three phases, with Phase 1 being further divided into Phase 1a and 1b (see Fig. 1), as follows:

- Phase 1a; Newhaven to Edinburgh Airport.
- Phase 1b; Haymarket to Granton Square.
- Phase 2; Newhaven to Granton.
- Phase 3; Edinburgh Airport to Newbridge.

As a result of the suspension of work on Line Three due to lack of Scottish Parliamentary approval and later on Phases 1b, 2 and 3 due to lack of funding (CEC, 2011), in September 2011 only the construction of part of Phase 1a from the Airport to central Edinburgh was started. However, the intention is to secure funding for the additional lines (CEC, 2013b).

West Edinburgh from the Gyle shopping centre to Newbridge has been identified by the Scottish Government as a national growth point. Tram Phase 1a at 18.5 km in length is, therefore, seen as vital to linking the 56 hectare development site at Leith through West Edinburgh growth point to the airport and "in responding to the expected growth in travel demand" (TIE, 2007, p. 41). The Business Case for the tram argues that the likely success of the development between Granton and Leith (Fig. 2), and therefore the CEC strategy, will be strongly affected by the provision of a reliable, sustainable public transport network, of which the tram plays an essential part (TIE, 2007, p. 41). The Business Case adds that in the absence of the tram Phase 1a and Phase 1b, the new proposed development in North Edinburgh may be diverted to less sustainable locations with less potential for successful transport integration (TIE, 2007, p. 41).

The Edinburgh South Suburban Railway (ESSR) is an existing double track railway line passing through the suburbs to the south of the city centre which is used by freight traffic crossing the city. The feasibility of reopening of the ESSR to passenger services, which were withdrawn in 1962, has been considered in a recent study for CEC by Atkins (2004).

Journey to work data shows that the corridor around south central Edinburgh in which the ESSR runs has high levels of public transport use, particularly to the city centre, but also for many peripheral journeys further afield (CEC, 2008). A number of objectives have been defined by CEC (2008) and Transform Scotland (2007) for the ESSR project to contribute to the wider strategy of the region and city. These include transforming cross-city links; improving accessibility to designated employment growth areas; provide an important feeder to Waverley Station and the programmed new bus/tram/train interchange at Haymarket; making a significant shift in peak period journey-to-work trips from the car to public transport; enhancing the connections between the areas served by ESSR and other public transport modes (i.e. Edinburgh Tram, the national rail network and bus services); ensuring access for all potential users to any new services or infrastructure; and minimising the environmental impacts of travel in the corridor of the railway (CEC, 2008; Transform Scotland, 2007).

The Atkins study in 2004 concluded that the most feasible option in the short- to medium-term would be to extend the existing North Berwick – Waverley/Haymarket services to Niddrie (see Fig. 3) (Atkins Transport Planning, 2004). However, the Atkins 2004 report argued that the construction of Line Three of Edinburgh's proposed tram system to the south east of the city would clearly reduce demand levels and significantly erode the case for the scheme since it would compete with the locations of planned stations on the ESSR (Atkins Transport Planning, 2004).

For CEC, however, the extent to which the tram and ESSR will attract current and future car drivers to public transport is critical. Also pertinent is how they will contribute to improved accessibility

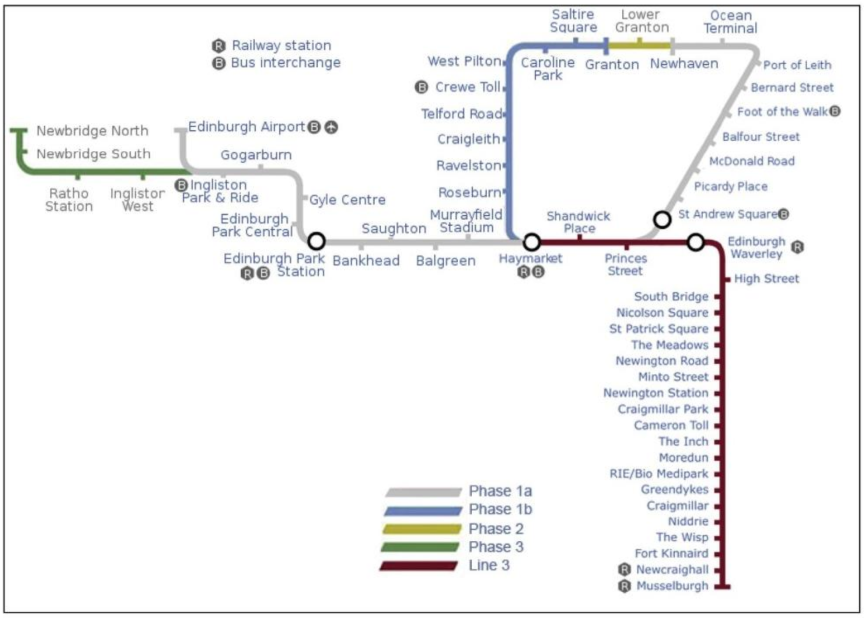

Fig. 2. Edinburgh Tram network. *Source:* http://www.edinburghtrams.com.

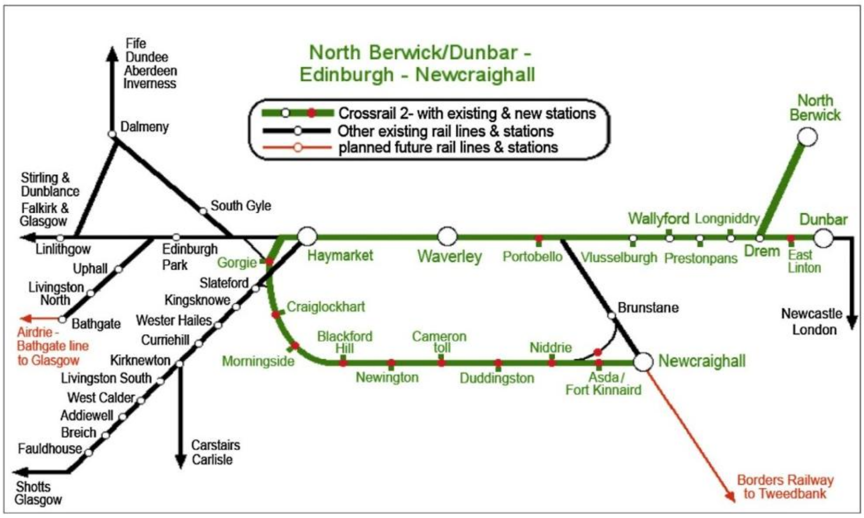

Fig. 3. Edinburgh South Suburban Railway (ESSR) re-opening proposal. *Source:* TRANS form Scotland (2007, p. 2).

and affect the relationships between local travel and activity choices. These latter issues are the subject of this research.

4. Conceptual framework and theoretical underpinning

Although many accessibility models have been recently developed and tested in scientific research (e.g. Gutiérrez and Gómez, 1999; Geurs and van Eck, 2001; Halden, 2002; Yigitcanlar et al., 2007; Curtis and Scheurer, 2010), the usability of accessibility models in planning practice is a much less-developed area of study. Many models are restricted to academic studies due to the complexity of their theoretical underpinnings which leads to a level of detail and complication that makes their output difficult for policy makers and practitioners to understand and interpret. Other models have been abandoned due to several failures or limitations related to operational and methodological issues. For example, some accessibility models are based on an inadequate theoretical basis or methodology by relying on very simple or inaccurate accessibility measures which either are not sensitive to changes in both the transport system and the land-use system, or fail to reflect actual travel behaviour.

Karou and Hull (2012) reviewed a number of current accessibility models, including: PTAL (London Borough of Hammersmith and Fulham), WALC (Transport Studies Group – University of Westminster), PTAM (West Yorkshire Passenger Transport Executive), CAPITAL (Transport for London), TRANSAM (Brown & Root), SONATA (SDG), Accession (MVA and Citilabs), SNAMUTS (Carey Curtis and Jan Scheurer), GenMod (Transportation Planning Department of Amsterdam), TMfS (MVA and David Simmonds Consultancy), ACCALC (Derek Halden Consultancy), LUPTAI (Tan Yigitcanlar and colleagues) and Space Syntax (University College London) and identified some limitations. Some of these models are inflexible and non user friendly in such a way which requires high modelling skills or a lot of time to operate and input or update the data. Other models require an external function to be integrated into the GIS environment which might be very expensive and needs a high level of expertise in operating the software. Being restricted to only one transport mode is another common limitation. In addition, most of the existing models have failed, somehow, to consider a number of issues in connection with how people perceive accessibility, including: measurement of the actual walk access time (or distance) when connecting with public transport or the private car; influence of physical features (e.g. slope); influence of traffic congestion; interchange option of public transport journeys between different modes or operators; influence of travel at specific times of day (i.e. peak time or off-peak time) and on specific days of the week (i.e. during weekday or the weekend); influence of the significance of urban activities; and the declining attractiveness of activities with increasing spatial separation (i.e. travel time or distance).

Several studies have investigated how to choose an appropriate accessibility measure or model and evaluate the usefulness of its application in planning practice (see Morris et al., 1979; Koenig, 1980; Cervero et al., 1995; Handy and Niemeier, 1997; Reneland, 1998; Halden et al., 2000; Ross, 2000; Geurs and van Eck, 2001; Geurs and van Wee, 2004; Keller et al., 2012). Although it is clear that there is no one best method for assessing accessibility, reviewing the literature revealed a number of issues that characterise the usefulness of an accessibility model for a particular situation in planning practice, as follows:

- Robustness of theoretical basis, providing an adequate representation of accessibility aspects, with a rational method of calculation.
- Sufficient level of data disaggregation.
- Not complex, simply operated, oriented towards clear objectives.
- Easily interpreted, understood and communicated with planners, researchers and policy makers.

SNAPTA is a GIS-based accessibility model which defines accessibility as "whether or not people can get to services and activities at a reasonable cost, in reasonable time and with reasonable ease". It offers better usability, covering aspects of accessibility adequately without making it very difficult to operate, interpret and, consequently, apply in practice. However, the model does not claim to provide the complete picture of actual travel behaviour and transport accessibility. It attempts to achieve a balance between the ease of interpretation and operationalisation and the complexity of the theoretical basis and data disaggregation. The performance of SNAPTA has been measured against the four above-stated criteria for creating a useful accessibility model in planning practice.

SNAPTA is intended to assist discussion and support decision-making within the fields of transport planning and land-use planning, particularly where government contexts call for more sustainable transport options to be developed. In this respect, the development of SNAPTA has been closely linked to the policy needs arising from the Edinburgh Local Transport Strategy (2007–2012) and subsequent reviews. Since such strategies present key sustainable transport ideas such as plans to boost transport and land-use integration and increase the reliance on public transport, SNAPTA provides an opportunity to deliver key elements of this strategy so that policy decisions are based on evidence of the impacts on accessibility. For example, using before-and-after analysis of network accessibility, SNAPTA helps to identify which centres need to be improved or where to promote the public transport network based on the criteria of accessibility measurement. The analysis output prompts practitioners and decision-makers to arrange the list of priorities and rethink the land-use patterns in locations with high public transport accessibility. The evaluation of spatial equity is another issue in which the application of SNAPTA can assist by highlighting the disadvantaged parts of Edinburgh where the residents do not enjoy equal access to opportunities (i.e. areas which require their residents to travel excessively to pursue the same amount and quality of a particular activity when compared with other areas around the city). Therefore, SNAPTA shows how transport and land-use integration can be clearly and visually communicated, and in so doing how the model's outputs can be used to influence CEC's transport and land-use decisions.

SNAPTA relies on a package of three accessibility measures with a different theoretical basis and criteria to quantify the spatial accessibility by different types of public transport modes to different types of activity opportunities, as follows:

(a) *Access time to city centre*. Calculating travel time or generalised cost between zones and the Central Business District (CBD) using public transport.
(b) *A contour measure*. The measure describes the total number or size of destinations that could be reached by public transport within a specific travel time. The outcomes can be expressed either by quantity or floor space area of opportunities or economic activities which makes the measure results simply interpreted. Different cut-off values for travel time have been used in the analysis according to the selected trip purpose.
(c) *A potential accessibility measure*. This measure is a gravity-based measure that includes a transport element, mainly the travel time between zones, and a land-use element determined by the quantity or size of opportunities per destination zone. A potential accessibility measure overcomes some of the methodological limitations of a contour measure. It uses an impedance function for travel distance, time or cost, reflecting the declining attractiveness of activities at a destination with increasing travel time (or distance) from the origin of the journey. However, the expression of the measure results in units that makes it less easy than the other two measures to communicate and interpret by non-modellers. The potential accessibility for the residents of each origin zone (A_i) can be defined by using Hansen's equation (1959), as follows:

$$A_i = \sum_J a_j . f(t_{ij})$$

where a_i is the attractiveness (i.e. quantity or size of opportunities) of destination zone j, t_{ij} is travel time, cost or distance from zone i to zone j, and $f(t_{ij})$ is an impedance function.

Several methods have been used to estimate impedance functions in accessibility studies (see Geurs and Ritsema van Eck (2001) for a discussion of these). This study uses a negative exponential function as the impedance function that can be expressed in the following equation:

$$f(t_{ij}) = e^{-\beta \cdot t_{ij}}$$

where β is a sensitivity parameter to travel time. With values ranging from 0 to 1, β reduces or increases the effect of travel time changes and determines the weighting of activity opportunities. Since this study measures accessibility at a local administrative level with a high spatial disaggregation (and relatively small zones), focusing only on use of public transport in which people are not very sensitive to a small variation of time (Boucq, 2007; Spiekermann and Wegener, 2007), a low value of 0.1 has been selected for β.

SNAPTA, therefore, takes into account the land use and transport characteristics of urban interactions and the availability of opportunities which can be accessed by public transport. It focuses on groups of people, and assumes that they have a set of social and economic activity needs to be met at different destinations, and that travel demand will be determined by the attractiveness of these locations and the quality of the transport infrastructure linking these places. Issues concerning the spatial equity of public facilities, the accessibility to workplaces and shops by public transport, and the changes to accessibility brought about by new transport infrastructure or the re-location of public facilities can all be interrogated through the model.

The use of the measures above for SNAPTA provides a package of accessibility measures that practitioners and decision makers can select. These measures have been widely used in the literature for diverse types of applications. They assess accessibility relying on different methodologies with different levels of complexity. Since each methodology is characterised by its own features to reflect various aspects of transport and land-use systems differently, the model users can set up the measurement framework in a way that serves the circumstances and objectives of different applications in planning practice and satisfies the priority of the aspects which must be covered. The fundamental difference between them is that the time access to city centre and contour measures focus on the separation between locations while the potential measure focuses on the interaction between locations (Gutiérrez et al., 1996). The theoretical underpinnings of the potential accessibility measure are that the interactions between an origin and destination will decline with increasing distance and time but that interactions are positively associated with the amount of activity at each location (Hansen, 1959).

5. Methodology of accessibility modelling

The modelling approach involves the development of the following scenarios that cover the key public transport projects programmed for Edinburgh's network (i.e. the tram system and re-opening ESSR) within different time frames:

(1) *Scenario A – the base year 2011,* reflecting the situation of Edinburgh's transport network in 2011.
(2) *Scenario B – the year 2014,* reflecting Edinburgh's transport network after the construction of part of Phase 1a (a single line running from the airport to the city centre).
(3) *Scenario C – long term development,* reflecting Edinburgh's transport network after the consideration of all tram lines including those envisaged or programmed for the long term, as follows:
  - Tram Phase 1a, the complete phase from and to Newhaven and Edinburgh Airport via Haymarket.
  - Tram Phases 1b, from and to Haymarket and Granton Square.
  - Tram Phase 2, from and to Granton Square and Newhaven.
  - Tram Phase 3, from and to Edinburgh Airport and Newbridge.
  - Tram Line Three to South East Edinburgh, from and to Haymarket and Newcraighall.
(4) *Scenario D – long term development,* reflecting Edinburgh's transport network after taking account of all the tram lines considered in Scenario C as well as re-opening ESSR (from and to Waverley and Niddrie via Haymarket including eight stations).

Six types of activity opportunities were selected to measure the accessibility to their locations by public transport within the Edinburgh Council's area. These are: (1) the central business district (CBD); (2) employment; (3) retail opportunities; (4) education opportunities; (5) health opportunities; and (6) leisure and recreation opportunities. SNAPTA uses the Scottish Census Data Zones (549 zones in Edinburgh Council's area) which are the key small-area statistical geography in Scotland based on 2001 Census with population between 500 and 1000 residents each (Scottish Executive, 2006b), so that contextual data on the population and socio-economic criteria can be used. The measurement assumes that all people living within a zone have the same level of accessibility regardless of their different travel demands.

The location and attributes of activity opportunities have been modelled in GIS (ARC/INFO). Land-use and socio-demographic data (at Data Zone level) including the total number of jobs, the floor space area of retail services and recreation facilities, and the number of patients in health care centres and hospitals, have been obtained under licence from the relevant government organisations. The data on the number of students in secondary schools and universities, and number of leisure and recreation facilities have been obtained from these organisations' websites. Once the required data are collected for each zone, they are linked to the associated centroids of zones within the GIS database. Since the model assumes that all individuals are gathered in the centroids where their journeys start and end, the determination of centroids are re-calculated on the basis of population density rather than geometric centres to avoid assigning population on non-residential areas such as parks and large unoccupied lands. However, in this study the accessibility impact of new transport interventions has been isolated from changes in the land-use system by fixing the data on activity opportunities in such a way that each zone holds the values of baseline year data on population, employment, retail, health, education, and recreation in all the scenarios.

A digital multimodal transport network of bus services, tramways and ESSR railways has been built in GIS. The network covers the whole area of study and consists of links and nodes. The nodes are chosen on the network to correspond to bus and tram stops and railway stations across the modelled area. For each transport link in the GIS data base, tabular attributes of its type, length and the time needed to pass that link have been built. SNAPTA takes into account walk access time from the origin, waiting time, in-vehicle time, interchange time and walk time to the destination.

Walk time is calculated as a constant multiplied by the straight-line distance from the origin (i.e. the centroid of origin zone) to the nearest public transport stop, from the disembark stop to the interchange stop, and from the final disembark stop to the destination (i.e. the centroid of destination zone). The calculation considers access to public transport services and interchange where the distance to a stop (or between stops) does not exceed 500 m, which is the maximum value of the range of 300–500 m walk defined by the Scottish Transport Appraisal Guidance (STAG) (Scottish Executive, 2003) as indicative criteria for an acceptable walking distance to bus stops in urban areas. SNAPTA uses the value of 1.2 as a constant multiplier for the straight-line distance in Edinburgh Council's area. This value is typically applied by the City of Edinburgh Council as a reasonable multiplier (personal communication with CEC). It is estimated based on the network patterns of

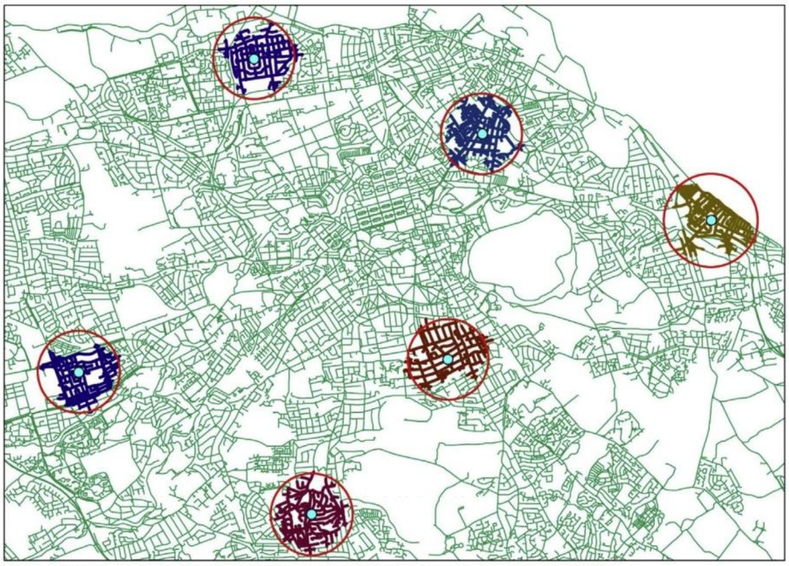

Fig. 4. Map showing how a multiplier of 1.2 is estimated based on a few example points around the city of Edinburgh with 800 m actual distance and 670 m radius circles. *Source:* City of Edinburgh Council, Services for Communities.

several example points around the study area with the 800 m actual distance and 670 m radius circles. Fig. 4 shows the location of six example points which have been selected randomly to estimate the multiplier value. Once walking distances are estimated, the model uses a walk speed value of 3 mph (or 4.83 kph) for average population to measure walking time (Jones et al., 2005 and Transport for London, 2010).

For the perceived walking time, the physical features that delay walk access from and to public transport facilities in the beginning and end of a journey are taken into account by estimating an extra walk time for each zone as a weighting value of walking time. This has been applied to slopes (e.g. for walking up a steep hill) and streets with heavy traffic volume which causes the delay before crossing. The total weighting value given to each zone is obtained by adding the slope weight up to 2 min to the traffic weight up to 2 min, meaning that the maximum extra walk time for each zone is 4 min.

Wait time at the stop of origin or interchange stop is calculated based on the minimum average of scheduled waiting time for the selected public transport service. For example, in the case of Edinburgh bus services, wait time is calculated using the scheduled waiting time for a service running every 10 min, since the most regular bus services in Edinburgh run with a frequency of 6 buses per hour during the morning peak time. This makes the minimum average of scheduled waiting time 5 min (0.5 * 60/frequency per hour) which is actually achieved by many services in the morning peak time. However, the trip calculations could also be performed with minimum wait time at the stop of origin (zero minutes), which occurs when an individual walks to the stop at precisely the time a bus/tram/train arrives.

The in-vehicle travel time of the currently running public transport services is calculated based on the timetables associated with the bus and tram stops or railway stations during the morning peak times, which already takes into account delay on the roads because of traffic congestion. The timetables of proposed services, particularly those for long-term development, are not all available at the time of analysis. In this case, travel time has been estimated based on the average time that a currently running service requires to pass through the same route or through another route which has the same speed limit and similar traffic volume.

Using the access time to city centre measure, accessibility is calculated based on the shortest journey time (or the fastest possible route) during the morning peak hours by public transport from the nearest node (bus stop, tram stop or railway station) in the network to the population-weighted centroid of each zone to the nearest node to the centroid of the CBD. The shortest possible journey time might be achieved by using one service only or though an interchange (one or more) between different services whether those services are provided by the same or different operators (i.e. Lothian Buses, FirstGroup Bus, E&M Horsburgh, Stagecoach Bus, Edinburgh Coach Lines) with the same or different transport mode (bus, tram or train).

The calculation of the potential accessibility measure is more complicated. It also involves the shortest possible journey times between any two zones using public transport. This generates a number of relationships for each type of opportunity which is equal to the number of origins multiplied by the number of destinations. Creating an origin–destination (OD) Cost Matrix is the technique that has been used in GIS to carry out the calculation of the shortest journey times on the network between zones. Once the travel time is computed for each relationship, the potential accessibility for the residents of each origin zone is obtained by applying Hansen's equation. A contour measure has been measured for each zone by calculating the size of the desired opportunity (land use attractiveness) that can be reached by using public transport from that node in the network nearest to the zone centroid within the specified cut-off travel time for the selected journey purpose. The study applied a cut-off value of 30 min for travelling to a large supermarket (for food shopping) and GP practice. A length of 40 min is applied to journeys for the purposes of work, shopping, secondary schools and leisure activities while 60 min is used for travelling to hospital and further and higher education institutions. These values have been identified by the Department for Transport (DfT) (2006) as the core accessibility indicators for the key public transport journey purposes. The

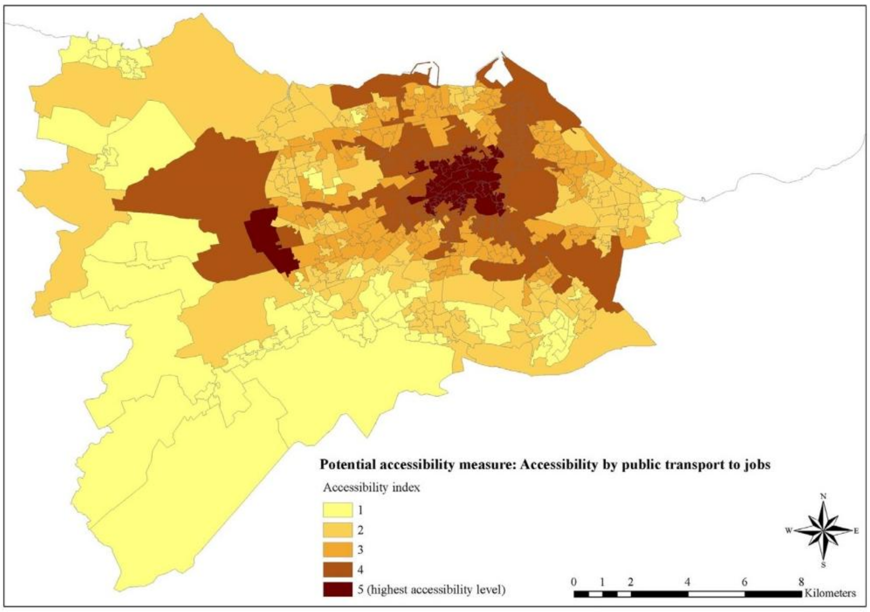

Fig. 5. Scenario A (baseline year 2011): accessibility to jobs (based on potential accessibility measure).

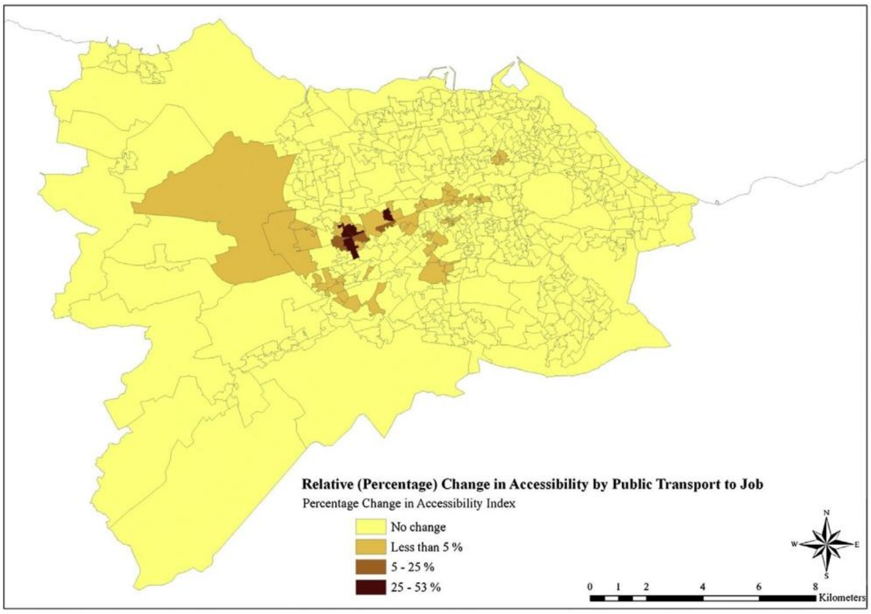

Fig. 6. Relative change (improvement) in potential accessibility to jobs between Scenario A and Scenario B.

variety in the cut-off values among different journey purposes can be explained by the fact that the choice of a supermarket and a GP practice is not as significant as the choice of leisure and education facilities. Closest Facility is the GIS technique implemented to execute this measure.

6. Findings

Once the calculations have been carried out, a simulation of the spatial distribution of accessibility is mapped in the GIS environment based on the sum of accessibility values that are generated for each zone acting as origin-location. Values of the absolute and relative (percentage) changes in accessibility between the baseline scenario and the development scenarios are computed to find out and demonstrate the contribution of the programmed transport infrastructure to the change in accessibility pattern to a particular activity across Edinburgh. Also, this allows a comparison of how the different measures incorporated in the model capture the accessibility changes.

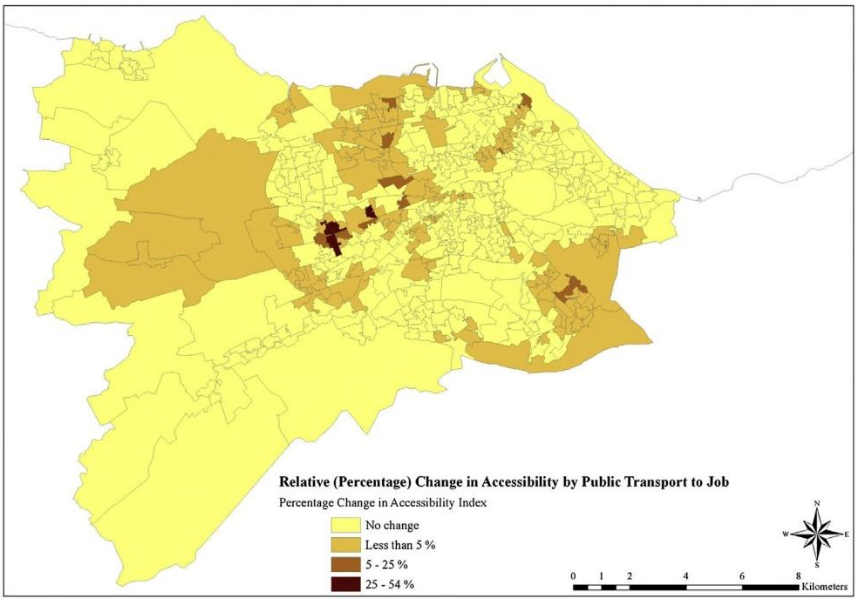

Fig. 7. Relative change (improvement) in potential accessibility to jobs between Scenario A and Scenario C.

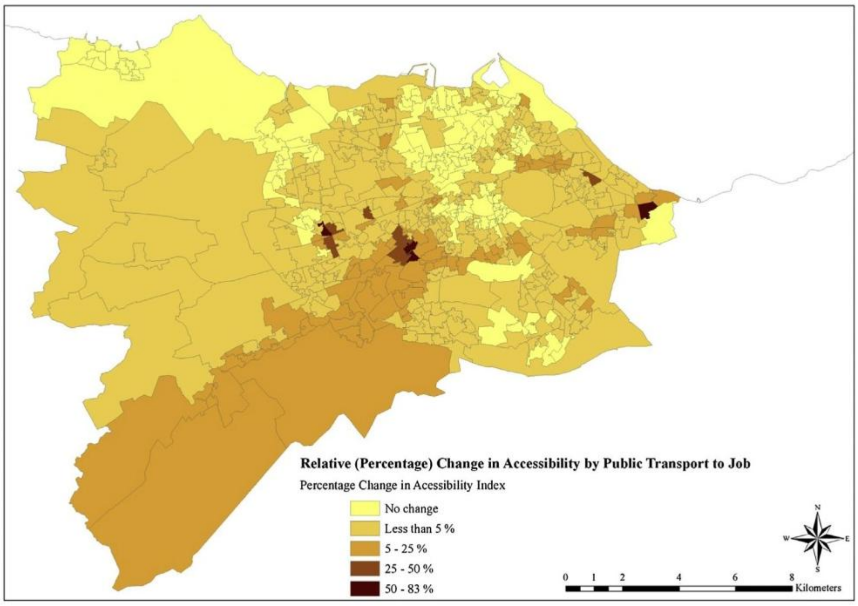

Fig. 8. Relative change (improvement) in potential accessibility to jobs between Scenario A and Scenario D.

The results of the accessibility analyses demonstrate interesting issues about the distribution of the impact of the tram and ESSR in Edinburgh. Due to space constraints, the results presented in this paper focus on the changes brought to accessibility to jobs only. The potential accessibility measure has been used taking into account the total number of jobs based in each zone as the attractiveness of destinations. It is not surprising that the analysis results of the current situation of the baseline scenario (see Fig. 5) and those of the development scenarios suggest that the zones with the best potential public transport accessibility to jobs during the morning peak time are located in the central area of the city followed by South Gyle Business Park in the west of Edinburgh. The map of relative change in accessibility to jobs between the baseline scenario and Scenario B after the completion of part of tram Phase 1a scheduled for 2014 shows that the spatial variation in accessibility is fairly small (Fig. 6). It indicates that the construction of the tram line from the Airport to the city centre has an insignificant impact on the potential interaction between most areas in the city for trips to the workplace, but has greatly improved the accessibility of some locations along the line by up to 53%.

According to Fig. 7, it is clear that the completion of all the tram lines considered in Scenario C has an impact on the accessibility of a larger area. The accessibility to jobs of the areas where the tram Phase 1b and the remaining part of Phase 1a are planned to run to in a loop around the northern suburbs, connecting the city centre with the Waterfront development site, has improved on average up to 5% with some locations having improvements of up to 25%. Similarly, in the south east of the city, Tram Line Three will improve the job accessibility of most residents by up to 5%.

A comparison between Scenario C and Scenario D identifies that overall, the predicted improvement on potential accessibility to jobs brought by the introduction of ESSR service to public transport network is significant. Fig. 8 shows that a considerable part of Edinburgh, particularly the south west of the city, would benefit by running ESSR with an accessibility increase of up to 25%. Moreover, the results highlight a substantial increase in the accessibility level of some zones around the city by up to 83% when all the tram lines and ESSR are implemented.

7. Conclusion

The model developed in this study is not intended to provide the complete picture of transport accessibility but it attempts to cover adequately the required aspects of accessibility measurement and respond to some common limitations in other models without making it very difficult to operate, interpret and, consequently, apply in practice. The challenge is not to argue that all the gaps addressed in SNAPTA are neglected in other existing models but it is more about building a practical accessibility model that could offer a balance between the ease of interpretation and operationalisation and the complexity of the theoretical basis and data disaggregation. The model has been tested and applied to the Edinburgh transport network, addressing the impact of the tram and ESSR on accessibility to different activities at a high level of spatial and data disaggregation of the land-use system.

The empirical conclusion obtained in this study has demonstrated the changes in potential public transport accessibility from the 2011 baseline case and through three different scenarios to the completion of the full infrastructure improvements identified in the Local Transport Strategy. GIS has been used to visualize the different types of data sets in map form portraying space–time accessibility to services and identifying the "hotspots" of unequal access. Whilst the current analysis provides information about the changes in accessibility between the 549 data zones, it cannot infer whether travellers' perceptions of the ease of reaching the facilities and services they require on a daily or weekly basis by public transport will also change.

The study has not looked into the factors central to understanding modal choice, which include cultural attitudes to specific transport modes and factors associated with gender, age, income and the number of hours spent working that influence travel behaviour (Weber, 2006). Although SNAPTA has been developed with a focus on public transport modes only which is considered as a serious limitation for some objectives, the model has the potential to include car-based modes as well. Therefore, further research will focus on enhancing SNAPTA by including accessibility by private car through building the road network taking into account the driving directions and the associated speed limits. In addition, the model will be expanded to cover a wider geographical area to assess accessibility and connections between the city of Edinburgh and the key destinations in the surrounding region such as major employment centres, universities and hospitals.

Acknowledgements

We are grateful to Damascus University, Syria which has financed this research and to participation in the COST TU1002 project. We also want to express our gratitude to the two reviewers for the comments and suggestions which have helped us to improve the paper.

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